When we draw the luminosity-curves found for the different star-clusters, they appear to agree very well with the curve found by Prof. Kapteyn for the stars in the neighbourhood of the Sun. And so this method of determining the parallax, applied by us, is justified.

In another article we shall compare our results with those of Shapley for globular clusters, and discuss the distribution of star-clusters in space. W. J. A. SCHOUTEN.

Aalten, Holland, 1918 Nov.

The Total Eclipse of 1919 *May* 29 *and the Influence of Gravitation on Light.*

THE coming eclipse of the Sun occurs in a region of the sky which is exceptionally rich in bright stars, and for this reason it affords a very favourable opportunity of investigating the influence of the Sun's attraction on the course of a ray of light. Attention was called by the Astronomer Royal to the importance of this occasion in a paper read before the Royal Astronomical Society in March 1917; and the Joint Permanent Eclipse Committee has organized two expeditions. The stations selected on the line of totality are Sobral in northern Brazil and the island of Principe in the Gulf of Guinea; Dr. Crommelin and Mr. Davidson will occupy the former, and Mr. Cottingham and the writer the latter station. In both places totality lasts over 5 minutes. Both expeditions are being equipped together at the Royal Observatory, Greenwich, and will probably leave England about the middle of March. It is intended to concentrate entirely on the one problem of gravitation and light; other eclipse problems can be postponed to a future occasion, but no equally favourable opportunity of measuring the deflection of light will occur for many years.

The prediction which it is hoped to confirm or disprove is that a ray of light passing near the Sun will be bent, the path being concave to the Sun. It is easily seen that if this is so the star will appear displaced away from the Sun. More precisely a star whose true position is just on the Sun's limb will appear displaced $1''\cdot75$ from the limb; and for other stars the displacement is inversely proportional to the distance from the Sun's centre. This is the value according to Einstein's theory, but another less revolutionary hypothesis suggests a deflection of half this amount. It is important that the deflection, if it exists, should be measured sufficiently accurately to discriminate between the different theories.

From experience at previous eclipses it appeared that astrographic telescopes would be suitable for this purpose, and the object-glasses of the Greenwich and Oxford instruments will be

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used by the two expeditions. These give a scale of 1 mm. = 1′, so that the displacement looked for is of the order of $\frac{1}{60}$ millimetre. This in itself calls for no extravagant precautions of accuracy; but the main difficulties arise from the awkward conditions of eclipse observations. The exposures must be sufficiently long to show a good number of stars without being so long as to drown in the corona those near to limb, which have the largest displacement. Exposures of various lengths will be tried; but it is expected that about 10 seconds will give the best results, and about 13 star-images should be shown. There is one rather faint star near the expected limit of the corona, and it will make a great difference to the weight of the result if this can be photographed. At Sobral experiments will be made with a long-focus lens of small aperture, in addition to the main programme with the astrographic.

If successful photographs are obtained at the eclipse, these will be compared with photographs already taken for the purpose with the astrographic telescopes at Greenwich and Oxford, which show the same stars in their undistorted relative positions. There will be differences of scale between the photographs compared, which can, perhaps, be determined and eliminated by check-photographs of other parts of the sky. But this is not essential, because the effect looked for is distinct from a change of scale; it increases as we approach the Sun, whereas the displacement due to scale increases as we go to the edges of the plate. Some uncertainty may arise from the effect of the corona on the star-images, either by an actual refraction of the rays passing through it, or by a spurious displacement of the estimated centre of the images on the foggy background. Both effects would be qualitatively of the kind looked for; but it seems scarcely likely that they would be of so large a magnitude.

Probably the chief interest in the experiment arises from the question whether it will confirm or disprove the relativity theory of gravitation published by Einstein in November 1915. This theory requires a deflection 1″·75 at the limb of the Sun. But there are reasons for anticipating half this deflection * quite apart from the new theory of relativity, and we may consider this point of view first. Indeed, Freundlich went to the Russian eclipse in 1914 for the purpose of measuring the deflection more than a year before the appearance of the new relativity theory.

It was shown by J. J. Thomson in 1881 that the electric field of a charged conductor must add to its inertia or mass—that is to say, it requires a greater force to set the conductor in motion because of the electric field which it has to carry with it. The additional mass is proportional to the electromagnetic energy of the electric field; and, accordingly, we have to recognize that

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* Einstein predicted the half-deflection in 1910.

electromagnetic energy has mass. With the discovery of the electric corpuscles emitted by atoms and of the electrical constitution of matter, it has come to be believed that the ordinary mass of matter is simply that of the electromagnetic fields of the charges constituting it—mass, in fact, is simply an aspect of energy. These results raise the question whether the proportionality of the gravitational effect—weight—to mass holds true generally. A partial answer is afforded by experiments made with the torsion balance on uranium—a radioactive substance which must contain a great deal of electromagnetic energy apart from that immediately bound to its electrons. The proportionality of weight to mass has been verified to a very high accuracy for uranium, so we seem to be justified in asserting that gravitation acts quite regularly, even in this case. In a ray of light we have yet another form of electromagnetic energy; and it is known both by theory and experiment that light has mass and that light carries momentum, which is manifested in the phenomena of radiation-pressure. Has it also weight? This can only be settled by experiment, and we are scarcely justified in making a prediction; but it may be pointed out that unless all forms of energy—material, radiant and gravitational—have weight, the gradual transformation of energy from weightless to weighty kinds, and *vice versâ*, may have interesting consequences in stellar evolution.

If gravitation acts on light, the momentum of a ray will gradually change direction when acted on by a transverse field of force, just as that of a material projectile does. Although the analysis differs in some unimportant respects, the effect is that light is deviated just as a particle moving with the same speed would be deviated according to Newtonian dynamics. Owing to the great speed, the deflection is very small: on the Earth light would drop 16 feet in the first second like everything else; but any course we could observe it over would be described in a minute fraction of a second, and the curvature would be inappreciable. In passing the Sun, light describes a hyperbolic path like a meteorite moving with a speed of 186,000 miles a second (on simple Newtonian theory); and it is easy to calculate that the total deviation of such a body on passing the Sun, if it grazed the surface, would be $0''\cdot 87$, or half the Einstein deflection.

It may happen that the ratio of weight to mass for light is not the same as for matter. If so, the deflection will be altered in the same proportion. The problem of the coming eclipse may, therefore, be described as that of *weighing* light.

On Einstein's theory we have to take a somewhat different point of view, because the theory is geometrical and it goes behind the conceptions of force and inertia which are fundamental in Newtonian dynamics. According to Einstein, the velocity of light is smaller in a gravitational field, being proportional to $1-2\Omega$, where Ω is the gravitation-potential *. From the point of view of weight and mass, it seems strange that the velocity should decrease as the light falls to the attracting body; but to discuss this paradox would involve a difficult digression. Since the velocity of light in matter is smaller than in vacuum, we can imitate the effect of the Sun's gravitational field by filling the space with a medium of suitable refractive index, increasing as we approach the Sun—forming, in fact, a converging lens. It is thus seen why the ray should be deflected. Evidently, the effect is qualitatively the same as that due to refraction by coronal matter, but it is presumably much more intense. The effect may also be compared to the bending of the sea-waves in a bay as they approach the shallow shore; the wave-front of the sea-waves and of the light gradually turns, because one end is moving slower than the other.

In this connection we may refer to the point raised by M. Jonckheere (*Observatory*, vol. xli. p. 216), that a condensation of the æther around the Sun would produce a similar effect. Presumably the suggestion is that the condensation is due to the presence of the massive Sun, and that its effect is to modify the velocity of light. But a modification of the velocity of light in the neighbourhood of a massive body is just the effect we are looking for; so the suggestion amounts to a hypothetical explanation or illustration of the Einstein effect, and is not to be regarded as an alternative to it.

It is superfluous to dwell on the uncertainties which beset eclipse observers; the chance of unfavourable weather is the chief but by no means the only apprehension. Nor can we ignore the possibility that some unknown cause of complication will obscure the plain answer to the question propounded. But, if a plain answer is obtained, it is bound to be of great interest. I have sometimes wondered what must have been the feelings of Prof. Michelson when his wonderfully designed experiment failed to detect the expected signs of our velocity through the æther. It seemed that that elusive quantity was bound to be caught at last; but the result was null. Yet now we can see that a positive result would have been a very tame conclusion; and the negative result has started a new stream of knowledge revolutionising the fundamental concepts of physics. A null result is not necessarily a failure. The present eclipse expeditions may for the first time demonstrate the weight of light; or they may confirm Einstein's weird theory of non-Euclidean space; or they may lead to a result of yet more far-reaching consequences—no deflection.

A. S. Eddington.

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* The units are such that the velocity of light and the constant of gravitation are unity. On this system the mass of the Sun is 1·5 *kilometres*.