RECENT ADVANCES IN SCIENCE

ASTRONOMY. By MICHAEL W. OVENDEN, M.A., B.Sc., F.R.A.S., University Observatories, Cambridge.

THE SOLAR ECLIPSE OF 1952 FEBRUARY 25.—From the beginning of January last, the town of Khartoum in the Sudan saw the influx of a large number of astronomers whose purpose was to observe the total eclipse of the sun on 1952 February 25. In all, there were some 18 different expeditions, and the opportunity of such a gathering for the discussion of eclipse problems was taken by the arranging of a number of colloquia on the various problems to be tackled on this occasion. A brief account of these meetings has been published by M. K. Aly of Helwan Observatory (*Observatory*, **72**, 63, 1952) and provides a useful summary of the diverse methods of observation now used at eclipses.

The corona naturally received much attention, and programmes of photometry by photoelectric and photographic means, spectrophotometry of coronal lines, and photometric measurement of polarisation were all undertaken. The Swiss expedition under Waldmeier planned a complete examination of the corona by these various methods as a unit, so that a complete picture of the corona at a given time could be built up : " In this way we hope to be able to go over from a model corona hitherto used in theoretical work to the real corona of the eclipse day." Most expeditions confined themselves to one or two techniques. The importance of coronal photometry at the present time is centred on building up a reliable picture of electron densities and temperatures in the corona, particularly the outer corona, for comparison with radio observations. Part of the light of the corona, the F-corona, is due to diffraction by dust particles. At Khartoum, observations were made with a lead sulphide cell in the infra-red at about 2 microns, for various distances from the solar limb, with a view to examining the size and location of the diffracting particles.

The absolute intensities of the chromospheric lines as a function of height in the chromosphere were to be measured by the Dutch expedition, and by the expedition from the High Altitude Observatory of the U.S.A. Such observations enable accurate electron densities for the chromosphere to be derived. One of the outstanding problems of the chromosphere at the present time concerns its kinetic temperature. From observations of Balmer and other lines in the chromospheric spectrum at the 1940 eclipse, Redman (*M.N.R.A.S.*, **102**, 140, 1942) deduced a kinetic temperature of 30,000° K. At this time, such a temperature appeared far too large; subsequent observations on radio wavelengths, and the identification of the coronal emission lines by Edlen (*M.N.R.A.S.*, **105**, 323, 1945), show that the corona is at a temperature of about 10^{6}° K., so that the chromospheric temperature looks more plausible. It is clear that high temperature gradients must exist in or near the chromosphere, but a comparison of the radio observations with electron densities obtained from optical spectra suggest that, at the heights observed by Redman, the electron temperature is $\sim$5000° K. (see, for example, Piddington, *Proc. Roy. Soc. A*, **203**, 417, 1950). At the present eclipse, Redman made a new and more accurate determination of chromospheric line widths and profiles. Zanstra planned to apply his new method of measuring electron temperature by the extent of the Balmer discontinuity (*Astr. Inst. Univ. Amsterdam*, No. 1, 1950); preliminary results suggest a temperature of only 10,000° K. in better agreement with the radio data (Koelbloed and Veltman, *ibid.*, No. 3, 1952). A similar discrepancy occurs for prominences, where the application of Zanstra's method leads to temperatures of 5000° K., while the profiles of the H-alpha line give 15,000° K. (Conway, *Dunsink Obs. Contributions*, No. 3, 1951). If the chromosphere is in fact the transition region between the photosphere and the corona, it may well depart radically from equilibrium, and the contradictions between the two sets of observations may be only apparent.

The radio observations outside of an eclipse can only be compared with visual observations by means of electron densities derived from visual spectrophotometry, and the scale of heights for the radio emissions is therefore somewhat uncertain. Eclipse observations in principle enable a scale of heights to be deduced independently of optical data. Previous eclipse measurements suggest a model for the sun of a low temperature chromosphere and limb-brightening (on centimetric wavelengths). For long wavelengths in the metre region the "surface" of the sun lies well into the corona, and the sun may be expected to depart radically from spherical symmetry. Observations of the 1952 eclipse from two stations have already shown that at these wavelengths the sun is markedly ellipsoidal (*C. R. Acad. Sci. Paris.*, **234**, 1597, 1952).

Two geodetic programmes were undertaken. Accurate positions and distances on the surface of the earth can be found by precise observations of the instant of mid-eclipse at various sites. Earlier expeditions have used accurately timed motion pictures either of the flash spectrum, or in integrated light when the distances between the cusps of the crescent image of the sun as a function of time have been used to determine mid-eclipse. On this occasion, a Greenwich expedition under Atkinson took motion pictures of the rate of rotation of the thin crescent sun as it appears just off the zone of totality. These methods all require clear weather. The U.S.A. Air Force attempted to define mid-eclipse by continuous photometry of the scattered sunlight, a method which in principle can be used even in completely cloudy weather. This is an important factor in geodetic observations, since many sites must be used in combination, and the criterion of clear weather at the time of the eclipse at (say) six sites is clearly rather stringent.

Finally, a new attack on the determination of the Einstein deflection of light by the sun was to have been made by van Biesbroeck. In view of the importance of this matter to theoretical physics, a summary of the present situation with regard to experimental determinations would seem to be of value.

THE DEFLECTION OF LIGHT BY THE SOLAR GRAVITATIONAL FIELD.— The first prediction of a deflection of light by the sun's gravitational field was made by Soldner as early as 1801 (Bode, *Astronomisches Jahrbuch für* 1804, p. 161). The calculation was made according to the corpuscular theory of light and Newton's law of gravitation. The value of the deflection at the solar limb on these assumptions should be 0·87″ ; owing to a mistake in his formula, Soldner actually obtained a value just twice this (allowing for revision of constants since Soldner's day), the value later to be predicted from General Relativity. This early calculation was not concerned so much with any test of the theory of light as to examine whether any corrections for solar, lunar or terrestrial gravitation need be made in astrometry. Following the rejection of the corpuscular theory of light on which it was based, Soldner's work was forgotten until revived during the controversies of the early days of Relativity.

Einstein made reference to the light deflection in 1908, and discussed it more fully in 1911 (*Ann. Physik*, **35**, 898, 1911). The equivalence of a uniform gravitational field with an accelerated frame of reference leads to the inertial property of radiation, and directly to a light deflection of 0·87″ (again allowing for revision of constants). With the development of General Relativity (Einstein, *Ann. Physik*, **49**, 769, 1916) the divergence of the solar gravitational field from the Newtonian must be taken into account; this leads to a limb deflection of just twice the earlier figure, *i.e.* 1·75″.

Of the three crucial tests of relativistic theory, that of the light deflection is perhaps the most satisfactory. The motion of the perihelion of Mercury of 43″ of arc per century is well above observational limits, and the agreement of observation with theory is good, but almost any plausible deviation from Newtonian gravitation would yield a similar result. The gravitational shift of spectrum lines is observationally unsatisfactory; for the sun, the effect seems to be zero except near the solar limb, where it gains its theoretical value, and for the white dwarfs the breadth of the spectrum lines vitiates the measurement (*see* Bondi, *Cosmology*, 1952, p. 94).

At first sight, it might appear that the measurement of a deflection of this order would be a simple matter, since in long-focus photographic astrometry errors $\sim$0·001″ are considered (*see*, for example, van de Kamp, *Pop. Astr.*, **59**, February–May 1951). Such a comparison is misleading. In astrometry as normally practised, the distance between two nearby stars is measured on the same plate, and the errors are determined primarily by photographic properties and atmospheric conditions. In the case of the light-deflection measured at an eclipse, it is necessary to compare a star-field photographed during the eclipse with the same field photographed six months later; to provide a suitable scale calibration to compare the two plates is no easy matter. In addition, the atmospheric conditions at the time of the eclipse and the distribution of stars within the field are not at one's disposal. The number of stars available may well be limited by the fact that an increase of exposure designed to record faint stars may defeat its own object by losing bright stars near the sun (which have the greatest weight in the solution) by fogging from the bright inner corona; long-focus instruments are thus desirable.

An analysis of the general problem of determining the true value of the light deflection has been given by Freundlich and Ledermann (*M.N.R.A.S.*, **104**, 40, 1944). The difference between the cartesian co-ordinates of the ith star on the two plates (eclipse plate and "night" plate) are expressed as:

$$\begin{cases} \delta x_i = N_1 - (y_i - \beta)\theta + (x_i - \alpha)^2 P + \\ \qquad\qquad (x_i - \alpha)(y_i - \beta)Q + (x_i - \alpha)S + (x_i r_i^2)L \\ \delta y_i = N_2 - (x_i - \alpha)\theta + (y_i - \beta)^2 Q + \\ \qquad\qquad (x_i - \alpha)(y_i - \beta)P + (y_i - \beta)S + (y_i/r_i^2)L \end{cases}$$

where N_1, N_2, θ are unavoidable errors of matching of origin and orientation of the two plates, P and Q are due to a possible tilt of the normal of one or both of the plates to the telescope axis, and S (the "scale factor") represents a possible change of focal length of the astrograph between the two exposures. L is the required light deflection.

It may be seen at once that to a first approximation the effect of L is formally similar to a change of scale of the plate. The most important of Freundlich and Ledermann's conclusions is that it is essential that a separate determination of S be made, since a straightforward least squares solution with S and L as unknowns yields almost degenerate normal equations. This scale correction has to be determined with an accuracy such that its standard deviation multiplied by the harmonic mean of the squares of the apparent distances of the individual stars from the sun's centre does not exceed the tolerance permitted in L. The stringency of this condition is well seen in the example given by the authors. In the case of plates taken at the 1929 eclipse with an astrographic lens of focal length 11·2 ft., during the eclipse the camera was turned to an adjacent star field to determine the scale factor. The eclipse plates showed a large number of stars with mean distances of 6·7 solar radii. Adopting a scale factor of 0·2259″ gave L = 0·77″; with a scale factor of 0·1875″, L = 2·45″; thus the whole determination can be vitiated by a change in S of only 0·0384″, equivalent to a change of focal length of only 0·13 mm. It is thus concluded that the scale of each plate must be determined in exactly the same position as that in which the eclipse exposures are made.

The nearer the star is to the sun's centre, the greater the weight it carries in the solution. Hence a large number of stars must be observed in the region of the bright inner corona, and to avoid fogging focal lengths of at least 20 ft. should be used, according to Freundlich and Ledermann.

Finally, corrections have to be made for aberration and atmospheric refraction; the correction in the latter case can be only partially satisfactory.

The first attempt to check Einstein's predicted deflection was made by the Greenwich expeditions to Sobral and Principe for the 1919 eclipse. As is well known, a positive result in good agreement with the theoretical value was obtained, and the prediction was considered confirmed. Since then, some ten attempts at remeasurement have been made; the results are summarised in Table 1. While the first expedition was in many ways one of the most satisfactory, primarily because of the favourable distribution of the star field available, it is impossible to feel as complacent about the agreement of theory and observation as in these earlier days.

TABLE I

Measurements of the Limb Deflection (L) at Solar Eclipses

Date.	Expedition.	Location.	Observers.	Instrument.	L. "	Mean Error.	Ref.	Re-reduction by	"	Ref.
1919	Greenwich	Sobral	Dyson Eddington Davidson	Cœlostat Cœlostat	1·98 0·93	0·16 —	*a*	Hopmann	2·16	*b*
1919	Greenwich	Principe	Dyson Eddington Davidson	Cœlostat	1·61	0·40	*c*	Danjon	2·06	*d*
1922	Greenwich	Australia	Dodwell Davidson	Astrograph	1·77	0·40	*e*			
1922	Victoria	Australia	Chant Young	Astrograph	1·75 1·42 2·16	0·40	*f*			
1922	Lick I	Australia	Campbell Trumpler	Astrograph	1·72	0·15	*g*	Jackson Freundlich Danjon	2·12 2·1 2·05	*h* *i* *d*
1922	Lick II	,,	,,	Astrograph	1·82	0·20	*g*	Danjon	2·07	*d*
1929	Potsdam I	Sumatra	Freundlich v. Klüber v. Brunn	Cœlostat	2·24	0·10	*j*	Trumpler Danjon	1·75 2·06	*k* *d*
1929	Potsdam II	,,	,,	Astrograph	—	—	*l*			
1936	Sternberg	U.S.S.R.	Michailov	Astrograph	2·71	0·26	*m*			
1936	Tokyo	Kosimilo	Matukuma	Cœlostat	2·13 1·28	1·14 2·67	*n*			
1947	Yerkes	Brazil	van Biesbroeck	Astrograph	2·01	0·27	*o*			

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The various expeditions made use, in general, of either an equatorially mounted astrographic telescope, or a fixed horizontal telescope fed by a cœlostat. In most cases, check fields were taken during the eclipse to determine the scale factor, which entails movement of either telescope or cœlostat. Motion of the telescope may disturb its setting and effective focal length by a significant amount, and possibly the adjustment of the photographic plate. On the other hand, under the thermal conditions at a solar eclipse, it is unlikely that a cœlostat mirror will remain optically flat, and its focussing properties may well differ in the orientations. To overcome these difficulties, the Potsdam expedition to the 1929 eclipse used a double camera fed by a single cœlostat, one camera to take the eclipse field, the other to take the check field simultaneously with the same position of the cœlostat. To compare the two fields and obtain the scale factor, a subsidiary optical system was used to record the image of the same graticule on both plates immediately after the eclipse. To avoid errors due to curvature of the coelostat, the optical system of the graticule should be moved from one position in the direction of the sun to a second position in the direction of the check field. In practice, the check-field telescope was moved. While this method should reduce the errors due to the movement of essential optical parts, the possibility of differential thermal changes between the two cameras and the coelostat during the interval between the taking of the plates and their calibration cannot be ruled out.

An attempt to avoid any motion of optical parts between the taking of eclipse and check plates by photographing the two fields on the same plate simultaneously was made by Michailov in 1936, and independently by van Biesbroeck in 1947. The essence of the method lies in the use of a half-silvered plane-parallel glass plate. The eclipse field is photographed through the plate, while the check field is reflected down the same optical axis by the half-silvered surface. Van Biesbroeck took the added precaution of using a check field at the same altitude as the sun to reduce refraction errors. Provided that the diagonal plate remains optically flat, the focal length of the system for both fields is identical, and the scale factor can be eliminated. However, the flat will be prone to thermal distortion. In the 1947 eclipse the distortion, primarily of an astigmatic character, so disturbed the stellar images on the check field as to render them useless for measurement. At the recent eclipse, van Biesbroeck made a second attempt with this method, but taking greater precautions to avoid thermal distortion of the flat.

The individual values are liable to some uncertainty in the process of reduction. Frequently, a given result will depend strongly upon one or two stars of high weight. For example, the three values quoted for the Victoria expedition are (i) using all 18 stars; (ii) rejecting 3 stars; and (iii) rejecting 2 stars. Also, the final value will depend upon the method of reduction used; results of an expedition have frequently been re-reduced by other workers at a later date with very different results. Some of such re-reductions are quoted in Table 1. In particular, Danjon devised a graphical method of reduction which he applied to a number of eclipses (*J. Phys. Rad.*, Series 7, **3**, 281, 1932). He expressed the radial displacement of a star image as

$$d = (L/r) + Sr$$

By putting $L = k(1{\cdot}754'')$, where $k \sim 1$, $X = (1{\cdot}754''/r^2)$, and $Y = d/r$,

$$Y = k.X + S$$

A plot of Y against X should thus be linear, with slope giving L, and intercept the scale factor. For the Greenwich (1919), the two Lick (1922) and the Potsdam (1929) expeditions, Danjon obtained on re-reduction by least squares the following values for L: 2·06″, 2·05″, 2·07″ and 2·06″ respectively, a mean of 2·06″ being adopted. Although this method may be of doubtful statistical validity, the agreement between the various expeditions is most satisfactory, and the method does usefully exhibit the errors of individual observations graphically.

Although it might be premature to consider the matter decided, the balance of evidence seems to point to a shift appreciably greater than the predicted value, say about $2{\cdot}0''/r$. As the prediction involves only the constant of gravity, the solar mass and the velocity of light, it does not seem possible to modify the theoretical prediction. It is therefore interesting to consider possible disturbing factors, although none have so far proved significant.

A number of workers (*see* especially Campbell and Trumpler) have been concerned with possible refraction anomalies produced by the terrestrial atmosphere due to the cooling effect of the passage of the lunar shadow, but such an effect does not seem capable of accounting for more than 0·1″. Refraction in the interplanetary material is quite negligible, but the rapid increase in density towards the sun of coronal matter might have caused sufficient refraction radial to the sun to produce an effect. The question was first discussed by Jeffreys shortly after the results of the Greenwich expeditions had been published (*M.N.R.A.S.*, **80**, 142, 1920), with a view to seeing whether the whole of the observed displacement could not be due to coronal refraction. He concluded that it could account for only one-millionth of the observed effect. Present knowledge of the corona suggests that the free electrons make the greatest contribution to coronal refraction, but a recalculation on this basis shows that the mechanism fails to be significant by several powers of ten. The only possibility of an alteration of this conclusion would appear to be if radio observations either at an eclipse or of the occultation by the sun of a radio star demand a radical revision of present ideas of the state of the outer corona.

The difficulties inherent in the measurement of the Einstein displacement at solar eclipses can hardly be said to have been solved. The only other method of observing the effect which might be on the limits of measurement is to observe the deflection produced by Jupiter. Although the grazing deflection is only $\sim 0{\cdot}02''$, the conditions for measurement would be much more favourable for the application of the normal techniques of photographic astrometry. The measurement would be difficult, but if the observational difficulties of eclipse measurement prove intractable it may be a last resort.

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THE ACOUSTICS OF BUILDINGS (*continued*)

1.—In the July 1952 article some recent papers on Architectural Acoustics were reviewed, particularly a selection of those published in the proceedings of the Building Research Congress held in London in 1951, but discussion of some papers was postponed until the present article.

The acoustical design of broadcasting studios presents special problems which have been studied intensively in recent years in various countries. In a further paper in the Building Research Congress Report, W. Furrer, of Switzerland, discusses modern continental practice. He points out that a new phase in the design of studios began with the realisation of the importance of sound diffusion. Even in studios in which the reverberation curve seemed to be about right, complaints were frequent both from musicians and engineers (who had difficulty in finding good microphone positions) until diffusers had been placed over the large flat surfaces. These diffusers often take the form of wooden cylinders or half-cylinders. The question then arose how the diffusion in a room could be defined and measured, especially to obtain a correlation between the results of subjective judgment of listeners and objective