A STUDY OF NOON F_2 IONIZATION IN RELATION TO GEOMAGNETIC CO-ORDINATES

J. N. BHAR AND P. DHAR BHOWMIK

INSTITUTE OF RADIO PHYSICS AND ELECTRONICS, UNIVERSITY OF CALCUTTA

(*Received for publication, October* 10, 1958)

ABSTRACT. The relation of F_2 layer noon critical frequency with magnetic dip and geomagnetic latitude is studied for constant values of solar zenithal angle. The constant-χ plots show two maxima situated on the two sides of the magnetic equator. An asymmetry between the northern and southern hemispheres is also revealed.

For chosen values of solar zenith distance the ratio of noon fF_2 at sunspot maximum to that at sunspot minimum is studied in relation to magnetic dip. The ratio is found to vary with magnetic dip displaying a minimum to the north of the magnetic equator.

I. INTRODUCTION

Chapman's theory of solar ultraviolet radiation producing the ionospheric layers in the upper atmosphere was based on certain simplifying assumptions. Inspite of this, the theory explains with remarkable success* not only the variations in time of the E layer ionization but also its geographical distribution. Routine ionospheric soundings carried out for nearly two decades at stations scattered all over the world have firmly established the validity of this theory in the case of the E layer, so much so that the nature of variations following from Chapman's Law has come to be regarded as "normal". Any departure from this is considered as abnormal or anomalous.

In this sense, the observed variations of the F_2 layer characteristics are found to be anomalous. One aspect of such anomaly was first disclosed by Appleton and Naismith (1935) who in their studies of the seasonal variations of F_2 layer ionization noticed that, fF_2 was less at summer noon than at winter noon, contrary to what is expected from Chapman's theory. Another aspect of the anomalous behaviour of the F_2 layer was also strikingly demonstrated by Appleton (1946) who showed that under equinox noon conditions "there is a belt of low values of f_0F_2 circling the earth and centred roughly on the magnetic equator ".

This equatorial belt effect has been studied subsequently by many workers (Appleton 1950, 1954; Liang 1947; Bailey 1948; Maeda 1955); however, these studies have been made by plotting the value of fF_2 at a given local time at a particular

---

*The remarks apply in regard to the general behaviour of E layer ionization. In finer details, however, certain departures from Chapman's Law have been revealed, attention to which has been drawn by Appleton and Lyons (1957).

epoch of the annual solar cycle against one or other of the geomagnetic co-ordinates. Such a plot obviously includes the possible variations of fF_2 due to varying zenithal angle χ of the sun for stations situated at different geographical latitudes. For example, the solar zenith distance at Singapore (Geographical Latitude 1.3°N) at noon on the equinox day is about 1°, while on the same day the noon value of χ at Slough (Geographical Latitude 51.5°N) is about 52°. According to Chapman's theory the wide difference in the χ value must by itself produce substantial difference in fF_2 at the two stations. In order to have a correct picture of the dependence of F_2 ionization on the geomagnetic field, this contamination due to variation of solar zenith distance must be eliminated. Such a plot should be very useful in examining the manner in which the terrestrial magnetic field might, to the exclusion of other factors, control the geographical distribution of ionization produced by the solar rays.

In a recent note (Bhar 1957) published elsewhere the true relation between noon fF_2 and magnetic dip after the elimination of the effect of solar zenith distance variation from place to place has been depicted using data for the year 1953. In the present paper, the same work has been extended making use of data collected over the period 1952-1955. Certain important aspects of fF_2 behaviour have been discussed on the basis of the observed data.

2. CONSTANT-χ PLOTS

The effect on noon fF_2 caused by the difference in solar zenith distance at different stations has been eliminated by plotting the noon values of fF_2 against magnetic dip or geomagnetic latitude—keeping the solar zenith distance χ as a fixed parameter instead of the equinox or any other epoch of the year. In other words, for stations at different geographical latitudes, such days of the year are selected as to give the same value of χ at noon for all the stations. For convenience, a table may first be prepared showing the dates on which χ_{noon} assumes certain selected values at the different stations. Table I given below is compiled to indicate the dates during the year on which χ_{noon} at the different stations assume the values 0°, 10°, 20°, 30°, 40°, and 50°. (This is followed by Table II which gives the location of each station in geographical as well as in geomagnetic co-ordinates). For each year, for a particular value of χ_{noon} and for a given station, noon fF_2 data for five days centred round the date shown in Table I is averaged. In cases where a particular value of χ_{noon} is attained on more than one date, five days centred round each of these dates are taken and values of noon fF_2 for all these days are averaged. This average value is taken as the representative value of noon fF_2 of the station concerned for the chosen zenith distance. A graph obtained by plotting such values of fF_2 against location (i.e., geographical latitude, geomagnetic latitude or magnetic dip) for different stations for a particular χ_{noon} will, for the sake of brevity, be called a constant-χ plot.

TABLE I

Dates on which solar zenith distance χ assumes certain specified values at noon at different stations

Station	Dates for which $\chi_{noon}=0°$	Dates for which $\chi_{noon}=10°$	Dates for which $\chi_{noon}=20°$	Dates for which $\chi_{noon}=30°$	Dates for which $\chi_{noon}=40°$	Dates for which $\chi_{noon}=50°$
Akita	—	—	May 19 July 25	Apr. 15 Aug. 28	Mar. 20 Sep. 24	Feb. 23 Oct. 20
Bagnoux	--	—	—	May 15 July 29	Apr. 12 Aug. 31	Mar. 18 Sep. 26
Bombay	May 16 July 28	Apr. 13 Aug. 30	Mar. 18 Sep. 26	Feb. 21 Oct. 22	Jan. 17 Nov. 27	—
Brisbane	—	Feb. 1 Nov. 12	Mar. 1 Oct. 13	Mar. 27 Sep. 17	Apr. 23 Aug. 20	June 5 July 8
Calcutta	June 6 July 7	Apr. 23 Aug. 20	Mar. 27 Sep. 17	Mar. 2 Oct. 12	Feb. 1 Nov. 11	—
Canberra		—	Feb. 8 Nov. 4	Mar. 7 Oct. 7	Apr. 2 Sep. 11	Apr. 30 Aug. 13
Capetown		—	Feb. 12 Nov. 1	Mar. 10 Oct. 4	Apr. 5 Sep. 8	May 4 Aug. 9
Casablanca		—	Apr. 27 Aug. 17	Mar. 30 Sep. 14	Mar. 4 Oct. 10	Feb. 5 Nov. 8
Christchurch		—	Dec. 22	Feb 14 Oct. 29	Mar. 12 Oct. 2	Apr. 6 Sep. 6
Dakar	Apr. 30 Aug. 13	Apr. 1 Sep. 11	Mar. 7 Oct. 7	Feb. Nov.		
Delhi	—	May 14 July 30	Apr. 12 Sep. 1	Mar. 17 Sep. 27	Feb. 20 Oct. 23	Jan. 15. Nov. 29
Djibouti	Apr. 20 Aug. 23	Mar. 24 May 28 July 15 Sep. 19	Feb. 28 Oct. 15	Jan. 28 Nov. 15	—	—
Falkland Is.			—	Jan. 13 Dec. 1	Feb. 20 Oct. 24	Mar. 16 Sep. 27
Freiburg			—	May 12 Aug. 1	Apr. 11 Sep. 2	Mar. 16 Sep. 27
Hobart			Jan. 4 Dec. 9	Feb. 16 Oct. 27	Mar. 14 Sep. 30	Apr. 8 Sep. 4
Huancayo	Feb. 18 Oct. 25	Jan. 11 Mar. 16 Sep. 28 Dec. 3	Apr. 10 Sep. 2	May 12 Aug. 1		

TABLE I (*contd.*)

Station	Dates for which $\chi_{noon}=0^\circ$	Dates for which $\chi_{noon}=10^\circ$	Dates for which $\chi_{noon}=20^\circ$	Dates for which $\chi_{noon}=30^\circ$	Dates for which $\chi_{noon}=40^\circ$	Dates for which $\chi_{noon}=50^\circ$
Ibadan	April 9 Sept. 4	Mar. 14 May 9 Aug. 4 Sep. 30	Feb. 16 Oct. 27	Jan. 6 Dec 7	—	
Inverness					May 9 Aug. 4	Apr. 9 Sep. 4
Johannesburg	—	Feb. 5 Nov. 7	Mar 5 Oct. 9	Mar. 30 Sep. 13	Apr. 27 Aug. 16	June 21
Khartoum	May 3 Aug. 10	Apr. 4 Sep. 9	Mar. 9 Oct. 4	Feb 11 Nov. 1	—	—
Macquarie					Feb. 11 Nov. 1	Mar. 9 Oct. 5
Madras	Apr. 25 Aug. 19	Mar. 28 June 10 July 3 Sep. 15	Mar. 3 Oct. 11	Feb. 3 Nov. 10	—	—
Maui	May 24 July 19	Apr. 18 Aug. 25	Mar. 23 Sep. 21	Feb. 26 Oct. 17.	Jan. 25 Nov. 18	—
Nairobi	Mar. 18 Sep. 26	Feb. 21 Apr. 13 Aug. 30 Oct. 22	Jan. 17 May 16 July 28 Nov. 27	—	—	—
Okinawa	—	May 5 Aug. 8	Apr. 6 Sep. 7	Mar. 11 Oct. 3	Feb. 7 Nov. 5	—
Panama	Apr. 14 Aug. 29	Mar. 19 May 18 July 26 Sep. 25	Feb. 22 Oct. 21	Jan. 19 Nov. 24	—	—
Puerto Rico	May 14 July 30	Apr. 12 Sep. 1	Mar. 17 Sep. 27	Feb. 20 Oct. 23	Jan. 15 Nov. 28	—
Poitiers	—	—	—	May 6 Aug. 7	Apr. 7 Sep. 6	Mar. 12 Oct. 2
Raratonga	Jan. 15 Nov. 28	Feb. 20 Oct. 23	Mar. 17 Sep. 26	Apr. 12 Aug. 31	May 13 July 31	—
Shibata	—	—	May 11 Aug. 2	Apr. 10 Sep. 2	Mar. 15 Sep. 28	Feb. 18 Oct. 25
Singapore	Mar. 24 Sep. 20	Feb. 27 Apr. 20 Aug. 24 Oct. 16	May 27 July 17	—	—	—
Slough	—	—	—	May 28 July 15	Apr. 20 Aug. 28	Mar. 24 Sep. 19
Tananarive	Jan. 27 Nov. 17	Feb. 27 Oct. 16	Mar. 24 Sep. 20	Apr. 19 Aug. 24	May 27 July 17	—

TABLE I (*contd.*)

Station	Dates for which $\chi_{noon}=0°$	Dates for which $\chi_{noon}=10°$	Dates for which $\chi_{noon}=20°$	Dates for which $\chi_{noon}=30°$	Dates for which $\chi_{noon}=40°$	Dates for which $\chi_{noon}=50°$
Tiruchy	Apr. 18 Aug. 25	Mar. 23 May 24 July 20 Sep. 21	Feb. 26 Oct. 17	Jan. 25 Nov. 18	—	—
Tokyo	—	—	May 3 Aug. 10	Apr. 4 Sep. 8	Mar. 10 Oct. 4	Feb. 11 Nov. 1
Townsville	Jan. 25 Nov. 19	Feb. 26 Oct. 17	Mar. 22 Sep. 21	Apr. 18 Aug. 25	May 24 July 20	— —
Upsala	—	—	—	—	May 19 July 25	Apr. 15 Aug. 28
Wakkanai	—	—	—	May 2 Aug. 11	Apr. 3 Sep. 9	Mar. 9 Oct. 4
Washington	—	—	May 15 July 29	Apr. 12 Aug. 31	Mar. 17 Sep. 26	Feb. 20 Oct. 23
Yamagawa	—	May 27 July 17	Apr. 19 Aug. 24	Mar. 24 Sep. 20	Feb. 27 Oct. 16	Jan 27 Nov 17

In demonstrating the geomagnetic influence on the worldwide distribution of F_2 region ionization, different workers have plotted fF_2 against different geomagnetic co-ordinates. Of these, geomagnetic latitude has the merit that plots against it are more convenient for mathematical analysis, whereas plots against magnetic dip* generally show the least amount of scatter. In the present paper, fF_2 data are plotted against both geomagnetic latitudes and magnetic dips of the stations.

3. THEORETICAL CONSIDERATIONS

In examining the observed worldwide distribution of local noon ionization of the ionospheric layers it is interesting first of all to know what one should expect from theoretical considerations. Evidently, Chapman's theory provides a good starting point for this purpose. The simplifying assumptions made by Chapman were that the upper atmosphere is isothermal—the constituent gases being distributed accordingly, that the ionizing radiation from the sun is monochromatic, and that the electrons and ions produced decay by simple recombination. It is now known that these assumptions are substantially valid for the case of the E and F_1 layers ; or at any rate, if there are departures from these

---

*Magnetic dip [as distinguished from geomagnetic dip given by $I = \tan^{-1} 2 \tan \lambda$, where λ is the geomagnetic latitude.

TABLE II

Values of geographical coordinates, geomagnetic latitude and magnetic dip of the respective stations

Station	Geog. Latitude	Geog. Longitude	Geomag. Latitude	Magnetic Dip
Akita	39.7°N	140.1°E	29.5°N	53°N
Bagneux	48.8°N	2.3°E	51.3°N	64°N
Bombay	19°N	73°E	9.7°N	24°N
Brisbane	27.5°S	153°E	35.9°S	56°S
Calcutta	22.6°N	88.4°E	11.9°N	31°N
Canberra	35.3°S	149°E	44°S	64.5°S
Capetown	34.2°S	18.3°E	33°S	60.5°S
Casablanca	33.6°N	7.6°W	38.5°N	50.5°N
Christchurch	43.5°S	172.7°E	48°S	68°S
Darkar	14.6°N	17.4°W	21.6°N	26°N
Delhi	28.6°N	77.1°E	18.9°N	41°N
Djibouti	11.5°N	43.1°E	6.8°N	5°N
Falkland Is.	51.7°S	57.8°W	40.4°S	46°S
Freiburg	48.1°N	7.8°E	49.4°N	63.5°N
Hobert	42.8°S	147.4°E	51.4°S	71.5°S
Huancayo	12°S	75.3°W	0.6°S	0°
Ibadan	7.4°N	4°E	10.4°N	2.5°S
Inverness	57.4°N	4.2°W	60.8°N	70.5°N
Johannesburg	26.2°S	28°E	26.7°S	59°S
Khartoum	15.6°N	32.6°E	12.9°N	13°N
Macquarie	54.5°S	159°E	61°S	79°S
Madras	13°N	80.2°E	3.1°N	11°N
Maui	20.8°N	156.5°W	20.7°N	38.5°N
Nairobi	1°S	37°E	4.2°S	25°S
Okinawa	26.3°N	172.8°E	15.3°N	36°N
Panama	9.4°N	79.9°W	20.7°N	35.5°N
Puerto Rico	18.5°N	62.2°W	30°N	51°N
Poitiers	46.6°N	0.3°E	49.1°N	62.5°N
Raratonga	21.3°S	159.8°W	21.S	38.5°S
Shibata	37.9°N	139.3°E	27.6°N	51°N
Singapore	1.3°N	103.8°E	10.1°S	16°S
Slough	51.5°N	0.6°W	54.3°N	66°N
Tananarive	18.8°S	47.8°E	23.8°S	52.5°S
Tiruchy	10.8°N	78.8°E	1°N	5°N
Tokyo	35.7°N	139.5°E	25.5°N	49°N
Townsville	19.3°S	146.8°E	28.4°S	46°S
Upsala	59.8°N	17.6°E	58.4°N	70.5°N
Wakkanai	45.4°N	141.7°E	35.4°N	59°N
Washington	38.7°N	77.1°W	50°N	70°N
Yamagawa	31.2°N	130.6°E	20.3°N	43.5°N

assumptions, these are not likely to affect substantially the behaviour of these layers so far as the latitude distribution of the ionization at local noon is concerned.

E and F_1 layers :

The basic continuity equation resulting from Chapman's simple theory is

$$\frac{dN}{dt} = q - \alpha N^2 \qquad \ldots \quad (1)$$

where N is the density of ionization, q is the rate of electron production per c.c. and α is the coefficient of recombination.

It is now established from observed data that in the case of E and F_1 layers, quasi-stationary conditions obtain roundabout noon; that is, dN/dt is negligible compared to the other two terms of the above equation. Under this condition the maximum value of N for the layer near noon is given by

$$N_m = \sqrt{\frac{q_0 \cos \chi}{\alpha}} \qquad \ldots \quad (2)$$

where χ is the sun's zenith distance at the time and q_0 is the value of q for $\chi = 0°$. At any station and in any season χ attains its daily maximum value at noon which we shall denote by χ_{noon}. The noontime maximum electron density is thus

$$N_{noon} = \sqrt{\frac{q_0 \cos \chi_{noon}}{\alpha}} \qquad \ldots \quad (3)$$

The expression indicates that N_{noon} and hence noon-time critical frequency of the layer is uniquely determined by χ_{noon} in a particular epoch of the solar cyclo, and is independent of the location of the station.

Thus, if fE_{noon} or fF_{1noon} is plotted against the location of a station (i.e., geographical latitude, geomagnetic latitude or magnetic dip) for a fixed value of χ_{noon}, the resulting constant-χ plot is expected to be a straight line.

F_2 layer :

An attempt to make a theoretical deduction regarding the latitude distribution of noon F_2 ionization presents formidable difficulties. Even assuming that there is no appreciable departure from the assumptions made in Chapman's theory, which appears improbable, a complication arises in the case of the F_2 layer due to the fact that dN/dt is not negligible i.e. quasi-stationary conditions do not obtain even at noon and the simple $(\cos \chi)^{\frac{1}{2}}$ law (Eq. 2) for N_m does not hold. In order to estimate the latitude distribution one has to resort to numerical solutions of Eq. 1. This was done by Millington (193?) who gave a series of curves representing the diurnal variation of ionization of the layer at different latitudes and in different seasons. From the curves for $\sigma_0 = 1$ $(\sigma_0 = 1/1.37 \times 10^4 \sqrt{q_0 \alpha})$ which may be assumed to fit the F_2 layer for the sunspot minimum period, one can estimate the values of N_{noon} for the F_2 layer at different geographical latitudes for a series of chosen values of χ_{noon}, say 0°, 10°, 20°, 30° and 40°. It is found that the plot of noon fF_2 against latitude for any of these values of χ_{noon} is a straight line with deviations not greater than $\pm$ 5%.

Thus, according to Chapman's theory the constant-χ curves for the F_2 layer would also be straight lines for all practical purposes.

Evidences, both theoretical and observational, collected during recent years, indicate, however, that the assumptions made in Chapman's theory require considerable modification. This is true in particular for the assumption regarding the process of electron decay. Extensive work has been done on various possible processes of electron decay in the F_2 region levels and it is believed that a decay rate represented by the αN^2 law may not be true for this region. Nevertheless, if the electrons produced are assumed to appear and disappear at the same spot in the ionosphere, as is implied in Chapman's theory, it is likely that the noon-time ionization of the F_2 region for a given value of χ_{noon} will not vary substantially from place to place over a wide range of latitudes, whatever be the actual process or processes of electron decay. In other words, the constant-χ plots would still approximate straight lines.

Recent studies indicate, however, that the appearance and disappearance of the electrons do not take place at the same spot The electrons (and ions) produced by solar ultraviolet radiation are subject to tidal and other forces, which cause them to drift (Martyn 1947, 1954). It now appears that the resulting motion of the electrons under the influence of the earth's magnetic field plays an active part in determining the ionization density of the upper regions of the ionosphere in relation to the terrestrial magnetic co-ordinates, and thus controls the worldwide distribution of the F_2 ionization.

4. DISCUSSION OF OBSERVED DATA

(i) *Constant-χ plots* : In figure 1 (*a, b, c,* & *d*) constant-χ plots of noon fF_2 against magnetic dip have been depicted for the four years 1952-55 which are centred more or less round the period of minimum sunspot activity. Figure 2 (*a, b, c* & *d*) shows the same plots depicted against geomagnetic latitude. For the sake of comparison constant-χ plots of noon fF_2 depicted against magnetic dip and against geomagnetic latitude are also shown for the sunspot maximum year 1948 in figures 3 and 4. It will be seen that the plots against megnetic dip show less scatter than those against geomagnetic latitude.

It is noted that the features reported previously (Bhar, 1957) on the basis of the data for 1953 are repeated in all the years. For example, for $\chi = 0°$, noon fF_2 is minimum at the magnetic equator and attains maximum values roughly at $\pm$ 30° magnetic dip. The variation of fF_2 with magnetic dip follows nearly

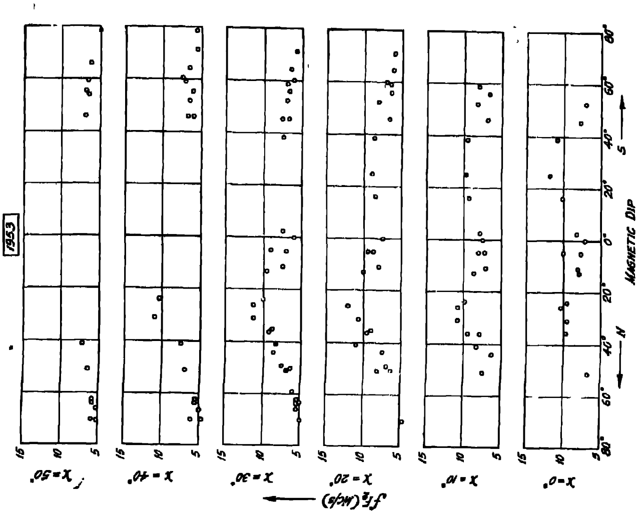

Fig. 1(*b*). Constant-χ plots of noon fF_2 against magnetic dip for χ = 0°, 10°, 20°, 30°, 40° and 50° for 1953.

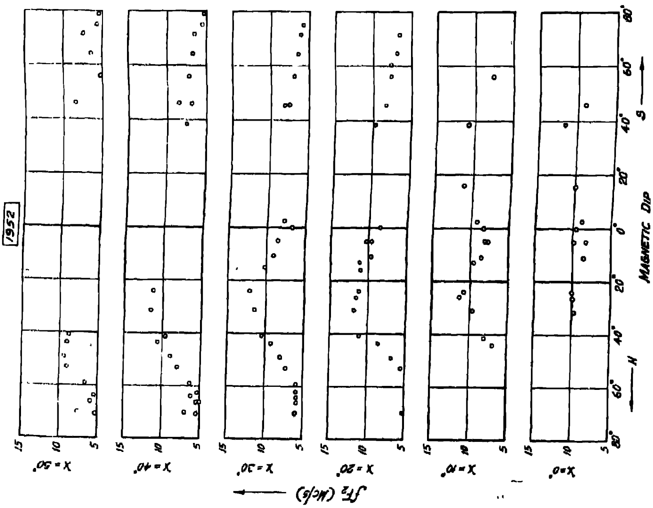

Fig. 1(*a*). Constant-χ plots of noon fF_2 against magnetic dip for χ = 0°, 10°, 20°, 30°, 40° and 50° for 1952.

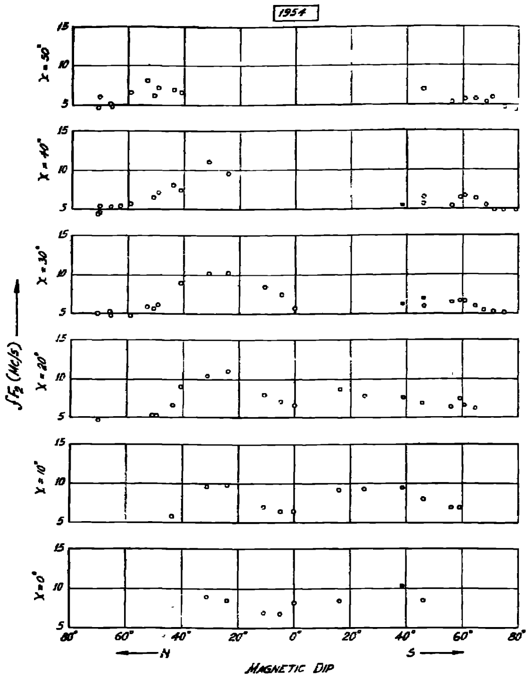

Fig. 1(c). Constant-χ plots of noon fF_2 against magnetic dip for χ = 0°, 10°, 20°, 30°, 40° and 50° for 1954.

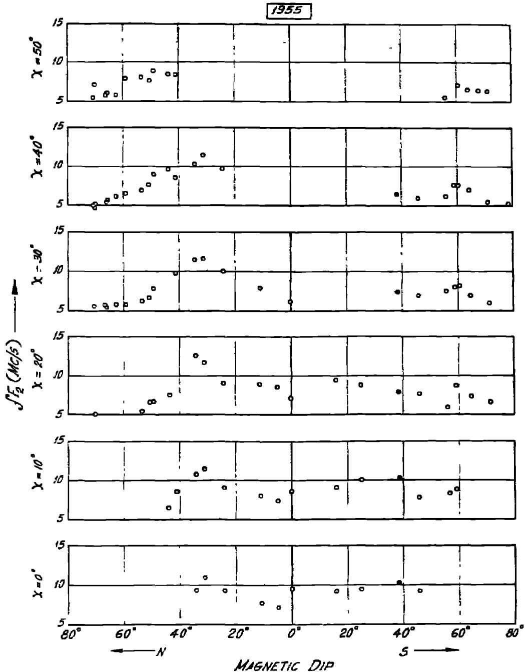

Fig. 1(*d*). Constant-χ plots of noon fF_2 against magnetic dip for χ = 0°, 10°, 20°, 30°, 40° and 50° for 1955.

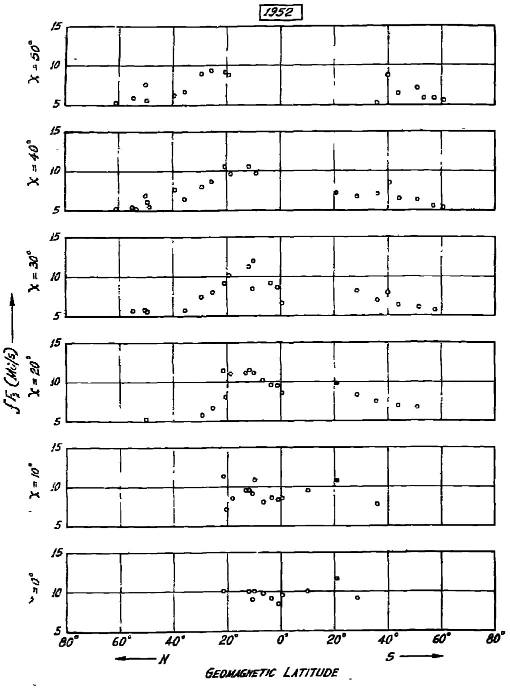

Fig. 2(*a*). Constant-χ plots of noon fF_2 against geomagnetic latitude for χ = 0°, 10°, 20°, 30°, 40°, 50° for 1952.

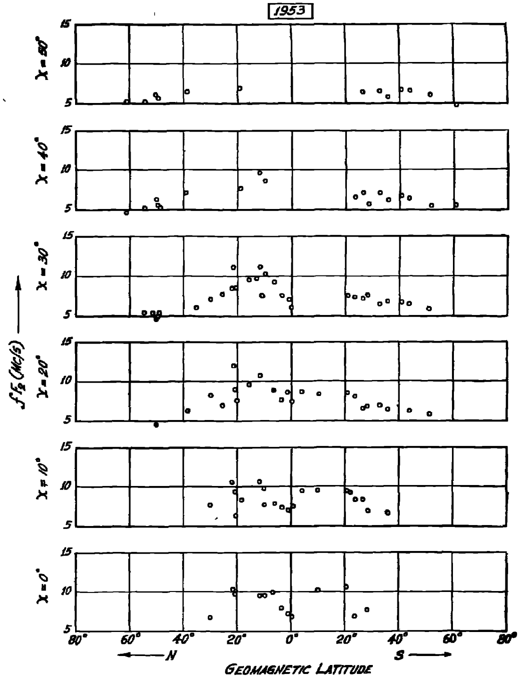

Fig. 2(*b*). Constant-χ- plots of noon fF_2 against geomagnetic latitude for χ = 0°, 10°, 20°, 30°, 40°, 50° for 1953.

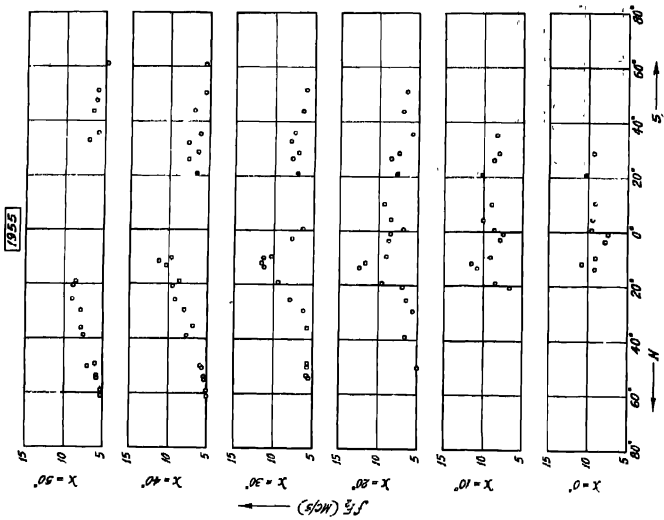

Fig. 2(d). Constant-χ plots of noon fF_2 against geomagnetic latitude for χ = 0°, 10°, 20°, 30° 40° and 50° for 1955.

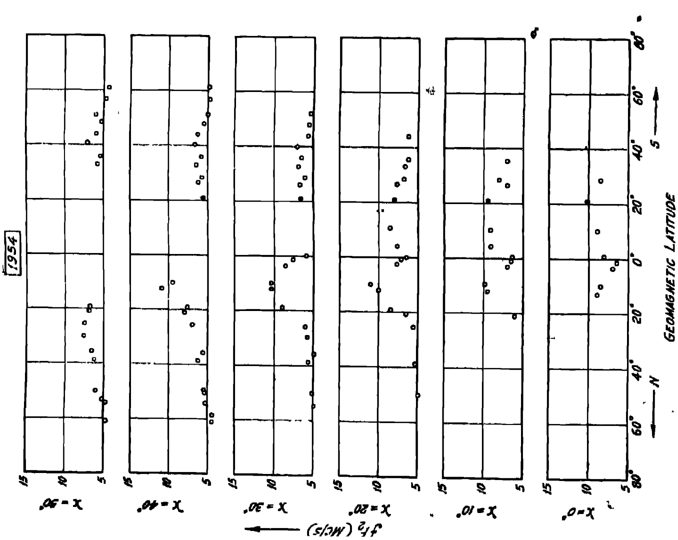

Fig. 2(c). Constant- χ plots of noon fF_2 against geomagnetic latitude for χ = 0°, 10°, 20°, 30°, 40° and 50° for 1954.

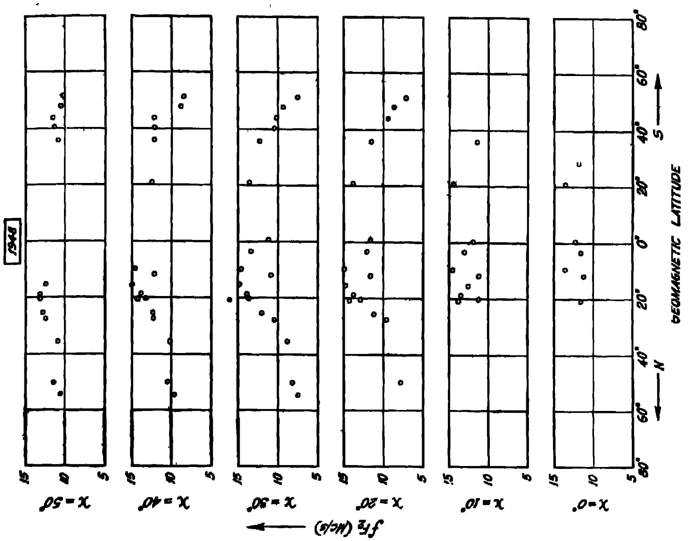

Fig. 4. Constant-χ plots of noon fF_2 against geomagnetic latitude for the sunspot maximum year 1948.

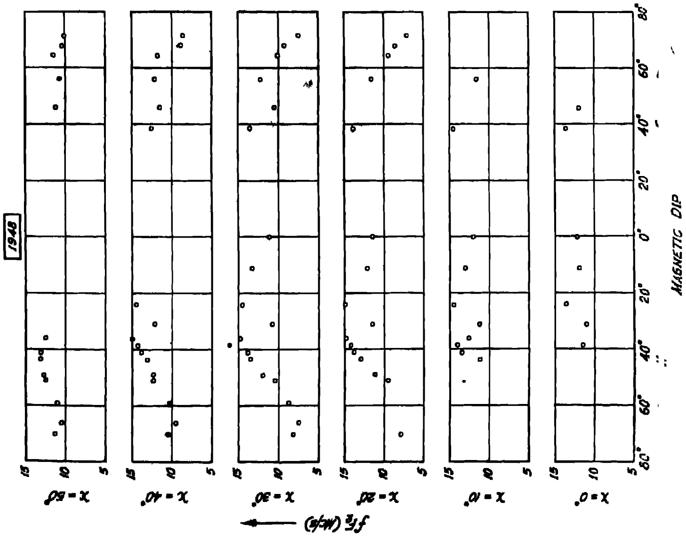

Fig. 3. Constant-χ plots of noon fF_2 against magnetic dip for the sunspot maximum year 1948.

the same trend for $\chi = 10°$. For $\chi = 20°$ and $30°$ respectively the peak on the north and the minimum at the magnetic equator are clearly maintained. But the peak to the south of the magnetic equator loses prominence. The southern peak gets flattened out as χ increases from 0° to higher values.

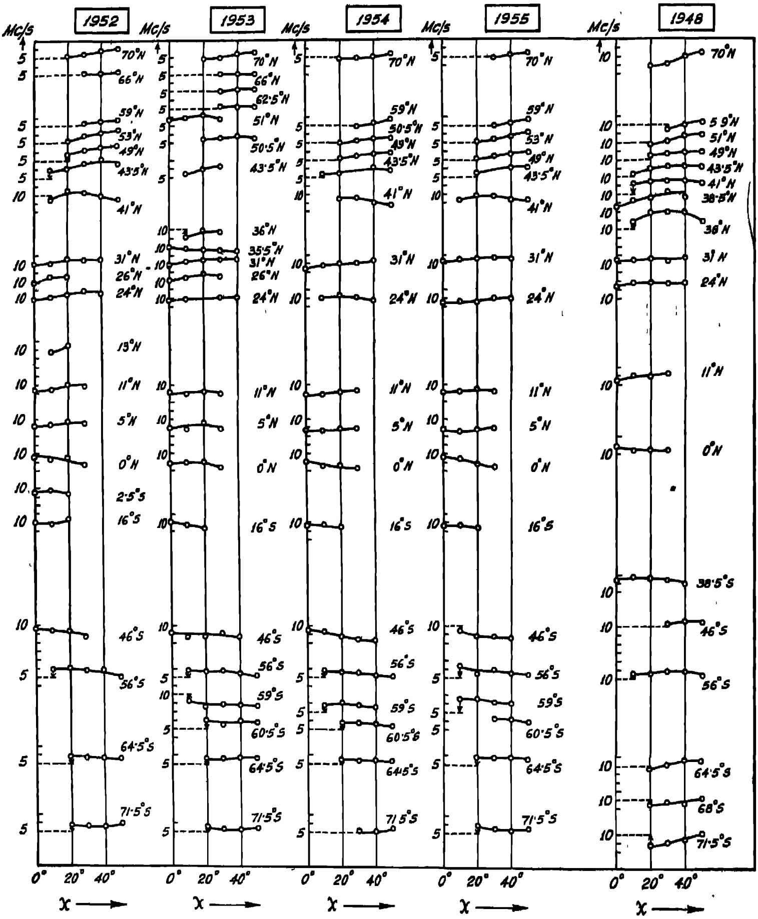

Fig. 5. Variation of average fF_2 against noon χ-values for respective stations for the years 1952–55 and 1948. Stations are arranged in order of magnetic dip (magnetic dip value is indicated on right hand side of each curve). Scale of ordinate :—Each small division represents 2.5 Mc/s. Arrows indicate reference levels.

In the plots against geomagnetic latitude (figures 2 and 4), the peaks appear at 10° to 15° north and south; the flattening of the southern peak for higher values of χ is also clearly noticeable in these figures.

(ii) *North-South anomaly in $f\mathrm{F}_2$—I relation* : Although paucity of data in the southern hemisphere dictates caution in making inferences in any detail, there seems to be no escape from the conclusion that the relation between noon $f\mathrm{F}_2$ and magnetic dip (for constant χ) exhibits some amount of asymmetry in behaviour about the magnetic equator. The observed facts on which this statement is based are discussed below.

In the first place, as observed above, for high values of χ (20° onward) the southern peak of each plot appears to be more or less flat in contrast with the northern portion.

Secondly, if the variations of noon values of $f\mathrm{F}_2$ with season, i.e., with χ is plotted for different stations north and south of the magnetic equator, the curves obtained exhibit dissimilar nature in the two hemispheres. Had the relation between noon $f\mathrm{F}_2$ and I (magnetic dip) been symmetrical about the magnetic equator the $f\mathrm{F}_2$—I curves of figures 1 to 4 should have been substantially alike in both the hemispheres. In fact, speaking in a very general way, noon $f\mathrm{F}_2$ appears to increase with χ for northerly stations whereas it decreases with χ for southerly stations. Figure 5 shows this for the four years from 1952 to 1955. Such north-south anomaly in the seasonal behaviour of noon $f\mathrm{F}_2$ has also been noticed earlier (Berkner and Wells, 1938). It is found, however, that similar curves drawn for the sunspot maximum year 1948 and depicted in the same figure for comparison, do not show this north-south anomaly. On the contrary, the curves exhibit a general increase of $f\mathrm{F}_2$ from low to high values of χ_{noon} in both hemispheres.

(iii) *Decrease of noon $f\mathrm{F}_2$ from sunspot maximum* (1948) *to sunspot minimum* (1954) : It is known that the value of noon $f\mathrm{F}_2$ at a particular station follows the solar cycle attaining a maximum during the epoch of maximum sunspot activity. Figure 6 depicts the ratio of noon $f\mathrm{F}_2$ at the epoch of sunspot maximum (1948) to that at the epoch of sunspot minimum (1954) plotted against magnetic dip for chosen constant values of χ_{noon}. In plotting the curves, the values of noon $f\mathrm{F}_2$ have been estimated from the plots of figures 1 and 3 by interpolation.

The plots show that the ratio varies with magnetic dip exhibiting clearly a minimum north of the magnetic equator. This means that the decrease of noon $f\mathrm{F}_2$ from sunspot maximum to sunspot minimum is not in the same proportion at all places.

5. CONCLUDING REMARKS

The information obtained from the analysis presented here indicates clearly that for constant solar zenith distance noon F_2 ionization is not the same everywhere but varies with magnetic dip or geomagnetic latitude. Furthermore, the shape of the constant-χ plots varies with the sunspot cycle. To explain these facts, which are not expected from Chapman's theory, two alternative possibilities suggest themselves. In the first place, the source of ionization of the F_2 region is not the sun or at least predominantly not so. Alternatively, the solar ultraviolet radiation is the main source of ionization but the observed variation with magnetic co-ordinates of the earth is the result of a balance between gain and loss of electrons at the site of observation, produced by processes more complicated than envisaged earlier. The authors believe that the latter alternative is more likely to be the correct explanation and that, besides the primary processes of solar photon absorption producing electrons and of recombination, attachment, etc., causing electron decay, the transport of electrons from one place to another under the influence of the terrestrial magnetic field govern *both* the gain and loss of electrons at any site.

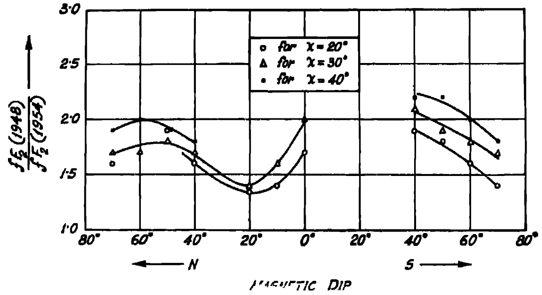

Fig. 6. Ratio of noon fF_2 in sunspot maximum year 1948 to that in sunspot minimum year 1954 plotted against magnetic dip for three different values of solar zenith distance.

Another phenomenon revealed by the analysis of the 1952-55 data is that even though the variation of noon F_2 ionization has a dip near the terrestrial magnetic equator with peaks on either side, the variation is by no means symmetrical about the equator. We consider this asymmetric behaviour in the two hemispheres as a significant phenomenon and any theory attempting to explain the equatorial depression of F_2 ionization should, in order to be complete, also explain this asymmetry.

ACKNOWLEDGMENTS

The authors are indebted to Professor S. K. Mitra for his kind interest in the work.

One of the authors (P.D.) is grateful to the Ministry of Scientific Research and Cultural Affairs, Government of India, for the grant of a Senior Research Training Scholarship.

REFERENCES

Appleton, E. V., 1946, *Nature*, 157, 691.

" 1950, *J. Atmos, Terr Phys.*, **1**, 106.

" 1954, *J. Atmos Terr. Phys.*, **5**, 349.

Appleton, E. V. and Lyon, A, J., 1957, *J. Atmos. Terr. Phys.*, **10**, 1.

Appleton, E. V. and Naismith, R, 1935, *Proc. Roy. Soc, A.*, 150, 685.

Bailey, D. K., 1948, *Terr. Mag. Atmos. Elect.*, **53**, 35.

Berkner, L. V. and Wells, H W., 1938, *Terr. Mag. Atmos. Elect.*, **43**, 15.

Bhar, J. N., 1957, *J. Atmos. Terr. Phys.*, **10**, 168.

Liang, P. H., 1947, *Nature*, 160, 642

Maeda, H., 1955, *Rep. Ionos. Res., Japan*, **9**, 60.

Martyn, D. F., 1947, *Proc. Roy. Soc. A*, **189**, 241.

" 1954, The Physics of the Ionosphere, p. 254 (Phys. Soc., London)

Millington, G., 1932, *Proc. Roy. Soc. A*, **44**, 580.