XI. *New Determination of the Mechanical Equivalent of Heat.*

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[Plate 26.]

The Committee of the British Association on Standards of Electrical Resistance having judged it desirable that a fresh determination of the mechanical equivalent of heat should be made, by observing the thermal effects due to the transmission of electrical currents through resistances measured by the unit they had issued, I undertook experiments with that view, resulting in a larger figure (782·5)* than that which I had obtained from the friction of fluids (772·6).†

The only way to account for this discrepancy was to admit the existence of error, either in my thermal experiments or in the unit of resistance. A committee, consisting of Sir Wm. Thomson, Professor P. G. Tait, Professor Clerk Maxwell, Professor B. Stewart, and myself, were appointed at the meeting of the British Association in 1870; and with the funds thus placed at my disposal I was charged with the present investigation, for the purpose of giving greater accuracy to the results of the direct method.

The plan I adopted was, in regard to the measurement of work, similar (as I afterwards found) to that used by Hirn, who has laboured so earnestly and successfully on this subject. He has described it as follows:—" L'appareil qui m'a servi pour cette étude consiste: 1°, en un cylindre en laiton de $0^{m}·3$ de diamètre, de 1^{m} de longeur, poli à sa périphérie externe, monté sur un axe solide en rapport avec un moteur d'un mouvement très régulier, et pouvant recevoir une vitesse variant à volonté de 60 à 600^{t} par minute; 2°, en un cylindre fixe, poli à son intérieur, concentrique au premier, éloigné partout de $0^{m}·03$ de celui-ci. Les disques ou plateaux formant les extrémités de la cylindre étaient munis, à leur partie centrale, de boîtes à étoupes par où sortait l'axe du cylindre interne. Tout l'intervalle compris entre les deux cylindres pouvait être rempli ainsi d'un liquide quelconque que les boîtes à étoupes empêchaient de s'écouler par les centres.

" Lorsque le cylindre intérieur tournait, le frottement que sa surface externe exerçait sur le liquide, et que le liquide, mis ainsi en mouvement lui-même, exerçait à

* Brit. Assoc. Report, Dundee, 1867, p. 522.

† Phil. Trans., 1850, p. 82.

son tour sur la surface interne du cylindre externe, tendait à faire tourner celui-ci. Deux leviers parfaitement parallèles, adaptés aux deux extrémités, et portant des plateaux de balance, permettaient d'empêcher la rotation à l'aide de poids qui indiquaient ainsi la valeur du frottement. La tare des leviers, la valeur du frottement des boîtes à étoupes, etc., étaient déterminées aisément en faisant tourner très lentement le cylindre interne dans les deux sens alternativement. Deux tuyaux verticaux, soudés aux deux disques de fermeture, et aussi près que possible des boîtes à étoupes, permettaient d'établir dans l'appareil un courant continu et parfaitement régulier d'un liquide voulu. La température de ce liquide était prise à l'entrée et à la sortie. Autant que possible, la température à l'entrée était tenue à autant de degrés au-dessous de celle de l'appartement que celle du liquide sortant était supérieure. Du reste, la loi de refroidissement de l'appareil était soigneusement déterminée de manière à ce qu'il fût facile de faire les corrections nécessaires.

"Cet appareil, qui dans son ensemble constitue une véritable balance à frottement des liquides, pouvait très aisément servir à faire connaître, d'une part, le travail dépensé pour tel ou tel liquide, pour telle ou telle vitesse, et d'autre part, à l'aide des corrections convenables, à faire connaître le nombre de calories produit par ce frottement dans un liquide dont la capacité calorifique était connue.

"Les résultats obtenus ont été en général d'une régularité satisfaisante. Six expériences consécutives faites sur l'eau, et avec différentes vitesses, avec des quantités diverses de liquide introduites par seconde entre les deux tambours, m'ont donné 432^{p}* pour le travail produisant une calorie, et par suite pour la valeur de l'équivalent."†

The method I adopted was to revolve a paddle in a suspended vessel of water, to find the heat thereby produced, measuring the work by the force required to hold the vessel from turning, and the distance run as referred to the point at which the force was applied. Fig. 1 represents the apparatus drawn one-eighteenth the actual size. A massive wooden framework, *a a*, resting on the asphalted floor of a cellar, is still further strengthened by means of timber abutting against the walls on every side. The perpendicular shaft *b* is supported by a conical collar‡ turned on it at *c*. It is revolved, along with the fly-wheel *f*, weighing about 1 cwt., by means of the doubling hand wheels, *d e*. A counter§ is placed at *g*, for the purpose of reading off the number of revolutions. The calorimeter *h* has an accurately turned groove, from which silk threads pass over the light, accurately-turned pulleys *j j*, to the scales *k k*. The

* This equals 787·4 in the measures I have adopted, viz., British feet, and degrees Fahr.

† 'Théorie Mécanique de la Chaleur,' 1865, p. 55. Maxwell has independently, in 1875, devised an apparatus of a similar description. He employs channelled cones, the revolution being on a vertical axis.

‡ Its surface, though only half a square inch, was found amply sufficient when castor-oil was employed as the lubricator. Other oils failed on trial.

§ In most of the experiments a second counter of my own construction was used to check the indications of the other. They were found in every instance to agree exactly.

hydraulic supporter, *w v*, was not employed in the first two series of experiments, and will be described further on. Three sides of the frame are boxed in permanently; the fourth, or front, has shutters with windows which can be removed at pleasure. A delicate thermometer, suspended within the frame, is observed through a telescope, as is also the thermometer employed in reading the temperature of the calorimeter.

Fig. 2 represents the section of the calorimeter, with its paddle, all of stout sheet brass; and fig. 3 gives a plan of the same. The dotted lines in the latter show the position of the fans in the upper part. The axle of the paddle works easily in the collar *m*, and is screwed into the boxwood piece *n*. There is another boxwood piece, *o*, fig. 1, placed to prevent any considerable quantity of heat arising from the friction of the shaft being conducted downwards. This friction was, however, so small that the precaution was afterwards found to be needless.

It will be seen in figs. 2 and 3 that there are four stationary vanes in the calorimeter, and two sets of rotating vanes, each of five arms, the upper set being fixed on the axis 9° behind the lower set. Hence no two vanes pass the fixed ones at the same moment, and inasmuch as the momentary alteration of resistance at crossing takes place 40 times in each revolution the resistance may be considered as practically uniform.

The circumference of the groove of the calorimeter was found by measuring its diameter in various places, and also by measuring it directly with a fine wire, allowing for the thickness of the latter. The results, obtained with a rule verified by the Warden of Standards, are—

Diameter in inches.		Circumference.
10·5850	. .	$\times\pi$=33·2538
10·5855	. .	$\times\pi$=33·2553
10·5855	. .	$\times\pi$=33·2553
Measured by wire $\frac{1}{120}$ in. diameter		=33·2538
" " $\frac{1}{55}$ "		=33·2563
Average		33·2549 inches=2·77124 feet.

The diameter of the silk cord, which was the finest that could be used with safety, was exactly $\frac{1}{100}$th inch. Hence the distance to be considered as run against the weights of the scales was, for each revolution, 2·77386 feet.

When a silk thread with a weight of 11,000 grains at each extremity was thrown over the small pulleys, 30 grains added to one of the weights was sufficient to keep both in motion. This friction, which includes the rigidity of the silk cord, taken with the distance traversed by the weights in their slight upward and downward motions during an experiment, gives the loss of work on the calorimeter from this cause. It did not amount to more than $\frac{1}{200000}$ subtractive from the equivalent, and could therefore be neglected.

The thermometer used to indicate the temperature of the calorimeter was the same which I employed in my former experiments. Those designated A* and D were calibrated with great care. I have recently compared them together at 50 different temperatures between 32° and 80° Fahr., the result being that if the less sensitive was assumed to be correct, the other, or A, nowhere appeared more than 0°·023 in error; but taking the averages for each consecutive 10° this error amounted to no more than 0°·008. I was anxious to compare these instruments with an air-pressure thermometer, and with that view have constructed an apparatus in which the height of the mercurial column is measured by a plummet hung over the axis of a graduated wheel, a method which I find capable of extreme accuracy, and which I purpose to apply to the construction of a new barometer. But owing to the use of caoutchouc in the connexion between the receiver and the rest of the apparatus, I fear that the zero point was subject to a slight displacement. The figures at which, after much labour, I have hitherto arrived, could not therefore be accepted as any improvement on REGNAULT's determinations of the expansion of air by heat.

The freezing-point of the standard D had risen from 13·3 divisions of its scale in 1844 to 15·14 in 1877. I think it probable that the boiling-point of this thermometer, if kept constantly at this temperature, would in the course of time fall as much. The five careful determinations of this boiling-point referred to 30 bar. and 60° are respectively 706, 706·4, 706, 705·9, and 706·15—mean 706·09. Subtracting 1·84, 704·25 will be the probable ultimate reading, from which if we take 15·14 we shall have 689·11 as the range between the fixed points cleared from the effects of imperfect elasticity of the glass. Mr. E. HODGKINSON has pointed out† that the "set" of imperfectly elastic bodies is proportional to the square of the force applied. Therefore the effect of imperfect elasticity in the glass of the thermometers will be insensible for the small ranges used in the experiments, and the factor 3·3822 for reducing the indications of D to those of A may be confidently relied on.

We have therefore $\frac{180}{689 \cdot 11 \times 3 \cdot 3822} = 0^\circ \cdot 07723$ as the most probable value of one division of A. In my former papers the number was taken as 0°·077214, which is so near that I shall continue to use it, trusting by long-continued observations of the fixed points to give it ultimately greater accuracy, and also by experiments above indicated to state it in terms of the absolute interval between these points.

The elevation of the mercurial column in A caused by the atmospheric pressure is five divisions, but inasmuch as in the limited time of an experiment the barometer never altered 0·1 inch, error from this cause was neglected. The depression occasioned by capillarity was 0·33 of a division.

A delicate calibrated thermometer E, each division of which indicated 0°·11195, was first used for taking the temperature of the air; but in consequence of a slight hitch

* Phil. Trans., 1850, p. 64.

† Brit. Assoc. Report, 1843, p. 23.

in the motion of the mercury, an instrument called G was afterwards employed, each of whose divisions was equal to $0^{\circ}\cdot1911$.

In registering the temperature of the air surrounding the calorimeter it was necessary to make allowance for the time which a thermometer takes in altering its temperature. I found that in a regularly rising or falling temperature E was $3^{m}\cdot8$ behind time, and G $3^{m}\cdot127$. This lagging of the thermometers was always carefully allowed for.

The capacity for heat of the calorimeter, calculated from the specific heat of brass given by REGNAULT, was equal to that of 5002 grains of water. But REGNAULT has shown how considerably the specific heat of metals of the same chemical composition is altered by changes in their hardness, and moreover there were the stoppers and other adjuncts to be taken into account. I therefore constructed the special apparatus represented by fig. 4, where B, B is a wooden box containing the calorimeter *h*; the projecting rim of the latter being supported by bits of string fastened at the top of three wooden legs, one of which is shown in fig. 5. In the lid of the box are three holes which the tubulures of the calorimeter just enter without touching. The paddle of the calorimeter can be agitated by means of the boxwood piece *n*. C is a copper vessel covered with a non-conducting substance: its lid is perforated to admit a stirrer, a thermometer, and a rod furnished with a caoutchouc stopper.

In experimenting with this apparatus, the calorimeter was first weighed after the water which it might have contained was shaken out. It was then placed on its three supports, and left for three or more hours in an apartment of uniform temperature, until its thermometer ceased to show alteration. The vessel C, containing an adjusted quantity of hot distilled water, and placed at some distance, had its gradually descending temperature noted from minute to minute. At a given moment it was rapidly transferred to the position shown in the figure; and then on pulling the plug out, *h* was filled in a few seconds. C was then quickly removed, and the caoutchouc stopper belonging to the tubulure through which the water had entered having been replaced, the temperature of the water was noted again from minute to minute while *n* was constantly moved. These observations afforded the means of eliminating the effects of radiation. Finally the calorimeter, as filled with the water, was again weighed.

In the first half of the following Table, A was employed in determining the temperature of the water introduced into the calorimeter, and D was the thermometer plunged into the calorimeter. In the latter half their positions were reversed. The temperatures are all given in divisions of A. *w* includes the estimated value of the air displaced, reckoned at 8 grains of water.

EXPERIMENTS on Capacity for Heat of Calorimeter.

No.	Water already in calorimeter. w.	First temperature of calorimeter. T.	Grains of water poured in. W.	Temperature of water poured in. T′.	Corrected resulting temperature. T″.	Thermal capacity of calorimeter. $\frac{W(T'-T'')}{(T'-T.)}-w$.
1	323·2	326·0	78887·6	457·63	449·47	4890·4
2	195·4	322·36	78996·6	464·62	456·5	4586·6
3	225·9	331·11	78984·6	475·84	467·4	4665·4
4	238·0	336·94	79042·6	505·36	495·35	4756·7
5	315·0	358·0	78916·8	504·04	495·4	4647·5
6	217·9	354·1	79029·6	512·36	502·13	5243·6
7	182·1	377·95	79127·7	514·1	506·18	4705·1
8	173·8	382·7	79044·7	534·42	525·29	4887·4
9	198·8	379·25	79059·2	613·83	599·82	4822·8
10	153·3	362·5	78959·2	614·04	598·56	5024·6
11	153·3	363·0	78920·2	673·03	654·57	4841·3
12	182·3	353·0	78914·0	641·11	623·77	4871·3
13	151·2	353·45	78789·2	658·06	640·11	4782·4
14	182·4	343·68	78574·0	668·01	649·02	4704·3
15	146·9	319·9	78817·7	654·83	634·85	4853·2
16	142·2	308·0	78933·2	640·97	621·13	4859·0
17	141·7	291·75	79021·7	668·07	646·07	4764·8
18	128·3	305·3	78946·7	647·78	627·8	4762·7
19	137·1	319·6	78895·2	681·64	660·31	4802·1
20	138·9	330·1	78821·7	654·51	635·38	4800·4
21	151·4	223·99	78774·7	624·35	600·3	4950·9
22	137·3	201·16	78996·2	638·52	612·66	4827·1
23	144·3	189·48	78965·7	637·71	611·18	4823·6
24	163·7	160·45	78884·7	636·91	607·95	4941·3
25	125·6	172·45	78801·2	643·44	615·12	4915·7
26	130·5	196·24	79026·7	613·78	589·46	4757·2
27	141·4	234·24	79094·2	665·48	640·53	4715·7
28	119·3	284·22	79031·2	669·39	647·19	4714·4
29	142·2	236·34	78913·2	669·26	643·56	4838·1
30	132·9	207·82	78976·7	662·14	635·38	4810·0
31	125·8	200·2	79019·7	674·56	646·63	4817·9
32	126·8	217·38	78915·7	667·95	641·0	4893·7
33	120·9	225·1	78824·7	672·3	646·14	4776·6
34	114·3	210·75	78986·2	673·03	646·03	4785·1
35	131·2	197·93	78806·7	648·93	622·51	4772·6
36	113·4	235·0	79024·2	684·54	658·32	4781·3
37	121·3	248·95	78882·2	675·41	650·4	4793·0
38	138·8	258·63	78865·7	682·38	657·24	4835·2
39	127·3	213·94	78696·0	682·26	654·53	4825·7
40	139·8	218·6	78811·7	681·67	654·57	4759·2
	Average . .	278·91	. .	624·71	604·25	4815·15

The average temperatures T′ and T″ are 78°·38 and 76°·8. Hence in order to express the foregoing result in terms of the capacity of a grain of water at 60°, we have, from the experiments of REGNAULT, 4815·15 × 1·00132 = 4821·5. Two further corrections were needed, one amounting, as was ascertained by means of experiments devised for the purpose, to 17·6, on account of the time allowed before the final reading of T″, limited to 8^{m}, not being sufficient to enable the caoutchouc stoppers and boxwood appendages to receive what would be their ultimate thermal distribution ; the other,

amounting to 3·3, arose from the thermal effect of the fall of water from one vessel to the other. Hence the final result for the capacity of the calorimeter, appendages, and thermometer, is 4842·4.

I thought it desirable to test this result by obtaining the sum of the capacities of the materials which composed the calorimeter. I had in my possession cuttings from the same sheets of brass that were used in the manufacture of the vessel and its paddle. These were formed into a compact bundle.

A copper vessel, A (fig. 6), filled with water, had a narrower vessel, C, immersed in it, to the bottom of which the material experimented on was let down by a fine wire. A Bunsen burner, *b*, kept the water at a constant temperature for not less than three hours, a continual agitation being given by revolving the stirrer *s*, formed on the principle of a screw propeller. The temperature having been noted, the material was rapidly lifted by the thin wire, and transferred to a small copper vessel, V, filled with distilled water, and furnished with a thermometer and stirrer. After 5^{m}, which time was required for the equal distribution of temperature, the immersed thermometer was read off, and its observation was repeated each succeeding minute for some time, in order to obtain the cooling effect of the atmosphere.* The following is a table of the results. The weight *w* of the bundle of brass was 2951·6 grains.

* The method first employed was the opposite one of plunging the material at the atmospheric temperature into a small vessel filled with hot water, and observing the temperature of mixture. The following specific heats were obtained by that method with brass and copper:—

	Brass.	Copper.
	·09200	·09516
	·08734	·09183
	·08945	·09295
	·09232	·08794
	·08734	..
Averages .	·08969	·09197

The wide discrepancy between the several results is owing to the great effect of the atmosphere on the small vessel, necessitating an absolute uniformity of stirring in order to give true temperatures.

No.	Thermal capacity of small vessel of water. W.	Temperature to which the brass was heated. T.	Temperature in small vessel before immersion of brass. T′.	Corrected temperature after immersion of brass. T″.	Time occupied in transferring the brass to the small vessel, in seconds.	Specific heat uncorrected for transfer. $\frac{(T''-T')\,W.}{(T-T'')\,w.}$
1	4733·2	901·25	174·78	213·24	5	0·08964
2	4762·8	900·58	175·5	213·8	4	0·08999
3	4747·0	947·27	213·26	252·29	3	0·09032
4	4727·7	952·13	158·0	200·56	4	0·09070
5	4750·3	1030·46	125·5	173·52	4	0·09018
6	4724·6	984·47	210·36	251·65	3	0·09019
7	4764·0	1069·6	197·95	244·3	4	0·09065
Average .		969·4 or 104°·92	179·34 or 44°·08	221·34 or 47°·32	3·86	0·09024
1	4756·0	894·49	104·35	145·72	30	0·08903
2	4794·2	985·82	154·5	197·44	30	0·08847
3	4717·4	994·44	165·33	208·97	30	0·08880
Average .		958·25 or 104°·06	141·39 or 41°·16	184·04 or 44°·44	30	0·08876

From the above we may estimate the correction arising from the time of transfer in the first seven experiments at ·00023, which, added to ·09024, gives ·09047 for the specific heat of brass at 76° compared with water at 46°. REGNAULT, in two trials, arrived at ·0939, but this appears to be in reference to water taken as 1·008. When reduced to water taken as unity it becomes ·09315, which still differs considerably from my result. The method of cooling used by REGNAULT in this instance does not appear to me to be capable of as great accuracy as the method of mixtures used by the same physicist for other substances.

The interest I felt in this part of my subject induced me to try some experiments of a similar nature with copper sheet. It was tied in a bundle like the brass. Its weight w was 2777·9 grains.

No.	W.	T.	T′.	T″.	Time of transfer.	$\frac{(T''-T')\,W.}{(T-T')\,w.}$
1	4734·5	855·26	199·3	232·62	6	0·09121
2	4772·7	900·58	172·4	209·57	4	0·09242
3	4738·5	946·26	218·85	255·49	5	0·09048
4	4732·2	948·07	166·18	206·18	5	0·09185
5	4786·3	1030·46	106·0	152·48	4	0·09121
6	4749·0	985·48	197·02	237·2	4	0·09180
7	4849·6	1069·0	103·35	208·46	4	0·09152
Average .		962·16 or 104°·36	166·16 or 43°·07	214·57 or 46°·80	4·57	0·09150
1	4749·9	891·11	106·6	145·2	30	0·08848
2	4815·1	985·14	161·46	201·14	30	0·08773
3	4768·0	997·47	170·35	210·99	30	0·08869
Average .		957·91 or 104°·03	146·14 or 41°·52	185·78 or 44°·58	30	0·08830

In the first seven the average time of transfer is $4^s \cdot 57$ and the proximate specific heat 0·091497. In the last three we have 30^s and 0·088302. From these the specific heat of the sheet copper at 75° is determined at 0·092094.

The boxwood piece *n*, fig. 2, had a brass nut in its centre by which it was screwed on the axle of the brass stirrer. Being a bad conductor, and having nearly the whole of its surface in contact with the air, only a small portion of its capacity for heat could be counted in reckoning the whole capacity of the calorimeter. I determined this portion by ascertaining the heat communicated to a can of water when the boxwood piece was immersed in it after having been screwed on the calorimeter filled with hot water, for different periods of time. Calling the difference between the temperatures of the air and the calorimeter T, the gain of temperature in the small can t, the capacity of this can of water c, and C the modified or virtual capacity of the boxwood piece, we have $C=\frac{tc}{T}$. The following results were obtained showing the gradual approach of this virtual capacity to a certain limit:—

Time that the boxwood was screwed on the calorimeter.	Virtual capacity.
3^m	45·6
6^m	57·5
8^m	63·9
12^m	67·3
60^m	76·0

The virtual capacity of the caoutchouc stoppers was determined in the same manner—

Time.	Capacity.
3^m	15·35
8^m	21·8
30^m	27·45

The several capacities making up that of the calorimeter are therefore summed as follows*:—

Brass, 51979 grains × ·09047 =	4702·54
Caoutchouc stoppers . . .	27·45
Boxwood piece	76·00
Thermometer	44·78
Total	4850·77

I had, therefore, great confidence in employing the value 4842·4, obtained, as already described, from experiments with the calorimeter itself.

* The specific heat of boxwood, which I obtained by immersion in mercury, was 0·417; that of the caoutchouc, 0·29.

In making an experiment for the equivalent the weight of the calorimeter filled with distilled water was first carefully ascertained. It was then screwed on to the axis, and the fine silk cords attached to the scales, *k k*, fig. 1, were adjusted. Thermometer A was then introduced into one of the tubulures, and after sufficient agitation of the water by means of the paddle itself, its indication was observed through a telescope. The thermometer was then removed and a caoutchouc stopper placed in the tubulure. The axle was then brought rapidly up to the velocity which produced friction sufficient to raise the weights about a foot from the ground. My son, Mr. B. A. JOULE, who turned the wheel, could, by observing the position of the scales in a mirror, keep them very steadily at a constant height during the whole time of revolution. The wheel having been rapidly brought to a standstill, the temperature of the calorimeter was again ascertained.

In the experiments in Table I. the number of revolutions of the axis when the weights were off the ground was added to half the number occupied in the acts of starting from rest and returning to rest.

Previously to, and subsequently to, every such experiment others were made under similar conditions as to the observation of temperatures, &c., in order to ascertain the effect of the atmosphere on the temperature of the calorimeter. The indications of the thermometer for temperature of air are always reduced to the graduation of thermometer A.

Experience had already shown me that the thermal effect of the air on the calorimeter was not exactly proportional to the difference of their temperatures. This might arise from variations in the radiating powers of brass and glass from day to day. By making experiments for the air-effect immediately before and after one for the equivalent, I sought to neutralize any error arising from this circumstance. The last column but one of the first part of the following Tables gives the amount of correction required to be applied to the temperature of the air so as to make the effect proportional to the difference of temperatures. The figures in the last two columns are then used for calculating the corrected rise of temperature in the last column but one of Part 2 of the Tables.

TABLE I., Part 1.—Experiments to ascertain the Effect of Radiation, &c. Time occupied by each of the first fifteen, 50^{m}; by the last two, 41^{m} and 41^{m} 30^{s}.

No.	Mean temperature of calorimeter.	Mean temperature of air.	Difference.	Rise of temperature of calorimeter.	Correction to air temperature.	Thermal effect of unit difference of temperature.
1*a* 1*b*	392·410 434·310	395·790 404·540	3·380+ 29·770—	0·20+ 3·40—	1·525—	0·1086
2*a* 2*b*	390·086 430·562	398·330 404·630	8·244+ 25·932—	0·62+ 2·96—	2·330—	0·1048
3*a* 3*b*	391·056 435·884	405·800 423·227	14·744+ 12·657—	1·52+ 1·35—	0·232—	0·1047
4*a* 4*b*	395·083 437·583	397·514 410·050	2·431+ 27·533—	0·26+ 3·06—	0·084—	0·1108
5*a* 5*b*	401·315 441·385	409·848 414·240	8·533+ 27·145—	0·61+ 3·13—	2·714—	0·1048
6*a* 6*b*	325·315 368·900	330·736 342·236	5·421+ 26·664—	0·49+ 2·96—	0·864—	0·1075
7*a* 7*b*	325·880 368·940	327·820 341·300	1·940+ 27·640—	0·16+ 2·88—	0·383—	0·1028
8*a* 8*b*	338·980 383·250	346·286 360·957	7·306+ 22·293—	0·74+ 2·30—	0·071—	0·1028
9*a* 9*b*	344·225 383·790	336·196 342·847	8·029— 40·943—	0·75— 4·52—	1·460+	0·1145
10*a* 10*b*	327·350 373·705	344·610 361·645	17·260+ 12·060—	2·00+ 1·29—	0·564+	0·1122
11*a* 11*b*	333·920 381·685	359·248 373·528	25·328+ 8·157—	3·12+ 0·67—	2·237+	0·1132
12*a* 12*b*	326·597 372·650	345·308 355·450	18·711+ 17·200—	2·26+ 1·74—	1·598+	0·1115
13*a* 13*b*	311·930 355·000	318·630 328·244	6·700+ 26·756—	0·66+ 2·96—	0·600—	0·1082
14*a* 14*b*	301·305 347·650	322·640 333·546	21·335+ 14·104—	2·37+ 1·30—	1·551+	0·1036
15*a* 15*b*	327·560 372·875	347·235 355·375	19·675+ 17·500—	1·92+ 1·85—	0·742—	0·1014
16*a* 16*b*	296·165 344·810	315·265 321·837	19·100+ 22·973—	1·71+ 2·38—	1·534—	0·0971
17*a* 17*b*	280·810 328·730	295·307 305·500	14·497+ 23·230—	1·15+ 2·20—	1·561—	0·0888

TABLE I., Part 2.—Experiments with Friction of Water and Brass. Weight, W, lifted in the first fifteen, 14619·5 grains; in the last two, 18122·9 grains. Average proportion of metallic to total friction, $\frac{1}{7\cdot 7}$. Time occupied by each of the first fifteen, 50^{m}; by the last two, 41^{m} and 41^{m} 30^{s}. Value, or V, of one division of the thermometer, 0°·077214. Circumference of groove of calorimeter, P, 2·77386 feet.

No.	Number of revolutions. R.	Capacity of the calorimeter. C.	Mean temperature of the calorimeter.	Mean temperature of the atmosphere.	Difference.	Rise of temperature of calorimeter.	Ditto, corrected for radiation, &c. T.	Mechanical equivalent or $\frac{R\,W\,P}{C\,T\,V}$
1	5545·0	84359·5	414·480	400·190	14·290 −	42·761	44·478	776·15
2	5378·0	84413·4	412·570	399·130	13·440 −	41·830	43·482	769·52
3	5522·6	84369·5	415·594	416·030	0·436 +	44·606	44·585	771·06
4	5685·2	84309·1	418·020	402·390	15·630 −	43·905	45·646	775·89
5	5321·3	84439·5	423·522	409·792	13·730 −	41·347	43·071	768·43
6	5756·5	84429·4	349·325	335·160	14·165 −	44·890	46·506	769·98
7	5753·5	84424·1	349·502	332·934	16·568 −	44·509	46·251	773·87
8	5740·7	84429·1	363·325	351·585	11·740 −	44·923	46·137	774·01
9	5714·0	84448·6	366·028	338·175	27·853 −	42·682	45·703	777·55
10	5725·7	84415·0	352·730	351·466	1·264 −	46·088	46·167	771·60
11	5695·0	84383·1	360·146	366·080	5·934 +	46·631	45·706	775·51
12	5702·2	84370·1	351·998	349·282	2·716 −	45·878	46·003	771·59
13	5681·2	84355·0	335·844	322·280	13·564 −	44·295	45·827	771·80
14	5702·3	84353·0	326·922	325·294	1·628 −	45·883	45·891	773·64
15	5670·8	84291·0	352·669	348·867	3·802 −	45·368	45·829	770·97
16	4965·5	84282·1	324·334	316·810	7·524 −	48·750	49·630	772·85
17	4953·3	84398·0	307·643	298·298	9·345 −	48·535	49·503	771·87
	Average		366·16 or 58°·46	..	..	..	..	772·72

The mean temperature of the atmosphere was derived from observations taken from minute to minute, but there were only two readings of the temperature of the calorimeter, viz., at the commencement and termination of an experiment, from which to determine its average temperature. Suppose *a b*, fig. 7, to represent the line of air temperatures during an experiment lasting 41^{m}: the temperatures of the calorimeter will be represented by a line similar to *c d e f*. The wheel was set in motion 2^{m} after the first reading was taken. The temperature then rose until, at 35^{m}, the wheel was stopped. The temperature then declined slightly, until, at 41^{m}, the last reading was taken. The line is slightly curved; a few seconds are occupied in starting and stopping the wheel, and the thermometer reads a little backwards. Taking all these circumstances into account, I found that the average temperature for the whole time was very accurately represented by $\frac{37\,\frac{c+f}{2}+4f}{41}$. The mean temperature of the calorimeter for other times of experiment was estimated in a similar manner.

To obtain the corrected rise of temperature in the last column but one, the correction to the air temperature indicated in the first part of the Table was supplied. For instance, in the first experiment the temperature of the air was

virtually 14·29+1·525=15·815 lower than that of the calorimeter. Hence 15·815×0·1086=1·717, which, added to 42·761, gives the value for T, 44·478.

Table II., Part 1.—Experiments to ascertain the Effect of Radiation, &c. Time occupied by each experiment, 41^{m}. Weight raised for an instant, 18229·0 grains.

No.	Revolutions. *r*.	Mean temperature of calorimeter.	Mean temperature of air.	Difference.	Rise of temperature of calorimeter.	Correction to air temperature.	Thermal effect of unit difference of temperature.
1*a* 1*b*	25·5 23·5	259·220 305·925	268·008 277·775	8·788+ 28·150−	0·945+ 2·478−	1·410+	0·0926
2*a* 2*b*	26·0 22·92	261·740 308·925	273·313 286·733	11·573+ 22·192−	1·572+ 1·850−	3·938+	0·1013
3*a* 3*b*	23·60 24·12	267·270 318·620	291·597 307·351	24·327+ 11·269−	3·590+ 0·660−	5·741+	0·1194
4*a* 4*b*	22·75 23·17	298·510 344·910	308·706 316·151	10·196+ 28·759−	1·00+ 2·33−	1·502+	0·0855
5*a* 5*b*	22·0 21·08	311·560 355·710	311·188 317·040	0·372− 36·670−	0·12+ 3·38−	1·685+	0·0914
6*a* 6*b*	21·7 21·04	285·095 331·865	300·273 308·541	15·178+ 23·324−	1·59+ 1·77−	3·054+	0·0873
7*a* 7*b*	21·3 19·8	292·760 340·435	304·393 312·739	11·633+ 27·696−	1·28+ 2·23−	2·709+	0·0892
8*a* 8*b*	21·0 21·2	277·730 328·775	295·705 311·147	17·975+ 17·628−	2·46+ 1·21−	5·890+	0·1031
9*a* 9*b*	19·83 18·79	301·550 351·365	321·510 324·762	19·960+ 26·603−	1·90+ 2·33−	0·955+	0·0908
10*a* 10*b*	18·33 17·85	300·370 352·595	325·183 335·507	24·813+ 17·088−	2·34+ 1·29−	2·198+	0·0866
11*a* 11*b*	18·2 17·24	277·800 329·570	304·655 317·940	26·855+ 11·630−	2·80+ 0·86−	2·587+	0·0951
12*a* 12*b*	16·0 18·74	288·400 336·980	321·267 331·820	32·867+ 5·160−	3·20+ 0·40−	0·935+	0·0947
13*a* 13*b*	18·0 17·66	313·820 364·075	331·190 358·747	17·370+ 5·328−	3·73+ 0·15+	6·279+	0·1577
14*a* 14*b*	17·32 18·0	308·585 356·840	329·613 340·123	21·028+ 16·717−	2·33+ 1·28−	3·334+	0·0956
15*a* 15*b*	32·0 18·6	309·885 359·100	331·872 340·480	21·987+ 18·620−	2·00+ 1·46−	1·485+	0·0852

TABLE II., Part 2.—Experiments with Friction of Water and Brass. Weight, W, lifted, 18229·0 grains. Average proportion of metallic to total friction, $\frac{1}{8 \cdot 3}$. Time occupied by each experiment, 41^m. $V = 0^{\circ} \cdot 077214$; $P = 2 \cdot 77386$.

No.	Number of revolutions. R + r.	Capacity of the calorimeter. C.	Mean temperature of the calorimeter.	Mean temperature of the atmosphere.	Difference.	Rise of temperature of the calorimeter.	Ditto, corrected for radiation, &c. T.	Mechanical equivalent, or $\frac{RWP}{CTV}$
1	4898·5	84349·7	286·242	271·743	14·499−	47·686	48·898	773·94
2	4826·5	84242·7	288·94	277·634	11·306−	47·477	48·223	774·09
3	4929·75	84191·7	296·43	298·242	1·812+	50·046	49·144	776·48
4	4839·5	84324·0	324·9	311·823	13·077−	47·288	48·278	774·80
5	4829·5	84270·0	336·865	312·924	23·941−	46·119	48·153	775·93
6	4734·3	84256·0	311·387	303·190	8·197−	46·893	47·342	773·74
7	4897·5	84234·5	320·1	308·110	11·990−	48·168	48·996	773·84
8	5061·7	84295·7	306·684	303·337	3·347−	50·640	50·378	777·30
9	5091·8	84294·0	330·182	321·677	8·505−	50·237	50·922	773·88
10	5165·9	84250·0	330·3	328·046	2·254−	51·800	51·805	772·38
11	5045·2	84302·0	307·173	309·280	2·107+	50·820	50·374	775·28
12	4613·66	84292·0	315·95	324·655	8·705+	47·250	46·337	770·62
13	4733·9	84304·0	342·25	343·864	1·614+	48·326	47·081	778·11
14	4782·17	84284·0	335·99	333·819	2·171−	47·771	47·660	776·73
15	4834·0	84244·0	338·125	333·930	4·195−	48·225	48·456	771·42
	Average		318·101 or 54°·76	..	..	..	..	774·57

Instead of reckoning one-half of the revolutions which took place in the acts of starting and stopping the wheel, as was done in the case of Table I., I have eliminated them in the last and subsequent Tables by starting the wheel till the scales were raised for an instant and then immediately stopped it at some period in each experiment for determining radiation. The revolutions called r in the first part of the Table being subtracted from the revolutions called $R+r$ in the second part, give the numbers used in calculating the equivalent. This latter plan obviated some slight error to which the former method was possibly liable.

The irregularities in the values of R arise from the variations from time to time in the friction of the bearing which supports the calorimeter on the axis. In the subsequent experiments I adopted a method which removed nearly the whole of the metallic friction. In fig. 1, v and w represent two concentric vessels. The inner one has a lid surmounted by three uprights, such as that represented by fig. 5. When water is poured into the space between the vessels, the uprights are raised so as to press against the bottom rim of the calorimeter, thus relieving its weight on the axis. The arrangement was eminently successful in producing an almost absolute uniformity of motion.

TABLE III., Part 1.—Experiments to ascertain the Effect of Radiation, &c. Time occupied by each experiment, 41^{m}. Weight raised for an instant, 16477·4 grains.

No.	Revolutions *r*.	Mean temperature of calorimeter.	Mean temperature of air.	Difference.	Rise of temperature of calorimeter.	Correction to air temperature.	Thermal effect of unit difference of temperature.
1*a*	19·0	385·526	427·236	41·710+	4·05+	1·237+	0·1060
1*b*	19·5	432·690	424·879	7·811—	0·62—		
2*a*	18·58	366·510	376·830	10·320+	1·02+	0·683+	0·0927
2*b*	19·42	409·710	386·590	23·120—	2·08—		
3*a*	18·75	338·865	364·127	25·262+	2·325+	0·862+	0·0890
3*b*	20·33	386·535	368·066	18·469—	1·567—		
4*a*	19·5	339·675	368·504	28·829+	2·51+	0·429—	0·0884
4*b*	20·75	385·410	372·488	12·922—	1·18—		
5*a*	19·17	357·290	378·033	20·743+	1·78+	0·027—	0·0859
5*b*	19·31	402·025	386·340	15·685—	1·35—		
6*a*	20·67	357·885	389·996	32·111+	2·97+	0·843+	0·0901
6*b*	20·93	404·650	397·150	7·500—	0·60—		
7*a*	19·33	355·780	383·923	28·143+	2·56+	0·600+	0·0891
7*b*	19·75	401·960	389·234	12·726—	1·08—		
8*a*	19·4	878·970	388·517	9·547+	0·90+	0·612+	0·0886
8*b*	21·2	421·730	392·446	29·284—	2·54—		
9*a*	19·46	342·575	361·843	19·268+	1·83+	0·503+	0·0926
9*b*	20·0	387·000	369·210	17·790—	1·60—		
10*a*	18·83	347·205	369·358	22·153+	1·75+	0·240—	0·0799
10*b*	20·43	391·930	373·889	18·041—	1·46—		
11*a*	19·0	349·530	378·721	29·191+	2·78+	1·341+	0·0911
11*b*	19·0	395·970	386·502	9·468—	0·74—		
12*a*	19·0	344·970	383·753	38·783+	3·54+	1·383+	0·0881
12*b*	19·0	393·040	390·749	2·291—	0·08—		
13*a*	18·0	348·125	372·988	24·863+	2·17+	0·627+	0·0851
13*b*	17·75	393·550	380·002	13·548—	1·10—		
14*a*	18·12	346·520	378·315	31·795+	3·00+	1·185+	0·0910
14*b*	17·0	393·310	386·409	6·901—	0·52—		
15*a*	17·73	356·395	390·069	33·674+	3·49+	0·688+	0·1016
15*b*	19·23	404·170	400·922	3·248—	0·26—		
16*a*	18·0	345·085	380·701	35·616+	3·17+	0·560+	0·0876
16*b*	16·72	392·365	386·442	5·923—	0·47—		
17*a*	19·0	366·715	388·706	21·991+	1·93+	0·086+	0·0874
17*b*	18·0	411·775	395·102	16·673—	1·45—		
18*a*	19·57	374·230	400·624	26·394+	2·46+	1·102+	0·0895
18*b*	18·97	420·020	408·859	11·161—	0·90—		
19*a*	18·72	396·755	412·830	16·075+	1·49+	0·501+	0·0899
19*b*	19·0	440·415	415·996	24·419—	2·15—		
20*a*	19·33	367·770	403·836	36·066+	3·46+	1·611+	0·0918
20*b*	17·77	415·070	411·934	3·136—	0·14—		
21*a*	17·0	386·805	415·792	28·987+	2·93+	1·158+	0·0972
21*b*	18·3	433·470	426·345	7·125—	0·58—		

TABLE III., Part 2.—Experiments with almost solely Friction of Water. Weight, W, lifted, 16477·4 grains. Average proportion of metallic to total friction, $\frac{1}{106}$. Time occupied by each experiment, 41^{m}. $V = 0^{\circ}{\cdot}077214$; $P = 2{\cdot}77386$.

No.	Number of revolutions. R + r.	Capacity of the calorimeter. C.	Mean temperature of the calorimeter.	Mean temperature of the air.	Difference.	Rise of temperature of the calorimeter.	Ditto, corrected for radiation, &c. T.	Mechanical equivalent, or $\frac{RWP}{CTV}$
1	4904·95	84160·7	412·530	422·744	10·214+	45·509	44·295	775·78
2	4940·58	84124·2	390·866	381·225	9·641−	43·909	44·740	774·04
3	4925·28	84118·1	367·765	364·627	3·138−	44·564	44·767	771·14
4	4922·92	84071·2	365·695	369·159	3·464+	45·125	44·857	769·56
5	4938·0	84012·2	382·816	380·063	2·753−	44·747	44·986	770·39
6	4936·3	83930·2	384·452	391·613	7·161+	45·580	44·859	772·82
7	4958·0	83940·7	382·015	386·005	3·990+	45·530	45·121	771·82
8	4925·3	83882·2	403·368	390·360	13·008−	43·643	44·741	773·64
9	4925·9	83907·2	367·897	364·284	3·613−	44·564	44·852	771·68
10	4927·6	83884·2	372·565	370·435	2·130−	44·706	44·857	772·09
11	4934·3	83911·2	375·915	381·468	5·553+	45·438	44·810	773·81
12	4935·0	83889·2	372·285	386·270	13·985+	46·150	44·795	774·38
13	4929·0	83880·2	373·936	375·248	1·312+	44·930	44·765	774·22
14	4923·22	83888·7	373·092	380·689	7·597+	45·487	44·688	774·61
15	4923·0	83872·7	383·670	395·008	11·338+	45·850	44·629	775·60
16	4923·0	83897·2	372·033	382·095	10·062+	45·707	44·776	773·00
17	4928·0	83889·7	392·412	390·767	1·645−	44·652	44·788	773·47
18	4926·0	83904·7	400·189	402·495	2·306+	45·105	44·800	772·69
19	4925·75	83891·2	421·652	413·149	8·503−	44·148	44·867	771·68
20	4926·33	83944·2	394·541	406·037	11·496+	45·763	44·559	776·68
21	4924·0	83938·7	413·330	419·217	5·887+	45·459	44·774	772·76
Average			385·86 or 59°·98	..	..	..	..	773·136

An error of four or five seconds in the time at which the wheel was started and stopped will account for the divergence of the revolutions in Nos. 1 and 7 from the average. For the rest, it will be seen with what great constancy the resistance of the paddle was kept up.

The weights were also so steady that the total distance run by them in their risings and fallings only amounted to about 30 feet in each experiment. This, taken with the friction of the pulleys = 30 grains, gives a quantity to be subtracted from the equivalent too small to require estimation.

TABLE IV., Part 1.—Experiments to ascertain the Effect of Radiation, &c. Time occupied by each experiment, 41^{m}. Weight raised for an instant, 7730·56 grains.

No.	Revolutions. r.	Mean temperature of calorimeter.	Mean temperature of air.	Difference.	Rise of temperature of calorimeter.	Correction to air temperature.	Thermal effect of unit difference of temperature.
1*a* 1*b*	9·5 8·62	362·355 374·950	358·090 363·536	4·265− 11·414−	0·45− 1·10−	} 0·684−	0·0909
2*a* 2*b*	10·0 9·9	361·090 375·040	363·847 368·448	2·757+ 6·592−	0·18+ 0·60−	} 0·599−	0·0834
3*a* 3*b*	10·0 10·24	355·495 368·430	352·673 357·570	2·822− 10·860−	0·31− 1·02−	} 0·688−	0·0883
4*a* 4*b*	10·57 10·25	346·515 361·985	359·807 365·790	13·292+ 3·805+	1·01+ 0·15+	} 2·150−	0·0906
5*a* 5*b*	9·66 10·74	340·260 354·970	346·208 356·487	5·948+ 1·517+	0·52+ 0·08+	} 0·711−	0·0993
6*a* 6*b*	10·82 10·66	357·855 373·890	368·538 382·515	10·683+ 8·625+	1·01+ 0·78+	} 1·646−	0·1118

TABLE IV., Part 2.—Experiments with almost solely Friction of Water. Weight, W, lifted, 7730·56 grains. Average proportion of metallic to total friction, $\frac{1}{43}$. Time occupied by each experiment, 41^{m}. $V = 0^{\circ}{\cdot}077214$; $P = 2{\cdot}77386$.

No.	Number of revolutions. R + r.	Capacity of the calorimeter. C.	Mean temperature of the calorimeter.	Mean temperature of the air.	Difference.	Rise of temperature of the calorimeter.	Ditto, corrected for radiation, &c. T.	Mechanical equivalent or $\frac{RWP}{CTV}$
1	3336·66	83963·7	369·487	361·043	8·444−	13·495	14·325	768·32
2	3344·2	83944·7	369·065	366·560	2·505−	14·078	14·337	769·39
3	3343·42	83959·7	362·809	354·425	8·384−	13·646	14·447	763·18
4	3341·23	83949·7	355·191	362·160	6·969+	14·927	14·490	760·44
5	3330·75	83975·0	348·411	350·362	1·951+	14·416	14·293	768·30
6	3335·33	83965·0	366·732	375·533	8·801+	15·040	14·240	772·19
Average			361·949 or 58°·14	..	..	..	..	766·97

It will be obvious that, in the experiments of the above Table, where the heat evolved was able to raise the temperature of the calorimeter little more than 1°, great accuracy could not be expected without taking the average of a very large number of observations. In fact, the degree of accuracy will increase nearly with the square of the rise of temperature per unit of time,* and the square root of the number of observations.

* *I.e.*, supposing the "Differences," for calculating the air correction, increase with the values of T.

TABLE V., Part 1.—Experiments to ascertain the Effect of Radiation, &c. Time occupied by each experiment, 41^{m}. Weight raised for an instant, 21729·56 grains.

No.	Revolutions. r.	Mean temperature of calorimeter.	Mean temperature of air.	Difference.	Rise of temperature of calorimeter.	Correction to air temperature.	Thermal effect of unit difference of temperature.
1*a* 1*b*	22·0 20·64	386·760 454·455	419·637 427·134	32·877+ 27·321−	3·52+ 2·37−	} 3·099+	0·09784
2*a* 2*b*	21·16 22·0	390·200 460·345	433·283 444·140	43·083+ 16·205−	4·40+ 1·33−	} 2·444+	0·09665
3*a* 3*b*	20·0 21·22	380·885 448·250	410·976 418·488	30·091+ 29·762−	2·77+ 2·50−	} 1·369+	0·08805
4*a* 4*b*	22·0 23·16	386·310 455·170	420·428 436·858	34·118+ 18·312−	3·62+ 1·64−	} 1·965+	0·10032
5*a* 5*b*	21·42 22·0	397·770 465·440	428·568 441·275	30·798+ 24·165−	3·46+ 2·12−	} 3·283+	0·10152
6*a* 6*b*	19·0 22·0	396·300 465·630	438·413 447·180	42·113+ 18·450−	3·84+ 1·42−	} 2·100+	0·08685
7*a* 7*b*	21·0 22·0	377·300 444·240	405·069 414·354	27·769+ 29·886−	2·60+ 2·52−	} 1·509+	0·08880

TABLE V., Part 2.—Experiments with almost solely Friction of Water. Weight, W, lifted, 21729·56 grains. Average proportion of metallic to total friction, $\frac{1}{108}$. Time occupied by each experiment, 41^{m}. $V = 0°·077214$; $P = 2·77386$.

No.	Number of revolutions. R + r.	Capacity of the calorimeter. C.	Mean temperature of the calorimeter.	Mean temperature of the air.	Difference.	Rise of temperature of the calorimeter.	Ditto, corrected for radiation, &c. T.	Mechanical equivalent, or $\frac{RWP}{CTV}$
1	5653·0	83924·2	425·354	419·585	5·769−	67·336	67·597	774·93
2	5653·16	83960·2	430·165	436·986	6·821+	68·582	67·687	773·54
3	5652·55	83970·5	419·268	413·363	5·905−	67·214	67·613	774·35
4	5648·66	84001·7	425·460	426·763	1·303+	67·877	67·549	774·00
5	5645·4	83986·2	436·432	433·830	2·602−	67·522	67·453	774·90
6	5646·5	83973·7	435·661	439·140	3·479+	68·215	67·730	772·17
7	5659·0	83970·7	415·580	408·720	6·860−	67·232	67·707	774·03
Average			{ 426·846 or 63°·14 }	..	..	..	..	773·99

The average number of revolutions per minute in the last two tables were 101·4 and 171·5. The fluid resistances, 7630·2 and 21548·5, were therefore almost exactly proportional to the squares of the velocities.

The foregoing results are collected in the following Table :—

Table.	Number of experiments.	Proportion of metallic to total friction.	Mean rise of temperature per A.	Temperature of the calorimeter.	Mechanical equivalent of unit of heat.
1	17	$\frac{1}{7\cdot7}$	45·907	58°·46	772·72
2	15	$\frac{1}{8\cdot3}$	48·803	54°·76	774·57
3	21	$\frac{1}{106}$	44·777	59°·98	773·136
4	6	$\frac{1}{43}$	14·355	58°·14	766·97
5	7	$\frac{1}{120}$	67·620	63°·14	773·99

The average of the first two gives 773·65 as the equivalent at a temperature of the calorimeter 56°·61 ; but inasmuch as the metallic friction is as much as $\frac{1}{8}$ of the whole, I prefer to use the last three, and to give each its due weight I will multiply the squares of the rise by the square root of the number of determinations :—

$$\text{For the 3rd series } (44\cdot777)^2 \times \sqrt{21} = 9188.$$
$$\text{For the 4th series } (14\cdot355)^2 \times \sqrt{6} = 504\cdot76.$$
$$\text{For the 5th series } (67\cdot62)^2 \times \sqrt{7} = 12097\cdot7.$$

Then—

$$\frac{733\cdot136 \times 9188 + 766\cdot97 \times 504\cdot76 + 773\cdot99 \times 12097\cdot7}{9188 + 504\cdot76 + 12097\cdot7} = 773\cdot467$$

is the equivalent at 61°·69 ; or, using REGNAULT's law of the increase of the specific heat of water with its temperature, 773·369 at 60°.

The latitude of the part of Higher Broughton, Manchester, where the experiments were made, is 53° 28½′ N. ; its elevation about 120 feet above the sea level. The equivalent at the sea level and the latitude at Greenwich will therefore be 773·492 foot lbs., defining the unit of heat to be that which a lb. of water, weighed by brass weights when the barometer stands at 30 inches, receives in passing from 60° to 61° Fah. With water weighed in vacuo the equivalent is finally reduced to 772·55.

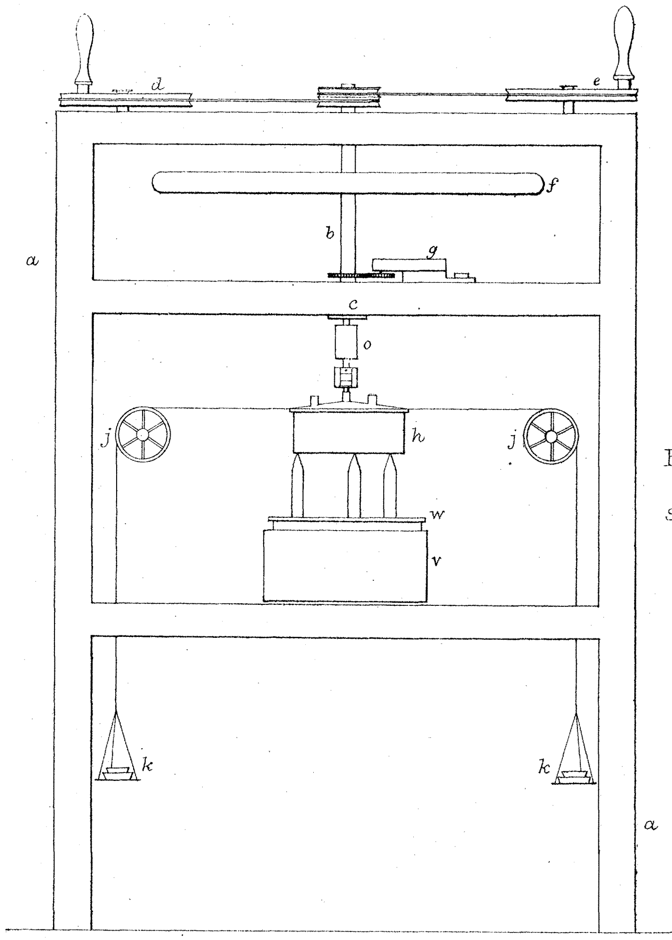

Fig. 1.

Scale 1/18

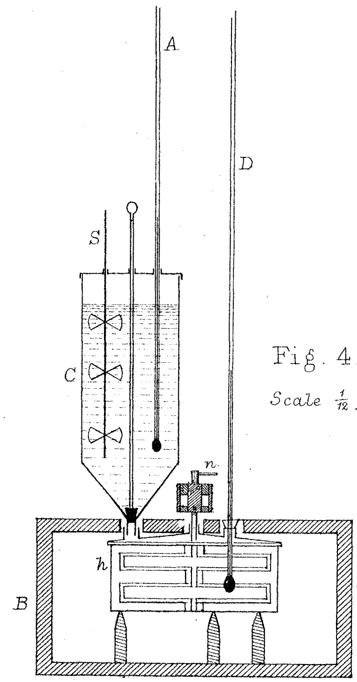

Fig. 4.

Scale 1/12.

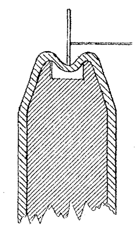

Fig. 5.

Scale 2/3.

Fig. 3.

Scale 1/6.

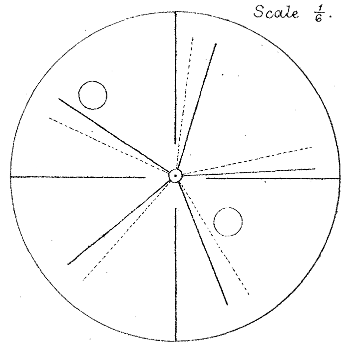

Fig. 2.

Scale 1/6