



## XXXII. An investigation into the relations between radiation, energy, and temperature

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	Mercury at room-temp.	Mercury at 360° C.
Positive charge	$\left\{ \begin{array}{l} -2 \text{ scale-div.} \\ -4 \quad \text{,,} \end{array} \right.$	$+3.75 \text{ scale-div.}$
Negative charge	$\left\{ \begin{array}{l} -4 \quad \text{,,} \\ -2 \quad \text{,,} \\ 0 \quad \text{,,} \end{array} \right.$	$\left\{ \begin{array}{l} +5 \quad \text{,,} \\ +3 \quad \text{,,} \end{array} \right.$

In both methods the mercury, when rapidly evaporating, condensed in drops upon the platinum disk C. Since, according to the present view, a molecule of mercury contains but one atom of mercury, the result of this experiment is the most conclusive of the proofs against the hypothesis investigated by these experiments, and which has been universally held to the present time. This result with mercury, agreeing as it does with the results obtained with the other liquids used, is totally opposed to the hypothesis hitherto entertained, and justifies the assertion that the vapour arising from electrified still surfaces of liquids is electrically neutral.

Physical Institute, Berlin,  
March 7, 1883.

XXXII. *An Investigation into the Relations between Radiation, Energy, and Temperature.* By Captain ABNEY, R.E., F.R.S., and Lieut.-Col. FESTING, R.E.\*

IN the course of researches on the subject of atmospheric absorption of solar radiation, on which we have for some time past been engaged, it incidentally became desirable to ascertain the relation between the radiation from a black body and its temperature—a subject which, though well worn, is by no means exhausted. Sir William Siemens has made the most recent contribution to this subject in a paper lately communicated to the Royal Society, in which he describes his endeavour to solve the question by noting the increase of electrical resistance of platinum wire with increased temperature and by taking the relationship of energy to resistance—a method of much promise, but which appears to us to be defective for the following reasons. Platinum wire is not black at ordinary temperatures, and it is at least doubtful whether it is such a good radiator as carbon; and, secondly, much of the energy must have been dissipated by convection-currents.

It has, however, struck us that a continuation of the experi-

\* Communicated by the Authors.

ments which we had some time ago initiated on the radiation from incandescence lamps might lead to results less liable to vitiation from external causes than those obtained from platinum wire.

Having in our possession incandescence lamps of many different patterns, we made careful simultaneous measurements of the radiation and of the energy in each when currents of varying strength were passed through the filaments.

A Grove's battery was employed in preference to a dynamo, because of the greater steadiness of the current obtained. The current was measured in some cases by a tangent galvanometer, and in others by one of Sir W. Thomson's current-meters, or by both in circuit, the difference of potential between the terminals of the lamp being measured by a Thomson's potential galvanometer, and the radiation from the lamp by a thermopile the receiving surface of which was coated with lampblack, and which was connected with a Thomson's reflecting galvanometer of .5-ohm resistance. The readings were taken of the first deflection caused by the thermoelectric current and checked by the total deflection. The former is the more rapid mode of proceeding, and, we believe, the more accurate of the two, as there is no change of zero-point during the time of observation. A pair of cardboard screens with narrow slits in them were placed between the lamp and the thermopile in such a way as to cut off as much as possible of the radiation from the glass of the lamp, and yet to allow to pass the radiation from a certain length of the filament. Another cardboard screen was interposed in front of the lamp after each observation to cut off all radiation.

The lamps were also heated in an oven to different temperatures up to 350° C., and the change of resistance of the carbon filament measured directly by means of resistance-coils. We hope to be able in a subsequent paper to refer to the measurements of higher temperatures, our investigations in this respect being not quite complete.

The results so far obtained may be summed up as follows:—The current can be expressed as a function of the potential; the radiation, after a certain temperature of the filament has been reached, bears a simple proportion to the energy expended in the lamp; the resistance can be formulated as a function of the energy and therefore of the radiation; and the temperature appears to be nearly a simple function of the resistance.

The curves described by using as ordinates and abscissæ the amounts of current and potential in the different experiments have the same general form, which appears from inspection to be that represented by the equation  $c = ap + bp^{\frac{3}{2}}$ ; where  $c$  is

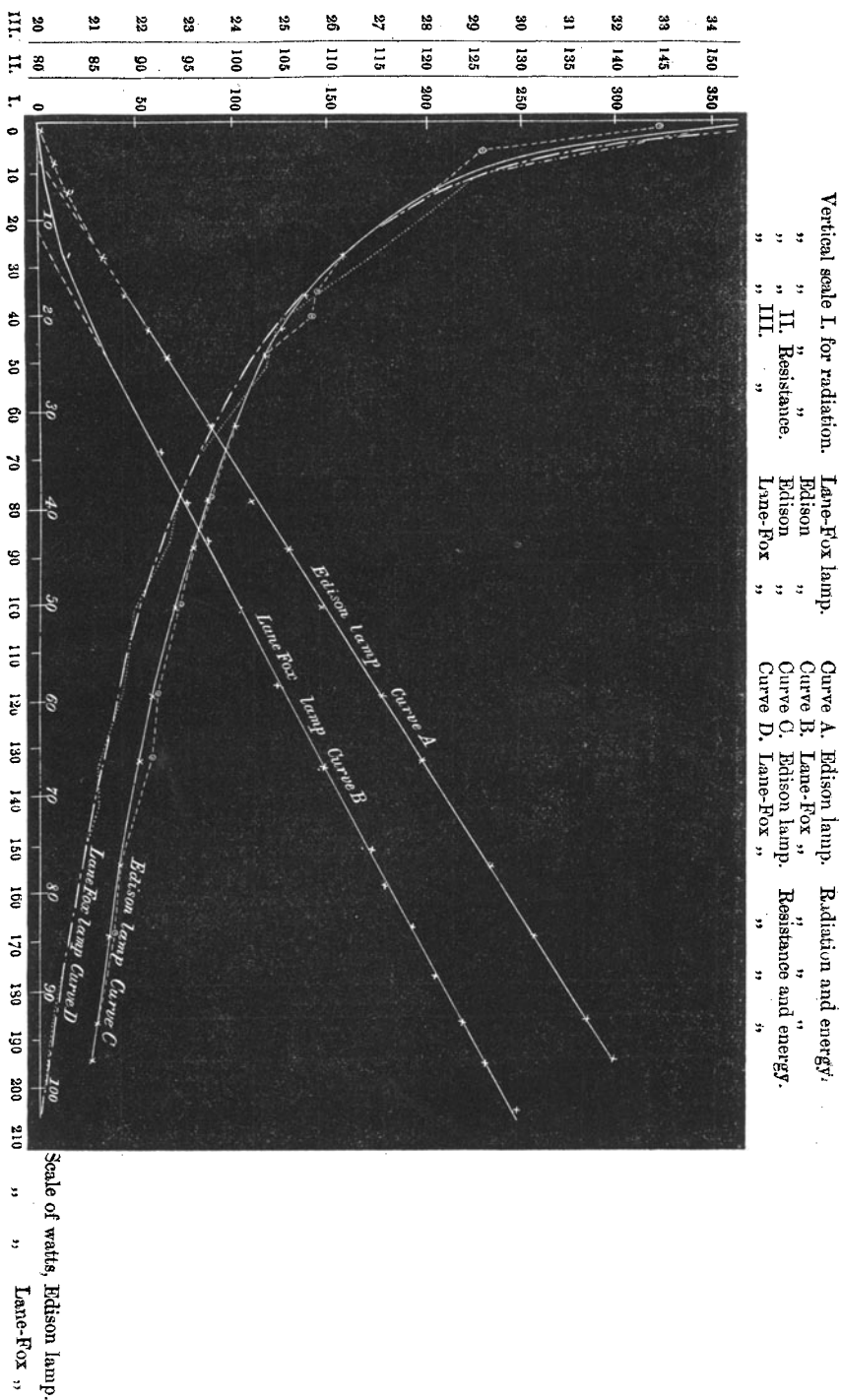
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the current and  $p$  the potential. The first term of the right-hand member seems to represent the amount of current which would pass if the filament could be kept at some particular temperature (probably the absolute zero), and the second the additional current due to increased conductivity caused by increase of temperature.

We append in a tabular form the results of typical experiments with four different patterns of lamps in which the dimensions of the carbon filaments differ considerably. These tables give the observed potentials and currents, together with the resistance and energy deduced from them, as well as the results obtained by the application of the above equation to the observed potentials; and it will be seen that these results correspond very closely with those deduced from the observed currents when the resistances have any considerable range. It should be remembered that for small currents, the deflections of the measuring instruments being very small, the percentage error of observation is liable to be large; these observations are therefore not so trustworthy as those of larger currents. It is probable that for these lower temperatures another term should be introduced into the equation, which may be disregarded at temperatures above, say,  $400^{\circ}$ .

From the above-stated equation another may be deduced for the value of the energy in watts: this would be  $w = p^2 (a + bp^{\frac{1}{3}})$ ; and the resistance in ohms would be  $\frac{1}{a + bp^{\frac{1}{3}}}$ . The form of equation between energy and resistance would be rather more complicated,  $w = \left( \frac{1-ar}{br} \right)^4 \times \frac{1}{r}$ .

If the curve of current in relation to potential be plotted, it will be found to be fairly smooth. It is, however, evident that a result obtained by the combination of two observations each of which is liable to a small error will probably be further from the truth than that obtained by a direct observation. On this account, in the curve of potential and resistance, the points indicating resistance are more unevenly distributed than those indicating current in the former curve. Similar irregularity will be found in a curve of potential and energy, and still greater in the case of a curve of energy and resistance (see diagram, curves C and D). An inspection of curves A and B in the diagram will show that, as stated above, the radiation is directly proportional to the energy when the latter is above 30 watts; the deviation from the straight line below this point is doubtless due to the temperature of the surroundings being commensurate with that of the filament.



One Edison 8-candle Lamp.								
No. of cells.	Potential, volts.	Current, ampères.		Resistance, ohms.		Energy, watts.		Radiation.
		Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	
5	9.68	.090	.0834	107.5	116.07	8.71	.807	1
6	11.44	.108	.103	106.0	111.07	1.24	1.18	2
10	19.14	.196	.195	98.0	98.15	3.75	3.73	5
15	28.16	.320	.320	88.1	88.00	9.01	9.01	20
20	37.18	.458	.460	81.5	80.47	16.93	17.10	43
23	42.24	.546	.545	77.5	77.50	23.90	23.02	61
25	46.20	.608	.613	76.4	75.37	28.09	28.32	74
27	49.70	.666	.674	74.8	73.74	33.10	33.50	89
30	54.56	.764	.764	71.6	71.57	41.68	41.68	117
32	58.30	.828	.835	70.8	69.82	48.28	48.68	138
34	60.72	.880	.882	69.0	68.62	53.44	53.56	154
35	63.36	.928	.934	68.3	67.84	58.80	59.17	174
36	64.68	.964	.960	67.5	67.37	62.35	62.09	185
37	66.44	1.004	.995	66.5	66.77	66.70	66.11	199
$a = .00471. \quad b = .00126.$								
Edison 16-candle Lamp.								
5	10.12	.07	.065	144.7	155.7	.71	.68	1.75
10	19.80	.156	.147	126.9	134.7	3.089	2.911	6
15	29.04	.240	.240	121.0	121.0	6.97	6.97	15
20	38.06	.340	.340	111.8	111.8	14.22	14.22	33
23	44.00	.404	.408	108.9	107.84	17.77	17.95	45
25	47.52	.448	.451	108.3	105.36	21.29	21.43	56
27	51.04	.492	.495	103.65	103.11	24.11	24.26	68
30	56.32	.560	.562	100.57	100.21	31.53	31.54	88
33	61.64	.630	.633	97.84	97.44	38.83	39.01	109
35	65.12	.678	.678	96.04	96.04	44.15	44.15	127
37	68.86	.726	.732	94.85	94.07	50.00	50.40	146
40	73.92	.800	.805	92.40	91.82	59.13	59.50	175
42	77.44	.852	.856	90.89	90.47	66.02	66.31	197
45	82.72	.932	.934	88.72	88.57	77.09	77.26	234
47	86.24	.980	.987	88.00	87.37	84.16	84.56	256
49	89.76	1.040	1.041	86.25	86.22	93.35	93.44	285
50	91.30	1.064	1.064	85.81	85.81	97.17	97.13	299
$a = .00387. \quad b = .000816.$								
British Electric-Light Co. Lamp.								
1	1.94	.013	.014	149.2	138.6	.025	.027	
2	3.87	.022	.020	175.9	193.5	.085	.077	
4	7.63	.050	.045	152.6	169.6	.382	.343	
6	11.61	.079	.076	147.0	152.8	.917	.883	
8	15.28	.109	.109	140.2	140.2	1.666	1.666	
10	19.14	.142	.144	134.8	132.9	2.718	2.756	
12	23.01	.184	.184	125.0	125.0	4.232	4.232	
13	24.89	.202	.203	123.2	122.6	5.028	5.053	
15	28.54	.242	.243	117.9	117.4	6.907	6.936	
20	37.84	.352	.352	107.5	107.5	13.32	13.32	
25	46.82	.475	.468	98.6	100.0	22.24	21.91	
30	55.72	.600	.596	92.9	93.5	33.43	33.21	
35	64.72	.730	.730	88.7	88.7	47.25	47.25	
40	73.26	.856	.856	85.6	85.6	62.71	62.71	
$a = .00315. \quad b = .00101.$								

Maxim Lamp.								
No. of cells.	Potential, volts.	Current, ampères.		Resistance, ohms.		Energy, watts.		Radiation.
		Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	
2	3.96	.048	.054	82.5	73.3	.19	.21	
4	7.82	.102	.114	76.4	68.7	.80	.90	
6	11.61	.165	.180	77.0	64.5	1.92	2.01	
8	15.31	.234	.245	65.4	62.4	3.57	3.75	
10	18.92	.309	.312	61.3	60.7	5.80	5.9	
12	22.70	.380	.386	58.7	58.9	8.60	8.8	
15	28.13	.497	.495	56.6	56.5	14.0	14.0	
20	37.00	.695	.690	53.5	53.6	25.8	25.5	
25	45.87	.892	.891	51.4	51.4	40.9	40.7	
30	54.09	1.11	1.09	48.7	49.5	60.0	59.5	
35	62.40	1.295	1.30	48.0	48.0	81.0	81.2	
40	70.56	1.50	1.503	47.0	46.9	106.0	106.2	
$a=.0113.$ $b=.0012.$								
Maxim Lamp.								
6	11.61	.185	.180	62.7	64.2	2.148	2.090	3
7	13.76	.211	.231	65.2	59.5	2.904	3.179	5
8	15.70	.246	.268	63.8	58.5	3.862	4.208	6
10	19.35	.317	.340	61.0	56.7	6.134	6.579	13
12	22.80	.387	.409	59.0	55.8	8.824	9.325	18
15	27.95	.510	.518	54.8	54.0	14.26	14.48	36
20	36.76	.713	.713	51.6	51.6	26.21	26.21	73
25	45.00	.915	.904	49.2	49.7	41.18	40.68	125
30	53.00	1.11	1.10	47.8	48.4	58.83	58.09	181
35	60.80	1.31	1.30	46.4	47.0	79.65	78.74	253
40	68.50	1.50	1.50	45.7	45.7	102.75	102.41	341
45	76.30	1.71	1.71	44.6	44.6	130.47	130.47	447
50	83.90	1.90	1.91	44.1	43.9	159.41	160.42	532
$a=.0127.$ $b=.0011.$								
Lane-Fox Lamp.								
5	9.03	.28	.26	32.55	34.73	2.53	2.35	3
10	18.06	.62	.613	29.13	29.36	11.20	11.19	5
15	27.09	1.00	1.03	27.09	26.30	27.00	27.90	14
20	35.26	1.43	1.45	24.66	24.32	50.41	51.12	40
23	39.99	1.71	1.71	23.37	23.37	68.39	68.39	62
25	42.56	1.86	1.86	22.89	22.89	79.17	79.17	77.5
28	47.30	2.15	2.14	22.00	22.10	101.69	101.22	104.5
30	50.53	2.32	2.33	21.78	21.68	117.23	117.73	126
32	53.54	2.50	2.52	21.41	21.24	133.85	135.91	145
33	54.83	2.58	2.59	21.25	21.17	141.46	140.91	155
35	57.62	2.75	2.77	20.95	20.80	158.45	159.59	180
36	58.91	2.85	2.84	20.67	20.74	166.89	166.30	193
37	60.20	2.94	2.94	20.47	20.47	170.99	170.99	205
38	61.49	3.03	3.036	20.29	20.22	186.31	186.38	220
40	64.07	3.20	3.20	20.02	20.02	205.02	205.02	245