I. "On the Retinal Currents of the Frog's Eye, excited by Light and excited Electrically." By A. D. WALLER, M.D., F.R.S.

II. "Observations on the Electromotive Phenomena of Non-medullated Nerve." By Miss S. C. M. SOWTON. Communicated by Dr. WALLER, F.R.S.

III. "Variation." By Professor J. C. EWART, F.R.S.

IV. "Certain Laws of Variation." By Dr. H. M. VERNON. Communicated by Professor LANKESTER, F.R.S.

V. "Data for the Problem of Evolution in Man. IV. Note on the Effect of Fertility depending on Homogamy." By Professor KARL PEARSON, F.R.S.

VI. "Mathematical Contributions to the Theory of Evolution. VII. On the Inheritance of Characters not capable of Exact Quantitative Measurement." (Revised.) By KARL PEARSON, F.R.S.

"Thermal Radiation in Absolute Measure." By J. T. BOTTOMLEY, M.A., D.Sc., F.R.S., and J. C. BEATTIE, D.Sc., F.R.S.E. Received November 28, 1899,—Read February 1, 1900.

The experiments* described in the following paper form a continuation of researches on thermal radiation by one of the present authors, the results of which have been communicated to the Royal Society from time to time since 1884.† The main object of the present experiments was to push forward the inquiry as to the amount, and the relative quality, of the radiation from surfaces of various kinds in high vacuum.

When a body is maintained at a high temperature the total radiation from its surface depends, other things being the same, on the temperature and on the character of the radiating surface. With a given temperature the total radiation, consisting of thermal, luminous, and actinic rays, seems to depend on the nature and on the ultimate texture of the radiating surface; and the proportion in which vibrations of longer and shorter period are present seems to be governed by the

* The experimental results of the paper were obtained two years ago. Various circumstances have prevented earlier publication; and it was originally intended to carry the investigation further before publishing. Want of opportunity, however, makes this difficult for the present; and we therefore deem it advisable to put our results on record just now, as they stand. The present investigation, as well as the former work referred to in the text above, has been assisted by grants from the Government Grant Fund.

† "On Thermal Radiation in Absolute Measure," J. T. Bottomley, 'Roy. Soc. Proc.' and 'Phil. Trans.,' 1884—1893.

coarseness or fineness of the structure of the surface at which the rays take their origin.

Very little progress has yet been made towards an investigation of the question just referred to; and the results of our experiments are intended to be a contribution in this direction.

In a former paper* by one of us the loss of heat in vacuum from the metallic surface of platinum wires was determined; and Schleiermacher† has compared the loss from bright platinum wires and from platinum wires whose surface was coated thinly with black oxide of copper. Further experiments on this part of the subject seemed highly desirable, and were, therefore, undertaken by us.

The radiating body was a platinum wire. The way in which it was mounted is shown in figs. 1 and 2.‡ The platinum wire, *ab*, is held,

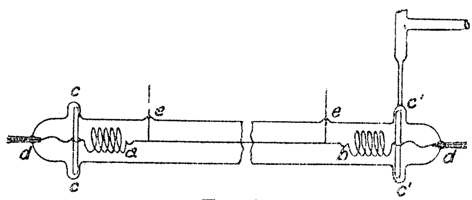

FIG. 1.

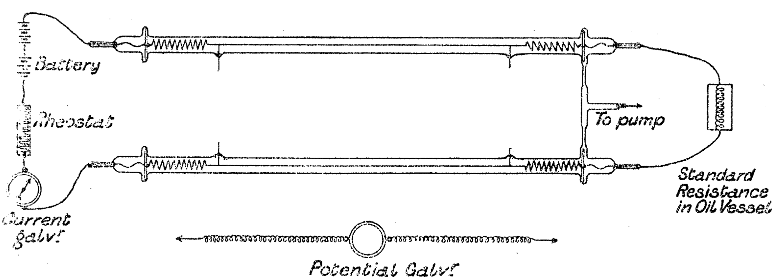

FIG. 2.

stretched between two spiral springs, in a glass tube. The outer ends of the spiral springs terminate in loops; and two pieces of glass rod, which are passed into tubes, *cc*, *c'c'* (see figure), pass through the loops, so that the springs pull on these glass rods. After the rods have been passed into their places, the ends of the tubes *cc*, *c'c'* are closed up, except one, which is used for exhausting. Flexible electrodes are soldered to the loops of the spiral springs, and are silver soldered to

* Bottomley, 'Roy. Soc. Proc.,' 1887.

† Schleiermacher, 'Wiedemann Annalen,' vol. 26, 1885.

‡ The arrangement has been already described, J. T. Bottomley, 'Phil. Trans.,' A, 1887, vol. 178, p. 448

stout multiple platinum terminals; and by means of these, which are fused, with the help of some white enamel, into the glass at *d*,*d*, the current is passed through the platinum wire. At *e*,*e*, platinum wires are brought through the sides of the tube, and serve as potential electrodes; and it is to keep the platinum wire *ab* in the middle of the length of the tube, and to avoid pulling unduly on the potential electrodes, that the two spiral springs, one at either end of the tube, are introduced.

Two exactly similar tubes were employed, as shown in fig. 2. They were connected together by a side tube, as shown; and by means of a branch tube, attached to this side tube and connected to a Sprengel pump, the air was withdrawn from both tubes at the same time; and by this arrangement it was provided that the vacuum in the two tubes should be at all times precisely the same.

In one of the tubes the platinum wire was brightly polished and perfectly smooth, just as it came from the maker's hands. The other tube contained a platinum wire cut from the same hank, but with the surface covered with an excessively fine coating of soot. The soot was put on by passing the wire carefully through the upper part of a clear paraffin flame.*

The usual arrangements were made for drying the vacuum of the tube, and of the pump, by means of phosphorus pentoxide; and the vacuum was measured by means of the Gimmingham modification of the McLeod gauge.

The wires were heated, as in the former experiments, by means of an electric current. Fig. 2 shows the electric connections. A battery consisting of a sufficient number of secondary cells was employed; and the current was controlled by means of suitable resistances, including a rheostat. In the experiments here described the platinum wires of the two tubes, the resistances, and the battery were all connected in series, so that the same current passed through all.†

The current in the circuit was measured by means of a Kelvin ampere gauge, and the difference of potentials at the two ends of each

* The texture of the soot depends greatly on the source from which it is obtained and on the way in which it is applied to the wire. Some preliminary experiments have been made with various coatings of soot, and comparisons have been attemped between surfaces finely coated with soot, and surfaces prepared with platinum black and with a fine coating of black oxide of copper chemically applied to the wire (*cf.* J. T. Bottomley, 'Phil. Trans.,' A, 1887, p. 449).

† In another set of experiments the platinum wires were joined in parallel, and, by means of two rheostats, one connected in series with each platinum wire, an attempt was made to regulate the current in each wire so that the temperatures in the two should be the same. This was found very difficult to carry out; but it is intended to renew the attempt, and determine simultaneously the radiation from two wires with different surfaces, in the same vacuum, and at the same temperature.

of the platinum wires was measured by means of a high resistance reflecting galvanometer.

This potential galvanometer had a resistance of about 5000 ohms, and it was possible to insert in the galvanometer circuit an additional resistance of 10,000 ohms.

In order to ascertain the absolute value of the readings of the potential galvanometer, a standard coil of platinoid wire, whose resistance was known very accurately, was joined into the circuit, as shown in fig. 2. This resistance was of considerable length, and it was kept cool by being immersed in a bath of oil.

The following was the order of experimenting. The pressure in the tubes was first reduced as much as possible by means of the Sprengel pump; then a very small current, practically unable to heat any part of the circuit, was sent through the two platinum wires and the standard coil, and the potential difference between the two ends of each was determined. This gave the ratio of the resistance of each of the platinum wires to that of the standard coil, all being cold, and at the same temperature. The current from the battery of storage cells was now suitably increased, and readings were taken in the following order :—The current passing was first read. Then the zero of the potential galvanometer was noted, and the deflection of the potential galvanometer when connected to the two ends of the standard coil was observed. The electrodes of the potential galvanometer were next applied to one of the platinum wires, and the deflection noted; then the deflection due to the second wire was observed. A second reading was taken from the first wire and also from the second wire. Usually these pairs of readings were identical, or nearly so, as no reading was taken until after the strong current had been passing through the circuit for sufficient length of time to allow the temperature of the whole to become perfectly steady. Generally speaking, five minutes or more was allowed for this purpose. Lastly the current was again read, and the zero of the potential galvanometer noted.

The readings detailed above enabled us to calculate the current passing through each wire and the resistance in that wire. The length and cross section of each of the platinum wires (practically identical) were also known. Thus the energy lost by radiation per square centimetre per second, C^2R/JS, could be calculated; C being the current, R the resistance and S the surface of the radiating wire, and J being the dynamical equivalent of heat, all in absolute measure.

The measurement of the electric resistance of the wires also enabled us to calculate the temperatures of the wires by means of the results of a separate determination of the electric resistances, at different temperatures, of the wires themselves.

In a former paper,* the precautions and difficulties connected with

* J. T. Bottomley, 'Phil. Trans.,' A, 1887.

the determination of change of resistances of platinum wires with temperature have been fully discussed. In the present case each platinum wire, after having been used in the radiation experiment, was wrapped round the bulb of an air thermometer* of special construction; the bulb and wire were then packed in asbestos wool, and placed in the laminated copper heating jacket described and figured in the paper just referred to. The jacket was heated by means of one of Fletcher's powerful "solid flame" burners, by means of which it could be kept for any length of time almost absolutely steady, at any temperature below the softening point of glass.

By means of stout copper electrodes the platinum wire was made one of the branches of a Wheatstone balance, and the electric resistance and temperature were simultaneously determined. A considerable number of readings between 15° C. and 350° C. were taken, and from these an empirical formula was constructed, or a curve drawn to represent the relation between temperature and pressure at all intermediate points.

In one respect, the determinations, an account of which is given in the present paper, are not perfectly satisfactory. We have not been able to take account in a proper way of the temperature of the enclosing envelope. In order to be able to see the condition of the wires, and in particular to observe their appearance when they became luminous, glass envelopes were used in these experiments; and owing to the nature of the arrangements and the method of experimenting, it was not found possible to immerse the glass envelopes in a cooling bath. Consequently the glass became more or less heated during the experiments, and the heating was unequal in the cases of the bright wire and the sooted wire. It has already been pointed out† that the proportions in which the radiations of longer period and shorter period are present in the total radiation depends on the radiating surface, other things being the same. In the case of the sooted wire, the quantity of long-period radiation is, in proportion, far in excess of that proceeding from a bright metallic polished surface. Consequently, with the same total electric energy supplied to both wires, the glass tube containing the sooted wire became much hotter than the tube containing the bright wire.

It has also been pointed out‡ that with a substance like glass, conducting badly and somewhat diathermanous, it is impossible to tell how

* J. T. Bottomley, "On a Practical Constant-volume Air Thermometer,' Proc. Roy. Soc. Edin.,' December 19, 1887, and 'Phil. Mag.,' August, 1888. This thermometer has proved perfectly satisfactory; and the separation of the volume gauge and pressure gauge make it extremely convenient for applications of the kind referred to in the text.

† 'Phil. Trans.,' A, 1887, p. 450.

‡ *Loc. cit.*, p. 444.

much heat is returned to the radiating wire from the interior skin of the tube, which no doubt rises to a high temperature during the experiment. To a certain extent, therefore, the results which we have obtained must be considered as not affording results strictly comparable with those formerly obtained in which a metallic envelope cooled with water was used.

The absolute value of the radiation observed ought to be somewhat lower in amount than would have been found had the enclosing envelope been of metal and properly kept cool, and the disturbance from this cause must have been relatively greater in the case of the dull, than in the case of the bright, wire.

Experiments were made with platinum wires from three separate hanks. A pair of wires of equal length was taken in each case. One of these was left with its surface exactly as it was on being taken from the hank; the other was sooted. The two wires were then fixed in the glass tubes. The wires are designated $\overbrace{Pt_1,Pt_2}$, $\overbrace{Pt_3,Pt_4}$, $\overbrace{Pt_5,Pt_6}$. The first of each pair is the bright wire; the second is the sooted wire. The diameters of the wires are as follows:—Pt_1 and Pt_2, 0·0542 cm., Pt_3 and Pt_4, 0·025 cm.; Pt_5 and Pt_6, 0·015 cm.

In Tables I and II specimens are given of the results obtained, in the manner described above, by observation and calculation. The remainder of the results are embodied in the curves appended, which it is hoped will be found self-explanatory. At the head of each table the particulars as to the wires referred to in the table are given.

In the following tables, III, IV, V, the loss of heat per square centimetre of surface for the several pairs of wires, bright and sooted, at various temperatures, is compared; and the ratio between the radiation from the sooted wire and the radiation from the bright wire is calculated. It will be seen that the numbers are in fair agreement. What may be the causes of divergence from exact agreement it is impossible to say at the present stage of the inquiry; but it may be conjectured that part of it at least is due to the difficulty, or impossibility, of keeping the vacuum which surrounds the wires in these experiments unchanged. When the pressure is very low, the accession of the smallest quantity of gas to the surrounding space causes an enormous change in the rate of loss of heat, as has been shown in a previous part of this research; and as the temperature rises it is always found that the vacuum becomes deteriorated, owing to the expulsion of gas from the body of the wire itself. This gas must be removed by a fresh application of the pump, and, in fact, during the experiments the pump must be kept always at work. Thus the vacuum is incessantly changing; and, moreover, as the indications of the McLeod gauge lag very much behind, it is not even possible to know the exact state of the pressure at the instant when it is desired to make an observation as to current

passing and resistance. The consequence is that owing to the constantly altering state of the vacuum an irregularity is introduced in the loss of heat, and the irregularity tells more in the case of small wires than in the case of larger sizes.

In the case of the bright wire, Pt_5, the loss of heat was somewhat abnormal. It is probable that the surface was lacking in polish.

It will be seen that the loss from the sooted platinum wires is about four to five times that from the bright wires at the same temperature. In the paper of 1894, already referred to, the radiation from a very brightly polished and burnished silvered copper globe, and that from the same globe sooted, were determined. The highest temperature reached was about 230° C., and in that case the sooted globe lost about ten times as much heat as the silvered globe under the same circumstances. When the silvered globe had become tarnished, the radiation from its surface was so much increased that the loss from the sooted globe was only three times that from the tarnished silver.

Table I.—May 18, 1897. Two Platinum Wires, Pt_1 and Pt_2, length 42·55 cm., diameter 0·0542 cm., from the same hank of wire. Pt_1 left with bright surface, Pt_2 thinly sooted.

Current in amperes.	Pt_1.			Pt_2.			Pressure in millimetres.
	Resistance in ohms.	Temperature.	Thermal energy lost per square centimetre per second.	Resistance in ohms.	Temperature.	Thermal energy lost per square centimetre per second.	
0·023	0·192	17	$0·033 \times 10^{-4}$	0·188	17	$0·0329 \times 10^{-4}$	0·00025
0·276	0·208	33	5·198	0·198	26	4·952	0·00025
0·552	0·259	89	25·98	0·209	36	20·96	0·00045
0·695	0·292	130	46·52	0·220	51	35·02	0·00045
0·940	0·337	185	97·97	0·237	71	68·90	0·00045
1·430	0·415	295	279·80	0·271	109	183·1	0·00045
1·937	0·484	453	599·5	0·317	167	393·0	0·00060
2·691	0·570	623	1371·0	0·377	249	912·2	0·00050
3·003	0·599	743	1776·0	0·398	280	1184·0	0·00060
3·770				0·437	343	2055·0	0·00500*
4·446				0·476	414	3106·0	0·00360
5·200				0·515	496	4517·0	0·00320
6·604				0·566	643	8166·0	0·00250

* Owing to increase in the pressure, the emission here must be considerably increased by convection.

Table II.—June 17, 1897. Two Platinum Wires, Pt_3 and Pt_4, length 39·2 cm., diameter 0·025 cm., from the same hank of wire; Pt_3 bright, Pt_4 sooted.

Current in amperes.	Pt_3. Resistance in ohms.	Pt_3. Temperature.	Pt_3. Thermal energy lost per square centimetre per second.	Pt_4. Resistance in ohms.	Pt_4. Temperature.	Pt_4. Thermal energy lost per square centimetre per second.	Pressure in millimetres.
0·0245	1·94	15	$0·9004 \times 10^{-4}$	1·94	15	$0·9004 \times 10^{-4}$	0·00040
0·0819	2·03	41	10·53	1·984	26	10·29	0·00040
0·1638	2·27	120	48·09	2·050	47	42·52	0·00025
0·2348	2·466	190	105·1	2·134	74	89·00	0·00033
0·3003	2·602	243	181·4	2·224	109	155·1	0·00025
0·3822	2·781	318	314·2	2·314	135	261·5	0·00025
0·4586	2·900	377	473·1	2·399	166	390·2	0·00025
0·5405	3·039	445	686·7	2·492	200	563·0	0·00025
0·6470	3·196	538	1034·0	2·610	245	844·7	0·00016
0·8479	3·418	719	1902·0	2·788	321	1552·0	0·00025
1·0230				2·919	383	2362·0	0·00050
1·1696				3·033	442	3209·0	0·00130
1·462				3·228	560	5338·0	0·0019
1·608				3·331	637	6658·0	0·0025
1·754				3·424	726	8149·0	0·0023

Tables III, IV, V, showing the Amount of Thermal Energy lost per sq. cm. per second by each of two precisely similar Platinum Wires at the same temperature, one of the wires having a Bright Metallic Surface and the other being Lightly Sooted.

Table III.

Pt_1 and Pt_2. Diameter of Wire, 0·0542 cm.

Temperature.	Energy lost by bright wire.	Energy lost by sooted wire.	Ratio sooted/bright.
200	1·1	5·3	4·8
250	1·8	8·9	4·9
300	2·7	12·8	4·7
350	3·8	19·8	5·2
400	4·9	26·1	5·3
450	6·2	33·3	5·4
500	7·9	42·0	5·3
550	10·0	50·0	5·0
600	11·9	58·5	4·9
650	13·8	68·7	5·0

Table IV.

Pt_3 and Pt_4. Diameter of Wire, 0·025 cm.

Temperature.	Energy lost by bright wire.	Energy lost by sooted wire.	Ratio sooted/bright.
150	0·7	3·3	4·71
200	1·1	5·9	5·4
250	1·8	9·2	5·1
300	2·7	13·5	5·0
350	3·7	18·6	5·0
400	4·9	24·1	4·9
450	6·4	31·0	4·9
500	8·0	38·7	4·84
550	10·1	46·5	4·6
600	12·1	54·0	4·5
650	15·9	67·5	4·2
750	21·8	86·5	4·0

Table V.

Pt_5 and Pt_6. Diameter of Wire, 0·015 cm.

Temperature.	Energy lost by bright wire.	Energy lost by sooted wire.	Ratio sooted/bright.
200	1·0	4·5	4·5
250	1·3	5 7	4·4
300	2·0	8·7	4·35
350	3·2	13·0	4·06
400	4·7	18·8	4·0
450	7·0	27·4	3·9
500	9·9	37·8	3·8
550	14·9	57·0	3·8

FIG. 3.—Curves showing emission of heat from Pt_1 (bright) and Pt_2 (sooted), from the same hank of wire, diameter 0·0542 cm., at various temperatures.

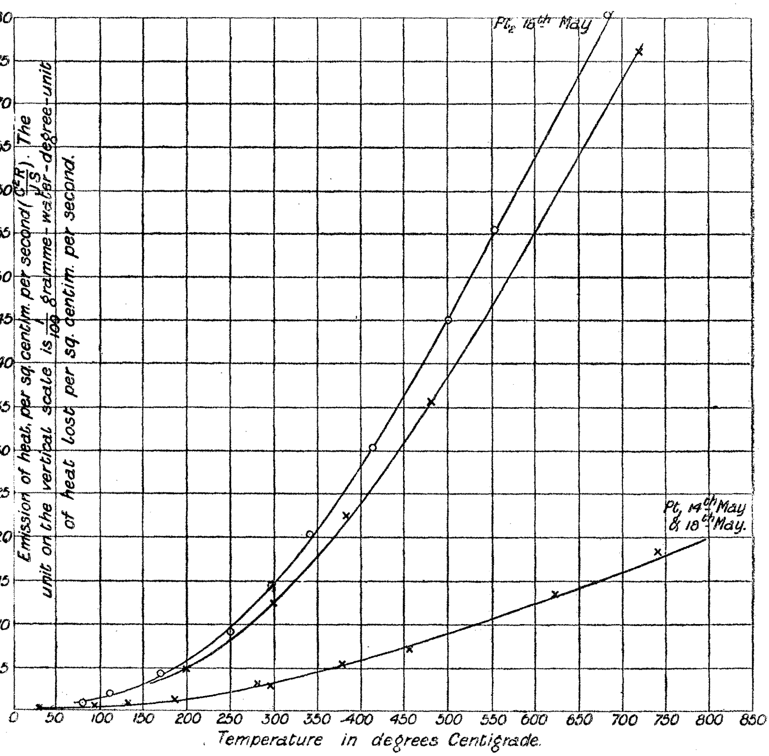

FIG. 4.—Curves showing emission of heat from Pt_3 (bright) and Pt_4 (sooted), from the same hank of wire, diameter 0·025 cm., at various temperatures.

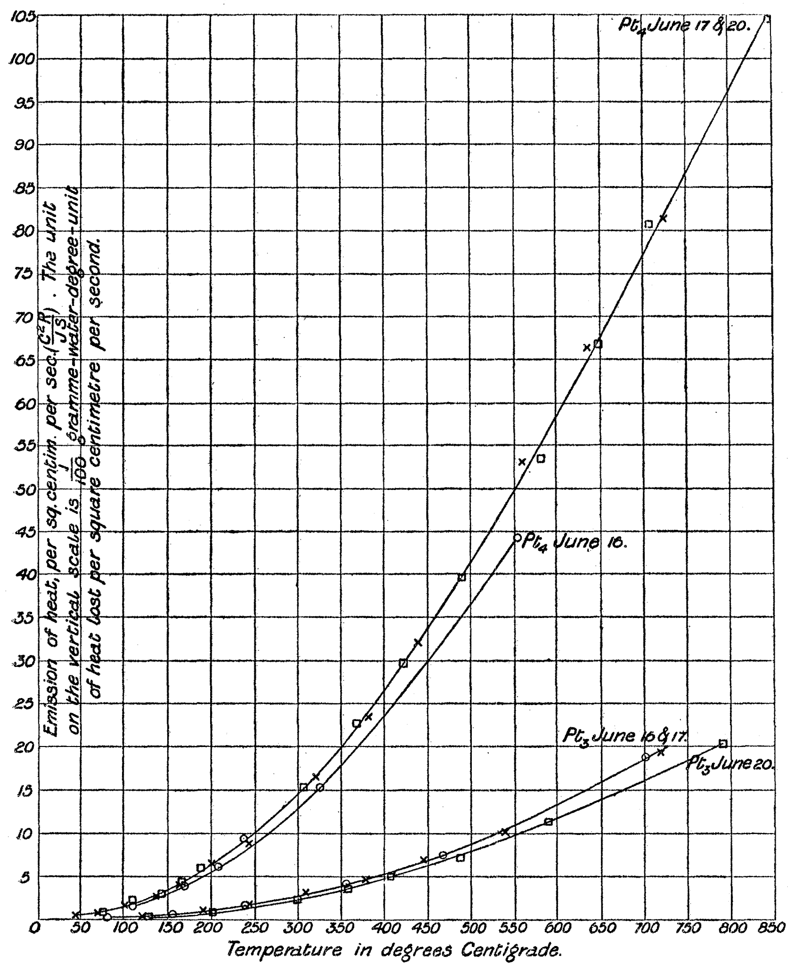

Fig. 5.—Curves showing emission of heat from Pt_5 (bright) and Pt_6 (sooted), from the same hank of wire, diameter 0·015 cm., at various temperatures.

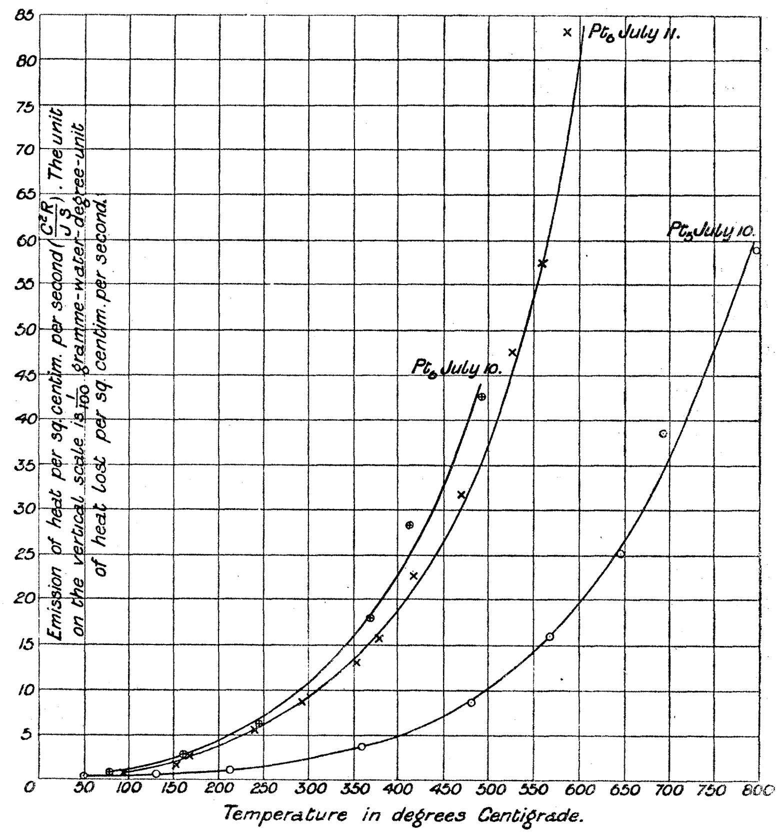

FIG. 6.—Emission of heat from three bright platinum wires, Pt_1, Pt_3, Pt_5, of different diameters as indicated.

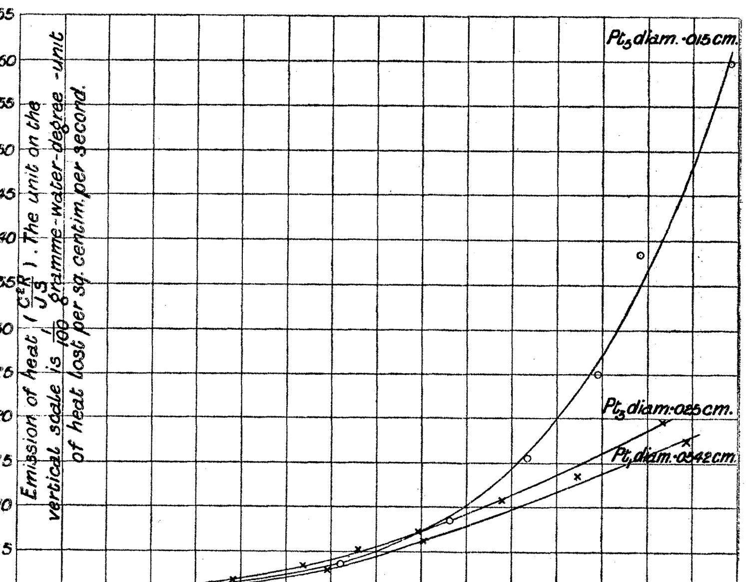

FIG. 7.—Emission of heat from three sooted platinum wires, Pt_2, Pt_4, Pt_6, of different diameters as indicated.