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D-Region Absorption at 10 and 15 Mc/s During the Total Solar Eclipse of July 20, 1963

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Riometer observations of ionospheric absorption at 10 and 15 Mc/s in both the ordinary and extraordinary modes were conducted in Alaska during the eclipse of July 20, 1963. The equipment was located so that the path of totality at 70 km height was directly overhead, and considerable reduction was detected from the ambient daytime absorption, which fell to some 40 percent of its normal value.

The behavior of the *D* region during an eclipse is considered theoretically, and the observations are analyzed in terms of this treatment. It is shown that the observations can be explained in terms of ionospheric parameters which, with one exception, accord with values given by other methods. The use of future eclipses in *D*-region studies is briefly discussed.

1. Introduction

During the solar eclipse of July 20, 1963, riometers on frequencies of 10 Mc/s and 15 Mc/s were operated near the path of totality at the Fishhook Bar, near Palmer, Alaska (61° 41.5′ N, 149° 14.3′ W, geogr.). The riometers were dual-polarized, recording both the ordinary and extraordinary components of the cosmic radio noise; the antenna beams were symmetrical about a vertical axis with maximum response at the zenith and half-power gain at 30° off axis. Using the methods of Little, Lerfald, and Parthasarathy [1964], it is possible from such records to determine the absorption suffered by each component in traversing the terrestrial ionosphere.

The absorption in decibels of a radio signal of effective angular frequency ω_e, traversing a path through the ionosphere, is given by

$$A(\omega_e) = \int_0^\infty k(\omega_e, h)\, N(h)\, dh \qquad (1)$$

where $k(\omega_e, h)$ is the absorption per unit path length effective at angular frequency ω_e for unit electron density, and $N(h)$ is the electron density as a function of height. The absorption efficiency $k(\omega_e, h)$ is a complex function of the electron collision frequency $\nu(h)$, the strength of the terrestrial magnetic field, and the angle between the magnetic field vector and the direction of propagation of the radio wave. The form of the magneto-ionic equations given by Sen and Wyller [1960] have been used to compute absorption values in this paper. Figure 1 shows the absorption efficiency values as a function of height for the case of radio waves penetrating the ionosphere vertically. The effective angular frequency $\omega_e = \omega \pm \omega_L$, where ω is the receiving frequency, ω_L is the longitudinal component of the angular gyrofrequency and the + and − pertain respectively to the ordinary and extraordinary polarizations. Because of the variation of absorption efficiency and electron density with height, the absorption occurs mainly in the height range 60 to 90 km. For this reason the riometers were situated somewhat south of ground-level totality so that the eclipse would be total in the *D* region overhead.

Thus, the riometer records a quantity closely related to the average electron density in the *D* region. During the eclipse the intensity of ionizing radiation is reduced, and the normal processes of recombination bring about a reduction of electron density. The object of the experiment was to investigate what can be learned from riometer data about these recombination processes. Previous investigations of recombination in the *D* region have, in any case, been mainly theoretical; experimental evidence on the subject is badly needed.

Absorption measurements by riometer had previously been made by Gordon [1961] during the eclipse of October 2, 1959. Observing conditions were unfavorable at the time, since totality occurred just

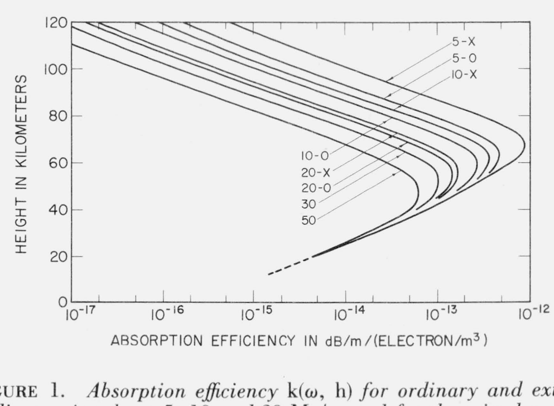

FIGURE 1. *Absorption efficiency* k(ω, h) *for ordinary and extraordinary signals at* 5, 10 *and* 20 Mc/s, *and for the mixed mode at* 30 *and* 50 Mc/s.

at sunrise; he used a 30 Mc/s riometer with an antenna directed toward the horizon. This antenna orientation resulted in several times more absorption than could be expected on a vertically directed antenna, but made quantitative interpretation very difficult. It is obvious that results from equipments using zenithal antennas of known polar diagram are more amenable to interpretation. The use of two frequencies, moreover, opened the possibility of finding the distribution of electron density with height in this region [Parthasarathy, Lerfald, and Little, 1963]. Conditions were still not ideal, however, because the eclipse path was near the auroral zone, with a consequent risk of contamination by sporadic ionization from auroral particles.

We shall first discuss the behavior to be expected during an eclipse, and will then present the observational results from the eclipse of July 20 and discuss their interpretation.

2. The Prospect: Theory of *D*-Region Behavior During an Eclipse

The following processes will be taken into account.

(i) Production of electrons by ionizing radiation: The total rate of production is the sum of contributions from electromagnetic and corpuscular emissions: the former from the visible solar disk and perhaps also from the corona (source of soft x rays); the latter from the steady flux of cosmic rays and, when the observations are made at high latitude, from sporadic auroral particles.

(ii) Formation of negative ions: Negative ions are formed by the attachment of electrons to neutral particles, and are dissociated by the processes of photodetachment and collisional detachment. In the equilibrium state the density ratio of negative ions to electrons is

$$\lambda = \frac{an^2}{\rho + \kappa n} \tag{2}$$

where a is the attachment coefficient, ρ the photodetachment coefficient (which depends on the sun's intensity in the visible and near infrared), κ the collisional detachment coefficient, and n the number density of neutral molecules.

(iii) Recombination with positive ions: Both the electrons and the negative ions can be removed by recombination with positive ions. If the rates of these processes are respectively α_e and α_i, the "effective recombination rate" of the electrons is

$$\alpha = \alpha_e + \lambda \alpha_i. \tag{3}$$

In terms of these processes, the changes of electron density can readily be shown [Nicolet and Aikin, 1960] to be described by

$$\frac{dN}{dt} = \frac{q}{(1+\lambda)} - \alpha N^2 - \frac{N}{(1+\lambda)} \frac{d\lambda}{dt}. \tag{4}$$

The derivation of (4) assumes that the electrons and negative ions come to equilibrium rapidly compared with changes of q: that is, that (2) applies throughout. As the time constant of process (ii) is only about one second in the D region, the assumption is valid for the present analysis.

2.1. Primary Effects of the Eclipse

The first effect of the eclipse is to modify the rate of production of ionization, q. Only the electromagnetic component is changed, so we may put

$$q = Fq_0 + q_c \tag{5}$$

where q_0 is the electromagnetic component from the unobscured sun, F is the fraction of the sun exposed, and q_c is the corpuscular component which, not coming from the sun, is unaffected by the eclipse. If the solar component is confined to the visible disk and uniformly distributed across it, F changes between unity and zero during the eclipse, as shown in the case $\frac{q_c}{q_0} = 0$ of figure 2. (The unit of "eclipse time" in fig. 2 is the time for the moon to move by one radius relative to the sun.) If any appreciable contribution comes from the corona, then the effective solar radius will be slightly increased and F will be slightly different. Also, active regions on the sun could result in irregularities in the change of solar ionizing flux during the course of the eclipse. At low latitude the corpuscular component q_c is probably constant during the eclipse, but this cannot be assumed at high latitude unless there is evidence that auroral activity is absent.

The second effect of the eclipse is to modify the photodetachment coefficient, and hence the ratio of negative ion density to electron density, λ. Thus

$$\lambda = \frac{A}{F\rho_0 + K}, \tag{6}$$

where ρ_0 is the photodetachment coefficient for unobscured sun and F the exposed fraction of the solar disk. For convenience we have put $an^2 = A$ and

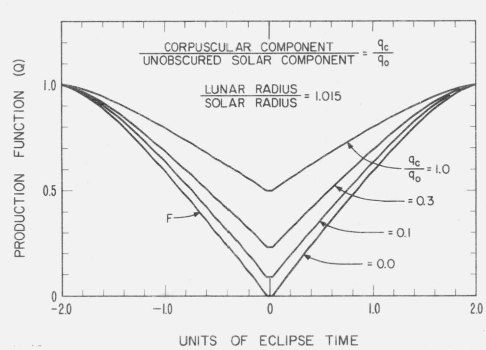

FIGURE 2. *Production function,* Q.
For the eclipse of July 20, 1963, one eclipse unit = 36½ min., duration of eclipse = 146 min, and duration of totality = 93 sec. If $q_c = 0$, Q is just the exposed fraction of the solar disk, F.

$\kappa n = K$. During the eclipse, therefore, λ changes between day and night values:

$$\lambda_D = \frac{A}{\rho_0 + K}; \ \lambda_N = \frac{A}{K}.$$

At a sufficiently great height, λ is always negligibly small. In the D region, however, it is probably significant at all times. For a height of 70 km, for instance, Nicolet and Aikin [1960] give $\lambda_D = 0.6$; Bailey [1959] estimates $\lambda_D = 40$, $\lambda_N = 300$.

It seems therefore, that both the recombination and the attachment processes may well affect the observations. Nevertheless, we will first treat them separately so as to study the peculiar effects of each process.

2.2. Behavior if λ is Constant During the Eclipse

If $\lambda = \lambda_D$ throughout the eclipse, (4) becomes

$$\frac{dN}{dt} = \frac{q}{(1+\lambda_D)} - \alpha_D N^2, \tag{7}$$

λ_D and α_D denoting the daytime values. The equilibrium electron density by day (N_D) is given by

$$\alpha_D N_D^2 = \frac{q_D}{(1+\lambda_D)}, \tag{8}$$

where q_D is the daytime rate of production. Whence, using (5) we obtain the convenient form

$$\frac{d}{dt}\left(\frac{N}{N_D}\right) = \alpha_D N_D \left\{Q - \left(\frac{N}{N_D}\right)^2\right\}, \tag{9}$$

where

$$Q = \frac{F + \dfrac{q_c}{q_0}}{1 + \dfrac{q_c}{q_0}}.$$

Solutions of this equation are given in figure 3 for different values of the parameter $\alpha_D N_D$ and for $\frac{q_c}{q_0} = 0$, 0.1, 0.3, and 1.0. According to Nicolet and Aiken [1960], α_D at 70 km is $6 \cdot 10^{-7}$ cm^3 sec^{-1} and N_D is about 300/cm^3. Thus, $\alpha_D N_D$ is about $2 \cdot 10^{-4}$ sec^{-1}, which puts it in the range which should give observable effects. If $\alpha_D N_D$ happens to be too small, say less than about 10^{-5} sec^{-1}, no effect will be seen; and if it is too large, say greater than about 10^{-2} sec^{-1}, the curve $\frac{N}{N_D}$ will be indistinguishable from the square root of the production function. In the intermediate range an actual measurement of α_D becomes possible if N_D and $\frac{q_c}{q_0}$ are known. N_D can be determined from the daytime level just before the eclipse or on adjacent days; and it may be possible to estimate the ratio $\frac{q_c}{q_0}$ from the variation of absorption with zenith angle.

Uncertainty about the value of $\frac{q_c}{q_0}$ or about the form of F will obviously make the determination of $\alpha_D N_D$ less certain, but the tail of the recovery curve might be helpful in this case. After last contact, when

$$\frac{F + \dfrac{q_c}{q_0}}{1 + \dfrac{q_c}{q_0}} = 1,$$

(7) has the solution

$$\tanh^{-1}\left(\frac{N}{N_D}\right) - \tanh^{-1}\left(\frac{N_1}{N_D}\right) = \alpha_D N_D t \tag{10}$$

where $N = N_1$ at time $t = 0$. In this way a determination independent of the form of the production function can be made—provided, of course, that a recovery tail is observed. If a tail is not observed it may only be possible to say that $\alpha_D N_D$ must be greater than or less than certain values.

As riometer observations over a band of frequencies can potentially be interpreted as profiles of electron density as a function of height [Parthasarathy, Lerfald, and Little, 1963], the variation of α_D with height might also be obtained. The electronic and ionic recombination coefficients, α_e and α_i, could then be obtained by means of (2) and (3), making use of the strong variation of λ with height.

2.3. Behavior if λ Changes During the Eclipse but Recombination Is Slow

Now let us suppose that $\alpha_D \approx 0$, so that there is virtually no recombination with positive ions for the duration of the eclipse. As the electron density (over periods of a second or more) is always related to the positive-ion density (N_+) by

$$N = \frac{N_+}{(1+\lambda)} \tag{11}$$

and since N_+ is constant in the absence of recombination, it follows that

$$\frac{N}{N_D} = \frac{1+\lambda_D}{1+\lambda} = (1+\lambda_D)\left[1 + \frac{\lambda_N}{1 + F\left\{\dfrac{\lambda_N}{\lambda_D} - 1\right\}}\right]^{-1}. \tag{12}$$

Then measurements of $\frac{N}{N_D}$ as a function of F will provide values for both λ_D and λ_N, from which the ratios $\frac{A}{\rho_0}$ and $\frac{K}{A}$ may be determined. If the changes of λ_D and λ_N with height are also known, we expect to find from them values of $\frac{A}{\rho_0}$ and $\frac{K}{A}$ which vary respectively as the second power and as the first power of the molecular density. This would provide some verification of the accuracy of the method.

2.4. Behavior if λ Changes During the Eclipse and Recombination Is Also Important

In general, both the recombination and the attachment processes will occur in the D layer. If the changes due to recombination happen to be small, then the effects of the two processes may be combined simply by multiplying each point of the curves in figure 3 by the factor $\frac{(1+\lambda_D)}{(1+\lambda)}$. The modification is symmetrical about totality. This may also be satisfactory as a first order treatment of other cases, but the general situation is complicated by the influence of λ on the effective production and recombination rates. This can been seen by writing (4) in terms of positive ion density:

$$\left.\begin{array}{l} \frac{dN_+}{dt}=q-\frac{\alpha_e+\lambda\alpha_i}{1+\lambda}N_+^2 \\ N_+=(1+\lambda)N \end{array}\right\}. \tag{13}$$

The basic recombination process is obviously influenced by changes of λ unless (it can be shown), $(\alpha_e-\alpha_i)$ is sufficiently small compared with $(\alpha_e+\lambda\alpha_i)$ $(1+\lambda)$, or unless λ changes by only a small amount. The various coefficients are not well enough established to say whether or not these conditions will be met.

Equations (4) or (13) can be solved numerically, and examples of such solutions are shown in figure 4. It is seen that a marked dip at totality is introduced into a curve which otherwise would pass through a minimum somewhat later than totality.

2.5. Some Interpretive Difficulties

Given an experimental curve showing the variation of $\frac{N}{N_D}$ during an eclipse, the problem is to isolate three kinds of variations:

(i) The change of ionizing flux during the eclipse;
(ii) the change of λ during the eclipse, which will provide information about the attachment and detachment coefficients;
(iii) the delayed change, giving information about the recombination coefficients.

If it could be assumed that the only ionizing radiation was from the visible solar disk and was uniformly distributed across it, the analysis would be relatively simple. The early and late parts of the eclipse, where λ is near to its daytime value, would be fitted to a theoretical recombination curve from figure 3a. Departures from this same theoretical curve near totality would then be interpreted in terms of changes of λ: the ratio between the two curves could be taken as $\frac{(1+\lambda_D)}{(1+\lambda)}$ in the first instance, and then the values refined by comparison with numerical computations. The presence of additional sources of ionization which remained steady for the duration of the eclipse would alter the basic recombination curve but not alter the effects of attachment. It would be necessary to estimate in some way a value for $\frac{q_c}{q_0}$ and then to use the appropriate set from figure 3.

In the presence of sporadic auroral ionization or gross nonuniformities in the ionizing flux from different regions of the solar disk, no precise solution is possible. An uncertainty is introduced whose seriousness can however be estimated if the general level of sporadic activity or nonuniformity is known. The possibility of auroral absorption makes observation at high latitude somewhat undesirable, but if there is no other choice the results could be improved by observing at several sites along the eclipse path. Then the sporadic effects would appear against different phases of the eclipse at the different sites, and only the systematic component would be taken as the true effect of the eclipse.

Ideally, multifrequency observations during the eclipse will give electron densities as a function of both time and height, and the analysis would aim to interpret the variation of electron density with time at each of several heights. Should the observations not be precise enough to give height information, the results can provide only "effective parameters" for some "effective ionospheric layer." In the present state of knowledge of the D region, this could still be valuable. However, the possibility that some of the absorption is in the E and F regions has to be kept in mind. Independent evidence on this point would be necessary.

3. The Reality: Analysis of the Eclipse of July 20, 1963

3.1. Observations

The absorption observed with the four riometers (recording the O- and E-modes at both 10 and 15 Mc/s) is shown in figure 5. These observations have been corrected for the finite beamwidth of the antenna and for mutual leakage between the two circularly polarized components. A correction has also been applied to the data for the apparent absorption introduced by F-region reflection of cosmic noise arriving from angles near the horizon (the so-called "aperture" or "iris" effect). The absorption normally observed during the same period of the day (adjusted to the same solar zenith angles) derived from about a month of control data recorded before and after the eclipse, is also shown. It can be seen at once that the eclipse produced a marked reduction of absorption. The records also display a fair amount of irregularity, which could be caused either by auroral activity which would increase the absorption, or by interfering signals which would apparently decrease it. The former is believed to have been the more serious during these observations. Whatever its cause, the irregularity presents a fundamental limit to the accuracy of any interpretation.

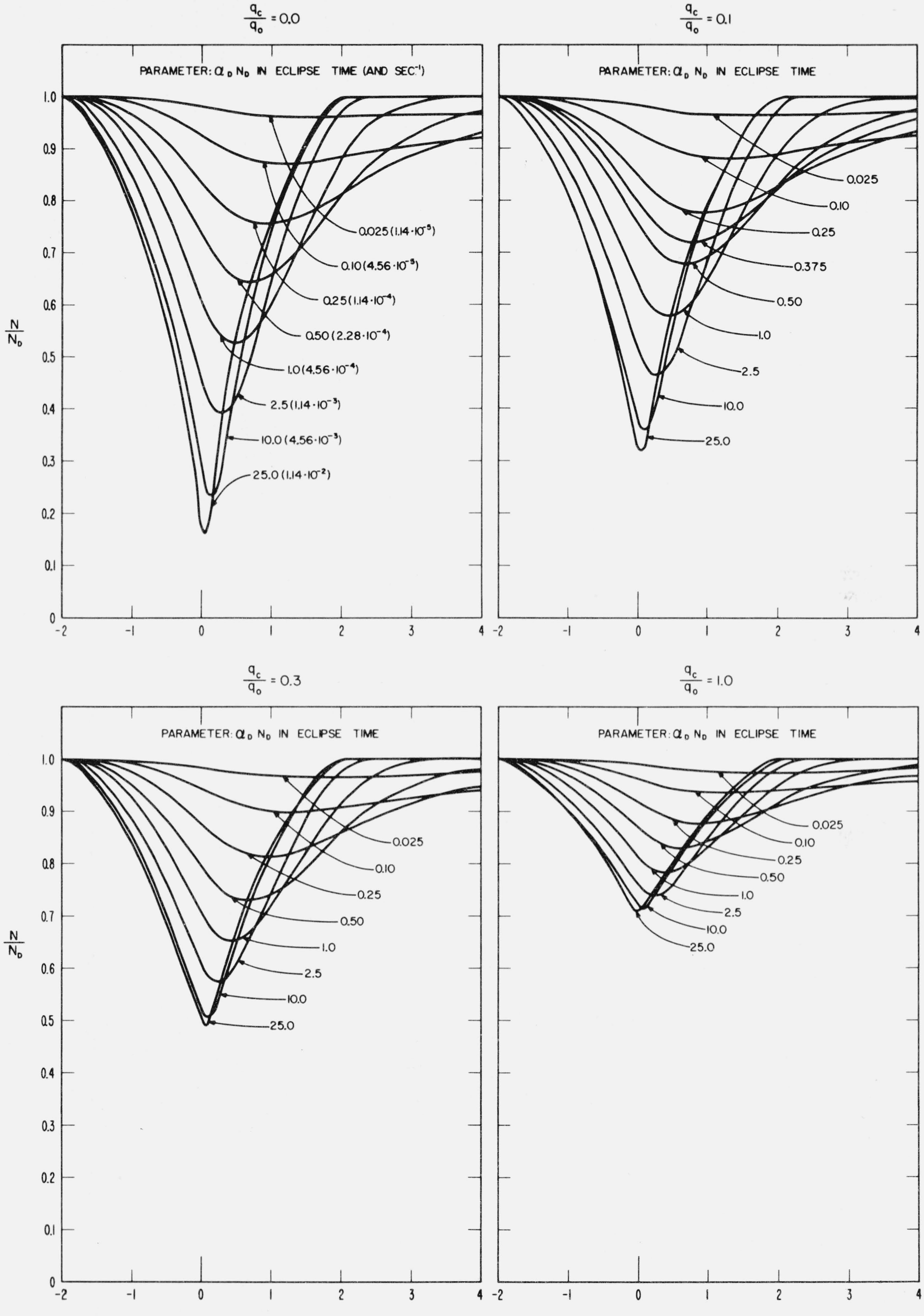

FIGURE 3. *Relative electron density* $\left(\frac{N}{N_D}\right)$ *at constant* λ.

For generality, the parameter $\alpha_D N_D$ is expressed in units of eclipse time. The values are repeated in brackets in sec^{-1} for the eclipse of July 20, 1963.

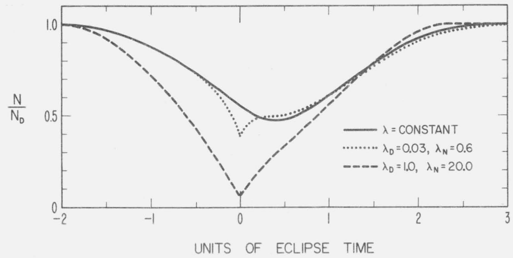

FIGURE 4. *Relative electron density* $\left(\frac{N}{N_D}\right)$ *with changing* λ.
$\alpha_D N_D = 1.37$; $\alpha_e/\alpha_i = 5.0$.

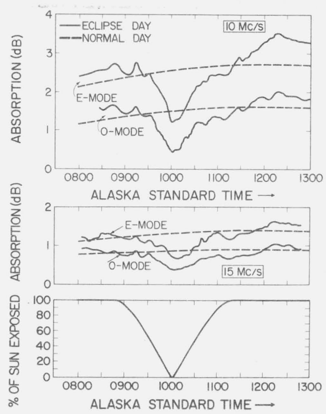

FIGURE 5. *Absorption during eclipse of July 20, 1963.*

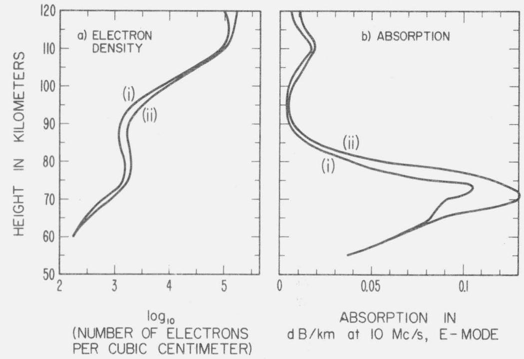

FIGURE 6. *Estimated profiles.*
The profile at the time of the eclipse is thought to lie between (i) and (ii).

3.2. Height of Ionization Being Observed

Because of the irregularity of the records it is not possible to work out any changes in the *D*-region profile during the course of the eclipse. Our interpretation will therefore be considered, in the first instance, to describe the behavior during the eclipse of an absorbing region lying between 60 and 80 km, these heights having been derived from the theoretical analysis of Lerfald and Parthasarathy (to be published). In this analysis the variation of absorption as a function of solar zenith angle during periods free from auroral activity has been used to investigate the validity of various ionospheric models. The $N(h)$ profiles between 50 and 90 km resulting from assumed ionizing fluxes and rate coefficients were computed using the method given by Nicolet and Aikin [1960] and the choice of model parameters narrowed by rejecting those giving results which are inconsistent with the observed variation of absorption with solar zenith angle. (The $N(h)$ profiles above 100 km were obtained from ionosonde data by the method of Paul and Wright [1963].)

Such an analysis leads to the conclusion that the appropriate profile lies between the two given in figure 6a. The corresponding profiles of absorption against height are shown in figure 6b. The absorption is a maximum between 70 and 75 km, and exceeds half the maximum value throughout the approximate range 60 to 80 km. There is a smaller *E*-region contribution above 100 km, which may amount to a tenth of the *D*-region contribution. In view of other uncertainties, no attempt was made to correct for this *E*-region absorption contribution, although it would be possible to do so.

3.3 Interpretation

From the observations of figure 5 a pattern has been abstracted to represent the effect of the eclipse. This eclipse pattern was derived by dividing the absorption on the eclipse day by the corresponding absorption on normal days, and taking an average over the four observing frequencies. The average was biased towards the channel showing the smallest absorption, and efforts were made to smooth out changes probably caused by sporadic auroral absorption. The resultant pattern is given in figure 7a; this pattern we now wish to interpret in terms of the recombination and attachment processes.

The recovery of ionization during the latter part of the eclipse is relatively slow, and the electron density is still well below the daytime value at last contact (eclipse time $=+2$). This means that recombination can be neither very slow nor very rapid. Before fitting a curve from figure 3, a value of $\frac{q_c}{q_0}$ must be chosen. The analysis which led to the estimated profiles of figure 6 also indicates that a value of $\frac{q_c}{q_0}$ between 0.05 and 0.5 would be most appropriate. The curves for $\frac{q_c}{q_0}=0.1$ and 0.3 have therefore been used, and of these the values $\alpha_D N_D = 0.375$ and 0.500 (eclipse units)$^{-1}$ give the best fits respectively. These values are equivalent to $1.7\cdot 10^{-4}$ sec^{-1} and $2.3\cdot 10^{-4}$ sec^{-1}, which are somewhat greater than, but still compatible with, $\alpha_D = 6\cdot 10^{-7}$ cm^3 sec^{-1} given by Nicolet and Aikin [1960] and $N_D = 700$ cm^{-3} indicated for 70 km in figure 6a. It is of some interest that it becomes difficult to fit a curve at all if $\frac{q_c}{q_0} > 0.3$; of our two values, $\frac{q_c}{q_0}=0.1$ might therefore be preferred.

As shown in figure 7b, the ratio between the observed eclipse pattern and the theoretical one assuming constant negative ion-electron ratio ($\lambda = \lambda_D$) is symmetrical about totality. In accordance with the foregoing discussion we shall therefore regard this ratio as an indication of $\frac{(1+\lambda)}{(1+\lambda_D)}$. Assuming that the solar illumination factor F is as in figure 2, we thus obtain the variation of $\frac{(1+\lambda)}{(1+\lambda_D)}$ with F shown in figure 8.

From the variation of $\frac{(1+\lambda)}{(1+\lambda_D)}$ with F may be determined the day and night values of λ: i.e., λ_D and λ_N. It follows from (12) that

$$\{R\lambda_D + (R-1)\}\left[F\left\{\frac{1}{\lambda_D} - \frac{1}{\lambda_N}\right\} + \frac{1}{\lambda_N}\right] = 1,$$

where $R = \frac{1+\lambda}{1+\lambda_D}$. To determine λ_D and λ_N from the observed variation of R with F, we differentiate this equation with respect to F and rearrange it to obtain

$$\left\{R + F\frac{dR}{dF}\right\} + \frac{\lambda_D}{\lambda_N - \lambda_D}\frac{dR}{dF} = \frac{1}{1+\lambda_D}. \tag{14}$$

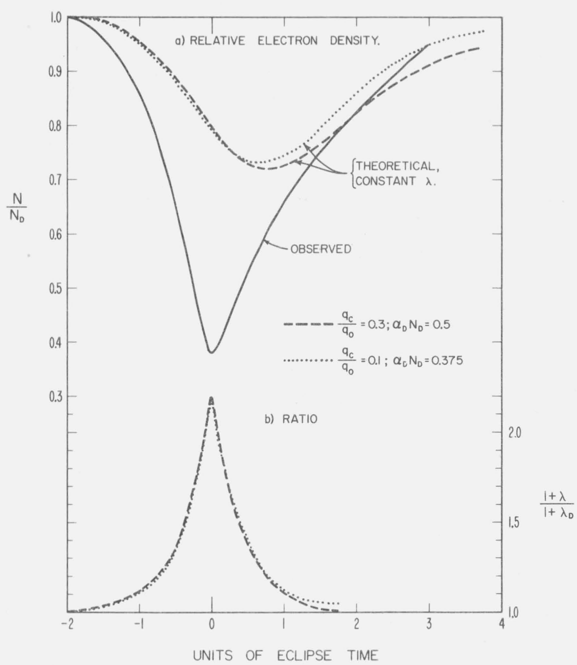

FIGURE 7. *Eclipse absorption pattern.*
(a) Relative electron density: observed, and theoretical at constant λ.
(b) Ratio, taken as $\frac{(1+\lambda)}{(1+\lambda_D)}$.

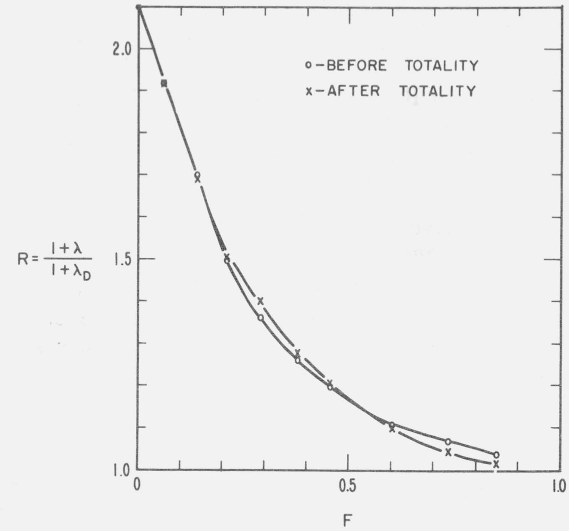

FIGURE 8. *Estimated change of* $\frac{1+\lambda}{1+\lambda_D}$ *with* F.

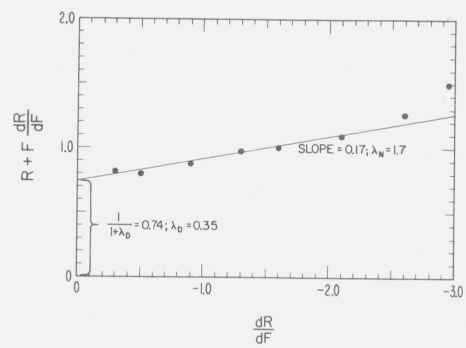

FIGURE 9. *Derived change of* $\left(R + F\frac{dR}{dF}\right)$ *with* $\frac{dR}{dF}$.

Values obtained from figure 8 are plotted in this form in figure 9. The relation is seen to be reasonably linear: the intercept gives $\lambda_D = 0.35$ and the slope gives $\lambda_N = 1.7$.

4. Discussion

4.1. Comparison With Other Results

If we accept that the measurements refer to the height range 60 to 80 km, then our estimate of λ_D agrees reasonably well with that of Nicolet and Aikin, who give $\lambda_D = 0.35$ at 72 km. The estimate of λ_N, however, is smaller than any given previously for this height. λ_N is a parameter about which relatively little is known, mainly because of ignorance of the collisional detachment coefficient, κ, [see Reid, 1964, for example]. Unfortunately, our derivation is also the least accurate part of the present analysis because of the possible contribution to the absorption from ionization at the higher levels, say above 80 km. Such a contribution might amount to 20 percent of the total and, being in a region where λ is much smaller than at 70 km, it would tend to persist throughout totality. Nevertheless, there is the experimental fact that nearly 40 percent of the absorption remained at totality; even assuming that half this was due to a high-level contribution, it is hard to make our effective value of λ_N greater than about 10.

4.2. Value of Riometer Observations During Future Eclipses

It appears that eclipse observations can reasonably be applied to the determination of certain ionospheric parameters, and such efforts would seem worthwhile if only to derive values of λ_N. This would be particularly so if changes in the *D*-region electron density profile against height could be measured.

The interpretation of absorption measurements is admittedly hampered by many side effects such as the contributions by the higher ionospheric layers, changes in the corpuscular ionizing fluxes, the contribution of the solar corona, or nonuniformities of emission across the solar disk. However, alternative methods of studying the *D* region used to date have similar problems and limitations. Since the change in integrated absorption during an eclipse at a frequency such as 30 Mc/s is only of the order of 0.1 to 0.2 dB, it is not possible to obtain definitive results using conventional riometers, which typically have a resolution of the order of 0.1 dB. Two alternatives are open: the development of equipments operating at frequencies such as 30 Mc/s which can resolve the absorption to about 0.01 dB, or absorption measurements at lower frequencies to take advantage of the approximate inverse-frequency-squared law of absorption. The latter choice has the advantage that the total absorption change expected and the difference between absorption on the ordinary and extraordinary polarizations is relatively large, but the method is limited by the effects of the higher ionospheric layers and the effects of propagated interference. It might be added that recent tests of equipment have shown that the conventional servo type riometer, which uses electronic (diode) switches operating at a few hundred cycles per second at the input, is more susceptible to interference than a nonswitching type of equipment. The latter would therefore be preferable for eclipse work.

The optimum conditions for an experiment of this type include low values of *E*- and *F*-region critical frequencies, an absence of sporadic corpuscular bombardment and an eclipse with a long duration of totality. A geographic location somewhat equator-ward of the auroral zone during a sunspot minimum period would probably provide the best conditions in practice.

5. Conclusions

(1) The eclipse produced notable effects in both the 10 and 15 Mc/s riometer observations, the absorption falling to 0.4 of its usual value for that time of day.

(2) The effect can be satisfactorily interpreted in terms of recombination and attachment processes in the *D* region. The values deduced for the recombination coefficient and for the concentration ratio of negative ions to electrons under day conditions are not inconsistent with those determined by other means. The ratio determined for night conditions is considerably smaller than other suggested values.

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