The Solar Flare of 23 February 1956*

1. Solar flares and their observation

A solar flare, as judged from optical observations, is usually believed to be a short-lived increase or burst of radiation which occurs with great suddenness in the neighbourhood of sunspots. It is a very common phenomenon during periods close to the maximum of the sunspot cycle, for it has been estimated, from a statistical study of the combined data of flare observations made at all solar observatories, that a flare occurs as frequently as once in every two hours. But in spite of this high frequency, observers at any given observatory often miss flares, not only because they are so transient but also because optical observations require favourable weather conditions.

By international agreement among solar observers, flares are classified into four classes; the latest recommendation of the International Astronomical Union is that this classification should be based *primarily* upon the area of the solar disk affected by the flare, although due weight ought to be given also to other optical factors, such as the brightness of the flare and the degree of broadening of lines in the flare spectrum. The determination of this optical class or importance of a given flare must therefore be, to a considerable extent, a matter of individual judgment on the part of the observer. The commonest and weakest flares belong to class (or importance) 1, while the less frequent, moderately strong ones fall in class 2. The severe flares are classed under importance 3 and the exceptionally severe ones are designated 3+. Flares of importance 3 and 3+ are not frequent; perhaps some half a dozen such flares occur per year during the most active phase of the solar cycle. It is, however, these severe flares which can yield the largest amount of scientific information likely to be useful in understanding the still obscure mechanism of solar flares; for, these are the brightest and also have the largest areas, so that if detected in time, they can be studied in sufficient detail. However, the observer of solar flares has to be extremely alert and persevering if he wants to observe the maximum phase of a flare, which is the most important phase but which is reached with great rapidity shortly after the commencement of the flare. When one considers the practical difficulties of flare observation, one can appreciate what a boon the Monochromatic Heliograph invented by Bernard Lyot must be to a solar observer.

Although their optical observation is fraught with many difficulties and largely depends upon a favourable combination of circumstances, solar flares produce a number of terrestrial effects which are fairly easily recorded by automatically recording instruments. Such records yield much valuable information, but without the optical observation of the concerned flares these records have to be regarded as circumstantial evidence rather than direct proof. It was, therefore, very fortunate that the great flare of 23 February 1956 was observed by optical means at certain observatories.

2. The flare of 23 February 1956

The flare began at about 0335 U.T. and ended at about 0510 U.T. and could, therefore, be optically observed only at observatories in the sunlit eastern hemisphere. Information available up-to-date shows that only the Kodaikanal Astrophysical Observatory and the Tokyo Astronomical Observatory (*Publ. astr. Soc.* Japan, 1956) succeeded in making optical observations of this important event which was unusual in certain respects. According to the Tokyo observers the flare was seen even with the naked eye as a small white spot on the projected image of the sun. It was, therefore, visible in white light like the great flare observed by Carrington and Hodgson in 1859 long before any observations in $H\alpha$ were thought of.

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At Kodaikanal the flare was observed first with the Spectrohelioscope in $H\alpha$ light, but was later observed with the Prominence Spectroscope and also photographed with the $H\alpha$ Spectroheliograph. It occurred at latitude 20°N and longitude 80°W within the large spotgroup (indicated by arrows in Fig. 1) which had crossed the central meridian on 18 February. The course of events as observed optically around the time of the flare on 23 February was as follows: At 0315 hrs the normal bright flocculus surrounding the large spotgroup close to the limb in the NW quadrant began to show signs of brightening; there was no unusual brightening noticeable on the routine disk spectroheliograms in $H\alpha$ and K taken earlier between 0200 and 0310 hrs. At 0330 hrs there was, however, an appreciable increase in the brightness of the flocculus near the NW limb and almost simultaneously an extraordinarily bright surge was observed to shoot out beyond the limb from the vicinity of the flocculus. The surge was so bright that even in $H\alpha$ light it seemed whitish. By 0335 hrs the flare was in progress with the $H\alpha$ line widening to about 3·5Å as observed with the spectrohelioscope as well as with the Prominence Spectroscope. The visual observations were continued till 0340 hrs at which moment the width of $H\alpha$ was 4·8Å. Between 0340 and 0350 hrs the observers broke off visual observations in order to try to photograph the spectrum of the flare with the unfortunate result that they completely missed the maximum phase of the flare, which occurred, according to the Tokyo spectrohelioscope observers at about 0342 hrs, when their spectrohelioscope indicated an $H\alpha$ width of more than 18 Å. The visual observations at Kodaikanal were resumed at 0350 hrs: the width of $H\alpha$ measured at that time was about 4·5 Å. Thereafter, the intensity of the flare as also the width of $H\alpha$ steadily decreased till the end of the flare. Although the Kodaikanal observations are lacking for the maximum epoch, it is nevertheless of particular interest to note that during the pre-maximum and post-maximum phases when the flare was under visual observation with the Prominence Spectroscope the $H\beta$ line was consistently narrower than the $H\alpha$ line (Das *et al.* 1949). With the Prominence Spectroscope the flare was also seen in emission in D_1, D_2, D_3 and b_1, b_2, and b_3 lines. Fig. 2 shows the flare as photographed at Kodaikanal at 0400 hrs with the $H\alpha$ Spectroheliograph. The flare area as estimated from this photograph and corrected for foreshortening exceeds 2000 millionths of the visible hemisphere. However, the estimate of a possibly discontinuous area of emission so close to the limb can be misleading. The Japanese observers, for instance, estimated the flare area to be only 1300 millionths as observed with their spectrohelioscope. On the basis of area it would perhaps be best to rate this flare class 3. Judged by this criterion of class the flare might not, therefore, seem to be anything very exceptional; but it was nevertheless quite unusual in that it was responsible for very special types of cosmic ray and other effects not previously known (*Res. Notes, J. atmos. terr. Phys.*, 1956). There is another interesting and significant point about this particular flare which emerges from the $H\alpha$ spectroheliogram secured at the Kodaikanal Observatory. It is this: It is often said that a flare is rather a burst of radiation than ejection of matter. Some theorists even claim that the flare phenomenon is just a case of electrical discharge in which there is no significant motion of matter. The vertical structure of the flare recorded on the spectroheliogram is, however more readily reconcilable with a considerable movement of matter than with a purely electro-optical discharge phenomenon.

3. Magnetic Records

The magnetograms of the Kodaikanal Observatory showed the usual disturbances associated with important flares, even though this flare occurred so close to the limb. A geomagnetic crochet was clearly recorded on 23 February by the H-components of all the three magnetographs of Kodaikanal, namely Watson, La Cour and Askania. Fig. 3 shows the crochets in the H-traces of the three instruments. All the crochets begin at about 0335 U.T. and end at about 0446 U.T. but

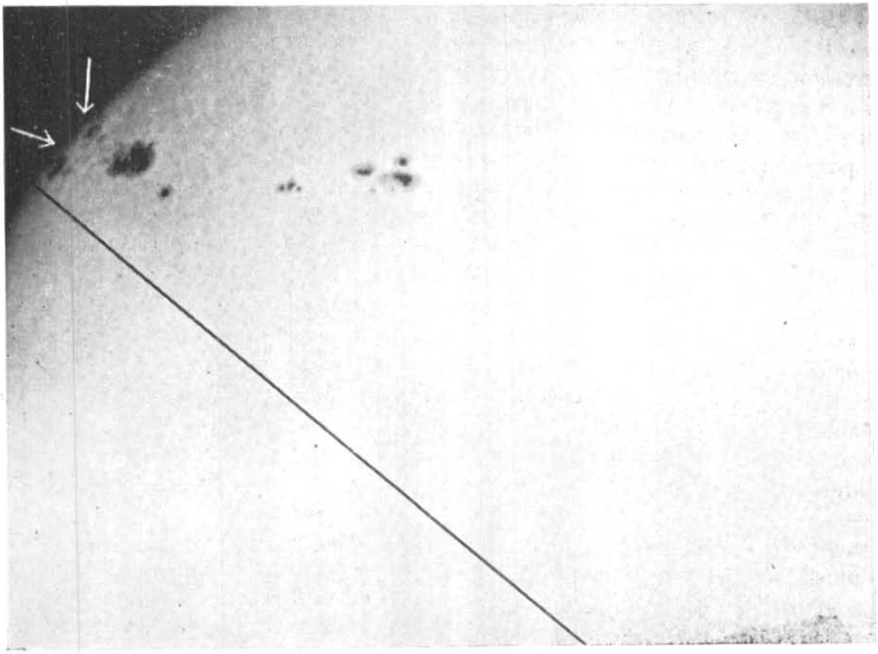

Fig. 1. Photoheliogram at 0217 hrs U.T. showing spotgroup responsible for flare

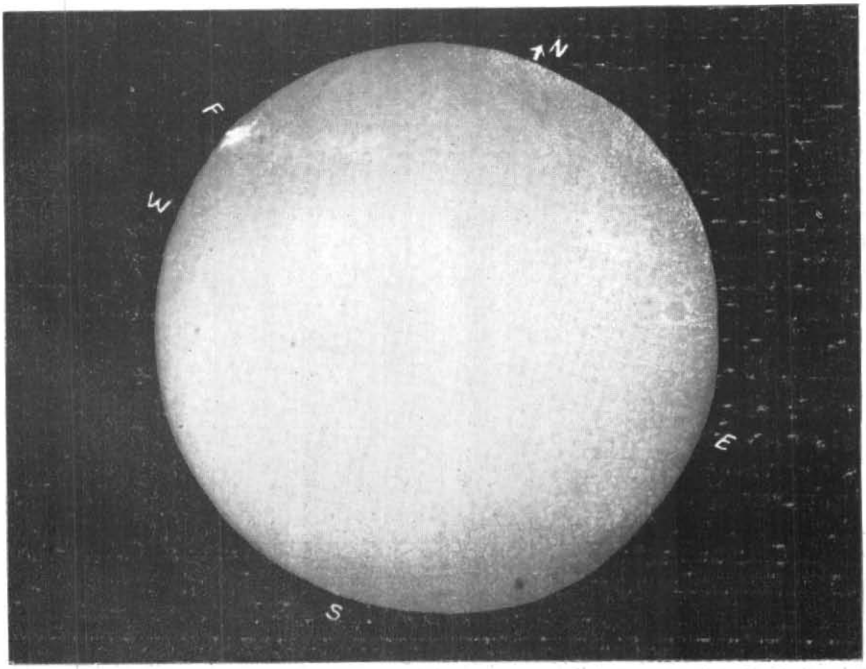

Fig. 2. Spectroheliogram in $H\alpha$ light at 0400 hrs U.T. showing flare at F

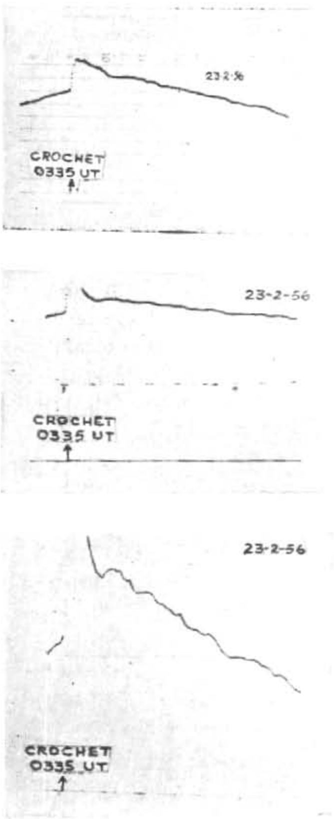

Fig. 3. *H* traces of Askania, La Cour and Watson magnetographs showing Crochet commencing at 0335 hrs U.T. on 23 February 1956

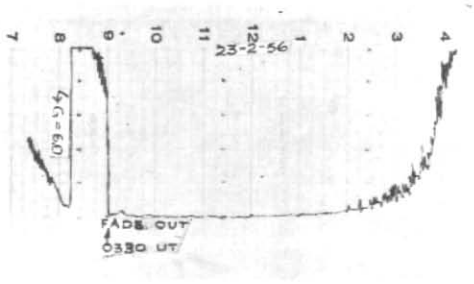

Fig. 4. Field intensity record of radio waves from Ceylon on the 60 m. band showing a Dellinger fade-out commencing at 0330 hrs U.T. on 23 February 1956

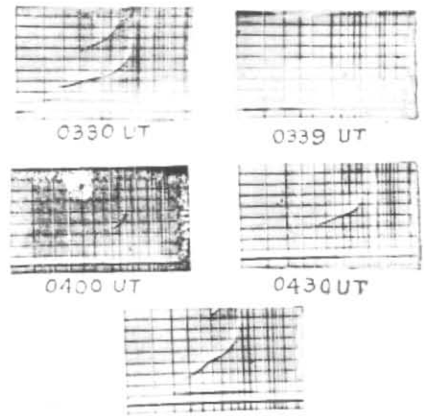

Fig. 5. The h'f ionospheric records between 0330 and 0630 hrs U.T. on 23 February 1956

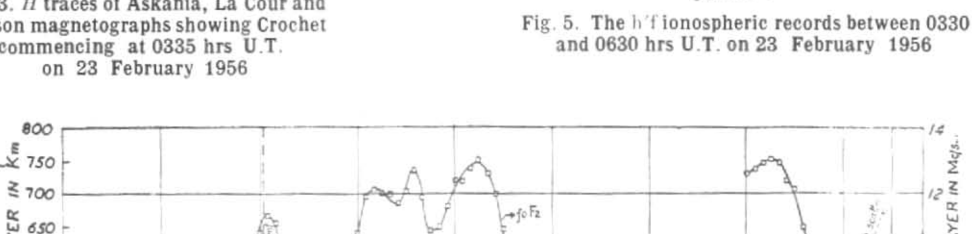

Fig. 6. Critical frequency (foF2) and minimum virtual height (h'F2) variations of F2 layer during geomagnetic disturbance of 25 February 1956

TABLE 1

Observing station	Date	Time U.T. Start.		End.		Type	Amplitudes			Maximum activity Green-wich day	Ranges		
		hr	min	day	hr		*D* ′	*H* γ	*Z* γ		*D* ′	*H* γ	*Z* γ
Kodaikanal	25 February	03	12	26	14	s.c.	1·5*	63*	13*	25	11	[468]	105
Alibag	25 February	03	06	25	22	s.c.	—1·3	39	—14	25	6·4	356	49

Note: [ ] Extrapolated, *Approximate

the maximum amplitude has unfortunately gone off the photographic chart in both the La Cour and Watson traces; however, the crochet is completely recorded on the chart of the photoelectrically recording Askania magnetograph showing a maximum amplitude of 68γ at about 0344 hrs, almost synchronously with the moment when the flare reached its maximum phase according to the spectrohelioscope observations of Tokyo Astronomical Observatory. This is quite according to expectation, as it is now a well-established fact that geomagnetic crochets are caused by the bursts of ultraviolet wave radiation emitted by solar flares.

An examination of the magnetograms of 24–25 February shows that a severe 'sudden commencement type' magnetic storm occurred on 25 February. The storm began with a sudden commencement of amplitude about 63γ in *H* at 0312 hrs on 25 February indicating an interval of nearly 48 hrs between the beginning of the solar flare and the onset of the geomagnetic storm. The corpuscles emitted by the flare, therefore, travelled with a velocity of approximately 868 km/sec. This corpuscular velocity appears to be rather small for a really great flare, but since no other flare of any importance was recorded in the interval the only reasonable conclusion is that the geomagnetic storm of 25 February was indeed associated with the flare of 23 February. It is interesting to note that although this flare appears to have been responsible for the most intense emission of cosmic radiation so far recorded, the geomagnetic storm associated with it is not the severest on record. The data concerning the magnetic storm of 25 February 1956 as derived from the magnetograms of Kodaikanal and of Alibag (Bombay) are summarised in Table 1.

It is evident from this table that the ranges in the three magnetic elements, though quite large, are not exceptional. There have been, in the past, magnetic storms of considerably greater severity; for instance, the s.c. storm of 28–29 March 1946 associated with the great solar flare of 27 March 1946 had a range in *H* amounting to more than 1000γ both at Alibag (1041γ) and at Huancayo (1033γ), while the *H*-range of the storm of 23 February 1956 was under 500γ. In this context it is of interest to recall that four previous examples are also known in which there were sudden increases in the high-energy component of cosmic radiation in association with important solar flares followed by geomagnetic storms. Ellison and Reid (1956) have indicated the time-intervals between the cosmic-ray maximum and the flare maximum for all the five cases. One may wonder if there is any dependence between these time-intervals and the degrees of severity of the magnetic storms. A comparison of the ranges of the geomagnetic storms in all the five known examples with the corresponding time-intervals, however, reveals no systematic relationship between the two quantities.

In the case of the flare of 23 February 1956 the time-interval (cosmic ray maximum *minus* flare maximum) is approximately 18 minutes according to Ellison and Reid. This time-interval becomes slightly less, about 15 minutes, if we derive it from the epoch of flare maximum observed by the Tokyo astronomers and the epoch of cosmic ray maximum from the ratemeter record reproduced by Cranshaw, Galbraith and Porter (1956); we obtain the same value of 15 minutes, if we take the beginning of the flare to be 0330 hrs as observed both at Kodaikanal and at Tokyo with the spectrohelioscope and the start of the increase in Cranshaw, Galbraith and Porter's cosmic ray ratemeter record as 0345 hrs. The time-interval, however, becomes only 10 minutes, if we identify the beginning (0335 hrs) of the geomagnetic crochet recorded by the magnetographs at Kodaikanal with the true beginning of the flare and take the moment of arrival of the cosmic ray particles to be 0345 hrs as above. Assuming that the cosmic ray particles were ejected from the flare region simultaneously with the burst of wave radiation from the flare, the travel-time of the particles from the sun to the earth therefore becomes either 15 minutes +8 minutes = 23 minutes or 10 minutes +8 minutes =18 minutes. The latter value appears to be the better estimate, considering all available optical, geomagnetic, ionospheric and cosmic ray observations; from this estimate the velocity of the cosmic ray particles works out to about 138,000 km/sec. It is interesting to compare this high velocity of solar cosmic ray particles with the velocity of 868 km/sec of the solar particles which, on the same occasion, caused the associated geomagnetic storm. This large velocity ratio is very similar to what Wild, Roberts and Murray (1954) found in their study of the so-called Type II and Type III radio noise bursts associated with solar flares. It is difficult to imagine, in the sun's atmosphere, a really convincing mechanism capable of accelerating solar corpuscles to such widely differing velocities; the process may well be deep-seated and intimately connected with the origin of the flare phenomenon.

4. Ionospheric observations

Two kinds of ionospheric observations are made at Kodaikanal on a routine basis, namely quarter-hourly vertical incidence soundings with a U.S. Bureau of Standards Type C-3 Automatic Multi-frequency Ionosphere Recorder (sweep: 1·0 Mc. to 25·0 Mc. in 30 seconds) and continuous recording of field-intensity of short-waves broadcast by certain transmitting stations. On 23 February 1956 the field-intensity record of radio waves from Ceylon on the 60-metre band (Fig 4) showed a Dellinger fade-out beginning at 0330 hrs which synchronised with the commencement of the flare as observed with the spectrohelioscope at Kodaikanal. The fade-out data derived from this field-intensity record are summarised in Table 2.

TABLE 2

Date	Hrs (U. T.)		Transmitter
	Start.	End.	
23 February 1956	0330	0630	Ceylon Transmitter, 60-metre wavelength

The h'f record of 23 February obtained by vertical incidence soundings by means of the Ionosphere Recorder was normal at 0330 hrs for all ionospheric layers. At 0339 hrs. however, the record revealed a complete Dellinger fade-out in all the ionospheric layers lasting until 0355 hrs. Pulse return from the F_2 region just began at 0400 hrs and by 0630 hrs conditions returned to normal. The ionograms reproduced in Fig. 5 show the sequence of events described above.

From an examination of the relevant ionospheric records along with those of the geomagnetic storm of 25 February much useful information can be derived regarding the perturbations in the F_2 layer over Kodaikanal connected with this magnetic storm. In order to facilitate this study, the observed values of critical frequency and of the minimum virtual height for a period from 1500 U.T. of 24 February to 1800 U.T. of 26 February have been plotted in Fig. 6; the fluctuations in ionic density ($\propto foF_2{}^2$) and in the minimum virtual height from the quiet-day hourly values are represented in Fig. 7, which gives, for purposes of comparison, also the departures $\triangle H$ of the H-component of the geomagnetic field at Kodaikanal obtained by subtracting the absolute hourly values in γ during the storm from the quiet-day values for the corresponding hours superposed on a common time-scale. The values of $\triangle H$ for Alibag obtained by subtracting the hourly values during the storm from the corresponding mean hourly values for the four preceding undisturbed days are also plotted in Fig. 7. In addition, Fig. 7 includes curves of departures $\triangle Z$ of the vertical component of the geomagnetic field both

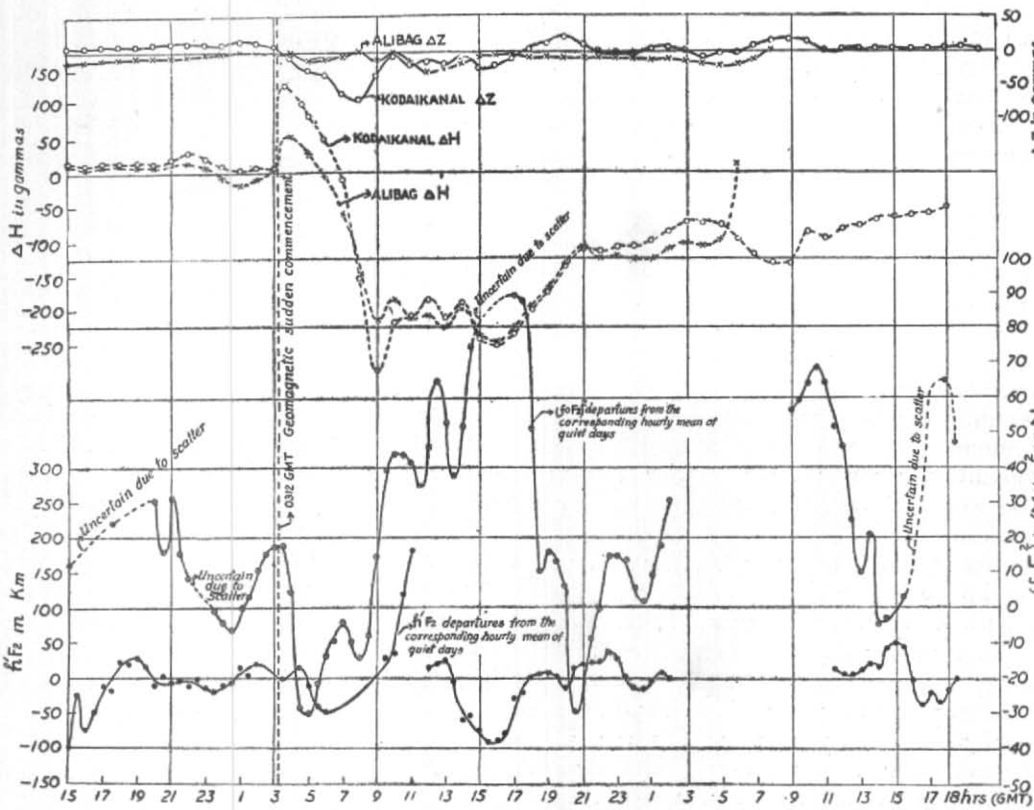

Fig. 7. Fluctuations in ionic density ($\propto$ foF_2^2)and minimum virtual height ($h'F_2$) of F_2 layer during geomagnetic disturbance of 25 February 1956
Departures ($\triangle H$) of the H-component at Kodaikanal and Alibag
Departures ($\triangle Z$) of the vertical component at Kodaikanal and Alibag

at Kodaikanal and at Alibag. The normal diurnal variation of foF_2 at Kodaikanal is represented in Fig. 8 which shows that the ionisation density in the F_2 region falls abnormally rapidly in the pre-dawn hours and has a minimum at midday. These peculiarities, which are common to all stations in the equatorial belt, are due to the fact that the F_2 region over Kodaikanal (situated only 0·6 degree to the north of the geomagnetic equator) departs considerably from the 'simple Chapman region', this departure being caused by solar tidal effect and the consequent vertical drift of ions.

It is clear from Figs. 6 and 7 that, as is usually observed, the ionospheric disturbances associated with the flare of 23 February began almost synchronously with the geomagnetic storm of 25 February which was also caused by the same flare. The electron densities in the F_2 layer showed a general rise due to the effect of the magnetic storm; this appears to be characteristic of equatorial stations, for Berkner and Seaton's (1940) analysis of the ionospheric observations at Huancayo (latitude 0·6 degree south of the geomagnetic equator) during a number of magnetic storms also showed the same effect. But the more striking feature of the F_2 layer perturbations of 25 February was the following : though the rapidity of fall in ionisation density during the pre-sunrise hours of the storm day was somewhat reduced, the midday minimum (or 'bite-out') was enhanced during the storm. This peculiarity appears to lend support to the view advocated by Martyn (1954) that, besides the vertical ionic drift, the diffusion process must also play a significant role in the mechanism of F_2 layer phenomena and that in the neighbourhood of the magnetic equator,

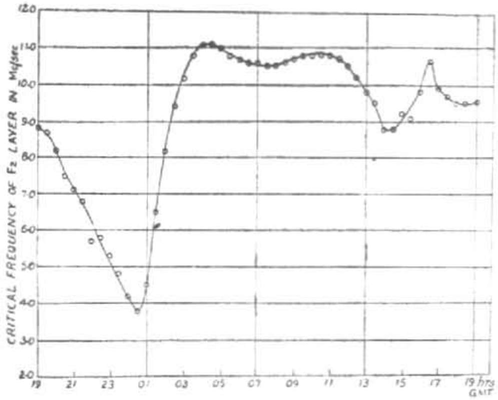

Fig. 8. Normal diurnal variation of foF_2 at Kodaikanal

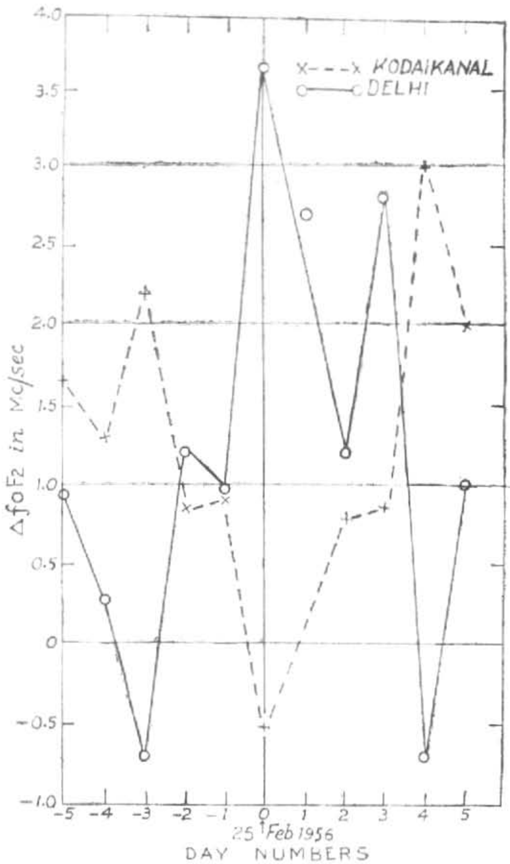

Fig. 9. Superposed epoch curves of ΔfoF_2 illustrating departures of noon F_2 layer critical frequency at Kodaikanal and Delhi based on zero day, *viz*., 25 February 1956 when Kodaikanal showed a storm effect

where vertical diffusion is least active, horizontal diffusion of ions ought to occur along the magnetic lines of force. The enhancement of the midday minimum in F_2 layer ionisation observed at Kodaikanal in association with the geomagnetic storm of 25 February could of course have been brought about by increased vertical drift occasioned by the magnetic storm; but there is evidence to show that in this instance at least horizontal diffusion also was operative causing a transfer of ionisation from the equator to neighbouring low latitudes. This can be seen from Fig. 9 in which the departures of noon values of foF_2 from the monthly mean values both for Kodaikanal and Delhi (geomagnetic latitude: 18°·9N; ionospheric data of Delhi taken from Bulletin No. RRC-A 14 published by C.S.I.R., New Delhi) have been plotted;—on the day of the storm the noon foF_2 value showed markedly *negative* departure at Kodaikanal, but it showed a markedly *positive* departure at Delhi. An examination of the observations of the lower ionospheric layers showed no significant effect of the magnetic storm on these layers.

Another peculiarity of the ionospheric observations at Kodaikanal during the magnetic storm is worthy of mention, namely, the absence of spread F. At Kodaikanal F-scatter is ordinarily present on undisturbed and slightly disturbed nights, but on 25 February there was no sign of it. The implications of this observation are not quite clear.

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