Bronze Medal, struck in honour of Dr. John Syer Bristowe, F.R.S. The obverse bears the effigy of Dr. Bristowe; the reverse depicts a student in his laboratory, and has the words "St. Thomas's Hospital" in the exergue. Mr. Allan Wyon.

November 22, 1894.

Sir JOHN EVANS, K.C.B., D.C.L., LL.D., Vice-President and Treasurer, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

In pursuance of the Statutes, notice of the ensuing Anniversary Meeting was given from the Chair, and the list of Officers and Council nominated for election was read as follows:—

President.—The Lord Kelvin, D.C.L., LL.D.

Treasurer.—Sir John Evans, K.C.B., D.C.L., LL.D.

Secretaries.—{ Professor Michael Foster, M.A., M.D.
The Lord Rayleigh, M.A., D.C.L.

Foreign Secretary.—Sir Joseph Lister, Bart., F.R.C.S.

Other Members of the Council.—Andrew Ainslie Common, LL.D.; William Crookes, F.C.S.; Francis Darwin, M.A.; Andrew Russell Forsyth, Sc.D.; Sir Douglas Galton, K.C.B.; Professor Alexander Henry Green, M.A.; Sir John Kirk, K.C.B.; Professor Horace Lamb, M.A.; Professor Edwin Ray Lankester, M.A.; Professor Alexander Macalister, M.D.; Professor John Henry Poynting, D.Sc.; Professor Arthur William Rücker, M.A.; Osbert Salvin, M.A.; Professor J. S. Burdon Sanderson, M.D.; Thomas Edward Thorpe, Sc.D.; William Henry White, C.B.

The following Papers were read:—

I. "A Determination of the Specific Heat of Water in terms of the International Electric Units." By ARTHUR SCHUSTER, F.R.S., Langworthy Professor of Physics at the Owens College, Manchester, and WILLIAM GANNON, M.A., Exhibition (1851) Scholar, Queen's College, Galway. Received November 13, 1894.

(Abstract.)

This research was originally undertaken by Professor Schuster and Mr. H. Hadley, before the authors were aware that Mr. E. H. Griffiths was engaged on a similar investigation. After a number of preliminary experiments, and just as the final arrangements for the conduct of the measurements were being definitely made, Mr. Hadley, on his appointment to the Head Mastership of the School of Science and Art, Kidderminster, had to leave Manchester. In the meantime Mr. Griffiths' important research was published, and we had to consider whether our own work, which was designed on a smaller scale, could compete with it in accuracy. We decided to complete the investigation, principally for the reason that, although we both aimed at determining what is commonly called the mechanical equivalent of heat through the heating of a certain mass of water by means of an electric current, the details of the experiments differed very materially, so that our two ways of dealing with the problem seemed to afford a useful test of the amount of agreement which at present may be obtained. Our investigation touches only a small part of that treated by Mr. Griffiths, as we did not attempt to measure the changes in the specific heat of water due to change of temperature. On the other hand, the more modest limits within which we have confined ourselves allowed us to use a much simpler apparatus.

On Mr. Hadley's departure, Mr. W. Gannon took his place. From the former gentleman we received a good deal of help in the divising and construction of some important parts of the apparatus.

The principle of the method we have used is extremely simple. The electrical work done in a conductor being measured by $\int ECdt$, where E is the difference of potential at the ends of the conductor, C the current, and t the time. We keep the electromotive force constant, and measure $\int Cdt$ directly by a silver voltameter. We do not, therefore, require to know the resistance of the wire, and we thus avoid the difficulty of having to estimate the excess of temperature of the wire over that of the water in which it is placed. We also gain the advantage of not having to measure time, and therefore of being able to complete the experiments more quickly than we could

have safely done if the length of time the current passed had to be measured with great accuracy.

The Results.

We divide our experiments into three series, but only attach any value to the third, as during the first two sets the thermometer was falling in the last period. We had hoped at first to be able to apply a small correction to eliminate the error which is due to the fact that a falling thermometer will read too high, and we made a large number of experiments to determine the correction. We arrived, however, at the result that the indications of a falling thermometer are so irregular that no correction is possible. Consequently in our third series the thermometer was rising during the whole course of each experiment.

We think it worth while to put on record an impression that the behaviour of our Baudin thermometer has altered since we first received it from the maker. As soon as it came some preliminary experiments were made to see if we could work with the thermometer while it was falling, and the observations seemed to show that the fall was sufficiently uniform. Our first three experiments gave results which were very consistent, and a minute after the current was broken the temperature seemed to fall already in a perfectly regular manner. But as we continued our work, the behaviour of the instrument seemed to deteriorate. Thus, in our experiment on March 8, the temperature had hardly fallen three minutes after the current had stopped. It is possible that this is due to accidental circumstances, for it is well known that different places of the bore of a capillary tube behave very differently. We wish, therefore, to express no opinion at present as to the probability of an actual change in the thermometer, but only to draw the attention of other experimenters to this point, which seems worth keeping in mind.

Our final value is

$$\begin{aligned} J = {} & 4{\cdot}1804 \text{ Joules on the mercury scale of hard French glass,} \\ & 4{\cdot}1905 \text{ on the nitrogen scale,} \\ & 4{\cdot}1917 \text{ on the hydrogen scale,} \\ & \qquad \text{at a temperature of } 19^\circ{\cdot}1. \end{aligned}$$

This result depends on the assumption that the electrochemical equivalent of silver is 0·001118, and that our standard Clark cell had an electromotive force of

$$1{\cdot}4340(1-\alpha\,\overline{t^\circ-15}) \text{ volts,}$$

where

$$\alpha = 0{\cdot}000814+0{\cdot}000007(t^\circ-15),$$

as given by Kahle ('Zeits. f. Instrumentenkunde,' vol. 13, p. 310, 1893). Glazebrook and Skinner's coefficient refers to a mean temperature of 7°·5, and is identical with the above at that temperature.

The comparison of the results of different observers will be facilitated by Table I, in which we compare the work done in ergs with the foot-pound at Greenwich and the kilogrammetre at Paris. This table has been calculated on the assumption that g at Paris is equal to 980·96, and at Greenwich equal to 981·24. We have prepared another table (II), which at any temperature will give the correction of an interval measured on our mercury thermometer to an interval measured on the nitrogen and hydrogen thermometers. This table has been calculated with the help of the equation given by Chappuis for the correction to the thermometer made of French hard glass.

In comparing our results with that of other observers, we have in the first place to consider the value which Mr. Griffiths has obtained in his very excellent series of measurements. His final result ('Roy. Soc. Proc.,' vol. 55, p. 26; 'Phil. Trans.,' clxxxiv, A, 1893) is

$$J = 4{\cdot}1982(1-0{\cdot}00266\ \overline{\theta-15})\times 10^7.$$

This refers to the nitrogen thermometer. At a temperature of 19·1°, the value would be reduced to 4·1936, which corresponds to our 4·1905 at the same temperature. Griffiths' value is to be increased slightly, owing to the fact that he really measures the difference between the specific heat of water and of air. This would increase the value of J by ·0011 about, so that the value of J at 19·1° would be raised to $4{\cdot}1947 \times 10^7$, which is exactly one part in a thousand larger than ours. The difference is small, but must be due to some systematic error, as both Griffiths' value and our own agree so well with each other, that ordinary observational errors and accidental disturbances could not have produced so large a difference in our results. The least satisfactory part of a calorimetric measurement must always be the application of the cooling correction, and we have considered it of great importance to reduce that correction as much as possible. The uncertainty of the cooling correction does not necessarily depend on its value; thus we can much diminish it by starting, as we have done in the third series, with the initial temperature of the calorimeter about as much below that of the water jacket as the final temperature is above it; yet the *uncertainty* of the correction does not seem to us to be diminished by that process. We may reasonably estimate the uncertainty due to the cooling correction, by calculating what the error in the observed rate of cooling, either at the beginning or the end of the experiment, must have been in order to produce a difference of one part in a thousand in the final result. We find in our own experiments that the error must

Table I.

Ergs × 10^{-7}.	Foot-pounds at Greenwich.	Kilogrammetres at Paris.
4·160	772·83	424·07
4·165	773·76	424·58
4·170	774·68	425·09
4·175	775·61	425·60
4·180	776·54	426·11
4·185	777·47	426·62
4·190	778·40	427·13
4·195	779·33	427·64
4·200	780·25	428·15
4·205	781·19	428·66
4·210	782·12	429·17

Table II.

	10°.	12°.	14°.	16°.	18°.	20°.	22°.	24°.
Correction to nitrogen thermometer	−0°·00369	0°·00337	0°·00305	0°·00275	0°·00247	0°·00220	0°·00194	0°·00170
Correction to hydrogen thermometer	−0°·00418	0°·00381	0°·00346	0°·00313	0°·00280	0°·00249	0°·00219	0°·00190

have amounted to more than 15 per cent. We consider it unlikely that so large an error occurred always in the same direction. Apart from the cooling correction, however, it is difficult to see how a difference of one-tenth per cent. in our result can be produced unless by the accumulation of a number of small errors.

The weak point of Mr. Griffiths' determination is the small quantity of water he uses, his result depending on the difference in his rate of rise after the addition of about 120 grams into his calorimeter. The highest water equivalent with which he worked was about 360 grams, of which 85 are due to the calorimeter itself. The chief objection to the use of such small quantities of water lies in the great cooling correction. In the experiments quoted by him at p. 482, the loss of heat due to radiation and conduction at the end of his experiment amounts to about 9 per cent. of his heat supply. If such loss had been wrongly estimated to 1 per cent., an error of one-tenth per cent. would result in the final value. The consistency of Mr. Griffiths' results shows that if an error occurred due to that cause, it must have been systematic; and we may point out how, with such a large cooling correction, serious errors may arise. In applying the cooling correction, it is always assumed that the loss of heat depends only on the difference of temperature between the calorimeter and enclosure; but, as has been already pointed out, this is not the case as regards conduction. Mr. Griffiths' calorimeter was suspended by three stout glass tubes, through one of which the stirrer was passing. The exhaustion in the space surrounding the calorimeter was never sufficient to do away with the conduction of air; so that we may take the larger part of the cooling to be due to conduction and convection. The loss of heat in that case must to some extent depend, not only on the temperature, but also on the *rate of change* of temperature. Whether the part which depends on the rate of change is sufficient to produce a sensible difference in the result, it is not easy to say. But the error produced would, with different currents and quantities of water, be the same in all cases, and could not therefore be detected by the inconsistencies thereby introduced into the results.

The difference between our value of the equivalent and that of Mr. Griffiths are, however, of smaller importance than the difference which exists between them and the equivalent as determined directly by Joule, Rowland, and Miculescu. Joule's latest value, which is the only one which needs consideration, is 772·65 foot-pounds, at 61°·7 Fah. The number refers to the degree as measured by Joule's mercury thermometer. Rowland adds to this a correction to the air thermometer of about 3, and another small correction for a change in the heat capacity of the apparatus, which brings the value up to about 776. The correction to the air thermometer has been obtained by

means of a comparison made by Joule himself with one of Rowland's thermometers. Joule's original thermometers have been temporarily placed by Mr. B. A. Joule in the hands of Professor Schuster, in order that an accurate comparison may be instituted between it and modern thermometers. A full description of the comparisons made will be given on another occasion. The result arrived at shows that the correction is less than that assumed by Rowland, and would bring his value up only to 775 at the temperature indicated. Griffiths compares his result with that deduced by Rowland from Joule's observations. Rowland combined the different values obtained by Joule in his various investigations, attaching weights according to his judgment as to their relative merits. He finds in this way that the difference between him and Joule amounts to one part in 350, but if equal weights are attached to all Joule's results, the difference is reduced to one part in 4281. Little value can be attached, however, to a combination of Joule's results which gives equal weights to that obtained in 1847 and that deduced from his latest and most careful work. There is, moreover, in Rowland's table a misprint or error in the reduction of Joule's 1847 result from foot-pounds to kilogrammetres, which lowers the value as given by Griffiths from 779·2 to about 778. It does not seem to us advisable to go beyond Joule's 1878 results, and the value assigned by him in this latest research should be taken as giving his final judgment on the matter. Reducing to the nitrogen thermometer of the Bureau International, Joule's result is 775 foot-pounds at Greenwich, at a temperature of 16°·5 C. At the same temperature Griffiths' number is 779·8.

Great weight must be attached to Rowland's determination, which at the temperature to which Joule's number applies is 777·6, and at 19°·1, 776·1, corresponding to our 778·5. Rowland's value is therefore halfway between our and Joule's result. But it must be taken into consideration that if the comparison between Rowland's and Joule's thermometers as made by the latter is to be trusted, Rowland's value referred to the "Paris" nitrogen thermometer would be slightly reduced. At any rate it seems probable that if his value is in error, it is rather in the direction of being too high. We have therefore a difference of three parts in a thousand to account for between our result and that of Rowland, and of nearly four parts in a thousand between Griffiths and Rowland at a temperature of 19°·1. These results are summarised in the following table:—

Table III.—Equivalent in foot-pounds at Greenwich at 19°·1 referred to the "Paris" Nitrogen Thermometer.

Joule.	Rowland.	Griffiths.	Schuster and Gannon.
774	776·1	779·1	778·5

We now turn to an investigation of Miculescu ('Annales de Chimie et de Physique,' vol. 27, 1892), in which the mechanical equivalent of heat is measured directly by what seems a very excellently devised series of experiments. Its result is $4{\cdot}1857 \times 10^7$. He does not state the exact temperature to which this applies, but all his experiments seem to have been made between 10° and 13°, so that we may assume 11°·5 to be the mean temperature of his experiments. Rowland's value at that temperature is $4{\cdot}1999 \times 10^7$. We must draw attention to one point in Miculescu's work which requires clearing up before we can give to it any decisive value. Everything in the experiments depends on the measurement of a couple, the arm of the couple being the distance between two knife-edges; one of them had to support a weight of more than 43 kilograms. The distance between these knife-edges is said to have been 28 cms. in all experiments. Very insufficient information is given, however, as to how that distance was measured, and it would almost seem as if the author had trusted to the maker in adjusting the central knife-edge to the zero point of that scale. If the apparatus is still in existence, it might be well to make sure that no error has been introduced through a wrong estimate of the distance of the lever arm.

In order to compare Miculescu's value with that of others, we must apply a temperature correction which is somewhat doubtful; but taking the mean of Rowland's and Griffiths' values as the most probable at present, we obtain at 15° the following table:—

Table IV.—Equivalent in foot-pounds at Greenwich at 15° referred to the "Paris" Nitrogen Thermometer.

Joule.	Rowland.	Miculescu.	Griffiths.	Schuster and Gannon.
775	778·3	776·6	780·2	779·7

If we remember that Rowland's number referred to the "Paris" nitrogen thermometer would probably be smaller by one unit, we are struck with the fair agreement there is, on the one hand, between the results of Joule, Rowland, and Miculescu, and on the other hand between Griffiths and ourselves.

As far as we can draw any conclusions from the comparison, it seems to point to a difference in the value obtained by the electrical and direct methods. Whether this difference is due to some remaining error in the electrical units, or to some undiscovered flaw in the method adopted by Mr. Griffiths and ourselves, remains to be decided by further investigation.

II. "On the Temperature of the Carbons of the Electric Arc; with a Note on the Temperature of the Sun." By W. E. Wilson and P. L. Gray. Communicated by Dr. G. J. Stoney, F.R.S. Received November 14, 1894.

[Publication deferred.]

III. "Observations of Sun-spot Spectra, 1879—1894." By J. Norman Lockyer, C.B., F.R.S. Received November 15, 1894.

[Publication deferred.]

Presents, November 22, 1894.

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