STELLAR PHOTOMETRY

By Joel Stebbins

In measures of the light of stars we are not concerned with absolute intensities, but rather with 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 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 introduction of photography would bring greater accuracy in stellar photometry, but at present the errors of the best photographic measures and of the best visual ones are about the same.

For a number of years we have been interested at our observatory in the development of an electrical method for the measurement of star light, based upon the property of the peculiar substance selenium. 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 principle of each of these devices is the conversion of a light effect over into a minute electric current which can be measured by a galvanometer or electrometer. In the photo-electric cells we use one of the metals, sodium, potassium, rubidium, or caesium. 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, which ionize the gas, and thus a current is produced. We are fortunate in having several of our physicists at the University of Illinois interested in photo-electric cells, especially Professor Jacob Kunz, and it is in the laboratory where the really important improvements are made. When we produce a cell which is twice as good as anything we have had before, this amounts to the same things as though some good fairy had suddenly doubled the light-gathering power of our telescope. There are certain advantages of the photo-electric cell over selenium, and while it is too soon to make a final estimate of the relative sensibility, the newer device is already five or six times as sensitive as the best we have ever had with selenium, and we expect a still further improvement.

The extreme sensibility required becomes apparent when we state that the image of a second magnitude star, say the Pole Star, near the focus of our twelve-inch telescope objective gives the same surface illumination on a photo-electric cell that would come from a candle at 500 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 5,000 meters, or roughly three miles.

We may now consider some of the applications to the stars, and although the results to be mentioned were all obtained with the selenium photometer, they could have been secured more easily with the photo-electric instrument if that had been available.

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 sixty-nine 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 the 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 *Aurigae,* 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 200 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 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 five times and probably does have fifteen times the solar diameter, while the companion is of half the linear size of the primary. The total mass of the system may be twenty 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 six 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 Aurigae 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 Coronae 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 five times their average radius, whose period of revolution is about four 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 measure 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 photoelectric 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.

PURIFIFCATION OF SEWAGE BY AERATION IN THE PRESENCE OF ACTIVATED SLUDGE

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ABSTRACT

By blowing air into sewage, then allowing the suspended matter to settle and decanting the supernatant liquid, adding fresh sewage and repeating the operation, there is accumulated sludge which has the property of purifying sewage in the presence of air in from four to five hours. The sludge obtained contains more nitrogen than sludge obtained by any other method of sewage purification. It has been shown by analyses and by experiments with growing plants that it is valuable as a fertilizer. By the process bacterial reduction of 95 to 99 per cent is affected. The cost of the process depends upon the cost of producing air. It has been estimated that it will be the most effective and most economical method of sewage purification. This will be especially true if the sludge can be readily recovered and disposed of for use as a fertilizer. Plants of considerable size have been constructed at Milwaukee, Cleveland and Champaign, and the process will be given a thorough trial.

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