



XXXIV. A simple method of determining the radiation constant: suitable for a laboratory experiment

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mark α is much easier and more accurate with the plunger than is the usual one by means of blotting-paper applied at A, and in addition the horizontal arm permits of its employment in the common thermostats with opaque sides, while reducing to a minimum the amount of contained liquid outside the bath.

The University, Birmingham.

XXXIV. *A Simple Method of Determining the Radiation Constant: suitable for a Laboratory Experiment. By A. D. DENNING, M.Sc., Ph.D., Demonstrator in Physics in the University of Birmingham*.*

THE following experiment was suggested to me by Prof. Poynting, F.R.S., as a laboratory experiment, and as it is by no means difficult to carry out and appears to give good results, it may be useful to give an account of it.

The principle of the method followed may be thus briefly described:—A hemispherical radiator, blackened inside, was quickly placed over a flat silver disk of known dimensions and which formed one of the junctions of a constantan-silver thermoelectric couple. From observations, at definite intervals of time, of the deflexions of the moving coil of a low-resistance d'Arsonval galvanometer included in the circuit, the initial rate of rise of temperature† of the disk was obtained and this result, when substituted in the equation (α), given below, gives σ the radiation constant.

For, suppose m = mass of silver disk,

s = its specific heat,

dT/dt = initial rate of temperature change,

then $ms \cdot dT/dt$ = initial amount of heat received by disk.

But if A = exposed area of disk,

R = radiation from that area per unit of time,

and R_1 = radiation from blackened hemisphere,

then the gain of heat by the plate

$$= (R_1 - R)A,$$

$$= ms \cdot dT/dt.$$

Using Stefan's Law, we may write:

$$R = \sigma T^4 \quad \text{and} \quad R_1 = \sigma T_1^4$$

where

σ = the radiation constant,

T & T_1 = the temperatures of disk and hemisphere, respectively, measured from -273°C .

* Communicated by the Physical Society: read May 12, 1905.

† The initial rate of temperature rise being taken to avoid gain of heat by disk from conduction and convection effects.

Consequently

$$ms \cdot dT/dt = A\sigma(T_1^4 - T^4),$$

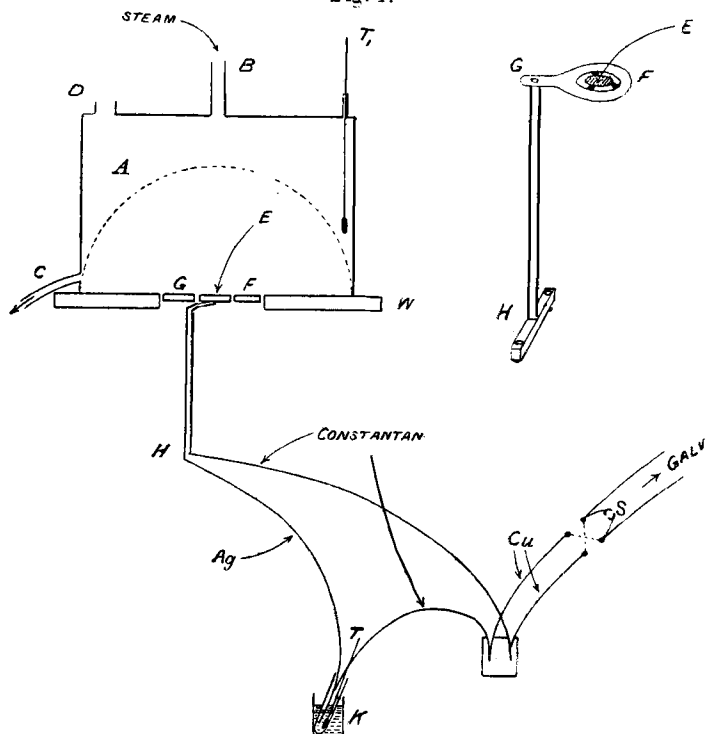
or

$$\sigma = \frac{ms}{A(T_1^4 - T^4)} \cdot \frac{dT}{dt} \dots \dots \dots (\alpha)$$

If the galvanometer readings were proportional to the current existing at the instant of reading, we should have dT/dt by simply noting successive deflexions at known times. But, owing to the moment of inertia of the moving part of the galvanometer and the viscous resistance, the reading will not always indicate the current at the instant, as will be seen from the investigation below (Appendix). In this case, however, the readings did indicate the temperature, when plotted to eliminate oscillations.

The actual arrangement of the apparatus is shown diagrammatically in fig. 1. A is a cylindrical vessel of

Fig. 1.



15.3 cms. internal diameter: to the underneath side of this vessel was soldered a polished copper hemisphere, indicated

in the figure by the dotted line, and which, before an experiment, was evenly coated with a layer of lampblack produced by the combustion of camphor. The space between the cylindrical and hemispherical vessels was used as a reservoir for steam or the other substances which were employed to maintain the hemispherical radiator at the temperature T_1 . The tube B served as an inlet and the tube C as an outlet for the steam; the wider tube, D, was subsequently added for the purpose of covering the hemispherical radiator with ice. During the course of a series of observations this part of the apparatus rested on the wooden board, W. (The stands supporting this latter are not shown in the diagram.)

As mentioned above, the elements of the thermo-junctions were silver and constantan. In order to have an appreciably large surface to receive the radiation at the one junction, the silver and constantan wires were soldered on to a silver disk, E. This disk, after having been thoroughly well polished, was mounted in a vulcanite frame, FG, which fitted into the wooden board carrying A. The disk also was lamp-blackened before being used. If it be considered desirable to prevent the disk receiving radiation at the sides, felt or some other non-conducting material might be so wrapped round the disk that only the top surface of it was exposed to the hemispherical radiator. The wires coming from the disk were led down the arm GH to the binding-screws at the bottom. The other junction of the thermo-couple was placed, together with a thermometer, T, in a test-tube containing oil in the glass beaker, K. The two constantan wires were further soldered to copper wires leading through a mercury commutator to the galvanometer. These last two (the Cu-constantan) junctions were passed through rubber tubing fitting into two holes in the lid of a tin canister packed with cotton-wool.

The dimensions of the silver disk were :

Diameter = 2.015 cm. Weight = 8.911 gr.
Thickness = 0.275 cm. Sp. Ht. = 0.0567.

This value for the specific heat was the mean of several determinations made by means of a Joly steam calorimeter.

Inasmuch as the source of steam and also the outlet from the vessel A were on the side CD of the apparatus, a long piece of sheet nickel, polished on the one side, was tacked on to the wooden stand W, with the idea of screening the underside of the silver disk from the hot air currents. It was also found advisable to further protect the disk from

draughts by loosely fixing under it a wide pad of cotton-wool, held in position by a wire passing between the retort stands supporting W, since otherwise the opening and shutting of doors, &c., was sufficient to occasion an irregular and jerky motion of the galvanometer-coil.

During the boiling of the water, the silver disk was covered by a screen with one edge resting on two thin corks to prevent actual contact between the disk and the screen. This screen was made by taking a piece of sheet nickel, approximately twice the size of the board W, doubling it into two with the dull side inwards and, after placing a layer of cotton-wool between the folds, wiring the two folds loosely together.

When steam had passed for some time through the vessel A, the latter was placed on the screen. At a particular instant the screen was removed, A was lowered over the disk and some six to ten readings of the position of the cross-wire image were taken at intervals of five seconds (in the majority of cases).

In order to find the temperature equivalent of the galvanometer deflexions, the silver disk was kept at a constant temperature, and the deflexions of the galvanometer were noted when the temperature of the other junction was altered by a known amount—subsequent reference is made to this point.

Before beginning an experiment it is necessary to ascertain that the two thermo-junctions are at the same temperature or to know the difference of temperature between them. In these experiments the following procedure was adopted:—By insertion of the shunt-key S the galvanometer was short-circuited and its zero-position found. Did the deflexions, consequent to the removal of the key, indicate that the temperature of the disk was too low, the hand was held over the disk until the cross-wire image returned to its initial position of rest; whilst if the temperature were too high, ether was poured on to a piece of cotton-wool resting on a crucible lid, and this was allowed to evaporate in the neighbourhood of the disk.

The results of a number of experiments extending over varying ranges of temperature are given in Table I. In the last column but one are given the values of the initial rate of change of temperature, whilst the last column contains the values found for $\sigma \cdot 10^5$. It will be noticed that in some of these experiments alcohol and acetone were passed through the radiating vessel and afterwards condensed in a condensing worm (not shown in fig.). But subsequent experiments

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TABLE I.

	Date.	Temperatures.		$dT/dt.$	$\sigma \cdot 10^5.$
		$T_1^\circ.$	$T^\circ.$		
Steam {	29/11/04	100.0 C.	18.7 C.	9.44	5.19
	12/12/04	99.5	15.6	9.71	5.30
	12/12/04	99.5	16.3	9.55	5.22
	17/12/04	98.5	17.4	6.47	3.36
Alcohol {	19/12/04	78.6	14.8	4.95	3.92
	19/12/04	78.6	9.2	7.25	5.39
	20/12/04	78.6	14.5	6.71	5.32
Acetone {	20/12/04	57	12.8	4.24	5.43
	20/12/04	57	13.1	4.24	5.46
Ice {	21/12/04	0	15.2	1.06	5.24
	21/12/04	0	14.7	1.06	5.42

(results recorded in Table II.) showed that easier manipulation and equally satisfactory results were to be obtained by simply placing hot water in A ; owing to the large bulk of water which A could hold (nearly two litres), its rate of cooling was comparatively slow ; whereas the observations necessary for each experiment were made in less than a minute.

TABLE II.

Date.	Temperatures.		$dT/dt.$	$\sigma \cdot 10^5.$
	$T_1^\circ.$	$T^\circ.$		
27/1/05	100.5 C.	16.6 C.	9.83	5.26
27/1/05	100.5	17.8	9.83	5.29
28/1/05	75.0	17.8	5.99	5.30
28/1/05	73.0	17.8	5.76	5.32
28/1/05	60.5	17.6	4.32	5.49
28/1/05	60.0	17.8	4.32	5.39
28/1/05	45.0	15.5	2.64	5.32
28/1/05	43.8	15.8	2.40	5.40
31/1/05	0	15.7	1.08	5.14
31/1/05	0	14.9	1.08	5.48

By quickly removing the radiator after sufficient readings had been taken and placing the cotton-wool saturated with

ether near the disk, it was possible to take several sets of observations in fairly quick succession—especially if a current of air were maintained across the disk. Owing to the small range of temperature prevailing when the ice was used and the possibility of disturbances due to convection, such close agreement with the other results as was actually obtained was hardly to have been expected. It has been thought advisable to include all the experiments made to indicate what kind of accuracy can be expected.

A glance at the values for σ given in the last columns of both tables will at once show that two of the values are very much lower than the other nineteen. The most probable explanation for this is that somewhere in the galvanometer-circuit there was poor contact and a consequent increase in the circuit-resistance—most likely in the mercury commutator, since these at times are very unreliable. Indeed, determinations of the equivalent of the galvanometer readings made from time to time during the course of the first series of experiments showed variations in the sensibility of the galvanometer. Hence it were better to measure the sensitiveness of the galvanometer directly before taking a series of observations by arranging that the simple reversal of a commutating-switch might place the galvanometer in circuit with a low resistance, the fall of potential along which is a constant small fraction of the E.M.F. of a storage-cell.

Ignoring these two values, we find uniformity and agreement among the remainder—the average of the residual nineteen results being about 5.3. The mean of Kurlbaum's more elaborate experiments was 5.32. The simplicity of construction of the apparatus and the principles embodied in its use will, it is hoped, recommend the experiment as a laboratory method of illustrating an important and fundamental law.

APPENDIX.

Note on Motion of Galvanometer Coil.

In order to take into account the effect of the moment of inertia of the moving coil and the viscous resistance of the medium, let us suppose that a steady difference of 1° C. between the thermo-junctions gives a steady deflexion of the galvanometer-coil of λ radians, then a steady difference of temperature of T' would give a steady deflexion

$$\theta = \lambda T'.$$

If the torsional couple per radian exerted by the suspension is μ , then the couple on the fibre in a steady state would be

$$\mu\theta = \mu\lambda T'.$$

But the observations are taken during the motion of the galvanometer-coil, *i. e.* when the change of temperature is not steady.

In this case

$$\mu\theta = \mu\lambda T - I \frac{d^2\theta}{dt^2} - K \frac{d\theta}{dt};$$

where

I = the moment of inertia of coil,
 K = the viscosity coefficient of the air,
 T = the initial difference of temperature;

that is

$$I \frac{d^2\theta}{dt^2} + K \frac{d\theta}{dt} + \mu\theta = \mu\lambda T;$$

putting

$$K/I = k \quad \text{and} \quad \mu/I = n^2.$$

the equation of motion becomes

$$\frac{d^2\theta}{dt^2} + k \frac{d\theta}{dt} + n^2\theta = n^2\lambda T.$$

Now, if T be approaching a steady value A , according to the exponential law we have

$$T = A(1 - e^{-pt});$$

consequently

$$\frac{d^2\theta}{dt^2} + k \frac{d\theta}{dt} + n^2\theta = n^2\lambda A(1 - e^{-pt}),$$

the solution of which gives

$$\theta = \lambda A \left(1 - \frac{n^2 e^{-pt}}{p^2 - kp + n^2} \right) - B e^{\frac{-kt}{2}} \sin \left(\sqrt{n^2 - \frac{k^2}{4}} \cdot t + \alpha \right).$$

The second term is evidently oscillatory so long as $n^2 > \frac{k^2}{4}$;

but if k be large it dies away rapidly, or to such an extent that it can be eliminated by plotting, and we have only to deal with

$$\theta = \lambda A \left(1 - \frac{n^2 e^{-pt}}{p^2 - kp + n^2} \right)$$

differentiating

$$\frac{d\theta}{dt} = \lambda p A e^{-pt} \cdot \frac{n^2}{p^2 - kp - n^2};$$

but from the differentiation of the exponential equation,

given above,

$$\frac{dT}{dt} = pAe^{-pt},$$

and since we only want the initial rate of rise of temperature

$$\frac{dT}{dt}_{t=0} = [pAe^{-pt}]_{t=0} = pA,$$

but

$$\frac{d\theta}{dt}_{t=0} = \frac{\lambda p A n^2}{p^2 - kp + n^2}.$$

Hence

$$\frac{dT}{dt}_{t=0} = pA = \frac{p^2 - kp + n^2}{n^2} \cdot \frac{d\theta}{dt} \bigg/ \lambda.$$

By plotting galvanometer deflexions against the times, we can eliminate the oscillations and obtain the initial rate of change of θ , i. e. $\frac{d\theta}{dt} \bigg/ \lambda$, from the curve. (And since we are only concerned with the ratio of $\frac{d\theta}{dt} \bigg/ \lambda$ we can use galvanometer scale-divisions instead of radians.)

Consequently, then, in order to obtain the initial rate of rise of temperature, the observed $\frac{d\theta}{dt} \bigg/ \lambda$ must be multiplied by

$$(p^2 - kp + n^2)/n^2.$$

Should $p^2 - kp$ be small in comparison with n^2 , this fraction may evidently be neglected. But to test this we must first find n , p , and k for the particular galvanometer in use.

(i) To find n :

If the circuit is open, k is negligible and $2\pi/n$ is the time of swing. Or, if the observed period of free swing be P then

$$n = 2\pi/P.$$

(ii) To find k :

For the deflexion θ on closed circuit we have

$$\theta = Be^{-\frac{kt}{2}} \sin \left(\sqrt{n^2 - \frac{k^2}{4}} \cdot t + \beta \right),$$

and if successive deflexions or elongations θ_1 , θ_2 , θ_3 , and θ_4 be observed it is easily seen that

$$\log \frac{\theta_1 - \theta_2}{\theta_3 - \theta_4} = \frac{k\pi}{\sqrt{n^2 - \frac{k^2}{4}}}.$$

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(iii) To find p :

From the exponential law we have

$$\frac{dT_1}{dt} = Ape^{-pt_1},$$

and therefore

$$\frac{d\theta_1}{dt} \propto Ape^{-pt_1} = A_1pe^{-pt_1} \text{ say.}$$

Similarly for time t_2 (where $t_2 = 2t_1$)

$$\dot{\theta}_2 = A_1pe^{-pt_2} = A_1pe^{-2pt_1},$$

that is

$$\dot{\theta}_1/\dot{\theta}_2 = e^{pt_1},$$

or

$$pt_1 = \log \dot{\theta}_1/\dot{\theta}_2.$$

But by plotting the deflexions against the times we get the deflexion curve

$$\theta = A_1(1 - e^{-pt}),$$

and from this curve we may measure $\dot{\theta}_1$ and $\dot{\theta}_2$ for a pair of times such that $t_2 = 2t_1$, and consequently we find

$$p = \frac{1}{t_1} \log \frac{\dot{\theta}_1}{\dot{\theta}_2}.$$

With the galvanometer used in these experiments the following values were obtained for these quantities :

$$p = 0.0069; \quad n = 0.654; \quad \text{and} \quad k = 0.127,$$

which, when substituted, give

$$\frac{p^2 - kp + n^2}{n^2} = \frac{427}{428},$$

which may be taken as 1, that is to say, the observed value of $\frac{d\theta}{dt}/\lambda$ could be taken as a measure of the initial rate of rise of temperature of the silver disk.