SOLAR ECLIPSES AND IONOSPHERIC THEORY

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(Received 1 March, 1968)

Abstract. This paper discusses the bearing that eclipse observations have on contemporary theories of the ionospheric E and F regions; in particular, on the determination of production and loss rates, and on the role of diffusion and temperature changes. Various complicating factors that arise are discussed, but the paper is not intended as a comprehensive survey of results obtained.

1. Introduction

A. SCOPE OF THE PAPER

From the earliest days of ionospheric research, great interest has been taken in the effects of solar eclipses. This is shown by the bibliography, 'Literature on Solar Eclipses and the Ionosphere', containing about 200 items dated from 1912 to 1955, which is appended to the book *Solar Eclipses and the Ionosphere* (Beynon and Brown, 1956). The book is a report on the symposium held in London in 1955, and contains a very full record of the subject as it existed at the time. Since then there have been many new developments.

Observations during an eclipse offer a special opportunity for studying both the solar ionizing radiations and the earth's ionosphere. They are not ideal for this purpose. The ionospheric physicist might wish that the sun could be regarded as a constant, uniform source of ionizing radiation; but investigations of the sun show that it is not. The solar physicist would like to regard the ionosphere as a detector for ionizing radiation. But the ionosphere does not meet the basic requirements of a good detector: straightforward operation, reproduceability, and a linear or other convenient type of response.

These remarks must be qualified. The high angular resolution provided by the moon's limb does make it possible to locate active regions on the solar disk. In this regard eclipse observations certainly contribute to solar physics. Also, the lower ionosphere – the D region below 90 km – seems to be quite a good detector for X-rays.

If, on the other hand, eclipse observations are to be used to study the ionosphere itself, detailed electron density information is desirable. For the E and F layers, this can be obtained by means of ionosondes; but for the D region, the ground-based techniques are more difficult, and there is not the wealth of data that exists for the other layers. Although some striking results have been obtained from rocket observations of the eclipsed D region (Smith *et al.*, 1965; Bowling *et al.*, 1967), they are not yet sufficient to permit a detailed discussion of the very complex physical situation which must then exist. Consequently the D region is not included in the scope of this article.

Space Science Reviews **8** (1968) 543–554; © *D. Reidel Publishing Company, Dordrecht-Holland*

The paper deals with the bearing of eclipse phenomena on the theory of the ionospheric E and F regions. It is not a compendium of results obtained. Section 2 of the paper is concerned with what might be called the 'classical approach' to eclipse analysis, which employs the well-known continuity equation for the electron density, and seeks to determine the rates of production and loss of ionization. Many of its results have been documented by RATCLIFFE (1956a) in the report of the 1955 Symposium. Sections 2.B–D of the present paper deal respectively with the E, F1 and F2 layers, and discuss various matters which arise in the interpretation of eclipse data.

Some of the most interesting new studies are those relating to transport and thermal processes, which are of greatest importance in the F region; these processes are electromagnetic movements, plasma diffusion, and temperature changes (Sections 3.A–C in this paper). The conclusions of the paper are recapitulated in Section 4.

B. THE IONOSPHERIC LAYERS BY DAY

It is convenient to summarize some outstanding features of the daytime ionosphere, together with some basic theoretical ideas (e.g. YONEZAWA, 1966).

The E layer is produced by two bands of solar radiation: soft X-rays in the wavelength range 10–170 Å approximately, and ultraviolet radiation between the ionization limits of atomic oxygen at 911 Å and molecular oxygen at 1027 Å. The rate of loss of ionization is given by the 'square law' formula αN^2, where α is the recombination coefficient. Typically the peak electron density $N_m\mathrm{E} = (1\text{–}2) \times 10^5\ \mathrm{cm}^{-3}$ at a height $h_m\mathrm{E} \simeq 110$ km.

The F1 layer is produced by ultraviolet radiation, longer than about 170 Å and shorter than the ionization limit of atomic oxygen at 911 Å. The helium emission lines at 304 Å and 584 Å are included in this band. Typically $N_m\mathrm{F1} = (2\text{–}4) \times 10^5\ \mathrm{cm}^{-3}$ and $h_m\mathrm{F1} \simeq 170$ km, but the F1 layer is observable as a distinct feature only under certain circumstances. This can be explained if the F1 layer is assumed to lie at a level of transition between the domains of the 'square law' loss formula αN^2 and the 'linear' formula βN (RATCLIFFE, 1956b).

The F2 layer is produced by the same radiation as F1, but its electron density is greater because the linear loss coefficient β decreases upward more rapidly than does the production rate q. The F2 peak occurs at about 250–350 km, and is thought to represent a level above which plasma (ambipolar) diffusion, and other transport processes, become more important than production and loss in determining the electron density distribution. The peak electron density $N_m\mathrm{F2}$ varies greatly but is generally in the range $(4\text{–}20) \times 10^5\ \mathrm{cm}^{-3}$.

2. Determination of Production and Loss Rates from Eclipse Data

A. THE BASIC EQUATIONS

The first important conclusion to be drawn from ionospheric eclipse data is that, since the effects in the E and F1 layers occur at about the same time as the visible eclipse, these layers are produced by solar photon radiation (APPLETON and CHAPMAN, 1935). One can show that if the ionization were produced by energetic particles emitted from the sun, and travelling slower than light, the interruption of the beam by the moon would occur some time before the visible eclipse. For the F2 layer the observations provide a less decisive test, because even on normal days N_mF2 can fluctuate by 10% from hour to hour, so any 'particle eclipse' effect would be difficult to identify. As will be seen later, eclipse effects in low latitudes seem consistent with photo-ionization (rather than particle) production of the F2 layer.

In numerical studies of eclipse effects, it is usual to start with the continuity equations for the electron density variations $N(t)$ at a fixed height:

$$\mathrm{d}N/\mathrm{d}t = E(t)\,q(t) - \alpha N^2 \tag{1}$$

$$\mathrm{d}N/\mathrm{d}t = E(t)\,q(t) - \beta N \tag{2}$$

Here $q(t)$ is the time-varying production rate in the absence of the eclipse; and $E(t)$ is the 'eclipse' function. All quantities in these equations, including $E(t)$, may be functions of height (h). Often $E(t)$ is taken to be the geometrical fraction of the sun's disk not obscured by the moon; this assumption implies that $E(t)=0$ at totality, which is not necessarily correct. Generally Equation (1) is used for the E layer and Equation (2) for the F2 layer; for the F1 layer the loss term is really more complex, but in practice the simple Equation (1) is often used. APPLETON (1953) showed that according to these equations, changes of N should theoretically lag behind changes in q by a time constant (the so-called 'sluggishness') given by $1/2\alpha N$ for (1) and $1/\beta$ for (2).

B. E LAYER RESULTS

By comparing the observed $N(t)$ curves with the theoretical Equation (1), it is possible to estimate q and α. Sometimes only the peak electron density N_mE is considered in the analysis, in which case the results obtained do not necessarily apply to a fixed height. During eclipses abrupt changes of dN/dt often occur, and are attributed to the covering or uncovering of active areas on the sun. If data from a number of stations are collated, the active areas can be located (e.g. MINNIS, 1958a; NESTOROV and TAUBENHEIM, 1962). Often the more intense sources are found towards the solar limb, and it is thought that 10% or so of the ionizing radiation originates in the solar chromosphere and corona and is not cut off at totality. If much of this radiation originates from the chromosphere, then there should exist a connection between the 'eclipse magnitude' (ratio of the angular diameters of the moon and sun) and the eclipse effect in the E region.

The determinations of α are very sensitive to the residual production rate at totality. With the assumption that the eclipse function $E(t)=0$ at totality, it is generally deduced that $\alpha \sim 10^{-8}$ cm^3 sec^{-1}; but if $E(t)$ is taken to be of order 0.1, the data usually give $\alpha \sim 10^{-7}$ cm^3 sec^{-1}. In some cases indefinitely large values of α can be made to fit the observations, provided that correspondingly large values of q are adopted.

Actually there are two important pieces of evidence, not obtained from eclipses, that 10^{-7} cm^3 sec^{-1} is the correct order of magnitude of α. The first comes from rocket measurements of the solar ionizing radiation under normal conditions, by which means ALLEN (1965) found $\alpha = 1.6 \times 10^{-7}$ cm^3 sec^{-1} for the E layer. The second is that laboratory measurements of recombination coefficients favour values of order 10^{-7} cm^3 sec^{-1} (e.g. BIONDI, 1964). Thus, if eclipse observations are to give useful information about α, it is important to investigate the residual production rate at totality.

In the normal E layer, there is a good correlation between N_mE and the flux of solar decimetric radiation (MINNIS and BAZZARD, 1959). According to radio astronomical measurements during a number of eclipses, summarized by CASTELLI and AARONS (1965), the residual solar flux of 10 cm wavelength is about 5–15%. Similar percentage residuals have been measured for X-rays of 44–60 Å – a possible source of E layer ionization – by rocket experiments during eclipses (KREPLIN, 1961; SMITH *et al.*, 1965). Unfortunately it is not known whether there is detailed correlation between production rates and solar 10 cm flux throughout an eclipse, even though such a correlation exists on a day-to-day basis.

Another complication arises from the complex photochemistry of the ionosphere. The simple analysis based on Equation (1) tacitly assumes that a single recombination coefficient α exists in the E region. BATES and MCDOWELL (1957) and BOWHILL (1961) pointed out that certain E region phenomena, including some eclipse effects, might result from the existence of two species of positive ions possessing different recombination coefficients. But although two main species of ion, NO^+ and O_2^+, have indeed been found in the E region by rocket-borne mass spectrometers (JOHNSON *et al.*, 1958), their recombination coefficients probably do not differ to the required extent. Moreover, MINNIS (1958b) and MCELHINNY (1959) did not find this idea too successful in explaining actual eclipse data. It is clear that information about the ion composition is essential to any detailed study of the E layer and indeed of the F1 layer also. At these heights, such information only seems obtainable by the use of rocket-borne instruments, or by the incoherent scatter technique (EVANS, 1967).

C. F1 LAYER RESULTS

Very similar remarks apply to the analysis of F1 layer eclipse data. The values of α which are generally obtained are similar to those found for the E layer, perhaps slightly smaller, but as mentioned earlier the loss coefficient in the F1 layer is not expected to conform accurately to either of the Equations (1) or (2). Hence the results must be interpreted with care, the more so since F1 is not a permanent feature of the daytime ionosphere. It has been suggested that the ratio of α_E and α_{F1} is better determined by eclipse data than the absolute values of either parameter (RATCLIFFE, 1956a), but so far no great use of this suggestion has been made.

Sometimes the F1 layer appears during an eclipse, at a time or location where it would not normally be expected to be seen; or sometimes an additional stratification appears above the normal F1 layer, usually rising in height and frequency as time advances (Figure 1). This is the so-called eclipse F1$\frac{1}{2}$ layer, which is most often seen in low magnetic latitudes. It is really no more than an inflexion on the electron density $N(h)$ profile. RATCLIFFE (1956a) has explained how this phenomenon can arise in a layer where the loss coefficient decreases upwards, as it does in the F region, so that the time constant $1/\beta$ increases upwards. This is illustrated by the data shown in Figure 1. At lower heights in the F region (e.g. 240 km) the interval $1/\beta$ is shorter, and recovery from the eclipse correspondingly quicker, than at a higher height (e.g. 300 km). This can lead to the formation of an inflexion in the $N(h)$ profile, during the recovery phase, as seems to happen around 1000–1100 hours in this instance; and in an extreme case an actual 'valley' might be formed. More detailed analysis of F1$\frac{1}{2}$ layer formation has been made by DE JAGER and GLEDHILL (1963) and OLATUNJI (1967). Possibly this phenomenon could yield further information on F region rates. It should be noted, however, that stratification phenomena unconnected with eclipses occur in the low latitude F region; they show some lunar control and are very likely due to transport processes (SKINNER *et al.*, 1954). Hence it is possible that the transport processes play some part in forming the eclipse F1$\frac{1}{2}$ layer.

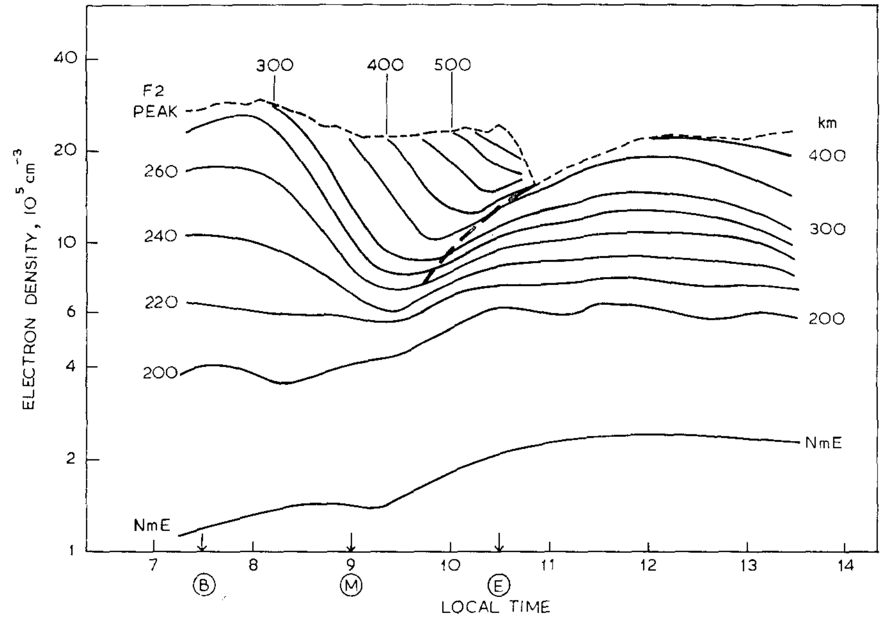

Fig. 1. Electron density variations observed at Singapore (geographic position 1 °N, 104 °E; magnetic dip − 18°) during the partial eclipse of 19 April 1958. The bottom curve shows N_mE; the top (broken) curve shows N_mF2; intervening curves refer to fixed heights (shown in km). The dotted line marks the approximate position of an 'F1$\frac{1}{2}$ ledge'. Letters *B*, *M*, *E* indicate the beginning, middle and end of the eclipse (Radio and Space Research Station).

The existence of stratifications complicates the calculation of accurate $N(h)$ distributions during eclipses. It has been suggested that minima ('valleys') may develop in the F region electron distribution during eclipses (GLEDHILL and WALKER, 1960), in which case appreciable errors could arise in calculating $N(h)$. This difficulty may add to another source of inaccuracy, namely the obliquity of ionosonde echoes, which occurs when the ionospheric layers become tilted because of the horizontal variations of the eclipse effects (MUNRO and HEISLER, 1958; GLEDHILL, 1959). However, MINNIS (1958b) has discounted the importance of oblique echoes in a case that he studied.

D. F2 LAYER RESULTS

Even under normal circumstances the F2 layer is extremely variable in its behaviour, so it is not surprising that a diversity of phenomena occur during eclipses. The reasons for this variability are probably connected with the transport and thermal processes discussed in Section 3 of this paper. Hence it would seem that useful information on production and loss rates can only be obtained in circumstances when these other processes are comparatively unimportant.

In low magnetic latitudes eclipse behaviour in the F2 layer seems to be more regular, no doubt because of the hindrance to diffusion offered by the geomagnetic field. For the eclipse of 12 October 1958, VAN ZANDT *et al.* (1960) obtained production and loss rates from $N(t)$ curves at several heights, obtained at Danger Island (11 °S; magnetic dip $-22°$). To analyse the data they used Equation (2), rearranged as

$$\frac{\mathrm{d}N/\mathrm{d}t}{N} = \frac{Eq}{N} - \beta \tag{3}$$

and plotted ($N^{-1}\,\mathrm{d}N/\mathrm{d}t$) vs. ($E/N$) at frequent intervals throughout the eclipse period, separately for each height. This procedure should give a straight line graph from which q and β can be determined, provided that allowance is made for the time variation of the normal production function $q(t)$. The success of this analysis seems to justify the assumption that, for F2 layer production, the eclipse function $E(t)$ is given by the unobscured fraction of the solar disk. The deduced values, $q = 880\,\mathrm{cm}^{-3}\,\mathrm{sec}^{-1}$ and $\beta = 6.8 \times 10^{-4}\,\mathrm{sec}^{-1}$ at 300 km, considerably exceed values obtained previously from other F region studies, but are now believed correct for the high level of solar activity prevalent during the eclipse.

SKINNER (1967) has applied the same analysis to data from another low latitude eclipse. His values of q and β are consistent with the results of Van Zandt *et al.* and of other workers when allowance is made for variations of solar activity. Skinner also showed that Equation (3) gave a better fit to this data than did an equivalent equation derived from Equation (1). This gives further justification to the representation of the rate of loss in the F2 layer as βN instead of αN^2.

The total electron content per unit column of the ionosphere (most of which is contained in the F2 layer) can be studied by the incoherent scatter technique; or by observing the Faraday rotation of radio signals reflected from the moon and of signals transmitted by artificial satellites. The incoherent scatter and moon-echo methods are limited in scope for eclipse observations because only a few installations exist. Both these methods were available for the 20 July 1963 eclipse in the North-eastern U.S.A.; the decreases of electron content observed on that occasion have been discussed by EVANS (1965a) and KLOBUCHAR and WHITNEY (1965). Using the satellite Faraday method, OLATUNJI (1967) measured a decrease of about 45% in the total content above 300 km in a low latitude eclipse. But owing to the nature of satellite orbits, it is only possible to obtain occasional measurements by this technique. Continuous measurements of total electron content can be made by means of geostationary satellites, which have yet to be exploited for eclipse observations.

3. Transport and Thermal Processes during Eclipses

The upper ionosphere is largely controlled by transport processes. Some of the phenomena observed during eclipses, particularly in the F region, may depend on these processes as described below.

A. IONOSPHERIC ELECTRIC FIELDS AND ASSOCIATED GEOMAGNETIC VARIATIONS

Changes of electron density during an eclipse must alter the electrical conductivity of the ionosphere (e.g. CHAPMAN, 1956). This may affect the distribution of electric field and must certainly alter the electric currents which flow mainly in the E layer. Such changes of current produce slight changes in the geomagnetic field observed at ground level. This mechanism implies that the time variation of the magnetic effects depends on E region processes, and can therefore be used to give information about E region parameters. For instance, in a recent analysis of magnetic effects BOMKE *et al.* (1967) deduced that $\alpha_E = 5.5 \times 10^{-8}$ cm^3 sec^{-1}, not inconsistent with other information.

According to the theory of MARTYN (1953), the ionospheric electric fields cause electromagnetic movements in the F layer, so it is conceivable that some F2 layer eclipse effects might arise in this way. Unfortunately the theory of these processes is so complicated, even under normal circumstances, that little progress has been made as regards its application to eclipses.

B. PLASMA DIFFUSION DURING ECLIPSES

The F2 layer at mid-latitudes is thought to be largely controlled by plasma diffusion, which determines the height h_mF2 at which the F2 peak is found. Theoretically, diffusion tends to smooth out differences in the behaviour of the layer at different heights. Below h_mF2, where diffusion is comparatively slow, the eclipse effect at any height should be governed by the local value of the loss coefficient β, according to Equation (2). Above h_mF2 loss is negligible because β is very small; but ionization can readily diffuse downwards to replace the loss at lower levels, the net result being that the electron density decays with a coefficient comparable to the value of β at height h_mF2.

The consequences of diffusion have been investigated theoretically by solving the time-varying continuity equation, with diffusion included, for eclipse conditions (BRIGGS and RISHBETH, 1961; GLIDDON and KENDALL, 1962). Some specimen results of such calculations are shown in Figure 2. When diffusion is excluded (full curves) the effect of the eclipse, measured by the greatest percentage reduction of electron density from normal conditions, decreases rapidly upward because of the increase of the time constant $(1/\beta)$ for loss. The time lag between totality and the greatest reduction of N also increases upwards, though it is obviously limited by the finite duration of the eclipse. The broken curves show what happens when diffusion is 'fast', the diffusion coefficient vs. height profile being assumed about 50% greater than is probably correct for the daytime ionosphere. In this case the percentage reduction of N is fairly constant with height above h_mF2 (about 300 km); the time lag is also more uniform with height than it is when diffusion is omitted (full curves). The dotted curves apply to 'slow' diffusion, in which the coefficient is reduced by a factor of 10; even in this case, diffusion does tend to equalize the effect of the eclipse at all heights above h_mF2, which for this model lies at about 350 km.

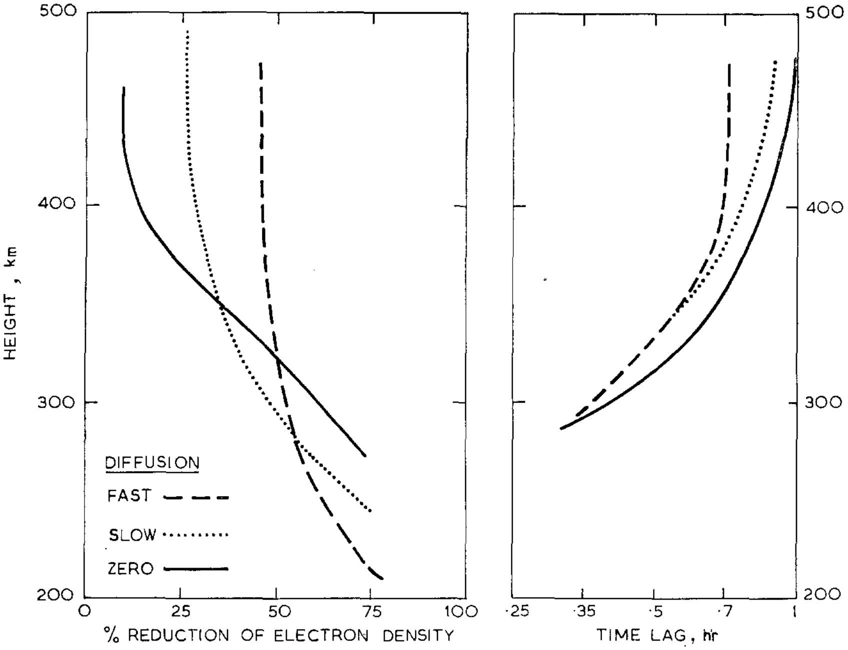

Fig. 2. Theoretical graphs relating to eclipse effects in the mid-latitude F2 layer. The hypothetical eclipse lasts 3 hours between first contact and last contact, with totality at 1130 hours local time. Details of the ionospheric model, including values of the 'fast' and 'slow' diffusion coefficients (see text), are given by RISHBETH (1963). The left-hand diagram shows the greatest reduction of electron density during the eclipse, expressed as a percentage of the normal electron density at the same hour; the right-hand diagram shows the time lag after totality at which this greatest reduction occurs.

The 'equalizing' effect of diffusion implies that the $N(t)$ variations should have a similar shape at all heights in the topside F layer. Such appeared to be the case in two eclipses observed by the Alouette I topside sounder (KING *et al.*, 1967); the observations also suggested that the layer moved bodily downwards during the eclipse, probably because of thermal contraction of the layer (Section 3.C). In a third eclipse different phenomena occurred, but these may have been caused by a magnetic disturbance which happened to be in progress at the time.

Since diffusion only takes place along magnetic field lines, it does not have the same effect in low magnetic latitudes as it does in mid-latitudes, and the behaviour of the layer is dominated by production and loss to greater heights. The analysis described in Section 2.D took advantage of this situation. Electric fields may be important also, but as mentioned in Section 3.A their effect during eclipses has yet to be studied.

C. REDUCTION OF ELECTRON TEMPERATURE

Another process which is controlled by the orientation of the geomagnetic field is the conduction of heat by ionospheric electrons. The following discussion concerns only mid-latitude conditions. It is well established that in the daytime F layer $T_e > T_i > T_n$, where T_e, T_i, T_n denote respectively the electron, ion and neutral gas temperature.

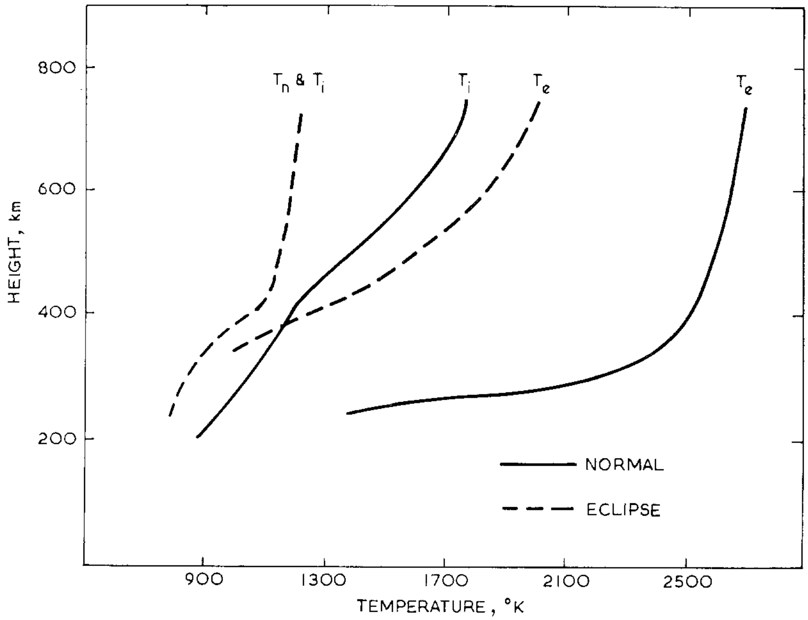

Fig. 3. Electron and ion temperature profiles at Millstone Hill (43 °N, 71½ °W), after EVANS (1965a). The full curves are daytime averages (0800–1400 local time) for July 1963; the broken curves are for the eclipse of 20 July 1963. Totality was at 1650; but since on normal days in the month there is little decrease of T_e between 1400 and 1700, the full and broken curves are reasonably comparable. As explained by Evans, the eclipse curve of T_i is derived on the assumption that $T_i = T_n$ at totality.

The excess electron temperature results from the large amount of energy acquired by newly liberated photoelectrons, which have poor thermal contact with the heavier particles. If photo-ionization is interrupted by an eclipse, T_e may fall rapidly, as the excess heat is drained away by conduction to lower heights. Reductions of electron temperature were indeed observed during the North-American eclipse of 20 July 1963, by rocket-borne probes (SPENCER *et al.*, 1965) and by the incoherent scatter technique (EVANS, 1965a). Evans' results are illustrated in Figure 3.

The effects of temperature changes on the F2 layer can be quite complicated. Since in some respects the F region plasma behaves as a gas possessing a temperature $\frac{1}{2}(T_e + T_i)$, a reduction of T_e tends to cause thermal contraction of the plasma, which (if sufficiently rapid) may lead to an increase in F2 peak electron density, such as sometimes occurs during eclipses. It should also cause a downward movement of the topside of the F region, leading to a marked reduction of electron density at heights above the F2 peak, which again has been observed (KING *et al.*, 1967). EVANS (1965b) has studied data from many past eclipses and found that increases of N_mF2 are observed when two requirements for a large reduction of T_e are met:

(1) The eclipse is virtually total (>90%) in the F1 layer, at which height the input of energy to the electrons is greatest.

(2) The magnetic dip angle is fairly large (>60°), to facilitate the loss of heat by conduction to lower heights.

As well as the reduction of T_e (by 50% in relation to comparable non-eclipse conditions) SPENCER *et al.* (1965) detected a decrease of T_n during the eclipse. T_n was estimated from the scale height of the molecular nitrogen distribution, and also by a 'velocity scan' technique. The eclipse decrease of T_n was 10–20%, which seems reasonable in relation to the time constant (a few hours) associated with the diurnal heating and cooling of the thermosphere. The magnitude of the eclipse effects of T_e and T_n provide evidence to support the common view that solar photon radiation is the principal daytime heat source for the thermosphere.

4. Conclusion

In the E and F1 layers, and to some extent in the low latitude F2 layer, the variations of electron density mainly depend on the production and loss processes. The idealized continuity equations, given in Section 2.A, should hold approximately; but it is difficult in practice to obtain accurate information about the photochemical rates from eclipse observations. Basically this is because one is using a variable source (the eclipsed sun) to study a complex system (the ionosphere), whose response time is comparable to the time-scale of the eclipse. Some other specific problems have been discussed in this paper, such as the question of uneclipsed radiation at totality and the complex photochemistry of the ionosphere (Section 2.B). There is also the technical difficulty of computing accurate electron $N(h)$ profiles, mentioned in (Section 2.C), which particularly concerns the F region.

These questions can only be resolved by the use of additional techniques, notably rocket-borne experiments. For instance, mass spectrometers can give information on ion composition, which is probably essential to an explanation of photochemical changes during eclipses. But it is not certain whether such experiments during eclipses can give any distinctive information about ionospheric photochemistry, that could not be obtained by the same experiments conducted under normal circumstances.

An important use of ionospheric eclipse observations is to study the location on the sun of sources of ionizing radiation. If data from a number of stations are available, then the sources can be located quite accurately. For instance, the radiation which produces the E layer is found to be partly concentrated in active areas, generally situated at the limb of the sun (e.g. MINNIS, 1958a). Even for this purpose, however, the ionosphere is not a perfect detector. This is because, according to the continuity Equations (1) and (2), the covering or uncovering of an active region changes only $\mathrm{d}N/\mathrm{d}t$; it does not immediately alter N. Ionospheric observations do not give unambiguous data on the question of radiation from outside the solar disk, as was discussed in Section 2.B.

For future studies of eclipse effects in the ionosphere, there would seem to be much scope in the D region. The experiments are difficult, and this topic has not been pursued in the present paper. Of the higher parts of the ionosphere, contrary to what might be expected, the F2 layer may be the most promising. This is because the convenient assumption, that the source of ionizing radiation is uniformly distributed over the solar disk, may be approximately true. To obtain useful information about production and loss rates, one must study circumstances in which the effects of transport processes are less marked than usual in the F2 layer. Two such possibilities are:

The equatorial F2 layer. Vertical diffusion of plasma cannot occur, because of the geometry of the earth's magnetic field; and though both electromagnetic movements and horizontal diffusion may operate, reasonable values of q and β have nevertheless been obtained. New information might be obtainable from studies of the low latitude 'eclipse F1$\frac{1}{2}$ layer'.

Sunrise F2 layer. At sunrise, $\mathrm{d}N/\mathrm{d}t$ is probably determined mainly by the photoionization rate q. Hence detailed analysis of $N(t)$ curves during an eclipse at sunrise might yield useful information about production rates and thermal effects. The eclipse of 15 February 1961 offered such an opportunity at many stations in Europe, though on this occasion the sun was rather active, which complicated the interpretation of the data (ILIAS and ANASTASSIADIS, 1964). Transport process may however be important even at sunrise.

Section 3 of this paper has dealt with transport processes during eclipses, such as electromagnetic motions – still quite unknown – and plasma diffusion in the F region (Sections 3.A, 3.B). Lastly, there is the new and interesting question of the variation of electron, ion and neutral gas temperatures during solar eclipses (Section 3.C). The considerable observed reduction of T_e supports the idea that the source of heat for the ionospheric plasma is solar photon radiation. These are phenomena, which have only come to light in recent years, and which deserve further study.

Acknowledgements

This article is adapted from a review presented at the N.A.T.O. Advanced Studies Institute on 'Solar Eclipse and the Ionosphere', held at Athens, 23–28 May 1966. Acknowledgement is made to Professor M. Anastassiadis, of the National Observatory of Athens, for his hospitality on that occasion; and to the author's colleagues at the Radio and Space Research Station for useful discussions. This paper is published by permission of the Director of the Radio and Space Research Station in the Science Research Council of the U.K.

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