

# On the diffraction of light by spherical obstacles

PROFESSOR C V RAMAN, F.R.S.

and

Mr K S KRISHNAN

## ABSTRACT

The diffraction of light inside the shadow, thrown by a small source of light, of a sphere and a circular disc of the same diameter, was studied, with special reference to the relative intensities of the central bright spots. With the source at about 2 metres from the obstacles, with a quarter-inch polished steel ball, the bright spot could be detected visually up to 3 cm behind the obstacle, while with a steel disc of the same diameter, with the edges perfectly sharp, smooth and circular, the spot could be traced up to 2 cm.

The relative intensities of the two spots were studied at different distances behind the obstacles, qualitatively by photography and quantitatively by visual photometry. At small distances behind the obstacles, the spot inside the shadow of the sphere is much feebler than the disc-spot, however approximating to the latter as we reach farther back from the obstacles, but even at 100 cm remaining appreciably feebler.

A general explanation is suggested.

## I. Introduction

It has long been known\* that at the centre of the shadow of a spherical obstacle thrown by a small source of light there is a bright spot similar to that found in the shadow of a circular disc; and, in fact, a spherical obstacle is often used instead of a disc to demonstrate the formation of the bright spot at the centre of the shadow of a circular boundary. It is usually assumed by experimenters† that at a point on the axis of the shadow a circular disc and a sphere of equal radius would give practically identical results. This, however, is not actually the case, and it is the purpose of this paper to draw attention to the notable differences that exist between the effects observed in the two cases.

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\*Rayleigh, *Scientific Papers*, **5**, p. 112, see also A O Rankine, *Proc. Phys. Soc. London*, **37**, p. 267 (1925).

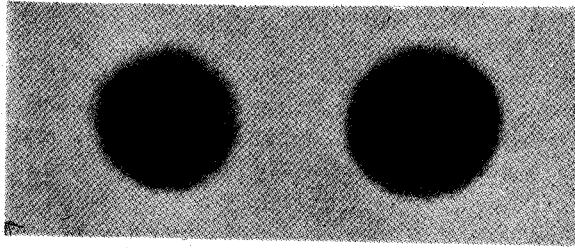
†Hufford, *Phys. Rev.* **7**, p. 545 (1916).

## II. The intensity of the bright spot

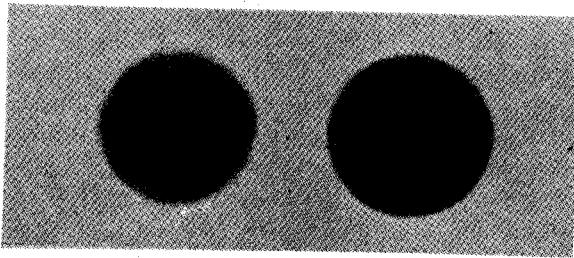
To compare the effects obtained in the shadow of a spherical obstacle and a circular disc of equal size, it is convenient to mount them side by side on a glass plate, so that the bright spots at the centres of their shadow may be seen at the same time. In most of our observations we used a quarter-inch (diameter) steel ball and an accurately made steel disc of the same size, cut on the lathe so as to have a sharp circular edge of razor-like smoothness and sharpness. They were attached by specks of wax, with sufficient space between them, to a glass plate, and held at a distance of about two metres from the source.

The diffraction patterns within the shadow of disc and sphere were seen simultaneously through a lens of sufficiently wide field of view. When a bright source of light is used, it is convenient to use a plate with two holes cut in it, to correspond with the shadow of the sphere and the disc, and place it in the field of view so as to cut off all extraneous light except that diffracted into the region of shadow. The removal of the glare outside the region of shadow is very helpful, and with this arrangement it is possible to trace the bright spots in the centre of the shadow up to within 3 cm of the object in the case of the sphere, and to less than 2 cm in the case of the disc, thus testifying to the accuracy of the edges. A series of photographs were taken of the diffraction patterns with the source of light 179 cm in front of the obstacles, and with the object plane of the camera at different distances behind them. Some of these are reproduced here (figures 1, 2, 3, 4). In the photographs the diffraction pattern on the right corresponds to the sphere and that on the left to the disc. We can easily see that the central white spots in the case of the sphere are much less bright than in the case of the disc. Thus, in figure 1, which corresponds to a distance of about 11 cm behind the obstacles, the spot in the case of the sphere is invisible in the photograph. At 13 cm, as shown in figure 2, it is just visible. At 25 cm, (figure 3) it is still much feebler than for the disc, and at 40 cm (figure 4) the difference in intensity of the two bright spots is still conspicuous. Further, we see in the photographs that the general illumination within the geometrical shadow is much greater for the disc than for the sphere. The spots in the shadow of the sphere were distinctly reddish in comparison with those for the disc, and the photographic intensity thus differed more than the visual intensity.

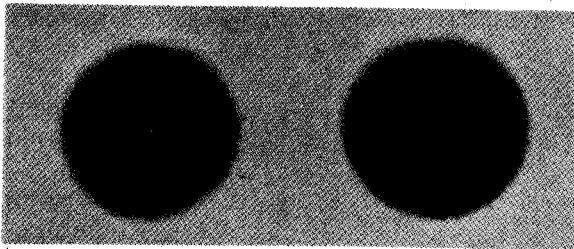
A quantitative study of the relative intensities of the central white spots of the two diffraction patterns was made with the help of an Abney rotating sector photometer placed just in front of the obstacles, and looking for the diffraction patterns through the eye-glass with the two apertures in its focal plane, mentioned already. The source of light was at a distance of 232 cm in front of the obstacles. The results are shown in the graph on p. 351 (figure 5). Owing to the difference in colour, some uncertainty arises in the visual estimates of equality of intensity. Further, for short distances behind the obstacles the comparison was by no means easy, owing to the spots having a very small size, and appearing against



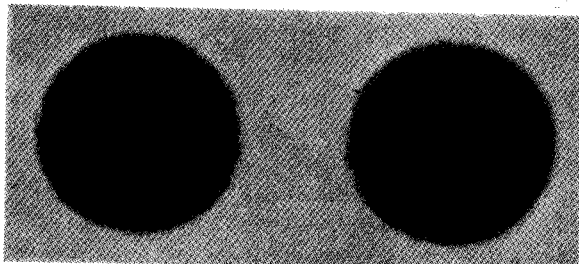
(1)



(2)



(3)



(4)

Figures 1-4

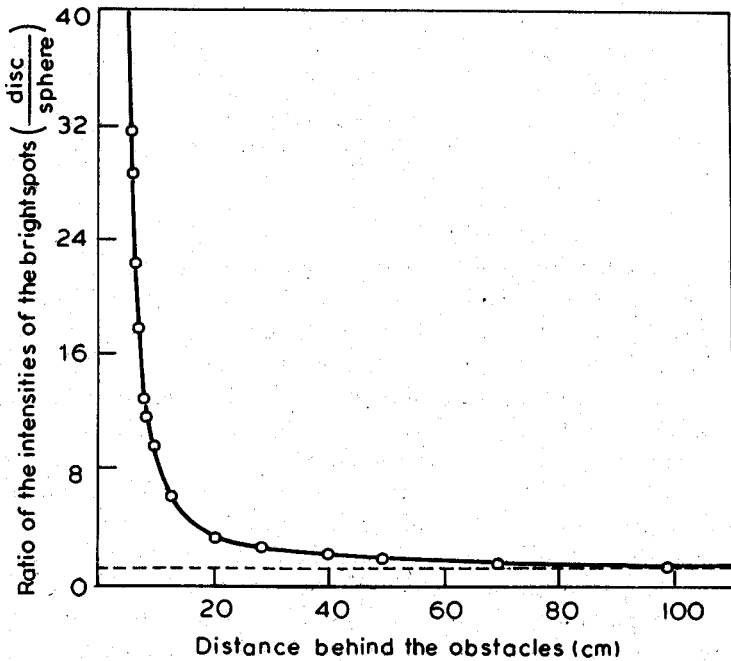


Figure 5

a luminous background. Owing to these circumstances, the measurements shown in the graph are only approximate. Nevertheless, they sufficiently indicate the general character of the phenomenon. The dotted line in figure 5 is the asymptote to the curve, and is slightly above the line of equality of intensities.

### III. Discussion of results

Without going into the mathematical theory of diffraction by a spherical obstacle, it is not difficult to give a general physical explanation of the above experimental results. In the case of the disc (figure 6a) the rays diffracted by the illuminated edge reach the point of observation directly. In the case of the sphere, however, the position is somewhat different. Drawing tangent cones enveloping

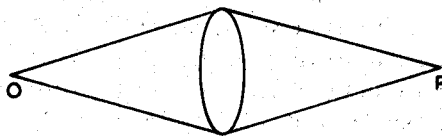


Figure 6a

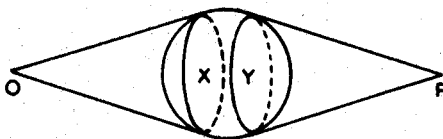


Figure 6b

the spherical obstacle, with the source and the point of observation as apexes (figure 6b), we see that they now touch the sphere at different circles of contact, X and Y respectively. Thus, the circle of contact Y, from which diffracted rays originating at the surface can reach the point of observation, lies within the region of geometrical shadow, and not at its edge, as in the case of the disc. The disturbance incident on the surface of the sphere has to creep round it, as it were, over the arc XY before the rays diffracted out by the sphere can reach the point of observation, and must suffer a very considerable diminution in the process. Thus, we can see that the intensity of the central white spot in the diffraction pattern of a sphere will be less than in the case of the disc at the same distance behind by a quantity depending on the length of the arc XY between the circles of contact of the tangentially incident and diffracted rays. Now the length of this arc will be the greater the nearer the point of observation approaches the sphere, so that the intensity of the sphere-spot, as compared with the disc-spot, ought to decrease as we approach the obstacles. Proceeding in opposite direction, the intensity at large distances will approach that of the disc, but still will be smaller than the latter by an amount which will depend on the distance of the source from the obstacle.

That the foregoing way of viewing the matter is not fanciful, but is really a statement of the physical processes occurring in the case, is evident from the following observations. A microscope is focussed tangentially on the circle of contact X already mentioned, which appears as a luminous edge in the field of view. If now the microscope is shifted laterally into the region of the geometrical shadow, we find that it has also to be drawn back longitudinally towards Y in order to keep the diffracting edge of the sphere in focus, whereas in the case of the disc such longitudinal movement is not found to be required. Further, the luminous edge of the sphere is found to diminish in brightness much more rapidly than in the case of the disc when the observer's eye is moved laterally into the region of shadow. Similar differences are also found when we compare the diffraction into the region of shadow by a sharp straight edge and by the edge of a cylinder.

We recognise that the explanation we have offered is only qualitative. The reality of the effects described is, however, unquestionable, and we have no doubt that a quantitative explanation will be forthcoming when the diffraction problem is considered on the basis of the electromagnetic theory for the case of the large sphere. This problem has been handled by Poincaré, Nicholson, Macdonald, Bromwich, G N Watson and others. The paper by Macdonald, on "The

Diffraction of Electric Waves Round a Perfectly Reflecting Obstacle,"\* might in particular be referred to, as the analysis contained in it approaches most closely to the point of view from which we have explained our experimental results. The formulae given by Macdonald are, however, not in a form capable of immediate application to the problem without considerable labour. As the experimental work was completed last summer, and as we are at present engaged on other work, we have thought it best not to defer publication of the results any longer.

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\* *Philos. Trans. R. Soc. London*, A210, 113 (1910). For other references see Bateman, "Electrical and Optical Wave Motion."