1730

1. I SUPPOSE the difference of Longitude betwixt a Ship at Sea and the Port it ſail'd from, might be almoſt as nearly known as its Latitude, if the Ship had along with it a Machine or Watch, that wou'd exactly point out what Time it is at the ſaid Port: But it is ſaid, the Motion of the Ship has render'd the Motion of all Machines that have been try'd ſo irregular, as to be of no ſervice to the Sea-Man, in the Matter of Longitude.

2. But Query; Wou'd any of theſe Machines that have been try'd, go ſo true as is there requir'd, if fix'd on Land: If not, the Motion of the Ship need not much be blam'd, tho' it might make it worſe.

3. Well; tho' it be impoſſible for any Machine, either by Land or Sea, to point out the time exactly for a long Time; yet ſuch a Machine as deſcribed below may perhaps by experience be greatly uſefull, during the time in which a Ship ſails to a far Port.

4. Some Years ago I made ſeveral alterations in order to render the Motion of Clocks more exact than heretofore, but when I came to try them by ſtrict obſervation as below, I judg'd the beſt performance of the beſt Pendulum Clock I ever ſaw, made, or heard of, to be incapable of this Matter, wou'd it go as well in a Ship at Sea in any part of the World, as in any one fix'd place on the Land. Yet from ſeveral obſervations, I ſtill endeavour'd to make further Corrections in this Motion; and in theſe 3 laſt Years have brought a Clock to go nearer the truth than can be well imagin'd, conſidering the vaſt Number of ſeconds of Time there is in a Month, in which ſpace of time it does not vary above one ſecond, and that moſtly the way I expect: So I am ſure I can bring it to the Nicety of 2 or 3 ſeconds in a Year. And 'twill alſo continue this exactneſs for 40 or 50 Years or more; however ſo as not to vary above 2 or 3 ſeconds from what it did the Year next before; for 'twill not want Cleaning, and the little it wears can but alter it inſenſibly little. This Nicety is owing partly to the Matter the Clock is made of, partly to the Contrivance it is made with, and partly to the Nice obſervations it is try'd by, and the convenient place it ſtands in. Theſe I will now treat of, and ſhow how I think their application, with ſome further Addition, may compoſe a Motion to go nearly as true in a Ship at Sea.

5. And firſt as to a Clock to be fix'd in a Houſe. The Pendulum Wheel is beſt made of Braſs,, but all the other Wheels rather better of Wood than of Braſs. But as I do not here undertake to treat in full, I need not mention what Wood or how I order it. Now my Pinnions are not made as the ordinary ones; for ſome parts thereof have when in uſe a relative Motion, which ſaid parts muſt be made of Wood, viz. Rolls, and move upon ſmall Braſs pins, which reach betwixt two Braſs plates, in which the Pins are fixed, on which I find by experience theſe Rolls of Wood move ſo freely, as never to need any Oyl ; But from the nature of the Contrivance the Friction will be abated in ſuch proportion, as the Diameter of the Pin to that of the Roll. And chiefly in the application of the Pendulum to the Wheels, or its Wheel (which is the head place) there 'tis abated no leſs than 40 times; And alſo the Pevets or ends of the Pendulum Wheel Axis moving upon Rolls of great Diameter in proportion to the ſaid Pevets do greatly abate the Friction: And the Wearing is alſo abated in a greater proportion. See the Figures explain'd below.

6. From what has been ſaid we may gather, that the draught of the Wheels, or the force impreſs'd on the Pendulum of ſuch a Clock is nearly always alike, i.e., not only always nearly equal, when the Wheels are drawn by a certain Weight (for in the adjuſting

a Clock, whoſe Pendulum moves in a Cycloid, there is occaſion to increaſe and decreaſe the draught of the Wheels by adding to, and taking from the Weight, as may be ſeen below). But I mean in a more eſpecial manner equal, no obſtruction or irregularity ariſing from Friction, be the draught of the Wheels, or chiefly that of the Pendulum Wheel more or leſs, which is ſo predominant in other Clocks, that their Pendulums mov'd in Cycloids, and were ſuch as deſcribed below; yet they cou'd not be brought to truth.

7. Now 'tis demonſtrated, that, if a Pendulum mov'd in a Cycloid and in Vacuo, it's Vibrations, whether it deſcribes greater or leſs Arches, wou'd be perform'd in equal Times: But then the Pendulum muſt be ſuppoſ'd always to retain the ſame Length. But there is no Wire, of any Metal whatever, whereof to make a Pendulum, but what is continually altering it's Length according to the degrees of Heat or Cold; and this I diſcover'd above 2 Years ago, before I ever heard a Word of, or read any about it. But a little after I had diſcover'd it I was ſhew'd the ſame in a Book, which had it been ſooner wou'd have been ſome ſervice to me.

8. But a Pendulum moving in a Cycloid to Regulate a Clock true, which is not in Vacuo, muſt not always keep it's ſame Length, unleſs the Air gave always the ſame reſiſtance; which

agrees both with reaſon and experiment. Viz., the Pendulum muſt be rather ſhorter in Warm than in Cold Weather, which is contrary to the operation of the Wire.

9. After I diſcover'd the Wire to be longer and ſhorter by Heat and Cold, I prepar'd a Convenience on the outſide of the Wall of my Houſe, where the Sun at 1 or 2 a Clock makes it very warm, to try the different quantity the one foot of metal alter'd in proportion to another; and by trying in the Cool of the Mornings and Evenings, and in the heat of the Days, I gather'd as followeth.

Steel Wire to Iron Wire as.....12.6 to 13.5
Steel Wire to Braſs Wire I had from Sheffield as.....12.6 to 23
Steel to Braſs London as.....12.6 to 20.5
Steel to Braſs from Holland as.....12.6 to 19
Steel to the ſame Holland Braſs Neal'd.....12.6 to 21.7
Steel to Silver and Copper as.....12.6 to 1 7.6

10. I had ſteel of two different thickneſſes, and both operated alike and another Steel Wire harder than them, which rather alter'd leſs, but very little leſs, ſcarcely diſcernable. The London Braſs Wire was thicker than the Sheffield, and the Sheffield than the Holland; but it ſeems from what's above that different

thickneſſes do not cauſe different Extenſion, but the degrees of hardneſs, and different Mixture and Nature of Metals do. For the Sheffield Braſs was the hardeſt of the 3, yet the Holland Braſs alter'd more, after Nealing: Still not ſo much as the Sheffield tho' hard.

11. Now a Pendulum that ſwings ſeconds, whoſe Rod or Wire is of the above mention'd Sheffield Braſs, is of a right Length, when the Weather and the Room where the Clock ſtands are very Warm and will be too ſhort, when very Cold, by about 1/66 or 0.1515 Inch; and accordingly the Clock will go in a Day or 24 Hours about 16.7 ſwings too faſt.

12. And to correct this altering of the Length of the Pendulum, I compoſe it of 9 Wires, viz. 5 of Steel, and 4 of Braſs, as explain'd, below.

13. But further, a Cycloid apply'd to a Clock Pendulum, muſt not be exactly as 'tis demonſtrated for a Pendulum to move in Vacuo. Becauſe 'tis here Maintain'd by the draught of the Wheels againſt the Air's, reſiſtance, which requires the Curve or Evolute of the Cycloid inſtead of being the Curve AB, to be the Curve AC. Suppoſing em but very little different. This need no more explaining.

14. Now a Pendulum, whoſe Motion is maintain'd againſt the Air's reſiſtance by the draught of ſuch Wheels as above, moving in ſuch a Cycloid as treated of in the laſt ſection, and alſo Naturally making it ſelf rather ſhorter when warmer, will perform it's reciprocations, whether deſcribed in greater or leſs Arches, exactly in equal Times.

15. For, let us ſuppoſe the Clock Pendulum to deſcribe any certain Arch, and the Air at any certain Weight: Now if the draught of the Wheels be increaſed, ſo that the Pendulum's Motion is maintain'd in a greater Arch, when the Air remains the ſame, then with ſuch a Cycloid as above the Clock will go true. And again, ſuppoſe the Air is lighter, and the Pendulum deſcribes a greater Arch without any more force from the Wheels the Clock will ſtill go true; becauſe the ſame Natural cauſe, which makes the Air lighter, will alſo make the Pendulum ſhorter: if order'd as explain 'd, Fig. 5. All this I find to agree with Experiment; but not ſo, 'till after I had diſcover'd and added, as followeth : in the two Next ſections. And for my ſtrict trying the Motion, I have two Clocks, but of that by and by.

16. The Pendulums being ſuſpended by the Clocks, and Clocks by the Caſes (as all commonly are) tho' the Caſes were very good and firmly fix'd to a Brick Wall, and the

Pendulums near the back of the Caſes ; yet the Caſes certainly yielded more to the ſwing of the Pendulum, when the Weather was warm and dry (by which the Clocks went ſlower) than when moiſt; tho' never at any Time could the Caſes be diſcern'd to ſtir in the leaſt : But this I accidentally diſcovered by one of the Weights ſwinging a little, which was, when it's ſtring (meaſuring from it's center of Gravity to that of ſuſpenſion) was equal to the length of the Pendulum. This I compar'd to an Uniſon in Muſick, but judg'd it to proceed more from the ſtiring of the Caſe, than from the Air; becauſe the center of ſuſpenſion of the Weight was much lower than that of the Pendulum, ſo likewiſe it's center of Gravity or Body. Therefore that I might not be deceiv'd by the ſuſpenſion of the Pendulum, I made two holes in each Clock-Caſe Back, through which into the ſeams of the Bricks I drove two ſtrong Irons, without touching or depending on the caſe at all, to which I ſcrew'd the plate by which the Pendulum and Cycloid are ſuſpended.

17. But, both from reaſon and a little experience, I find it not convenient for the Pendulum of a Clock to Vibrate in ſmall Arches, not if ſuch Arches, tho' a little different, were perform'd in equal Times (but it is demonſtrated that when a little different they are but perform'd very nearly ſo) for it is impracticable for a Clock to maintain the

Motion of a Pendulum in exceedingly ſmall Arches, without diſturbing it's truth. And if the Arches be a little bigger, 'twill then to bring it to exact truth require a Cycloid, but ſtill impracticable. For if we ſuppoſe the Pendulum Wheels in ſundry Clocks to have the ſame draught, at any the ſame diſtance from their Centers, and each Pendulum Wheel to have the ſame number of Teeth, or we ſuppoſe em to have different draughts directly as the number of Teeth ; we muſt then allow that the Weight of their Pendulum Balls, ought to be reciprocally as the Square of the Arches they then deſcribe, in regard to their Motion being maintain'd, check'd, and reſiſted by the Wheels : For let us inſtance in two Clocks whoſe Pendulums ſwing ſeconds, and ſuppoſing the Pendulum Ball of one to be 2 Pound Weight, and to Oſcillate in an Arch of 12 Gr, and the other Pendulum ſo order'd by it's communication to the Wheel, as to Vibrate but 3 Gr; 'tis plain, in the latter there will be as much command to irregulate the Motion of a Ball of 32 Pound Weight, as in the other of it's 2 Pound; becauſe the Wheel can impreſs 4 times the force upon it, when as at the ſame time the Ball has but $\frac{1}{4}$ of the force ariſing from deſcent, that the other has; or (which is the ſame thing) but the ſame Momentum, was the Ball 8 Pound Weight. Therefore to ſuſpend a Ball for a little Vibration, will require a ſtrong ſpring at the Top, which to apply for truth to ſuch a very little portion of the Cycloid, as

will then be made uſe of, is impracticable. Nay, if the ſpring was weak, 'tis, not ſo practicable, as in a larger Vibration. But a ſtrong ſpring and heavy Ball are ſcarcely practicable with a Cycloid, tho' the Vibration was larger, except the Pendulum was proportionably longer. But we have here ſuppoſ'd the draught of each Pendulum Wheel the ſame : But if we ſuppoſe $\frac{1}{4}$ of that draught to do for the leſſer Vibration, 'twill then vary more in it's draught; becauſe there is more difference geometrically (as we may almoſt compare it) betwixt 0 and 1 than betwixt 3 and 4, but this difference in draught will not (in ſuch contrivance as treated of Sect. the 5) irregulate the Motion of the Pendulum; only 'twill have as much, or more need of a Cycloid. But we muſt here ſuppoſe the Ball to be 8 Pound Weight, ſo conſequently with it's ſpring not practicable ſo as to be regulated as above. That there will be more variation in a leſſer draught of the Pendulum Wheel, than in a greater, may thus be more clearly ſhewn. Let the Pendulum ſwing ſeconds as before, and let the Pendulum Ball for the leſſer vibration be cut 2 Pound Weight, i.e, equal in Weight to the other Pendulum Ball ; then the Weights which draws the Wheels in each Clock, ought to be in a duplicate Ratio of the Arches the Pendulums deſcribe : And as this leſſer Arch is here ſuppoſed to be cut $\frac{1}{4}$ of the other, the Weight which draws theſe Wheels, ought but to be equal to 1/16 Part of the Weight which

draws the other Wheels; for then the Pendulum would but have as much power to regulate the Motion, as in the other. Now I know by experience (in ſuch contrivance as above treated of, ſect. 5 and with each Member of a convenient ſize) yet much leſs than 1/16 Part of the Weight, which is able to maintain the large vibration, will in fine Summer Weather cauſe the Pendulum Wheel to move forward; but 1/16 Part of the Weight is not ſufficient in all ſorts of Weather even to cauſe it to move forward much leſs to maintain this leſſer Vibration, with as conſtant a draught, as the larger Vibration is maintained; except the works co'd be made to move 16 times freer, the which I co'd fairly demonſtrate to be impoſſible : Therefore a Clock cannot be made to go ſo true, with a little Vibration, as with a larger, Now this variation or different draught of the Pendulum Wheel proceeds from the communication of all the Wheels, which in ſuch contrivance, as treated of ſect. the 5, is very little, when the Wheels are drawn by a convenient Weight, and the ſame in regard to the Pendulum, as if the Weight which draws the by heels was increaſed or decreaſed ; but not ſo in the other Clocks. But from what is ſaid below (ſect. the 25) there may ſeem to ſpring a ſmall objection, which I think convenient here to anſwer; and i.e. that the Pallats drawing the Pendulum Wheel a little back every beat, the difference in the Friction amongſt the Wheels cannot be

the ſame in reſpect to the Pendulum, or different Weight to draw the Wheels; becauſe when the Friction is moſt, the Pendulum Wheel has leſs force forward, and not ſo willing to be drawn back. I anſwer it is ſo in other Clocks, but not ſo here : For the holes in the Centers of the Rolls (viz..., the Rolls of the pinnions, as well as them on which the Pendulum Wheel moves) are rather wider than the Pins are thick, whereon they move, elſe they could not move freely; but as they cannot ſlide or turn thereon with the leaſt force, they muſt have rather a deſire to rebound or give back, and conſequently in this caſe the more the Friction increaſes, the greater will be its deſire to give back; but the Limb of the Wheel is but drawn back very little, which near the Centers of the Rolls is almoſt infinitely leſs. Therefore the leſs force the Pendulum Wheel goes forward with, the leſs it will be drawn back with. So this ſcruple if not clear remov'd is very much leſſen'd. But farther, as this retrogradation of the Pendulum Wheel is much leſs than is requir'd to be in other Clocks, and the larger the Vibration of the Pendulum is, the leſs proportion this ſmall retrogradation bears to the Vibration, and the Contrivance Naturally permits or with eaſe maintains a large vibration ; and for reaſon above the Vibration,, ought not to be little : Therefore this gives infinitely leſs irregularity (if any at all) to the Pendulum, than the other way.

18. But I ſaid above (ſect. 4) that I had not as yet got a Clock ſo near the truth as it may be brought, and that is becauſe the Curviture or Evolute of my Cycloids is not Cut exactly true; for I have but lately invented, how an Engine may be made to Cut the Curve ſo exactly true as it ought to be, but have not yet made it. And now I come to treat of my ways of Trying the truth of the Motion.

19. I have two ways for trying the truth of the Motion, the which together is very Compleat. One is by the apparent Motion of the fixed Stars with a very large ſort of an Inſtrument, of about 25 Yards Radius, compoſ'd of the Eaſt ſide of my Neighbours Chimney (which is ſituated from my Houſe towards the South) and the Weſt ſide of an exact place of ſome one of the upright parts of my own Window Frames; by which the Rays of a Star are taken from my ſight almoſt in an Inſtant : And I have another perſon to count the ſeconds of the Clock, begining a little before the Star Vaniſh : So I obſerve what ſecond is Mention'd when it Vaniſheth ; and I have a Table Calculated to ſhow how much ſooner any ſuch Star is to Vaniſh every Night, or before the 24 Hours of the Pendulum Day is expir'd.

20. But my other way is the better part of the Completion : and that is the two Clocks plac'd one in one Room and the other in

another, yet ſo, that I can ſtand in the Doorſtead, and hear the beats of both the Pendulums, when the Clock .Caſe heads are of ; and before or after the hearing can ſee the ſeconds of one Clock, whilſt another Perſon count the ſeconds of the other : by which Means I can have the difference of the Clocks to a ſmall part of a ſecond. And in very Cold and Froſty Weather, I ſometimes make one Room very warm, with a great Fire, whilſt the other is very Cold. And again the contrary. And ſometimes the like in Summer by the Sun's Rays in at the Windows of one Room, and alſo a Fire, whilſt the other is cloſe ſhut up and Cool. Thus. I prove the Operation of the Pendulum Wires, and adjuſt the ſame to what is treated of above, ſections 8 : 14 : 15. And to prove or adjuſt the Cycloid to Vibrations perform'd in different Arches as requir'd (ſections 14 : 15) I cauſe the Pendulum to deſcribe ſuch by increaſing and decreaſing ; the draught of the Wheels, and that by adding to and taking from the Weight; by which I can make 8 or 10 Times more difference, than Nature ever will, and yet the effect be nearly the ſame (in ſuch Contrivance as is treated of ſect. 5) as if Nature itſelf had alter'd the Weight of the Air ſo much.

21. Now as to the place wherein to ſet a Clock, 'tis not convenient it ſhould be damp : but dry Rooms, and where there is a Fire in Winter are beſt. Mine are in low Rooms,

which are often without Fire a Fortnight or 3 Weeks together in very bad Weather, and yet I can diſcern no alteration in em. I ſold one 3 Years ago which ſtands in an upper Room, where there is ſeldom any Fire, and it's Pendulum deſcribes the ſame Arch now, that it did half a Year before I ſold it; and ſo I believe will Continue to do a long Time. It is made as treated of ſect. the 5, and with an imperfect Cycloid, but not ſuch a Pendulum as truth requires, ſect. the 12. And now I come to the Explication of the Figures, and their application for the compoſing of the Sea Clock.

Figure 1

22. Let AB be a portion of a Wheel, CDE the Pinnion which it turns, let aaa etc. be Rolls, which move relatively on ſmall pins at their centers to ſubmit to the Teeth of the Wheel as they reach nearer to, or draw farther from, the Center of the Pinnion; by which there is no Friction at the Teeth, but only at the Center of the Rolls, which muſt be leſs than if it were at their Circumferences, as the Circumference of a Pill to that of a Roll. This as well for the Sea as Land.

Figure 2

23. Let A repreſent two bits of Glaſs, whereon each end of the Axis of the Pendulum being a Sharp Edge of Braſs moves in a little notch in the Glaſs, which renders

that Friction inſenſible, as alſo the Wearing (for 'tis but the Axis of the Pallats, which communicates force to the Pendulum; for the Pendulum it ſelf is otherwiſe ſuſpended, viz. by a thin Braſs Spring). Let the Arch CD, and the leaſt Vibration the Pendulum muſt make to let tile Wheel move forward, be ſimilar; therefore the Arch a.a, is deſcribed with the ſame Vibration by the Center whereon the Pallats have their relative Motion, and from the extremities of the ſaid Arch or Vibration a.a. and with the length of each Pallat may be deſcribed the portions of circles ee,ff. which muſt cut the Limb of the Wheel ſo, that there be half the ſpace of one of the Teeth between; becauſe one Vibration lets but the ſpace of half a Tooth go. Now if theſe Pallats were faſt at their relative Center a, ſo that they had no relative Motion, their Friction at the Wheel wou'd be equal to that of the common way, if the Arch deſcribed by Vibration was as large, and maintain'd with the ſame draught of the Wheels ; but that cou'd not be, for 'twou'd require a deal more. But without that, as their length or Radius is at leaſt 60 Times the ſemidiameter of the Pin, on which they relative move, I may ſafely ſay (as in ſect. 5) the friction is 40 Times leſs than the other, and the wearing, is ſtill leſs, eſpecially in regard to the Motion being alter'd thereby; for the Wheel preſſing againſt the End of the Wood (or the Pallats being made length-way of the Wood) there will ſcarce be any impreſſion

made in 40 or 50 Years : for the Wheel has no drop, and it's, draught is but very little, in compariſon to what it wou'd require to have with the other Pallats. But ſuppoſe it does make a little impreſſion ; ſince the extremity or Edges of the Teeth has not to do, as the common way has, i.e. to ſlide out of the little hole that's worn, and then over it: for here the tooth takes the Pallat along with it, and never departs from the ſame relative place, untill the other Pallat take hold, and then it departs from it perpendicular to the ſurface of the Pallat; therefore no ſliding, and conſequently no alteration of the Motion on this account. But again, if we ſuppoſe the Pallats to alter in length the quantity of a little impreſſion and a little wearing at their Center of relative 'Motion; yet this, as they are apply'd like Tangents to the Wheel, can make no ſenſible difference in the impulſe at the Pendulum in many Years. But theſe we cannot have in the Sea Clock ; but we may have the like in Nature, as; explain'd. Fig. 4. Now by experience I cannot find, that the Pendulum ever alters in it's Vibration above 1/30 part of the whole Vibration, and part of what it alters muſt be owing to the Air, and the other part we cannot well attribute to difference in Friction in ſuch Pallats as treated of above: For certainly when the Friction: increaſes in other Joynts of the Clock, there will leſs force come to the Pallats; and conſequently, as they are not Oyl'd, nor ſlide at the Wheel, the Friction

muſt there rather decreaſe. So the leſs force the Wheel impreſſes on the Pallats or Pendulum, with leſs the Pendulum can draw it back, as Nature requires and treated of, ſect, the 17.

Figure 3

24. Let GH repreſent two Rolls, on which one end or Pevet of the Pendulum-Wheel Axis moves, (the other end alſo haveing, the ſame) but one of :em at each end bears moſt of the Weight that's there; ſo the Friction is abated almoſt as the Diameter of the Pin to that of that Roll. Theſe may be apply'd to the Sea Clock.

Figure 5

25. Let AA be two Axes for two Ballances (or ſuch artificial Pendula as explain'd below Fig. 6) we need not ſignify whether they be Horizontal, or Vertical, but parallel. Let them have at each end in the Centers of the Pevets a Braſs Wire, of a competent thickneſs and length fixed faſt, and then ſtretch'd ſtark in the ſame direction with the Axis, by which means the Axes cannot ſhove end-way, and the Wires will twiſt with an elaſtick force to the Vibration. But theſe Axes will be drawn towards each other, (as below Fig. 6) from which they muſt be ſuſpended by Rolls, at their Pevets, (as mention'd in the laſt ſection) but here let them be only portions of Roll of great Radii, ſo the Friction at their Centers

will not be felt, and we may ſuppoſe theſe Ballances to move nearly as free as a Natural Pendulum ſuſpended by a ſpring. But we cannot communicate :em to the Wheel, as treated of ſect 23. Therefore, as one Axis or Ballance is to move one way, whilſt in the ſame Time the other moves the other way, (as will be ſhewn Fig. 6) let there be fix'd to each Axis at b a fine ſmall Braſs ſpring, and let it be exactly fitted to the portion of the Circumference of the Axis from b to c, leaning againſt the Axis; then at c let it go off in a Tangent (to the Axis) to t, and ſuppoſing the Ballances at one extremity of their Vibration, one of the ſprings will take hold of the extremity of the Tooth of the Wheel O, where 'tis alſo a Tangent to the Wheel; then the Wheel Moving forward, or towards F, the ſpace of half a Tooth, and drawing ſo much of the ſpring from off the Axis, and the Ballances performing one Vibration as from D to C, (for we will ſuppoſe that Arch and the Vibration ſimilar) then the other ſpring will take hold of the Tooth d, and there drawing the Wheel a little back, the other ſpring will fly off to z, i.e. 'twill return into the poſition it was in, before the Wheel drew ſome of it from off the Axis. Now theſe Pallats will have leſs Friction than the other, Fig. 2. But they cannot be apply'd to a Natural Pendulum. And the Wearing will alſo be inſenſible; for here is no ſliding nor droping, but they take and leave as the other do.

Figure 5

26. Let s be a thin Braſs ſpring ſuſpending a Natural Pendulum in a Cycloid, and B the Ball of the Pendulum; and let the thick upright Lines repreſent Wires of the Sheffield Braſs (as in ſect 9) and the ſmall Lines Wires of Steel. Theſe are fixed faſt in Over-thwarts or Bridges; of which there are 3 at the Upper end, and 2 at the Lower, and this Pendulum will make it ſelf ſhorter when Warmer , as requir'd ſect 14.15; tho' all the Wires be then lengthened. See the Computation, as followeth. And firſt, let us ſuppoſe it at a certain Length, and the Weather at a certain Temperature, and let us ſuppoſe the Braſs ſpring (etc..) at the Top to be. 1/5 of the length of the other part of the Pendulum, viz the Wires. And then ſuppoſing the Weather to be Warmer, and each Wire to be lengthened (as in ſect the 9) viz. Steel 12.6 indefinitely ſmall parts, the Braſs 23 ſuch parts, and the Braſs Spring at the Top 1/5 of that i.e. 4.6. But the parts will be bigger or leſs according to the degrees of Heat.

Braſs at the Top.....4.6

Add

The two out moſt Steel Wireſ from the higheſt Bridge at the upper end, to the lower, at the lower end 12.6

17.2

So this loweſt Bridge will be too low 17.2

Subtract

Then the two outmoſt Braſs Wireſ from the loweſt Bridge, to the Middle moſt at the Top.....23.0

So this Middle Bridge will be too high 5.8

Subtract

Then the next two Steel Wires from this middle Bridge at the Upper end,to the upper Bridge at the lower end.....12.6

So the upper Bridge at the lower end will be too low 6.8

Subtract

Then the other two Braſs Wires from this upper Bridge, at the lower end; to the loweſt Bridge at the upper end.....23.0

So this loweſt Bridge at the upper end will be too high.....16.2

Subtract

Then the Steel Wire down the Middle, from this loweſt Bridge at the upper end, to the Center of the Ball about.....13.3

So the Pendulum is shortened about.....2.9

And now I ſhall treat of the Artificial or Portable Pendula.

Figure 6

27. Let AA be 2 Axes, on which 2 Ballances or the 4 Pendulum Halls BBBB are ſupported. Let the Balls he all of an equal Weight exactly; and alſo at equal diſtance from their Axis; or Center of Motion to that of Vibration or Gravity. Let them be communicated to their Axes with Wires, ſuch as in Fig. the 5. So that they be nearer the Center of Motion when Warmer; but rather ſomewhat nearer than in the Natural Pendulum ; becauſe ſome part of their ſupport, (or rather a bigger part of it than in a Natural Pendulum) will not by this means be brought nearer, But of their ſupport in particulars I ſhall not here enlarge : but ſuppoſing it both poſſible and practicable for any two of them, both ſingular and together with what ſupports :em to be made ſo exact an Equilibrium as requir'd, I ſhall proceed. Let the two portions of Circles ab and ed be of equal Radii, and fix'd to each Axis with their Centers exactly in the Center of Motion Let two ſmall Braſs Wires, but flat (or thin like the Pendulum or Spiral Spring of a Watch) and Elaſtick; be ſtretch'd from a of one Arch to c on the other, and from b of one Arch to d on the other, by which means one balance

cannot relative move one way without the other move the ſame ſpace or quantity the other way, ſo conſequently if the whole Body of the Clock be turned one way (whether it be ſlowly, or faſter than ever the Ship can turn it, any portion of the Circle, (whether coinciding with the plain in which the Ballances Vibrate, or inclining thereto) it cannot alter the relative poſition of the Ballances, but they will ſtill remain as if the Clock had not been moved. Let SS be two Worm Springs, and let each be ſuſpended by the middle at f; let them have fix'd at each end at e a ſmall Wire, ſuch as was ſpoken of laſt, by which from g, in the portions of the Circles g h i, let the ſprings be ſtretch'd to a convenient degree, that ſo as the Ballances Vibrate, one one way, and the other the other way, one ſpring will be ſtrech'd out, whilſt the other draws it ſelf in, and the thin Wires will be conſtantly apply'd to the Arches g h i, and (the Ballances performing two Vibrations in one Second of Time) the ſaid Arches will be portions of Circles of about 10 Inches Radius : So the Angle of Contact will be very ſmalland as the Wires are thin and Elaſtick, the Motion will be very little obſtructed by their application to the, Arches; therefore almoſt as free as that of a Natural Pendulum. And the wearing, may be compar'd to that of the ſpring which ſuſpends a Natural Pendulum in a Cycloid, which is inſenſible. But ſuppoſing the Motion not ſo free as a Natural Pendulum, if it

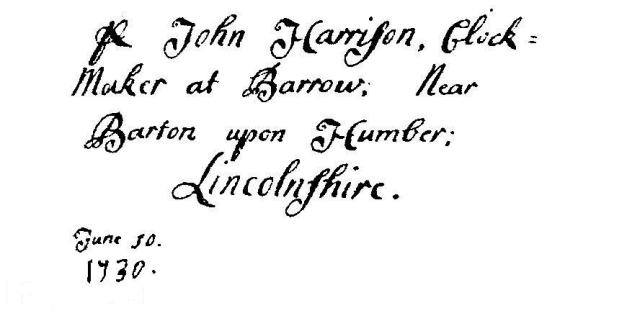
do not alter in degrees of freeneſs, it is the ſame in repect to the truth of the Motion, as if it was entirely free; and we muſt ſuppoſe that if it do alter, it will be as the degree of Heat or Cold. Therefore it may be attributed (in regard to the Motion) to heavier or lighter Air, which is accounted for above. But this may ſeem to be ſuper added to the Air's reſiſtance, I own it is, yet both together will not give ſo much reſiſtance, I think to 4 ſuch ſhort Pendula, as performs 2 Vibrations in one ſecond, as 1 Pendulum 4 Times as long (which perform 1 Oſcillation in a Second) meets with from the Air alone, ſuppoſing cm to deſcribe ſimilar Arches: But whether it be more or leſs, the difference in it's reſiſtance may be accounted for in the ordering and adjuſting the Wires (ſect 26.20) But greater or leſs Vibrations may not be perform'd in equal Times, no more than in a Natural Pendulum without a Cycloid. And here whether greater Vibrations take more or leſs Time than leſs ones, they may be reduced to exact equality by part of the Arches g h i , viz, that part from h to i being made a portion of a Circle, reſpecting; ſome other Center k, or if not ſo, ſome other Curve. But if it be objected, that the ſprings SS which are treated of above will be rather weaker when Warmer, I anſwer the Arches g h i (which are part of the ſupport of the Balls, but not fix'd faſt to em) will be farther from the Center of Motion at the ſame time;

Therefore will almoſt countervail what wants in the ſpring : and the Complement as above; ſir the Balls rather ſomewhat nearer than in the Natural Pendulum; etc.

28. In the laſt ſect is ſhewn, that the Ballances cannot alter their relative poſition by turning the Whole Clock into another poſition, but that is Suppoſing the Clock not in Motion, ſo conſequently, if it were in Motion, the Motion wou'd not be alter'd thereby. But the Clock may be ſuſpended from the Ship with Hinges, in Nature to them of the Mariner's Compaſs, and ſo that it alter it's Poſition but very little, tho' the Ship Toſs much, nor receive any great Shocks from the Waves.

29. Now if there were Clocks made as deſcribed above, (of which I have had experience, even ſuch Clocks as may be made to go to 2 or .3 Seconds in a Year) and fix'd at Sundry Ports in the World, where Ship, reſort, or rather each Clock made (but however it's Cycloid etc., corrected) at the Port where it is to be fix'd (becauſe nearer the Equator Pendulums Oſcillate ſlower) theſe wou'd be good ſtandards to ſet the Sea Clocks by; when the Ships are ready to ſail. And if the Sea Clocks were made as here treated of (which is alſo practicable) I think they wou'd not be much inferiour to the other. But if in the Ship;

they. ſhou'd vary 4 or 5 ſeconds in a Month, it wou'd not always be one way, which makes the variation leſs in regard to it's uſe, (for the mean of what is always one way implies the want of better adjuſting) and 4 ſeconds of Time being but 1 Minute of the Equinoctial; (or but little more than a Mile towards the Equinoctial, and not ſo much towards the Poles) ſuch little variation cannot deceive the Sea Men much in the Time they ſail to a far Port, or to where there is another fix'd Clock.



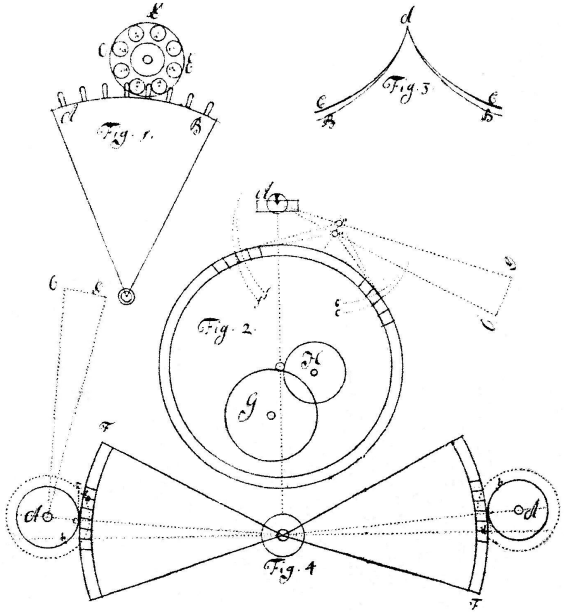


Fig. 1.
Fig. 3
Fig. 2.
Fig. 4

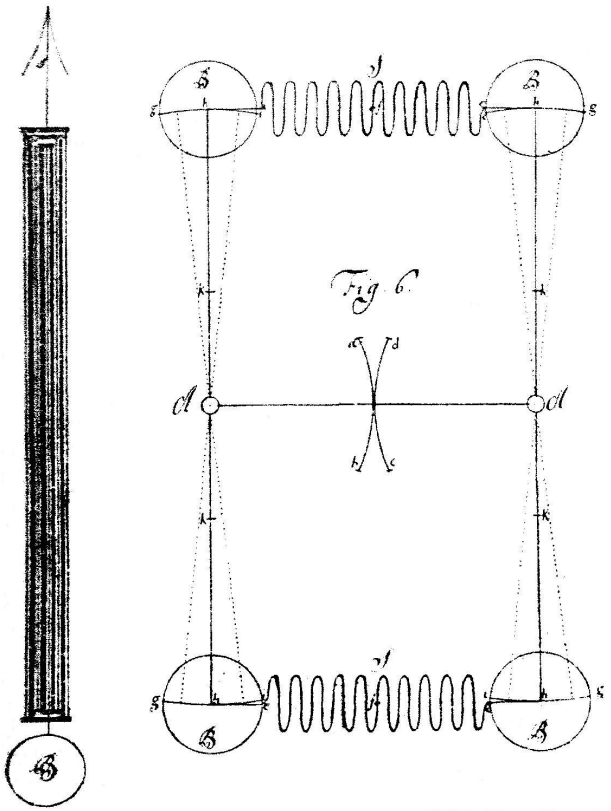


Fig 6.