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AND
RADIANT ENERGY.

BY
PROFESSOR S. P. LANGLEY.

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XVIII.

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BY PROF. S. P. LANGLEY.

Presented Jan. 12, 1881.

OUR knowledge of the distribution of heat in the solar spectrum really begins with this century and the elder Herschel, and, since his time, great numbers of determinations have been made, all with scarcely an exception, by means of the prism, the early ones through the thermometer, the later ones by the thermopile and galvanometer. It was very soon seen that the prism exercised a selective absorption, and that the form of the heat-curve varied with the material of the refracting substance, but a far more important and more subtle error was left almost unnoticed. The elder Draper, I believe, long since pointed out that the prism, contracting as it does the red end, and still more the ultra-red, gives false values for the heat, from this latter cause alone, and displaces the maximum ordinate of the heat-curve toward the lower or ultra-red end. Dr. Müller (Poggendorff's Ann. CV.), indeed gives a construction showing how we may, from the incorrect curve of the prism-spectrum, obtain such as a grating would give could we use one; but he despairs of being able to get measurable heat from the grating itself, whose spectra are so much weaker than that from the prism, while even the latter are very hard to measure with any exactness by the pile.

No one, so far as I know, has hitherto succeeded in measuring the heat from a diffraction grating except in the gross, or by concentrating, for instance, like Draper, the whole upper half and the whole lower half of its spectrum upon the pile, and thus reaching some results, not without value, even as thus obtained, but of quite other value than those which may be expected when we become able to measure with close approximation the separate energy of each wave-length.

I have tried at intervals for the past four years to do this, and having long familiarity with the many precautions to be used in delicate measures with the thermopile, and a variety of specially sensitive piles, had flattered myself with the hope of succeeding better than my predecessors. I found, however, that though I got results, they were too obscure to be of any great value, and that science possessed no instrument which could deal successfully with quantities of radiant heat so minute.

I have entered into these preliminary remarks as an explanation of the necessity for such an instrument as that which I have called the Bolometer (βολή, μέτρον), or Actinic Balance, to the cost of whose experimental construction I have meant to devote the sum the Rumford Committee did me the honor of proposing that the Academy should appropriate.

Impelled by the pressure of this actual necessity, I therefore tried to invent something more sensitive than the thermopile, which should be at the same time equally accurate, — which should, I mean, be essentially a "*meter*" and not a mere *indicator* of the presence of feeble radiation. This distinction is a radical one. It is not difficult to make an instrument far more sensitive to radiation than the present, if it is for use as an indicator only; but what the physicist wants, and what I have consumed nearly a year of experiment in trying to supply, is something more than an indicator, — a *measurer* of radiant energy.

The earliest design was to have two strips of thin metal, virtually forming arms of a Wheatstone's Bridge, placed side by side in as nearly as possible identical conditions as to environment, of which one could be exposed at pleasure to the source of radiation. As it was warmed by this radiation and its electric resistance proportionally increased over that of the other, this increased resistance to the flow of the current from a battery would be measured (by the disturbance of the equality of the "bridge" currents) by means of a galvanometer.

In order to test the feasibility of this method, various experiments were made. To secure a radiating body which will not vary from one experiment to another, or from day to day, is no easy matter. The source employed during the preliminary trials has been commonly the flame of a petroleum lamp within a glass chimney, the radiation being limited by a circular opening of 1 cm. diameter in a triple cardboard screen.* In these first trials a single thin metallic strip, being stretched between appropriate metal clamps connected with the bridge by coarse insulated wires, was enclosed in a cylindrical wooden case, which being

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* Very special precaution must be taken to prevent the screen itself from getting heated.

pointed to the aperture in the screen could be opened or closed at pleasure, and the resistance of the strip measured, as it varied through the effect of the radiant heat. In this way were examined various metals such as gold-foil, platinum-foil and various grades of platinum-wire, including some $\frac{1}{1000}$ cm. in thickness; gold-leaf gummed on glass; extremely thin sheet-iron, both blackened with camphor-smoke and without such treatment, etc. The lamp-black augmented the heat registered, but, if too thick, produced anomalies of its own, due to its hygroscopic properties, which doubtless exist when it is used on the thermopile, but are not so obvious there. For example, the warm breath on such a lamp-blacked strip gave the indication of *cold* at the first moment, possibly owing to the *decreased* resistance from absorbed moisture.

Metals deposited on films of glass are found not to answer our purpose, because of the great amount of heat conducted away by the glass, however thin.

The requirements include, as was seen both from these preliminary trials and from obvious theoretical considerations, considerable electric resistance, great change of that resistance by temperature, laminability, sufficient tenacity in the thin metal to enable it to support its own weight, and freedom from oxidation.

Iron would fulfil these conditions very well except the last, but it is liable to rust. This tendency can be partly overcome by the application of a thin coat of oil. Gold-leaf produced by the ordinary gold-beater's process lacks continuity, being filled with minute rents, and other metals are disqualified by other objections, such for instance as low melting-points. That the temperature of metallic strips of the thickness used may be very high, in spite of their great radiating surface and even when the battery is feeble, is seen from such an example as the following: —

An iron strip 7 mm. long, 0.088 mm. broad, 0.003 mm. thick, having the resistance of about $2\frac{3}{4}$ ohms, was subjected to a current of about 0.6 Weber which had before produced a uniform cherry-red glow throughout the same length of platinum wire $\frac{1}{250}$ cm. thick. The iron glowed more brightly, but only for about 2 mm. at the centre, and was melted at that point in about five seconds.

A number of experiments were tried to determine the proper excess of temperature of the strips used in the Bolometer over that of the surrounding case, for this excess (due to the heating by the battery current) must always exist; and the amount to give the best effect depends on many circumstances, and can only be determined by trial.

For instance, an iron strip 7 mm. long, 0.176 mm. wide, and 0.004 mm. thick, was made one arm of a Wheatstone's Bridge, and, with a battery of one gravity cell, the successive resistances of the strip were measured as its temperature altered, while the currents through it were made to vary by introducing definite resistances in the circuit. Then having the measured resistances of the strip, from the approximate formula $t = \frac{R - r}{.004\,r}$ (where R is resistance of iron at temperature t in Centigrade degrees, r the resistance at 0°) we obtain the temperatures which are given below in the fourth column. The temperature of the room was 27° C.

Total Resistance in Circuit.	Absolute Current.	Resistance of Strip.	Temperature of Strip.
ohm.	Weber.	ohm.	° C.
279.4	0.0045	1.180	27.0
27.4	0.046	1.184	28.1
17.4	0.072	1.188	28.9
12.4	0.101	1.195	30.6
7.4	0.169	1.217	35.7
6.41	0.195	1.231	39.1
5.43	0.230	1.255	44.7
4.45	0.281	1.297	54.5
3.50	0.357	1.382	74.5
2.60	0.481	1.616	129.3

We see from the above that, when the temperature of the strip is raised very little above its surroundings, a change of one-hundredth Weber in the absolute current will raise its temperature less than half a degree; but that when it is raised more than two or three degrees above the surrounding temperature by the current, such a small increase of that current is accompanied by a greater rise in the temperature of the strip, and when the temperature of the strip is considerable, though not excessive, the same change of .01 Weber will raise this temperature by eight or ten times the former quantity; and hence (as it is important to notice) strong currents, and consequent high temperature in the strip, though giving larger galvanometer deflections, involve a yet greater increase of the probable error of an observation on the galvanometer, caused apparently by air-currents about the heated strip.

A number of experiments with a similar iron strip (resistance 0.9 ohm) in a Wheatstone's Bridge (whose other arms were 0.9, 0.4, and 0.4 ohms) showed that with a half-ohm galvanometer a deflection of about 204 divisions could be obtained by exposure to lamp radiation as before described. The total current was 0.58 Weber; and, as one division of the galvanometer scale corresponded to about .000 0002 Weber, the differential current was .00 004 08 Weber, which allowing an increase of .004 in resistance for each added degree of temperature indicates* that the strip had been heated somewhat less than 0° 15 c. by the lamp radiation. A small (spherical-bulb) mercury thermometer placed at the same point rose six times this amount. Evidently only a small portion of the energy conveyed to the strip is retained as increased temperature. The immensely greater part is lost by re-radiation, conduction, and convection. This happens to the mercury thermometer to a very much smaller extent, since the comparatively slow conveyance of heat between its outer and inner layers enables it to retain a larger amount.

The conduction from front to back of the thin strip is practically instantaneous, and the equilibrium between heat received and heat radiated is so soon established that the effect upon the galvanometer is not increased perceptibly by prolonging the exposure after the needle has reached the end of its swing. Hence the time of exposure will, in general, be regulated by the sensitiveness of the galvanometer, and will very rarely exceed eight to ten seconds. The strip itself takes up and parts with (sensibly) all its heat in a fraction of *one* second.

This promptness in the action of the metal strip gives it a great advantage over the thermopile for measures of precision. But, beside this, the deflection produced by the single strip and bridge is greater than that from the thermopile, if the element of time enter into the comparison, and still more if the relative areas exposed to radiation be considered.

Although (for the reasons just cited) far from as sensitive as we can make it, such a strip then is yet more sensitive than the pile. A number of thermopiles, selected as the most sensitive in the writer's collection, have been exposed to the same source of radiation, placed at the same distance as in the previous experiments. They were directly connected with the unshunted galvanometer and enclosed in various cases, as follows: —

A. Large thermopile, by Elliott (Tyndall-lecture pattern), composed of sixty-three couples, on customary stand, but without cones. Face blackened. Area of working face = 15 mm. by 16 mm. = 240 sq. mm. Internal resistance 5.96 ohms.

B. Very sensitive thermopile of extra small elements (16 couples) with cardboard diaphragm aperture 6.6 mm. diameter. Area of working face (circle 6.6 mm. diameter) = 34 sq. mm. Internal resistance 0.97 ohm.

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* See Formula, page 355.

C. Delicate linear thermopile (7 couples). Working face about 1 mm. by 10 mm. = 10 sq. mm. Internal resistance 0.72 ohm.

S. The iron strip, which was about 7 mm. by .176 mm. and whose working face was therefore about 1 sq. mm. Internal resistance 0.9 ohm.

The time of exposure was about five seconds for the thermopiles, and about one half this for the strip, the latter time corresponding to the rapid swing of the (designedly) insensitive galvanometer.

In the table, the first column gives the name of instrument; the second, the cross-section of the beam of radiant heat which is received upon it; the third is the actual deflection in galvanometer divisions; and the fourth the deflection for each square millimetre of exposed surface. The fourth column then (since the radiant energy falling on the broad pile could obviously be concentrated on the narrow strip with but little loss) gives approximately the relative sensitiveness of these instruments, using the same galvanometer ($R = .5$ ohm) without considering the element of time: if that be considered, the relative sensitiveness of the strip will be still greater.

Instrument.	Area.	Deflection.	Sensitiveness.
	sq. mm.	div.	
A	240	211	.9
B	34	125	3.7
C	10	147	14.7
S	1	204	204.0

The total current employed with the last was about .58 Weber, of which one half passed through the strip, and this is somewhat greater than can be advantageously used in actual work. To increase the efficiency of the strip, another method is used in practice, which will be described immediately; but these numbers give only a rough comparison of the efficiency of the two instruments under similar circumstances.

Instead of a narrow metal strip, we might use one as broad as it is long, or, if we desired to increase the resistance while exposing the same area, we could cut this, for example, into ten narrow strips standing side by side, but only joined at their alternate ends, the electric current being passed through the members of the series successively. The single square strip, possessing $\frac{1}{100}$ of the resistance of ten narrow ones taken in sequence, could be used with a low-resistance galvanometer and a battery, arranged for "quantity," transmitting a much larger

current; and if there were no limit to the current which could be advantageously used, other than that of the inconvenience of a large battery, this method might perhaps be practically advisable, as it certainly is the simplest. But the heating of the thin metallic strips by the current itself, imposes the necessity of keeping the latter below a certain maximum value. Employing always this greatest allowable current, a greater effect[*] will be produced with the ten narrow strips than with the one broad one (using a galvanometer of much greater resistance than that used with the single broad strip). This subdivision of the metal has greatly increased the mechanical difficulties of construction, and I have felt that to make the apparatus generally useful I must learn how to overcome these difficulties, so that it can be produced at a not too great cost for ordinary use by the scientific student. It would at any time also, I repeat, have been easy to make a far more *sensitive* instrument than I am about to describe; but, from the first, my chief aim has been to produce one trustworthy, in the sense that it gives exact quantitative results.

After nearly a year's labor (I began these researches systematically in December, 1879), I have procured a trustworthy instrument. It aims, as will have been inferred from the preceding remarks, to use the radiant energy, not to develop force directly as in the case of the pile, but indirectly, by causing the feeble energy of the ray to modulate the distribution of power from a practically unlimited source.

To do this I roll[†] steel, platinum, or palladium into sheets of from $\frac{1}{100}$ to $\frac{1}{500}$ of a millimetre thickness; cut from these sheets strips one millimetre wide and one centimetre long, or less; and unite these strips so that the current from a battery of one or more Daniell's cells passes through them. The strips are in two systems, arranged somewhat like a grating; and the current divides, one half passing through each, each being virtually one of the arms of a Wheatstone's Bridge. The needle of a delicate galvanometer remains motionless when the two currents are equal. But when radiant heat (energy) falls on one of the systems of strips, and not on the other, the current passing through the first is

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[*] We cannot say exactly how much greater, since our formulæ do not take account of the temperature as actually modified by re-radiation and conduction, but only of the amount of heat imparted.

[†] Experiments are now in progress with still thinner films of metal produced by electrical or by chemical deposition. I have had the good fortune in experiments now making in this direction, to secure the aid of Professor A. W. Wright of Yale College, and of Mr. Outerbridge of the United States Mint at Philadelphia.

diminished by the increased resistance; and, the other current remaining unaltered, the needle is deflected by a force due to the battery directly, and mediately to the feeble radiant heat, which, by warming the strips by so little as $\frac{1}{10000}$ of a degree Centigrade, is found to produce a measurable deflection. A change in their temperature of $\frac{1}{100000}$ degree can, I believe, be thus noted; and it is evident that from the excessive thinness of the strips (in English measure from $\frac{1}{2000}$ to $\frac{1}{12500}$ inches thick) they take up and part with the heat almost instantly. The instrument is thus far more prompt than the thermopile; and it is also, I believe, more accurate, as under favorable circumstances the probable error of a *single* measure with it is less than one per cent. When the galvanometer is adjusted to extreme instability, the probable error of course is larger; but I have repeated a number of Melloni's measurements with the former result.

I call the instrument provisionally the "Bolometer," or "Actinic Balance," because it measures radiations and acts by the method of the "bridge" or "balance," there being always two arms, usually in juxtaposition, and exposed alike to every similar change of temperature arising from surrounding objects, air-currents, etc., so that the needle is (in theory at least) only affected when radiant heat, from which one balance-arm is shielded, falls on the other.

Its action, then, bears a close analogy to that of the chemist's balance, than which it is less accurate, but far more sensitive. The sensitiveness of the instrument depends, as has been explained, upon the amount of current used. With the current which experience has recommended, as leaving a very steady galvanometer needle, this sensitiveness appears to be from ten to thirty times that of my most delicate thermopiles, area for area; but I consider this quality valuable only in connection with its trustworthiness as a *measurer*, always repeating the same indications under like conditions.

The working face of the instrument, as I have used it, exposes about one half of one square centimetre to the source of radiant heat (it can easily be made of any other size, larger or smaller); and the strips are shielded from extraneous radiations by the most efficient precautions which a rather long and painful experience in guarding against them has taught me.

DESCRIPTION OF FIGURE 1.

There are two disks of hard rubber, each 30 mm. in diameter and 3 mm. thick in the thickest part. Each has a concentric opening 8 mm. square. The first has four hollow brass cylinders, *a*, *c*, *b*, *d*, and the second four corresponding holes in the ebonite, a', c', b', d'. When these cylinders are in the holes they act as steady-pins. In the part $a\,c\,b\,d$ are eight parallel channels, each about ½ mm. wide and 1 mm. deep, symmetrically disposed across the square. The seven ridges between these channels are each rather narrower than the channels, so that the whole width from outside to outside is a little less than 8 mm. On the part of $a'\,b'\,c'\,d'$ corresponding are seven similar channels, the centre one being in the centre of the square. On each side of the square in $a\,b\,c\,d$ are four similar channels, and on each side of that in $a'\,b'\,c'\,d'$ are three channels. When the two disks are put together (one may be supposed to revolve like the lid of a box about the imaginary hinge $X\,Y$), the ridges on one fall into the channels of the other. At e, f, g, h, are split pins of platinum, and at e', f', g', h', corresponding hollow cylinders of platinum to receive them.

The current enters by the brass of the hollow steady-pin, a, and passes eight times across the square as shown, then crosses over through the pin e to e', passes seven times across the square, back by $h'\,h$ to the first disk and then out by the pin b. Where the current crosses the square, it is conducted by strips of iron, each a little less than 0.5 mm. wide and about 0.004 mm. thick, laid in the channels. There are therefore, when the disks are put together, fifteen of these strips drawn parallel across the square, each at the bottom of its channel, of which eight lie in one plane in the first disk and seven in another plane in the second disk, the two planes being about 1 mm. apart when the disks are fitted together. The strips in each set lie opposite the openings between the strips of the other set. The other current enters at c, goes along four iron strips, up the pin f to f', then three times along iron strips, then round to the other side of disk *number two*, then three times along iron strips, then down a copper wire to g', then through g back to disk *number one*, then four times along iron strips and out at d. There are therefore twenty-nine strips disposed in two circuits,* fifteen in the central circuit (these fifteen form virtually one arm of the bridge), and fourteen in another circuit which surrounds the former. These fourteen, disposed in two groups for symmetry, form then the second arms. Every joint is soldered.

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* These strips are preferably not soldered, but continuous, being struck by a punch from a single film of metal. The number of these and their size is varied in different instruments, which may be adapted to a low or a high resistance galvanometer. The slight difference of resistance between the central and side strips it is intended to make up by resistances introduced within the balance-case, so that the use of a resistance box will not be necessary.

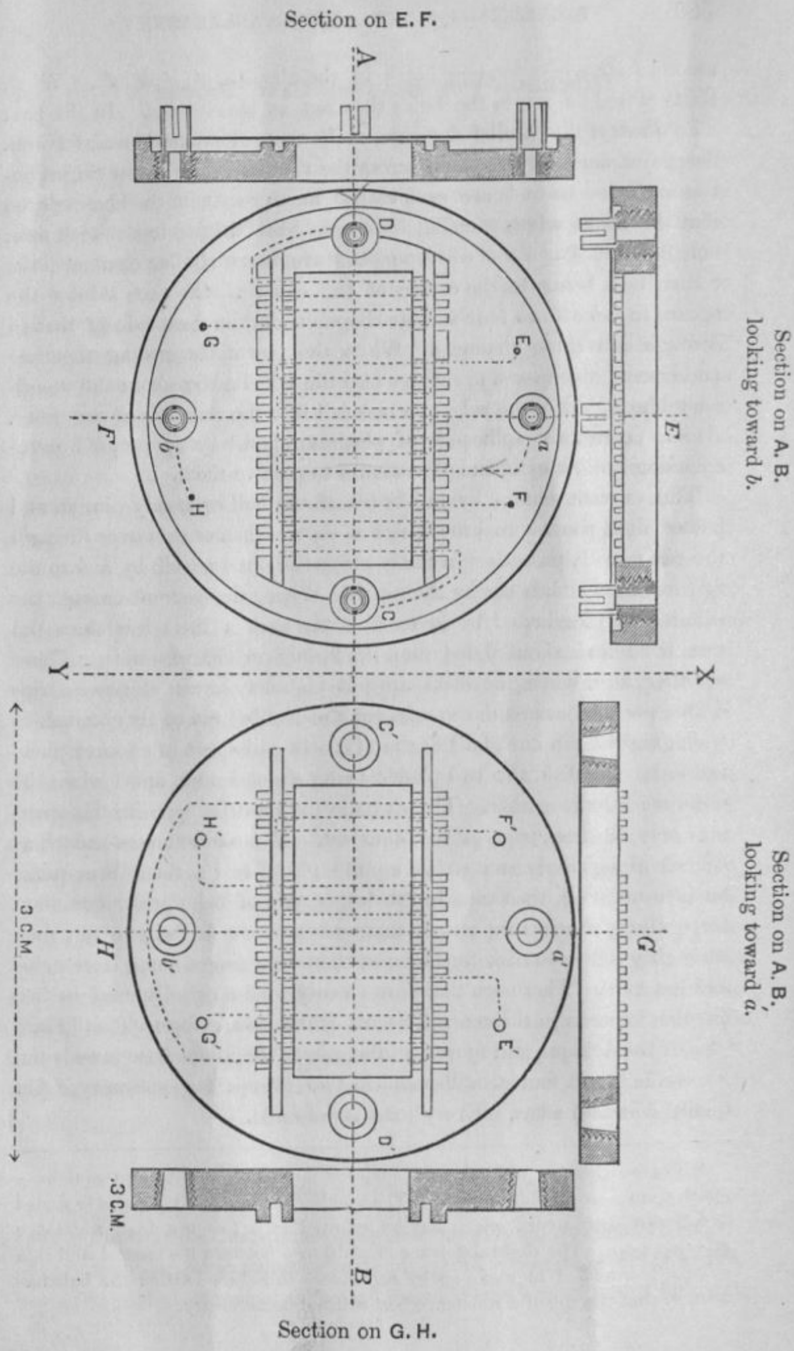

FIG. 1. THE BOLOMETER.

SCALE: *Twice full size.*

DESCRIPTION OF BALANCE CASE, FIGURE 2.

To protect the Bolometer effectually from air-currents and sudden changes of temperature, and to enable it to be handled more easily, it is enclosed in a chamber situated in the axis of a long cylindrical holder of non-conducting material (wood or ebonite), which can itself be held by a suitable clamp pointed accurately in any direction or laid in a horizontal position on *Ys*. This chamber is lined with copper, to secure an equable distribution in the heat of its walls. Through a circular opening, 15 mm. wide in front, the grating of strips can be seen, and over all is slipped a hollow cylindrical cover of wood or ebonite 15 cm. long, within which is a second tube containing four or more concentric cardboard diaphragms pierced by apertures 6 mm. in diameter. These disks of cardboard are separated by ebonite rings, and form a succession of drum-like chambers, through whose apertures the radiation passes unobstructed, but by which the entrance of air-currents from without is effectually stopped. In front of all, a revolving cardboard diaphragm with suitable stops admits or shuts out the radiation at pleasure. At the back of the copper-lined chamber is a layer of solid non-conducting material, through which pass the connecting wires, terminating in metal plugs insulated from the copper lining. With these plugs the four terminals of the double grating are connected by clamping-screws. The Balance Case is prolonged yet 15 cm. farther back, forming a tube in which may be included and protected from air-currents an adjustable resistance or rheostat by which the two arms may be brought to perfect equality. It is advisable to have the two halves as nearly as possible equal at the first; since, if unequal, the increment of resistance in the larger, caused by a general rise of temperature, exceeds the corresponding increment in the smaller, necessitating a frequent readjustment of the variable resistance and producing a "drift" in the galvanometer needle, which slowly changes its direction according as the temperature of the room rises or falls. This "drift" is not a peculiarity due to the use of the Bolometer, however, as a similar drift, due to different causes, affects the galvanometer (if equally delicate) when used with the thermopile.

DESCRIPTION OF CONNECTIONS, FIGURE 3.

The Bolometer, *A*, is connected with the distant coils, forming the rest of the Wheatstone's Bridge, by four insulated copper wires, *u*, *v*, *y*, *z* (twisted together and covered with flannel to reduce the effect of vary-

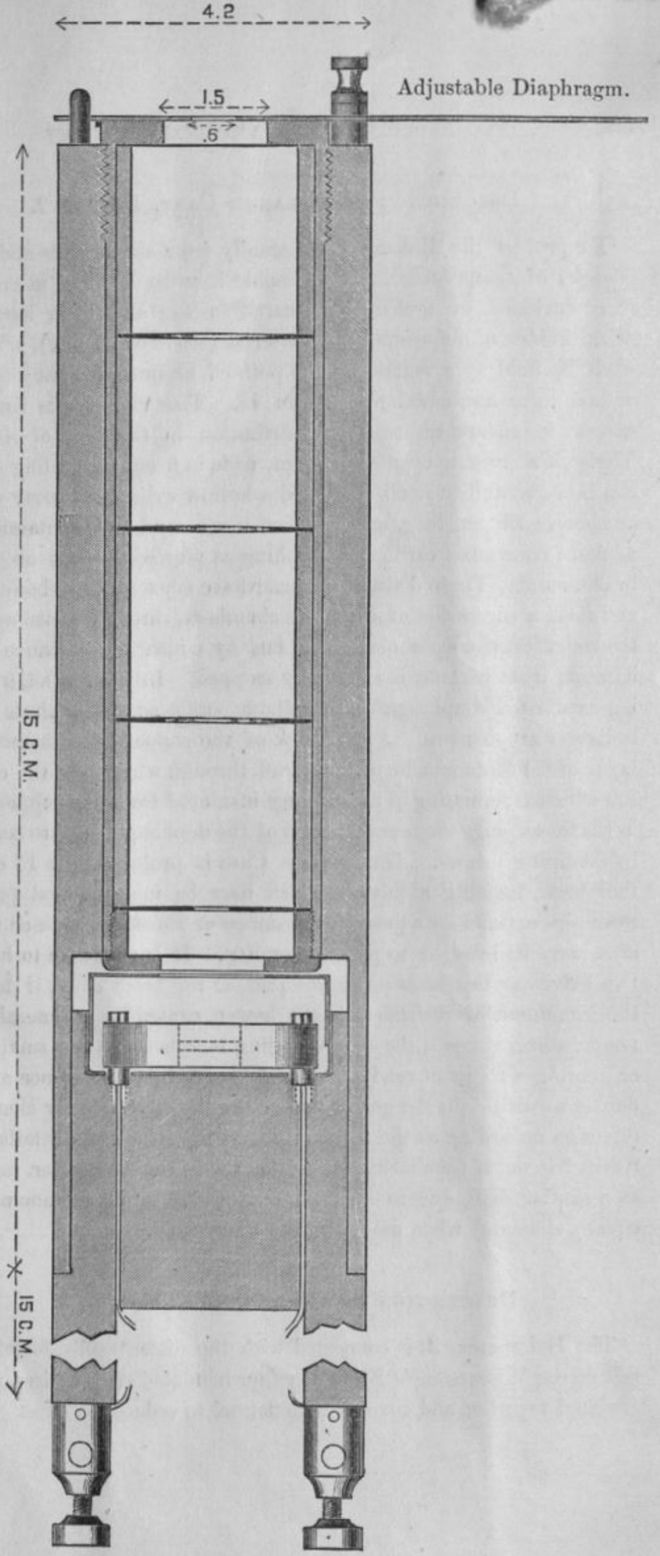

Fig. 2. SECTION OF BOLOMETER CASE AND BOLOMETER.

Full size.

ing temperature in these to a minimum). The binding posts, etc., should also be protected against temperature changes.

In order to prevent gross variations in the electric current from variations in the battery, which might vitiate the results slightly by affecting the differential current, there is introduced in the circuit leading to the Wheatstone's Bridge, W, a shunted galvanometer, g, whose deflection indicates the amount of current passing through the latter. This can be varied within certain limits by altering the resistance of a battery shunt, R (see Fig. 3). Knowing this current, we can easily compute the differential current flowing through the sensitive "bridge" galvanometer, for any given change in either arm of the bridge, by using the following approximate formula: —

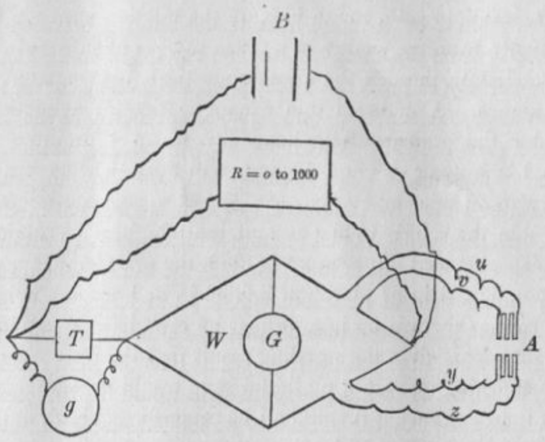

Figure 3.

Designating by a Resistance of one arm of Wheatstone's Bridge.
" na " other " "
(n being in practice very slightly greater than unity.)
" x Resistance of each of the other arms.
" g " galvanometer.
" b " one cell of battery (resistance of line wire neglected).
" E The electromotive force of one cell.
" c " differential current.

We find for the value of the current produced in the galvanometer through the bridge, in terms of the whole current C (making $n = 1$ in the denominator), —

$$c = \frac{(n-1)\,ax}{2\,(2\,ax + ga + gx)}\,C.$$

But $$C = \frac{2E}{2b + a + x}$$

$$\therefore c = \frac{(n-1)\,ax}{(2\,ax + ga + gx)\,(2b + a + x)}\,E.$$

It is desirable to get a rough idea of the relation between work derived directly from the energy in a given ray (as of sunlight), and that coming mediately, through the effect upon the battery current modified by the balance. A sunbeam one square centimetre in section, which will, under the ordinary Allegheny sky, warm 1 gramme of water 1° C. in 1 minute or $\frac{1}{60}°$ in 1 second, will raise the temperature of a sheet of water 1 mm. by 10 mm., or $\frac{1}{10}$ of a square centimetre in area and $\frac{1}{500}$ mm. thick, $83\frac{1}{3}°$ C. in 1 second, if all the heat be retained; and, since the specific heat of platinum is .032, the same sunbeam will raise a corresponding strip of platinum 2,603° C. in 1 second, it being supposed here that there is no loss of heat by re-radiation, conduction, or convection. This gives the startling result that the heat received from ordinary sunshine on such a platinum strip would be sufficient to *melt* it in less than a second, if it could all be retained, and is an independent testimony to the rapidity with which these thin strips take up and part with their heat, and to the promptness of action of the balance, whose actual temperature is raised but a very few degrees by this radiation.*

The heat produced in a strip of the above description by a current of $\frac{1}{10}$ Weber is found to be (using C. G. S. notation), —

$$\frac{(.01^2) \times .5 \times 10^9}{4.2 \times 10^7} = .00119 \text{ gramme degree per second,}$$

capable of raising the temperature of the strip 1,866° C. in 1 second *if all retained.* A current of $\frac{1}{10}$ Weber raised a narrower *iron* strip 12°.8 C. (see Table, p. 345). As in the first example it may be shown by calculation that only a small fraction, in this case about $\frac{1}{230}$ of the heat developed, is retained.

It is intended eventually to enclose the Balance in a vacuum, and to study more closely the losses by radiation which occur in it, apart from the losses produced by conduction and convection, which in a very perfect vacuum are practically negligible; for the conduction through the metallic connections of the strips themselves is wholly insignificant, owing to the excessively small cross-section of the latter in proportion to their length. With the value of the loss by radiation thus obtained, the above results, which are of course presented only as a first approximation, can be corrected.

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* The resistance of one arm of an Actinic Balance, exposed to radiation from the sun at an altitude of 50° with an ordinary blue sky, was increased by an amount which indicated that its temperature had been raised by 7° C. By calculation it was found that the energy in the sunbeam would have been sufficient *if all had been retained* to heat the strips in 1 second about 450 times this amount.

The preceding remarks comprise what is most essential in a description of the working apparatus founded on the method of changed electric resistance.

I write far from large libraries, and do not pretend to give the bibliography of the method, if it have one. The only notices of a use of the principle involved in this instrument that are known to me are the following: —

1. On the Measurement of Resistance to the Conduction of Electric Currents, and on a Galvanic Differential Thermometer, by A. F. Svanberg. Poggendorff's Annalen, 1851, vol. lxxxiv. p. 411.

2. On Measuring Temperatures by Electricity, by C. W. Siemens. Proceedings of the Royal Institution of Great Britain, March 1, 1872, vol. vi. p. 438.

Mr. Siemens has made subsequent special applications of this principle.

This paper, as a description of the apparatus for measuring radiant energy, ends here; but I may mention the following results which have been obtained with the instrument in other researches, to give a more just idea of its efficiency as a working-tool for the physicist.

In illustration of the work which the balance may be used for, take the following repetition of one of Melloni's experiments.

Source of heat, petroleum lamps (argand burner with glass chimney) at 15 cm. distance. Radiation limited by screen with 1 cm. circular aperture at 10 cm. from the steel Balance.

The unimpeded radiation was compared with that transmitted by distilled water and by an aqueous solution containing ten per cent (by weight) of common alum. The liquids were contained in a glass cell (sides 2.5 mm. thick, distance between sides 19.0 mm.). Temperature 21° C. Galvanometer not sensitive.

Deflection (mean of five trials) —

by radiation through distilled water and glass = 16.5 div.
" unimpeded = 107.6 "
" through 10% alum solution and glass = 13.7 "
" unimpeded = 103.8 "

Percentage of radiation transmitted —

by distilled water = 15.3
„ 10% alum solution = 13.2

The following galvanometer readings for "lamp radiation" (as just described) are given in full to show the method of procedure, and also the liability to variation in successive exposures when great instrumental sensitiveness is not required: —

Before exposure, stationary at	Exposed, settled at	Exposure ceasing, returned to	Deflection.
div.	div.	div.	div.
—24	+106	—24	+130
—24	+105	—26	+130
—27	+102	—29	+130
—29	+100	—29	+129
—29	+101	—29	+130
			Mean = + 129.8

This is given as a fair sample of the average error on such work as is involved in most of Melloni's experiments; where great sensitiveness in the galvanometer (according to the modern standard of what constitutes sensitiveness) is not required.

The first measures, on nearly homogeneous rays in the *diffraction* (reflection) spectrum, ever taken by any one that I know of, were taken by this instrument on Oct. 7, 1880, used with an extremely delicate reflecting galvanometer by Elliot, of about 20 ohms resistance and a reflecting grating on speculum metal by Mr. Rutherford of 681 lines to the millimetre. Measures have been taken every fair day since, the source of energy being the sun.

The rays from a slit five metres from the grating fell directly on it (without any collimator); these were, after diffraction, received on a silvered glass mirror, and this formed an image of the first spectrum about 20 centimetres long (from $\lambda = .0004$ to $\lambda = .0007$) and 8 mm. wide. The "Balance" then, whose acting face is only about $\frac{1}{30}$ the length of the visible spectrum, and less than $\frac{1}{100}$ the length within which energy is found in a degree sufficient for it to measure, receives nearly homogeneous rays (which have passed through no absorbing medium whatever except the solar and terrestrial atmospheres), and this extremely minute amount of heat is found to give a galvanometer deflection of some hundred divisions, where thermopiles have hitherto failed to register any (on homogeneous rays).

The corrections for minute selective absorption in speculum metal and silver reflections, and in the metal of Balance strips, are still to be applied. The rough galvanometer deflections for different wave-lengths are, where the slit used is so narrow as to give all the principal Frauenhofer lines sharply on the screen, as follows. (In corresponding curves, wave-lengths are abscissae; reduced mean galvanometer deflections, ordinates.)

					mm.				
λ =	.00035	.0004	.0005	.0006	.0007	.0008	.0009	.0010	.0011
					div.				
Defl.	12	55	207	246	198	129	80	58	41

The corrections for the underlying second and third spectra not being fully applied, it can only be said that these values are trustworthy (as first approximations) as far as from .00035 mm. to .0007 mm. The values below .0007 which give the sum of first, second, and third spectra are, perhaps, too large. They are hitherto unpublished, and they at least, though as yet approximative, show that the *heat maximum in a normal spectrum is not in the ultra-red, but is at least as far up the spectrum as the orange near D;* and this result may be relied on, any smaller values below $\lambda = .0007$, as well as all favorable atmospheric circumstances (high sun, blue sky, etc.), rather tending to move it toward the violet.

These measures show a certain approximation of the "heat" curve to the "light" curve, though these are commonly drawn with their maxima in entirely different parts of the spectrum. Viewing the actual distribution of energy here, and then comparing it with the so-called "heat," "light" and "actinic" curves of the text-books, we have evidences, I think, of interesting results already reached by this instrument, and which have been possible only by its use. Among these, we observe that (contrary to the statements of our text-books, and contrary, as I think, to most present scientific opinion) the great proportion of all solar heat received at the earth's surface does *not* apparently lie in the non-luminous parts of the spectrum. Not only is the heat maximum in the luminous part, but the total sum of non-luminous heat (as far at least as our measures extend) is relatively small, the joint effects of ultra red and ultra violet radiations (so far as measured) not making up the sum of those in the visible portion. This is a result to me unexpected, but which I think may be relied on; and it is, if true, sufficiently important to make me hope that the society will feel that the instrument whose construction they have promoted is already of utility.

The above illustrations form parts of other researches, and are borrowed for this paper merely to show the action of the instrument, and to enable each reader to judge for himself of its value as a *measurer* of radiations.