An accessible ‘translation’ of:

A DESCRIPTION CONCERNING SUCH MECHANISM AS WILL AFFORD A NICE, OR TRUE MENSURATION OF TIME;

TOGETHER WITH SOME ACCOUNT OF
THE ATTEMPTS FOR THE DISCOVERY OF
THE LONGITUDE BY THE MOON:

AS ALSO AN ACCOUNT OF THE
DISCOVERY OF THE SCALE OF MUSICK.

JOHN HARRISON

INVENTER OF THE TIMEKEEPER FOR THE LONGITUDE AT SEA.

PREFACE

With the firm objective of enabling access to what is widely regarded as a prohibitively complex and time-consuming manuscript, this publication is a modern (2011) 'translation' of John Harrison's final (1775) pamphlet, commonly referred to as 'Concerning Such Mechanism' or 'CSM'. Text relating to Harrison's principles of timekeeping and the determination of longitude at sea has been considered; Harrison's explanation of his theories of music is not included. This is not a technical interpretation; every effort has been made to preserve Harrison's original meanings without interference. In the interests of clarity and relative ease of reference, there has been some rearrangement of text and an occasional omission or abbreviation of repeated content. Paragraphs have been created from an original text almost bereft of such. Footnotes have been appropriately integrated within the text, for ease of reference. Literary elegance has been sacrificed to sensible translation. The original manuscript (see BIBLIOGRAPHY) should be considered the work of reference.

David Heskin. Lancashire, England, June 2011

CONVENTIONS

Parentheses thus: [indicate input by the author of this transaltion]

Combined quotation marks and italics thus: *'indicate an extract from CSM '*.

Amplitude – maximum displacement from the stationary or mean position (recoil as specified).

BIBLIOGRAPHY

With thanks to Mr Anthony Zwygart and Mr Bob Holmström, a facsimile of CSM is currently available on the NAWCC Horological Science website at: http://www.hsn161.com/HSN/CSM_Zwygart.pdf

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1st Edition. June 2011

Regarding the nature of a pendulum, primarily implying in itself; and secondarily, the ways (good or bad) in which it may be applied to the drive from the wheels of a clock etc.

Firstly (without considering the chief matter, which is what pertains to different amplitudes, or more correctly, what advantage pertains to, or accrues from large amplitude) the bare length of a pendulum can only be properly assessed in proportion to the length of the pallets, together with related detrimental influences; in other words, the equivalent distance from the centre of motion at which impulse is applied and the effects of the differing states of oil.

Sometimes, some men, being ignorant of my principles and about to do something they imagine to be extraordinary, render the matter still worse, even far worse. My good friend, Mr Graham directed that his so-called astronomical clocks (despite them being poor regulators, or defective timekeepers) should incorporate pallets of such a length that escapement impulse is applied no closer to the centre of motion of the pendulum than its length divided by about 14½. The effect is to render the power of a long pendulum no better than a short one. Furthermore, Mr Graham maintained poor, little or feeble pendulum motion using greatly sloping escapement pallets, jamming, wedging, pushing and pressing forward with a quicker motion, followed by a motion, possibly twice as great, during which time the pallets are obliged to recede on a perpendicular to the escape wheel. The effect is to further diminish the power or regulation of the pendulum Those effects, taken together, effectively render the pendulum very short indeed; expressed in the same terms as above, hardly as much as 10; in fact, it would not be amiss to state 7¼, which is certainly very improper[1]**.** Also, not only does the inconsistent transmission of power by the pallets to the pendulum degrade the natural stability of the pendulum, but so too does the presence of oil, as demanded by the poor escapement design. Variations due to changes in the oil at the pallets (and at the movement train pivots) should never be permitted to affect the pendulum motion, yet nothing is done prevent it! Such effects will have an especially bad influence on small pendulum amplitude combined with impulse applied at so remote a distance from the pendulum centre of motion.

The learned part of the world (through Mr Graham) has become so stupidly confident in this nonsense, it can hardly be persuaded that anything else could ever be better. Thus far, the public (unlike myself) are not aware of anything else and no proper steps have been taken to inform them; they may well remain in the dark (or at least in a mist).

'..whenas, it has ever been surprising to me, how such stupidity could take place and spread itself in the world; for the first time I saw Mr Graham and he shewed it me, I thought, that either he must be out of his senses, or I must be so!'

[1] By the way, a very bad example for church and turret clocks, with a pallets disposition, or dead-beat way, according to Mr Graham. Even the different weight of the driving rope, when the driving weight is up, compared to almost down, greatly affects the pendulum amplitude. The same effect may be observed in the discharge of the striking. There is clearly considerable room for improvement. Mr Graham didn't think it proper to include so much as the day of the month in his clocks (as well he might not). With a pendulum correctly incorporated (and assuming the same of the train) such things would be of no consequence, should there be an excess of energy.

Now, regarding the first of my points: The length of the pendulum, relative to the distance from the centre of motion at which impulse is applied, should be in a proportion of approximately 100 to 1. There must be no wedge-like thrusting action by the escapement. Moreover, there will be no variations due to alterations in the stickiness of oil, because my escapement design requires no oil. The friction of my escapement is so greatly reduced that it doesn't come to $1/100^{th}$ of that of common escapements (meaning Mr Graham's), even when the oil applied to those escapements is at its greatest state of fluidity. It may be assumed that the entirety of the very small friction is applied approximately $1/44^{th}$ of the length of the pendulum from its centre of motion, from which, in combination with the very small magnitude, friction is rendered immaterial and may be ignored. The pivots of the escapement and crutch arbor are brass knife-edges, pivoting in polished notches cut into glass, which must also create insensibly little friction. As a relevant example, with the movement on a table, the escapement (with crutch attached, but without the pendulum) will swing freely on its knife-edges (at an amplitude low enough to avoid contact with the escape wheel) for ten minutes, before coming to rest. The air (at that rate of oscillation and being so light a matter) may be supposed to be sufficient to cause stoppage in that length of time.

It is argued that Mr Graham's pendulum motion requires very little impulse (which is due to it being applied so far from the centre of motion). What an extremely lazy way of thinking! As already implied, variations in pendulum motion are not caused by force as such, for the greater the force can be made, the more constant that force will be in proportion to itself. Related influences aside[2], any variations in timekeeping must, as above, be due to variations in the states of the oil, chiefly at the pallets. A small impulse will be affected in greater proportion. Variations must arise when small impulse is combined with its application at a great distance from the centre of motion of the pendulum, together with the weak, small, feeble pendulum amplitude.

If such weak impulse was a good thing, then why not apply it at a distance from the centre of motion equal to the length of the pendulum? The impulse could then be reduced even further. How pointless that would be, for the corresponding pendulum amplitude would become so small as to hardly be a motion at all. The property and power of the pendulum would have been lost; such a force (unrealistically assuming it could be maintained) would create huge instability. Assuming the pendulum bob to be immensely heavy would have no effect (yet that is what Mr Graham's approach is pretty much akin to, or too closely resembles).

From the above, by way of a corollary and a principle applicable in general to this entire topic, the escape wheel passing through too much space in a second and the pendulum passing through too little space in a second (i.e. each of its swings) must endow the escape wheel and escapement with too much authority over, or bad effect upon, the pendulum. The consequence will be that the differing states of the oil, chiefly at the pallets, in combination with (and partly due to) the different states of the air, must and will cause considerable variations in the motion of the clock.

[2] A firm pendulum suspension point must first be ensured, i.e. a firm wall, with no dependence upon the clock, clock case or any wainscot. Without that (as previously was common) the true performance of a clock must be no better than chance.

If a clock constructed according to Mr Graham's methods (nowadays very common) or any of the other (still the most common) clocks is subject to increased friction at the pallets (due to the above, or any other causes), a touch of fresh oil (applied at one or two teeth of the escape wheel) will cause a different pendulum motion. In the case of Mr Graham's clocks, with a small pendulum amplitude and the other poor characteristics described earlier, most especially when the oil is foul, a touch of fresh oil will cause the pendulum amplitude to increase and the clock to thereby go faster. Dr Bradley also occasionally experienced and reported a variation of approximately two seconds a day faster when the escapement was freshly oiled. No doubt, the clock would have gone faster still had the movement pivots also been freshly oiled[3]. When the pendulum amplitude is larger, a touch of oil will still, as just described, cause an increase in amplitude, but the effect will then be to cause the clock to run more slowly. This is a more satisfactory outcome than in the former case, because it is in accordance with the nature of a pendulum, whereas the former is contradictory to it, notwithstanding whatever mass may be, or could ever be, in the pendulum bob, as with respect to the force to maintain its motion[4]!

[3] Note that Mr Graham's attempt to reproduce my compound pendulum failed, by a good deal, to use sufficient redoublings of brass and steel wire, being 2 inches (or more) shorter than my proven amount (without which, my clock would go too slow in summer). It should be understood that the shorter the redoublings of the wires, the longer will be the pendulum when warm.

Given his impulse at a great distance from the centre of motion of the pendulum, poor escapement design and feeble pendulum amplitude [described in more detail earlier], it is clear that warm conditions would increase the slipperiness of the oil, thus hastening the pendulum motion. Cold conditions (generally speaking) would increase the stickiness of the oil. This agrees with Dr Bradley's observations of the effect of fresh oil.

[4] Some have spoken of how long a pendulum will swing when free, but take no notice of how long it swings when within a clock, operating below the escaping amplitude, with a pallet engaged with a driven escape wheel tooth. Neither do they take notice of the most important effect (upon how long the pendulum swings), which is the difference between clean and newly oiled pallets, compared to when the oil is foul.

Other very significant factors aside, shorter pallets, a higher torque to the escape wheel, larger pendulum amplitude and correct recoiling instead of dead periods ought to have been employed, rather than so many improper, degenerate principles[5].

[5] It is, or must be very proper that the following be documented, should apparently unaccountable timekeeping errors (as high a two seconds a day, as with Mr Graham's clocks) occur in future, due to natural causes (assuming no alteration to the pendulum rating nut after it, or the clock, have been truly adjusted).

Had Mr Graham arranged for the acting pallet faces of his escapement to begin their impulse some time after the middle of each *'vibration'* (as much as, perhaps, one sixth of the pendulum *'vibration'* after the mid point, with further refinement based upon experience), then the better action at the start of impulse might have improved matters (and not only with respect to the effect of fresh oil, but also the effect of variations in drive from the train). The improvement would be achieved despite Mr Graham's application of impulse too far from the centre of motion of the pendulum and his inadequately small pendulum amplitude. At all times the pendulum would need to be firmly suspended from a wall, using brass or iron, without which, progress would be extremely inadequate or deficient.

At this point, it must be understood that, in order to maintain continuous pendulum motion, the later any help or force is applied to a pendulum, the longer will be the time it will take in being performed. From that, moreover, (or as a consequence), the greater that force, the longer each pendulum *'vibration'* will, or would thereafter still be, *'viz. as jointly by or from its Lateness, or, as mathematically speaking, the more Time each must as still take up in its being performed'*. Consequently, it is difficult to say precisely whether greater slipperiness would make the clock go faster, for it might just as easily go slower.

Throughout the above, it has been assumed that the escapement could accommodate such late impulse, whereas, it might not, because of the necessary degree of weakening of the escape wheel teeth tips. In addition, the small amplitude and unstable escape wheel torque could render the clock more susceptible to stoppage. Overall, therefore, a very deficient arrangement.

One can only wonder why such nonsense has persisted and why, amongst all of our mathematicians and geometricians, none have identified the truth. How has such a dishonourable oversight prevailed, not only for such a long time, but for any length of time? Even Dr Bradley's demonstration of the effect of fresh oil (in combination with the feeble pendulum amplitude and sudden impulse applied at a great distance from the centre of pendulum motion) has still not revealed the great weakness of the arrangement to them, which (I say) is very inadequate.

Instead of dead portions at the pallets, there should be hooking or, more correctly, a little convex slanting or bowing the other way in that part of the pallets, in order to (in some measure) assist the pendulum during the last part of its ascents and hinder it at the beginning of its descents. The escape wheel teeth should be curved forwards, to accommodate that (difficult to execute). That, together with everything else (although undiscovered by such 'learned men' as above) will cause the clock to go slower (corrected using the common adjustments) and no longer faster from a touch of oil. However, the degree to which this might best be done is uncertain, given the amount of friction. The gridiron pendulum would require adjustment, in order to provide appropriate compensation for the later impulse, in addition to temperature.

The facts given above clearly demonstrate (as was the intention) the impracticability of small amplitudes.

Although the above will bring things closer to the truth, if oil is required at the pallets (of the sort and in the applications I've been referring to), I may be bold enough to say that the clock will still not keep the same time in any two days, when the weather is variable. That applies to Mr Graham's method, or the more common sort, even whether oil was required at the pallets or not. Variable weather would alter the pallet actions upon the pendulum, Mr Graham's being no better than the other way. Pendulum temperature compensation will never be capable of true adjustment by any available means and, as a consequence of that alone (was there nothing else), Mr Graham's or the more common way will never be properly fit for astronomy.

But, desisting from studies of pallets with oil and imperfections (and accepted by the world from Mr Graham), it should be understood that in my escapement, oiling of the pallets could never cause the motion of the pendulum to

alter; on the other hand, it would cause such problems at the pallets as to prevent them interchanging at all, thereby stopping the clock. Without oil, the escapement pallets will not only function at all times (i.e. in all seasons) but will do so with a great freedom from friction. When combined with the other properties of my escapement, of which more later (and on a better foundation, involving the whole clock, than any previous), a very great timekeeping precision (to less than a second in a month) is then achieved. It is certain that my next clock, when finished, properly set up and duly adjusted, will come even closer to the truth.

And now, whether this, or any part of this might be thought strange with regard to my friend Mr Graham's method, then (to some extent in parallel with it) may I ask the reason why, of the many hundreds of musicians there are and have been in the world (and some of them mathematicians), nobody has yet discovered the true or real scale of music, or its foundation? They think it must always, to some extent, (although not to a small extent) act contrary to its nature, namely in the tuning of the organ, harpsichord and spinet! Why, the great Mr Handel had his organ etc. tuned thus!

Notwithstanding the above, should it still be thought strange with regard to my worthy friend, Mr Graham, I shall state herein, as if upon oath (as according to Lord Morton's proceedings) that I have neither said, nor shall express, anything other than what I have said to him, face to face, including the tenor of my saying it. We argued and discussed cases and principles more than once, most extraordinarily during our first meeting: reasoning, sometimes debating (although, in general, with a very good understanding of one another). At that first meeting, we talked from ten in the morning to eight at night, including dinner, for he invited me to stay and dine. To present the principles we discussed, I had drawings of parts of the pendulum clock I'd made and of my intended timekeeper for determining longitude at sea.

I had previously approached Dr Halley, who received me all the better when he discovered my intention of determining longitude by means of the accurate measurement of time, because he had long been investigating methods of determining longitude by observing the moon. I subsequently learned from Mr Graham that Dr Halley had become tired of the method, concluding that it would never be any good (although Dr Halley didn't tell me of that during our meeting). Noticing that the operation of my pendulum was markedly different to Mr Graham's, he advised me to visit him, which I thought to be a very bad idea. However, Dr Halley advised me that I should see Mr Graham without further discussion, I being more involved with machinery (for determining longitude) than astronomy. He assured me that Mr Graham was an honest man who would do me no harm (i.e. would never pirate anything from me), but, on the contrary, would certainly help me, if it was within his power. At the same time, he cautioned me to begin with Mr Graham in as few words as possible, to let him know that I had something worthwhile to tell him.

Notwithstanding that advice and despite my best efforts to follow it, Mr Graham began, I thought, very roughly with me, which occasioned me to be rough, too. However, we broke the ice, which couldn't support it, leading to the discussion I described earlier. Mr Graham eventually became extremely surprised by the ideas or methods I'd developed, or found it necessary to develop, and from them could see sufficient reason to believe that my clock might keep time to a second a month; consequently of great service in the primary task of adjusting a longitude timekeeper.

As Dr Halley had said, Mr Graham proved to be a very great friend to me, not only by assisting me with The Board of Longitude etc., but also by willingly lending me money without security or interest. Together with what other gentlemen gave me, that was encouraging: £80 from Mr Charles Stanhope, £100 from the East India Company and £10 from each of Dr Heberden, Mr Folkes and Mr Short, £5 from Lord Barrington and £10 from an unknown person. From those, with several others (indeed, many others) I was encouraged. Otherwise, from the encouragement of the public alone, I could never have gone through with the matter, or completed it.

So, after that (to some extent historical piece) to continue:

Firstly, in order to fairly or correctly assess the proper circumstances, quality or efficacy of an escapement (together with other unparalleled properties, as below) it must follow that the power of a pendulum (for a given bob weight) is proportional to about the square of the arc it describes. Therefore, if a bob of 3 pounds weight is sufficient to regulate a clock when the pendulum describes an arc of 12 degrees, then 48 pounds must be required in order to achieve the same regulation, or have the same power, if the pendulum describes an arc of 3 degrees. The assumption

is that the escapement is properly arranged and constructed. In that respect, my escapement could not be applied to the latter, smaller arc (nor should it). My escapement has never been applied to either arc, or to any arc, by anyone other than me, there being no model, drawing or sufficient instruction yet communicated to the world. Without those, the task, although natural to me, would prove difficult for others, it being so far from their beaten path. The execution would have been no easy matter for Mr Graham, had he attempted it, or had his integrity allowed him to attempt it, because of what must be executed first, with no instruction. With regard to the matter, Mr Graham said to several gentlemen that I deserved £20,000 for my improvement to clockwork, was there no longitude involved, because he had good reason to think that nobody else would ever have achieved such perfection. Indeed, there is good reason, with regard to the whole clock, to be inclined to think in the contrary direction, as he did. However, such methods, although adequate for common uses, will never perform correctly for astronomy.

Accepting that large pendulum amplitudes are necessary, it remains to be understood that a pendulum cannot truly or strictly regulate a clock with continuous perfection[A] unless, first of all, the force from the escape wheel[B] is exactly the same[C] as that required to generate exactly the same period[D] [E] [6] as the pendulum[F] would have if free[G] and in a vacuum. From due contemplation and experience, I have perfected this. The force from the escape wheel is so distributed that, should it vary, or should the air resistance vary, or should both vary at the same time (see the note)[7], the above condition will be met. This assumes that the pendulum will be rather shorter when warm than when cold. A degree of perfection is achieved by means of *'something at the top'* [pendulum suspension cheeks] (although not Mr Huygens' cycloid, for that would be unsuitable[8]), so as not to gain or lose as much as one second in a month[9].

[A] nor could anything (or anything in lieu of what is) called a cycloid; [B] maintaining pendulum motion against air resistance; [C] or the same [equivalent] taken overall; [D] taken over two successive swings, in order to account for the operation of the escapement [asymmetrical impulse]; [E] as nearly as possible; [F] of the same *'mathematical length'* [same period]; [G] without any force from the wheels of a clock.

Pendulum suspension (a highly important matter) must be from a brick wall, with no association with or dependence upon the clock, its case or wainscot, otherwise the true excellence of what I have explained (and more) could not be achieved[10].

To avoid an omission of this point, my clock would never need any cleaning[11].

[6] Note that, as just hinted, the actions of each escapement pallet upon the pendulum are not equal. That is not easily perceived by looking at the clock or the motion of the seconds hand, although, in this very important respect, with this escapement arrangement, they are quite different. With regard to the essential point in hand, this is of no disadvantage, because the action of one in association with the action of the other is correct for the purpose, of which more below.

[7] This very important matter is from the escape wheel acting (via my escapement) more weakly upon the pendulum during every one of its descents (from the extremity of the swing, where it is weakest of all), through the bottom (or middle) and then (still continuing) more and more strongly upon the pendulum during every one of its ascents. It will be strongest of all just before the interchange of the pallets, the interchange not being far from the extremity of each swing. During the small, additional 'overswing' ('or as it were overplus part'), recoiling of the escape wheel will be necessary, not only for the interchange of the pallets, but also, to some extent, with regard to the effect of a cycloid (although not entirely). The pendulum must also (from its combination of brass and steel wires) be rather shorter when warm that when cold, mathematically speaking.

To develop this matter a little further, as I order it, if the force from the pallets (using the force from the escape wheel) upon the pendulum just before the interchange of the pallets is assumed to be 3, then just after their interchanging (and in the opposite direction) *'it must but be about as 2'*. It may be assumed that the purpose is met by arranging for the mean between the actions of each pallet to achieve this (as may later be observed from the drawing). Further to the purpose, during the small recoiling of the escape wheel it will become less and less towards the extremity of each swing, but any increase in the total amplitude at any time will increase the effectiveness of the force (from its quantity or duration, still during recoil) in the required measure. The composers will improve matters a little, still from, or with respect to, the duration (though always small) of the recoil. It should be understood that, if

impulse was to be uniformly distributed throughout the entire swing of the pendulum, then the greater the impulse (with some recoiling of the escape wheel) the more it must tend to cause a greater amplitude to be performed sooner. That doesn't apply to the situation described previously, but, for the purpose, must be thought about, or considered, in another way: the greater the force towards the end of the swing (compared to the force at the beginning and assuming no recoil), the slower the swing must be, or the longer the time it must take up in being performed. However, with proper recoiling and an artificial cycloid correctly adapted, that will not occur. This assumes large pendulum amplitude (essential to this and other purposes), maintained by a movement, in air (as it must be). Air resistance is not to be avoided, as some have foolishly imagined, being of great value, as will be shown.

I shall be bold and say that never before has such a strict or exact mensuration of time appeared in the world, or to the public. I don't know where any equivalents to the above clock (as per Mr Maskelyne) or my watch (described later) will be found, no matter how many more pointless trials are made. I have good reason to think nothing will ever be found.

I have previously mentioned a drawing, but don't intend to include that or its explanation. My encouragement hasn't been suitable; in other words, my reward for my watch has been too backward, so I don't feel any obligation at present. It would be the first step. I was, unfairly, only compelled to explain my watch as far as I had advanced with it and, I thought, relating to its principal parts, but (though I told them what I thought) I had made some mistakes (or incorrect understandings) regarding some of the devices. Note that no sea trial improved my way of working, or would ever have improved anything, being only a loss of time, or a hindrance (except once, in order to fulfil the ruling of the Act of Parliament). Great trouble, hindrance and expense caused* by giving power to unskilful, interested novices, at the same time learned men (styled as Reverend), who didn't want to use my ingenious method.

* No sea trial was needed at all, but there needed to be pretty many more land trials than I had the time to do, in order to achieve what was it was fully capable of. Still, things were not as bad as Mr Graham, who set his pendulum going for the first time and thereafter didn't conduct any experiments, in any effort to determine whether there was room for improvement. Nor could any land trial of my first watch by a novice ever contribute towards making it perfect.

On land, (through my continued diligence, by the good performance of my clock and without foolish obstruction or interruption) I've lately discovered (or found a means of discovering) a way of achieving great precision, as described below. With regard to any trial, the watch doesn't and won't need anything more than adjustment (i.e. using such a clock as mine is, or rather, as my next clock will be). The mistakes mentioned above must remain for other workmen. Until I am more generously or genteelly rewarded for what I have so highly or deservingly done (for the public good), they shall not be instructed by or from me. The remaining part of my discovery (still the more valuable) shall sleep (unless I am better treated), save only for my own contentment or satisfaction, for I won't do one stroke more. Nor shall I endeavour to find a place for an observatory, with suitable facilities for the purpose. Having been paid short and furthermore been subject to expense, trouble and hindrance, I will also be short, until my discoveries or I are treated better than thus far. For, without doubt, it must be worth all, or more than all, of the money it would cost, being such an extraordinary thing, including the clock, that could never have been expected to appear in the world. There is good reason to believe that, had it not been for me, they would never have appeared (being so far from the beaten path), yet still I was ill-treated. The longitude, an affair of such importance, determined so exactly, easily and in such a useful way and more, yet to be so treated! *'O fie!'*

[8] Invalid principles, in assuming that the spring (as they call it), at the top of the pendulum, has no strength, with respect to bending or conforming to the cycloid, yet is still strong enough to suspend the pendulum. Furthermore, assumes that the pendulum should, or does, move all by itself in a vacuum. Consequently, with respect to a long pendulum with an arc of vibration no greater than fifteen degrees and drive from the escape wheel of a clock, it must do more harm than good, I say. However, Mr Huygens etc. don't consider it this way at all, the mathematics or geometry only causing mischief; more of this later.

[9] Strong proof indeed, of the distribution of force or drive from the escape wheel of my clock (of optimised proportions, partly from the number of teeth, corresponding to one revolution in four minutes). Chiefly and indispensably from those proportions, in combination with the arrangement of my pallets, the pendulum has no more irregularity in air than it would have if free and in a vacuum (was it possible to achieve, observe and assess such

motion over a long period of time). Therefore, may I ask, if such a matter is not highly worthy of encouragement, what other sort of ingenuity or discovery in the world is (the sister to this, my longitude timekeeper, excepted)?

[10] It should be understood that I discovered, by virtue of some disagreeable experiments, that if wood is involved in the pendulum suspension i.e. the wainscot, clock case (or in common clocks, (though out of the question for mine) the raising board upon which the clock stands), the clock would go faster in moist weather than in dry. The strength of the pendulum suspension attachment must have increased due to moisture. Some years after I told Mr Graham of this, he noticed that when he relocated one of his clocks to the opposite side of his room, its daily rate altered by six seconds. Given the care he'd taken in the relocation, he could only ascribe the change to a different strength of wainscot. Being very surprised by this (despite what I'd told him) he reinstalled the clock in its first location, using the original fixings, and the rate recovered, more or less. Remaining at the first location, he inserted a wooden bar between the back of the clock case and the wainscot, screwed the back of the clock to it and its ends to the wainscot and it ran faster, with a greater pendulum amplitude. Mr Graham became very much altered by this, in respect of everything he'd done, for upon serious reflection, he thought that such behaviour might not always be all. In combination with what else might relate to their very small amplitudes, he thought that passing coaches and carts, doors opening and closing etc. might be affecting his pendulums and that being in a different place in the room might, with respect to both, be related. I had earlier assured him that, with a pendulum correctly applied to a clock, no alteration in its motion could arise from such things, but only from what the pendulum itself could do, i.e. with regard to the strength or stability of what it was suspended from.

On the subject of wood, by the way, set a monochord to the pitch of a bell (or, if you please, a great bell, of 20 or 30 cwt) in dry weather, using a lever and weight. If the temperature and string tension are kept constant and the weather becomes moist, the pitch of the monochord will become considerably sharper than the bell, because the vibrations will have been quickened by the stronger foundation for the string. For this experiment the monochord must not be kept in a room where there is a fire.

A further confirmation is the tuning of a single instrument with strings (I say a single instrument, because that will render the effect most obvious). For instance, regarding the tuning of the viol (that being the instrument with which I experienced this), in order to tune each string perfectly (assuming the strings to be correctly adapted), the pitch must be set somewhat flatter in dry weather than in damp, otherwise the strings will be too greatly tensioned in the former case, thereby, to some extent, impairing perfect tuning.

[11] Furthermore, upon due reflection, it is certain that a clock may still be made to perform better than my present clock, to which I've been referring. In that respect, I have, for some time, had such a clock for that purpose, in the greater part made. However, since I didn't intend to install it in the place or house in which I live (not rightly convenient), I didn't rush to finish it. I've recently wanted to do some experiments on my present, going clock, which will allow a better completion of my other clock (or any similar ones hereafter). I'm also waiting for justice regarding my scandalously frustrated reward or encouragement for service to the public. *'Oh fie, England!'*, an Act of Parliament broken, after twice fulfilling it in the best, most complete or useful manner that could ever have been wished for. It must be said that had the facts been preserved, it would have been a national disgrace. However, right now, before these papers are published, the case had been altered, the chief instruments of the fraud i.e. *'the vile holy priests, were over-set, their ingenuous, or disingenuous villainy, being at the height, or as when got to the height fell, and indeed it was a very great fall, the matter being so excessively high; and if they should rise again, yet still it can never be so high as to see at all times, (if ever at any time, so as to be depended upon) viz. the longitude right clear by the moon.'*

It is very important to state how extremely useful air resistance is, or must be. Given a suitably large amplitude, air resistance ideally satisfies what *'the nature of the thing may be said to require'*. Without air resistance (i.e. in a vacuum), with effectively no friction from the escapement, the pendulum amplitude would almost be unlimited, thereby rendering accurate time measurement impossible, since we shall never be able to keep an account of, or usefully observe, its measurements of time in a vacuum without the wheels of a clock movement. Consequently, a small pendulum amplitude must be avoided, for the impulse would be extremely small, mainly to make up for friction, made even worse if applied at a great distance from the centre of motion of the pendulum. For such a clock using oil, any small variations in friction will be great and irregular in proportion to the small impulse. For, although

a pendulum will, by proper means, maintain a constant period (albeit of differing amplitudes), that implies no corruption from a clock movement; in such circumstances, small amplitudes could never be correctly maintained.

A conveniently large amplitude (i.e. convenient in other respects as well as this) will generate air resistance, which, when correctly balanced against impulse, makes for a far better controller, or master, than a small amplitude (with the deficiencies described earlier) can ever be. In fact, if the amplitude was extremely small, it would become quite insipid and unworthy of observation at all. A total arc of 2 or 3 degrees could hardly be regarded as any better, was it not, to some extent, to be described by a massive or excessive weight of pendulum or bob. Provision of temperature compensation, or something largely equivalent, might improve matters. Nevertheless, it cannot be considered surprising if a little alteration in the slipperiness or stickiness on the surface of such pallets (acting at such a great distance from the centre of motion of the pendulum, with a feeble pendulum motion, as Mr Graham arranged it) causes the clock to vary by a second in a day.

'*...whereas, if proper steps be taken, or can be taken, in or for the adjusting of my next clock, there must be even more reason (and that, withal, as from experience in my other clock) that it shall perform to a second in a hundred days, yea I say, more reason than that Mr Graham's should perform to a second in one.'*

And now (to some degree) we shall see to what extent and how alike the principles explained previously with regard to my pendulum clock are preserved in my watch, or timekeeper for the longitude.

Firstly, in my watch for determining longitude at sea, the radius of the balance wheel relative to the circular arc described by the edge of the pallets is approximately 32 to 1[12]. The suitable mass of the balance wheel rim, strength of the balance spring (which is more effective than natural gravity is on a pendulum, as will be described shortly), large angle of balance oscillation (of approximately 255 degrees), change of direction five times every second and small radius of action of the escape wheel on the balance renders it as effective, in timekeeping terms, as a much longer pendulum. The strength of the balance spring in proportion to the force from the escape wheel is as high as 80 to 1, or even more, which could be described as extremely strong 'artificial gravity'[13]. Common practice is a ratio of approximately 3 to 1, with no reason to believe that it would ever have been exceeded. Watchmakers or those engaged in the liberal sciences were unable, or had never in the least considered, how far they or others had only advanced in such matters. They had never found any reason to consider whether or not they might advance any higher (before they'd heard me speak of it) or whether it might be important that it be advanced and what bulk or size of watch might be the most suitable. Without those things, temperature compensation (had any such thing been considered necessary) could never have worked usefully. It may not be amiss for me to remark that, after something by way of a trial in this matter, after many toilsome experiments or alterations, I succeeded to a surprising degree in finding a strange difference for the better between 80 to 1 and 3 to 1! Such considerable labour was vital to my being satisfied that I'd achieved the best possible solution and to ensure that even if (after a long time) Mr Maskelyne equalled it, it would be impossible for him to go any further.

[12] The radius of the balance being 1-1/8 inch, i.e. in a decimal 1.125 inches and that of the pallets 0.035 of an inch.

[13] The limb of the balance thereby moves through about 25 inches in a second, notwithstanding (as a further augmentation of its power or dominion) a change of direction 5 times. Those things, in addition to the arc described, mean that the motion is prodigiously quick, or even violently powerful, in the middle of each oscillation. The motion of the balance is rapid and powerful; 25 inches in a second is no less than 34 miles in a day, for faint, sleepy work could never be suitable. A long pendulum could never match such a velocity, until the length reached 13 feet. Even then it wouldn't be, in effect, as quick, by virtue of lesser velocity, being only sufficient to achieve a swing from one side to the other in 2 seconds.*

* By the way, there can be no reason for a pendulum of any church clock to be any longer than one beating 2 seconds.

Should it be argued that the length of such a pendulum is much longer than the radius of this balance, it must be remembered that the length of the pallets must be considered. It must also be remembered or understood that (as already implied to some extent) no ponderousness in a pendulum or balance can ever make up for a lack of velocity. Indeed, velocity was very much wanting in my three large machines, notwithstanding the high mass of the balances

or what philosophy might teach us to think. However, I didn't understand that when designing my three large machines, nor (if I may be so bold) would the World or I have ever understood it, had I not discovered it by accident with my third machine. It would, however, be too tedious to explain fully, so I'll desist, although awareness of it is highly relevant.

I shan't expand upon other beneficial features incorporated within my watch, including the escapement pallet form and compensation for variations in temperature.

The 80 to 1 ratio (of primary importance) may be understood, or perceived as follows: Without the balance spring attached, the balance executes one vibration in two seconds, whereas with the spring, that increases to ten vibrations in two seconds. Velocity must certainly vary as the square root of the applied force; therefore the balance with no spring (i.e. no artificial gravity, as it were) taking two seconds to execute one vibration, would have $1/100^{th}$ of the energy of the balance with the spring fitted, executing ten vibrations in the same time. The effect of small differences in the 80^{th} part (explained earlier) will therefore be rendered proportionally extremely small.

Besides what might have ever arisen from the common experiments of workmen (i.e. nothing), there is no likelihood or possibility that any improvement or discovery herein would ever have been revealed, or appeared in the World, from the mechanical illustrations or operations exhibited at Cambridge, Oxford etc. (being, in the main, experiments that need not be performed at all; hornbook work, as it were). This discovery of mine is, as it were, repugnant to them, or at least beyond their experience. Notwithstanding such very weak mechanics[14], they are, in a most stupendous but surfeiting manner, my masters! But what was to be expected? Moreover, at the same time, they are my rivals and antagonists, with their determination of longitude by the slow and intricate motion of the moon, great difficulties and uncertainties of observation, great error (for the most part) due to the calculations involved. From Dr Halley's experiences, assuming the Lunar Tables to be correct, the observations alone (when any could be made) could not be relied upon. Mr Graham told me that Dr Halley had ceased pursuing the matter; an ingenuous decision, given that it could never, with certainty, be to any public good. It is certain that no better observations can be made now than they could in Dr Halley's time.

From experience, I can be bold and say that my watch (or timekeeper for the longitude) will improve to 1 second in a fortnight when my last improvement, with a little alteration to receive it[15], is executed. I described it in my drawings in the latter end of 1772, when I was eighty years of age. Surely to be regarded as an age well spent[16], being so much for the public good (i.e. if it is allowed to be), as well as nice future employment for ingenious men (though not for priests at Cambridge and Oxford).

[14] In particular, I took some pains with Mr Shepherd (i.e. when he was my friend) but could make nothing of him (any further than that one wheel turned another), although it was at his request; very unfit gentlemen to be my masters. The longitude reward (part of it) withheld in their secret closets, during which time they received a tidy reward. Notwithstanding that, they took great care of my watch, for they locked it away for some months in a closet at the Admiralty, because it had performed so well on two voyages. So they kept it like a piece of treasure, for fear that nobody else would ever be able to make another; a fair sign that they didn't understand it. Consequently regarded as absurd that they should *'(at that rate)'* have anything to do with it. To make matters worse, Lord Morton, who didn't understand it any better than they, put, or infused it into their heads that it was all achieved by chance.

[15] Those improvements being to the parts above the upper plate of the watch (as workmen call it), also with a little alteration to the shape of the pallets. These will be more easily done in future, in all respects, as well as when done to afford a greater degree of truth.

[16] Considering what tedious experimentation is necessary, so as to identify secrets, never before considered, in order to truly conquer the thing!

I promised to say more about the pendulum. I have already said that Mr Huygens' cycloid can be of no service, being assumed to be in a vacuum etc. (unless that can be called being of service), with a very thin spring at the top of the pendulum (for thin to the purpose it must be[17]). That would only cause the spring to neck, or break off in a

short time, at the top of the cycloid. Nor can the arcs of a long pendulum (15 degrees at most) be said to need it. Therefore, anything in lieu of a cycloid must be chiefly to preserve the spring (or pendulum suspension) from ever breaking. The spring, being very thin (although it may be short) is best made of gold[18] *'allayed'* with copper, well hammered to thinness (being thereby more elastic than when *'allayed'* with silver).

[17] My pendulum must not be as monstrously heavy as Mr Graham's, for a thin spring cannot bear it.

[18] Also used, by the way, for the pivot pin of the escapement's wooden pallet arms, where friction is insensible.

The *'cycloid to the purpose'* must, to some extent, be a reverse of Mr Huygens', in that it must occasion small vibrations of the pendulum that will cause the pallets to interchange sooner than they would without it. At the arc necessary for pallets interchange (or, rather, a little larger) the length of the pendulum (by virtue of adjustment) must beat seconds. When the arc goes beyond that, the pendulum must still beat seconds. From that, the continuation of the circular curvature of the cheeks (i.e. of this artificial cycloid) may be ascertained. However, I shan't discuss how the radius of each cheek must suit the purpose, i.e. as a result of the action of the escapement. Cambridge or Oxford education won't help with that, or with the action of the escapement (i.e. so as to precisely define them, assuming such things had been thought of). However, since each cheek, with regard to the property of the escapement explained previously, must be the arc of a circle (suitably formed, as required, starting with a larger radius than required in order to enable more accurate manufacture) they can be formed to a mathematical truth, whereas the other form (according to Mr Huygens) could not, if that was required.

Now to the purpose. Assuming that the escapement pallets are arranged as I stipulate, in order to correctly distribute the force from the escape wheel and incorporate proper recoiling, then the cheeks may be so arranged as to generate a constant pendulum period, despite any increase in escape wheel force (and an associated increase in pendulum amplitude) or any decrease in air resistance (also with an associated increase in pendulum amplitude). The latter is mainly achieved because, for the most part, the same cause of any decrease in the resistance of the air also shortens my gridiron pendulum (if appropriately constructed and adjusted). Bear in mind that, with my type of clockwork, the force from the escape wheel will vary very little anyway, as a result of which (or due to other things) the pendulum amplitude will rarely vary more than very little, regardless of the weather.

It is unsurprising that the overall result is a timekeeper capable of exceptional performance; my great and worthy friend Mr Graham was astonished by it. It is certain that such principles, when correctly adapted to a watch, must provide the best means and an easy method of measuring longitude. Yet those people who understand none of this are elected to be my masters[19]. They find my method repugnant to their learning and a hindrance to their own financial gain. Dr Bradley once told me that had it not been for my watch[20], he and Mr Irwinn could have secured £10,000. My masters (or, rather, improper inspectors) still want people to fall in love with the method they promote (disregarding the great problems associated with it). By their method, it must be far more, if not a hundred times more difficult to measure to a degree of longitude (and that only when opportunities seldom arise) than to tell the time to a minute using the hour hand of a watch. Nobody can deny that.

[19] By way of appearing to conduct fair trials, they are empowered to employ anyone to test my timekeepers, despite such employees being as clueless as they. An evil situation, for sure! Their Cambridge and Oxford mechanics haven't understood anything either. On the other hand they've written and published a great deal, relating, so they think, to longitude, or at least so as to make others believe that to be the case. Whereas their ideas achieve no more than that of Mr Whiston, throwing a bomb aloft in the dark, at Shooter's Hill (beginning just after I arrived). He only made a great noise, but achieved nothing else of any value. They should be asked what use the columns in their nautical almanac are; the answer could be no better than 'Nothing', except as a lot of stuff with which to dazzle the world. Although it is ever so true in itself, it cannot possibly have anything to do with longitude at sea! How strange it would be for any of the commissioners to permit themselves to be imposed upon! I wish that not only they, but also the entire nation understood it all as well as I do.

[20] Which, I believe was the death of him, because he (based upon frequent conversations with me and from his sagacity) was the only one amongst them who understood my methods and what they were likely to achieve. Before

his association with Mr Irwinn, he seemed to be very sorry when I was having any difficulties, mainly with the creation of my diamond pallets (although that problem is of no difficulty now).

To return to the clock, the first task must be to adjust it to what it is capable of, albeit without having a second one available, of exactly the same sort. That will not be easy[21], in view of the deficiencies and scarcity of celestial observations; at the time of adjusting, the required frequency and precision will be lacking when most needed. That doesn't include the adjustment of the screw at the bottom of the pendulum i.e. for fast and slow in general, that being an easy matter. When all adjustments are completed and the clock stands correctly in a fixed location, it will, I suppose, or have reason to believe from experience, hold its truth for ages[22]. This is not to say that it couldn't, without difficulty, be removed from the location in which it was adjusted, to another suitable location, firmly and skilfully installed and readjusted with respect to fast and slow as the latitude of that location might require.

The last adjustment mentioned above is of no great difficulty, whereas the first, essential adjustments will be very difficult, when done alone, without a second clock. With a second clock, the best part is when they are already adjusted and both pendulums are viewed at the same instant. One clock is placed in one room, the other in another[23], with the door of each clock case open. The clocks are placed such that, by a little turning of the eyes from the door stead, they can be compared to 1/20th of a second or less.

Without that, a troublesome and tedious recourse to the stars is needed, the right ascension being the most suitable. It is known annually, but even if not, the clock's rate may still be derived from it i.e. as closely as such deficient methods (for this purpose) can achieve. Still, that must be better than using the sun. It is very important to remember that this can never be as easily or so well accomplished as when by or from two clocks. Such observations can only be fit for testing clocks such as Mr Graham's, but to adjust a clock to perfection (i.e. meaning a clock capable of responding in good earnest to such adjustments) could never be achieved in a very long time. The stars will be better than the sun, the Equation Tables still not being correct; neither is our lately famous (or, regarding its design, infamous) Nautical Almanac. Neither, as already implied, can any celestial observation ever be precisely made, not only for this purpose, but when most needed.

Whereas, with the correct use of my clocks (with proper arrangements and apparatus) even the Equation could be corrected, because the eccentricity of the Earth's orbit and whatever else may pertain to the matter could thereby be more precisely known. However, it should be understood that my watch, in its perfection (with not only no need for fixing, but also with far more or further usefulness, in different places than the clock) would be best for a Transit of Venus etc, or any other application that might require it.

[21] There are four different things to adjust, two of which (the escapement composers of the pallets to relative rest and the corresponding curvature of the pendulum suspension cycloid cheeks) may be regarded as one, i.e. in their joint effects, although not quite. The remaining two adjustments relate to the pendulum temperature compensating gridiron wires (by their correct provision) and their redoubling, plus the pendulum rating nut. Since rectification of those things must relate to the adjustment of the clock (i.e. initially by the master workman) it will be quite impossible to perfect using celestial observations, or any other method, unless the foundations, or principles of the clock are in accordance with what I have shown and could further show.

[22] As an aside, one of the greatest professors (and one of my masters at the Board of Longitude) rudely applied to me for a clock. They must think little of me, being short and greatly abusive with me, telling me what should belong to an astronomical clock, which I am very sure would be worth nothing for such a purpose. They can, however, tell us how two colliding marbles, such as boys play with, will behave. It must be fairly and properly considered how the nation (or the world) will become aware of what is better, or truly fit for the purpose. I once thought of giving a clock to the observatory at Greenwich, but my poor treatment rendered it too tedious. Nevertheless, my next, or second clock will be better than if I'd finished it sooner. If I live to see it finished, that will be my wages. One would think that a minstrel at the playhouse is much better off, except that this has been my great delight and must be nobler than his achievements.

[23] A chimney being in each room, so that either may be heated by a fire, when correct to do so. If neither clock was adjusted, it would be of no great difficulty to achieve it for both.

'And now, if the Royal Society please, I will shew them the Draught of the Clock which I have in great part made…' and not only the drawing of the pallets, but also the pallets themselves, in order that they may see at least some reason for what I found from such a design of escapement; not only extraordinary attributes, but the things I've discussed already and others besides. The indispensable construction of the pallets (to do their duty as described earlier) is a consequence of a suitable extension to the periphery of the escape wheel and its number of teeth (i.e. for seconds beating, one revolution in four minutes). Otherwise, they could not do their duty with regard to their action upon the pendulum or (expressed another way) contribute to a precise mensuration of time[24]. I'd say that the pallets must be by far the most important thing of all. My great and worthy friend Mr Folkes said this, in some measure, in his speech to the Royal Society (30th November, 1749). In comparison, it must certainly be fairly clear that the bad effect of oil, or difference in friction (without oil, could that be done) at such a great distance from the centre of motion of the pendulum (as with Mr Graham's method) and with a small amplitude can only be looked upon as ridiculous, or even quite repugnant to reason. A pendulum with temperature compensation, from a firm suspension, must have some effect, but Mr Graham's pallets cannot be said to do anything with regard to its natural property. Nothing worse could be contrived, being, as it were, a mere jerking, stamping, nonsensical fancy[25]. It is as if it was designed so that the clock might better be heard going, as if how it went or would go was irrelevant. I'd say this certainly seems to be the case, whatever his initial reason might otherwise have been. In the whole, in comparison to the account I've given of mine, anyone with judgement, even without experience, must think it visibly bad (with no strict regularity, as I've shown, to be expected from it, at least for any length of time).

[24] It may be observed that the escape wheel will move only a little in a second (half a space between the teeth), but the pendulum will move through a great distance. However, ignoring the amplitude, it should be remembered that the length of a pendulum, at best, is only as in proportion to the length of the pallets or, more correctly, to the distance at which the escape wheel acts from the centre of motion of the pendulum. This ignores any deficiencies, which, in Mr Graham's clock are not inconsiderable, but will remain unstated.

[25] Yet it seems to have become rooted in, or in possession of men's minds that, whatever any man may devise, it must be like this, otherwise the first observation or cry will be that it doesn't beat dead! This is indeed surprising, since it has no relevance to what must be done to provide the truth and, consequently, not corrupt or in the slightest confuse the natural attributes of the pendulum, in order that the benefits of a large amplitude are achieved.

But now, to continue, (and as predicted by my worthy friend Mr Folkes) it is more important to describe the construction of the pallets of my small machine, watch or timekeeper for the longitude[26], especially as in my last drawing. They will precisely suit, in all respects, the nature of a pendulum (i.e. more properly than my first watch; in fact somewhat better, or more to the purpose than my second watch). It should also be noted that the wheel of quite hard steel and the pallets of diamond should, as much as I am able to judge thus far, retain their shapes for a long time. In other respects (chiefly from my last drawing, which also renders the pallets easier to make) it should hardly ever be incapable of displaying the time (whether at sea or on land) to within a second in a fortnight. Had not my work been foolishly hindered, the nation would have benefited earlier. On the contrary, having experienced such extremely ill treatment, for some time I even hated the thought of ever making one wheel turn another, whereas there is a great deal more to be thought about than what that involves. Alas, I suppose that, having none of the advantages of a University man, Knight or Earl, even an Act of Parliament could not, or at least not so well, support me. I had no knowledge of whether it would or not until some time after my son returned from his second voyage, notwithstanding that he was sent on both voyages because of the Act. In both cases, longitude (from my timekeeper) was measured closer to the truth than required. A fine commendation to the nation in one respect, but quite contrary in another. However, had it only been possible for the Professors of Art or Sciences at Cambridge and Oxford, using their high algebra etc.[27], to have discovered or comprehended such a mechanism as that of which I am now, by the blessing of God, the master. Had I only then been appraised of it, notwithstanding my country origins, or the methods of determining longitude by the moon (the use of which must depend upon fickle points or uncertainties[28], which the professors must hardly be ignorant of). What a fool I was, that I never had witnesses to my conversations with Mr Graham, or with anyone else, as proof of my understanding of the matter.

[26] The amplitude, or crossing as workmen call it, must be suitably very large. That, together with 5 vibrations every second, the weight, but most especially the large diameter of the balance, produce a quick and powerful, even, as it were, 'boisterous' motion, as described previously.

[27] Not because of their divinity, due to which they wear their gowns, for that would hardly allow them to have anything to do with it.

[28] For which reason, Dr Halley abandoned the method. He was so pleased that my method would likely be for the public good, that he promised Mr Graham he would attend the Board of Longitude, come rain, snow or blow.

However, be now as it will, if it so pleases Almighty God to continue my life and health a little longer, they, the professors (or priests) shall not deprive me of the pleasure of bringing my watch to a second in a fortnight. I am determined in this matter, despite the bad treatment I've received. Dr Bradley once said to me (although I had already thought of it) that timekeeping at sea to within ten seconds a week would still have been far better than none at all. I am not concerned about the money any more (not having any reason to be and being weary of the affair).

'...the Devil may take the priests'.

Dr Bradley admitted to me that there would always be errors in tables, in preparing an instrument, in observation and from refraction. Moreover, he admitted that, overall, a little deviation from the truth (ignoring any error in the setting and the performance of a common watch) might have extremely ill consequences. Nevertheless, it seemed that, from a love of money, he could even have broken through all! Now the parsons want to promote the same method for determining longitude, which is to say methods that will always involve very great difficulties, uncertainties and tedious calculations, which must be associated with and be liable to mistakes[29]. Consequently, taken as a whole, they may sometimes, perhaps often, cause enormous damage. From the love of money the professors or priests prefer this to what may be done with ease and pleasure, frequently and to a great exactness (for if the love of money is not the case, they must be no better than as if out of their senses, for parsons would certainly never concern themselves in such a matter and with such energy if money wasn't at the bottom of it).

But now, since experience in anything is the best proof of its usefulness, goodness etc: Mr Charles Green (one of the best observers) and my son journeyed together from Barbados, along with Captain Manley. For most of the voyage the weather was fine. Yet Mr Green only attempted to make observations during the daytime, or at such a time when the sun and moon were in a suitable position with respect to one another i.e. in distance between 40 degrees and 100, or not much greater than that either way. At the same time the horizon needed to be suitably clear. He needed to make several attempts, when those infrequent opportunities arose. With much difficulty, he achieved a total of two observations, whereas my son could observe with ease, using the watch, on all but 3 or 4 days. However, Parliament never witnessed, or was ever allowed to hear of, or know anything about this, or of anything such as this. Knowledge of such things is more relevant than all of the rest, about which so great a commotion was made. No trials of the performance of my watch at sea were needed, or at least no such tedious or troublesome trials as were conducted. The affair would have been completed sooner, had there been a proper understanding of the nature of the mechanism and had the Act of Parliament permitted it. No trials would then have been necessary, except for those things relating to adjustment; by which I don't mean by an adjusting-plate, as in common watches, which is irrelevant. There are other things relating to the watch, as well as the pendulum clock, which (in the case of the balance) I haven't yet perfected. The further improvement I've spoken of will render it capable of true adjustment, but I haven't had the opportunity, chiefly because of the trouble and hindrance caused by the Lunar-Men. However, Mr Ludlam (a University gentleman) says that I've had enough time. It would be difficult to say whether there would ever have been enough time to bring this small machine, my watch, up to what it is capable of. I am now sure that a second in a fortnight can be achieved[30], which I myself, at first, thought impossible, as would others (nay, Mr Ludlam himself). This might have been the case, had it not pleased God that I should live so long. Regarding my further improvement, I may not achieve complete success at first, for there may be a small delay whilst I conduct experiments[31]. However, when properly completed, the task will thereafter be easy and my watch will perform as I stated above, so as to never materially deceive mariners (i.e. when measuring the altitude of the sun, to determine longitude)[32]. I think everyone should be pleased *'...in that it hath so pleased God that I have had such a length of life, &c. wherein to bring so noble and useful a thing to such great perfection, yea, even to nearly the truth itself;* [33]*'*, But still the professors or priests, as above, absurdly think it would be better if the money were theirs, rather than what this (or such other things of mine) can be to the nation. They wanted to influence Parliament so as to have my money, notwithstanding what my watch had achieved[34]! Now I am certain that my last improvement will ensure that the performance of a watch of such as size as may be carried in the pocket (though I wouldn't advise it always be

kept there) will enable longitude to be determined more certainly or exactly, more frequently and more easily than it ever could by using the moon. Consequently the more, by far, to be relied upon.

[29] As occurred in one of the two observations by Mr Green (and as was proven by my watch), which he could only make as described below. As a consequence, he sweated over his figures for some hours.

[30] But suppose that this (or the components chiefly responsible for it) is not truly achieved in every watch, but that, now and then, one was a little incorrect, to the extent that it might, as a result, sometimes vary by 4 seconds in a fortnight. It would still be doing its job well, but any greater than that may then be regarded as careless, or work by an unqualified person or persons. Perhaps it might be foolishly designed, or its construction altered, with the intention of reducing cost or production time. To determine longitude to such perfection, or so exactly, must deserve every assistance. The considerable safety issues demand that nothing should be deficient. Proper facilities must be provided, for the absolutely correct adjustment of such watches or timekeepers. That is not to imply (or mean at all) the adjusting of foreign or nonsensical things in the matter, about which so great a commotion has been made. Neither does it mean other abortive, pretentious, silly inventions, *'viz. as pertaining to the tacking about in a brisk gale'*.

[31] In that respect, moreover, from the series of experiments I have at last, by virtue of length of time etc. been able to undertake, I can boldly confirm that it can be honestly demonstrated (though I don't think it appropriate or necessary to show how to demonstrate it here) that no timekeeper (whether with a pendulum, or a balance, or by any artist) can ever be capable of going higher than, or bettering mine. That was far from the case with Mr Graham, as may be, with fairness, proven. Nor would Mr Maskelyne ever be able to show how to improve my watch (not even the first one, which certainly afforded room for improvement) was he to keep it for an enormous length of time. If he was to attempt such a thing so strange and foreign to not only his education, but also his abilities and interests, he could never arrive at a *quod erat demonstrandum*, nor whether it could be, or not be. I am now sure that it can, as surely as the properties of a circle and of a triangle etc. must apply for eternity. Indeed, it has always been my delight to search after and achieve perfection if possible, whether I would ever have received anything for my labour or not, and not to fall short, or creep towards, or be uncertain, in coming within the bounds of the Act of Parliament. For that perfection and the safety of ships etc. I have indeed laboured long, but, thank God, I have achieved it. Whereas no other method will be as fit for the purpose or will ever fully achieve it, despite it already being a work in hand for a considerable length of time. In that respect, notwithstanding whatever may at any time be written or schemed, and though absolutely true within itself, or in theory ever so true, it can still only be as if upon a bad or dubious foundation, i.e. with regard to any truth or certainty of determining longitude at sea. Therefore, as a consequence, the more there is of it, with yet more still required, the worse it must be to like it, or as a result, rely upon it.

[32] But here it may be noted, that what will sometimes render an observation in this case to be 2 or 3 miles in error, will or may, by the moon, make it as many degrees wrong; that is to say refraction, was parallax not to be intermingled.

[33] It must be understood that the adjustment of such a longitude watch, i.e. to the extent it is capable of, cannot be done (in any reasonable time) by one or more of Mr Graham's clocks, nor, indeed, from any observation, but only from a clock having a performance such as mine. Consequently, proper places, suitably furnished, must, where needed, be of very great utility indeed, surpassing in usefulness or importance all observatories in the World.

[34] But what can these men be said to have done, when it was already done (i.e. to fulfil the Act of Parliament) before they began? Done in the best manner that could ever be wished for. Notwithstanding that, they would not let the whole of it be paid, thinking it more correct to rob the proprietor of half of his wages. *'Whiston was pissed on, and Ditton shit on, but surely these men ought to be besmear'd or bespatter'd with both…'*. After longitude was determined by a good and easy method, they wanted to determine it using a very troublesome, tedious, difficult and uncertain endless method! Or rather, from uncertain endless methods, for beside using the moon, also using Jupiter's satellites, which, with respect to our need to determine longitude, are not worth mentioning. Notwithstanding that, they certainly must, by the hand of providence, be highly created, in addition to the moon, for something else. Therefore, they should have told us what for.

Now, in the former part of this book I have dealt with matters relating to the strict measurement of time and have shown the deficiencies of such methods as Mr Graham had adopted or used for that purpose. I have also dealt with the improper, troublesome erroneous and tedious method that the professors at Cambridge and Oxford would choose for determining longitude at sea. *'And now I am about to treat of another concern…'*

[A large body of text relating to Harrison's theories of the scale of music effectively absorbs the (quite considerable) remainder of CSM. That topic is not included herein.]

[The final page of CSM concludes:]

'Now, whether my style of writing in this affair, be right proper to the purpose or not, I thought it must be better than that the contents of this book should be in danger of sleeping in oblivion; yea, notwithstanding what I had – as verbally communicated to the world'.