Kodaikanal Observatory.

BULLETIN No. LXXII.

REPORT OF THE INDIAN ECLIPSE EXPEDITION TO WALLAL, WEST AUSTRALIA.

BY J. EVERSHED, F.R.S.

The expedition was organised mainly for the purpose of obtaining photographs of the star-field surrounding the eclipsed Sun, in order to redetermine the deflection of light near the Sun. It appeared to be of great interest and importance to undertake this work because of a certain ambiguity in the results of previous eclipse expeditions, and we had at Kodaikanal a 12-inch photo-visual lens which is particularly well adapted for this problem giving a large field of good definition and a larger scale than the lenses used previously, or that would be likely to be used by other expeditions.

In addition to this work it was proposed to take out a spectrographic outfit and attempt to photograph the spectrum of the corona on the east and west limbs simultaneously, in order to determine the displacements of the green corona line due to the solar rotation, and to get improved values of the wave-length of this line. The results of previous eclipses gave values of the angular rotation in the coronal region largely in excess of the mean values obtained from sunspots and from displacements of lines in the reversing layer, and seemed to indicate a very remarkable law for the angular rotation at different levels; but, owing to the low dispersion hitherto used at eclipses, the values obtained are not very reliable, hence the desirability of repeating the measures with more powerful instruments such as were available at Kodaikanal or could be constructed without much difficulty.

Owing to the proximity of the eclipse track to the south of India, the direct distance from Kodaikanal being less than 600 miles, it was at first proposed to occupy one of the Maldive Islands, and negotiations were entered into with the Surveyor-General of Ceylon, who kindly supplied me with the best information available with regard to these islands. Assuming that transport would be available, application was made to the Government of India through Dr. Gilbert Walker, F.R.S., Director-General of Indian Observatories, for a special grant of money to be supplemented if necessary by private funds which would be available. Professor Raman of Calcutta kindly promised to join the expedition and assist in the work as planned above. I should also have had the assistance of Mr. Bamford of the Colombo Observatory and one or two of the staff at Kodaikanal. Unfortunately for this programme, we underestimated the difficulties of transport from Ceylon to the Islands. Native craft trading between Ceylon and Mali was said to be impossible. The Ceylon Government was approached through the Governor of Madras, who kindly interested himself in our plans, but without avail, and the Government of India, while voting a sum of Rs. 4,500 for the expedition, was unable to provide a vessel suitable for the work. I have to thank Dr. Walker for his great efforts on behalf of the expedition and for his interest in the work generally.

The only alternative to the Maldives which seemed to offer a good chance of success was to occupy a site on the north-west coast of Australia. Negotiations were therefore entered into with the Commonwealth Government, resulting in a cordial invitation to join Dr. Campbell's party at Wallal near Broome. As the funds available would not admit of a large party to Australia, I was compelled to limit the personnel to three only, including myself and Mrs. Evershed. Professor Maclean of Wilson College, Bombay, kindly arranged to join us and assist in the work, but was unfortunately prevented by illness from coming. It then became a serious question whether the expedition should not be abandoned for want of the necessary assistance. In this dilemma, Professor Ross of the University of Western Australia very kindly arranged with the University authorities to depute Mr. Everson of the Physics Department specially to assist the Indian expedition. I take this opportunity to thank Professor Ross for his efforts on my behalf and the University authorities for lending me Mr. Everson, without whose unflagging energy and efficient aid it would have been impossible to get the instruments erected in time.

CONSTRUCTION AND TESTING OF THE INSTRUMENTS.—A large amount of preliminary construction work was undertaken in the Observatory workshop, beginning about a year before the eclipse date. A large camera box was available, having been originally made for the Indian eclipse of 1898, and this was adapted for the Einstein camera and for taking 12 × 12½ inch plates. A wooden framework covered with metal sheeting was constructed for the tube connecting the camera with the 12-inch lens. A substitute had to be arranged for the lens, as this is in daily use for the two spectroheliographs of the Kodaikanal Observatory. After many trials, I finally used a 9-inch parabolic mirror in combination with a convex mirror arranged as a "Skew Cassegrain" of the type advocated by Dr. Common in 1905. The solar image could be adjusted to have precisely the same diameter as was given by the lens, and the definition of a star-image was quite satisfactory with an aperture reduced to 7 inches. This arrangement was put into operation in December 1921, and the large lens mounted where it could be used for testing the performance of two coelostats and for photographing star-fields.

A polar heliostat by Grubb, not in use, was dismantled and the mirror and declination axis remounted as a coelostat. The Grubb driving clock was modified by adding one gear-wheel to give the correct speed. The mirror of 11-inch aperture when tested at large angles of incidence was found to be far from perfect. I therefore decided to use this coelostat for supplying light to the spectrographs, where the fault would not be of great consequence. A second mirror of 6-inch aperture by Common (also imperfect) was attached to the upper end of the axis to supply light to the second spectrograph.

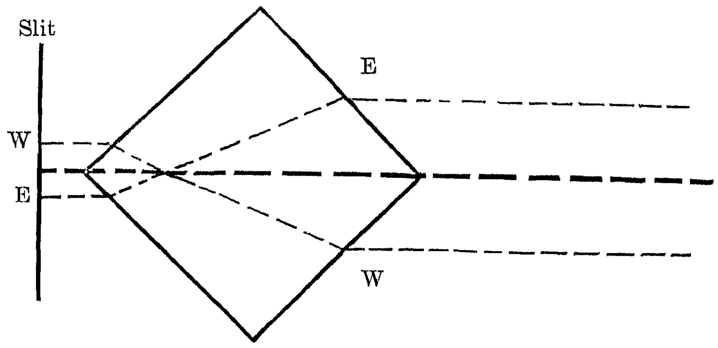
Through the kindness of the Astronomer Royal I obtained the loan of a 16-inch coelostat from the Joint Eclipse Committee of the Royal Society and the Royal Astronomical Society for use with the Einstein camera. Before despatching it, Sir F. Dyson had it tested at the National Physical Laboratory. The report from this Institution was anything but satisfactory both as regards the mirror and the driving mechanism, but as nothing else was available it was sent to Kodaikanal after providing an excellent new driving clock for it by Messrs. Cooke & Sons. As soon as the instrument was received at Kodaikanal in May, it was set up and the uniformity of its movement tested, when it was found that although no appreciable irregularity could be observed with a solar image of about 4 inches diameter, yet when stars were photographed there was shown to be a very marked periodical error, even in the best parts of the sector. Tests were made with the coelostat correctly adjusted in altitude but with the polar axis slightly out of the meridian. In this way by regulating the clock, star images could be made to drift slowly in declination; but instead of this movement appearing on the plate as a straight line of a length proportional to the exposure time, it appeared as a sine curve with a period of one minute, corresponding to one revolution of the driving screw, and with numerous smaller irregularities. As the driving screw was found to be worn and out of truth, and the teeth of the sector injured in many places through the wear and tear of previous eclipse expeditions, it was decided to construct a new screw and refigure the teeth of the driving sector. Fortunately, the Observatory possesses a good screw-cutting lathe, and a new screw was made without much difficulty of the same diameter and pitch as the old screw, also a gun-metal nut rather longer than the screw and cut into four segments accurately clamped together: this was for correcting the screw by Rowland's method of grinding. Many days were spent in grinding and polishing the screw until it was considered to be free from the grosser errors. Next, another similar screw was cut on a length of tool-steel, and ground with the same nut. This was used to re-cut and grind the sector, which was mounted on the slide-rest of the lathe. Finally, the sector was very carefully ground on the first screw. Many difficulties due to inexperience in this work, had to be met and overcome; and it was not until the day of despatch of the cases of instruments to the railway that I was able to complete the work on the sector. Tests of the actual performance of the coelostat had to be deferred until the instruments were re-erected in Australia.

Owing to the bad running of the coelostat, photographs of the eclipse field could not be obtained before leaving for Australia, and it was intended, if satisfactory eclipse plates were secured, to set up the instrument in Madras (latitude 13° north) on our return to India, and get control plates under similar conditions of temperature and focal length, with the star-field in the morning sky, at an altitude of 58° as at Wallal, and at approximately the same hour-angle, but east instead of west.

I proposed to replace the imperfect 16-inch mirror by a 12-inch siderostat mirror by Cooke that was available, but on testing this it was found to be no better than the 16-inch. Either would have given good images near normal incidence, as would have been the case at the station originally selected in the Maldives, but their performance at the Australian station where the angle of incidence was 32½° seemed doubtful. An order was then sent to Messrs. Hilger for a mirror of the largest diameter that could be produced in the limited time available, and a 9-inch of very excellent figure was made, but unfortunately was not received in time for the eclipse.

THE CORONA SPECTROGRAPHS.—The high dispersion auto-collimating prism spectrograph built for photographing Venus spectra was taken to the eclipse without modification, excepting that the small reflecting prisms in front of the slit used for comparison spectra were removed. A second spectrograph was built specially for the eclipse: it is also of the auto-collimating type, but of larger aperture and smaller dispersion. The prisms are of four inches effective aperture and used with a collimator-camera lens of seven feet focus. This gives a dispersion for wave-length 5300 of about 4 angstroms per millimetre, with excellent definition.

As it was desired to photograph both east and west coronal spectra simultaneously, giving an exposure lasting six minutes, both spectrographs were fitted with optical arrangements for bringing the images of the two limbs on to the slit. The simplest way to effect this with little loss of light was to place an optical cube of very transparent glass immediately in front of the slit, a 90° edge of the cube ground and polished perfectly sharp dividing the slit into two equal lengths, as shown in the diagram. The Sun's image after passing through the cube is focussed on the slit, the function of the cube being to split the image into two halves which are reversed on the slit, the east and west limbs facing one another.



OPTICAL CUBE FOR CORONA SPECTROGRAPH.

The size of the cube and the focal length of the image lens are so arranged that there is an interval between the two limbs equivalent to about 10′ of arc In this space the east and west images of the lower corona are formed, the angle of the cube sharply dividing the images at a height of 5′ above each limb. At the base of each corona spectrum it was hoped to photograph point images of the flash spectrum, so that points of known wave-length would be available on either side of the coronal spectra for determining the wave-length of the corona line. This arrangement was applied to the high dispersion spectrograph, with which an image lens of 5 feet focus was used. The second spectrograph was designed to deal with the 4-inch image formed by a lens of 40 feet focus. For this a special apparatus was constructed for reflecting the opposite limbs on to the slit. This consisted of a divided circle bearing reflecting prisms at opposite ends of a diameter, and a silvered right-angle prism mounted at the centre, the sharp edge of this prism bisecting the spectrograph slit and defining the division between east and west spectra. The circle could be rotated to any position angle, as in similar devices for solar rotation work.

This apparatus was not used at the eclipse, as there was not enough time available before eclipse day to get it into perfect adjustment. The spectrograph was therefore used in an attempt to get a single coronal spectrum image on one limb only.

To avoid trouble with the driving clocks, always liable to occur under the dusty conditions of an eclipse installation, both coelostat clocks were fitted with the double-drive arrangement whereby both ends of the driving rope are attached to the drum and pull in opposite directions, passing over pulleys outside the clock and round the pulley on the weight, which does not rotate but merely serves to equalise the force on the two ends of the rope. The driving force in this way acts as a couple on the drum, instead of the one-sided pull as ordinarily arranged, with half of the weight ineffective in driving the clock. Only one-half of the usual mass is therefore required, unnecessary friction is avoided, and the clock never stops running for any obscure reason. The one disadvantage is that for the same fall the clock only runs for half the time it will go with the ordinary method of drive; but it is easy to arrange for a length of fall sufficient for 45 minutes which is ample for eclipse work.

THE JOURNEY TO WALLAL.—The expedition sailed from Madras on July 28 and arrived at Broome via Singapore on August 18. Here we had to await the arrival of the expeditions from Perth, including the American and Canadian parties. During the ten days' halt I was fortunate in obtaining the use of a workshop and tools, and so was able to construct two large dark slides for the Einstein camera, making five in all. Timber and cement were purchased, and moulds made for the concrete piers that would have to be erected at Wallal. The Resident Magistrate of Broome, Col. Mansbridge, D.S.O., very kindly allowed me to build a pier in his compound for use on our return from the eclipse in an attempt to photograph a high dispersion spectrum of Canopus.

On the 28th of August the various eclipse parties arrived from Perth, and we had the pleasure of meeting Dr. and Mrs. Campbell of the Lick Observatory, Dr. and Mrs. Adams of New Zealand, the members of the Canadian and Australian expeditions, Professor Ross from Perth, and Lieut.-Commander Quick in charge of the naval unit deputed to convey the expedition to Wallal and to form our camp there. The schooner "Gwendolen" hired by the Australian Navy arrived off Wallal on the early morning of the 30th.

ERECTION OF INSTRUMENTS.—Owing to the difficulties of landing some 35 tons by weight of instruments, and getting them up from the shore to the camp, a distance of about a mile, the work of erection could not be fairly started until September 2. During the 18 following days it was all we could do to get the big camera and the two spectrographs erected and adjusted, leaving no sufficient margin of time for rehearsals. A large concrete pier was built for the lens mounting and the 16-inch coelostat, another pier 22 feet to the west of the coelostat for the Einstein camera, and a third pier to the east to carry the smaller coelostat and image lenses for the spectrographs. These piers raised the instruments between 3 and 4 feet above the ground level.

The camera box was bolted to a heavy stone slab cemented to the western pier. The top of this pier and the slab were not made level but inclined 19° downwards towards the north, so that the edges of the plate-holders were 19° out of the vertical. The purpose of this inclination was to get as many of the brighter stars of the eclipse field as possible on to the plates. Had the plates not been inclined in this way, two of the brighter stars would have fallen outside the corners of the 12 × 12½ inch plates.

The wooden mould surrounding the camera pier was not removed when the cement had set, as it was found very convenient for attaching the handle for operating the focussing screw and for fixing two pulleys, one for the cord controlling the coelostat slow motion, and the other for the cord operating the exposing shutter, a large aluminium disc attached inside the connecting tube of the camera about three feet in front of the focal plane.

The accurate adjustment of the camera with respect to the lens was not a very easy matter. The azimuth was computed to be 1° 4′ south of west for the centre of the plates, and this point had also to be arranged precisely level with the centre of the lens. The theodolite attached to the coelostat was found to be too small and inaccurate to be trusted : I therefore set up in front of the coelostat a good 6-inch Cooke theodolite. With the telescope adjusted level and pointing $1^{\circ}\ 4'$ south of west I was able to observe the exact point at the camera-end at which the centre of the plate should be placed. The 1-inch theodolite object-glass faced the upper part of the 12-inch lens, thus avoiding the coelostat mirror turned edgewise. The large lens in this way formed a collimator for the theodolite. After fixing this point with certainty, the slide for the plate-holders was secured at the correct position. The coelostat was then adjusted as accurately as possible in altitude, and roughly in azimuth, and finally on the day preceding the eclipse the azimuth was corrected by bringing the Sun's image exactly to its computed position in the field of the camera. Means were provided for accurately adjusting the camera-end so that the plates would be normal to the axis of the lens, the usual squaring-on adjustments of the lens being first manipulated to bring the axis central on the plate. Focussing was effected by movement of the object-glass, the mounting of which was provided with long machined ways and a screw movement.

In order to maintain a fairly uniform temperature, especially inside the camera-tube, the entire apparatus was covered by two large tents, one covering the tube and object-glass, and the other forming a darkened chamber in which the operation of changing the plates could be safely effected. The coelostat was protected as far as possible by a light framework of wood, to which white sheeting was attached. On the day of the eclipse the outer fly of the tents was kept wet until the eclipse itself began to take effect in preventing the great rise of temperature which usually occurred inside the tents during the day.

About a week before the eclipse, tests were made of the performance of the coelostat. The result was that all hope of getting perfect plates had to be abandoned. With the mirror set to the hour-angle at which totality would occur, marked astigmatism appeared in the star-images, and this was due to the faulty figuring of the surface and not to any temporary effect of temperature changes. Another mirror by Cooke of 12 inches diameter had been brought from Kodaikanal in case of accident to the silver surface ; but this one as already stated was no better than the 16-inch. A drastic cutting down of the aperture from 12 inches to 6 or 8 inches was the only remedy. In attempting to regulate the driving-clock to give stationary images, it was found that the irregularities previously observed with the old screw were considerably reduced in amplitude, but by no means cured. A star-image would remain apparently stationary for about 20 seconds, and then begin to wander. All attempts to discover the cause of the trouble were unavailing, and one could only hope that plates exposed for less than 20 seconds might with luck give good images, but they could not be expected to show many stars.

ADJUSTMENT OF THE SPECTROGRAPHS.—The high-dispersion spectrograph was placed to the eastward of the smaller coelostat, and the second spectrograph to the westward, the two mirrors of this coelostat being adjustable independently one reflecting east and the other west. Both spectrographs were mounted on packing cases filled with earth, and each was protected by a tent, and by a great mass of non-conducting material packed around the prism chambers. The slit and exposing shutter of the second spectrograph were placed in a convenient position in the main tent which covered the Einstein camera. The adjustment of the prisms and the focussing of these spectrographs was effected with less difficulty than usual, notwithstanding the constant exasperation from innumerable flies attacking one's eyes the moment an observation was attempted.

OPERATIONS AT THE ECLIPSE.—Great care was essential in the final adjustment and focussing of the Einstein camera. The visual and photographic foci had been previously determined and found to be practically identical, but the lens was sensitive to temperature change, and so the focus determined at night would not necessarily be the same during the eclipse. The method adopted for focussing was as follows :—A blank slide with a large opening at the back was fitted with a clear-glass photographic plate (fixed without exposure) : this was ruled with fine cross-lines on the film, defining the centre and the direction of right ascension and declination. The crescent Sun about five minutes before second contact was brought to the central position with the south cusp just overlapping the line ruled north and south. Mr. Everson then placed a screen over the object-glass having two apertures, one inch in diameter and eight inches apart, and the cusp was examined with a lens and the focus slightly readjusted from the previously determined focus of stars at night. By this method, it was estimated that an error of one or two millimetres, or say one part in four thousand of the focal length, would show by a doubling of the sharp cusp, the apertures being placed approximately at right angles to the cusp. Actually a difficulty was experienced in the brilliancy of the light, and much darker shade glasses should have been used to examine it with comfort. After focussing in this way, it was found that by removing the focussing slide and moving a piece of paper across the focal plane the point of coincidence of the two images could be estimated with some accuracy.

After focussing, a dark slide was put in readiness for exposure, and the narrowing crescent which could be seen projected on the slit of the spectrograph was watched, and just before disappearance the signal was given for exposing the two spectrographs ; as these needed no further attention until the end of totality I was able to give undivided attention to the exposure of the five plates of the Einstein camera. There was ample time during the five minutes of totality for changing the slides and operating the five exposures, which had to be short on account of the defects of the coelostat. The exposures varied from five seconds to fifteen seconds duration, the short exposures being made near the beginning and end of totality. Mr. Everson meanwhile changed the aperture over the lens from six inches to eight inches, after the third exposure. The plates used were the fastest I could obtain, the " Stella " brand of Elliott Brothers, Barnet (H. and D. 500). This plate has excellent contrast and fine grain, and has been used very successfully for Venus and star spectra.

I purposely worked deliberately, nevertheless owing to want of sufficient practice in rehearsing a slight mistake was made in the first exposure, and a hitch occurred in the last, the slide being very difficult to close ; in fact it took the whole of the last minute of totality to get the slide safely closed and removed from the camera : I thus lost my chance of getting a good view of the corona with binoculars, as I had intended.

The three middle exposures were operated according to programme, and at the first streak of sunlight the signal was given for closing the spectrograph shutters, one of these being operated by Mr. Everson and the other by Mrs. Evershed, who also took down the times of opening and closing of all the exposures.

All the slides were immediately put safely into bags, and at night the first of the coronal plates and the two spectrograph plates were developed. The coronal plate was not satisfactory, showing a considerable amount of fog and other defects. The spectrograph plates were total failures, the corona line not appearing at all on either of them. This is probably due to the unusual faintness of the radiation at this eclipse, as indicated by photographs taken with low dispersion by Dr. Moore of the Lick Observatory party. The plates used were Ilford Special Rapid Panchromatic.

As the development of the large plates under difficult conditions at Wallal was found to be extremely risky, especially in the drying, the four undeveloped plates were taken from their slides and carefully packed in the tin box in which they had been received, to be developed subsequently at Broome, where ice could be obtained.

When these were developed, however, all were found to have failed for one reason or another. The fifteen seconds exposure plates showed movement of the star images and poor definition of the corona due to the bad driving of the coelostat, and the two short exposure plates in some unexplained way had been badly fogged over two-thirds of the surface, as though the slides had been withdrawn this amount in daylight. The negatives were perfectly clear over the remaining portion where the ends of the coronal streamers appeared beautifully defined. This completed the failure of our eclipse expedition.

A considerable amount of risk is inevitable in all eclipse expeditions, but it is usually associated with the chances of fine weather. Failure under the ideal conditions of a perfectly clear sky, with excellent definition, and a long duration of totality, is deplorable, especially when public funds have been risked.

Notwithstanding the vast amount of trouble and anxiety involved in working the 16-inch coelostat, I am still of opinion that the method is good for the Einstein problem. For only with a coelostat is it practically possible to get an adequate scale. All my experience in measuring the minute displacements of lines in the solar spectrum tends to show that scale is all-important. With insufficient dispersive power there are always large and seemingly inexplicable differences from plate to plate, variations which are at any rate greatly in excess of the probable errors of measurement. The ambiguous result of the measures of star images at previous eclipses, the displacements varying all the way between the Newtonian and the Einstein law, is a good example of the same difficulty. The question of the coelostat mirror introducing complications is, I think, a bogey. Plane mirrors can now be constructed of large size and perfect figure, and experience with mirrors, good and bad, has shown that little is to be feared from distortion of the surface when the silvering is fresh and good, and simple precautions are taken.

Finally, if British manufacturers could be induced to abandon the old methods and apply ball bearings to all moving parts in astronomical instruments, as should have been done thirty years ago, an enormous gain would result in the uniformity of movement so essential in this research.

Our admiration for the American installation was perhaps tinged with envy. As a matter of course, all polar axes were fitted with ball or roller bearings, and with a simple and most effective method of driving without the use of any gearing whatever. We have great hopes that the excellent plates obtained by Dr. Campbell with his 15-foot cameras will finally yield conclusive evidence as to the amount of the deflection, though we could wish that the focal length had been twice as great.

PHOTOGRAPHING STAR SPECTRA.—Our next work was to set up the 16-inch coelostat and 12-inch lens at Broome, and try to obtain high-dispersion photographs of the spectrum of Canopus under the favourable conditions of the star's high altitude in this southern latitude, and the excellent definition. Mr. Everson again assisted in putting up the instruments, and Dr. Trumpler of the Lick expedition very kindly took a turn at guiding during the long exposures required between midnight and dawn, and he assisted me also in re-silvering the mirror.

The main difficulty encountered was to maintain a constant temperature in the prism chamber, as the diurnal variation was large, and this accounted for a number of failures. We did however succeed in obtaining one good spectrum of Canopus, and also one of the star Achernar ; and these are of great interest in connexion with my previous work on the spectrum of Sirius.

We are very greatly indebted to Col. Mansbridge for his kindness and hospitality during this time : he gave us the free use of his house and compound for this work, which occupied several weeks.

We should like also to refer with gratitude to the welcome we received from the inhabitants of Broome generally, who gave us every assistance and took a keen interest in our work. At their request I gave a public lecture on the Sun, and showed a number of slides illustrating our work at Kodaikanal.

Thanks are also due to the steamship companies who generously carried our three tons cargo of instruments free or at a nominal charge, and to the ships' officers who handled it with scrupulous care.

While at Wallal, we were the guests of the Royal Australian Navy who catered for us generously and provided commodious tents to live in. We wish to thank very heartily Commander Quick and his men for the assistance given us and for their care of our instruments, which were landed at Wallal and brought back to Broome under difficult conditions completely uninjured.

We left Broome on October 24, and reached Kodaikanal on November 20, just missing by one day the weekly steamer from Singapore to Madras.

THE OBSERVATORY, KODAIKANAL,
26th February 1923.

J. EVERSHED.

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