

having burn'd it with Soap in the manner describ'd. It is no Treasure; but if you have none of it, it may be worth your Acceptance.

I am, Sir,

Utrecht, Jan.
15th, 1733. O. S.

Your, &c. &c.

Petrus Van Muschenbroek:

VIII. *An Account of some Observations made in London, by Mr. George Graham, F. R. S. and at Black-River in Jamaica, by Colin Campbell, Esq; F. R. S. concerning the Going of a Clock; in order to determine the Difference between the Lengths of Isochronal Pendulums in those Places. Communicated by J. Bradley, M. A. Astr. Prof. Savill. Oxon. F. R. S.*

ALtho' it is now above Sixty Years since Mr. Richer first discovered, that Pendulums of the same Length, do not perform their Vibrations in equal Times in different Latitudes; and tho' several Experiments made since in different parts of the Earth concur to prove, that Pendulums swinging Seconds are in general shorter as we approach the Equator; yet what the real Difference is between their Lengths in different Latitudes, does not seem to have been determined with sufficient Exactness,
by

by the Observations that have hitherto been communicated to the Publick; as may be gathered from the 20th Propofition of the third Book of *Sir Isaac Newton's Principia*, where they are compared as well with each other, as with the Theory of that illustrious Author. It were therefore to be wished, that more of this kind of Experiments could be made with greater Accuracy in proper Places, by such Persons as have sufficient Skill and Opportunities to do it; that we might thereby be enabled to judge with more Certainty, concerning the true Figure of the Earth, and the Nature of its constituent Parts.

As an Inducement to such as may have it in their Power to put the like again into Practice; I shall lay before the Society, an Account of a very curious Experiment of this sort lately made in *Jamaica*, by our worthy Member *Colin Campbell*, Esq; whose Knowledge and Abilities in every respect qualifies him for the Improvement of Arts and Sciences; and whose Genius prompts him to cultivate them so assiduously, that I doubt not but we shall soon have the Satisfaction of receiving many other valuable Observations from him, particularly such as relate to Astronomy; he having furnished himself with an Apparatus of Instruments not unworthy the Observatory of a Prince. Among these is a Clock whose Pendulum vibrates Seconds, made by our ingenious Member *Mr. George Graham*, justly esteem'd for his great Skill in Mechanicks; who judging that an Opportunity was now offered of trying with the utmost Exactness, what is the true Difference between the Lengths of Isochronal Pendulums at *London* and *Jamaica*,

maica, readily embraced it; and in framing the Parts of the Clock, carefully contrived, that its Pendulum might at pleasure be reduced to the same Length, whenever there should be occasion to remove the Clock from one Place, and set it up in another.

This Clock being chiefly designed for Astronomical Observations, had no striking Part, and its Pendulum was adjusted to such a Length, that in *London* it vibrated Seconds, of Siderial, and not of Solar Time. When it was finished, Mr. *Graham* fix'd it up in a Room situated backward from the Street, and on the Northside of his House, to prevent its being disturbed by Coaches, or other Carriages that passed thro' the Street, and that it might be as little effected by the Sun as possible. Having set it going, he compared it with the Transits of the Star *Lucida Aquila* over the Meridian, which passed

| | th | h. | <i>l</i> | <i>ll</i> | |
|----------------|----|------|----------|------------------|-----------------|
| | 20 | at 8 | 59 | 15 | } by the Clock. |
| | 22 | at 8 | 59 | 18 | |
| <i>August,</i> | 23 | at 8 | 59 | 20 $\frac{1}{2}$ | |
| 1731. | 25 | at 8 | 59 | 22 | |
| | 28 | at 8 | 59 | 25 $\frac{1}{2}$ | |
| | 29 | at 8 | 59 | 26 | |
| | 30 | at 8 | 59 | 27 | |

Hence it appears, that the Clock gain'd twelve Seconds in ten Apparent Revolutions of the Star.

In order to estimate how much the Pendulum may be lengthened by greater Degrees of Heat, or how much slower the Clock would go on that Account, when

when removed into a warmer Climate, a Thermometer was fixed by the side of it; and between the Hours of Ten and Eleven in the Morning, and at Night, notice was taken at what Height the Spirits stood, and the mean Height for each Day was as follows.

| | th | Therm. | |
|----------------|----|-----------------|----------------------------------|
| | 21 | $32\frac{1}{2}$ | Divisions. |
| | 22 | $30\frac{1}{4}$ | |
| | 23 | $28\frac{3}{4}$ | |
| | 24 | $27\frac{1}{2}$ | |
| <i>August,</i> | 25 | $28\frac{1}{2}$ | Hence the mean Height |
| 1731. | 26 | $27\frac{1}{4}$ | for all these Days was |
| | 27 | $27\frac{1}{2}$ | about $28\frac{1}{2}$ Divisions. |
| | 28 | $27\frac{1}{2}$ | |
| | 29 | $27\frac{1}{2}$ | |
| | 30 | $27\frac{1}{2}$ | |

The Clock-weight that keeps the Pendulum in Motion is 12 lb. $10\frac{1}{2}$ oz. and is to be wound up once in a Month. The Weight of the Pendulum itself is seventeen Pounds, and (during the Time that the Clock was compared with the Transits of the Star) it vibrated each way from the Perpendicular $1^{\circ} 45'$. The Magnitude of the Vibrations was estimated by means of a Brass Arc, which was fixed just under the lower end of the Rod of the Pendulum, and divided into Degrees, &c.

August 31, Mr. *Graham* took off the Weight belonging to the Clock, and hung on another of 6 lb. 3 oz. and with this Weight the Pendulum vibrated only $1^{\circ} 15'$ on each side; and the Clock went one
Second

Second and an half slower in 24 Hours, than when its own Weight of 12 *lb.* 10½ *oz.* was hung on.

This Experiment shews, that a small Difference in the Arcs described by the Pendulum, or a small Alteration in the Weight that keeps it in Motion, will cause no great Difference in the Duration of the Vibrations; and therefore a little Alteration in the Tenacity of the Oil upon the Pivots, or in the Foulness of the Clock, will not cause it to accelerate, or retard its Motion sensibly; from whence we may conclude, that whatever Difference there shall appear to be, between the going of the Clock at *London* and in *Jamaica*, it must wholly proceed from the lengthening of the Pendulum by Heat, and the Diminution of the Force of Gravity upon it.

A particular written Account of the Observations and Experiments hitherto taken Notice of, was delivered to me by Mr. *Graham* in *September*, 1731; about the same Time the Clock was put on Ship-board to be carried to *Jamaica*. He likewise sent very full Directions to Mr. *Campbell*, describing in what manner the Clock was to be fixed up, and how the Pendulum might be reduced exactly to the same State as it was when in *England*; but no Intimation was given concerning the going of the Clock, that the Experiment might be made with all possible Care, and Caution, and without any Byass, or Prejudice, in favour of any Hypothesis, or former Observations.

In *July* 1732, we received an Account of the Success of the Experiment, by the Hands of Mr. *Joseph Harris*, who was present at the making of it in *Jamaica*, whither he went the Year before with

with Mr. *Campbell*, in order to assist him in his Design of erecting an Observatory for the Improvement of Astronomy, and the Promoting other parts of Natural Knowledge in that Island: But his ill State of Health obliging him to return into *England*, he brought with him the Original Journal of the Observations of the Transits of two Stars (*viz. Sirius & β Canis Majoris*) over the Meridian, compared with the Clock, after it was fixed up in *Jamaica*, as Mr. *Graham* had directed; together with the Height of the Spirits of the forementioned Thermometer, upon the several Days of Observation.

The chief of those Observations are contained in the following Table, the First Column whereof shews the Day of the Month; the Second, the Name of the Star, and the Time by the Clock of its observed Transit over the Meridian; the Third contains the Hour of the Day, when the Thermometer was observed, together with the Height of the Spirits at those Hours; the Morning Hours being denoted by the letter A, and those of the Afternoon, by the Letter P.

| 1732 | Canis Majoris. | Time of Transit. | Hour of Day. | Thermometer. | 1732 | Canis Majoris. | Time of Transit. | Hour of Day. | Thermometer. |
|------|----------------|------------------|--------------------|------------------|------|----------------|------------------|-------------------|------------------|
| Jan. | β | h / '' | h | | Jan. | β | h / '' | h | |
| 23 | β | 11 59 50 | 10 $\frac{1}{2}$ A | 14 $\frac{3}{4}$ | 26 | β | 11 53 35 | 8 A | 20 |
| | α | 12 22 14 | 9 $\frac{1}{2}$ P | 11 | | α | 12 16 00 | 2 P | 8 $\frac{1}{2}$ |
| 24 | | Cloudy. | 11 $\frac{1}{2}$ A | 15 $\frac{1}{4}$ | | | | 9 P | 10 |
| 25 | β | 11 55 40 | 8 $\frac{1}{2}$ A | 17 $\frac{1}{2}$ | 27 | β | 11 51 31 | 7 A | 17 $\frac{1}{2}$ |
| | α | 12 18 4 | 9 $\frac{1}{4}$ P | 11 $\frac{1}{4}$ | | α | 12 13 55 | 2 P | 8 $\frac{1}{2}$ |
| | | | | | | | | 9 $\frac{1}{4}$ P | 12 $\frac{1}{2}$ |

| 1732 | Majoris. | Caenis | Time of Transit. | Hour of Day. | Thermo- meter. | 1732 | Majoris. | Caenis | Time of Transit. | Hour of Day. | Thermo- meter. |
|------|----------|--------|--------------------|-------------------|-------------------|------|----------|------------------------|--------------------|------------------|-------------------|
| Jan. | | | | | | Feb. | | | | | |
| 28 | 3 | 11 | 49 26 | 7 A | 20 $\frac{1}{2}$ | 8 | 3 | Cloudy. | 6 $\frac{1}{2}$ A | 21 $\frac{1}{2}$ | |
| | 2 | 12 | 11 51 | 2 P | 11 | | 2 | 11 48 50 | 8 $\frac{1}{2}$ P | 8 $\frac{1}{4}$ | |
| | | | | 10 P | 12 | | | | | | |
| 29 | 3 | 11 | 47 22 | 6 $\frac{1}{2}$ A | 19 | 9 | 3 | 11 24 20 | 9 $\frac{1}{2}$ A | 14 | |
| | 2 | 12 | 9 46 | 3 P | 9 | | 2 | 11 46 44 | 8 $\frac{1}{2}$ P | 8 | |
| | | | | 9 P | 11 $\frac{1}{4}$ | | | | | | |
| 30 | | | Cloudy. | 7 A | 20 $\frac{1}{2}$ | 10 | 3 | 11 22 12 $\frac{1}{2}$ | 7 $\frac{1}{2}$ A | 16 | |
| | | | | 4 P | 7 | | 2 | 11 44 37 | 11 $\frac{1}{2}$ A | 10 | |
| | | | | 11 P | 13 | | | | 3 $\frac{1}{4}$ P | 3 $\frac{3}{4}$ | |
| 31 | 3 | 11 | 43 12 | 7 A | 20 | 11 | 2 | 11 20 6 | 7 $\frac{1}{2}$ A | 16 | |
| | 2 | 12 | 5 37 | 9 P | 8 $\frac{1}{2}$ | | 2 | 11 42 30 | 12 | 9 $\frac{1}{2}$ | |
| Feb. | | | | | | 12 | 3 | 11 18 0 | 10 A | 17 $\frac{1}{2}$ | |
| 1 | 3 | 11 | 41 8 $\frac{1}{2}$ | 10 A | 18 $\frac{1}{4}$ | | 2 | 11 40 24 | 12 | 13 | |
| | 2 | 12 | 3 33 | 11 P | 16 | | | | 8 P | 5 $\frac{1}{2}$ | |
| 2 | 3 | 11 | 39 0 | 9 $\frac{1}{2}$ A | 17 $\frac{1}{2}$ | 13 | | Clouds. | 9 A | 17 | |
| | | 12 | 1 23 $\frac{1}{2}$ | 2 P | 9 | | | | 8 P | 6 | |
| | | | | 5 P | 6 | | | | | | |
| | | | | 9 P | 8 $\frac{1}{2}$ | | | | | | |
| 3 | 3 | 11 | 36 53 | 8 $\frac{1}{2}$ A | 19 | 14 | 3 | Cloudy. | 7 $\frac{1}{2}$ A | 16 | |
| | | | | 1 P | 9 $\frac{1}{2}$ | | 2 | 11 36 15 | 12 | 11 | |
| | | | | 9 P | 9 | | | | 8 P | 10 | |
| 4 | 3 | 11 | 34 46 | 6 $\frac{1}{4}$ A | 18 | 15 | | Clouds. | 9 A | 18 | |
| | 2 | 11 | 57 11 | 12 | 9 $\frac{1}{2}$ | | | | 12 | 13 $\frac{3}{4}$ | |
| | | | | 9 P | 8 | | | | 8 $\frac{1}{2}$ P | 7 $\frac{1}{2}$ | |
| 5 | 3 | 11 | 32 40 | 7 $\frac{1}{2}$ A | 19 $\frac{1}{4}$ | 16 | 3 | Cloudy. | 8 A | 14 | |
| | 2 | 11 | 55 5 | 3 $\frac{1}{2}$ P | 6 | | 2 | 11 32 41 | 8 P | 7 | |
| | | | | 8 $\frac{1}{2}$ P | 8 | | | | | | |
| 6 | 3 | 11 | 30 35 | 7 A | 18 $\frac{1}{2}$ | 17 | 3 | 11 7 34 | 12 | 12 | |
| | 2 | | Cloudy. | 4 P | 7 $\frac{1}{2}$ | | 2 | 11 29 59 | 8 P | 6 $\frac{1}{4}$ | |
| | | | | 8 $\frac{1}{2}$ P | 8 | | | | | | |
| 7 | 3 | 11 | 28 31 | 7 A | 20 $\frac{1}{2}$ | 18 | 3 | 11 5 29 | 12 | 12 $\frac{1}{4}$ | |
| | 2 | 11 | 50 55 | 12 | 12 | | 2 | 11 27 53 | | | |
| | | | | 8 $\frac{1}{2}$ P | 8 $\frac{1}{2}$ | | | | | | |

The Pendulum, during this Interval, vibrated about 1° 52' each way from the Perpendicular.

The

The Transits of the Stars over the Meridian, were observed with a Telescope, fix'd at Right Angles to an Horizontal Axis, whose Ends lay exactly East and West; by the turning of which Axis, the Line of Collimation of the Telescope, was constantly directed in the Plane of the Meridian. This Instrument was daily adjusted to a Mark, fix'd in the Meridian; and in the Journal, between the 2d and 3d of *February*, the following Remark was made.

N. B. *This Day was hotter than usual, as appears by the Thermometer; and the Transit Instrument had lost the Level a little, but after we had adjusted it, it pointed exactly to our Meridian Mark, and therefore we are at a loss for the Cause of this Difference in the Clock.*

From the foregoing Table it appears, that the Clock lost 54' 21" in 26 Revolutions of the Stars; that is, about 2' 5" in one Revolution; the Difference from this Medium somewhat varying, upon account of a greater, or less degree of Heat on different Days.

The Mean of all the observed Heights of the Thermometer from *January* 26th, to *February* 18th, was about 12½ Divisions. Therefore, the Difference between the mean Heights of the Thermometer, at *Jamaica*, and *London*, during the Intervals of the respective Observations, was 15½ Divisions; the Spirits standing so much higher in *Jamaica*, because of the greater Heat in that Island.

That we might be able to judge, how much the different Degrees of Heat, corresponding to any Number of Divisions upon this Thermometer, would cause

the Clock to go slower, by lengthening its Pendulum, Mr. *Graham* took Notice of the lowest Point, to which the Spirits sunk at *London* in the Winter, 1731; and the greatest Height to which they rose in the following Summer; and comparing the Motion of the Spirits in this Thermometer, with the Alterations in another made with Quicksilver, which he has for some Years made use of; he concluded, that at *London* the Spirits in this Thermometer would stand (*communibus Annis*) about 60 Divisions higher in Summer than in Winter.

By several Years Experience, he has likewise found, that his Clocks (of the same sort with Mr. *Campbell's*) when exposed, as usual, to the different Degrees of Heat and Cold of our Climate, do not vary in their Motion above 25 or 30 Seconds in a Day.

From these Observations and Experiments therefore we may reasonably conclude, that sufficient Allowance will be made for the Lengthening of the Pendulum by Heat, if we suppose the Clock, upon that Account, to go one Second in a Day slower, when the Spirits of this Thermometer stand two Divisions higher, and in the same Proportion for other Heights.

Admitting then, that the mean Height of the Thermometer, while the Clock was compared with the Stars at *Jamaica*, exceeded that at *London* between 15 and 20 Divisions; if we allow 8, or 9 Seconds, upon that Account, the remaining Difference must be wholly owing to the Difference of the Force of Gravity in the two Places.

Upon comparing the Observations, it appears, that in one apparent Revolution of the Stars, the Clock went 2' 6 $\frac{1}{2}$ " slower in *Jamaica*, than at *London*; deducting

ducting therefore $8''\frac{1}{2}$, on account of the greater Heat in *Jamaica*, there remains a Difference of $1' 58''$, which must necessarily arise from the Diminution of Gravity, in the Place nearest the Equator.

I have allowed the Clock to have lost somewhat more, on account of the Difference of Heat, than the mean Heights of the Thermometer may seem to require, upon a Supposition, that the total Heat of the Days, compared with the Cold of the Nights, bears a greater Proportion in *Jamaica*, than *London*; but if that Supposition be not admitted, then the Clock in *Jamaica*, must have gone rather more than $1' 58''$ in a Day slower than in *England*.

Mr. *Campbell's* Observations were made at *Black-River*, in 18° . North Latitude. Now if we suppose, with Sir *Isaac Newton*, that the Difference in the going of the Clock, is owing to the greater Elevation of the Parts of the Earth towards the Æquator, it will follow from these Observations, and what is delivered by him in the 20th Prop. of the 3d Book of his *Principia*, that the Æquatorial Diameter is to the Polar, as 190 to 189; the Difference between them being $41\frac{1}{2}$ Miles; which is somewhat greater than what Sir *Isaac Newton* had computed from his Theory, upon the Supposition of an uniform Density in all the Parts of the Earth.

I shall not enter into the Dispute about the Figure of the Earth, but at present suppose, with Sir *Isaac Newton*, that the Increase of Gravity, as we recede from the Æquator, is nearly as the Square of the Sine of the Latitude; and that the Difference in the Length of Pendulums, is proportional to the Augmentation, or Diminution of Gravity. Upon these
Suppo-

Suppositions, I collect from the forementioned Observations, that, if the Length of a simple Pendulum (that swings Seconds at *London*) be 39.126 *Englisch* Inches, the Length of one at the Æquator, would be 39.00, and at the Poles 39.206. And (abstracting from the Alteration on account of different Degrees of Heat) a Pendulum Clock that would go true Time under the Æquator, will gain 3' 48'' $\frac{1}{4}$ in a Day at the Poles; but the number of Seconds which it would gain in any other Latitude, would be to 3' 48'' $\frac{1}{4}$ nearly, as the Square of the Sine of that Latitude is to the Square of the Radius: From whence it follows, that the Number of Seconds which a Clock will lose in a Day, upon its Removal to a Place nearer to the Æquator, will be to 3' 48'' $\frac{1}{4}$ nearly, as the Difference between the Squares of the Sines of the Latitudes of the two Places to the Square of the Radius. Thus the Difference of the Squares of the Sines of 51° $\frac{1}{2}$, and 18°, the Latitudes of *London*, and *Black-River* being to the Square of the Radius, as 118 to 228 $\frac{1}{4}$, the Clock will go 1' 58'' in a Day slower at *Black-River* than at *London*, as was found by Observation.

It may be hoped, that Mr. *Campbell's* Success in this Experiment, and the little Trouble there is in making it, will induce those Gentlemen who may hereafter carry Pendulum-Clocks into distant Countries, to attempt a Repetition of it after his manner; that is, by keeping or restoring the Pendulums of their Clocks to the same Length in the different Places, and carefully comparing them with the Heavens, and at the same Time taking notice of the different Degrees of Heat, by means of a Thermometer.

From

From a variety of such Experiments, we should be enabled to determine how far Sir *Isaac Newton's* Theory is conformable to Truth, with much greater certainty than from those Trials which are made by actually measuring the Lengths of simple Pendulums; because a Difference of one hundredth Part of an Inch, in the Length of a Pendulum, corresponds to Eleven Seconds in a Day; and it being easy to observe how much a Clock gains, or loses in a Day, even to a single Second; it is certain, that by means of a Clock, compared in the manner abovementioned, we may distinguish a Difference (in the Lengths of Isochronal Pendulums) of one Thousandth Part of an Inch, or less; whereas it will be scarce possible to measure their true Lengths, without being liable to a greater Error than that. Besides, by taking Notice how much a Clock gains, or loses, upon the falling or rising of a Thermometer, we can better allow for the different Degrees of Heat in this, than in the other Method of making the Experiment, by actual Measurement; since it may not be easy to determine how much the Measure itself, which we make use of, will be lengthened by different Degrees of Heat.

For these Reasons, I esteem Mr. *Campbell's* Experiment to be the most accurate of all that have hitherto been made, and properest to determine the Difference of the Gravity of Bodies in different Latitudes, and therefore I shall subjoin a Table, which I computed from it, containing the Difference of the Length of a simple Pendulum, swinging Seconds at the *Æquator*, and at every fifth Degree of Latitude, together with the Number of Seconds that a Clock would gain in a Day, in those several Latitudes, supposing

it went true, when under the *Æ*quator; by means of which any one may readily compare other the like Observations with his; and thereby discover whether the Alteration of Gravity in all Places be uniform, and agreeable to the Rule laid down by Sir *Isaac Newton* or not.

| The Latitude of the Place. | The Difference of the Length of the Pendulum in Parts of an <i>Engliſh</i> Inch. | Seconds gained by a Clock in one Day. | The Latitude of the Place. | The Difference of the Length of the Pendulum in Parts of an <i>Engliſh</i> Inch. | Seconds gained by a Clock in one Day. |
|----------------------------|--|---------------------------------------|----------------------------|--|---------------------------------------|
| Deg. | Inch. | Seconds. | Deg. | Inch. | Seconds. |
| 5 | 0. 0016 | 1. 7 | 50 | 0. 1212 | 134. 0 |
| 10 | 0. 0062 | 6. 9 | 55 | 0. 1386 | 153. 2 |
| 15 | 0. 0138 | 15. 3 | 60 | 0. 1549 | 171. 2 |
| 20 | 0. 0246 | 26. 7 | 65 | 0. 1696 | 187. 5 |
| 25 | 0. 0369 | 40. 8 | 70 | 0. 1824 | 201. 6 |
| 30 | 0. 0516 | 57. 1 | 75 | 0. 1927 | 213. 0 |
| 35 | 0. 0679 | 75. 1 | 80 | 0. 2003 | 221. 4 |
| 40 | 0. 0853 | 94. 3 | 85 | 0. 2050 | 226. 5 |
| 45 | 0. 1033 | 114. 1 | 90 | 0. 2065 | 228. 3 |