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THE PENDULUM CLOCK
OR
THE MOTION OF PENDULUMS ADAPTED TO CLOCKS.

By Geometrical Demonstrations.

This book is divided into five parts, the parts of which are concerned with : -

1. A ***description*** of the **OSCILLATING CLOCK**.

2. The ***fall of weights***, and the ***motion of these along a cycloid***.

3. The ***size and evolution of the curve***.

4. The ***centre of oscillation or movement***.

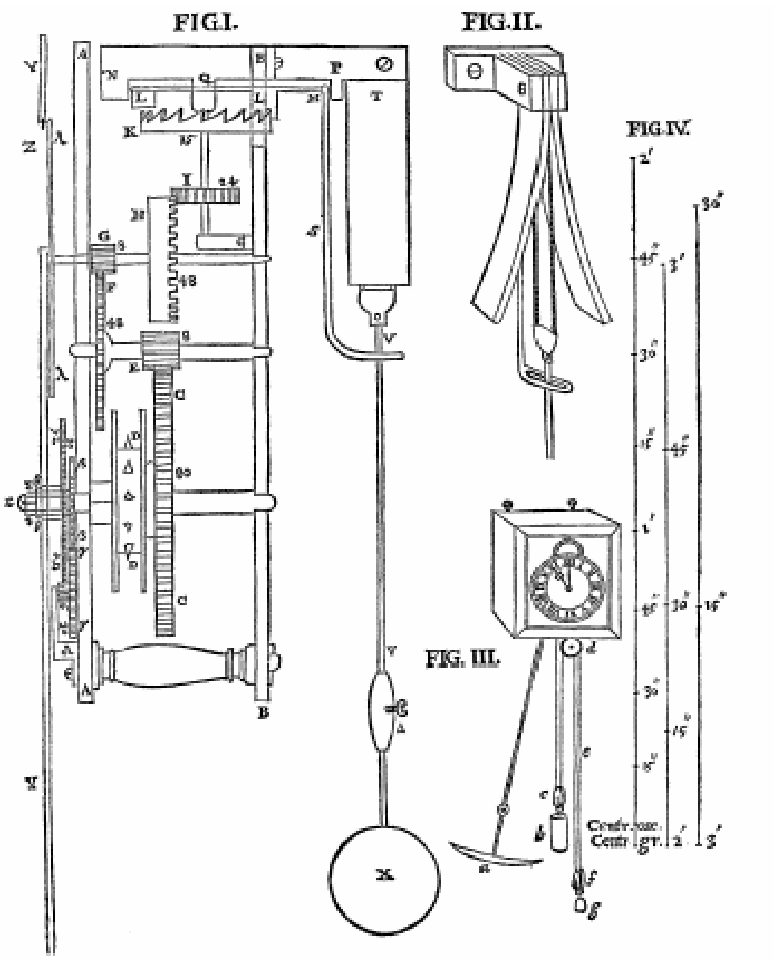
5. ***The construction of another kind of clock*** is shown, in which the motion of the pendulum is in a circle, and Theorems concerned with ***centrifugal force***.

Sixteen years ago we published a little book, after having invented the pendulum clock. Truly, observing that as we have discovered many things in that time along the way leading to the completion of the work, it seems fitting that the individual discoveries should be set out here in this book. Indeed, not only are these discoveries pertinent to the perfection of the clock we have invented, and as such they can be considered the most important part of it, but also these observations are relevant for the fundamentals of all such clock mechanisms, which had earlier been in a very poor state. Indeed it is not in the nature of a simple pendulum to provide equal and reliable measurements of time, since the wide lateral excursions often made may be observed to be slower than more narrow ones; however, we have been led in a different direction by geometry, from which we have found a means of suspending the pendulum, with which we were previously unacquainted, and by giving close attention to a line with a certain curvature, the time of the swing can be chosen equal to some calculated value and is seen clearly in practise to be in wonderful agreement with that ratio. As we have checked the lapses of time measured by these clocks after making repeated land and sea trials, the effects of motion are seen to have been avoided, so sure and reliable are the measurements ; now it can be seen that both astronomical studies and the art of navigation will be greatly helped by them. The curved line that a nail fixed to the circumference of a running wheel traces out in air by the continued rotation of the wheel has been given the name cycloid by our geometers of the day, and on account of other things, a great many of its properties have been diligently pondered over. As we have said, we have considered this curve on account of its ability to measure time, and we have learned that it is completely trustworthy and there is so much of the art of insisting on repetition present in this curve. It is now some time since we supplied our friends with this intelligence (for not long afterwards the first version of the clock was presented), and now we can present the same account demonstrated to the declared utmost accuracy, and with all the relevant reading matter. In the first place it is not necessary to go beyond the great Galileo and to establish firmly the teachings of the descent of a body under gravity; and just as in his teachings the highest peak is the most desired, so we have found that this is a property of the cycloid.

Again, in order that it can be adapted for the use of pendulums, a new consideration has to be made of curved lines, and one may know that these lines have the property that each curve generates the evolute of the other. From which a comparison arises between the length of the curve with a straight line [*i. e.* the curve is rectifiable], as I have described in detail later also rather than now, on account of the theory required to be postulated, that to me seems novel and elegant.

The rest of the book is concerned with setting forth the nature of the Compound Pendulum, the use of which in the construction of this automaton I demonstrate, to which it is required to add a contemplation on the Centre of Oscillation, which many have treated in a less happy manner; in which, with the attention turned to many theorems, unless I am mistaken, that are worthy of discovery, pertaining to lines, planes, and solids. Before all this is indeed set forth, the mechanical construction of the clock itself, and with the application of the pendulum, in the form that has been found to be the most useful in astronomical applications, and for the likeness of the rest, if there is the need for a change, that can be easily put in place.

Since truly it has happened with the singular success of this invention, which one generally becomes accustomed to, and which I had predicted to soon be the case, as more of these authors wished, if the honour could not be theirs, then it could be divided a little more to some of their nation rather than to ourselves; I finally consider here the unjustness of these attempts that come to mind. It is hardly necessary to say anything to these people except for one thing, truly a mention might be made that for the last sixteen years I have neither said nor written anything concerning clocks of this kind, and despite any rumor that might be carried by anyone, the invention and construction of these has arisen and been brought to perfection entirely by my own careful considerations (moreover, I speak of the use of the simple pendulum transferred for use in clocks, for I believe that no one will move a controversy about the addition of the cycloid). In the following year, which was indeed the fifty-eighth of this century, the delineation and description of the automaton were published with the drawn figures; the models, as also the work itself and the little book, were dismissed at every turn. For when all these things are taken into account, neither the testimonies of the learned, nor the acts of the Batavian Orders, try as they might, have managed to put this work on a sure footing; and it is readily apparent to consider that it was these other authors who had spent seven years in the same construction, and they and their friends who brought the clock to perfection, according to their own books they have offered for sale. Truly Galileo is the first man they try to discredit, if they have made an attack on him, truly not a completed invention they say; they seem to have taken away the praise from him rather than from me, obviously in any case I could have had a better outcome than eventuated for him with the same thing. Moreover they contend how recently a certain educated man had desired to be shown the way out either by Galileo or his son, when a clock of this very kind was shown; I do not know how much they hope that is going to be believed, since it is hardly likely for a useful invention to remain unknown for a total of eight years, and then be brought into the light and published by me. [Recall that Galileo died in 1643, and Huygens is writing this comment in hindsight1673; thus, if Galileo had such a clock, presumably it would have become known during this length of time.] Because if they assert that the abandoned work was hidden, then from this likewise they understand that this can be extended to any other work, about which it is desired to argue about the origin of the invention. And thus indeed that may give the approval that I alone made the discovery, and neither will that be of any further concern to me, unless one can be shown, and that may then lie hidden to all men. And this indeed is the reason for the defence against the things people have been saying. Now we may go on to the construction of the automaton itself.



PENDULUM CLOCKS

PART ONE.

The labeled diagram of the clock is presented for inspection from the side [Fig. 1, end-elevation], where in the first place there are two plates AA and BB of length a little over half a foot, and two and a half thumbwidths across; these are joined at the corners by four small columns, and the plates are set one and a half thumbwidths apart. From both sides of these plates, the axes [or arbours] of the special wheels are inserted. The first toothed wheel is the lowest which is called C, with 80 teeth cut into it, and to the axis of which the little drum with the sharp iron spikes has been fastened in position also, in order that the chord with the weights hung on is held in position, and an account of which will be given later. Hence, by the force of the weight the wheel C is turned; this moves the nearby pinion wheel E with eight teeth, together with the toothed wheel F placed in position on the same axle, which has 48 teeth. Another pinion wheel G follows this wheel [8 teeth], and on the same axle as H, wheel H, which has the same number of teeth as the preceding wheel [48 teeth]. But this wheel is of the kind that our clockmakers call a crown wheel. The pinion I and the wheel K which are held on the same axle are turned at the same time (by the teeth of H), along the vertical. The pinion has 24 teeth, and the toothed wheel 15, and these have the form of saw teeth. The winged axis LM lies above the middle of the wheel K, of which the ends are held in position by the two L-shaped ends of the rod NQ & PQ, separately fixed to the plate BB. Truly it is to be noted that the part Q projecting downwards from the rod NQ, which with the hole extending through the rectangular shape the axle LM is passed, and at the same time holds the axis of the wheel K and the pinion I in place, that we have said to be common, with the lower part of this supported by the plate N. In the plate BB a large hole has been cut out, by which the winged rod LM is extended further, which with the fine point of a pin is inserted at P; thus this is freer to move than if the plate BB itself were holding it up; and likewise beyond the rod there must be a projection, which is necessary in order that a crutch lever S can be attached, which can change direction along with the rod. Moreover this motion is to and fro, now in this direction, now in that direction, when the teeth of the wheel K meet the small wings LL in turn, known by common account, and which hence does not need a more careful explanation. [p.6]

Again the crutch S, with its innermost part turned round and with an oblong hole drilled through it, is around the iron rod of the pendulum, to which the lead weight X is fastened. This rod has been suspended above by two strings between twin plates, of which only one T is shown here; and thus we have established another figure nearby, which sets out a complete account both of the form and curvature of the plates and of the suspension of the pendulum. Though more time will be spent later concerning the true curvature of these plates.

Moreover, now we can say more concerning the movement of the clock, as we will pursue the remanding parts of the figure later, and it is readily apparent that the motion of the pendulum bob VI is sustained by the force of the wheels due to the pull of the weight, once after it had been set in motion by hand ; and likewise the pendulum bob stops swinging when all the wheels cease to move, and thus the standard rule is prescribed for all clock movement. Indeed the crutch, acted upon by the lightest of impulses from the rotation of the wheel, does not so much yield to be pulled by the pendulum, but both helps for a short time with the return of this particular motion, and with the continual returns of this motion, which otherwise by their own will, or truly by travelling through the air, might fail a little, and be inclined to come to rest. Truly, on the contrary, it is in the nature of the pendulum to be brought back following the same course, and it is not able to be changed from that course by any reason except for a change in the length; and after the curve of the plates, between which the pendulum is suspended, we have caught up with that evenness of motion; by no means is it allowed for the wheel K to sometimes step faster or slower, although often as with common clocks, it may attempt to do this ; for the individual teeth of this wheel by necessity are working together to cross in equal intervals of time. Truly it has hence become clear that the remaining wheels which precede, and finally also the hands of the clock, are to effect equal fractions of turns, since all are moved proportionally. On account of which if there was anything at fault in the making, or a change of the air temperature makes the axes of the wheels harder to turn; and provided that the motion of the clock is not interrupted at any stage; nothing on account of these inequalities, or slowing of the motion, is to be feared; either the correct time will always be measured, or it will never be measured correctly at all.

Again, the hands of the clock are turned in order. YY is the third parallel plate at the front, situated a quarter thumbwidth distance from the noted plate AA. On that plate the circles of the time have been described, with the same centre X, from which the axle of the wheel C is protruded. The innermost circle of which has been divided into twelve hours, the other into 60 minutes. Truly the axle of the wheel C is modified, beyond the plate AA, by the wheel β, with a narrow close-fitting tube which is continued as far as E through the plate YY; and thus [p. 7] is placed inside that axle, in order that both are carried round; yet it is able to be turned without the other, when the need arises. To E the hand is fixed, that thus goes around in an interval of one minute or the sixtieth part of the hour, as we will soon show. Truly, the wheel that we have called β drives another wheel with the same number of teeth [30], together with a pinion with six teeth attached, with the common little axle of these thus supported by the plate A and by the angled plate δ. Finally the wheel ζ having 72 teeth is moved by this pinion and the little attached tube, which is stretched out beyond the plate Y to θ, a little closer to the plate than the tube assigned to the wheel β, which is encircled within it. The hour hand is placed upon the end θ, a little shorter than that we have designated for the first minute hand, as it must be able to be carried around within by the rotation. Truly the seconds, in order that the short times can be shown without error, are inscribed on a circle λ attached to the axle of the wheel H, which is produced as far as the plate Y, and divided into sixty parts, with a hole cut in the plate Y through to Z; allowing these divisions, with the point of the axle fixed near the top hole, to be observed directly [there is thus no pointer for this scale, which itself moves]. Truly the whole arrangement of these hands and circles of the hours is set out clearer in the small figure [Fig. III] , with reference to the exterior of the clock.

The remaining length of the pendulum is three feet, for the wheels placed in the order as we have discussed, as it is required that each second is measured by the returning pendulum; since it is not convenient to show this on the diagram, the fifth part is taken from the top part of the suspension where the curved plate T begins, as far as the centre of weight we have called X. I say three feet, not with regard to losing any respect which a European nation may have for this or that measure in common use at home, but surely and for all time for the measure of the foot taken from the length of this pendulum itself, which from now on will be called CLOCK FEET, [Huygens returns to this aspect of the work in Part IVB of this translation, where we consider his clock as a time standard, or horarium, for lack of a better word.] indeed all other measurements of feet that we may wish to handle should be referred to this incorruptible definition. Nor indeed, for the sake of a few words, will any of the modern ventures in the manner of the Parisian foot be ignored, while it will be agreed that the Parisian foot to the clock foot is as 864 to 881. But the most exact measurement of this length we will perform for most setups are taken from the centre of oscillation. Now the times of rotation of the individual wheels and pointers will be described along the way, in order that everything above about the number of the teeth described to square can be understood correctly.

Indeed with one rotation of the wheel C, it is apparent that the wheel F goes round ten times, and truly the wheel H goes round sixty times, & the top wheel MK goes round 120 times: when there are 15 teeth on this wheel, and from these in turn the pinnules L L move to and fro [p. 8] with one complete rotation of the wheel K enumerates 30 of these hits 30, from which the same total number of strikes and restrikes of the pendulum is 30 and thus with a rotation of 120, there corresponds 3600 simple oscillations of the pendulum VX, [the period of one second is taken for a swing from one side to the other, and is thus half of the modern period], which brings about the number of seconds in the hour. And thus the wheel C goes round in a time of one hour, and with that likewise the hand assigned to [the rotating cylinder] ε, which shows the time in minutes. And since the wheel β also rotates once in the same interval of time, and by that γ [both with 30 teeth] is made to turn through a revolution, and by its pinion with 6 teeth of its own, to which the wheel ζ rotates in multiples of one twelfth of a complete rotation, and it is apparent that 12 hours are taken for complete rotation, and as many as that are indicated by the hand connected to θ [The protruding shorter end of the outer cylinder]. And since we have shown that for 60 turns of the wheel H there is a single rotation of the wheel C; hence that wheel, together with the fixed disc λ, is carried around 60 times in a single hour, that is, one of the first small amounts of time, and thus the 60th parts of the circle λ show the time for the passing of the second small amount of time: and thus everything has been shown to manage itself correctly. The weight X within the plumbob is of three pounds, the whole of lead, or a copper surface holding lead. Neither is there much concern about the weight of the metal, but rather, on looking at the above shape, which is indeed of the greatest concern, as to how small the force of the air experienced as the weight crosses can be considered. The form is moulded in the shape of a cylinder lying oblong and with both ends pointed, such as is seen at *a* in the smaller diagram of the clock. As for these prepared for navigation, the shape of an upright lens is more fitting.

Again from the same diagram, and concerning the other weight *b*, by which the motion of the clock is made continuous, the reason the weight has been suspended in this way, which was unknown at first, and which it was necessary to be found by us, lest as that weight was being drawn up again, the running or the clock might meanwhile stop or could be hindered for a certain time, which always has to be guarded against here. Thus the chord is prepared to be continuous and returning to itself, with the ends appropriately joined to each other. It is wrapped around that first little cylinder joined to the lowest wheel C, which in the large diagram is called D; thus the descending chord enters the pulley *c* from its own second part, to which the weight *b* is attached. Hence it ascends over the little wheel *d*, fixed externally to the clock, which has sharp pointed barbs of iron fixed on the circumference, and thus is adapted with iron teeth, in order that it is turned by pulling with the chord *e*; and truly in no way is it possible to make a contrary rotation. [Huygens has utilised the ratchet and pawl mechanism here.] From this little disc the chord descends to the other pulley *f*, to which a small weight *g* is attached, which is sufficient to hold the large weight *b* in place, lest otherwise that by the rotation of the little wheel it may descend. And in as much as the rope has descended to the pulley *f* , it thus is returned again to the little wheel *d*. Thus from which [p. 9] it can be seen, that by having half the weight *b* always trying to make the wheels of the clock turn, nor indeed then to cease since by pulling by hand the chord can be forced to ascend; and thus the motion of the clock need never be interrupted, nor a moment of time lost.

Certainly there is no possible way to assign a weight to *b*, but where less is sufficient to conserve the motion, that may argue a better and more accurate fabrication of the clock. For us, the weight has been reduced to 6 pounds, which is the best we have had up to the present, assuredly with the diameter of the little wheel D around a thumbwidth, that was furnished for use ; likewise with a weight of 3 pounds for the pendulum bob, and as many feet for the length. Which length, as we may also suggest, hangs within the length of the box of the clock, passing through an oblong hole, and producing as many oscillations as is necessary. Truly the clock itself, suspended at the height of a man, persists in its movement for 30 hours.

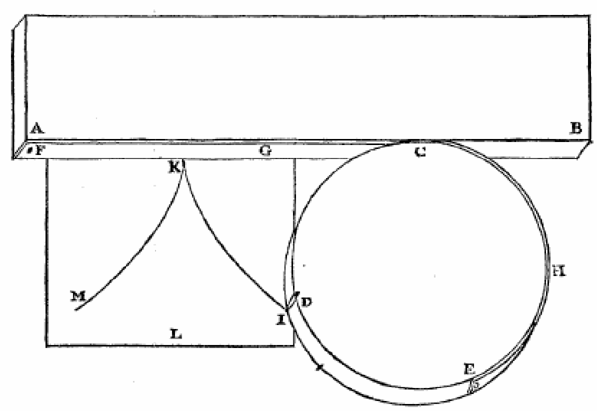
There now remains to be described the form of the plates we have mentioned, between which the pendulum bob is to be fixed, and the particular purpose of which is to maintain an outstanding equality of movement for the clock. Indeed, without these plates the oscillations of a simple pendulum are not of equal duration (although with some it has seemed otherwise) , but these which follow shorter arcs have shorter times : and that is readily understood in the first place from an experiment of this kind. If indeed two strings are taken of the same length, and with the innermost part to the weights secured equally, and then each can be suspended separately, and then one of these is pulled out a distance along a line to the perpendicular with the other momentarily, and then they can be sent off at the same time by hand; and soon both will be seen to carry the same parts, but that will prevent those pendulum swings which are too short. However the ratios of the numbers for the times for any arcs can be defined, by striving for reliable knowledge, and truly as it is wished for those nearby, just as the time of descent for the whole quadrant of the circle is to the time for the shortest arc nearby as 34 to 29. Indeed as the difference cannot be ascribed to the air resistance, as indeed it can be wished, but the motion arises from a natural property of the circle. Since by another argument too, from these it can be concluded, where with the construction of the isochronous pendulum, the pendulum does not recede at all from a circular line, as will soon become apparent.

But perhaps it can be seen that with our clocks and with these, where the latitude of the oscillation is always the same, there will be no inequality at any future time, and therefore no correction need be made to the pendulum weight. Since clearly it should be thus if the latitude of everything is always to remain the same [p. 10]. But when it can exceed a little or be a little less, from many small differences finally something big enough is got up, and that itself is bound up with experiment. Although indeed the force due to the weight shall always be the same, with respect to the wheel nearest to it, yet the force transmitted by all the others, depending on the care with which the wheels have been filed, the same [i. e. effective] force does not always reach all the way back to the hanging weight. Cold weather too makes the wheels harder to turn; likewise from evaporation or from becoming dirty, in which case oil is added. But the oscillations of these clocks shall be especially unequal which are carried by the sea, on account of the incessant tossing about of the ship, thus as indeed with all the clocks in the world, but for these especially, anything will help with the remedy which avoids the sideways swinging of the pendulum, with narrower swings of equal times instead.

Hence to defining the shape of the plates in which the remedy is put in place, in the first place the length of the pendulum needs to have been decided, which is easily obtained since the lengths of the pendulums between themselves are as the squares of the times for single swings. Thus as we may have defined the length of the pendulum as three feet that measures the seconds; the fourth part of this, or nine inches, should be the length for which the half second will be observed. Likewise if the length of the pendulum is sought, of which the simple returns passed through in space of an hour is 10,000, in this way the ratio is entered into. Truly for a pendulum of three feet, we know that 3600 single swings are to be counted in an hour : hence the individual times for this swing, are greater than the times of the pendulum sought, in the proportion 10000 to 3600, or 25 to 9. Whereby as the square of the number 25 to the square of 9, that is, as 625 to 81, thus the length of the pendulum of 3 feet will be to that which is sought, truly 4 and $\frac{66}{100}$ inches.

Hence with the length of the pendulum reckoned as three feet for the clock we have proposed, then the cycloidal line, which will give the curvature of the plates T, is described in this way.

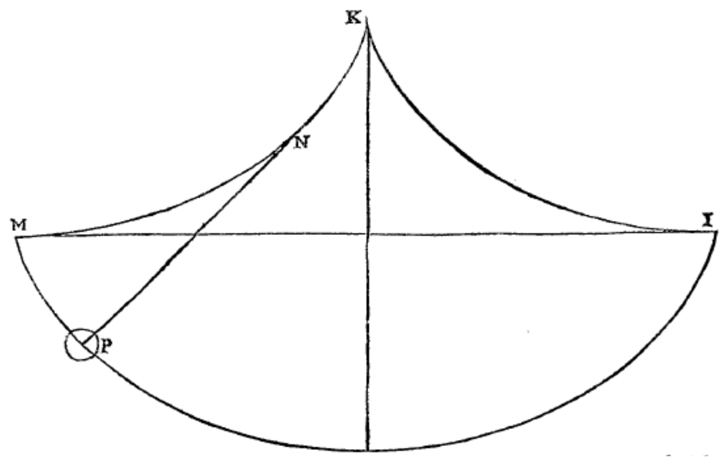
Upon a flat table the rule AB is fixed, half a finger wide. Then there is present a cylinder C D E truly with the diameter of the base equal to half the length of the



pendulum; and F G H E is a small bandage, or better a thin metal foil, fixed to the rule at the point F of this, and to some point of the circumference of the cylinder E, thus in order that it shall be partially wrapped around the cylinder alongside the rule A B. Moreover a sharp iron point DI shall be fixed to the cylinder, projecting a little below the base, and thus in order that the circumference of the cylinder corresponds exactly to it. [p. 11]

Thus with these in place, if the cylinder is rotated along the rule A B, with the metal foil in between as far as FG, and with that always extended as far as possible, the sharp point I applied below on the plane table will describe the curved line KI, which is called the cycloid. Truly the circle CDE is the originator of the curve, applied to the base of the cylinder. Since if now we apply the plate KL to the rule A B ; that first part of the cycloid KI is traced out, then we invert the plate, and in the facing surface the similar curve KM is inscribed, arising from the same point K. Then we will have formed the figure MKI, following these lines carefully for the figure of the plates it is necessary to adapt, through the gap between which the pendulum is hanging. Moreover the small portions of the arc KM, KI are sufficient for the use of the clocks ; with the remainder of the curve not to be used in the future, and to which the string of the pendulum does not have access.

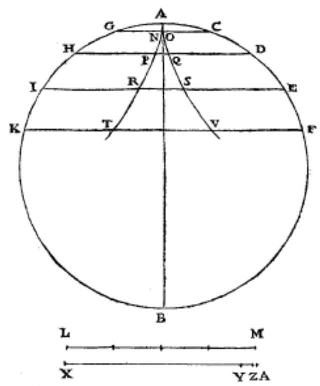
Truly, in order that the wonderful nature of the line and the effect may be understood better, the whole semicycloids KM and KI, here seen to be expressed by another diagram, between which the pendulum KNP is suspended and moving, [of length] twice the diameter of the generating circle, and the oscillations of any amplitude, as far as the largest of all through the arc MPI will be made in the same times : and thus, so that the centre P of a sphere hung on, is always moving to and fro on the line M P I which is part of a whole cycloid. I do not know of any other line with this conspicuous quality, except for this given line, as truly it describes its own evolute. Moreover these things which have touched on, concerning the descent of the weight and the evolute of the curve, we will go through and each will be explained in what follows. [p. 12]



Moreover it is possible otherwise also, to describe a cycloid through points found. The circle with diameter AB is described, which shall be equal to half the length of the pendulum. In the circumference of which some number of equal parts are taken AC, CD, DE, EF, and AG, GH, HI, IE, and GC, HD, IE, KF can be joined, which are parallel to each other. Then the straight line LM is taken equal to the arc AF, and this is divided into as many equal parts as there are in the arc AF, and of these parts one is placed equal to the individual lengths CN and GO on the line CG; truly with two parts of the line LM, are made equal to the individual lengths DP and HQ on the line DH. With three parts truly, the individual lines ER and IS on the line EI; and thus again if more parts were to be accepted; and finally the whole length LM shall be made equal to the individual lines FT and KV in the longest line FK. Now if the curves are described by the points AOQSV and ANPRT, these again will be the parts of the cycloid sought between which the pendulum is required to be fastened.

Moreover a straight line LM equal to the arc AF is found as follows: if at first with two straight lines, the halves of which subtend the arc AF, and the length of each chord is put equal to XY, truly this is equal to whole length of the subtended arc AF if the part XZ is taken from AF, and to the difference YZ a third ZΔ to the total XZ is added on. For the total XΔ is now almost equal to the total length of the arc AF, as a sixth to the circumference is permitted, (an neither is more needed here at any time) not by one sixty thousandth part of the length will it be deficient, that with these which are concerned with the magnitude of the circle we have previously written about, has been shown.

With these facts established, their application in restraining the motion of the clock can also be indicated, from which the true measure of time by the clock is to be composed. Hence in the first place, or how it can have the correct motion, will be examined in this way. [p. 13]



A reliable place for observation by eye is chosen, from where the stars can look down, and likewise the roofs or walls of the nearby houses, thus placed in order that, with a certain star selected from a fixed number of approaching stars, may cease to be seen at the same time. To that place, an opening the same size as the pupil of the eye is set up, in order that in the following days, without error, the eye can be repositioned to the same point. Now to that moment, when a certain star disappears from view, and the time is noted by the clock. And the same for the next day, or better after the passage of several days, it is done again. Because if only a space of one day passes between the observations, from that from which the first observation was noted, there will be a difference of 3 minutes [or primary scruples], and 56 seconds [or secondary scruples]. Thus indeed it will agree that the length of the pendulum is correct; when the revolution of the mean solar day is so much greater than for any sidereal day. Regarding mean solar days, since solar days from meridian to meridian, are not all equal to each other, as will soon be explained further. For truly finally after many days of repeated observation, much of the reason for individual differences ought to be worked out. For example, in the first observation, to the moment of the disappearance or the star, the time is noted to be 9 hours, with 30 minutes and 18 seconds; then, after seven days, with the same star disappearing, the clock notes 8 hours, with 50 minutes and 24 seconds. This hour is less from the first by 30 minutes and 54 seconds. Which, on division by seven, will give a daily retardation of 5', 24". But that should be 3'.56", which is less than that by 1'.46". [p. 14.]

Thus just this much is lost by the clock daily from the true value, or from the mean measure of the days.

TABULA ÆQUATIONIS DIERUM.

Dies.	Januar. Min.	Januar. Sec.	Febr. Min.	Febr. Sec.	Mart. Min.	Mart. Sec.	Apr. Min.	Apr. Sec.	Maj. Min.	Maj. Sec.	Jun. Min.	Jun. Sec.
1	10	40	0	32	2	15	11	18	18	32	18	10
2	10	10	0	24	2	28	11	37	18	39	18	1
3	9	41	0	18	2	42	11	56	18	46	17	51
4	9	13	0	13	2	56	12	15	18	53	17	41
5	8	45	0	9	3	11	12	34	18	59	17	30
6	8	17	0	6	3	26	12	53	19	4	17	19
7	7	50	0	3	3	41	13	12	19	9	17	8
8	7	23	0	1	3	56	13	31	19	14	16	57
9	6	58	0	0	4	12	13	49	19	18	16	46
10	6	34	0	0	4	29	14	6	19	22	16	35
11	6	10	0	0	4	46	14	23	19	25	16	24
12	5	47	0	2	5	4	14	39	19	28	16	13
13	5	24	0	4	5	22	14	55	19	29	16	1
14	5	2	0	8	5	40	15	10	19	29	15	49
15	4	41	0	12	5	58	15	25	19	29	15	37
16	4	21	0	16	6	16	15	39	19	28	15	24
17	4	2	0	21	6	33	15	53	19	26	15	11
18	3	44	0	26	6	51	16	7	19	24	14	58
19	3	27	0	32	7	9	16	21	19	21	14	45
20	3	11	0	40	7	27	16	34	19	18	14	32
21	2	55	0	48	7	45	16	47	19	15	14	19
22	2	39	0	57	8	3	16	59	19	11	14	6
23	2	23	1	6	8	22	17	11	19	7	13	53
24	2	7	1	16	8	41	17	22	19	2	13	40
25	1	52	1	26	9	1	17	33	18	57	13	27
26	1	38	1	37	9	21	17	43	18	51	13	15
27	1	25	1	49	9	41	17	53	18	45	13	3
28	1	13	2	2	10	1	18	3	18	39	12	52
29	1	2			10	21	18	13	18	33	12	41
30	0	51			10	40	18	23	18	26	12	30
31	0	41			10	59			18	18		

Dies.	Jul. Min.	Jul. Sec.	Aug. Min.	Aug. Sec.	Sept. Min.	Sept. Sec.	Octob. Min.	Octob. Sec.	Nov. Min.	Nov. Sec.	Dec. Min.	Dec. Sec.
1	12	19	10	4	16	23	26	30	31	55	25	34
2	12	8	10	8	16	42	26	49	31	55	25	10
3	11	58	10	13	17	1	27	8	31	54	24	45
4	11	48	10	18	17	21	27	26	31	52	24	20
5	11	38	10	23	17	41	27	43	31	50	23	55
6	11	28	10	28	18	1	28	0	31	47	23	30
7	11	18	10	34	18	21	28	16	31	43	23	4
8	11	9	10	41	18	41	28	32	31	37	22	38
9	11	0	10	49	19	1	28	47	31	30	22	11
10	10	52	10	58	19	21	29	2	31	22	21	43
11	10	47	11	7	19	41	29	16	31	13	21	14
12	10	38	11	16	20	1	29	30	31	3	20	44
13	10	31	11	25	20	22	29	43	30	53	20	14
14	10	25	11	36	20	43	29	56	30	43	19	44
15	10	19	11	48	21	4	30	9	30	32	19	14
16	10	13	12	1	21	25	30	22	30	20	18	44
17	10	7	12	14	21	47	30	34	30	8	18	14
18	10	2	12	28	22	9	30	45	29	55	17	44
19	9	58	12	42	22	31	30	55	29	40	17	14
20	9	54	12	57	22	52	31	4	29	23	16	44
21	9	51	13	12	23	13	31	12	29	6	16	14
22	9	49	13	27	23	33	31	19	28	48	15	44
23	9	47	13	43	23	53	31	26	28	30	15	14
24	9	46	13	59	24	13	31	32	28	11	14	43
25	9	46	14	16	24	33	31	38	27	51	14	12
26	9	46	14	33	24	53	31	43	27	30	13	41
27	9	47	14	50	25	13	31	47	27	8	13	10
28	9	49	15	8	25	33	31	50	26	45	12	40
29	9	52	15	26	25	52	31	53	26	22	12	10
30	9	56	15	45	26	11	31	55	25	58	11	40
31	10	0	16	4			31	55			11	10

I

ding to

the sun. But here now the natural daily variations have to be taken into account. Indeed , as has now been said, not all the days are of equal length amongst themselves, as now I have said; not all the days of this kind are equal to each other; and though the distinction shall be small, however over an interval of many days that can grow to the extent that it cannot be ignored. Indeed even if both the most perfect description of the sun is on hand, and the motion of the automatic clock for the measurement of the days is the most true, it cannot be avoided; that nevertheless it eventuates that for certain times of the year, there will be a discrepancy often of a quarter of an hour or even of half an hour between the solar and sidereal times, and with the clock stopped they can be made to agree again. Indeed this will be understood from the table for equalising the lengths of the solar day that we have submitted here; and after we have shown how to use this, as follows :

The equalisation of the table may be taken, from which the first day is assigned by making the clock agree with the sun, or with a sundial. Likewise the equalising of the clock for some day is sought as well as the measurement of the time for that day. Because now if from a previous equalisation, with the following made larger, the hour of the clock might be greater than the hour of the sundial, between which these differ from each other by the table equalities. And if a later day should arise when a greater equality should be found, the excess will be from the hour of the pointer of the sundial, or that from which the sun is observed. As if, for example, on the 5th day of March on the same hour the clock and the sundial are in agreement, and from the equality of which is found in the table, 3 minutes and 11 seconds. It would be pleasing to know the correction for the 20th day of the same month, and whether the automaton may be measuring the hours correctly or not : the equalising amount written for the this subsequent day is found to be 7 minutes and 27 seconds, which because it exceeds the preceding amount by 4 minutes and 16 seconds, the hour of the sundial ought to be behind the hour indicated by the automaton by this amount. Hence, if the difference is found, then it is easy to gather, by how much in individual days the automaton is to be advanced or retarded.

[It seems appropriate to add a comment here: Huygens is faced with a dilemma, for he has essentially two clocks, one of which is the earth's rotation itself, and the other is the time as measured by his clock (It is now understood that the length of the solar day does vary a little, possibly due in part to changes in air and water currents on the surface of the earth during the year, but the effect is much less than what Huygens had in mind). The clock is initially synchronised with the sundial and set in motion, and is later found to be out of synchronisation by an amount that can be calculated from the table. Huygens considers that the length of the solar day as measured by his clock varies by as much as almost half an hour in the course of the year, as he still wishes to keep the solar day of the sundial as one of his time references; the other being the sidereal day, which he measures every few days, and for which the error is of the order of a minute or so daily, as he has informed us. Thus, Huygens applies the correction by either adding or taking it (depending on the time of year when the synchronisation was put into effect) to the sundial time to get his clock time, or viceversa. When the synchronisation with the sundial starts in February, his clock will go slower in subsequent months by thermal expansion of the length of the pendulum. Hence, if this were the case, then he would be adding the time differences to his clock; on the other hand, if the clock and sundial were synchronised in the heat of the summer, then the errors would be subtracted, as his clock would run faster during the winter months; this is a common problem associated with such pendulum clocks.]

Here in working out this table, I have considered a two-fold cause, each of which is known to astronomers : the obvious obliquity of the ecliptic, and the anomalous motion of the sun. Since for the reason postulated, and as also for these clocks constructed above that we have built, it has been shown to be the case by trial, that without these causes none of the effects would occur ; for the equalities proposed here have been found by common consent, and the observations of the sun, which often for many months on end daily occupies the meridian circle.

[Thus, the asymmetric position of the sun in the sky in the different seasons is cited as the reason for what Huygens perceived as a discrepancy in the length of the solar day.]

Now after [p.15/16.] we have discussed both ways by which the length of the day can be measured, but with the first [*i. e*. sidereal] better, an examination is decided, if there is a greater variation in the mean length of the day to be found from the longitude of the clock, thus in order that the a difference will rise above three or four minutes. The rest will be attributed to the increase or decrease in the length of the pendulum itself. Where this rule has been applied, the motion of the clock will be speeded up or slowed down by as many minutes in the individual day, as a line of $\frac{7}{10}$ of an inch is taken from or added to the length of the pendulum. And since the time for the swing will almost obey this rule, the remaining correction comes from the movement of the small weight Δ, attached to the stem vv, which is conveniently moved. That weight has the shape of a lens, the section of which follows the axis we have shown in Fig. I. And because it is hardly equal to a twentieth or thirtieth part of the weight X, hence it happens that by descending a large enough space from the first position, the movement of the small weight still does not affect the motion of the pendulum much, truly with the acceleration attributed to the mean length [*i. e*. the centre of mass] of the stem, thus decreased or increased with the motion up or down. Indeed a short time is required to find the position of that point which gives the truest measure of the length of the days, we have divided the length up in a certain ratio, sought from the laws of motion, a little below the centre of the rod, with the weight Δ surely a fiftieth part of the weight X, and equal to the weight of the rod VV. Which divisions are indeed shown in Fig. IV, where the lower part of the pendulum is seen to be in three parts, of which AB is the lowest part, on which the weight is to be hung on. The point A is the centre of gravity of the weight X, moreover from the point C, with the individual sections giving a reduction of 15 minutes of time daily, when the weight Δ is moved by such an interval. Moreover the demonstration of the divisions and the method of finding these, is given in Part IV of this book, concerned with the centre of oscillation.

Others of these clocks are carried by the sea, and give service in investigating longitude. We can describe this form here, if these indeed are suitable for this use, and in like manner as with the preceding, we have performed trials and determinations; and if indeed now it may be deduced that they seem to be lacking a little in perfection yet so many useful things have been discovered. Moreover what was attempted with some good fortune, and what henceforth I should attempt, there is no shame in explaining.

The first two clocks of this kind were carried by a British ship in the year 1664, which a man of the Scottish nobility, who was a friend of mine, had looked after in the making of copies of our clock. These clocks had a coil spring in place of the steel plate for the weight, by the force of which the wheels are turned, [p. 17], as they are accustomed in small amounts by these clocks. Moreover, in order that the movements of the ship can be borne, the clock should be suspended from a steel pillar enclosed by a copper cylinder, and the rod which kept the motion of the pendulum going (that was but six inches from the length of the pendulum) had been produced to twice the length downwards, in order that it could be retained by an inverted letter shape; lest the motion of the pendulum should go off in a circle, by removing the source of the danger. This ship, in the company of three other ships for the journey, later returned to Britain, and the Admiral returned the clock. Truly, when it set sail from the shore of Guinea, and it arrived at the island called St. Thomas [Ilha de Sao Tome], which lies under the equinoctial circle [*i. e*. the equator], here with the clocks put in agreement with the sun, a run towards the west was started on, and for around 700 miles progress was made on course, then again with a favourable wind from the South-West to the shores of Africa to be bound. But on holding to that course for two hundred or three hundred miles, the pilots on the other ships, fearing that they might run short of water to drink before reaching Africa, had urged the master that the course be changed to these islands of the Americas called the Barbados, in order do satisfy the need for water. Then from the council had of the masters themselves, and from the decrees arising from the Ephemeredes and from their own individual calculations, to have discovered that the other calculations differed from his own; one indeed by 80 miles, another by a hundred, and the third even more. Indeed the admiral himself, since he could gather from the hands of the clocks that they were not more than around 30 miles away from the island called *del Fuego*, which is one of the group not far from Africa, which are called the Cape Verd Islands [Ilhas Do Capo Verde], and that they would be able to reach it the following day; by having trust in his pendulums he ordered that course to be followed, and at noon of the following that island came into view, and a few hours later the ships were presenting themselves at the outpost. And this indeed comes from the Admiral's report.

From that time truly the trials were repeated an number of times, at one time with the help of the Dutch, at others with the French, and that under the order of the Most Serene King, with a varied outcome, but thus as more often due to the careless manner in which the clocks were intrusted rather than the clocks themselves being at fault. Truly the best success was in the Mediterranean sea, with the expedition to the island of Crete, where the most illustrious Duke of Belfort, was bringing help to the Candia [The name of the capital in these days] besieged by the Turks, with French troops he had sent, and where he died in the battle. The favour was given to the trial of the clock that he was sailing with on board, and an Astronomer skilled in using these had been placed in charge; and from the observations of which, during the individual days spent, the longitudes of these places either to which the ships were driven, or discerned by eye as they sailed past, could be compared with that which they had left [p.18], which was exactly measured out by the aid of the clocks, and we verified thus, with the descriptions of geography, those places which had been well noted, and could discover in the same manner these places with a different longitude designated. As between the port of Toulouse [1^0, 27'E] and the town of Canadia [now Iraklion; 25^0,1'E] a difference was found of 1 hour and 22 minutes, that is 20 degrees and 30' [actually 23^0,34'], and again from Canadia by returning to

Toulouse the difference was approximately the same, which concensus most assuredly is an indication of the truth.

Between the same port of Toulouse [1^0, 27'E] and a certain island of which the name is *Maretimmo* [~12^0,28'E] near a promontory of Sicily which points to the West, and which used to be called Lilybaeum, the difference of the observed hours is 25 minutes and 20 sec., from which the corresponding degrees of longitude are 6 and 20 minutes. Likewise from Toulouse [1^0, 27'E] to the island called Sapienza [~20^0, 32'E], which is placed to the west of the Peloponnisium peninsula, by one hour, 5', 45", to which corresponds 16 degrees and 26 minutes.

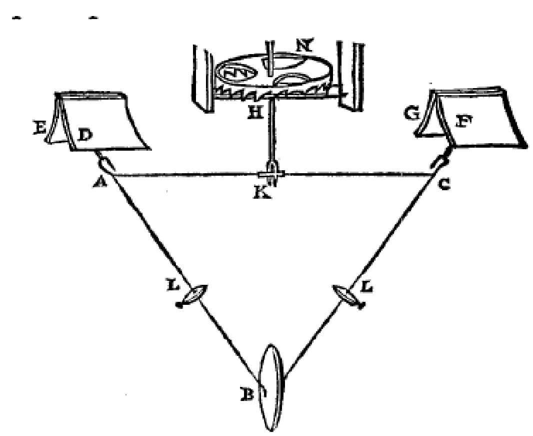
The clocks were compared with the sun at sunrise to the East, and at sunset to the West, with a calculation from the given height of the pole star and with the other instant of time. And this ratio with the ships standing at anchor was seen to be the best of all, since, without the aid of instruments, the observations of the sun by eye could be performed.

Indeed the pendulum for these clocks was nine inches long, with half the weight. The wheels were driven around by the force of the weights, and likewise for those enclosed in the case the pendulums were each four feet long. In most with the case a weight of more than one hundred pounds was added, which served to keep the machine suspended vertically better on board ship.

Moreover, though the constant steady motion of the automaton itself has been verified from these experiments, nevertheless we have also attacked the problem by another method to perfect the clock even more, which was in this manner. To that wheel which has the iron teeth, and which is closest to the pendulum, we have hung a small weight from a skillfully constructed chain, by which it can be moved on its own, with all the rest of the machine acting as before so that by half a minute to the hour the weight could be restored to the previous height [or time] ; by nearly the same reason as was seen in explanation of the construction of the clock above, when the other weight was raised by the string, while the other weight bestowed its motion to the clock. [Thus, in this way, the period of the clock could be adjusted slightly, without stopping the clock to reset the position of the cursor weight on the pendulum rod].

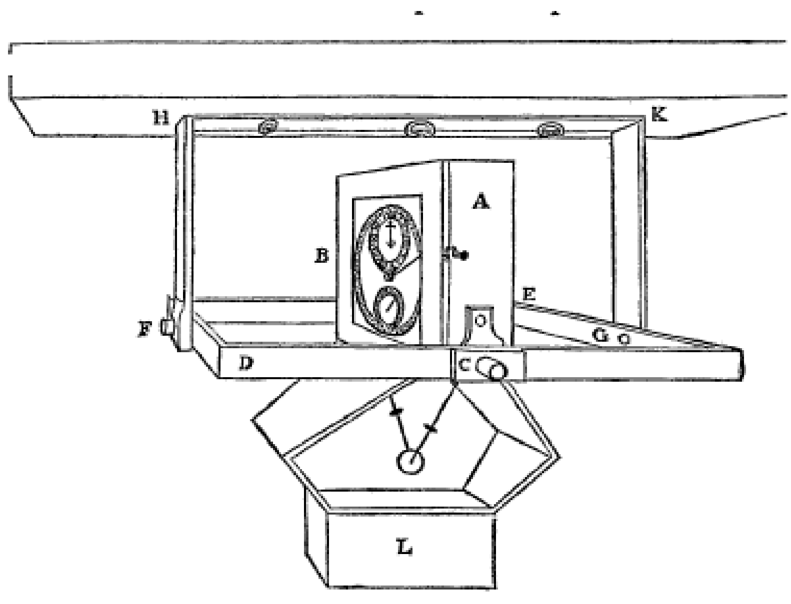
Thus from this construction, just as since everything can be reduced to the motion of a single wheel, the equality of the clocks is more apparent than previously, and it is worth mentioning, since with two clocks constructed in this form and which we can suspend in like manner, truly the cross bar is assigned two fulcrums ; the motions of the pendulums [p. 19] thus share the opposite swings between the two, as the two clocks at no time move even a small distance [from their relative motion], and the sound of both can be heard clearly together always: for if the innermost part is disturbed with a little help , it will have been restored in a short time by the clocks themselves. Looking on for some time with admiration, thus unaccustomed, finally I have found that for the apparatus set up with care, from the motion of the connecting bar itself, that it is not at all sensitive to a cause aimed at upsetting it. Truly the to and fro motions of the pendulum clocks share out the motion from any weight with which they are burdened; and this motion must be effective for a pendulum pressed upon by some act, for if one pendulum is given a contrary motion, as by being struck blows with a nail, so that finally at last by necessity they must deviate, then finally there is no [relative] motion between the pendulums. Thus, such a cause finally has no permanent effect; perhaps the motion of the clocks from elsewhere might be more equal in time and agreeing better between themselves than these. [Thus, Huygens compares the motions of two similar clocks hung up together, and finds that they agree remarkably well between themselves, even if one is disturbed in some way. This is of course the now well known phenomenon of coupled oscillations, where there is a phase difference of 180 degrees between their oscillations.]

With the remaining trials conducted for navigation in the ocean, especially for violent storms with the waters agitated, and at first it was learned with certainty that particular care had to be taken to keep the clocks going without stopping, since due to the ship shaking so much that it was hard to bear, that should be a cause of concern. On account of which we have changed the form of the pendulum and also the suspension of the clock itself, and here we give a short account new of these new developments. The pendulum has the form of a triangle, in



the lower vertex of which can be seen the lead lens fixed in position. The other remaining angles of the [triangular] pendulum have been suspended by strings between cycloidal plates. The foot of the rod H is forked K and the midpoint receives the horizontal movement given by the parallel motion of the serrated wheel N. [One presumes that the fork is held in position for most of the swing of the pendulum, and is allowed to rotate by half a turn when the pendulum is at its maximum amplitudes]. The motion of all the wheels has its beginning not only from the weight or from the steel plate, but also from the drum [pinion K]. In the adjoining figure, ABC is the triangular pendulum; with B the lead lens ;and the cycloidal plates EF, FG; [p. 20] HK the forked rod; N the wheel with the iron teeth, which is below the rest of the wheels of the clock. LL are the small weights that adjust the time of the motion of the pendulum.

[One should bear in mind that this work was done before Newton's *Principia*, and long before there was an understanding of work and energy; hence there is a certain vagueness about cause and effect in the working of the clock.]



A different manner of suspension is shown in this figure; where the case of the clock AB with the first of two axes, of which a part of one C is apparent, with an iron rectangle DE put in place; which then holds another metal frame FHKG with an axis of its own FG, which is solidly fixed to the rafters of the ship. In the inside of the box a weight of 50 pounds has been hung. Thus, by having these axes, for whatever the inclination of the ship, the position of the clock is kept in a vertical position. Moreover the axis C, with the opposite to itself, have thus been arranged, in order that the points of the suspension of this pendulum correspond to a straight line as we have said: from which it shall be the case that there will never be any movement induced from the oscillations of the machine itself, where there is nothing greater that could destroy the motion of the pendulum. Again the width of the axes CC and FG are equal to a thumbwidth, with a lead weight suspended below, obviously they withdraw the freedom of movement from the clock, and in order that if stronger jolts of the ship from below were making displacements, it would immediately revert to its own quiet plumbline.

And indeed these are thus the adjustments to the machine surviving that have been deduced and brought together from the sea trials, and which I hope will bear almost certain success, since as far as one can say to have established from trials, it has been found that all these bear the different kinds of motion much better than before.

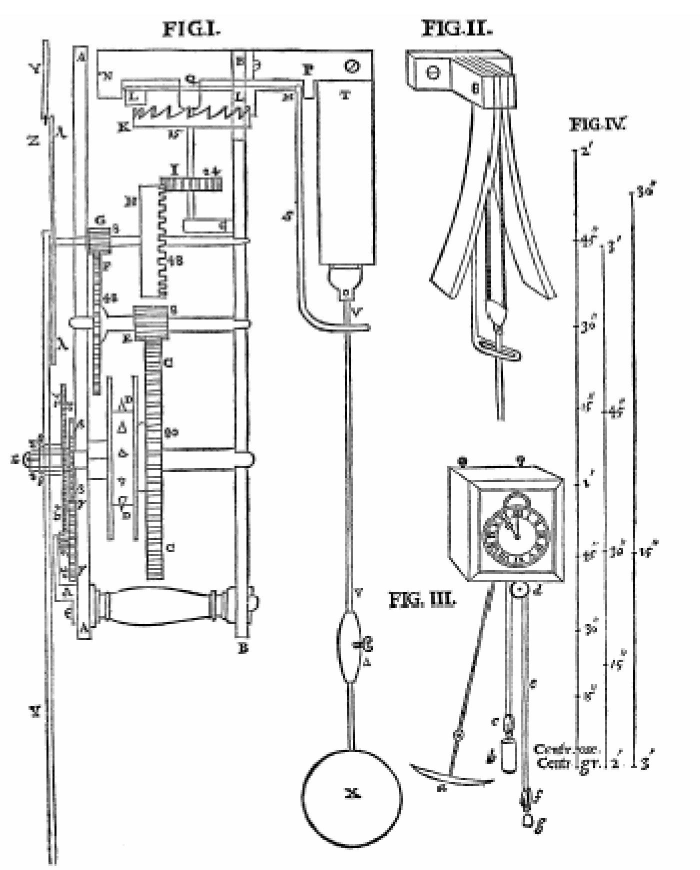
HOROLOGII OSCILLATORII.

Annus agitur sextus decimus ex quo fabricam horologiorum, tunc recens a nobis inventorum, edito libello publicam fecimus. Ab illo vero tempore cum multa invenerimus ad perfectionem operis spectantia, visum est ea singula hoc libro exponere. Quae quidem adeo ad perfectionem ejus inventi pertinent, ut potissima ejus pars censeri possint, ac velut fundamentum totius mechanicae hujus, quo prius destituta erat. Mensura enim temporis certa atque aequalis pendulo simplici natura non inerat, cum latiores excursus angustioribus tardiores observentur; sed geometria duce diversam ab ea, ignotamque antea penduli suspensionem reperimus, animadversa lineae cujusdam curvatura, quae ad optatam aequalitatem illi conciliandam mirabili plane ratione comparata est. Quam postquam horologiis adhibuimus, tam constans certusque eorum motus evasit, ut post crebra experimenta terra marique capta, manifestum jam sit & Astronomiae studiis & arti Nauticae plurimum in iis esse praesidii. Haec ea est linea quam defixus in circumferentia currentis rotae clavus, continua circumvolutione, in aere designat; a Geometris nostri aevi cycloidis nomine donata, & ob alias multas sui proprietates deligenter expensa; a nobis vero propter eam quam diximus mensurandi temporis facultatem, quam nihil tale suspicantes, ac tantum artis vestigiis insistentes, inesse ipsi comperimus. Hanc cum jam pridem amicis horum intelligentibus notam fecerimus (nam non multo post primam horologii editionem animadversa fuit) nunc eandem, demonstratione quam potuimus accuratissima firmatam, omnibus legendam proponimus. Itaque in hac tradenda demonstratione potissima pars libri versabitur. Ubi primum necesse fuit novis nonnullis demonstrationibus stabilire & promovere ulterius viri maxii Galilei de descensu gravium doctrinam, cujus fructus desideratissimus, atque apex veluti summus, haec ipsa quam invenimus cycloidis est proprietas.

Quae porro ut ad pendulorum usum aptari posset, nova curvarum linearum consideratio adhibenda fuit, earum scilicet quae sui evolutione alias curvas generant. Unde comparatio inter se longitudinis curvarum cum rectis nascitur, quam ulterius etiam quam praesens necessitas postulabat prosecutus sum, propter theoriae, ut mihi visum est, elegantiam & novitatem.

Caeterum ad explicandam Penduli Compositi naturam, cujus utilitatem in constructione horum automaton demonstro, adjungenda fuit Centrorum Oscillationis contemplatio, a pluribus quidem, sed minus feliciter, hactenus tentata; in qua theoremata complura animadversione, ni fallor, digna reperientur, ad figuras lineares, planas, solidasque pertinentia. Ante haec omnia vero praemittitur ipsa horologii mechanica constructio, pendulique applicatio, ea forma quae ad usus astronomicos aptissima reperta est, ad cujus instar reliquae omnes, mutatis quae opus est, facile ordinari possint.

Quia vero contigit egregio hujus inventi successu, quod fieri plerumque solet, quodque futurum praedixeram, ut plures sese ejus auctores esse cuperent, aut si non sibi ipsis, suae tamen nationis alicui potius quam nobis eum honorem tribui vellent, iniquis eorum conatibus tandem aliquando occurrendum hic arbitror. Nec sane aliud fere opponere iis necesse fuerit praeterquam id unum, nempe ante annos sexdecim, cum nec dicto nec scripto cujusquam de horologiis hujusmodi mentio facta esset, aut rumor ullus omnino ferretur (loquor autem de penduli simplicis usu ad horologia translato, nam de Cycloidis additione nemo credo controversiam movebit) constructionem eorum propria meditatione me adinvenisse & perficiendam curasse. Insequenti anno, qui nempe hujus saeculi quinquagisimus octavus fuit, delineationem automati descriptionemque typis vulgasse; exemplaria, tum operis ipsius, tum libelli, quaquaversum dimisisse. Nam cum haec ita omnibus nota sint, ut nec testimoniis eruditorum, nec Bataviae Ordinum actis, quibus possent, confirmari opus habeant, facile apparet quid de illis existimandum sit, qui septem post annis eandem constructionem, quasi a se suisve amicis profectam, libris suis venditarunt. Qui vero Galileo primas hic deferre conantur, si tentasse eum, non vero perfecisse inventum dicant, illius magis quam meae laudi detrahere videntur, quippe qui rem eandem, meliore quam ille eventu, investigaverim. Cum autem vel ab ipso Galileo, vel a filio ejus, quam nuper voluit vir quidam eruditus, ad exitum perductum fuisse contendunt, horologiaque ejusmodi re ipsa exhibita, nescio quomodo sibi creditum iri sperent, cum vix verisimile sit adeo utile inventum ignoratum manere potuisse annis totis octo, donec a me in lucem ederetur. Quod si dedita opera celatum fuisse dicant, idem hoc intelligunt a qualibet alio posse obtendi, qui sibi originem inventi arrogare cupiat. Itaque probandum quidem id foret, neque eo magis ad me tamen quicquam pertineret, nisi una quoque ostendatur, id quod omnes latebat, mihi soli innotuisse. Et haec quidem necessariae defensionis causa dicenda fuere. Nunc ad ipsius automati constructionem pergamus.



HOROLOGII OSCILLATORII.

PARS PRIMA.

Descriptionem ejus contens.

Figura adscripta horologium a latere inspiciendum praebet, ubi primum laminae bina sunt AA, BB, semipedali aut paulo ultra longitudine, latae pollices duo & semis, quarum anguli quatuor columellis coaptantur, ut sesquipollice inter se distent. His laminis rotarum praecipuarum axes utrinque inseruntur. Prima atque infima est quae notatur C, dentibus 80 incisa, cujus axi orbiculus quoque D affixus est, aculeis ferreis asper. ut funem cum appensis ponderibus contineat, quae qua ratione ordinentur postea dicetur. Ponderis itaque vi rota C vertitur; haec movet proximum tympanum E dentium octo, unaque rotam F eodem axe haerentem , cui dentes 48. Hanc excipit tympanum aliud G, & in eodem axe rota H, quibus dentium numerus idem qui tympano rotaeque praecidenti. Sed haec rota ejus est generis quas a forma coronarias vocant artifices nostri. Hujus dentibus agitatur tympanum I simulque rota K, quae eodem axe tenetur, ad perpendiculum erecto. Tympano dentes 24; rotae 15, atque hi ad instar serrae dentium incisi. Supra mediam rotam K transversus jacet axis pinnatus LM, cujus extrema sustinent hinc inde gnomones NQ & P, seorsum affixi laminae BB. Notanda vero in gnomone NQ pars deorsum prominens Q, quae oblongo foramine patens transmittit axem L M, simulque retinet eum quem rotae K tympanoque I communem esse diximus, inferiori sui parte gnomoni N innitentem. In lamina BB foramen amplum excavatum est, quo ultra ipsam extendatur axis pinnatus LM, qui subtili cuspide insertus gnomoni P, liberius ita movetur quam si ab ipsa lamina BB sustineretur simulque ultra eam promineret, debet enim prominere necessario ut affigi possit clavula s, quae simul cum eo versationes faciat. Est autem hic motus reciprocus, nunc in hanc nunc in illam partem, quum dentes rotae K alternatim occurrant pinnulis LL, nota vulgo ratione, quaeque proinde diligentiori explicatione non indiget. [p.6]

Porro clavula S, ima sui parte reflexa ac foramine oblongo terebrata, penduli virgam ferream, cui plumbum x affixum est, amplectitur. Haec vero virga superne duplici filo suspensa est inter geminas lamellas, quarum una T hic tantum cernitur; itaque alteram figuram juxta descripsimus, quae utriusque formam flexumque & totam hanc suspendendi penduli rationem exprimeret. Quanquam de vera laminarum istarum curvatura pluribus postea agendum erit.

Nunc autem ut de motu horologii dicamus, nam reliquas figurae partes postea exequemur, facile equidem apparet & vi rotarum, a pondere tractarum, perpendiculi VX motum sustentari, postquam semel manu incitatum fuerit; & simul perpendiculi statos recursus rotis universis, totique adeo horologio movendi legem normamque praescribere. Clavula enim, quantumvis levi rotarum impulsu acta , non tantum obsequitur trahenti perpendiculo, sed & singulis recursibus paulisper ejus motum adjuvat, atque ira perennem reddit, qui alioqui suo sponte, vel verius occursu aeris, deficeret paulatim, vergeretque ad quietem. Rursus vero, quum ejusmodi sit natura penduli ut eodem semper tenore feratur, neque ab eo ulla ratione praeterquam mutata longitudine dimoveri possit; utique postquam flexu lamellarum, inter quas suspensum est aequalitatem illam consequuti fuimus; nequaquam permittitur rotae K, ut nunc citius nunc tardius incedat, etsi saepe, ut in vulgaribus horologiis, id facere conetur; sed necessario singuli dentes ejus coguntur aequalibus transire temporibus. Hinc vero manifestum est, & reliquarum quae praecedunt rotarum, & denique etiam indicum aequalibus conversiones effici, cum omnia proportionaliter moveantur. Quamobrem siquid in fabrica vitii fuerit, vel, ob aeris mutatam temperiem difficilius rotarum axes volvantur; dummodo non eo usque ut omnis horologii motus interrumpatur; nulla propter haec inaequalitas aut motus retardatio timenda erit, semperque aut recte tempus metietur aut omnino non metietur.

Indices porro hoc pacto circumaguntur atque ordinantur. Tertia lamina prioribus parallela est YY, pollicis quarta parte distans ab ea quae notatur AA. In ea circuli horarii descripti sunt centro eodem X quo protenditur axis rotae C. Quorum circulorum interior duodecim horarum divisionem habet, alter scrupulorum 60. Axi vero rotae C aptatur, ultra laminam AA, rota β, tubulo coherens qui usque ad E continuatur trans laminam YY; atque ita [p. 7] insidet axi illi, ut una cum illo circumferatur; sine illo tamen, ubi opus fuerit, converti possit. Ad E index imponitur, horae spatio circuiturus atque ita scrupula prima, seu sexagesimas horarum, demonstraturus. Rota vero quam diximus β, aliam rotam, totidem quot ipsa habet dentium, impellit, atque una affixum ei tympanum cui dentes sex, axiculo eorum communi hinc lamina A, inde gnomone δ suffulto. Hoc tandem tympano rota ζ movetur, dentes habens 72, tubulumque affixum qui & ipse ultra laminam Y ad θ porrigitur, paulo citra quam definit tubulus rotae β, quem intra se complectitur. Parte extrema θ apponitur horarius index, brevior aliquanto illo quem scrupula prima signare diximus, cum interiore gyro ferri debeat. Secunda vero scrupula ut absque errore demonstrentur, imponitur axi rotae H, usque ad laminam Y producto, orbis λ, cui circulus in sexaginta partes divisus inscribitur, incisoque in lamina Y foramine ad Z, eae divisiones, cuspide in summo formamine defixa, praetereuntes notantur. Haec vero tota indicum circulorumque horariorum dispositio ex figura monori clarius perspicitur, exteriorem horologii formam referente.

Caeterum penduli longitudinem, rotis quemadmodum diximus ordinatis, eam esse oportet ut scrupula secunda singulis recursibus metiatur, quae longitudo tripedalis est, cumque commode in schemate exhiberi nequiret, ejus quintam partem a suspensione summa, ubi incipit flexus laminae T, ad usque centrum ponderis X expressimus. Tripedalem dico, non alicujus respectu perdis qui apud Europae gentem hanc illamve in use sit, sed certo aeteroque pedis modulo ab ipsa hujus penduli longitudine desumpto , quem PEDEM HORARIUM in posterum appellare liceat, ad illam enim omnium aliorum pedum mensurae referri debent quas incorruptas posteris tradere vuluerimus. Neque enim, verbi gratio, ignorabitur unquam venturis saeculis Parisini pedis modus, dum constabit eum ad Pedem Horarium esse ut 864 ad 881. Sed de hujus mensurae exactissima constitutione pluribus agemus in iis quae de Centro Oscillationis. Nunc tempora conversionum in singulis rotis indicibusque obiter designabimus, ut recte omnia ad dentium supra descriptorum numerum quadrare intelligantur.

Ergo una quidem conversione rotae C, decies circumire apparet rotam F, sexagies vero rotam H, & centies vicies supremam MK: cui quum dentes sint quindecim, iisque alternatim pulsentur [8] pinnulae L, L, una conversione rotae K numerabuntur ictus 30, quibus respndent totidem itus reditusque penduli VX ideoque conversionibus 120, respondebunt oscillationes simplices 3600, qui numerus est scrupolorum secundorum unam horam efficientium. Itaque horae tempore semel circumit rota C, cumque ea simul index ad E impositus, qui scrupula prima demonstrat. Et quoniam eodem temporis spatio etiam rota β, & per eam γ, convertitur, cum tympanidio suo dentium sex, ad quem numerum duodecuplus est numerus dentium rotae ζ, apparet duodecim demum horis hanc circumduci, totidemque indicem illi conjunctum in θ. Denique cum rotae H sexaginta conversiones respondere ostenderimus singulis conversionibus rotae C, hinc illa, una cum affixo orbe λ, sexagies in singulas hors circumferetur, hoc est, semel unius scrupuli primi tempore, ideoque partes sexagessimae orbiculi λ secunda scrupola transitu suo ostendent: atque ita omnia recte se habere manifestum erit. Pondus X in imo perpendiculo trilibre est, plumbeum totum, vel aenea superficie plumbum contnente. Nec tantum metalli gravitate sed & figura insuper prospiciendum (plurimi enim refert) ut quam minimum occursu aeris impedimentum sentiat. Eoque in cylindri jacentis oblongi & utrinque praeacuti formam fingitur, qualis cernitur ad *a* schemate horologii minore. Quanquam in his quae ad navigationem parantur, forma lentis erectae aptor visa est.

Porro eodem schemate & ponderis alterius *b*, quo motus horologii continautur, suspendendi ratio expressa est, quam, incogitam prius, investigare nobis necesse fuit, ne interim dum fursum retrahitur pondus istud, cessaret vel impediretur aliquatenus horologii cursus, quod hic omnino cavendum erat. Paratur itaque funis continuus atque in se rediens, extremitatibus apte inter se connexis. Is primum orbiculum rotae infimae conjunctum, qui in schemate majori notatus est D, amplectitur; inde descendens, altera sui parte trochleam *c*, cui pondus *b* appensum est, subit. Hinc super orbiculum *d* ascendit, extrinsecus horologio affixum, qui ferreos per circumferentiam aculeos habet, atque insuper ferratis dentibus ita est aptatus ut volvatur tracto fune *e*; nequaquam vero inpartem contrariam revolvi possit. Ab hoc orbiculo descendit funis ad alteram trochleam *f*, cui pondus exiguum g appenditur, quantum sufficit continendo majori *b*, ne aliter quam revoluto orbiculo descendat. Namque a trochlea *f* rursus ad ipsum orbiculum d, unde descenderat, funis revertitur. Quibus ita se [p. 9] habentibus, manifestum est semper pondus *b* dimidia sui gravitate conari ut rotas horologii circumagat, nec tunc quidem cessare cum manu funem e trahente ascendere cogitur; adeoque horologii motum nusqua interrumpi, nec momentum temporis deperdi.

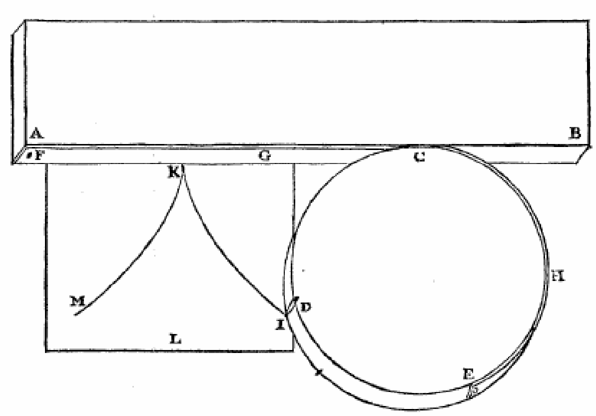
Gravitatis modus in pondere *b* definiri certo non potest, sed quo minor conservando motui suffecerit, eo melius accuratiusque fabrefactum automaton arguet. In nostris, quae optima hactenus habemus, ad sex libras redactum est, posita nimirum orbiculi D diametro pollicari fere, uti exhibita fuit; item perpendiculo pondere trilibri, ac totidem pedum longitudine. Quae longitudo, ut hoc etiam admoneamus, trans capsam horologii dependet, oblongo foramine perviam, quantum oscillationibus peragendis necesse est. Ipsum vero horologium, ad hominis altitudinem suspensum, horis 30 moveri perseverat.

Superest nunc forma lamellarum describenda inter quas perpendiculum affigi deximus, quarumque ad aequabilem horologio motum praestandum vel praecipua est opera. Absque his enim Penduli simplicis oscillationes (etsi nonnullis aliter visum est) non erunt aeque diuturnae, sed brevioris temporis eae quae per minores arcus incedent : idque primum experimento huiusmodi facile deprehenditur. Si enim fila accipiantur ejusdem longitudinis duo, paribusque in parte ima ponderibus religatis, utrumque seorsum suspendatur, tumque alterum eorum procul a linea perpendiculari, alterum parumper duntaxat extrahatur, simulque e manu dimittantur; non diu utrumque simul in partes easdem ferri videbitur, sed praevertet illud cujus exiliors erunt recursus. Sed & temporum per quoslibet arcus rationes numeris definiri possunt, certa scientia nixis, & vero quam libuerit propinquis, veluti quod tempus descensus per totum circuli quadrantem est ad tempus per arcum minimum fere ut 34 ad 29. Adeo ut nequaquam resistentiae aeris ea diversitas imputanda sit, ut quidam voluere , sed ex ipsa motus natura circulique proprietate nascatur. Quod alio quoque argumento concludi possit ex ipsa Penduli isochroni constructione, ubi a circulari linea haud parum reciditur, uti mox patebit.

Sed videatur forsan in nostris horologiis hisce, ubi eadem semper est oscillationum latitudo, nullius momenti futura quam diximus inaequalitas, adeoque nec correctione ulla perpendiculi opus fore. Quod sane ita esset si latitudo omnium plane eadem [p. 10] constante maneret. Sed cum pauxillum quandoque excedat vel deficiat, ex mulitsminimis differentiolis tandem magna satis conflatur, idque ita esse reipsa atque experimentis evincitur. Etsi enim eadem semper sit ponderis vis, rotae sibi proximae respectu, tamen per tot alias transdita, quantcunque cura limatae fuerint, non seper eadem ad perpendiculum usque pervenit. Praeterquam quod frigore quoque difficilior motus rotarum efficitur; itemque evanescente aut sordescente quod illis additur oleo. Sed praecipue inaequales fiunt oscillationes horologiis quae mari vehuntur, ob jactationem navis continuam, adeo ut omnibus quidem in universum, sed his maxime omnium remedio opus sit, quo reciprocationum Penduli latiorum angustiorumque tempora aequalia evadant.

Ad definiendam ergo lamellarum formam in quibus positum est remedium istud, in primis Penduli longitudinem statuisse oportet, quae facile ex eo habetur, quod sint inter se longitudines perpendiculorum, sicut temporum quae in singulos recursus impenduntur quadrata. Adeo ut cum tribus pedibus definiverimus longitudinem perpendiculi quod scrupula metitur, ejus quarta pars, sive inciae novem debeantur ei quod semisecunda notaturum sit. Item si Penduli longitudo quaeratur, cujus recursus simplices 10000 horae spatio peragantur, hoc modo ratio inibitur. Penduli nempe tripedalis scimus 3600 recursus in horas singulas numerari : ergo hujus recursuum tempora singula, majora sunt temporibus Penduli quaesiti, proportione 10000 ad 3600. sive 25 ad 9. Quare ut quadratum numeri 25 ad quadratum 9, hoc est , ut 625 ad 81, ita erit longitudino pedum 3 ad eam quae quaerebatur, nempe unciarum 4 cum $\frac{66}{100}$.

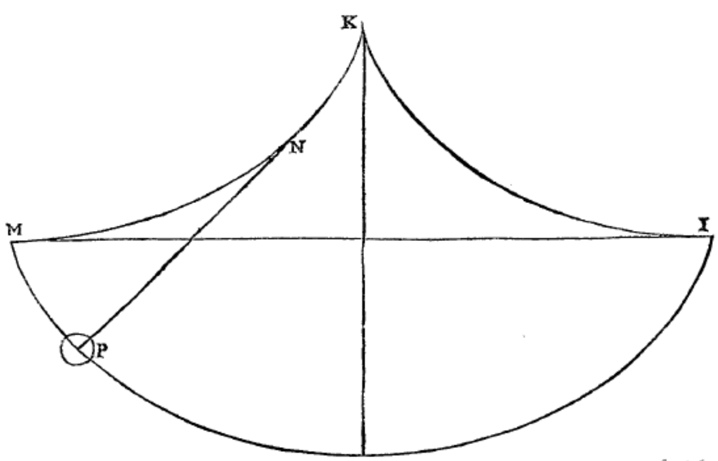
Posita ergo longitudine perpendiculi, puta pedum trium in horologio a nobis proposito,



inde Cyclois linea, quae curvaturam laminarum T datura est, hoc modo describetur. Super tabula plana affigatur regula A B, semidigiti crassitudine. Deinde fiat cylindrus C D E eadem illa altitudine, diametrum vero baseos, dimidiae perpendiculi longitudini, aequalem habens; sitque F G H E fasciola, seu potius bractea tenuis, affixa regulae in huic F, cylindro vero in circumferentiae puncto aliquo E, ita ut partim huic circumvoluta sit, partim extendatur juxta latus regulae A B. Cylindro autem infixa sit ferrea cuspis D I, pauxillum ultra basis inferiorem prominens, atque ita ut circumferentiae ejus exacte respondeat. [p. 11]

His ita se habentibus, si cylindrus secundum regulum A B volvatur, bracteolae tantum FG crassitudine intercedente, eaque semper quantum potest extensa, describet cuspis I subjecto tabulae plano lineam curvam KI, quae Cyclois vocatur. Circulus vero genitor erit CDE, cylindri adhibiti basis. Quod si jam laminam KL ad regulam A B applicuerimus; exarata primum ea cycloidis portione K I, invertemus deinde ipsam, & in superficie adversa similem lineam K M, ab eodem puncto K egredientem, incidemus. Tum figuram MKI, accurate secundum, lineas istas, efformabimus, cui figurae lamellarum interstitium aptari oportet, inter quas per pendiculum suspenditur. Sufficiunt autem ad horologiorum usum portiones exiguae arcuum K M, K I; reliquo flexu inutili futuro, ad quem perpendiculi filum accedere non potest.

Verum, ut mirabilis lineae natura atque effectus plenius intelligantur, integras semicycloides KM, KI, alio schemate hic exprimere visum fuit, inter quas suspensum agitatumque Pendulum KNP, diametri circuli genitoris duplum, cujuscunque amplitudinis oscillationes, usque ad maximam omnium per arcum MPI, iisdem temporibus confecturum sit: atque ita, ut appensae spherae P centrum, in linea M P I, quae & ipsa cyclois integra est, semper versetur. Quae proprietas insignis nescio an alii praeter hanc lineae data sit, ut nempe se ipsam sui evolutione describat. Haec autem quae dicta sunt, in sequentibus, ubi de descensu gravium, deque evolutione curvarum agemus, singula demonstrabuntur. [p. 12]

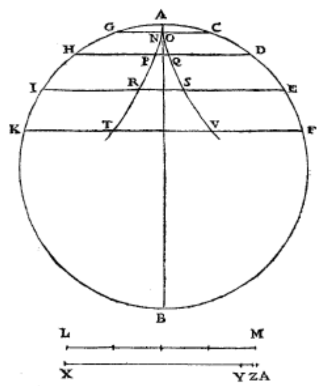


Licebit autem aliter quoque, per inventa puncta, cycloidem designare. Describatur circulus diametro AB, quae dimidiae longitudini perpendiculi aequalis sit. In cuius circumferentia sumptis partibus aequalibus quotlibet, AC, CD, DE, EF, AG, GH, HI, IE, jungantur GC, HD, IE, KF, quae erunt inter se parallelae. Deinde arcui AF sumatur aequalis linea recta LM, eaque in partes aequales totidem dividatur quot sunt in arcu AF, earumque partium uni aequales ponantur singulae CN, GO in recta CG, duabus vero partibus rectae LM, aequales fiant singulae DP, HQ in recta DH. Tribus vero, singulae ER, IS in recta EI; atque ita porro si partes plures fuerint acceptae; ac tandem toti LM aequales fiant singulae FT, KV I linea extrema FK. Iam si curvae describantur per punct

AOQSV, ANPRT, hae rursus quaesitae cycloidis partes erunt, inter quas perpendiculum affigi oportet.

Recta autem LM aequalis arcui AF invenitur, si primum duabus rectis, quae semissibus arcus AF subtenduntur, aequalis ponatur XY, totius vero arcus subtensae AF aequalis ab eodem termino accipiatur XZ, differentiaeque YZ triens ZΔ ad totam XZ adponatur. Nam tota XΔ toti arcui AF tam prope aequalis erit, ut licet sextans fuerit circumferentiae, (neque major hic unquam requiritur) non una sexies millesima parte suae longitudinis deficiat, uti in his, quae de Circuli Magnitudine antehac scripsimus, demonstratum est.

Explicitis quae ad horologii fabricam attinent, nunc quoque illud declarandum est, quo pacto ad veram horarum mensuram componi debeat. Ergo primum, an recte se habeat motus ejus, hoc modo examinabitur. [p. 13]



Oculo observatoris certus eligatur locus, unde sidera despici possint, simulque tecta parietesve vicinarum aedium, sic posita, ut, cum eo appulerint stellae quadeam e fixarum numero, simul videri desinant. Eo loco foramen, ad pupillae magnitudinem, constituatur, ut sequentibus diebus, absque errore, oculus ad idem punctum reponi possit. Iam ad momentum ipsum, cum stellarum aliqua e conspectu abit, notetur tempus horologio indicatum. Atque idem postero die, vel potius aliqot diebus intermissis, fiat. Quod si tantum unius diei spatium duabus observationibus intercesserit, illo, quod prima observatione annotatum fuerat, scupulis primis 3, secundis 56. Ita enim recte se habere perpendiculi longitudinem constabit; quum tanto superetur quaelibet siderum fixorum revolutio a die solari mediocri. Mediocri dico, quoniam dies solares, de medie ad meridiem, non omnes inter se aequales sunt, ut mox amplius exponetur. Si vero post plures demum dies observatio repetatur, in singulos tantundem differentiae causa computandum erit. Sit, exampli gratia, in prima observatione, ad momentum evanescentis stellae, adnotata horologii hora 9, cum scrupolis primis 30. secundis 18; deinde, septimo post die, eadem disparente stella, indicet horam 8, cum scrupulis pr. 50, sec. 24. Haec hora deficit a priore scrupulis pr. 30, secundis 54. Quae, in septem divisa, dant retardationem diurnam scrupulorum 5'. 24''. Debebat autem esse scrupulorum 3'.56'', quae illa minor est scrupulis 1'.46''. [p. 14.]

Itaque tantundem quotidie deficit horologium a vera, seu media, dierum mensura. Caeterum alio quoque modo, ad solem, horologii motum examinare licebit. Sed hic

TABULA ÆQUATIONIS DIERUM.

Dies.	Januar. Min.	Sec.	Febr. Min.	Sec.	Mart. Min.	Sec.	Apr. Min.	Sec.	Maj. Min.	Sec.	Jun. Min.	Sec.
1	10	40	0	32	2	15	11	18	18	32	18	10
2	10	10	0	24	2	28	11	37	18	39	18	1
3	9	41	0	18	2	42	11	56	18	46	17	51
4	9	13	0	13	2	56	12	15	18	53	17	41
5	8	45	0	9	3	11	12	34	18	59	17	30
6	8	17	0	6	3	26	12	53	19	4	17	19
7	7	50	0	3	3	41	13	12	19	9	17	8
8	7	23	0	1	3	56	13	31	19	14	16	57
9	6	58	0	0	4	12	13	49	19	18	16	46
10	6	34	0	0	4	29	14	6	19	22	16	35
11	6	10	0	0	4	46	14	23	19	25	16	24
12	5	47	0	2	5	4	14	39	19	28	16	13
13	5	24	0	4	5	22	14	55	19	29	16	1
14	5	2	0	8	5	40	15	10	19	29	15	49
15	4	41	0	12	5	58	15	25	19	29	15	37
16	4	21	0	16	6	16	15	39	19	28	15	24
17	4	2	0	21	6	33	15	53	19	26	15	11
18	3	44	0	26	6	51	16	7	19	24	14	58
19	3	27	0	32	7	9	16	21	19	21	14	45
20	3	11	0	40	7	27	16	34	19	18	14	32
21	2	55	0	48	7	45	16	47	19	15	14	19
22	2	39	0	57	8	3	16	59	19	11	14	6
23	2	23	1	6	8	22	17	11	19	7	13	53
24	2	7	1	16	8	41	17	22	19	2	13	40
25	1	52	1	26	9	1	17	33	18	57	13	27
26	1	38	1	37	9	21	17	43	18	51	13	15
27	1	25	1	49	9	41	17	53	18	45	13	3
28	1	13	2	2	10	1	18	3	18	39	12	52
29	1	2			10	21	18	13	18	33	12	41
30	0	51			10	40	18	23	18	26	12	30
31	0	41			10	59			18	18		

Dies.	Jul. Min.	Sec.	Aug. Min.	Sec.	Sept. Min.	Sec.	Octob. Min.	Sec.	Nov. Min.	Sec.	Dec. Min.	Sec.
1	12	19	10	4	16	23	26	30	31	55	25	34
2	12	8	10	8	16	42	26	49	31	55	25	10
3	11	58	10	13	17	1	27	8	31	54	24	45
4	11	48	10	18	17	21	27	26	31	52	24	20
5	11	38	10	23	17	41	27	43	31	50	23	55
6	11	28	10	28	18	1	28	0	31	47	23	30
7	11	18	10	34	18	21	28	16	31	43	23	4
8	11	9	10	41	18	41	28	32	31	37	22	38
9	11	0	10	49	19	1	28	47	31	30	22	11
10	10	52	10	58	19	21	29	2	31	22	21	43
11	10	47	11	7	19	41	29	16	31	13	21	14
12	10	38	11	16	20	1	29	30	31	3	20	44
13	10	31	11	25	20	22	29	43	30	53	20	14
14	10	25	11	36	20	43	19	56	30	43	19	44
15	10	19	11	48	21	4	30	9	30	32	19	14
16	10	13	12	1	21	25	30	22	30	20	18	44
17	10	7	12	14	21	47	30	34	30	8	18	14
18	10	2	12	28	22	9	30	45	29	55	17	44
19	9	58	12	42	22	31	30	55	29	40	17	14
20	9	54	12	57	22	52	31	4	29	23	16	44
21	9	51	13	12	23	13	31	12	29	6	16	14
22	9	49	13	27	23	33	31	19	28	48	15	44
23	9	47	13	43	23	53	31	26	28	30	15	14
24	9	46	13	59	24	13	31	32	28	11	14	43
25	9	46	14	16	24	33	31	38	27	51	14	12
26	9	46	14	33	24	53	31	43	27	30	13	41
27	9	47	14	50	25	13	31	47	27	8	13	10
28	9	49	15	8	25	33	31	50	26	45	12	40
29	9	52	15	26	25	52	31	53	26	22	12	10
30	9	56	15	45	26	11	31	55	25	58	11	40
31	10	0	16	4			31	55			11	10

jam inaequalitatis dierum naturalium ratio habenda erit. Sunt enim, ut jam dixi, non omnes ejusmodi dies inter se aequales; & quanquam exiguum sit discrimen, tamen plurium dierum intervallo saepe eo usque excrescit, ut haudquaquam contemni possit. Etenim si & solarium quam perfectissime descriptum habeatur, & horologii automati motus ad verissimam dierum mensuram exactus sit, neque ab ea recedat; eveniet tamen necessario ut, certi anni temporibus, saepe horae quadrante, aut etiam semihora, inter se discrepent, ac rursus statis temporibus ultro concordent. Hoc enim ita esse, ex tabula temporis aequatoria quam subjicimus, intelligetur; postquam usum ejus ostenderimus, qui est hujusmodi.

Accipiatur aequatio tabulae, assignata diei qua primum cum sole, sive cum sciotherico, horologium ut conveniret fecimus. Itemque aequatio diei, qua quaeritur quam bene ad dierum mensuram temperatum sit. Quod si jam prior aequatio major fuerit sequente, superare debebit hora automati horam gnomonis eo, quo inter se aequationes istae differunt. At si posterioris diei aequatio major inveniatur, erit excesssu penes horam gnomonis, sive eam quae ex sole obervatur. Ut si, exempli gratio, die 5 Martii in eandem horam conveniant sciothericum horologium atquae automaton, cujus diei aequatio invenitur, in tabula, scurpulorum primorum 3 secundorum 11. lubeatque scire ejusdem mensis die 20. an automaton horas aequales recte metiatur necne: invenietur dei posteriori adscripta aequatio scrupulorum primorum 7, secundorum 27. quae quia superat praecedentem scrupulis primis 4, secundis 16, debebit tanto serior esse hora sciotherici, quam quae automato indicatur. Unde, si diversum apperiatur, facile inde colligetur, quantum in dies singulos exuperet automaton, aut retardet.

In computanda tabula hac duplicem causam adhibui, utramque Astronomis nota, Eclipticae nimirum obliquitatem, & solaris motus anomaliam. Quod cum ratio postulat, tum experientia quoque, his ipsos horologiis superstructa, quaeque sine his nequaquam haberi poterat, evincit; quandoquidem, cum aequatione hic proposita, observatones solis, quas saepe per complures mentes, quotidie ad momentum quo meridianum circulum sol occuparet, instituimus. planissime consentire inventae sunt. [p.15/16.]

Jam postquam utrovis modo eorum quos diximus, sed priore potius, examen nstitutumfuerit, si multum aberrare a media dierum longitudine horologium reperiatur adeo ut differentia ultra tria quatuorve prima scrupula ascendat, remedium adhibebitur aucta aut diminuta ipsius penduli longitudine. Ubi haec tenenda est regula, tot scrupulis primis, in singulos dies, motum horologii acceleratum aut retardatum iri, quot $\frac{7}{10}$ unius lineae auferentur pendulo aut addentur. Cumque ad veram mensuram hoc pacto jam prope reductum erit, reliqua correctio transpositione exigui ponderis Δ, virgae v v adhaerentis, commode peragetur. Id pondus lentis formam habet, cujus sectionem secundum axem in figura I expressimus. Et quia tantum vicesimam tricesimamve partem aequat ponderis X , hinc fit ut sat magnis spatiis e priore loco descendens, haud multum tamen perpendiculi motum afficiat, accelerando nempe quoties versus mediam virgae longitudinem attrahitur, retardando cum inde sursum aut deorsum movetur. Ne vero diu punctum illud quaerendum sit quo verissimam daturum sit dierum mensuram divisimus certa ratione, ex motus legibus petita, inferiorem virgae medietatem, posito nimirum pondere Δ parte quinquagesima ponderis X, parique gravitate ipsius virgae v v. Quae quidem divisiones figura IV exhibentur ubi penduli portio inferior in tres partes secta cernitur, quarum , quae infimo loco ponenda, est AB. Punctum A est centrum gravitatis ponderis X, a puncto autem C, partes singulae, quindecim scrupulorum primorum diffentiam diurnam efficiunt, ubi tali intervallo mota fuerit lens Δ. Demonstratio autem divisionumque inventio, dabitur in iis quae de Centro Oscillationis.

Caeterum illorum quoque quae mari vehuntur, longitudinum investigandarum gratia, formam hic describeremus, si quaenam maxime ad hunc usum accommodata sit, aequae ac in praecedentibus, exploratum determinatumque haberemus; etsi quidem jam nunc eo res deducta sit, ut parum deesse videatur ad perficiendum tantae utilitatis inventum. Quid autem & qua fortuna hic tentatum fuerit, quidve deinceps tentandum rester, exponere non pigebit.

Prima duo hujusmodi horologia Britannica navi vecta fuere anno 1664, quae vir nobilis e Scotia nobisque amicus ad nostrum exemplum fabricari curaverat. Haec ponderis loco laminam chalybeam habebant in spiram convolutam, cujus vi rotae circumagerentur, [p. 17], quemadmodum in exiguis illis quae circumferri automatis adhiberi solent . Ut autem jactationem navis perferre possent, e chalybea pila, cylindro aeneo inclusa, horologia suspenderat, clavulamque quae penduli motum continuat (erat autem semipedali longitudine pendulum) deorsum productam geminaverat, ut literae F inversae formam referret; ne videlicet in gyrum evagari posset penduli motus, unde cessationis periculum. Navis haec, cum tribus aliis quas itineris socias habuerat, postquam in Britanniam reversa est, Praefectus classis haec retulit. Se nempe, cum a Guineae littore solvisset, atque ad insulam sancti Thomae dictam, pervenisset, quae aequinoctiali circulo subjacet, compositis hic ad solem horologiis, occidentem versus cursum instituisse, atque ad septingenta circiter milliaria continuo tramite progressum, tum rursus vento favente Libonoto ad Africae littora declinavisse. Cum autem ad ducenta trecentve milliaria eo cursum tenuisset, magistros aliarum navium, veritos ne priusquam Africam attigissent aqua ad potum deficerentur, suasisse ut ad insulas Americana, Barbatorum dictas, aquandi gratia deflecteret. Tum sese concilio nauclerorum habito, jussisque ut Ephemeridas ac supputationes singuli suas proferrent, reperisse caeterorum culculos a suis diversos abire, unius quidem 80 milliaribus, alterius centenis, tertii amplius etiam. Ipsum vero, cum ex horologiorum indicio collegisset non amplius quam triginta circiter milliaribus abesse insulam *del Fuego* dictam, quae una est earum, non procul ab Africa distantium, quae a Viridi promontorio nomen habent, eamque postero die teneri posse; confisum pendulis suis eo cursum dirigi imperasse, ac die insequenti sub meridiem eam ipsam in conspectum venisse insulam, paucisque post horis navibus stationem praebuisse. Et haec quidem ex Praesecti illius relatu.

Ab eo vero tempore aliquoties tum Batavorum tum Gallorum opera, idque Regis Serenissimi jussu, repetita fuere experimenta, vario eventu, sed ita ut saepius negligentia eorum quibus horologia commissa erant quam ipsamet automata culpari possent. Optimus vero successus fuit in Mediterraneo mari, experitione in Cretam insulam, quo illustrissimus Dux Berfortius, Candiae a Turcis obsessae auxillium laturus, cum Gallorum copiis missus erat, ubi & in praelio occubuit. Is in ea qua vehebatur navi, horologia hujusce experimenti gratia habebat, virumque Astronomiae peritum iis praefecerat, e cujus observationibus, in singulos dies habitis, longitudines locorum ad quae in ea profectione aut appulerunt [p.18] naves, aut quae praetervecti dignoscere oculis potuerant, horologiorum opera exacte demensas fuisse comperimus, atque ita ut Geographicis descriptionibus quae melioris notae habentur eaedemmet longitudinum differentiae designatae reperiantur. Namque inter Toloni portum Candiamque oppidum differentia hor. 1 scrup. 22' reperta fuit, hoc est graduum longitudinis 20 scrup. 30' ac rursus a Candia Tolonum revertentibus differentia proxime eadem qui consensus certissimum veritatis est indicium.

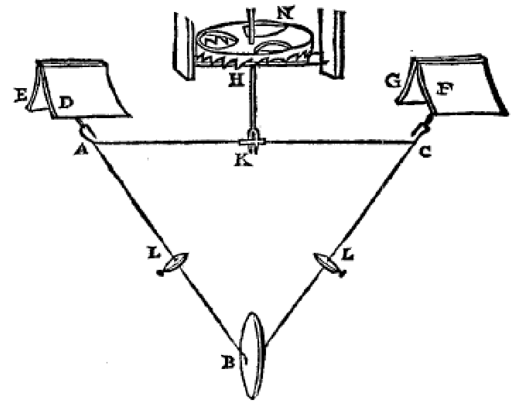
Inter eundem Toloni portum & insulam quandam cui Maretimo nomen est, prope promontorium Siciliae quod Occidentem spectat, Lilybaeum olim vocatum, differentia horaria observata est scrup. prim. 25, sec. 20, quibus respondent gradus longitudinis 6, scrup. 20. Idem a Tolono ad insulam Sapienza dictam, quae juxta Peloponnesum est Occidentem versus, hora 1, scurp. prima 5', sec. 45", quibus respondent longitudinis gradus 16, scrup. 26.

Horologia ad solem examinata fuerant, mane ad Orientem, vespere ad Occidentem, supputato ex data poli altitudine utroque temporis momento. Atque haec ratio cum naves in anchoris stant omnium optima videtur, quod, absque instrumentorum ope, solis oculis eae observationes peragantur.

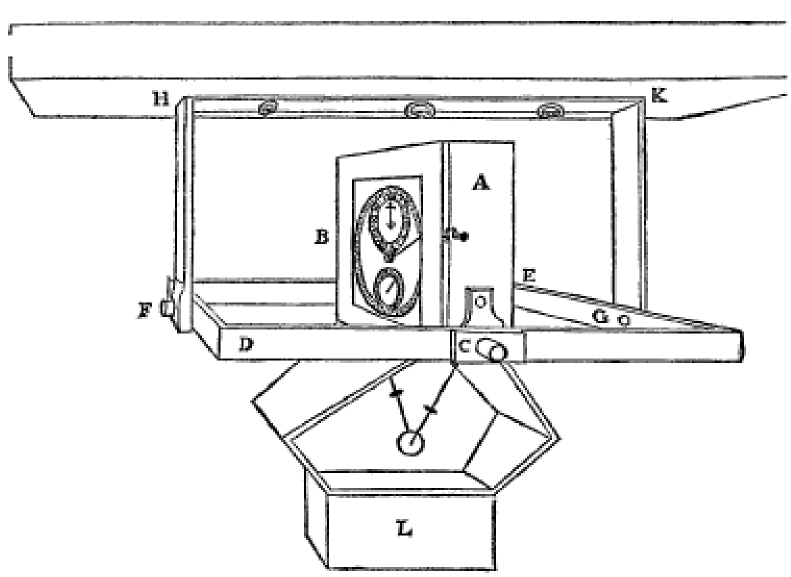
Pendulum vero unciarum novem longitudine inerat horologiis hisce, pondere semissis. Rotae ponderum attractu circumagebantur, eademque cum illis theca inculsae erant quaternum pedum longitudine. In ima theca plumbum insuper centum atque amplius librarum additum erat, quo melius perpendicularem situm suspensa in navi machina servaret.

Quanquam autem aequabilis admodum sibique constans automati motus per haec experimenta comperiebatur, tamen alia quoque ratione ulterius illud perficere aggressi sumus, quae erat hujusmodi. Rotae illi quae ferratos dentes habet, penduloque proxima est, pondus exiguum ex catenula affabre constructa appendimus, quo sola ipsa moveretur, reliqua omni machina nihil aliud agente quam ut singulis semiscrupulis horariis plumbum illud exiguum ad priorem altitudinem restitueret; eadem fere ratione atque in constructione horologii superius exposita videre est, ubi pondus altero fune attilitur, dum altero gravitatem suam horologii motui impertit. Quibus ita constructis, cum veluti ad unicam rotam omnia essent redacta, major adhuc quam antea apparuit horologiorum aequalitas, illudque accidit memoratu dignum, quod cum duo ad hanc formam constructa ex eodem tigno suspendissemus, tignum vero fulcris duobus impositum esset; motus penduli [p. 19] utriusque ita ictibus adversis inter se consensere, ut nunquam inde vel minimum recederent, sed utriusque sonus una semper exaudiretur: imo si data opera perturbaretur concordia illa, semetipsam brevi tempore reduceret. Miratus aliquandiu rem adeo insolitam, inveni denique, instituto diligenti examine, a motu tigni ipsius, licet haudquaquam sensibili, causam petendam esse. Nempe pendulorum reciprocationes horologiis, quantolibet pondere gravatis, motum aliquem communicare; hunc vero motum, tigno ipsi impressum, necessario efficere ut si aliter quam contrarius ad unguem ictibus pendulum utrumque moveatur, eo tamen necessario tandem deviant, ac tum demum tigni motum penitus interquiescere. Quae tamen cause non satis eddicaciae haberet, nisi & horologiorum motus aliunde aequabilissimus foret atque inter se consentiens.

Caeterum experimentis in Oceani navigatione habitis, ac praesertim procella vehementiore aquas agitante, compertum fuit primum ac praecipuam curam de motu horologiorum absque interruptione conservando habendam esse, quod jactationem navis tantam aegre tunc perferre illa animadversum sit. Quamobrem nova denique ratione & penduli formam immutavimus, & aliter horologia ipsa suspendimus. Pendulum trianguli formam habet, in



cujus vertice deorsum spectante plumbea lens affixa est. Anguli utrique reliqui filis inter laminas cycloidales suspensi sunt. Basis clavulam bifurcatam puncto sui medio recipit ab eaque movetur, illa vero ab rota serrata horizonti parallel motum accipit. Motus rotarum omnium non a pondere se a chalybea lamina, tympano inclusa, principium habet. In figura adjecta pendulum triangulare est A B C; lens plumbea B; laminae cycloidales E F, F G. [p. 20] Clavula bifurcata HK; rota ferratis dentibus N, quae caeteris horologii rotis inferior est. Lentuculae ad temperandum penduli motum LL.



Suspensionis modum altera haec figura exhibet; ubi theca AB axibus primum duobus, quorum alter C tantum apparet, rectangulo ferreo DE inserta est; quod deinde rectangulum rursus axibus suis F G ferreo gnomone F H K G sustinetur, qui contignationi navis immobiliter affixus est. In ima theca pondus 50 librarum appensum est. Quibus ita se habentibus , quacunque navis inclinatione perpendicularem positum servat horologium. Axis autem C, cum sibi opposito, ita collocati sunt, ut ad rectam lineam respondeant punctis suspensionum penduli ejus quod diximus : quo sit ut motus ipsius oscillatorius machinam nequaquam commovere possit, quo nihil est alioque quod magis penduli motum destruat. Porro axium CC, & FG crassitudo, quae pollicem aequat, gravitasque plumbi inferius appensi, nimiam movendi libertatem horologio adimun, faciuntque ut si forte succussu navis graviore commitum fuerit continuo ad quietem perpendiculumque suum revertatur.

Et haec quidem ita adaptata machina ut in mare deducatur experientiaeque committatur superest, quae & certam pene successus spem praebet, quod iis quae hactenus instituere licuit experimentis, multo melius quam priores illae omnem motus diversitatem perferre reperta sit.