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THE ADAPTATION OF SELENIUM TO MEASUREMENTS OF ENERGY TOO SMALL TO BE MEASURED BY OTHER DEVICES.

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As a brief introduction to the subject matter of this paper, a review of the various devices used in energy measurements will not be amiss. The devices are not numerous, and they are familiar to every one at all conversant with the methods of physics. They are the thermometer, the differential thermometer, the thermopile, the bolometer, the radiomicrometer, and the radiometer. Several other devices have at different times been suggested and used, but the above represent the most important ones.

In regard to the relative merits of the various devices above, it is hard to be certain. Coblentz of the Bureau of Standards, who has devoted careful study to these devices, has come to the conclusion that they can all be made about equally sensitive, and that each has its peculiar merits. The nature of the problem is the important thing in deciding which device to use. However, in comparing the sensitiveness of the various types of instruments that have been used in different pieces of work, one finds a great deal of confusion, and there is a crying need for a more exact standardization of these instruments than has hitherto been extensively used. A few considerations will make this statement clear. One commonly hears, for example, of a radiation receiving device so sensitive that it will detect the presence of a candle at a distance of nearly two miles. That statement is decidedly indefinite, and yet we see similar statements in many of our texts. Here are some of the questions that one should feel like asking after reading such a statement. What sort of candle is used? A paraffin candle gives a greater amount of energy than a tallow candle in, roughly, the ratio of 14 to 9, in accordance with a test made by us quite recently. How large a receiving surface is used, and what is the material of that surface? Are there any auxiliary devices to enable one to collect more radiation than usually would fall upon the receiver? How sensitive a galvanometer is used (providing that the device requires a galvanometer)? How far from the galvanometer is the receiving scale for the spot of light? How much absorption has been allowed for, both in the intervening air, and in the protecting devices of the instrument? It is through failure to answer specifically such questions as these that one is practically unable to make any comparisons as to sensibility among the various radiation receiving devices that have been used in actual researches. We suggest that anyone working with such an instrument should specify the following things: the area of the receiving surface, and whether it can be considered as practically a black body; the figure of merit of the galvanometer used (if one is used); the scale distance; the resistance of the galvanometer and thermopile (or other device); and lastly, the number of watts falling per square mm. upon the surface, that are necessary to give one mm. deflection of the combination of instruments. The Bureau of Standards is putting out standard lamps which when supplied with certain definite currents are calibrated so as to give definite numbers of watts per $mm.^2$ at a given distance. This is surely superior to the candle. If such information as this is given, it is evident that comparisons among such devices can very readily be made.

To illustrate the above let us cite the example of a linear thermopile with which we have been working. This instrument is of the Rubens type, made by Coblentz of the Bureau of Standards. It is of his special series-parallel design, and the wires are of bismuth and an alloy of bismuth and tin. This instrument has a blackened receiving surface of 22.5 $mm.^2$, and a resistance of 2.25 ohms. This thermopile when used with a galvanometer having a figure of merit with the scale at 125 cm. of 5×10^{-10} amperes per mm. and a resistance of 1.35 ohms. gave one mm. deflection when a total energy of 4.1×10^{-8} watts fell upon the receiving plates. This was an energy of 1.8×10^{-9} watts/$mm.^2$ on the receiving surface. It may be added that with this same combination of instruments, a paraffin candle at a distance of 200 cm. gave 140 divisions on the scale. Assuming no absorption, and assuming further the inverse square law, this candle would give one division at a distance of about 78 feet. This at first thought does not compare favorably with Boys'[1] distance of sensibility of about two miles (In fact his work indicates 1.3 miles). However, examination of his work shows that he used a sixteen inch mirror with which to concentrate his beam of light from the candle. If the same device were applied to our apparatus, the candle (assuming no atmospheric absorption) could be placed at a distance of about one and one-fourth miles. So our instrument compares very favorably with Boys' apparatus.

Nichols[2] claims that the radiometer used by him in his work on stellar radiation was approximately twelve times as sensitive as Boys' radio-

[1]Proc. Roy. Soc., **47**, 480, 1890.
[2]Astro. Phys. Jour., **13**, 101, 1901.

micrometer. This would enable him, using the same sixteen inch mirror, to have his candle, assuming no absorption, at a distance of 4.5 miles.

This introductory section has been for the double purpose of calling attention to the need for more exactness in describing the action of such heat receiving instruments, and to give an idea of the relative sensibility of our thermopile, for in advocating the use of the selenium cell for energy measurements, we want to make it certain that the cell

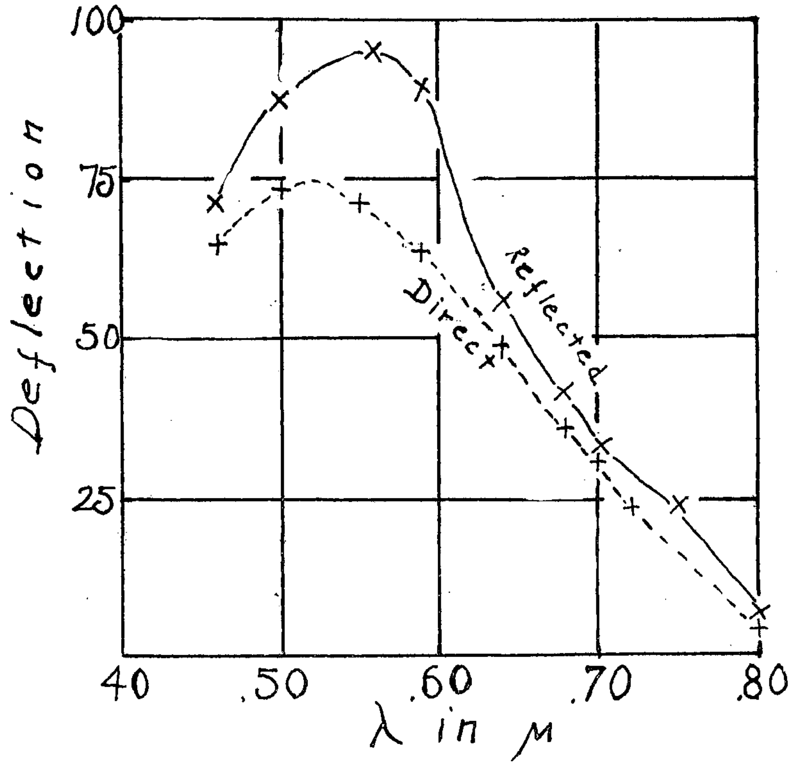

Fig. 9. Sensibility of the selenium cell.

is for its purposes more sensitive than any other receiving device. Our selenium cells have been compared directly with the above thermopile.

At the outset it must be admitted that the selenium cell is not usable for total radiation measurements, for it is not sensitive to any extent beyond the red end of the spectrum. Either curve of Fig. 9 will make the range of sensibility evident. It extends a little into the ultra violet (although our curves do not extend that far) and ends rather abruptly in the deep red, at about wave length 0.80μ. However, there are many experiments where it is satisfactory, and sufficient to measure from a source the energy that is contained in the range of the visible spectrum. For example, one of the most difficult pieces of research has been the attempt to detect heat radiation from the stars. Success has been attained, by use of the ordinary devices, only with the brightest of the fixed stars, but the selenium cell makes it a comparatively simple matter to detect the light energy, and further, if the cell is calibrated, its distribution among the various wave lengths, not only for these bright stars, but also for much fainter ones. Stebbins'[3] work with variable stars, for example, is a sample of the sensibility of the selenium cell for this sort of research. The work of Stebbins, however, was undertaken merely to determine the amount of light coming from the stars, with no special thought of the use of the cell for the determination of the energy of radiation. Before one can think of using the cell for such purposes, he must be certain of at least two things; first, whether the selenium is selectively sensitive to the various wave lengths in the visible spectrum, and second, whether the selenium acts in any way as a black body.

The first point mentioned above is indicated in the curve of Fig. 9, marked, *direct*. It will be seen that this particular selenium cell is selective in its response to the different wave lengths in the visible spectrum. It must be noted that care was exerted to see that the energy was the same for all these wave lengths, as was determined with the use of the above described thermopile. Unfortunately there is no unique type of sensibility curve for selenium, as we have shown in former papers,[4] so that any given cell must be calibrated before it can be used in energy determinations, wherever variation of wave length enters into the problem. The next important point to decide is whether the cell acts to a sufficient extent like a black body. This was determined in the following simple manner: A selenium cell was placed in the path of the light coming from a monochromatic illuminator. The light falling upon this cell was reflected to the same cell that was used in obtaining the curve marked *direct* in the above discussion. The energy was adjusted until about the same deflection was obtained for a given wave length in the two cases, and then the spectrum was traversed. The resultant sensibility curve is marked *reflected* in Fig. 9. It will be noted that the shape of the two curves is very similar, showing that when equal energy falls upon the selenium surface, practically

[3]J. Stebbins, Ast. Phys. Jour. **27**, 188, 1908.
[4]Phys. Rev. N. S. **2**, 487, 1913.

equal amounts of the various colors are reflected. Secondly, and just as important, calculation of the amount of the energy reflected showed clearly that not more than two per cent of the incident energy was reflected, the remainder being absorbed into the cell. This is the more surprising in view of the fact that the surface of the selenium is far from black in appearance, and though it is dull in luster, it is rather light gray in color. So, then, we have conclusively proved that the selenium cell, while limited to the visible spectrum, is nevertheless, in this region virtually a black body, and although it is not equally sensitive to light of different wave lengths, such a cell can readily be calibrated, so that it can be made a most useful agent for this type of work.

Little has been said here concerning the sensibility of the cell in comparison with the thermopile, but on that point there is in our minds no question at all. Almost any one of our cells, in connection with just a moderate E. M. F., and a galvanometer much less sensitive than the one we use with our thermopile, will give a deflection from 10 to 100 times that of the thermopile with equal incident energy. And it must be remembered that the thermopile that we are at present using is probably not much less sensitive than the most sensitive heat receiving devices that have hitherto been used. It may be added lastly, that the variation of sensibility of the selenium cell among the wave lengths in the visible spectrum is not always so pronounced as is represented in the cell used in obtaining the curves for Fig. 9. In fact, we have tested some cells that have shown nearly a horizontal line, or equal sensitiveness throughout the spectrum, and we do not believe we are unduly optimistic when we express the expectation of eventually learning how to produce at will a type of cell that will show this uniform behavior.

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