THE "BOLOMETER,"

BY

PROF. S. P. LANGLEY,

ALLEGHENY OBSERVATORY, PA.

READ BEFORE THE

AMERICAN METROLOGICAL SOCIETY,

DECEMBER, 1880.

NEW YORK:
PUBLISHED BY THE SOCIETY.
GREGORY BROS., PRINTERS, 34 CARMINE ST.,
1881

In memoriam
George Davidson
1825-1911
Professor of Geography

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By Prof. S. P. Langley.

I have been honored by a request from President Barnard, to explain to the Metrological Society a new instrument for measuring radiant energy which I have called the Bolometer (βολη μέτρον). The instrument has been made in large part at the cost of the American Academy, as administrators of Count Rumford's bequest, and for a more detailed account, reference may be made to a paper presented to them on the 8th December, 1880, which will appear in their printed transactions.

The thermometer, it is well known, was supplanted as a measurer of minute quantities of evanescent heat, nearly half a century since, by the Thermo-pile of Nobili, which in Melloni's hands so enlarged our knowledge of radiant energy. During this lapse of almost fifty years, no very essential addition or improvement has been made in the pile. We have better galvanometers, but we use them to record the indications of the same instrument that was employed two generations ago. Meantime numerous very important new questions are presenting themselves, which science cannot answer; as in this field of radiant energy, experiment has not kept pace with the advance of opinions, apparently theoretically just, but as yet unverified and unverifiable by the final appeal to fact. Of the more important of these questions, none compares in consequence, with that of the distribution of energy in the solar spectrum, for this means a knowledge of the distribution of the total energy by which we ourselves, and all animated nature, exist and act. The only means in any sense trustworthy, of learning the laws of this distribution, is by direct measurement of it in the spectrum, where it appears as *heat;* for our interpretation of it as light, or even as chemical action, does not yet admit of being stated in units of force, with like precision. The heat however, even in the prismatic spectrum, is almost immeasurebly slight, and in the pure or *diffraction* spectrum it has hitherto been found wholly so. Measures in the prismatic spectrum, are liable to gross error ; measures in the diffraction spectrum would be precious as comparatively exempt from these, but have been found beyond our reach.

After spending a long time in the apprenticeship, I grew familiar with the numerous precautions needful in using the thermopile, on excessively feeble radiations, and made successive attempts to measure the heat in the diffraction spectrum with the most delicate procurable apparatus, and with all the aid suggested by some years' experience in this special kind of research. I could not however flatter myself with the belief that I had succeeded where others had failed. I obtained evidences of heat in different parts of the diffraction spectrum, it is true, and to some measurable extent, but I could not feel that I had *measured* in any proper sense, and I became convinced that accurate measurement was impossible without more delicate and also more accurate apparatus.

This has been the cause of my devoting nearly a year's experiment toward the construction of a sort of *meter* of minute amounts of radiant "energy," (or perhaps I should here say of radiant "heat.") I insist on the word "*meter*," because I have not tried to make a thermoscope, or indicator, so much as a measurer, and because I believe I could have made a far more sensitive instrument with a tithe of the labor, had I not always kept in view the need of this quality of strict proportionality between effect and cause. To illustrate my meaning, we may suppose the finger to be applied to an electric key which may discharge a grain of powder, or may explode a mine. In this case there is no proportionality between the immediate cause and the final effect, and this is a rough but not unfair illustration of the principle of the thermoscopic class of instruments, which is here rejected. I sought my analogy rather in the pressure of this finger against the resistance of a spring valve in a steam engine, where an enormous but definitely graduated power may be released for each degree of pressure exercised at the valve, and the power of the finger be multiplied a million-fold with a constant proportionality between the cause and the result. I have worked by a method which has been employed by Siemens, and by perhaps others, for other purposes, but which I believe there has been no previous application to the present use.

If a wire conveying an electric current be warmed, less electricity flows through it than before. If two such wires, carrying equal currents, meet in a suitable galvanometer, the needle, solicited in opposite ways by equal forces, remains still. Now if one wire only be warmed, the current in one wire is diminished while the other flows as before. The needle is then deflected by a force equal to the difference of the two currents, and proportionate at the same time to the power of the battery and to the (possibly very feeble) radiation which warmed the wire, and which thus has been employed to modulate a force enormously greater than its own, which may be in one sense said to be magnified in proportion. The analogy with the finger and throttle-valve is not far to seek, and the principle thus stated is not hard to grasp, but the application in the concrete working tool is difficult. I have not yet resolved all difficulties by any means, but as I have brought the new apparatus to the point where it is a real measurer of radiant heat, more delicate, and I believe more accurate than the thermopile, I feel warranted in describing it even in its actual condition of progress. I should first observe, that since it is by a changed resistance, that we work, we should have a large part of the resistance of the circuit in the small part on which the exciting ray falls, and that to enable it to receive and part with its heat rapidly, the conducting wire should in this portion be laminated, so as to present a greatly increased surface with the same cross section. We observe also, that we cannot use unlimited battery-power on account of the undue heating, (of the portion of the circuit exposed to radiation) by the battery-current itself, an effect which must always be borne in mind. We may for instance choose if we please, between having this part of the circuit possess a resistance of a ohms, and convey a current of b webers, or possess a resistance of $a\,n$ ohms conveying a current of $\frac{b}{n}$ webers. If n is a considerable number the latter construction will generally be much more efficient but also far more difficult. We can obtain ten (or twenty) times the resistance in the same area by making the laminated portion in ten (or twenty) parallel contiguous strips, and though this latter construction is mechanically more difficult, it has been adopted in the instruments actually in use. Their (theoretical) disposition is as follows :

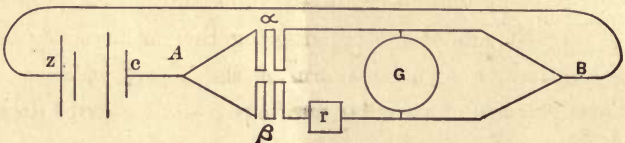

Fig. 1

The current from the battery divides at A into two ; one branch containing a number of parallel strips (α) the other a similar number (β), (α and β are in practice always close together) and these evidently form two of the arms of a Wheatstone Bridge. (G) is a very sensitive galvanometer which may be at any distance from α and β. $\boxed{r}$ is a resistance box introduced in the circuit to enable us to balance the galvanometer currents in spite of any minute inequality in α and β. The currents reunite at B $\cancel{\beta}$ and return to the battery.

In the actual construction (as arranged for a high resistance and small current) the parts α, β, are formed of strips of metals reduced by rolling or, by chemical or electrical deposition, to extreme thinness. The metals chiefly experimented with have been gold, copper, tin, iron, steel, platinum, and palladium, and of these the latter three give most promise. One great difficulty has been to get them thin enough by rolling, as the processes of the goldbeater will not answer. By the help of Messrs. Miller, Barr and Parkin, of Pittsburgh, who have furnished steel from their mills in sheets only $0^{\text{m.m}}.05$ thick and by the aid of a working jeweller of Pittsburgh, who has re-rolled these with special treatment, I have obtained a sheet of steel finally of about $\overset{\text{m.m.}}{0.002}$ thick or such that over 12000 of them laid one on the other would not make up one English inch. I have also a specimen of Platinum even finer, through the kindness of the officials of the U. S. Mint at Philadelphia;* and, I am under continued obligations to Mr. Outerbridge of that institution as well as to Prof A. W. Wright, of New Haven.

This steel, platinum, or palladium is cut in strips from $\overset{\text{m.m.}}{0.5}$ $\overset{\text{m.m.}}{0.5}$ wide, $\overset{\text{m.m.}}{5.5}$ long and $\overset{\text{m.m.}}{0.002}$ to $\overset{\text{m.m.}}{0.004}$ thick and twenty such strips placed side by side and occupying together an area of ¼ of one square centimeter form one arm of the electric balance. The other arm consists of a similar number of similar strips disposed in two systems one on either side of the first, thus:

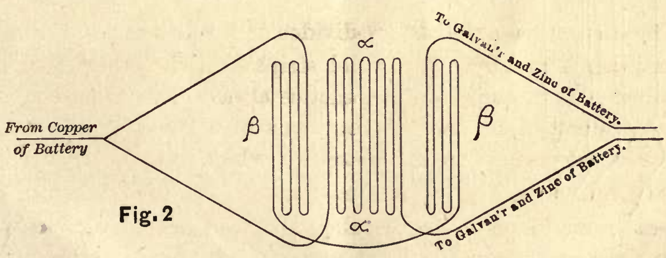

Fig. 2

The figures are of course merely explanatory, and do not illustrate the actual form of the working instrument.

The actual disposition is here only very roughly indicated, but it will be seen that though there are really but the two balance or bridge arms α and β as in the first figure, one of these arms (β) is itself made in two parts, so as to lie on both sides of the other.

Now, let the system just shown be entirely enclosed in a hollow cylinder

* A small specimen of this steel is transmitted herewith.

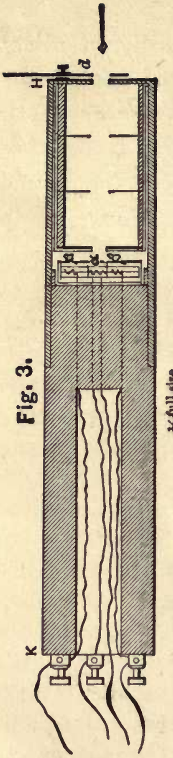

Fig. 3.

H K having non-conducting walls and protected by a diaphragm cover *d* (which can be opened at pleasure,) against radiant heat, which can only, in any case, reach the arm α by passing down the whole length of the axis of the cylinder. The double arm $\beta\beta$ does not lie in the axis of the cylinder, and is permanently cut off from all external radiation. The result is, that every change of temperature in the environment of the balance-arms, α β, affects them both alike. Whether the apparatus itself be warm or cool, held in the hand, or surrounded by ice, the change of resistance is equal in both arms, and the galvanometer needle, solicited in opposite ways by currents which have remained equal to each other, remains at zero. But if radiant heat is admitted by opening the diaphragm *d*, it warms one of the arms (α) *only* (the other β being covered) and the needle is deflected not as in the thermopile by the feeble energy residing in the ray, but by the energy of the battery which this feeble ray modulates.

The action of this instrument is very prompt, the thin strips taking up and parting in less than a single second with the heat, which would require from five to ten minutes to produce a like result with the pile. The amount of energy which may thus be measured is surprisingly small. I believe that a change of temperature of $\frac{1}{1000000}$ of one degree centigrade in the strips, can be indicated on the galvanometer, and I compute (very roughly) that a beam of solar or other heat not so weak but that it would cause a recognizable change on the galvanometer *in one second*, would yet be so small that if let fall on a kilogramme of ice at 0°C it would be over 1000 *years* in melting it!

It will be remembered that in dealing with amounts of energy only less minute than this, our instrument is not merely an indicator but a measurer.

Perhaps the best evidence of the utility of such a capacity of minute measurement, is in the fact that the distribution of energy in the diffraction spectrum is now at last being determined by it. The detailed results must be looked for elsewhere, but they promise to materially affect our present received opinions on some points not merely of high theoretical but of high practical importance. Among the theoretical ones, I will barely mention, that the representations of the three curves for heat, light and actinism, given in the text books, are proven experimentally to be wholly misleading. There is here no evidence that *any* solar energy as received at the earth's surface increases and then diminishes, in the upper part of the spectrum, as ordinarily figured by the so-called 'actinic' curve; and the curves of "heat" and "light" approach each other. We thus contribute to the experimental demonstration of a great generalization of modern physics *i.e.* that "heat," "light" and "actinism" are not entities, but names given to different effects of one and the same solar energy. We do very much more, for we indicate the real distribution of this energy, and are led to new knowledge, of consequence in its bearings on the science of meteorology, and matters of immediate practical importance. I here, however, am describing, not these results (which I will not enlarge on further), but the instrument for obtaining them, which I trust will shortly be ready for the use of others who may wish to try it, and which I hope will prove to be what I have specially tried to make it—a useful working tool to the physicist in the degree that it is a real METER of radiant energy.

False Conception of the time

Allegheny Observatory,

Allegheny, Pa.

December 23, 1880.

June 12/81