The Photoelectric Measurements of the Variation of Light from a Weak Source Superimposed Upon a Bright Constant Source

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Following the total eclipse of the sun in 1932, it was suggested to the author that a method for observing the solar corona during times of bright sunshine might be possible, whereby a photoelectric cell would be the observing device.

By the proposed method a small opening would be placed in front of the photoelectric cell. This opening would act as a scanning hole, to scan the area just outside of the image of the sun produced by the telescope. This small opening would move spirally from the edge of the image of the sun outward, the center of the spiral path being the center of the sun. The light gathered by this method of scanning would fall upon the photoelectric cell. The cell would be connected to a suitable amplifier, the output of which was to control a sort of mechanical pen, spiralling syncronously with the scanning hole, which would draw the image of the corona as "seen" by the photoelectric cell.

B. Lyot[2] has developed a rather successful coronagraph at the Pic du Midi Observatory in France, in which two spectrographs and a spectroheliograph are used. Lyot's coronagraph makes no use of photoelectric cells.

The photoelectric cell has been used in astronomical connections for measuring the light of the night sky[3] and for measuring daylight[4]. For measurements of this type a direct current amplifier or an electrometer is used, the latter being preferred by the workers in the field[5].

A. M. Skellett[6] has proposed a method similar to the one proposed here. His proposal was published after considerable work on this problem had been done by the author.

The proposed method of spiral scanning would use the methods of amplification similar to those used in television. In television the cell is connected through an alternating current amplifier, so that the neon tube or kinescope[7] connected to the output side of the amplifier responds to the changes in the illumination falling on the cell. The amplifier does

[1] This paper is a part of a thesis for the Ph.D. degree in the Department of Physics in Indiana University, 1939.

[2] Lyot, B., 1932. Comptes Rendus. **194**:443-446, and Zeits. f. Astrophysik. **5**:73-95.

[3] Lord Rayleigh, 1929. Proc. Roy Soc. **124**:395-408.

[4] Alkins, W. R. G., and Poole, H. H., 1929-30. Opt. Soc. Trans. 31. **4**:233-240.

[5] Hughes and DuBridge, 1932. Photoelectric phenomena, p. 445. McGraw-Hill.

[6] Skellett, A. M., 1934. Proc. Nat. Academy of Sciences. **20**:461-464; and 1940. Bell Laboratories Record. **18**:162.

[7] Ramsey, R. R., 1935. Fundamentals of radio. Ramsey Publishing Company.

not respond to the total illumination falling on the cell because an unchanging light would result in a direct current input to which the amplifier would not respond.

During the first stages of this research attempts were made to study the sun's corona. A four inch lens having a focal length of twelve feet was set up horizontally on a stone slab on the side of the room. Sunlight was thrown on the lens by the use of two mirrors. The image produced by the lens was focused upon a small metal box in which there was a small opening. Behind the opening a photoelectric cell was placed. The photoelectric cell was resistance-capacity coupled to an alternating current amplifier which had a measured gain of about 56,000. This amplifier[8] consisted of two resistance-capacity coupled stages using 24A screen grid tubes. These were resistance-capacity coupled to a type 47 output tube. The screen grid voltages of the 24A tubes were made variable by means of a potentiometer arrangement. The image of the sun, about 3.4 centimeters in diameter, was allowed to "drift" over the opening over the cell, because no heliostat was available. An output meter and a loudspeaker were used to detect any amplifier response. No characteristic response was noted in the region of the corona.

When the image of the sun was allowed to drift across the metal box so that the image of a sunspot passed over the opening in front of the cell, a noise was heard in the loudspeaker which was much the same as static on a radio just before a thunderstorm. Perhaps this sort of thing might be expected, because a sunspot is a sort of storm on the sun. Sunspot images of various sizes were allowed to pass over the opening, and in each case a decided response was noted.

Of course the results were affected by the vibrations of the building and by winds. When thin clouds were passing over the sun, however, the response of the amplifier was rather small. Therefore the author believes that he is the first to listen to the "roar" produced by the variation of light in sunspots.

In order to get reliable results concerning the sunspots and in order to study the corona, it would be necessary to perform the experiment in an observatory, far removed from machinery and traffic.

Because funds were not available for the purchase of a heliostat, nor for the purchase of materials needed to construct the scanning equipment, no attempts to reproduce the corona were made. Rather, it was decided to make various tests in order to find out whether or not the proposed scanning plan was feasible.

The plan was to study the response of the photoelectric cell to changes in intensity of a varying light when the dim light was superimposed upon the light from a bright, unchanging source. The bright light was a sort of blinding light. Thereby conditions similar to bright atmospheric glare with the weak, variable coronal light mixed with it would be set up.

Characteristic intensity curves for the cells were plotted, microamperes of photoelectric current against lumens. To obtain the data

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[8] The amplifier was constructed by Ivan Conrad.

for these curves the photoelectric cell was connected to a microammeter as shown in figure 1.

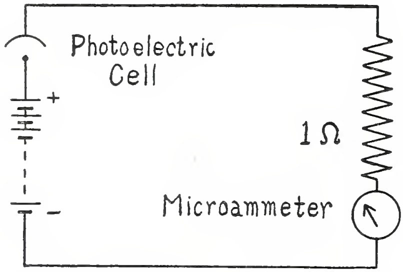

Fig. 1. Wiring diagram of the arrangement used for obtaining data for the intensity curves.

The number of lumens falling on the cell was controlled by placing a light of known candle power at various known distances from the cathode of the cell. The number of lumens falling on the cell was calculated from Ca/d^2, where C is the candle power on the source, a is the cathode area of the cell, and d is the distance of the source of light from the cell.

The curve shown in figure 2 was taken in this manner for the General Electric cell PJ23. It is typical of the curves taken for several different cells.

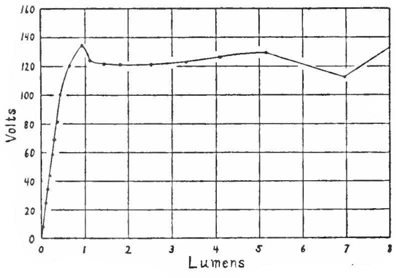

Fig. 2

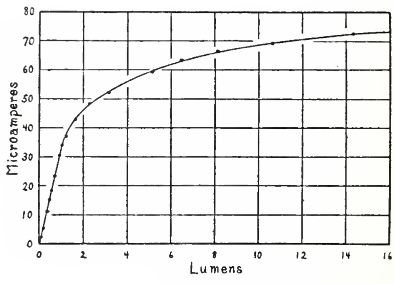

Fig. 3

Fig. 2. Intensity curve for the PJ23 photoelectric cell. The source of light was an 82 candle power, direct current source.

Fig. 3. Output curve for the PJ23 cell. The source was a 200 watt a. c. lamp.

The theory of Einstein and the work of Elster and Geitel has shown that a strict proportionality exists between photoelectric current and intensity of light over a wide range.[9] Therefore the curve of figure 2 should be a straight line. Due to the limits of the cell there seems to be a certain "saturation current", the value of which depends upon the type of cell being used.

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[9] Hughes and DuBridge, 1932. Photoelectric phenomena, pp. 28 and 31.

The cell was then coupled to the previously described amplifier, and data for an output curve were obtained. The output voltages were recorded for various illuminations from an alternating current lamp. The source was, therefore, variable. The curve shown in figure 3, showing output voltages plotted against lumens, was obtained for the PJ23 cell. The output curves for other cells were similar.

From figure 3, the maximum reliable response is found at an illumination of about .6 to .8 lumens. This illumination is found to be on the straight line portion of the curve shown in figure 2.

It may be concluded, then, that if the output of the amplifier is to be reliable, the total illumination falling on the cell must be less than .8 lumens, corresponding to the straight line portion of the curve shown in figure 2.

In order to determine the response of the cell and amplifier to variable illumination, the apparatus was arranged as shown in figure 4.

The amplifier and photoelectric cell were placed in the copper box shown at A. The copper box was used as an electrostatic shield. The cell was directly behind the opening at B. The opening B was arranged to provide various sizes of openings in front of the cell. M is an output meter. S is the source of light. D is the slotted disc.

According to Talbot's law[10], which applies to photoelectric cells, if the retina of the eye is excited with periodic light, a continuous impression will result, which is the same as that which would result if the total light received during each period were uniformly distributed throughout the period.

A curve was plotted from data obtained using a 32 candle power, direct current source at S in figure 4. Output volts were plotted against lumens. The lumens were calculated by application of Talbot's law. The curve obtained is shown in figure 5.

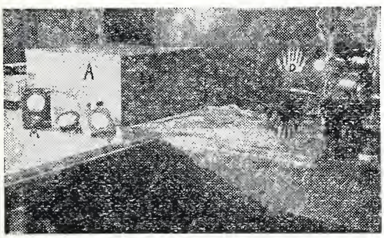

Fig. 4

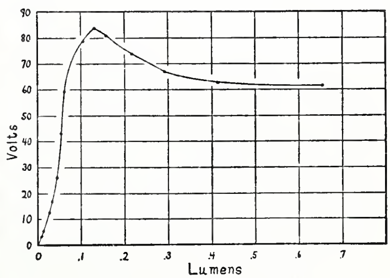

Fig. 5

Fig. 4. The arrangement of the apparatus used to get the data for the curve shown in figure 5.

Fig. 5. Output curve for the PJ23 cell, using an 82 candle power source, interrupted 50% of the time by a slotted disc. The disc was kept at 13 cm. from the opening in front of the cell. The source distance was varied.

The maximum variable illumination for reliable response is seen to be .13 lumens.

[10] Carruthers, G. H., and Harrison, T. H., 1929. Phil. Mag. **7**:792-811.

In view of the curves shown in figures 4 and 5, the following conclusions were drawn. When the photoelectric cell has a constant light falling on it which brings the photoelectric current up to the point where the intensity curve begins to bend, and that constant light has superimposed upon it a light of varying intensity, the photoelectric current produced when the varying light is at its maximum brightness is not proportionally greater than the photoelectric current produced when the varying light is at a minimum; so that the variation of the photoelectric current is not as great as it would be if the total illumination at the maximum intensity of the varying light were below the intensity of light where the curve begins to bend. Therefore the output curve reaches a maximum value and then falls off, even though the total illumination and the variable illumination intensity increases. It seems that when the constant illumination is increased above a certain value the cell becomes "blinded". When the cell is used in solar observations, the total illumination falling on the cell must be kept below that certain value, which can be accomplished by varying the size of the opening over the cell. For the cell PJ23 the total illumination, including the variable illumination, must be less than .8 lumen, and the variable illumination must be less than .13 lumen when Talbot's law is applied.

A test was made to show that the cell response depended upon the total illumination falling on the cathode of the cell. The response was independent of the amount of cathode area exposed.

The intrinsic brilliancy of the sun, in candles per square centimeter, is 160,000[11]. By calculation from this datum it is found that the number

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of lumens striking the earth per square centimeter is 10.9.

Abbott's measurements during the eclipse of 1908[12] show the ratios of sky light 20 degrees from the uneclipsed sun, the light from the corona at 1.5′ of arc from the limb of the sun, and the light from the corona at 4′ of arc from the limb of the sun, to the light from the sun at zenith. By calculation from these data the illuminations striking the earth per square centimeter are: from the sky at 20 degrees, 1.53×10^{-4}; from the corona at 1.5′ of arc, 1.42×10^{-5}; from the corona at 4′ of arc, 4.36×10^{-6}. The ratio of sky light at 20 degree from the uneclipsed sun to the light from the corona at 1.5′ of arc from the limb of the sun is 10.8, and to the light from the corona at 4′ of arc from the limb of the sun is 35.1. The ratio of the light from the sun at zenith to that from the corona at 1.5′ of arc from the limb of the sun is 7.67×10^{5}.

In order to find the ratios of bright illumination to weak illumination that could be detected with the apparatus being used, an 82 candle power bulb was placed near the opening B, and a 1.5 candle power bulb was placed at S, in figure 4.

Using different distances for the 1.5 candle power and 82 candle power bulbs, ratios of bright illumination to weak, variable illumination as high as 1.75×10^{5} were detectable through the cell and amplifying system. This means that the ratio of atmospheric glare to coronal light

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[11] 1938. Handbook of chemistry and physics. Cleveland Rubber Publishing

[12] Abbot, C. G., 1929. The sun. Appleton.

must be less than $1.75x10^5$ to be detectable. Since the ratio, $1.75x10^5$ is less than $7.67x10^5$, the ratio of bright sunlight to the coronal light at 1.5′ of arc, given above, the corona would not be observable if light direct from the sun struck the cell.

The method of scanning would require, if a clear image is obtained, a very small opening over the cell. The response of the cell for different sizes of openings and illuminations was determined. For an opening $\frac{1}{16}$ inch in diameter, the smallest definite response obtained was for .0000165 lumens falling on the cell, or .000833 lumens per square centimeter. The image of the corona at 4′ of arc from the limb of the sun, produced by the four inch lens of focal length 12 feet, assuming no absorption of light, has an illumination of $3.89x10^{-5}$ lumens per square centimeter. .000833 is 21.4 times $3.89x10^{-5}$. The area of the image necessary for observation with the $\frac{1}{16}$ inch opening in front of the cell must be 21.4 times the area of the image of the sun produced by the 4 inch lens. The image of the sun must be approximately 15.72 centimeters in diameter, or larger.

For the image of the corona at 1.5′ of arc from the limb of the sun, produced by the 4 inch lens, the illumination is $1.27x10^{-4}$ lumens per square centimeter. .000833 is 6.56 times $1.27x10^{-4}$. The image of the sun must, then, have an area 6.56 times the area produced by the 4 inch lens. The image of the sun must be approximately 8.7 centimeters in diameter. This size image would require a telescope with a focal length of approximately 368 inches. Finer detail would require a smaller opening and a larger telescope.

Conclusions

1. In this research, the writer has made the first systematic experimental observation of the response of a photoelectric cell to a weak variable light superimposed upon a bright constant light, or blinding light.

2. The writer has found that it is possible to use a photoelectric cell to observe the variations of light from sunspots. He believes that he is the first to listen to the "roar of solar tornadoes", or to the "roar of sunspots".

3. A weak varying light superimposed upon a bright constant light $1.75x10^5$ times as bright as the weak light can be detected by the methods of this research. The ratio is probably great enough to permit the observation of the corona above atmospheric glare.

4. The method proposed seems feasible, and it seems that it can be used with a telescope that produces an image of the sun 8.7 centimeters in diameter, or larger, if the $\frac{1}{16}$ inch opening is used over the cell. For finer detail a smaller opening and a larger telescope would be required.

Acknowledgment

The author wishes to use this means to thank Dr. R. R. Ramsey, who suggested the problem, for his supervision and help during the research and during the preparation of the manuscript.