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PHOTOGRAPHIC PHOTOMETRY.[1]

By M. J. JANSSEN.

A dozen years ago I undertook to lay the foundations of a science of photographic photometry, with special reference to its application to astronomical physics. I applied the fundamental principle of my researches—a principle to be restated below—to the measurement of the comparative intensities of solar and lunar light, to that of the earth light on the moon, to the radiating activity of the sun as compared with several stars, notably Sirius, and finally to the law of decrement of the light in passing away from the head along the tail of the comet C of 1881, which had been photographed at Meudon, the first among such bodies.

Perhaps these researches were not as energetically followed up by me as they ought to have been, for their astronomical importance is great, and they might have furnished valuable terms of comparison for the future. But I have had the satisfaction of seeing the principle adopted by the International Congress of Photometry for the measures of photometric order for which they laid down the rules. In order to renew attention to the subject, I here reproduce a résumé of my researches, wishing that it may become the starting point of new investigations.

Photometry has to determine the ratio of intensities of two lights. For example, to determine the ratio of luminosity of a candle and a Carcel lamp is one problem of photometry, and to evaluate in Carcel lamps the power of an electric source of luminous radiation is another.

We often have to make comparisons of this sort in the heavens. They are always highly interesting and sometimes lead to beautiful discoveries. Thus, we know that the moon is an opaque ball not self-luminous, but shining because lit up by the sun's rays. Now, we may ask what proportion of the incident light it remits, in what measure the surface shows specular reflection, and what is the relative amount of light of the full moon as compared with that of the luminary from which its rays are borrowed. Independent of the curiosity of such data in themselves, it is clear that if the study of them is carried deep enough it may lead to important conclusions relative to the nature of materials at the surface of the moon.

[1] Translated from Annuaire du Bureau des Longitudes, Paris, 1895.

So, also, the study of the planets would be advanced by photometric observations which should afford a knowledge of the relations of their surfaces and atmospheres to light.

A special importance attaches to photographic photometry in its application to the fixed stars. The quantity of light a star sends us depends chiefly on its distance and its radiating power, so that either of these two factors being known the apparent light will determine the other. Thus, if the parallax of a star and the amount of light which it sends to us are known, we can deduce the intrinsic amount of its radiation—that is to say, its rank among the hosts of suns with which the spaces of heaven are sown. Add to this knowledge that of the qualities of its light, and you will have a total from which the magnitude, the constitution, and the activity of the luminary in question may be almost completely defined.

Similar remarks apply to comets and nebulæ. Thus, celestial photometry constitutes one of the most important methods of astronomy; and it is very interesting to see what aid it can derive from photography. For this purpose I have employed a method which I proceed to describe.[1] We know that in the common photometric method the ratio of emission of the two sources of light is obtained by removing the brighter of them until they each illuminate the shadow due to the other equally. This is one of numerous methods not hitherto used in photographic photometry. In a photograph, in order to judge of the brightness of a luminous or illuminated body, we have nothing but its photographic action, or the greater or less opacity of the metallic deposit which it occasions on the sensitive film. Now, the blackness of this deposit is very far from being proportional to the time of action of the light. Could we see the deposit increase, and could we measure its amount while the action of a steady light was going on, we should find that it increased rapidly at first, and afterwards slower and slower, until it became practically stationary. Thus, we can not take as measure of the intensity of a source of light the degree of opacity of the metallic deposit which it occasions, since that opacity is not proportional to its action during a determinate time. But if, in place of considering the different degrees of opacity in relation to equality of the time of action, we consider on the contrary the variable time necessary to obtain a deposit of one fixed opacity, we shall have a sure basis for the comparisons, and this, in fact, appears from experiment.

The fact is, that to produce in a sensitive film a metallic deposit of given blackness a certain sum of radiant action is needed, and whether this sum is brought into existence in a longer or shorter time makes no difference. Hence it follows that the energy of a source is increased by the time necessary to effect the given degree of blackness—that is to say, according to this principle, two sources are to one another inversely

[1] Comptes rendus de l'Académie des Sciences, XCII, 1881, April 4. Annuaire du Bureau des Longitudes for 1882.

as the times they occupy in producing a given shade upon the same sensitive film, or in other words, to produce equal photographic effects.

This is the principle I have adopted in my investigations into photographic photometry. I have assured myself experimentally of the legitimacy of this principle by ascertaining the relative amounts of time necessary to obtain tints of the same opacity on one sensitive film placed at increasing distances of the source of light. It is found that these times increase as the squares of the distances. Thus, for distances 1, 2, 3, 4 - - - 8, etc., the times are in the ratio of 1, 4, 9, 16 - - - 64, etc. It is necessary to work with one and the same film, to avoid all stray light, to develop the plates in one bath, and, in a word, to use all precautions possible in order to establish this law. We may also mention that to obtain the best results possible it is needful to take care to choose the opacity which corresponds to the most rapid variation which happens toward the beginning of the action.

Let us see how this method can be applied to the photometric study of the heavenly bodies.

For a long time astronomers and physicists have sought to determine the luminous intensity of the moon relatively to that of the sun. Bouguer appears to be the one who came nearest to the truth. Employing a candle as middle term of the comparison, he found the light of the full moon at its mean distance to be about $\frac{1}{300000}$ of that of the sun. The employment of a candle is open to criticism, because its light is of a hue much warmer than that of the sun and still more so than that of the moon—a circumstance which must have introduced peculiar difficulties in making the photometric matchings of shades. Bouguer would have much improved his method had he subjected the candle-light to the sifting action of a suitable blue glass, so as to brings its color nearer to that of the lunar rays.

However that may be, it is remarkable that that old determination agrees closely with the photographic measures which I obtained in taking series of solar and lunar images and comparing the times of exposure to which correspond photographs of the same intensity.[1] It is to be further noticed that Bouguer's determination refers to the integral of visible rays, while the photographs are caused by more refrangible rays.

One could only infer that the lunar rays are highly photographic and have great intensity in the blue and violet. The hue of moonlight might have enabled us to foresee that result.

The comparison of the light of the sun and moon speaks volumes in regard to the admirable elasticity of our visual organ. When a country is lit up by the full moon it only receives $\frac{1}{300000}$ of the light of noon-

[1] Instead of taking photographs of the luminaries themselves, we can also, as I did at the time, avail ourselves of bands of successive intensity obtained by sunlight and moonlight. Thus, for the moon, we exposed to its light a holder whose curtain uncovered successively and at equal intervals of time the different parts of a sensitive plate, giving, after development, a series of bands of increasing opacity, which were compared with a plate exposed to sunlight for $\frac{1}{1000}$ second.

day. One might suppose that such a prodigious lowering of the illumination would produce apparently total darkness. Yet our organ takes on such increased sensibility under those circumstances that we can not only find our way about, but distinguish objects, make out details, and even enjoy the landscape. Nay, in some fine tropical regions bright nights seem almost like day.

Before quitting the subject of the moon let us say a word about the earth light. Everybody knows the appearance of "the new moon in the old moon's arms." It is a faint light on the darker side of the moon showing the main features, i. e., the great "seas" or dark patches, to the naked eye, and in a large telescope showing almost everything that can be seen at full moon, though not so well as at other phases.

The genius of Lionardo (less correctly Leonardo) da Vinci divined that the cause of this was the light reflected from the earth. Photographic photometry can give us the relative brightness of this light. In an experiment made with a telescope of 0.50 meter aperture and 1.60 meters focal length I obtained an image of the lunar ball, rendered visible by earth light in sixty seconds, showing the great accidents of its surface. On the other hand, from a series of photographs of the full moon it was found that one obtained by an exposure of one-eightieth of a second had the same intensity. We infer that the ratio of intensity of full earth light to sunlight at the moon's surface is $\frac{1}{2000}$. Arago had found $\frac{1}{4000}$ in one observation, $\frac{1}{2000}$ in a subsequent one. The value $\frac{1}{5000}$ seems probably nearer the truth. These determinations are to be regarded as merely preliminary to a thorough study in which the situations of the three luminaries are to be taken account of and the specular distinguished from irregular reflection from the earth.

Fixed stars in the focus of a telescope appear nearly like points, not lending themselves advantageously to photometric comparisons, least of all by the photographic method. Accordingly I have proposed, instead of putting the sensitive plate in the focal plane of the instrument to place it a little forward of that plane. In this way, instead of a point each star makes a little disk bounded by the section of the cone of rays from the objective by the plane of the film. With a well-corrected lens this disk will be uniformly illuminated. I term this disk the "stellar circle." With first-magnitude stars and a telescope of moderate size a few seconds suffice for obtaining such a photograph as is most suitable. We can obtain on one and the same plate a series of such circles of graduated exposures.

Forming a similar series with a second comparison star, the differences in the times of exposure being constant in each series, though not quite equal in the two, it will only remain, after the development, to pick out two circles, one from each series of equal intensities, just as in reading a vernier we find two coincident lines. The photographic luminosities of the two stars will be inversely as the times of exposure.

When the problem is to compare a star with the sun a special device is required on account of the enormous light of the latter. We can

then make use of the photographic photometer. Suppose we have a holder fitting a sensitive plate, and over the latter a metallic shutter pierced with holes of the size of the "stellar circles." Before this plate let a second plate move by virtue of a spring, this second plate having a triangular window. When the window, in consequence of the action of the spring, passes before the holes of the shutter it will determine for each of them a photographic action, which will be measured by the width of the triangular window at that point and by the velocity of the slide, which can be evaluated by a tuning fork. Thus a series of circles of graduated intensity will be obtained comparable with the "stellar circles." These circles are due to direct sunlight. But to render the results more strictly comparable it will be proper to lay the telescope objective down on the plate, so that the effects of absorption and reflection may be the same as when the stars were photographed.

By this method, the results of which were duly reported to the Academy of Sciences,[1] the radiating powers of several stars were investigated. In particular it was used to compare the light of our sun with that of the brightest star in the heavens, the Dog Star, or Sirius. It showed that that colossal orb had an intrinsic radiation in the photographic spectrum ten times that of the center of our planetary system.

But it is especially when we wish to measure the luminosity of special parts of an object, and are not content with knowing the total radiation, that the advantages of the photographic method are manifested. We have, for example, been able to evaluate the light of different parts of the tail of comet 1881 *b*, and to give quite closely the law of the decrease of that light as the distance from the nucleus increases.

The arrangement employed was as follows: On the photographic plate, fitted into a holder, was placed a screen with an opening representing the comet's tail. Before the apparatus was a shutter in which a triangle had been cut out, having its base rectilinear, but its sides curved. When this triangular window moved in the direction of the line of its base the times of exposure of the different parts depended on the forms of the curved sides. The whole base moved along that point of the opening in the screen that represented the nucleus, while the vertex of the triangle passed over the part of the opening representing the extreme and evanescent portions of the tail. Here the time of exposure vanished. In intermediate parts, say, at distance x from the base, the time of exposure was proportional to the distance, $2y$, from one side of the triangle to the other along a line parallel to the base and to the motion. A number of such shutters were constructed, the curves of the sides being determined by one of the equations $Ay = x^m$, m having a constant value for each shutter, but different values for different shutters. The whole being exposed to uniform illumination and the shutter moved by a spring an artificial figure of a comet was obtained with each shutter—

[1] April 4, 1891.

that is, with each value of m. When $m=2$ the photographic action would be inversely as the second power of the distance from the nucleus. With $m=3$, it would be inversely as the third power, etc.

Now, the different pictures so obtained being compared with the photograph of the real comet, it was found that the intensities could best be matched in all parts by taking m between 4 and 6, so that the result was that the intensity of the light in the comet's tail, in the photographic part of the spectrum, varied inversely as the fourth to sixth power of the distance from the nucleus.[1] At such enormous rate does the light diminish as we pass away from the nucleus.

The method of "stellar circles" comes into play again when we wish to reproduce the conditions under which any celestial photograph has been taken, especially in the study of nebulæ. A nebula is not an object having a definite outline, like the sun, the moon, etc. Its image is rather like a nimbus cloud, its different parts differing greatly in brightness. The consequence is that differences in the power of the telescope, the time of exposure, the sensitiveness of the film, the transparency of the atmosphere, etc., result in pictures so different that they sometimes would not be supposed to possibly represent the same thing. If, for instance, a nebula has brilliant parts scattered in it, a photograph with short exposure will show these parts only as isolated from one another, while with a long exposure the intervening places will be all filled up with little variation of intensity. In 1881 we obtained at Meudon a series of photographs of the great nebula in Orion, which show how surprisingly the aspect of that object may change with greater or less exposure.

Nevertheless, if we wish to hand down to posterity monuments which shall allow changes in the nebula to be put out of doubt, we must contrive some way in which the photographs of future ages shall be rendered comparable with those of to-day. Here the "stellar circles" afford valuable assistance. Suppose that on the plate which has just received the photographic impression of the nebula we form stellar circles of some five stars, well chosen, not variable, and situated in the neighborhood. Then we shall obtain, after the development, along with the image of the nebula those of the stellar circles of comparison. The ratios of the times of exposure of the nebula and the circles will be carefully noted. Later, then, when the time comes to make a comparable photograph, we have only to ascertain the time of exposure which, with a new telescope and a new photographic preparation, is required to produce stellar circles of the same diameter from the same stars of equal intensity, and we find by the rule of three the time of exposure requisite to obtain an equivalent photograph of the nebula.

It is remarkable that we can, by such device, obtain, after any lapse of time, no matter how different all the conditions may have become, a photographic image altogether comparable with that of times gone by.

[1] Annuaire du Bureau des Longitudes for 1882.

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