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 Propoſition 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 Aquilæ* over the Meridian, which paſſed

	th		h.	′	″	
Auguſt, 1731.	20	at	8	59	15	by the Clock.
	22	at	8	59	18	
	23	at	8	59	20½	
	25	at	8	59	22	
	28	at	8	59	25½	
	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	32½	Diviſions.
	22	30¾	
	23	28¾	
	24	27¾	
Auguſt,	25	28¼	Hence the mean Height
1731.	26	27¼	for all theſe Days was
	27	27½	about 28½ Diviſions.
	28	27½	
	29	27½	
	30	27¼	

The Clock-weight that keeps the Pendulum in Motion is 12 *lb.* 10½ *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° 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° 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 Shipboard 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. Syrius* & 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.
		h	′	″	h	
Jan. 23	β	11	59	50	10½ A	14¾
	α	12	22	14	9½ P	11
24	Cloudy.				11½ A	15¼
25	β	11	55	40	8½ A	17½
	α	12	18	4	9¼ P	11¼

1732	Canis Majoris.	Time of Tranſit.			Hour of Day.	Thermometer.
		h	′	″	h	
Jan. 26	β	11	53	35	8 A	20
	α	12	16	00	2 P	8½
					9 P	10
27	β	11	51	31	7 A	17½
	α	12	13	55	2 P	8½
					9¼ P	12½

1732	Canis Majoris.	Time of Transit.	Hour of Day.	Thermometer.
Jan.		h ′ ″	h	
28	β	11 49 26	7 A	20½
	α	12 11 51	2 P	11
			10 P	12
29	β	11 47 22	6¾ A	19
	α	12 9 46	3 P	9
			9 P	11¼
30	Cloudy.		7 A	20½
			4 P	7
			11 P	13
31	β	11 43 12	7 A	20
	α	12 5 37	9 P	8½
Feb.	β	11 41 8½	10 A	18¾
1	α	12 3 33	11 P	16
2	β	11 39 0	9½ A	17½
		12 1 23½	2 P	9
			5 P	6
			9 P	8½
3	β	11 36 53	8½ A	19
			1 P	9½
			9 P	9
4	β	11 34 46	6¼ A	18
	α	11 57 11	12	9½
			9 P	8
5	β	11 32 40	7½ A	19¼
	α	11 55 5	3½ P	6
			8½ P	8
6	β	11 30 35	7 A	18½
	α	Cloudy.	4 P	7½
			8½ P	8
7	β	11 28 31	7 A	20½
	α	11 50 55	12	12
			8½ P	8½

1732	Canis Majoris.	Time of Transit.	Hour of Day.	Thermometer.
Feb.		h ′ ″	h	
8	β	Cloudy.	6½ A	21½
	α	11 48 50	8½ P	8¼
9	β	11 24 20	9½ A	14
	α	11 46 44	8½ P	8
10	β	11 22 12½	7¼ A	16
	α	11 44 37	11½ A	10
			3¾ P	3¾
			8½ P	6
11	β	11 20 6	7½ A	16
	α	11 42 30	12	9½
			8½ P	5¾
12	β	11 18 0	10 A	17½
	α	11 40 24	12	13
			8 P	5¾
13	Clouds.		9 A	17
			8 P	6
14	β	Cloudy.	7½ A	16
	α	11 36 15	12	11
			8 P	10
15	Clouds.		9 A	18
			12	13¾
			8½ P	7½
16	β	Cloudy.	8 A	14
	α	11 32 4	8 P	7
17	β	11 7 34	12	12
	α	11 29 59	8 P	6¼
18	β	11 5 29	12	12¼
	α	11 27 53		

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 $2'\ 5''\frac{11}{26}$ 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 $12\frac{1}{2}$ Diviſions. Therefore, the Difference between the mean Heights of the Thermometer, at *Jamaica*, and *London*, during the Intervals of the reſpective Obſervations, was $15\frac{1}{2}$ 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 $8''\frac{11}{2}$, 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 *Engliſh* 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 hundreth 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

it went true, when under the Æquator; 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 *Engliſh* 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 *Engliſh* 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