STUDIES OF INSTRUMENTS FOR MEASURING RADIANT ENERGY IN ABSOLUTE VALUE:

AN ABSOLUTE THERMOPILE

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CONTENTS

I. INTRODUCTION

One of the chief needs in the measurement of radiant energy is a reliable radiometer which evaluates the observations in absolute measure. Such an instrument should be a primary one, capable of measuring radiant energy directly. Because of the lack of such a primary instrument, a calibration of radiometers against a standard of radiation is advocated; and such standards of radiation have been prepared[1] by this Bureau.

There are several apparently trustworthy methods for making measurements of radiation in absolute value. One of the problems undertaken in this Bureau is the study of various instruments used in making these absolute measurements; and the purpose of the present paper is to report on the results obtained with one of these instruments.

One of the by-products of this investigation will be the evaluation of the coefficient or the so-called Stefan-Bolzmann constant of total radiation of a uniformly heated cavity or so-called black body. As will be shown in a subsequent paper, the different methods employed by various experimenters in evaluating this constant give somewhat discordant results. It is therefore desirable to emphasize at the very beginning of this paper that, until it can be shown which of these various methods is the most reliable, it is undesirable to depend upon a single numerical value.

In beginning the subject of radiometry in absolute measure, it seemed desirable to study instruments which might prove of use in general radiometric work (e. g., useful as radiation pyrometers), leaving for later investigation the more cumbersome and complicated devices for determining with the highest precision the coefficient of total radiation of a uniformly heated cavity or so-called black body.[2] The first communication[3] on this subject gave the results of a study of the "Radiobalance."[4] This is an ingenious device in which the radiometric receiver consists of a thermojunction which can be heated electrically. In this manner the heat generated in the receiver by absorbing radiant energy is

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[1] This Bulletin, 11, p. 87; 1914.

[2] This Bulletin, 12, p. 553; 1916.

[3] This Bulletin, 9, p. 51; 1912.

[4] Callendar, Proc. Phys. Soc., London, 23, pt. 1; Dec., 15, 1910.

neutralized by the well-known Peltier (cooling) effect, which occurs when an electric current is passed through a thermojunction. The result of the study of this instrument showed that while it has many good points it did not appear to be sufficiently reliable for a primary instrument. The investigation of the instrument used in the present work was undertaken in order to determine its reliability as a precision radiometer, i. e., to determine whether it is a primary instrument capable of measuring the radiation constants directly or whether it is a secondary instrument which must be calibrated by exposing it to a standard of radiation. The first question raised in regard to the use of a receiver of this type is the uniformity of temperature distribution when heated electrically from within and when heated by absorbing radiant energy incident upon its front surface. From the concordant results obtained with metallic strips, differing by 10 times in thickness, and having different kinds of absorbing surfaces, it is evident that whatever errors (if any) are introduced, are much smaller than the variations observed with the various receivers constructed of the same kind of material.

II. APPARATUS AND METHODS

Below are given the essential features of the instruments used in this research. A more complete description of the thermopile, galvanometer, and other accessories is given in a previous paper.[5]

1. THE RADIOMETER

The radiometric receiver,[6] Fig. 1, which was the subject of the present investigation is a very simple device, consisting of a very thin strip of metal, blackened to absorb radiation. Behind this metal strip, at a distance of 2 to 3 mm, is placed a thermopile of bismuth-silver having a continuous receiving surface of tin. The thermopile is connected with an ironclad Thomson or a d'Arsonval galvanometer which serves merely as a null instrument to indicate the rise in temperature of the metal strip.

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[5] This Bulletin, **11**, p. 132; 1914.

[6] For further details, see this Bulletin, **11**, p. 157; 1914.

2. CONSTRUCTION OF THE RECEIVERS

The strip of metal serves three purposes—(1) as a receiver for absorbing radiant energy, (2) as a source of radiation which can be produced by heating the strip electrically, and (3) as a standard of radiation to test the galvanometer sensitivity, by heating the strip electrically by a standard current.

The use of a thermopile, separated from the receiver, makes it possible to use various receivers. The radiometric apparatus was therefore designed so that the receivers could be mounted over the thermopile as shown in Fig. 2. Each receiver, as shown in Fig. 2, is a complete unit consisting of an insulating base of slate *B* (cut from an ordinary writing slate), 3 mm in thickness, to which are attached the copper electrodes, *E E*, 0.5 mm in thickness, the receiver *R*, the potential terminals *P P*, the knife-edge slits *S S*, at the front, and the strips of copper, *C C*, at the rear, which are used for the purpose of preventing radiations, not intercepted by

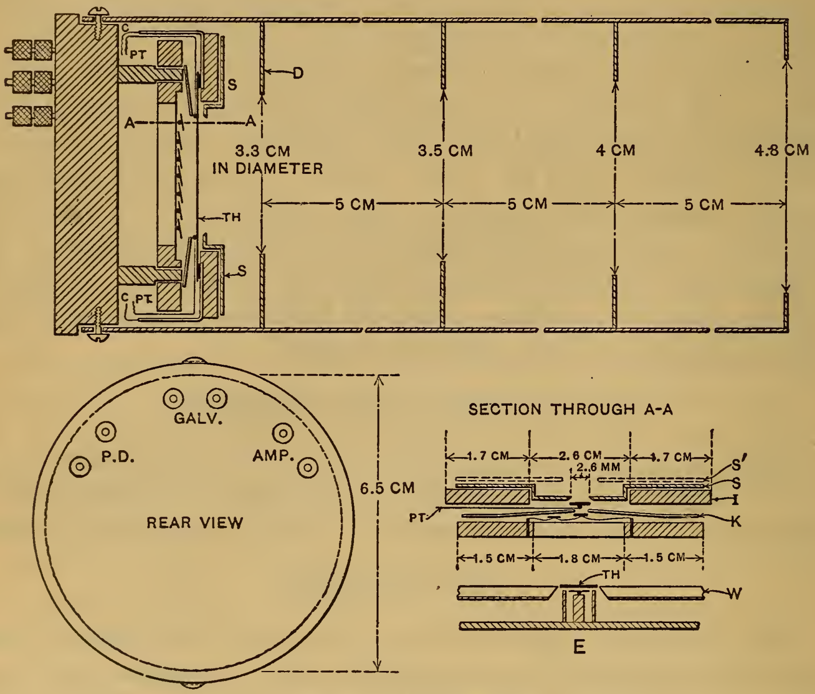
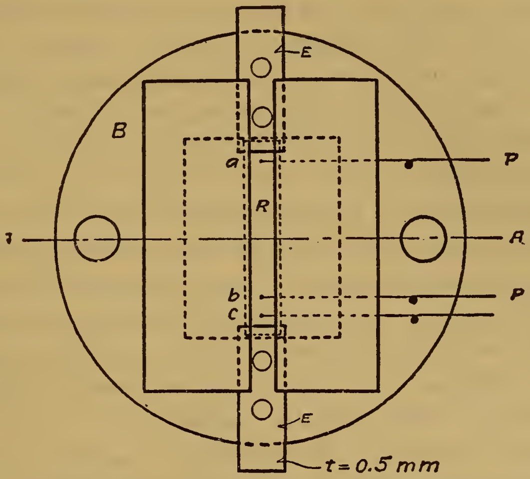
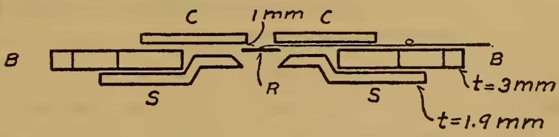


Fig. 1.—*The radiometer*

the receiver, from falling upon the thermopile. The platinum used for receivers was the "platinum in silver" material used for bolometers. This material was cut into strips, by means of a specially constructed cutting device, and soldered to the electrodes, which were then covered with Chatterton compound in order to protect them from the nitric acid which was used in removing the silver from the platinum. The platinum strip was then cleaned electrolytically by dipping it in hydrochloric acid. After attaching the potential wires, the strip was coated electrolytically with platinum black.[7] Incidentally, it may be added that the platinum cholride seems to deteriorate rapidly with usage, giving grayish deposits, so that it is necessary to use freshly prepared solutions.



REAR VIEW OF RECEIVER



END SECTION THROUGH AA

FIG. 2.—*Showing the construction of the receivers*

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[7] This Bulletin, 9, p. 305; 1913. Kurlbaum, Ann. der Phys. (3), 67, p. 846; 1899.

The potential leads *P P* consisted of No. 36 silk-covered copper wire attached to the holder by means of Chatterton compound. To the end of this copper wire was soldered a fine platinum wire 0.025 mm in thickness, and (for several receivers) to the end of this platinum wire was soldered a short piece of (Wollaston) platinum wire about 0.01 mm in thickness. To the free end of the latter was attached a bead of solder from 0.01 to 0.03 mm in diameter, and this was melted to the platinum strip by means of the small nichrome[8] heater now used in performing such delicate operations. If the bead of solder is dipped in a solution of zinc chloride, there is no difficulty in attaching it to the platinum strip, and the juncture will be only 0.05 to 0.1 mm in diameter. This juncture is covered with shellac to permit repairs in case of breakage, and to protect the solder from the platinum chloride solution when depositing the platinum black. These potential terminals were situated at a distance of 3 to 4 mm from the copper electrodes. In order to test the effect of the potential contacts, an additional wire, *c*, was attached to two of the receivers. The platinum potential wires are shellacked for insulation.

The opening in front of the platinum receiver is defined by means of knife-edged strips of metal, along the sides and across the ends. The latter were placed directly over the potential terminals. When it was found impossible to detect a difference in the radiation constant, as measured with and without these slits (which were made of thin copper) across the ends, they were discarded and the entire length of the receiver was exposed to radiation. This eliminated the conduction of heat from the region between the potential terminals, which were then used to define the length of the receiver. Knife-edge slits *S S* were used over the sides of the receiver, in order to define its effective width which is difficult to determine after the receiver has been covered with platinum black; and, especially so, after smoking it with lampblack when a layer of soot 0.05 mm in width may adhere loosely along the edge. These knife-edged slits were of two kinds: (1) Brass ones 0.5 mm in thickness, and (2) slits of aluminum 1.95 mm in thickness. Both types were bright over a width

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[8] This Bulletin, 9, p. 7; 1912.

of about 1 cm along the knife-edge, on the side exposed to the radiator. Measurements were made without the slits and the value of the radiation constant was usually slightly higher than with the slits. In view of the possibility of diffusely reflected radiations from the radiator reaching the thermopile, the slits were used. It would have been desirable to use a hemispherical mirror in front of the receiver, as in previous work,[9] and thus eliminate the correction for the loss of radiation by diffuse reflection, but the uncertainty then arising as to the exact area exposed and as to numerous adjustments, etc., appeared to introduce greater errors than would arise from a lack of proper correction for reflection, which correction was determined directly. The receiver of the thermopile had an area of 1.8 by 19 mm, the length being somewhat less than the distance between the potential terminals on the receiver *R*. The thermopile was covered permanently with a piece of cardboard, about 0.4 mm in thickness, which had an opening, about 2.5 mm in width and 20 mm in length, to admit radiations from the receiver. This cardboard shield was used to exclude the radiations coming from that part of the receiver which extends from the potential terminals to the copper electrodes. In addition to this shield, each receiver mounting was covered on the rear side with heavy (0.8 mm) strips of copper (or sheet iron folded as in receiver No. 6), *C C*, Fig. 2, to protect the thermopile from possible stray radiations which might not be intercepted by the receiver. These strips of metal were painted on both sides with lampblack, then blackened by holding them in the flame of a sperm candle. This method of construction places the thermopile surface at a distance of about 3.5 mm from the receiver, which greatly reduces the sensitivity. However, it eliminates the question of convection currents produced by the warming of the receiver. In the first part of the work the shields, *C C*, were not used, and consequently the thermopile was much closer to the receiver, which increased the sensitivity. The same numerical value of the constant of radiation was obtained as with the greater separation of the receiver and the thermopile.

The method of blackening the receivers with soot is of some importance. The thick metal plates used as shields were painted

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[9] This Bulletin, 10, p. 2; 1913.

with lampblack and smoked by drawing them through the tip of the flame of a sperm candle. This produces a deposit of soot which reflects but little more than 0.5 per cent.[10] However, as indicated in the previous paper relating to this subject, the cold deposits of soot from an acetylene flame or sperm candle reflect a little over 1 per cent. In order to obtain the blackest deposit from a sperm candle, the wick must be free from old, charred material which produces a "hard" bluish smoke, having a high reflecting power. On the other hand, the wick must not be trimmed too short. The best results are obtained by using a freshly trimmed candle in which the flame is burning at its normal height. The smoke is produced with a sheet-iron cone about 8 cm long and 4 cm at its base, flattened at the top, leaving an opening 1.5 by 10 mm for the escape of the soot. When the candle is burning properly this funnel is held over the flame by means of a crucible tongs, and the object which is to receive the soot is passed back and forth, at a distance of 2 to 5 cm, over the top of the metal cone, which is not permitted to become hot. As to the thickness of the deposit of lampblack, that seems to be a matter of guesswork. The paint is a mixture of lampblack in alcohol and turpentine which is thoroughly shaken and allowed to stand a few minutes so that the coarse agglomerations may settle to the bottom. The coating of paint applied to a receiver is of such thickness that in bright sunlight the metal underneath is barely perceptible through the thin spots in the paint. This surface of lampblack paint is then exposed in the smoke of a sperm candle until it is thoroughly covered with soot. Some layers of soot were, no doubt, as much as 0.1 mm in thickness, although the deposit is usually just sufficient to cover the paint.

The receivers made of manganin or therlo and painted with lampblack, Fig. 3, do not have an appreciable (to 1 part in 2650) temperature coefficient of resistance. On the other hand, the temperature coefficient of resistance of platinum, which is positive when unblackened, becomes negative after it is given a coating

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[10] This Bulletin, 9, p. 283; 1913.

of platinum black. This is illustrated in Fig. 3, which shows the change in resistance of the strip when heated to different temperatures, as indicated by the current which was passed through the strip in order to raise it to the same temperature as was produced by the absorption of radiant energy.

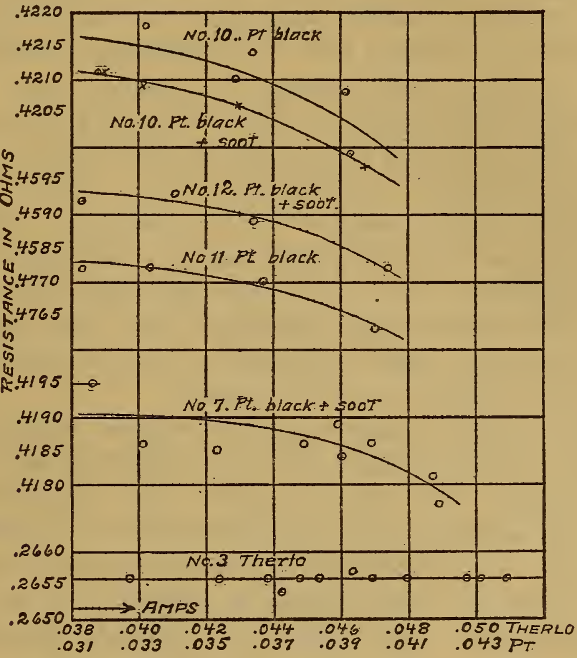

FIG. 3.—*Showing the change in resistance with temperature (heating current) of receivers of therlo, No. 3, and platinum*

3. THERMOPILE AND GALVANOMETER

These two instruments have been described elsewhere,[11] and it will be sufficient to add that the thermopile with its auxiliary receiver required, at a minimum, from 12 to 15 seconds (depending upon the receiver used) to produce a maximum galvanometer deflection. This long period requires uniform conditions in order to obtain accurate measurement. No observations were made, therefore, on very windy days when the thermopile was affected

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[11] This Bulletin, 11, p. 132; 1914.

by air currents. The sensitivity was such that it would have been possible to observe the rise in temperature of the thermopile by means of a d'Arsonval galvanometer. Two such instruments were available, but they happened to respond to vertical tremors in the laboratory so that readings could not be made with an accuracy higher than 0.2 mm in a maximum deflection of 60 to 70 mm. A deflection of this size (75 per cent larger than normal) was obtained by reducing the critical damping resistance of 100 ohms to 50 ohms. This increase in sensitivity was, of course, at the expense of the period. The d'Arsonval galvanometer was therefore used simply as a check on the observations made with an ironclad Thomson galvanometer of 5.3 ohms, which was operated on a single swing of 1.5 to 2 seconds. But even on this short period the instrument was too sensitive, so that an external resistance of 60 to 120 ohms was constantly used in the circuit. The galvanometer deflections were then from 150 to 200 mm, and under these conditions it was the usual experience to repeat the readings to 0.3 to 0.5 mm.

The galvanometer being completely shielded magnetically, the unsteadiness observed was found to be caused by air currents in the thermopile. On rare occasions the galvanometer was momentarily deflected, which was attributed to radiotelegraphic disturbances. Great steadiness in the galvanometer is necessary because of the long wait (about 30 seconds at a minimum) to obtain the complete scale reading. No difficulty was experienced with the galvanometer, and in the present work plenty of time could be allowed for the receiver and the thermopile to attain a steady temperature. Moreover, after the deflection had attained a maximum it would stay at that point whether the stimulus was applied for 20 or 30 seconds or for a much longer period. This is an important point in radiometric work of this type. The galvanometer was not completely damped on a swing of less than 2.5 seconds, and, because of the quickness of the response of the thermopile, especially when the receiver was of thin bolometer platinum, the maximum steady deflection was attained by executing one large throw and one or two small vibrations before the needle came to rest. This large first throw of the galvanometer needle was slightly different when the receiver was heated radiometrically and electrically, especially for the thick manganin receivers, but there was no marked difference in the time of attaining the final deflection. In view of the fact that observations made with the damped and undamped galvanometer showed no difference in the final result (and it should not do so, since plenty of time was given to obtain a steady deflection), no errors are to be expected from this source.

4. WATER-COOLED SHUTTER AND DIAPHRAGM

The water-cooled shield employed consisted of a tank, *A*, 25 cm in diameter and 1.5 cm in thickness, which faced the radiator, and a tank, *B*, 20 cm in diameter and 3 cm in thickness, which faced the radiometer. The water-cooled shutter, *S*, Fig. 4, consisting of a thin metal box 3.5 by 3.5 by 0.8 cm, was operated in vertical ways between these two shields. A mercurial thermometer, *T*, having its bulb in the water flowing through this shutter, was used to measure the temperature, *T*, used in equation (1). A more detailed illustration of a similar shutter is given elsewhere,[12] and some of the parts are shown in Fig. 6. The side of the shutter facing the radiometer was smoked in a sperm candle, and in connection with the conical-shaped opening (painted black and smoked) in the water-cooled diaphragm, *B*, it formed a miniature black body, the temperature of which remained constant throughout a series of measurements. The temperature of the water varied, of course, from day to day, being as low as 10° C in the winter, and averaged 15° C during this investigation. The temperature of the shutter was easily kept constant to within 0.5° C. The opening in the diaphragm, *B*, which must be accurately known, was defined by means of a series of small perforated disks of brass 8 mm in diameter and 1.5 mm in thickness, which were mounted in a recess provided for the purpose. These brass disks were provided with accurately cut, knife-edged holes having the following diameters: No. 1 = 5.410, No. 2 = 4.939, No. 3 = 3.987, and No. 4 = 2.005. This design enabled one to easily change the size of the opening which admits radiation upon the receiver and thus study the effect upon the radiation constant.

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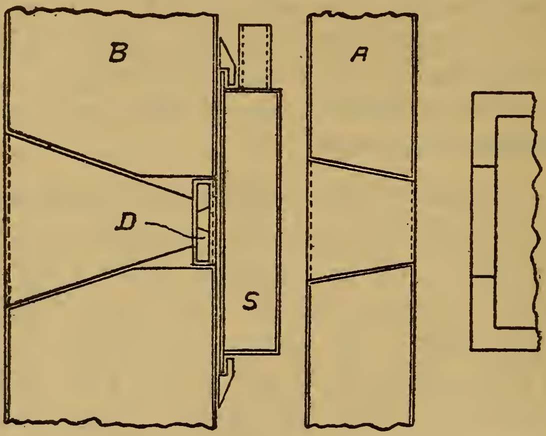
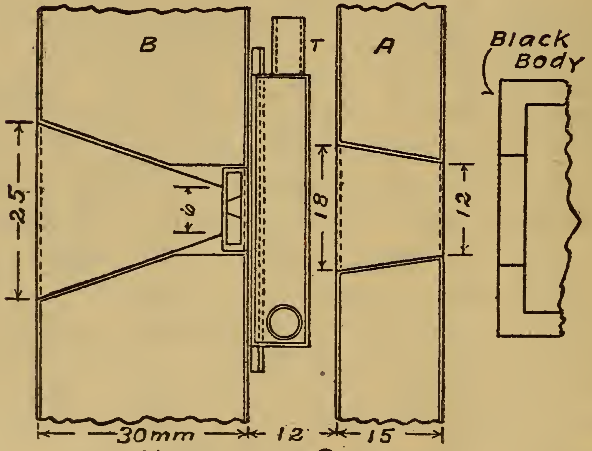
[12] This Bulletin, 10, p. 30; 1913.

The amount of radiation emitted through the smallest diaphragm, for the temperatures used, was small. This increased the errors of observation. However, from the data given in Table 1 (receiver No. 4), series XXXVII to XLVI, it appears that the size of the opening used did not affect the numerical value of the results, which have a range in variation of about 1 per cent.



HORIZONTAL SECTION



VERTICAL SECTION

FIG. 4.—*Water-cooled shutter and diaphragms*

TABLE 1

Data Showing that the Size of Water-Cooled Diaphragm Has No Appreciable Effect Upon the Radiation Constant

[Receiver No. 4; slits entirely removed; length of receiver, 26.565 mm; width, 5.536? 5.575]

Diaphragm No. 2.—d=4.939 mm

Series	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$					
		t_0	t_1	a	b	c	d	e	f
	mm	°C	°C						
XXXVII	343.3	10.0	1005.0	5.45	5.56	5.52	5.53	5.55	5.51
XXXVIII	496.8	11.8	1004.5	.52	.51	.50	......	......	......
XXXIX	522.7	14.5	1022.3	.50	.50	.47	.48	.48	.50
XL	440.3	14.7	1022.2	.48	.48	.48	......	......	......

Mean value $\sigma = 5.49 \times 10^{-12}$ watt cm^{-2} deg^{-4}

Diaphragm No. 4.—d=2.005 mm

XLI	420.7	19.8	1055.5	.56	.51	.48	......	......	......
XLII	422.0	16.5	1056.5	.41	.41	.41	......	......	......
XLIII	503.1	16.5	1056.4	.43	.40	.35	.36	.40	.42

Mean value $\sigma = 5.44 \times 10^{-12}$ watt cm^{-2} deg^{-4}

Diaphragm No. 3.—d=3.987 mm

XLIV	451.0	18.5	1055.7	.37	.38	.39	.42	.41	.42
XLV	497.3	16.3	1052.1	.46	.49	.47	.50	.49	.51
XLVI	421.2	19.5	1051.0	.48	.46	.48	.49	.48	.50

Mean value $\sigma = 5.46 \times 10^{-12}$ watt cm^{-2} deg^{-4}

5. THE RADIATOR

The radiator, or so-called black body, was the one (painted Marquardt porcelain) used in a previous investigation [13] of the constant of spectral radiation. The device was operated as in the previous work, to which reference may be made for details of construction. The temperature measurements were made with thermocouples as heretofore, the radiator being operated at a sufficiently high temperature (1000° C) to produce sufficient radiant energy for measurement, and yet not at a sufficiently high temperature to affect the calibration of the thermocouples.

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[13] This Bulletin, 10, p. 2; 1913. (See Fig. 4 B.)

Furthermore, at this temperature the radiator is easily held constant to 0.°1, which is necessary in view of the fact that under certain conditions a change in temperature of 0.°1 was perceptible with the receiver. This radiator was painted with a mixture of cobalt and chromium oxides. A series of measurements was made upon an exactly similar radiator which was unpainted. This white porcelain radiator gave a value of the radiation constant which is about 1 per cent less than that obtained from the painted tube. This will be discussed in a subsequent paper, in view of the fact that it has nothing to do with the study of the radiometer which was under investigation.

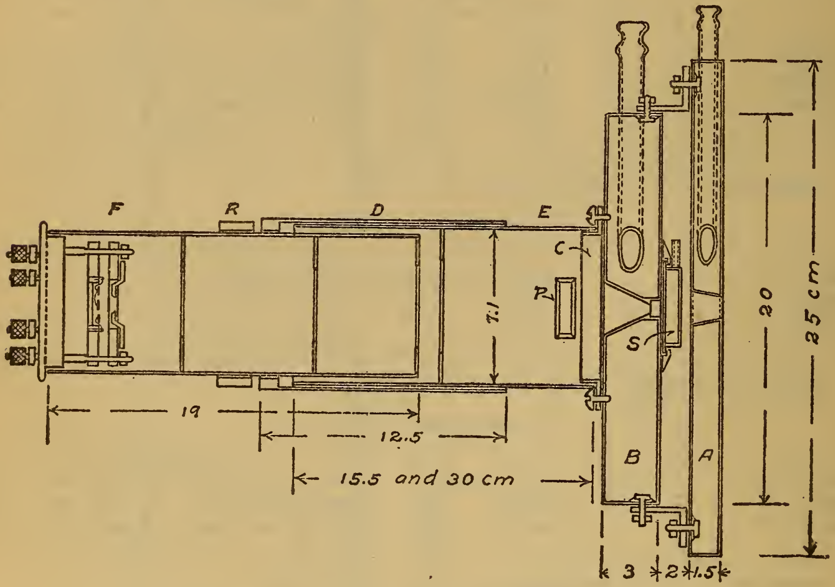

FIG. 5.—*Assembled apparatus.*

6. THE ASSEMBLED APPARATUS

In Fig. 5 is shown a drawing of the assembled apparatus, excluding the radiator, which, of course, would face the water-cooled diaphragm, as shown in Fig. 6. The construction and operation of the radiator, *R*, Fig. 6, has been described elsewhere,[14] and it will

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[14] This Bulletin, 10, p. 24; 1913.

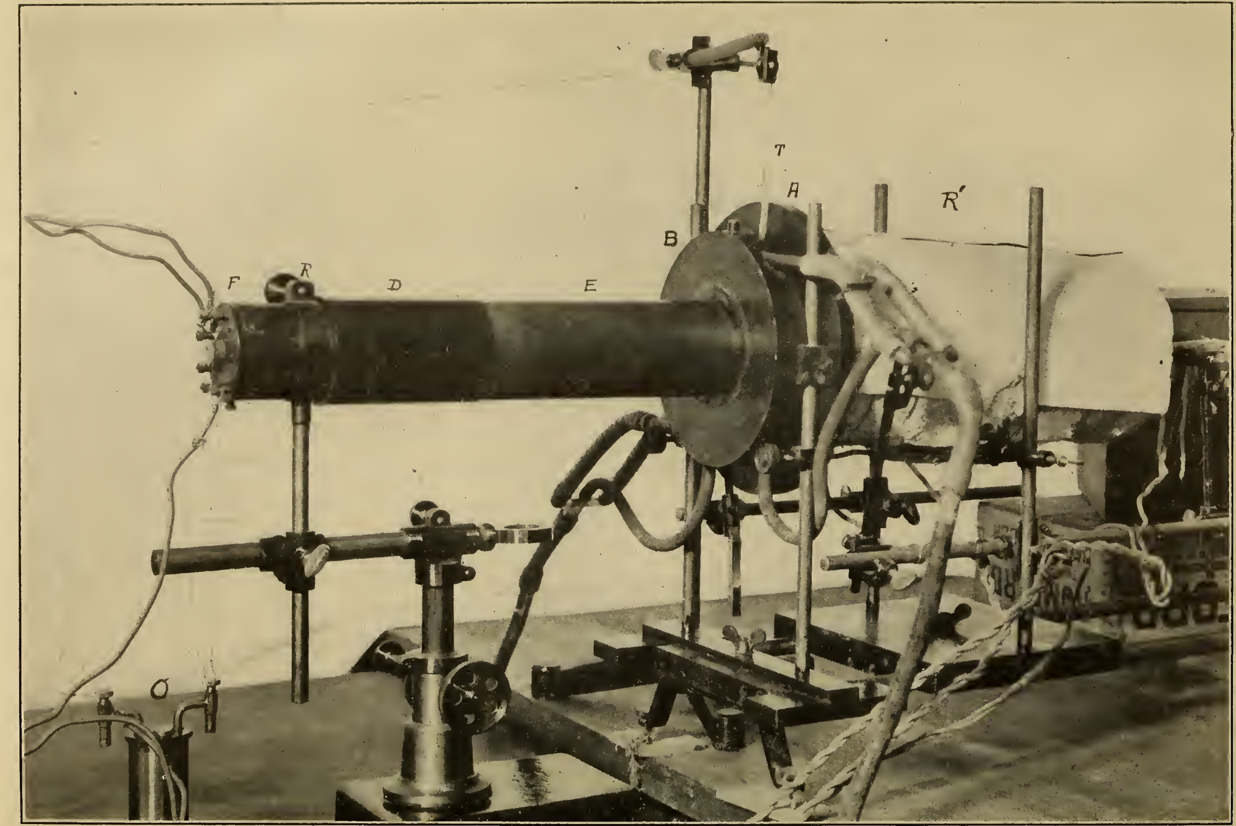

FIG. 6.—*Photograph of the assembled apparatus used in evaluating radiant energy in absolute measure*

be sufficient to add a few of the essential details concerning the method of adjusting the apparatus.

Instead of using an optical bench, the apparatus was kept in alignment and the optical path was varied by means of a series of telescoping brass tubes, *D E*, as shown in Figs. 5 and 6. For this purpose a collar, *C*, was permanently attached to the water-cooled diaphragm, *B*, over which one end of the brass tube, *E* (15 or 30 cm long), was slipped, making a tight-fitting juncture. This tube had diaphragms and, in order to further prevent reflections, the inside surface was smoked in an acetylene flame. Resting within the collar, *C*, and well below the line of the incoming radiations, was a small aluminum box (dimensions 4 by 2 by 1 cm) containing phosphorus pentoxide to absorb the moisture. The whole was quite air-tight, so that the pentoxide would last for several days.

An outer brass tube, *D*, having a guard ring, permitted telescoping the well-diaphragmed radiometer tube, Fig. 1, into the brass tube, *E*, without injuring the lampblack surface of the latter. The wide ring, *R*, which was permanently attached to the radiometer tube insured accurate alignment by always bringing it in contact with the ring on the tube, *D*. The cone of rays coming through the opening in the water-cooled shutter was not sufficiently wide to strike the side of the tube, *E*, and, as described in the previous paper, the radiometer tube was constructed so as to reduce stray radiations to a minimum.

A reference line, *F*, was cut upon the radiometer tube at a distance of 28 mm from the base, and the variable distance, D', between this reference line and the face of the water-cooled shutter, *B*, was measured with a meter stick. The complete distance, *D*, between the surface of the split jaws of the receiver and the water-cooled diaphragm is determined from this variable distance, D', the distance (29.2 mm) from the surface of the water-cooled tank, *B*, to the surface of the water-cooled diaphragm, Fig. 4, *D*, and the distance of the surface of the slit jaws from the base of the receiver. These dimensions are easily measured and they need not be determined with the greatest accuracy. For example, an error of 1 mm would affect the final result by 1 part in 200, when as a matter of experience it is believed that this distance was measured with an accuracy of 0.2 to 0.3 mm or, say, 1 part in 700.

The question of the alignment of the radiometer, the water-cooled diaphragm, and the center of the radiating wall of the black body may be of considerable importance, although experimentally no difference in the radiation constant could be detected by rotating the telescoping tube about the water-cooled shutter as an axis, thus exposing the radiometer to the side wall of the radiator. The alignment of this apparatus was made by illuminating the interior of the radiator by means of an especially constructed Nernst glower, about 5 mm long, placed within the radiator and operated on a transformer, which enabled one to sight upon the center of the radiating wall and then (by changing the focus) upon cross wires temporarily stretched over the outer opening in the radiator. With the telescope thus aligned, the opening in the water-cooled diaphragm was adjusted to its proper position in front of the radiator and centrally on the cross hairs. On placing the radiometer in position in the telescoping tubes and sighting upon its rear face, the axis of the radiometer was found displaced only about 1 mm from the central cross hairs, which was a far more accurate adjustment than was required.

The length of the receiver and the size of the opening of the water-cooled diaphragm were such that when the distance between the receiver and the diaphragm was less than 30 cm, there was a possibility (as shown by geometrical construction) that radiations coming from the edges of the opening in the first diaphragm within the radiator might fall upon the receiver. However, the whole interior for a distance of 8 to 10 cm from the radiating wall is uniformly heated, and no marked difference was found in the values of the radiation constant as determined at very short distances from the water-cooled diaphragm.

7. METHOD OF MAKING OBSERVATIONS

The method of operation is very simple. The receiver is exposed to a source of radiation, say, a uniformily heated cavity or so-called black body (heated to a difinite temperature) and its rise in temperature is noted by reading the deflection produced on the galvanometer needle. The galvanometer sensitivity having been determined, an electric current of sufficient strength is passed through the strip to heat it, and thus cause a deflection which is the same size as that obtained when the strip was exposed to radiation. The energy expended in heating the receiver is determined by measuring the drop in potential between two terminals (which define the length of strip exposed to radiation) and the electric current through the strip. The current is determined by measuring the drop in potential across a standard resistance of 1 ohm, *O*, Fig. 6. These emfs were measured with a Leeds and Northrup type K potentiometer having a range of 1.5 volts and provided with shunts having the following ratios: 1:1, 1:0.1, and 1:0.01.

The complete outfit was designed to be used with the potentiometer and galvanometer equipment which obtains in the average laboratory.

In practice the radiator was heated to a uniform temperature, and the radiometer was exposed to radiation for a few minutes in order to establish temperature uniformity within the connecting apparatus. Two observers made the required readings. The one observer made the galvanometer readings and operated the switch for electrically heating the radiometer. The other observer recorded the galvanometer deflections, maintained a constant temperature in the radiator (which was operated on a storage battery) while radiometric observations were in progress, and made the potential measurements each time the first observer applied a heating current to the radiometer. This insured high accuracy, for sometimes the (portable) storage cell used was found to vary. It was therefore desirable to make the potential measurements for each heating of the receiver.

A complete set of measurements consisted in exposing the receiver from 5 to 10 times to the black body radiations, and noting the galvanometer deflections. The receiver was then heated electrically a similar number of times by closing and opening a knife switch and noting the galvanometer deflections which could be very easily made the same size (to within 1 per cent.) as those obtained by exposing the receiver to the black body. From such a set of measurements the constant of the radiometer (or the constant of radiation) may be determined. However, to make certain of the readings another set of observations was made on the black body. In Table 2 is given a typical set of observations, first on the radiator, then for electrical heating, followed by a repetition of the observations on the black body. When conditions were more unsteady a greater number of galvanometer readings were taken. Usually from three to four such pairs of determinations were made for a given distance between the receiver and the water-cooled diaphragm, the order of heating the receiver, electrically or radiometrically, being interchanged. This eliminated some of the very small changes in galvanometer sensitivity which (in the course of an hour, the time required for making the measurements) occurred in the galvanometer. The change in galvanometer sensitivity, if any, was easily made apparent by using the same heating current for the three to four pairs of determinations. The appended tables show the precision of the single pairs of determinations, each determination being the mean of the "pair" just mentioned.

Since the receivers were mounted upon a piece of slate there was no chance for appreciable leakage, and none could be detected by insulation tests. The various receivers, after mounting them in front of the thermopile, when heated electrically produced the same deflection on reversal, showing that the thermopile was thoroughly insulated from the receiver.

TABLE 2

Illustrating Observations

[Receiver No. 3; series CXL; temperatures, $t_0=15°$, $t_1=1040.8°$ C; voltage=0.010797; amperage=0.046436; resistance in series with the galvanometer=60 ohms; requires 15 seconds to attain maximum deflection.]

Stimulus	Galvanometer deflections
Radiation from black body	15. 48 . 42 . 43 . 46 . 46 cm
Electrical heating	15. 36 . 38 . 36 . 40 . 38 M=15. 38 cm
Radiation from black body	15. 46 . 46 . 46 . 43 . 46 Mean=15. 45 cm

8. METHOD OF REDUCTION OF DATA

The evaluation of the observed data is an easy matter. The galvanometer deflection produced by electrically heating the receiving strip was found to be proportional, over a considerable range, to the energy input. It is, therefore, an easy task to observe the galvanometer deflection produced by exposing the receiver to the radiator, and to determine the electrical power put into the receiver in order to produce closely (say within 1 per cent) the same deflection. The exact amount of energy necessary to cause the same deflection as that produced by absorbing radiant energy is obtained by multiplying the observed energy input by the ratio of the galvanometer deflections. This gives the "constant" of each receiver. In order to reduce all the measurements to a common basis, and at the same time obtain a value of the coefficient, or the so-called Stefan-Bolzmann constant, of total radiation, the custom of previous experimenters is followed in reducing the present data. For this purpose it is necessary to know the area, A_1, of the water-cooled diaphragm, the area, A_2, of the receiver which is exposed to the radiation emanating from, A_1, the distance, D, between these two surfaces, the absolute temperature, T_1, of the shutter, and the absolute temperature, T_2, of the radiator. The electrical energy input necessary to produce the same (deflection) rise in temperature that was produced by exposing the receiver to the radiator is EI, both of which quantities are measured with the potentiometer as already described. Under these conditions the energy consumed by the electrical stimulus may be equated to the energy emanating from the radiator, or,

$$EI=\frac{\sigma}{\pi}(T_2^4-T_1^4)\frac{A_1A_2}{D^2} \tag{1}$$

where σ is the coefficient of total radiation, E is the voltage and I is the current.

Usually the distance between the two surfaces A_1 and A_2 are so close that experimenters have had to apply a second term correction. In Gerlach's[15] work the correction applied was

$$\frac{A_1A_2}{D^2}\left(1-\frac{1}{6}\,\frac{a^2+b^2+a_1^2+b_1^2}{D^2}\right)$$

where the sides of the openings in the rectangular diaphragms were a, b, a_1, b_1. A shorter correction factor is

$$\frac{A_1A_2}{D^2}\left(1-\frac{1}{4}\,\frac{a^2+b^2}{D^2}\right)$$

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[15] Gerlach, Ann. Der Phys, (4), 38, p. 1; 1912.

which results from neglecting the effect of the first diaphragm, which is very small in the present work. In either case this second term correction is quite negligible in the present investigation, since it usually amounts to less than 2 parts in 1000.

9. CORRECTIONS FOR DIFFUSE REFLECTION FROM THE RECEIVER

The diffuse reflecting power of lampblack (soot) and electrolytically deposited platinum black, for different spectral regions was previously investigated.[16] However, in view of the different values of the radiation constant obtained with the various receivers, it seemed desirable to make reflectivity measurements on some of the receivers used in the present work for a spectral energy distribution similar to that of a black body at the temperature (1000°) used in this investigation. This question was therefore undertaken anew, using the apparatus and methods previously employed. The main difficulty experienced was in the warming of the sample when exposed to radiation and the consequent reradiation upon the thermopile. This was aggravated by the warming of the glass window (by absorbing long waves) which had to be used to prevent this reradiation falling upon the thermopile. This warming (and cooling) effect would continue for 1.5 minutes, when using radiations which were absorbed by the glass window. On the other hand, using the radiations from an acetylene flame, transmitted by an absorption cell of water 1 cm in thickness and hence but little absorbed by the glass window, the same measurements could be made in 30 to 40 seconds, which was the period for obtaining temperature uniformity in the thermopile.

As a source of radiation having a spectral energy distribution closely that of a black body, a strip of thin nickel, covered with nickel oxide, was used. The coating of oxide was heated to 900 to 1000°.

The thermopile was covered with a glass window 0.88 mm in thickness, which transmits radiations to about 4.5 μ. The absorption cell of water, used in producing more homogeneous radiations, was 1 cm in thickness; and it was opaque to all wave lengths greater than 1.4 μ. The wave length of maximum emis-

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[16] This Bulletin, 9, p. 283; 1913.

sion when using such a cell is about 0.95 μ. When this absorption filter was not in the path of the rays the maximum radiation when using an acetylene flame was at 1.2 μ, and when using the nickel strip heated to about 900° the maximum emission was at about 2.4.

Measurements were made on samples previously investigated and they were found in fair agreement with the values previously obtained. The samples of lampblack Nos. 1 and 2 were painted on the brass blocks previously used, then smoked with soot from a sperm candle. The sample of "Platinum black No. 20" was previously examined, and was found to have a diffuse reflectivity of 1.29 per cent for homogeneous radiations of wave length $\lambda = 4.4\ \mu$.

In order to examine these receivers they were mounted upon the brass blocks used in the previous investigation. The mixture of oxides of cobalt and chromium, mentioned in Table 3, was similar to that used in coating the inside of the radiator. A second sample was painted upon a piece of porcelain and heated in a blast flame. It had a more grayish appearance than that which obtains in the radiator. These samples, and the one of Marquardt porcelain, were examined in order to obtain data for the discussion of the blackness of the radiator.

TABLE 3

Diffuse Reflecting Power of the Receiver

Reflecting surface tested	Acetylene flame		Nickel oxide—no absorption cell, $\lambda_m = 2.4\mu$
	No absorption cell, $\lambda_m = 1.2\mu$	Using cell, $\lambda_m = 0.95\mu$	
	Per cent		
Lampblack paint covered with soot, No. 1	1.26		
Lampblack paint covered with soot, No. 2	1.30		
Platinum black No. 20	1.41	0.83	
Receiver No. 7.—Platinum black, resmoked	1.22		1.65
Receiver No. 13.—Platinum black, smoked	1.27		
Receiver No. 11.—Platinum black	1.31		1.78
Receiver No. 9.—Platinum black, smoked	1.45	1.13	
Mixture of oxides of chromium and cobalt			7.1
Mixture of oxides of chromium and cobalt after heating to 900° C			12.3
Marquardt porcelain			58.5

In applying these corrections for loss by reflection from the radiator it is to be noted that, of the total amount of radiation emitted by a black body at a temperature of 1050° C, only a small part is of wave lengths greater than 4.5 μ, so that even though the reflecting power for these longer wave lengths may be greater (by several parts in 1000) than the values here used, the effect upon the final value is negligibly small in comparison with other experimental errors which are of greater magnitude.

It is of interest to note that there is but very little difference in the reflection from the various receivers, which, of course, one could perceive by comparing them side by side in diffuse daylight. The different values of the radiation constant, obtained with different receivers, is therefore not attributable to a difference in the reflecting power of the absorbing surfaces.

It is to be noted that there is a considerable difference in the observed reflecting power, depending upon the source of radiation. However, as noted above, there is a good reason for believing that this is caused by the absorption of the infra-red rays, of wave lengths greater than 4 μ, which are far more abundant in the spectrum of nickel oxide than in that of acetylene. Any slight warming of the glass window, caused by absorbing these infra-red rays, will affect the thermopile just as obtains in the apparatus used for measuring the constant of radiation, and an erroneous value will be obtained. It is difficult to eliminate this warming effect, especially when using radiations of such heterogeneity as obtains in the nickel-oxide spectrum. This matter was discussed in the previous paper to which reference may be made. The values of the reflecting powers, obtained using homogeneous radiations of wave length $\lambda = 4.4$ μ, are in close agreement with those obtained in the present work using the acetylene flame. The correction adopted for loss of energy by reflection from the receivers used in the present investigation is $R = 1.4$ per cent for lampblack and $R = 1.5$ per cent for platinum black. This probably overcorrects rather than undercorrects the observations, but it will assist in eliminating a small absorption by atmospheric water vapor and carbon dioxide for which no correction has been made. From the experiments with receivers Nos. 6 and 10, the difference in the reflecting power of lampblack and platinum black is not as great as here given, the difference being only from 1 to 2 per cent. From the experience gained in the present work, as well as from previous work, it is concluded that the preparation of a good deposit of platinum black is a rather difficult task. The platinum-chloride solutions seem to deteriorate rapidly on standing after being used, which tends to produce grayish deposits. It is therefore desirable to prepare fresh solutions.

Numerous experiments have been made by various observers showing that the reflecting power of lampblack and platinum black is of the order of 2 per cent. Only one recent experimenter is in disagreement, his[17] value being of the order of 18 per cent, which is in agreement with the early observations by Melloni. However, there are good reasons for questioning the experimental procedure. It seems obvious that if, with the crude radiometers obtainable half a century ago, Melloni could find a diffuse reflection of 18 per cent from lampblack, then it should be still easier to prove the existence of such a high reflectivity by the employment of the highly sensitive instruments now available. But as a matter of fact, the modern instruments must be operated at a very high sensitivity in order to detect and to measure the diffuse reflection of lampblack and platinum black, which would not be the case if the diffusely reflected radiation were one-fifth the intensity of the incident radiation.

10. ACCURACY ATTAINABLE

It is difficult to estimate the accuracy attained in the final results. The various receivers (especially Nos. 8 and 9) gave values which have a range of over 3 per cent, although measurements made with a given receiver usually have a range of only about 1 per cent, which is considerably smaller than hitherto attained. It is important to note that the value of the radiation constant is based upon observations with a far greater number of receivers than were heretofore employed. The wide range in values seems to be due to some peculiarity in the receivers, which has not yet been located; for the various recognized sources of

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[17] Fery, Compt., Rend., 148, p. 777; 1909.

error do not account for this variation. Among these possible sources of error are the following:

(1) An incorrect evaluation of the galvanometer deflection. In the preliminary work, an account of which was given elsewhere,[18] the galvanometer was not thoroughly shielded from magnetic perturbations and the tendency was to read the deflection as quickly as possible. The data (Table 4) are therefore not

TABLE 4

Data on the Radiation Constant obtained in 1914

Series	Receiver		Distance	Temperature	Correction applied for reflection	σ		Remarks
	Length	Width				a	b	
	No. 2							
	mm	mm	mm	°C	Per cent			
VIII	24.356	3.192	356.1	922.3	1.4	5.73	5.72	Slit on side and ends.
IX	24.354	3.192	356.1	922.3	....	.72	.73	End jaw slits off.
	No. 1							
XI	23.092	2.150	463.3	896.5	1.3	.71	......	Slit on side.
XII	....	....	316.0	894.3	....	.60	.60	Do.
XIII	....	....	330.0	894.4	....	.73	.71	Do.
XIV	....	....	309.3	880.1	....	.70	.70	Do.
XV	23.092	2.545	310.1	879.5	....	.80	.80	No slit.
	No. 3							
XVI	24.910	4.990	314.0	944.5	1.3	.56	.52	Slit; battery changing.
XVII	....	....	326.8	943.8	....	.51	.52	Slit.
XVIII	....	....	268.3	943.2	....	.56	.49	Slit; battery changing.
XX	24.910	5.051	270.6	867.9	....	.61	.59	No slit; battery changing.
XXI	....	....	309.8	866.8	....	.63	.64	No slit.
XXII	....	....	255.3	867.0	....	.57	......	Do.
XXIII	....	....	255.3	867.0	....	.57	......	Do.
XXIV	24.910	4.992	283.3	881.4	....	.52	.52	Slit; battery changing.
XXV	....	....	307.4	881.5	....	.58	.60	Slit.
XXVI	24.910	4.435	307.4	901.4	....	.73	.73	Slit narrower.
XXVIIa	....	....	324.0	901.5	....	.73	......	Slit; battery changing.
XXVIIb	....	....	281.4	900.6	....	.63	.62	Slit.
	No. 4							
XXVIII	26.565	5.508	292.5	938.0	1.8	.51	.53	Slit; battery changing.
XXIX	....	....	320.5	938.0	....	.49	.52	Slit; battery reset.
XXX	....	....	298.1	937.8	....	.53	.54	Slit.
XXXI	....	....	323.2	937.4	....	.53	.56	Do.
XXXII	26.565	5.536	324.5	938.8	....	.61	.62	No slit.
XXXIII	....	....	324.5	920.9	1.3	.62	.63	No slit; smoked.
XXXIV	....	....	289.3	920.5	....	.63	.64	Do.
XXXV	26.565	5.490	288.5	930.4	....	.57	.55	Slit; smoked.
XXXVI	....	....	320.3	930.0	....	.57	.57	Do.

Mean value $\sigma = 5.61 \times 10^{-12}$ watt cm^{-2} deg^{-4}

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[18] Coblentz, Phys. Zs., **15**, p. 762; 1914.

included in the final result. In the present work there was no need of haste for, as already mentioned, the galvanometer was not subject to disturbances and this possible source of error was eliminated.

(2) Errors may be introduced by improper evaluation of the electric current used in heating the receiver. These heating currents could easily be kept constant to one division on the potentiometer dial, which represented 0.00001 ampere, the actual current used in some cases being as high as 0.06 ampere. Under certain conditions this would represent a variation of about 0.2 mm in the observed galvanometer deflection or an error of 1 part in 500 to 900.

(3) The variations in the reflecting power of the absorbing surfaces, as already mentioned, do not account for the different values of the radiation constant. This was abundantly demonstrated throughout the work. For example, using receiver No. 10, which had an excellent coating of platinum black, the radiation constant differs but little (see series CXV to CXX, Table 5), from the value obtained (see series CXXI to CXXII) after smoking this receiver with soot from a sperm candle. Another example is receiver No. 7 which underwent various treatments (see series LXXXII, LXXXIX, and XCVII). For the latter series this receiver had been given an unusually heavy coating of soot, which easily peeled off. Nevertheless, the radiation constant is practically the same as previously observed.

(4) The effect of the potential terminals was tested by attaching an additional terminal, *c*, Fig. 2, at a distance of about 3 mm from the one used in this work. This test was applied to receivers Nos. 10 and 12. For receiver No. 10, in which the connections were poor, the resistance per millimeter length (0.021145 ohm) was 0.6 per cent less, and for receiver No. 12 it was 0.4 per cent less for the longer distance. Part of this decrease in resistance observed for the longer distance (*a* to *c*) is to be attributed to a lowering of the resistance by the solder at the juncture *b*, Fig. 2, so that the actual error introduced by the uncertainty of the location of the juncture of the potential terminal is probably less than 0.3 per cent. The length of the receiver was defined by

measuring the distance between the point of emergence of the potential wires from the juncture with the receiver.

(5) The width of the receiver exposed to radiation was defined by the distance between the knife edges of the slits. These distances could easily be measured to 0.001 mm by means of a Zeiss comparator. The effect of shadowing different widths along the edges of the receiver (series XXVI to XXVII, also X to XV and LXXXII) was tested, but no certain results were observed. Furthermore, the slit edges could easily be adjusted so that they did not overlap the edges of the receiver by more than 0.1 mm, which is negligible as regards cooling by conduction from the exposed surface. This question was also investigated by Gerlach,[19] who likewise found no effect for overlapping of the edges of the slits and the receiver.

(6) The slits at the side of the receiver might become warmed by exposure to radiation and, in turn, might radiate to the receiver. One test to determine this effect was to cover the opening between the slits with a strip of sheet aluminum 0.5 mm in thickness and exposing it to the radiator, which was heated to about 1000°. The effect of warming, if any, was estimated to be of the order of 1 part in 500 to 1000. From the concordant values obtained with the brass slits (thickness, $t=0.5$ mm), and the aluminum slits ($t=1.95$ mm) already mentioned, it seems evident that if there is any warming of the slits it is negligible.

However, it is important to have the receiver properly protected, as is evident from the following test on receiver No. 4, which was about 5.6 mm in width. The slits were removed and a strip of copper 6 mm wide and 0.3 mm in thickness, painted with lampblack, was placed close (1 mm) over the receiver. An exactly similar shield of copper was placed at a distance of about 3 mm in front of this plate and the whole was exposed to the radiator for 10 seconds, after which the shutter was closed. On first exposing this device there was no response until after the lapse of about 10 seconds (shutter was then closed), when there was a small galvanometer deflection which increased rapidly to about 7 mm. at the end of 30 seconds, then decreased to zero at

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[19] Gerlach, Ann der Phys. (4), 38, p. 1; 1912.

the end of 75 seconds. On removing the lampblack from the front strip of copper (which was not polished), there was but little response at the end of 10 seconds and the maximum deflection was only about 2.5 mm. This was about 1 per cent of the whole deflection for the incident radiation. The slowness of the initial response was due to the warming of the first strip, which then radiated to the second one. It is, of course, possible that some of the radiations incident upon the receiver came from warming of the blackened shields (*C C*, Fig. 2), which were unavoidably exposed to the radiator. The whole, while emphasizing the importance of protecting the receiver, also indicates that when using highly polished surfaces on the front of the knife-edged slits the errors, caused by warming, are negligibly small.

(7) An uncertainty of 1° in the temperature measurements at 1000° C represents an error of 0.3 per cent and at 2200° C it represents an error of 0.16 per cent in the radiation constant. On using the radiometer to measure temperatures an error of 1 per cent in the radiation measurements is equivalent to an uncertainty of 3°.2 at 1000° and 6°.2 at 2200° C. While these errors appear to be small, from the nature of the scale reading, it is necessary to keep the temperature of the radiator constant to 0.°1, for it frequently was observed that a variation of 0.°1 in the temperature of the radiator had a perceptible effect upon the galvanometer deflection, which affected the result by perhaps 0.1 per cent. Under certain conditions a change in temperature of 0.°1 produced a change of 0.5 to 1 mm in the galvanometer deflection.

(8) As already mentioned, the uncertainty in measuring the distance between the water-cooled diaphragm and the receiver is negligibly small.

(9) Absorption of radiation by water vapor and carbon dioxide was reduced by having the optical path inclosed and absorbing the moisture with phosphorous pentoxide. That the atmospheric absorption occurs was shown by direct tests, using receiver No. 11. For this purpose measurements were made with and without the brass tubes *D E*, Fig. 5, in place. The first test (series CLV and CLVI), with the optical path (53 cm) constant,

showed that the presence of the tube did not affect the measurements within the errors of observation. These errors were considerably increased by unsteadiness caused by air currents when the tube was not in place. With the aligning tubes in place, but using no drying material, the value of the radiation constant increased from $\sigma = 5.43$ (series CLVI) to $\sigma = 5.5$ (series CLVII and CLVIII) for a decrease of 25 cm in the optical path, or an actual increase of about 1.5 per cent. On the other hand, using drying material to remove the moisture, all the determinations made with this receiver are very much higher (by 3 to 4 per cent) than those observed without the drying material, and the inverse square law holds with greater exactness. It is probable that the values would have been still more constant for different distances if greater care had been taken in drying the air. For example, when in any series of observations the distance is changed by lengthening the optical path, the whole column of air is not free from moisture at the start. It would have been better to have set the apparatus with a long air path and allow it to stand overnight in order to remove the moisture, then make the series of observations by decreasing the air path, i. e., the distance, which would be accomplished by the expulsion of dry air and the maintenance of constant conditions. Further data on atmospheric absorption are given in a subsequent paper.

(10) As already mentioned, black-body conditions within the radiator were obtained by painting the interior of the porcelain tube with cobalt oxide. Tests were made by exposing the receiver to different parts of the interior of the radiator. This was accomplished by tilting the whole radiometric outfit (see Fig. 5) about the water-cooled diaphragm as an axis of rotation, thus exposing the receiver to the side walls of the radiator. This test showed no definite variation in the resulting galvanometer deflection, thus indicating that the interior of the radiator was uniformly heated.

III. EXPERIMENTAL DATA

The data given in the appended tables were obtained with a large assortment of receivers, differently prepared and operated under various conditions as to width and thickness of the metal strip, distance between potential terminals, kind and thickness of the absorbing layer, etc. The receivers Nos. 1, 3, and 5 were constructed of strips of manganin or "therlo," which were from 0.008 to 0.011 mm in thickness. The others were constructed of platinum used for bolometers, the thickness being 0.001 mm or less in thickness. The distance between the heavy copper electrodes was from 30 to 31 mm. In Table 4 data are given showing that the value of the constant is not affected by the distance of the receiver from, or the temperature of, the radiator. In Table 5 the data were obtained under a great variety of working conditions. The individual receivers will now be described.

TABLE 5

Values of the Constant of Radiation as Determined with Various Receivers

[The mean values (uncorrected for reflection from receiver) are based on the data which are free from doubt as to water vapor, blackness of the radiator, stray light resulting from the absence of slits, etc. The doubtful data are marked with an asterisk, thus (*).]

Receiver No. 5.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
XLVII..........	18.561	5.640	380.5	25.5	1056.5	5.734	With brass slits; painted and smoked.
					.6	.745	
					.2	.758	
					.1	.731	
XLVIII.........	....	....	457.9	16.5	1056.2	5.749	
					.0	.732	
					5.9	.735	
XLIX...........	....	....	421.1	17.0	1056.1	5.720	
					5.9	.744	
					.9	.743	
					.9	.743	
					4.6	.693	
					.6	.740	
L*.............	18.561	5.662	424.0	17.0	1057.4	5.771	Slits drawn back.
					.4	.793	
					.4	.830	
					.2	.807	
					6.5	.794	
LI*............	....	....	....	25.0	1056.3	5.827	No slits.
				.3	5.9	.871	
Mean value..	....	....	....	....	....	5.736	

TABLE 5—Continued

Receiver No. 6.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
LII	20.061	5.979	422.0	18.3	1057.2	5.504	With brass slits. Pt. black; poor coating.
					6.2	.529	
					.2	.515	
					.2	.582	
LIII*	20.061	6.025	423.9	23.5	1056.3	5.845	No slits
					.2	.883	
LIV	20.061	5.983	422.0	17.5	1059.4	5.678	With slits; smoked. Thermopile is shielded with sheet iron; two layers of paper between. Metal shields are smoked.
					60.0	.672	
					.2	.682	
LV	....	....	402.3	25.5	1060.2	5.648	
					58.8	.706	
LVI	....	....	394.6	10.0	1059.5	5.721	d'Arsonval galvanometer.
					60.0	.696	
					59.5	.696	
LVII	....	....	394.6	10.0	1059.5	5.692	Thomson galvanometer.
					.1	.723	
					8.6	.712	
LVIII	....	....	387.1	13.0	1076.2	5.642	
					8.6	.704	
					8.1	.717	
					7.5	.670	
LIX	....	....	417.7	22.0	1078.3	5.723	
					.2	.709	
					.0	.709	
					.0	.657	
LX	....	....	390.0	11.0	1078.1	5.663	
					.1	.701	
					.1	.696	
					7.8	.659	
LXI	....	....	419.2	11.3	1077.4	5.695	
					.3	.722	
					.3	.740	
					.2	.747	
LXII	....	....	374.9	12.0	1075.6	.645	Rear of furnace is 2° too high.
					.4	.646	
					.4	.645	
Mean value	....	....	....	....	....	5.672	

TABLE 5—Continued

Receiver No. 5.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma\times10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
LXIII..........	18.561	5.638	399.8	17.5	1069.8	5.730	Brass slits; repainted and smoked. P. D. terminals shellacked and insulated.
					70.6	.696	
					68.7	.742	
					.6	.714	
LXIV..........	....	....	375.5	17.5	1068.2	5.714	
					7.9	.734	
					8.0	.704	
					8.0	.710	
LXV..........	....	....	441.0	19.2	1068.3	5.687	
					7.8	.747	
					7.2	.746	
LXVI..........	....	....	379.5	16.0	1077.9	5.747	
					.9	.721	
LXVII..........	....	....	465.6	17.0	1078.1	5.611	Poor series. Galv. unsteady.
					7.9	.642	
LXVIII..........	....	....	432.5	17.0	1078.0	5.762	
					7.7	.727	
					.0	.751	
LXIX..........	....	....	376.5	17.0	1044.1	5.712	
					38.3	.749	
					36.8	.748	
LXX..........	....	....	375.5	18.4	1072.2	5.687	
				22.5	69.2	.701	
					8.6	.755	
					.3	.745	
LXXI..........	....	....	410.6	22.0	1066.5	5.780	Galv. unsteady; windy.
					.1	.778	
					.0	.755	
Mean value..	....	....	....	....	....	5.725	

Receiver No. 3.—Diaphragm No. 3; d=3.987 mm

LXXII..........	24.910	5.000	377.8	16.5	1053.0	5.603	Aluminum slits reset; receiver resmoked.
				18.0	60.0	.581	
					59.9	.586	
					.3	.581	
LXXIII..........	....	....	424.1	22.0	1058.2	5.577	
					7.3	.564	
LXXIV..........	....	....	417.0	16.5	1068.5	5.628	
					.1	.617	

TABLE 5—Continued

Receiver No. 3—Continued

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma\times10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
LXXV	....	....	442.8	12.0	1080.8	5.675	
					79.9	.625	
					7.7	.598	
					6.7	.677	
LXXVI	....	....	419.9	11.0	1068.3	5.612	
					8.5	.631	
LXXVII	....	....	418.2	13.0	1073.8	5.608	
					2.2	.575	
				12.5	4.7	.642	
					0.4	.624	
					69.7	.616	
LXXVIII	....	....	397.0	12.0	1062.4	5.575	
					54.9	.528	Poor series. Temp. changing.
					2.3	.564	
					46.4	.530	
LXXIX	....	....	397.2	12.0	1067.7	5.662	Excellent series.
					.8	.645	
					.9	.655	
LXXX	....	....	376.1	12.5	1067.6	5.624	
					.5	.645	
					.3	.623	
LXXXI	....	....	459.5	12.6	1066.8	5.613	
					4.2	.596	Temp. suddenly changed.
					.0	.645	
					.2	.627	
Mean value	....	....	....	....	....	5.607	

Receiver No. 1.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	t_0	t_1	Coefficient of radiation $\sigma\times10^{12}$	Remarks
LXXXII	22.985	2.537	376.7	14.0	1068.6	5.831	Brass slits. Repainted and smoked.
					.5	.831	
				13.5	.0	.828	
					7.4	.834	
					.1	.838	
LXXXIIa	....	....	395.3	19.0	1065.7	5.751	Poor series. Very unsteady.
Mean value	....	....	....	....	....	5.819	

TABLE 5—Continued.

Receiver No. 7.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma\times10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
LXXXIII	24.659	7.952	396.1	11.5	1071.0	5.547	Brass slits. Coated with Pt. black; surface washed with alcohol and lampblack paint; coated with soot.
					69.8	.577	
					.0	.559	
					.5	.563	
				12.0	.1	.565	
					8.8	.579	
					.8	.577	
					.7	.606	
LXXXIV	....	....	391.3	19.7	1068.7	5.622	
					9.1	.598	
					.0	.560	
					.3	.541	
					.2	.559	
					.9	.586	
					.8	.590	
					.2	.580	
LXXXV	....	....	459.5	20.0	1068.3	5.557	Probably slightly low, due to water vapor.
					.2	.574	
					.4	.555	
LXXXVI	....	....	459.5	16.0	1069.3	5.553	
					8.9	.571	
					9.2	.547	
LXXXVII	....	....	428.6	16.0	1069.1	5.561	
					8.7	.551	
					.6	.564	
					.2	.561	
					.1	.577	
LXXXVIII	....	....	391.2	16.0	1067.4	5.621	
					.9	.612	
					.9	.606	
					.7	.588	
LXXXIX	24.659	7.966	391.2	25.2	1073.0	5.578	Painted black and smoked on both sides. Rear shields overlap more. No drying material.
					.6	.597	
XC	....	....	409.2	16.0	1072.3	5.565	Drying material inserted.
					.1	.572	
					.3	.605	
					.3	.619	
					.4	.601	
					.3	.609	
XCI	....	....	474.6	19.6	1068.7	5.588	Good series.
					.5	.591	
					.6	.582	
XCII	....	....	375.8	27.0	1070.4	5.554	Temp. t_0 is high because of slow water circulation.
					.1	.563	

TABLE 5—Continued

Receiver No. 7—Continued

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
XCIIb........	....	....	431.1	27.0	1068.1	5.548	
					7.7	.544	
					.7	.560	
XCIII........	....	....	453.6	27.0	1065.7	5.550	
					6.5	.523	
XCIV........	....	....	375.6	11.0	1072.4	5.600	d'Arsonval galv. Vertical tremors.
XCV........	....	....	400.5	13.0	1071.2	.625	
					.1	.616	
					0.7	.629	
XCVI........	....	....	400.5	13.0	0.8	5.617	Thomson galv.
					.8	.599	
					.7	.608	
XCVII........	24.659	7.964	381.2	17.5	1076.7	5.576	Resmoked; given a thick, soft layer of soot.
					.4	.600	
					.2	.587	
					.1	.561	
XCVIII........	....	....	433.9	17.0	1075.6	5.590	
					4.8	.594	
Mean value..	....	....	....	....	....	5.580	

Receiver No. 8.—Diaphragm No. 3; d=3.987 mm

XCIX........	23.989	7.074	378.6	11.2	1075.6	5.876	Brass slits. Coated with Pt. black; washed with sol. of lampblack; smoked.
					.6	.873	
C........	....	....	404.8	11.5	1075.4	5.946	
					.0	.930	
					4.5	.946	
CI........	....	....	436.4	11.5	1075.3	5.864	
					6.6	.904	
					.0	.894	
CII........	23.989	7.085	377.0	12.0	1074.5	5.880	Resmoked; washed with mixture of alcohol and turpentine; smoked.
					3.3	.885	
					2.8	.878	
CIII........	....	....	405.0	13.5	1071.2	5.913	
					.0	.915	
					0.9	.900	
CIV........	....	....	432.4	13.0	1070.3	5.887	
					.1	.848	
					9.9	.849	
					9.4	.870	
CV........	....	....	376.8	11.5	1076.0	5.791	Galv. unsteady.
					5.4	.856	

TABLE 5—Continued

Receiver No. 8—Continued

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
CVI............	23.989	6.857	379.4	12.5	1075.0	5.934	Resmoked rear surface. Reset metal guard plates at rear. P. D. terminals shellacked. Reset slits farther from receiver. Galv. unsteady.
					0.3	.999	
					68.7	.998	
					.6	6.007	
CVII...........	....	....	379.4	12.0	1068.4	5.949	
					.7	.927	
					9.3	.934	
Mean value..	....	....	....	....	....	5.906	

Receiver No. 9.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	t_0	t_1	Coefficient of radiation $\sigma \times 10^{12}$	Remarks
CVIII...........	24.917	6.205	380.3	12.0	1072.3	5.794	Brass slits. Strips across ends. Small hole in receiver. Pt. black; painted; smoked.
					.4	.837	
					.3	.855	
					.0	.872	
CIX............	....	....	413.4	12.0	1072.3	5.921	
					.6	.909	
					.3	.910	
CX.............	....	....	396.6	12.5	1072.0	5.903	Good series.
					.1	.889	
					.2	.898	
					.3	.895	
CXI............	....	....	377.7	13.2	1078.0	5.791	
					.0	.849	
					7.8	.835	
CXII...........	....	....	409.3	13.5	1077.7	5.896	
					.1	.926	
					.3	.924	
Mean value..	....	....	....	....	....	5.877	

Receiver No. 3.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	t_0	t_1	Coefficient of radiation $\sigma \times 10^{12}$	Remarks
CXIII..........	24.910	5.005	378.6	13.2	1105.5	5.632	Aluminum slits. Receiver resmoked.
					1.5	.628	
					.6	.626	
					.5	.628	
CXIV...........	....	....	413.8	13.2	1098.4	5.638	Distance is questioned.
					7.4	.634	
					.8	.660	
Mean value..	....	....	....	....	....	5.635	

TABLE 5—Continued

Receiver No. 10.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
CXV	19.947	6.721	376.4	21.5	1076.9	5.681	Brass slits. Excellent coating of Pt. black. One P. D. terminal has but little solder; other has solder spread out in a thin layer.
					7.0	.688	
CXVI	....	....	406.2	14.0	1081.9	5.730	
					.7	.718	
					.3	.757	
CXVII	....	....	440.1	14.0	1079.3	5.712	
					.3	.717	
CXVIII	....	....	378.0	12.0	1080.1	5.719	
					.0	.705	
CXIX	....	....	411.3	13.0	1079.4	5.732	Sensitivity changing.
					.5	.757	
					.0	.779	
					8.8	.752	
CXX	....	....	461.3	13.2	1079.5	5.722	
					8.7	.710	
					.3	.739	
CXXI	....	....	378.1	13.0	1085.0	5.775	Smoked.
					4.8	.789	
CXXIa	....	....	412.3	13.5	1082.8	5.739	
					.4	.756	
					.2	.763	
					.0	.767	
CXXII	....	....	442.0	14.0	1084.0	5.682	
					3.6	.734	
					.3	.712	
					2.7	.743	
Mean value	....	....	....	....	....	5.734	

Receiver No. 7.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	t_0	t_1	Coefficient of radiation $\sigma \times 10^{12}$	Remarks
CXXIII	24.659	7.959	376.6	13.6	1071.9	5.669	Brass slits. Paint removed; coated with Pt. black; smoked on both sides. Thermopile broken and repaired. Strip is now 1 mm nearer pile.
					2.3	.662	
CXXIV	....	....	412.9	13.8	1082.4	5.684	
					.3	.691	
CXXV	....	....	472.8	14.0	1083.8	5.717	
					3.0	.693	
CXXVI	....	....	448.7	14.5	1082.3	5.688	
					.2	.653	
					.7	.679	
Mean value	....	....	....	....	....	5.682	

TABLE 5—Continued.

Receiver No. 3.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma\times10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
CXXVII	24.910	5.005	376.7	14.0	1079.6	5.618	Aluminum slits. Smoked.
					.3	.600	
					80.6	.633	
					.4	.626	
CXXVIII	....	....	429.2	15.0	1078.6	5.618	Good series.
					.0	.610	
CXXIX	....	....	412.5	14.2	1077.6	5.648	
					6.8	.629	
CXL	21.620	4.953	377.0	15.0	1040.7	5.662	Serial number should be CXXX. Brass slits. Removed paint; repainted; smoked. Reset P. D. terminals. Radiator heating coil burned out; heated on outer coil.
					.7	.666	
					1.1	.654	
CXLI	....	....	408.7	15.0	1059.9	5.675	
					60.3	.683	
					.6	.677	
CXLII	....	....	471.1	15.0	1062.5	5.613	
					.5	.615	
					.5	.622	
CXLIII	....	....	444.9	14.0	1063.2	5.649	
					.0	.652	
					2.6	.662	
Mean value	....	....	....	....	....	5.641	

Receiver No. 11.—Diaphragm No. 3; d=3.987 mm

CXLIV	22.389	6.481	376.2	15.5	1077.5	5.649	Slits. Excellent coating of Pt. black. Ends of slits not covered. Radiator heated on outer coil.
					.6	.663	
					.5	.646	
CXLV	....	....	410.5	15.0	1076.0	5.670	
					5.5	.698	
					.5	.692	
CXLVI	....	....	479.4	15.0	1074.3	5.659	
					3.9	.661	
					.8	.660	
CXLVII	....	....	450.1	15.5	1075.1	5.658	
					.0	.654	
					4.9	.656	
					.6	.657	

TABLE 5—Continued

Receiver No. 11—Continued

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma\times10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
CXLVIII*			377.0	15.5	1078.0	5.572	Unpainted radiator. Bare front couple; see this Bulletin, 10, p. 34, Fig. 4 A. Heated on outer coil. Ends of slits of receiver covered.
					.1	.566	
					.3	.572	
CXLIX*			419.4	16.0	1078.7	5.592	
					.7	.591	
					.7	.603	Mean value=5.576.
CL*			475.7	16.0	1078.6	5.557	
					.4	.560	
					.2	.565	
CLI*			442.9	16.0	1078.1	5.569	
					7.9	.585	
CLII			379.8	17.0	1082.0	5.610	Painted black body. Heated on outer coil. Couple repaired (broken at junction) and covered as shown in this Bulletin, 10, Fig. 4 B.
					1.2	.620	
					.0	.637	
CLIII			417.6	17.0	1084.0	5.637	
					.0	.625	
					3.7	.627	Mean value=5.622.
CLIV			446.5	17.0	1084.5	5.605	
					.5	.614	
CLV*			523.9	20.0	1075.6	5.377	No inclosing tube to radiometer. Heated by both coils; humid air.
					.9	.479	
					.7	.430	
CLVI*			523.9	20.3	1089.7	5.432	With inclosing tube. No drying material.
					90.0	.424	
					89.9	.453	
					90.0	.435	Mean value=5.467.
					89.5	.453	
CLVII*			272.3	20.5	1088.5	5.479	
					.7	.495	
					.4	.513	
CLVIII*			336.4	20.5	1088.2	5.521	
					7.9	.523	
					.6	.525	
CLIX			376.8	20.0	1076.2	5.623	With drying material.
					.0	.631	
					.0	.624	Mean value=5.621.
CLX			420.8	21.3	1074.1	5.634	
					.0	.609	
					.0	.602	
CLXI			484.2	20.4	1071.5	5.567	Rear of furnace was 4° too high.
					.7	.558	
					.7	.559	
CLXII			446.1	20.8	1071.0	5.581	
					0.8	.596	
					.8	.574	
Mean value						5.629	

TABLE 5—Continued

Receiver No. 13.—Diaphragm No. 3; d=3.987 mm

Series	Length of receiver	Width of receiver	Distance	Temperature		Coefficient of radiation $\sigma \times 10^{12}$	Remarks
				t_0	t_1		
	mm	mm	mm	°C	°C		
CLXIII.........	21. 418	5. 340	376. 4	21. 0	1076. 2	5. 584	Aluminum slits. Coated with Pt. black; smoked on both sides.
					. 2	. 582	
					. 0	. 599	
CLXIV.........	....	....	424. 5	21. 5	1075. 3	5. 596	
					. 3	. 617	
					. 3	. 607	
CLXV*.........	21. 418	5. 340	480. 6	21. 0	1076. 1	5. 561	Low values due to humidity.
					. 2	. 568	
					. 2	. 568	
CLXVI.........	....	....	455. 8	21. 0	1076. 2	5. 579	
					. 0	. 586	
					5. 8	. 588	
Mean value..	....	....	....	....	....	5. 593	

Receiver No. 12.—Diaphragm No. 3; d=3.987 mm

CLXVII........	22. 385	6. 365	376. 7	21. 0	1078. 3	5. 651	Brass slits. Poor deposit of Pt. black; smoked on both sides.
					7. 4	. 660	
					. 1	. 657	
CLXVIII.......	....	....	418. 6	21. 0	1075. 9	5. 687	
					6. 4	. 675	
					6. 6	. 679	
CLXIX.........	....	....	486. 2	20. 0	1077. 8	5. 656	
					8. 1	. 671	
					. 3	. 668	
CLXX..........	....	....	448. 3	20. 0	1078. 0	5. 699	
					7. 9	. 686	
					. 8	. 688	
CLXXI.........	22. 385	6. 326	377. 1	21. 5	1075. 3	5. 605	Aluminum slits. Soot brushed off and resmoked.
					. 6	. 614	
					. 5	. 631	
					. 6	. 624	
CLXXII........	....	....	478. 8	21. 5	1085. 3	5. 626	
					. 1	. 608	
					4. 9	. 604	
CLXXIII.......	....	....	440. 0	21. 4	1084. 5	5. 623	
					. 8	. 621	
					. 7	. 620	
CLXXIV.......	....	....	401. 5	215.	1084. 8	5. 660	
					. 7	. 651	
					. 4	. 640	
Mean value..	....	....	....	....	....	5. 647	

Receiver No. 1 was made of "therlo," 0.007 to 0.008 mm in thickness, painted with lampblack and smoked with soot from a sperm candle; potential terminals 0.025 mm diameter; aluminum slits 2 mm in thickness. For a subsequent series of measurements LXXXII, Table 5, the paint was removed, the potential terminals were reset, the strip was repainted, and brass slits 0.5 mm in thickness were used. The strip being narrow the sensitivity is greatly reduced, which increases the errors of observation. For this reason the apparently higher values of the radiation constant, when using a very narrow receiver, are not considered to be attributable to the narrow slits. However, the error due to shadowing of the receiver by the jaw slits would be larger for a narrow strip than for a wide one, thus causing a higher value.

Receiver No. 2 was made of platinum less than 0.001 mm in thickness, covered electrolytically with platinum black. The potential wires were of platinum 0.0055 mm in diameter. The aluminum slits were 2 mm in thickness, and the edges were about 1.5 mm away from the receiver.

Receiver No. 3 was made of "therlo"; thickness about 0.008 mm, painted with lampblack and smoked. The slits were the ones of aluminum used with the preceding receivers. Subsequently the receiver was resmoked (the dust having been brushed off with a fine, especially prepared brush) and the measurements were repeated (series LXXII to LXXXI). To check the measurements on receivers No. 7 and No. 9, further measurements (CXIII to CXIV and CXXVII to CXXIX) were made. On examination with the rear metal shields removed, it appeared as though these aluminum slits had not overlapped sufficiently, which might have produced a low value. The work was therefore repeated (CXL to CXLII) after having removed the old paint, reset the potential terminals (to eliminate a possible conduction from the ends), repainted and resmoked the receiver, and attached the brass slits which were used with the other receivers. A slightly higher value of the constant was then found.

Receiver No. 4 was made of platinum. It had an excellent coating of platinum black. The potential terminals, of platinum 0.025 mm in thickness, lay flat upon the receiver for a length about 1.5 mm instead of making contact at the ends of the potential wires. In determining the distance between the potential terminals an error of 1.5 to 2 per cent was inadvertently made. The distance should have been measured at the point where the wire is free from the receiver instead of along the central axis of the receiver. This receiver was used in various subsidiary tests (e. g., on the effect of using water-cooled diaphragms having different openings) where the measurements were relative, and, because of the defect in the potential terminals, it is not used in considering the absolute measurements.

When using such a receiver without the jaw slits it is difficult to define the effective width exposed to radiation. For example, the mean value of the width of this strip before blackening, with platinum black, was 5.515 mm and after blackening the width was 5.536 mm. After smoking this receiver the width was 0.05 mm greater than before smoking. A similar example is receiver No. 6, which was 0.06 mm narrower after wiping the soot off the edges.

RECEIVER NO. 5 was made of manganin, 0.011 mm in thickness, which was painted with lampblack and smoked. The slit jaws were of brass, 0.5 mm in thickness, situated at a distance of 1.3 mm from the receiver. This particular set of brass slits (previously used) was used with the various receivers subsequently investigated. The potential terminals were of platinum wires, 0.025 mm in diameter, the tips of which were soldered to the strip of metal. This method was used in attaching the potential leads to all of the receivers subsequently constructed.

For series XLVII to LI, each shield *C C*, Fig. 2, overlapped the receiver by about 2.5 mm. After repainting and smoking the receiver the brass slits were reset and the shields, *C C*, overlapped the edges only about 1 mm. However, there is no marked difference in the results. (See series LXIII to LXXI.)

RECEIVER NO. 6 was made of platinum, with potential leads 0.025 mm in thickness and brass slit jaws. The shields *C C*, Fig. 2, at the rear of the receiver were of sheet iron, 0.3 mm in thickness, folded double, with a layer of thick paper intervening.

Measurements were made with this receiver when covered with platinum black (series LII to LIII), and when smoked and soot removed from the edges (series LIV to LXII); with a Thomson galvanometer and with a d'Arsonval galvanometer (series LVI); with and without slits. The results show that there is but little difference between the diffuse reflecting power of lampblack and platinum black. Similar tests were made with receiver No. 10, giving results in agreement with the above data.

RECEIVER No. 7 was made of platinum, with potential leads 0.025 mm in diameter and brass slits. The coating (deposited four minutes) of platinum black was very poor. The front surface was therefore washed with a very dilute solution of lampblack in alcohol. This made an excellent surface, which was then given a light coating of soot from a sperm candle. (See series LXXXIII to LXXXVIII.) The blackening being unsymmetrical, both surfaces of the receiver were given a thicker coat of lampblack and then smoked (series LXXXIX to XCVI).

In order to determine whether a still thicker coating of soot would affect the value of the radiation constant, the front surface of the receiver was given an additional coating of soot, which was deposited in a thick soft layer which could be easily brushed off in large patches (series XCVII to XCVIII). The thick layer of soot has no marked effect upon the results obtained. The supposed effect of such a thick coating of soot on the front surface is to reduce the value of the constant. This is due to the fact that in the electrical heating a smaller energy input would be required when the surface layers are unsymmetrical and the rear one is the thinner. A d'Arsonval galvanometer was used (series XCIV–XCV) with no marked effect upon the results. The soot and paint were then removed and an attempt made to blacken the surface with platinum black. The surfaces were rough and not very black, so that both sides were smoked (series CXXIII to CXXVI). The value of the constant is perhaps 1.0 to 1.5 per cent larger, instead of being smaller than that previously observed. This last blackening of the receiver increased the heat capacity to such an extent that it required 35 seconds to establish temperature equilibrium after exposure to radiation. It may be added that all of these platinum receivers attained temperature in 8 to 10 seconds, and that an exposure to radiation for 15 seconds was necessary because the thermopile required that length of time to attain temperature equilibrium.

Receiver No. 8 was made of platinum which was heated electrically in order to anneal it and especially to clean the surfaces which had a discolored appearance. In the annealing process the solder at the ends alloyed with the platinum strip, which then sagged considerably. The potential terminals were of platinum 0.025 mm in diameter, and the slits were of brass. The surface of the platinum was discolored and did not take a good deposit of platinum black. A thin coating of lampblack paint was therefore applied to both surfaces, which were then smoked (series XCIX–CI). The surfaces were resmoked and painted with a mixture of alcohol and turpentine, after which they were smoked (series CII–CV). This did not change the high value of the radiation constant. The slits were reset, being placed at a greater distance (1.8 mm instead of about 1.3 mm) from the receiver. The rear surface of the receiver was resmoked, which should increase the value of the constant; the potential wires were given an additional coating of shellac, and the guard plates at the rear of the receiver were reset. In spite of all of these manipulations the value of the constant (series CVI–CVII) remained the same, and no clue has been found to account for the high values.

Receiver No. 9 was constructed of platinum, which was annealed as was No. 8. The potential terminals were of platinum 0.025 mm in diameter, and brass slits were used. The alloying with the solder made the ends brittle, one end of the receiver having a small hole near the copper electrode. Like receiver No. 8 this receiver sagged as a result of this alloying with the solder. The surfaces of both of these receivers were wavy and uneven, and slightly curved at the edges. The surfaces did not take an even coating of platinum black. They were, therefore, given a thin coating of lampblack paint and then smoked. The value of the radiation constant is high as obtained with receiver No. 8 (series CVIII to CXII). To show that this value was due to something connected with these receivers, the observations were continued, using receiver No. 3 (series CXIII to CXIV), which gave its customary value of the constant which represents more nearly the "constant of the receiver" than the "constant of radiation." The general appearance of receivers 8 and 9 was such that one would hardly use them in accurate determinations.

RECEIVER No. 10 was constructed of platinum, which was cleaned by making it the anode in depositing platinum black upon a strip of platinum. A freshly prepared solution of platinum chloride was used, which gave an excellent (six minutes) deposit of platinum black

Three potential leads (*a*, *b*, *c*, Fig. 2) were applied, the extra one being used to test the effect of the potential terminals. The terminal wires were of platinum 0.01 mm in diameter and about 3 mm long, attached to similar wires 0.025 mm diameter. After attaching the wires to the receiver the diameter of the soldered connection was: $a = 0.1$ mm, $b = 0.08$ mm, $c = 0.06$ mm. Unfortunately two of these connections (*a*, *b*) became detached (by the solution) while cleaning and blackening the receiver. They were reattached by soldering them upon the platinum black, which caused the connection *a* to be somewhat larger in diameter than that just quoted.

The brass slits of previous experiments were used (series CXV–CXX) and to test the loss by reflection the receiver was smoked (series CXXI–CXXII) without disturbing the slits, the edges of which were covered to prevent them from becoming blackened with soot. The value of the radiation constant is somewhat higher, corresponding with the smaller reflecting power of soot.

The distance between the potential terminals *a–b* was 19.947 mm and from *a–c* it was 22.157 mm. The resistance per millimeter length between the terminals $a\text{–}b = 0.021145$ ohm and $a\text{–}c = 0.021020$ ohm, or an apparent decrease of about 0.6 per cent for the longer distance.

RECEIVER No. 11 was constructed of platinum. Before blackening it the surface was cleaned electrolytically by using the receiver as an anode, then dipping it in hydrochloric acid, which removed a whitish tarnish that is frequently found on platinum from which the silver has been removed. The platinum black was deposited for 6.5 minutes in a freshly prepared solution. It was the most uniform deposit, and in all appearances the best coat of platinum black in the whole series. At the completion of the work its reflecting power was determined as described elsewhere in this paper.

The potential terminals of platinum 0.01 mm in diameter (as described under receiver No. 10) were attached after cleaning the receiver and before applying the platinum black. The two soldered connections with the receiver were only 0.072 and 0.055 mm in diameter.

This receiver was used (with brass slits) in determining the radiation of a blackened porcelain radiator (CXLIV to CXLVII) and also of an unpainted radiator (CXLVIII to CLI). It was used also in determining the effect of moisture (CLV to CLVIII), which appears to produce a definite lowering of the value of the constant.

For the series of observations extending from CXLIV to CLIV the radiator was heated by the outer heating coil, which no doubt produced a different temperature distribution within the radiator. If this had any effect upon the constant, it was not appreciable.

Receiver No. 12 was constructed of platinum cleaned in hydrochloric acid. There were three potential terminals, of platinum wire 0.01 mm in diameter, to determine the effect of the terminal. The diameters of the soldered connections were: $a=0.07$ mm, $b=0.11$ mm, $c=0.90$ mm.

The platinum black was deposited for 6.5 minutes. The front surface had a brownish appearance and the rear surface had a grayish appearance. Hence, both surfaces were smoked with a thin coat of soot from a sperm candle. Brass slits (series CLXVII to CLXX) and aluminum slits (series CLXXI to CLXXIV) were used, but in view of the fact that for the latter series the soot had been brushed off the front surface of the receiver, which was then resmoked, the difference of about 1 per cent in the radiation constant is probably as much attributable to the smoking as to the different slits. The distance between the potential terminals a to b was 22.385 mm and from a to c it was 24.740 mm. The resistance per millimeter length between the terminals $a-b=0.020486$ ohm and $a-c=0.020400$ ohm, or a decrease of about 0.4 per cent for the longer distance.

RECEIVER NO. 13 was constructed of platinum cleaned in hydrochloric acid. The platinum black was deposited 6.5 minutes and the surfaces not being uniformly black, especially on the rear side, both sides were given a thin coat of lampblack soot from a sperm candle. The total length of this receiver was 31 mm, the potential terminals, of platinum 0.01 mm in diameter, being separated 21.418 mm. The soldered contacts of the potential terminals were 0.05 mm in diameter. Aluminum slits were used. The value of the radiation constant (series CLXIII to CLXVI) is practically the same as that obtained with a majority of the other receivers. It is probably somewhat too low, due to incomplete removal of atmospheric water vapor.

A summary of the results obtained with the various receivers is given in Table 6.

IV. SUMMARY

The present paper gives the results of an investigation of the behavior of a bismuth-silver thermopile suitably modified to measure radiant energy in absolute value. Instead of exposing the thermopile directly to the incident radiation a blackened metal strip intervenes. This metal strip functions (1) as a receiver for absorbing radiant energy; (2) as a source of radiation (by heating it electrically) which can be evaluated in absolute measure, and by using a constant current for heating the strip; (3) as a standard source of radiation for testing the sensitivity of the radiometer, which includes both galvanometer and thermopile.

The present investigation pertains to 13 receivers, made of manganin, "therlo," and platinum, differing in width from 2.5 to 8 mm, and in thickness from less than 0.001 mm for platinum to 0.011 mm for manganin. The manganin and "therlo" receivers were painted with a thick coat of lampblack, then smoked. The platinum receivers were covered with platinum black and afterwards smoked. In this manner (the same values being obtained in the two cases) it was shown that there is but little difference in the reflecting power of these two kinds of absorbing surfaces. (See receiver No. 10, Table 6.)

TABLE 6

Summary of the Dimensions of the Receivers and of the Slits, the Kind of Absorbing Surfaces, and the Results Obtained with Each Receiver

[The value of the radiation constant for each receiver (uncorrected for diffuse reflection) is the mean of the values not marked with an asterisk (*) in Table 5. Receivers 1, 3, and 5 are of manganin or "therlo"; the others are of platinum.]

Receiver No.	Length between potential terminals	Width of strip	Width of slit	Serial number of test	Value of radiation constant $\sigma \times 10^{12}$	Remarks
	mm	mm	mm			
1	23.095	2.545	2.150	X to XIV (inc.)	5.60	Repainted and smoked. Aluminum slits.
	22.985	....	2.537	LXXXII	5.819	Repainted and smoked. Brass slits.
2	24.354	3.584	3.192	IV to IX	5.67	Platinum black. Aluminum slits.
3	24.910	5.035	4.990	XVI to XXV	5.50	Painted and smoked. Aluminum slits.
			5.000	LXXII to LXXXI	5.607	Resmoked.
	21.620	....	4.953	CXL to CXLIII	5.653	Repainted and smoked. Brass slits.
5	18.561	5.667	5.640	XLVII to XLIX	5.736	Painted and smoked. Brass slits.
			5.638	LXIII to LXXI	5.725	Repainted and smoked.
6	20.061	6.025	5.979	LII	5.533	Platinum black. Brass slits.
			5.983	LIV to LXII	5.691	Platinum black. Smoked.
7	24.659	7.965	7.952	LXXXIII to LXXXVIII	5.574	Platinum black; painted; smoked on front. Brass slits.
			7.966	LXXXIX to XCVI	5.586	Repainted; smoked on both sides.
			7.964	XCVII to XCVIII	5.585	Front resmoked, thick layer.
			7.959	CXXIII to CXXVI	5.682	Paint removed; coated with Pt. black; smoked on both sides.
8	23.989	7.10	7.074	XCIX to CV	5.885	Platinum black; painted; smoked. Brass slits.
			6.857	CVI to CVII	5.964	Resmoked rear surface.
9	24.917	6.25	6.205	CVIII to CXII	5.877	Platinum black; painted; smoked. Brass slits.
10	19.947	6.8	6.721	CXV to CXX	5.726	Platinum black, excellent coat. Brass slits.
				CXXI to CXXII	5.746	Platinum black. Smoked.
11	22.389	6.5	6.481	CXLIV to CXLVII	5.663	Platinum black, best coat of all. Slits.
				CXLVIII to CLI	5.576	Unblackened radiator.
12	22.385	6.4	6.365	CLXVII to CLXX	5.673	Platinum black; smoked on both sides. Brass slits.
			6.326	CLXXI to CLXXIV	5.625	Platinum black. Resmoked. Aluminum slits.
13	21.418	5.5	5.340	CLXIII to CLXVI	5.593	Platinum black; smoked on both sides. Aluminum slits.

The method of operation is unsymmetrical in that when the receiver is exposed to radiation the heating is produced in the lampblack surface, while in passing an electrical current through the strip the heat is generated within the receiver. However, from the data obtained with receivers differing 10 times in thickness, and covered with different kinds and thicknesses of absorbing material, it appears that the manner of heating the receiver has but little effect upon the final result.

For any one receiver, operated under different conditions, the precision attained is usually much better than 1 per cent. For the different receivers the maximum range in the value of σ, which was caused by two receivers giving high values, is of the order of 3.5 to 4 per cent. Excluding these two receivers (Nos. 8 and 9), the range of values for the different receivers is of the order of 1.5 to 2 per cent. This seems to be independent of the length and width of the receiver, and of the kind of slits used. The accuracy attained with this method of evaluating energy in absolute measure, as estimated by the departure of individual determinations from the mean value, appears to be of the order of 1 per cent. To this extent one can consider the present device a primary instrument for evaluating radiant energy in absolute measure.

The device commends itself as an instrument of precision because of its quickness of action, its freedom of surrounding conditions, its high sensitivity, and its simplicity of operation. It can be designed to suit the equipment of the average laboratory. The device can be much simplified and used as a radiation pyrometer. In practice it is advisable to calibrate the receiver by exposing it to a black body heated to about 1000° when it is desired to make refined radiation measurements. The loss of energy by diffuse reflection from the blackened surface of the receiver was investigated and it was found that there was but little difference in the reflecting power of the different surfaces examined.

In view of the fact that this instrument has proved to be applicable for precise measurements, the complete radiometric outfit, including the radiator, has been placed in an evacuated inclosure. The radiation measurements in absolute value will be made at certain fixed temperature points as defined by the melting points of metals such as gold, silver, palladium, and platinum. In this manner it is hoped to eliminate the effect of atmospheric absorption and otherwise improve in the reliability of the measurements.

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