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THE ELECTRICAL PHOTOMETRY OF STARS[1]

IN measures of the light of stars there are some advantages and some drawbacks as compared with photometric work in the laboratory. First of all, we are not concerned with absolute measures of intensity, but what we want to know is how the light of a heavenly body varies. If the light is constant, there is not much to be learned, but if it changes, we may infer a great deal from the law of variation. In laboratory and commercial photometry, it is customary to measure what may be called the visual brightness of a source of light, but with the stars it is immaterial for many purposes whether we study the changes of the red, or the blue, or any other part of the spectrum, though in fact any complete stellar photometry should include measures in all regions, infra-red, visible and ultra-violet.

The chief disadvantage in stellar photometry is that the stars are so faint that it is usually not feasible to expand their images out into surfaces, and most forms of stellar photometer depend upon comparisons of two point images by the eye. Although the eye is a wonderful instrument, especially in the range of intensity over which it may be used, the limit of accuracy attained by looking first at one light and then at another is much the same as though instead of using a balance we should weigh objects by lifting them in our hands. It is safe to say that no observer has ever been able to get visual results accurate to 1 per cent., and in the best measures there are occasional errors of 10 per cent., 20 per cent. and even more. It was hoped that the introduc-

[1] Read at the meeting of the National Academy of Sciences, April 20, 1915.

tion of photography would bring greater accuracy in stellar photometry, but at present the errors of the best photographic measures and the best visual ones are about the same.

The use of the property of selenium as a basis of some form of photometer has been made by various investigators, but not many have tried it on faint objects. The principle of converting a light effect into an electrical one is quite simple, for what we call a selenium cell is a bridge or resistance. Light from a bright source like the sun, falling upon a selenium element of 1,000,000 ohms, will reduce the resistance to say 20,000 ohms or one fiftieth of the original. For faint lights there are some special electrical connections which give the best arrangement, but let it suffice to state that as used with our telescope a selenium cell is connected as one arm of a Wheatstone bridge, that we use a d'Arsonval galvanometer, and current is supplied by a few dry cells.

The nature of the problem becomes apparent when we state that the image of a second magnitude star, say the Pole Star, near the focus of a 12-inch telescope objective gives the same surface illumination on a selenium cell that would come from a candle at 150 meters' distance, without any intervening lens. Therefore, to measure the light of such a star with a probable error of 1 per cent. is equivalent to the detection of a candle at 1,500 meters, or roughly a mile. In theory, to work with faint lights we might increase the voltage and use a very sensitive galvanometer, but unfortunately selenium is not so uniform in its action that the sensitiveness of an apparatus can be increased without limit, and the peculiar irregularities of behavior have prevented selenium from being of wider application. It is especially susceptible to temperature changes, and after exposure to light requires considerable time for recovery. It becomes more sensitive and extraordinarily more regular with decrease of temperature, and conditions are probably best when a cell can be maintained at a uniform temperature of about —20 degrees Centigrade.

We have found it best to keep an ice pack about the cell at the end of the telescope for work in moderate or warm weather, and the whole apparatus is wrapped up in a blanket. The observer, looking through the eyepiece which receives a portion of the light from a star, makes the exposures while a recorder in another room reads the galvanometer. As this second room may be heated, it is our custom, especially in winter, to reverse astronomical practise by having the chief observer write down the notes, while the assistant is sent up into the cold dome to manipulate the telescope.

There is another device, however, which bids fair to supplant entirely the selenium photometer, namely, the photo-electric cell made from one of the alkali metals. The sensitive metallic surface is in an exhausted tube with a small quantity of inert gas, and the effect of light is to release electrons from the surface, which ionize the gas, and thus a current is produced. We are fortunate in having several of our physicists at Illinois interested in photo-electric cells, especially Professor Jacob Kunz, and it is in the laboratory where the really important improvements are made. Only recently we managed to produce a cell which is twice as sensitive as anything we had before, and this amounts to the same thing as though some good fairy had suddenly doubled the light gathering power of our telescope. The great advantages of the photo-electric cell over selenium are first the freedom from irregularities, and next the very short time of recovery. It is too soon to estimate the relative sensibility but at least a tenfold improvement over the best obtained with selenium is expected with the new apparatus.

We may now consider some of the more strictly astronomical features of the work, and the results to be mentioned were all secured with the selenium photometer. There is one star in the sky which for a hundred years has aroused more interest than any other, namely, the well-known variable, *Algol*. Once in 69 hours the star is found to lose two thirds of its light, due to the eclipse of the main body by a large and relatively faint companion. This principal eclipse has been known and studied for a century, but it has often been pointed out that if the eclipse theory is true then, unless the companion is entirely dark, there should be a second eclipse when it passes behind the main body. This decrease in light midway between the primary eclipses was sought for in vain by visual observers, but observations with the selenium photometer established the presence of a diminution amounting to 6 per cent. There is also a continuous variation between minima, showing that the companion is brighter on the side toward the primary, partly because of reflection, but chiefly because of the heating effect. As the brighter body gives off more than 200 times as much light as the sun, it is easy to show that on the surface of the companion nearest the primary there is received more radiation per unit area than is emitted by the sun, and even on its fainter side, this body, which has often been called dark, has much more than the solar intensity. The scale of miles is not exactly known, but each body has slightly more than the solar diameter, the companion being a trifle larger, and the distance between centers is less than five times the average radius of the spheres.

Another case is the second magnitude star, *β Aurigæ*, which was one of the first of the so-called spectroscopic binaries to be discovered. As the spectrum lines are single and then double on successive nights, we have a system of two bodies with a period of revolution of about four days. The bodies will be in conjunction as seen from the earth when the spectrum lines are single, and this is the time to look for eclipses. The photometric observations show that exactly at the predicted times the light of the system decreases 7 per cent., the eclipses following each other at intervals of half the period. We have then a twin system, each component having 2.6 times the diameter of the sun, 2.4 times the mass, and being 1/7 as dense. The surface brightness of each body is at least 12, and possibly 25 times that of the sun, the total light of the system being 150 to 300 times the solar light. Therefore the sun if placed beside these dazzling objects would look like an insignificant dark body.

The next star which has been observed is *δ Orionis*, the right hand one of the three in the Belt of Orion. This object has given us a great deal of trouble, and we have spent something like two hundred hours at the telescope in an effort to smooth out some of the irregularities in the light curve. There are two eclipses, one of 8 and the other of 7 per cent., showing that the companion is nearly as intense as the primary. There is also a variation due to the ellipticity of the orbit, the two bodies being brighter when they are nearer together as a result of a tidal or heating effect. The larger body must have 5 times and probably does have 15 times the solar diameter, while the companion is of half the linear size of the primary. The total mass of the system may be 20 times the sun's, and we can say definitely that the mean density of the system is 0.006 on the solar standard, that is, the bodies average only 6 times as dense as air. A fair estimate of the total light is that it is equal to 5,000 suns.

These three stars, *Algol, β Aurigæ* and *δ Orionis* represent three types of eclipsing binary. The first has a large faint companion, in the second there are twin components, while in the last case the bodies are unequal in size but nearly equal in intensity. As these were actually the first three stars studied with the selenium photometer, and something new came out of each, it is evident that there is plenty of work to be done on similar objects of which there are thousands in the sky. There are at least two other variables which we have picked up, *α Coronæ Borealis,* and the bright star *Spica.*

In fact the large proportion of stars which are variable brings up a number of questions. We may study a large number of stars and find a certain number of eclipsing variables. The proportion of variables gives the probability of such discoveries in a further search, but also we can say that for every variable found there are a definite number of other binary systems the planes of whose orbits are inclined so that we miss the eclipses altogether. From considerations of this nature, it has been possible to conclude: The preponderant type of close binary with components of the same order of size, and of equal or unequal brightness, consists of bodies whose distance between centers is approximately 5 times their average radius, whose period of revolution is about 4 days, and whose mean density is 1/20 that of the sun. Systems of greater or less relative separation are not so numerous, or we should find more of them among the eclipsing variables. This particular discussion is based upon the variables which have been found by visual and photographic methods, but there is abundant field for work in the same line for the electrical photometers. The point to emphasize is that not only will systematic studies of stars which vary in light give us direct information, but indirectly we can draw far reaching conclusions about stars which are apparently constant.

Of the many other problems in photometry which may be attacked with good prospect of success may be mentioned the case of our sun, which, according to Abbot, is a variable star. There can not be the slightest doubt of the variation, for a single sunspot is enough to change the total light, the only question is how much? However, the changes in the light are probably measures of the general activity of the sun, rather than of local disturbances like spots. In direct measures of the sun's radiation the chief difficulty lies in the proper allowance for the absorption of the earth's atmosphere, but this trouble may be eliminated by comparing the reflected solar light from one of the planets with the light of a number of stars. Probably Saturn is a good object for this purpose, as there are few markings on its surface, but Uranus would be still better on account of its slower motion, and the greater number of comparison stars which could be found for it.

In the present paper, an attempt has been made to indicate in a general way the work we are doing, and evidently there is considerable variety in it. The production of a good electric cell, and its proper installation in a photometer is a problem in experimental physics, and any success which has come has been through the efforts of several men of widely different training and interests. In the experiments with selenium I had the collaboration of Dr. F. C. Brown, and now, with photo-electric cells, Professor Jacob Kunz is doing his best to perfect our methods. By combining our knowledge and experience we have been able to carry on researches which would have been hopeless for one man alone. And so it seems to me that a report on such joint work is peculiarly fitting before this academy, which I assume, if it stands for anything, stands for cooperation and mutual help among men of science.

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MR. EDISON'S SERVICE FOR SCIENCE[1]

ALL the world is indebted to Mr. Edison, but the portion of it that is under special obligation is the educational world, particularly the schools of technology. It is not merely that he has helped them by criticism and constructive suggestion; it is not merely that by financial assistance he has enabled them to carry on scientific investigations in fields that he has cultivated with such remarkable success; but it is mainly because he has himself been for a generation an educational institution of the first rank. As much as any other school he has had a profound influence throughout the country in arousing in the minds of young men some sense of the limitless possibilities of science when devoted to the service of man and some appreciation of the conditions under which great problems of industrial improvement must be attacked if lasting victories are to be won. It has been a great thing for America to have such a central figure in this age of applied science—a man with such a hold on the popular imagination as to force men to watch what he is doing, for in studying Edison there can not fail to be revealed something of the underlying forces that mould the world of modern industry.

I have said that Mr. Edison is an institute of technology or a school of applied science. Such an institution, if it be worth anything, stands preeminently for three things: for belief in science and in its powers of service, for understanding and appreciation of the method of science, and in the third place, for faith in the gospel of work.

Edison more than any one else in this country has taught men to see something of what science can do. It would, of course, be impossible on such an occasion as this to enumerate the accomplishments of a life so rich in great achievements. With such an embarrassment of riches, it is scarcely practicable even to single out a few of his great accomplishments. Many of you are familiar with what he did in the early days by way of improving the duplex and quadruplex systems of telegraphy, you know of his invention of the contact transmitter and his development of the loud-speaking telephone, of his marvelous invention of the phonograph (Edison being the first to make a record that would *reproduce* sound), you think of his wonderful work in 1878 and later years in developing the incandescent lamp, and you realize that he practically made the *whole* incandescent system, not only inventing the lamp, but turning his attention to all its adjuncts, improving the dynamos for such work and providing the necessary means for the distribution of power over large areas. You recognize that he laid the foundations for the design of central power stations and that his Pearl Street Station was a landmark in the history of science. His work in this field is truly phenomenal, the three-wire distribution, the system of feeders entering the network of mains at different points, the underground conductor system, the bus system in stations, the innumerable accessories of switches, fuses, meters, etc., that he provided are each achievements that would make the fame of any individual. You appreciate the remarkable character of his later work in developing the apparatus of moving pictures and you agree that what he has done still more recently in perfecting the alkaline storage cell is a splendid example of energy and persistence in attacking a difficult problem. Thinking of all these things, you can not fail to be impressed with two things—the enormous range of his activities and the wonderful simplicity of many of his devices. After all, simplicity of device is always the sign of the master, whether in science or in art. In studying Edison you have something of the same impression as in studying Newton

[1] Address at the Civic Forum, New York, May 6, 1915, on the occasion of the presentation of its medal for public service to Mr. Edison.