THE STRUCTURE OF THE F REGION OF THE IONOSPHERE

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Summary

The effects of temperature cycles, of a decay coefficient non-uniform with height, and of vertical tidal drifts upon the structure of the F region of the ionosphere are considered. Special attention is devoted to the behaviour of the level at which the maximum electron density occurs.

Both decay by recombination and decay by attachment are examined. It is concluded that the diurnal and seasonal height variations of the F_2 region are not the result of vertical tides alone acting on an isothermal Chapman region. A qualitative explanation of these variations is obtained by postulating, in addition, a diurnal temperature cycle, provided the decay coefficient does not change rapidly with height. Under the alternative hypothesis, that a single ionization process forms both F_1 and F_2 regions by bifurcation when the decay coefficient changes rapidly with height, the height variations appear to require discontinuities in the height gradient of the decay coefficient; tidal drifts are still necessary but a diurnal temperature cycle, if it exists, is not of major importance.

I. INTRODUCTION

In endeavouring to unravel the complexities of the F_2 region, there has been a tendency in the past to concentrate attention upon the maximum electron density, N_m, if only because the behaviour of N_m bears some resemblance to that of the simple Chapman region. If the departures of the level, $h^m_{F_2}$, at which N_m occurs, from the Chapman norm are large, the reason is that $h^m_{F_2}$ is much more sensitive to the parameters determining the structure of the region than is N_m, as is evident from the influence of vertical tidal drifts upon an ionized region whose relaxation time is large (Weiss 1953). Further examples are presented below. Physically, such behaviour is not unexpected, in view of the "cell" motions and the long relaxation times involved.

It is therefore to be expected that the study of height variations should yield interesting and significant results; consequently several mechanisms, any or all of which may be effective in shaping the profile of an ionized region, are considered below from this standpoint. They are (1) temperature, (2) decay coefficient, (3) solar zenith angle, (4) vertical tidal drifts.

II. THE EFFECTS OF TEMPERATURE CYCLES

Lepechinsky (1951) has examined the rate of ion production in an isothermal atmosphere subject to a diurnal or seasonal temperature cycle, and his results are first reiterated in a form more suited to subsequent developments. Let the

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scale height H be $H=H_0F(\chi)$, where χ is the solar zenith angle, and choose a datum level

$$h_0^0=H_0 \ln [A\rho_0H_0F(\chi)],$$

where ρ_0 is the density at $h=0$. Then, denoting the maximum value of noon ion production by I_0^0 and defining

$$z=[h-h_0^0F(\chi)]/H,$$

the ion production formulae become

$$\begin{aligned} I&=[I_0^0/F(\chi)] \exp (1-z-e^{-z} \sec \chi), \quad \ldots\ldots\ldots\ldots (1)\\ I_m&=I_0^0 \cos \chi/F(\chi),\\ h(I_m)&=F(\chi)(h_0^0+H_0 \ln \sec \chi),\\ z(I_m)&=\ln \sec \chi. \end{aligned}$$

As a representative example, a linear diurnal temperature cycle for the equator at the equinoxes may be postulated, that is,

$$\left.\begin{aligned} &\text{day}: && F(\chi)=1\pm\frac{12\mu}{\pi}\varphi,\\ &\text{night}: && F(\chi)=1-12\mu, \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (2)$$

where μ is a constant which specifies the rate of change of temperature with time and φ is the time in radians measured from local noon as zero, so that $\chi=\varphi$. The positive sign applies to the morning hours, when $\varphi<0$. With $\rho_0H=$constant, $h_0^0=4H_0$, and $\mu=0\cdot04$, so that H ranges from 53 to 70 km, the diurnal variation of $h(I_m)$ shown in Figure 1 is obtained. During most of the day $h(I_m)$ lies below the noon level (here 280 km), in marked contrast to normal Chapman behaviour.

Associated with a diurnal temperature cycle may be a cyclic expansion and contraction of the atmosphere as a whole. The resulting transport of cells of ionization and modifications of electron density may be taken into account in exactly the same manner as tidal cell displacements. If v be the vertical cell motion, measured positive upwards, the electron density contours are found by solving the continuity equation for electrons,

$$\frac{\partial N}{\partial t}=I-\alpha N^2-\frac{\partial}{\partial h}(Nv), \quad \ldots\ldots\ldots\ldots (3)$$

after the manner indicated by Weiss (1953). The simplest treatment is to assume that the structure of the atmosphere remains isothermal at any instant throughout the diurnal temperature cycle and that the pressure at the datum level remains constant. The laws of motion are then

$$v=\frac{h}{H}\frac{\mathrm{d}H}{\mathrm{d}t}, \quad \frac{\partial v}{\partial h}=\frac{1}{H}\frac{\mathrm{d}H}{\mathrm{d}t}, \quad \ldots\ldots\ldots\ldots (4)$$

and, with $F(\chi)$ given by (2),

$$h=h_0F(\chi), \quad v=\pm h\mu/F(\chi), \quad \frac{\partial v}{\partial h}=\pm\mu/F(\chi), \quad \ldots\ldots (5)$$

where h_0 is the noon level of a chosen cell of ionization. With the assumption of constant density at the datum level these equations of motion are modified by the addition to the velocity of a term independent of height, thus :

$$v=\left(1+\frac{h}{H}\right)\frac{\mathrm{d}H}{\mathrm{d}t}, \quad \frac{\partial v}{\partial h}=\frac{1}{H}\frac{\mathrm{d}H}{\mathrm{d}t},$$

but the distinction is important only close to the datum level.

The continuity equation (3) has been integrated with the equations of motion (5) and (2), and with physical conditions representative of the F_2 region. The behaviour of h_m, the height at which the relative maximum electron density $\nu_m=N_m/N_0$ occurs, is illustrated in Figure 1. As before, $\rho_0 H=$constant, $h_0^0=4H_0$, and $\mu=0\cdot04$. N_0 is the noon maximum equilibrium electron density. The

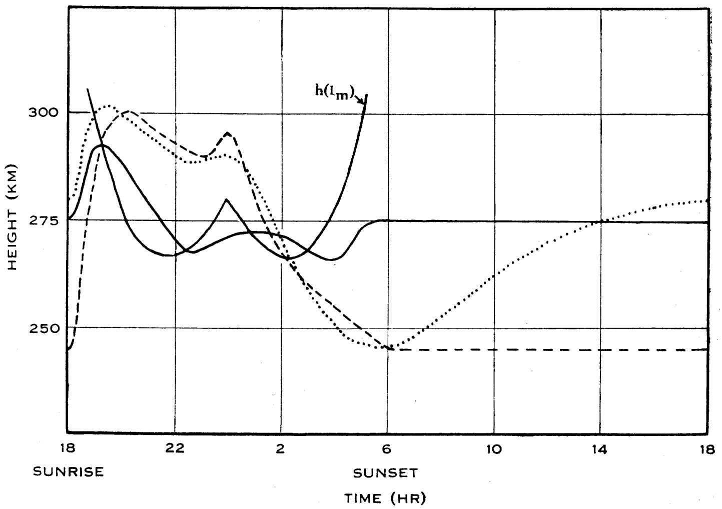

Fig. 1.—Movement of the level of maximum electron density, z_m, under diurnal temperature cycles.

$h_0^0=280$ km, $\mu=0\cdot04$ (see text).

———— No cell motion.

– – – – Cell motion, $\alpha=$constant.

· · · · Cell motion, $\alpha=\alpha_0 \exp(-z/10)$.

case of no cell motion, $v=0$, with I given by (1), is also shown. The third curve relates to a region for which the rate of decay decreases slowly with height, $\alpha=\alpha_0 \exp(-z/10)$, where α_0 is the value of the decay coefficient at the datum level $z=0$. It is easily seen that an increase in the range of the daily temperature cycle (increase in μ) is accompanied by a rise in the noon level of h_m when cell motion is taken into account, but by a fall in noon h_m when cell motion is ignored. An increase in h_0^0/H_0 implies a rise in noon h_m relative to sunrise (and sunset) h_m.

The foregoing examples cannot be considered as representing the actual atmosphere. It is not to be expected that the upper atmosphere would in fact retain an instantaneously isothermal structure during a cycle of temperature changes. Indeed, from several independent sources (see, e.g. Gerson 1951) there is evidence of a temperature gradient between the E and the F_2 regions.

The rates of ion production in an atmosphere in adiabatic equilibrium, with temperature rising linearly with height, have been evaluated by Gledhill and Szendrei (1950); their conclusions that the larger the temperature gradient or the base temperature, the higher the level of region formation, the thicker the region, and the lower the electron density are clearly consistent with the results of Lepechinsky. Seasonal temperature changes in the upper atmosphere appear to be substantiated and a diurnal cycle may reasonably be inferred. This being the case, Figure 1 may serve to indicate the way in which a diurnal temperature cycle can influence h_m for the F_2 region. The main effect is to raise the level of h_m above that appropriate to the simple Chapman region, for which the day-time level of h_m is lower than the night-time level except immediately after sunrise. The detailed electron density profiles, not reproduced here, show that ν_m is essentially the same as on the simple Chapman theory. Further calculations show that the addition of a semi-diurnal tidal drift of electrons, whose phase is consistent with the observed night-time elevation of $h^m_{F_2}$, would suffice to account for the day-time elevation of the F_2 region, which is typical of summer conditions over most of the world.

At the level of the F_1 region the relaxation time is sufficiently short that neither tidal drifts nor thermal cell motions can materially alter electron density profiles. If a diurnal temperature cycle is present at F_1 levels, then $h^m_{F_1}$ should closely follow $h(I_m)$. The fact that the F_1 region follows Chapman behaviour appears to suggest the absence, at F_1 levels, of appreciable temperature cycles, either diurnal or seasonal.

III. The Low Attenuation Region

The F_2 region has been described by Bates (1949) as a low attenuation region, exhibiting less solar control than a normal Chapman region. According to this same author the ionizing process responsible for the F_1 region will provide a sufficient rate of ion production at higher levels to account for the F_2 region also, when regard is taken of the decrease of recombination coefficient from the F_1 to the F_2 region. In addition to the "recombination" law under which removal of electrons proceeds according to the law $\mathrm{d}N/\mathrm{d}t=-\alpha N^2$, attention has been directed by certain authors (e.g. Bates and Massey 1946) to the possibility that an "attachment" law, $\mathrm{d}N/\mathrm{d}t=-\beta N$, may apply to the F_2 region, rather than the recombination law. In respect of the attachment law an "effective recombination coefficient" may be defined by writing $\alpha=\beta/N$. Now, despite the large scatter in the measured value of the recombination coefficient (see, e.g. Bates and Massey 1946), there can be no doubt that it decreases by one and probably two or more orders across the F region as a whole, and, whether the F region originates in one ionizing process or in two, it is pertinent to examine the structure of an ionized region for which the decay coefficient is height dependent.

The characteristic of a low attenuation region is that the rate of ion production depends primarily on the concentration of the active constituent, and only secondarily on the solar zenith angle χ. Since in the Chapman ion production formula, $I=I_0 \exp(1-z-\mathrm{e}^{-z}\sec\chi)$, the factor $\exp(-\mathrm{e}^{-z}\sec\chi)$ becomes negligible for $z>2$, the upper levels of the isothermal Chapman region will serve as an example of a low attenuation region. The absence of tidal and thermal displacements is assumed.

(a) Recombination Law

If the recombination coefficient falls off exponentially with height, the structure of the region at any given level is determined by the equations (cf. Chapman 1931)

$$\left.\begin{aligned} &\text{day:} && \frac{\mathrm{d}\nu}{\mathrm{d}\varphi}=q^2-p^2\nu^2, \\ &\text{night:} && \frac{\mathrm{d}\nu}{\mathrm{d}\varphi}=-p^2\nu^2, \end{aligned}\right\} \qquad (6)$$

which are the forms assumed by the continuity equation (3) in the absence of vertical drift ($v=0$) when time is measured in terms of φ and the electron density by the relative electron density $\nu=N/N_0$. N is the electron density at any level at a given time and $N_0=(I_0/\alpha_0)^{\frac{1}{2}}$ as before is the noon maximum equilibrium electron density; α_0 is the recombination coefficient at the level $z=0$. $q^2=a \exp(1-z)$ and $p^2=a \exp(-\gamma z)$, where γ is a constant specifying the rate of decrease of the decay coefficient with height. The adjustable parameter a is defined by $a=(1\cdot 37\times 10^4 N_0\alpha_0)^{-1}$. A range of values of a from $40/\pi$ to $1/\pi$ should cover all possibilities for noon conditions for either F_1 or F_2 regions. The day-time solution of (6) is

$$\nu=\frac{q}{p}(k\mathrm{e}^{2qp\varphi}-1)/(k\mathrm{e}^{2qp\varphi}+1),$$

where k is a constant of integration. Reckoning time from sunrise as zero, then for the equinoxes the relative electron densities at sunrise and sunset are respectively

$$\nu_0=\frac{q}{p}(k-1)/(k+1),$$

$$\nu_{12}=\frac{q}{p}(k\mathrm{e}^{2qp\pi}-1)/(k\mathrm{e}^{2qp\pi}+1). \qquad (7)$$

The night-time solution of (6) is

$$\frac{1}{\nu}=\frac{1}{\nu_{12}}+p^2\varphi,$$

and at sunrise

$$\frac{1}{\nu_0}=\frac{1}{\nu_{12}}+p^2\pi. \qquad (8)$$

If $qp\pi\ll 1$, it is found, by equating (7) and (8), that $k=3+2\sqrt{2}$, independent of p and q. For larger values of $qp\pi$, the expression for k is more complex; these solutions are not investigated here. The electron density profiles are, for $qp\pi\ll 1$,

$$\left.\begin{aligned} &\text{sunrise:} && \nu_0=\frac{1}{\sqrt{2}}\exp\tfrac{1}{2}(1-z+\gamma z), \\ &\text{sunset:} && \frac{1}{\nu_{12}}=\frac{1}{\nu_0}-a\exp(-\gamma z).\pi. \end{aligned}\right\} \qquad (9)$$

(b) Attachment Law

If decay proceeds according to an attachment law, with the rate of decay falling off exponentially with height, the relevant equations determining the structure of the region are

$$\text{day:} \qquad \frac{d\nu}{d\varphi}=q^2-p^2\nu,$$

$$\text{night:} \qquad \frac{d\nu}{d\varphi}=-p^2\nu.$$

q and p have the same significance as in equation (**6**) if the attachment coefficient at the datum level, β_0, has the value $\beta_0=\alpha_0 N_0$. The solutions of these equations, found in a manner similar to the above, are

$$\left.\begin{array}{ll}\text{sunrise:} & \nu_0=\exp(1-z+\gamma z)/[1+\exp(p^2\pi)],\\ \text{sunset:} & \nu_{12}=\nu_0\exp(p^2\pi).\end{array}\right\} \quad \ldots\ldots (\mathbf{10})$$

These latter profiles are valid for all values of p and are limited in applicability only by the extent to which neglect of the factor $\exp(-e^{-z}\sec\chi)$ is warranted. The attachment profiles (**10**) for $\gamma=0\cdot75$ are drawn in Figure 2.

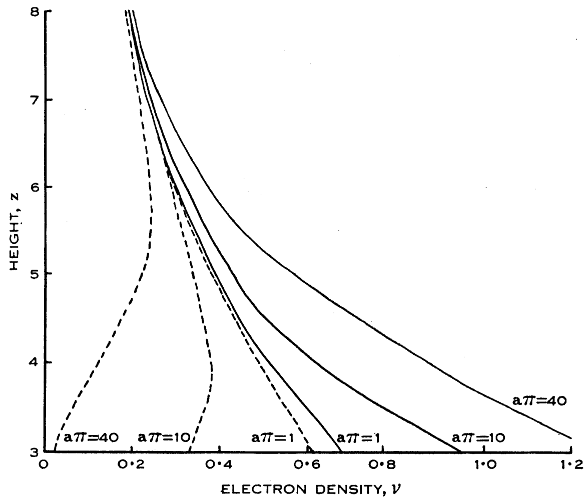

Fig. 2.—Electron density profiles for low attenuation region, $\gamma=0\cdot75$.
– – – – Sunrise. ———— Sunset.

For large values of z, under either decay law, the region profiles become independent of a and hence of the absolute value of the decay coefficient. For smaller z, the attachment profiles become sensitive to a, especially for small γ, a dependence which is expected to apply also to the recombination profiles. At very high levels, the diurnal cycle in electron density tends to vanish, ν becoming independent of φ and depending only upon z, under which conditions seasonal influences can enter only through the period of illumination of the region.

It will be observed that at not too low levels or too small γ, $\nu_{\text{attach}}\to(\nu_{\text{recomb}})^2$ at sunrise For $a\pi=1$, this is true for all γ, as can be shown by extrapolation of (**9**) to $\gamma=0$ using the profiles of Chapman (1931), and also for all hours because of the small cycle in ν which is associated with small values of a. A similar relation of course holds for the equilibrium region with $d\nu/d\varphi=0$, but the conditions envisaged here are far from equilibrium.

On the hypothesis that the rate of removal of electrons falls off exponentially with height, layer formation is not possible unless $\gamma<1$, since if $\gamma>1$, $\nu\rightarrow\infty$ as $z\rightarrow\infty$. This contradicts the conclusion reached by Mitra (1952) that there may be a well-defined maximum of electron density even if $\gamma>1$. Other laws may of course be postulated which lead to layer formation at all times, e.g. $p^2=ac^n(z+c)^{-n}$, where c and n are arbitrary positive constants. Such a law will yield a maximum of electron density for all values of n.

IV. Night-time Behaviour with Height-Dependent Decay

The profiles of Figure 2, for $a\pi=10$, 40 focus attention upon the fact that during the night, in the absence of ion production and other complicating factors, the level of maximum electron density of an ionized region across which the rate of decay decreases with increase in height, will invariably rise. One example, where tidal drifts have been included, has been given by Weiss (1953). The factors which determine the extent of the rise in z_m may readily be formulated.

From the night-time solution (**8**) for the recombination law the condition for the maximum of ν_m is easily found to be

$$\frac{1}{\nu_{12}}\frac{\partial\nu_{12}}{\partial z}=\varphi\nu_{12}\frac{\partial p^2}{\partial z}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{11})$$

For p^2, take as before $p^2=a\exp(-\gamma z)$, and for ν_{12}

$$\nu_{12}=\exp K(1-z-e^{-z}), \qquad \ldots\ldots\ldots\ldots\ldots (\mathbf{12})$$

which for $z>0$ and with K a positive constant will serve to represent the upper portions of profiles of the type drawn in Figure 2. The failure of (**12**) to represent the behaviour of the region for $z<0$ is of no consequence as $z_m>0$ always. Then (**11**) becomes

$$K(1-e^{-z_m})=\exp K(1-z_m-e^{-z_m})\varphi\gamma a e^{-\gamma z_m}. \qquad \ldots\ldots\ldots (\mathbf{13})$$

For the attachment law we have, more simply,

$$K(1-e^{-z_m})=\varphi\gamma a e^{-\gamma z_m}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{14})$$

The graphical solutions of (**13**) and (**14**), for $\varphi=\pi$, are presented in Figure 3, which shows how the extent of the rise in z_m after 12 hr depends on γ, K, and a. It will be seen that the rises of z_m are by no means small, and that the attachment law invariably gives larger rises than the recombination law. The association of small rises in z_m with large values of γ is physically self-evident. The curves have not been drawn beyond $\gamma=1$ because, as already indicated, region formation is impossible for $\gamma\geqslant1$. Some uncertainty attends these results because (**12**) may not adequately represent the initial conditions at sunset (although experience with complete integrations suggests that the sunset profiles above z_m are of this shape), but the conclusion appears inescapable that a small rise in z_m at night implies either a long relaxation time or a very small gradient of the decay coefficient with height.

V. The Complete Region Profiles

The conclusions of the preceding sections are corroborated by several integrations over 24-hr periods of the continuity equation (3) for electrons, which have been performed for the equator at the equinoxes. The results—diagrams of z_m and of ν_m—are collected in Figure 4. For the recombination law ion production follows $[1/F(\chi)] \exp (1-z-e^{-z} \sec \varphi)$ and decay the law $[1/F(\chi)]^2 e^{-\gamma z} \nu^2$ with $\gamma=0,\ 0{\cdot}25$. For the attachment law, ion production is as above, and decay follows $[1/F(\chi)]^2 e^{-\gamma z} \nu$, $\gamma=0,\ 0{\cdot}1,\ 0{\cdot}25,\ 0{\cdot}5$, and $0{\cdot}8$. In both cases $F(\chi)$ is given by equation (2) with $\mu=0{\cdot}04$, and for the third term

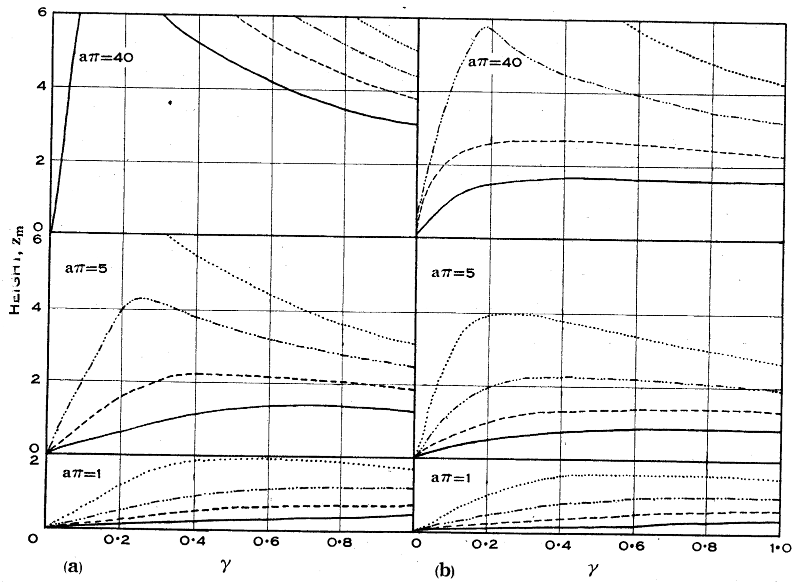

Fig. 3.—Night-time rise of the level z_m, after 12 hr, when decay decreases with increasing height. Ascending portions of some curves omitted. (*a*) Attachment, (*b*) recombination.

————	$K=2$.	—··—··—··—	$K=\frac{1}{2}$.
– – – –	$K=1$.	· · · · · · · ·	$K=\frac{1}{4}$.

of the continuity equation the value of $\partial v/\partial h$ given by (5) has been adopted, that is, $\partial v/\partial h=\pm\mu/F(\chi)$. The inclusion of the factors in $F(\chi)$ in these expressions admits the possibility of including thermal motions as in Section II but, as $F(\chi)\sim 1$ except near sunrise and sunset and the velocity gradient is small at all times, Figure 4 will depict with sufficient accuracy the behaviour of z_m and ν_m for the static isothermal region. Profiles for the sequence $0\leqslant\gamma\leqslant 0{\cdot}8$ for the attachment law are shown in Figure 5.

From these diagrams the following conclusions may be drawn:

(*a*) A rough approximation to the profile, and even to the behaviour of ν_m, can be obtained by putting $d\nu/d\varphi=0$.

(*b*) The movement of z_m, which is similar in form with either law of decay, cannot be inferred by putting $d\nu/d\varphi=0$.

(c) Although the separation between z_m and $z(I_m)$ increases as γ increases, during the middle part of the day the level of ν_m is to be found not far from the level of the maximum rate of ion production. Such a conclusion is of course only valid for values of γ somewhat less than 1.

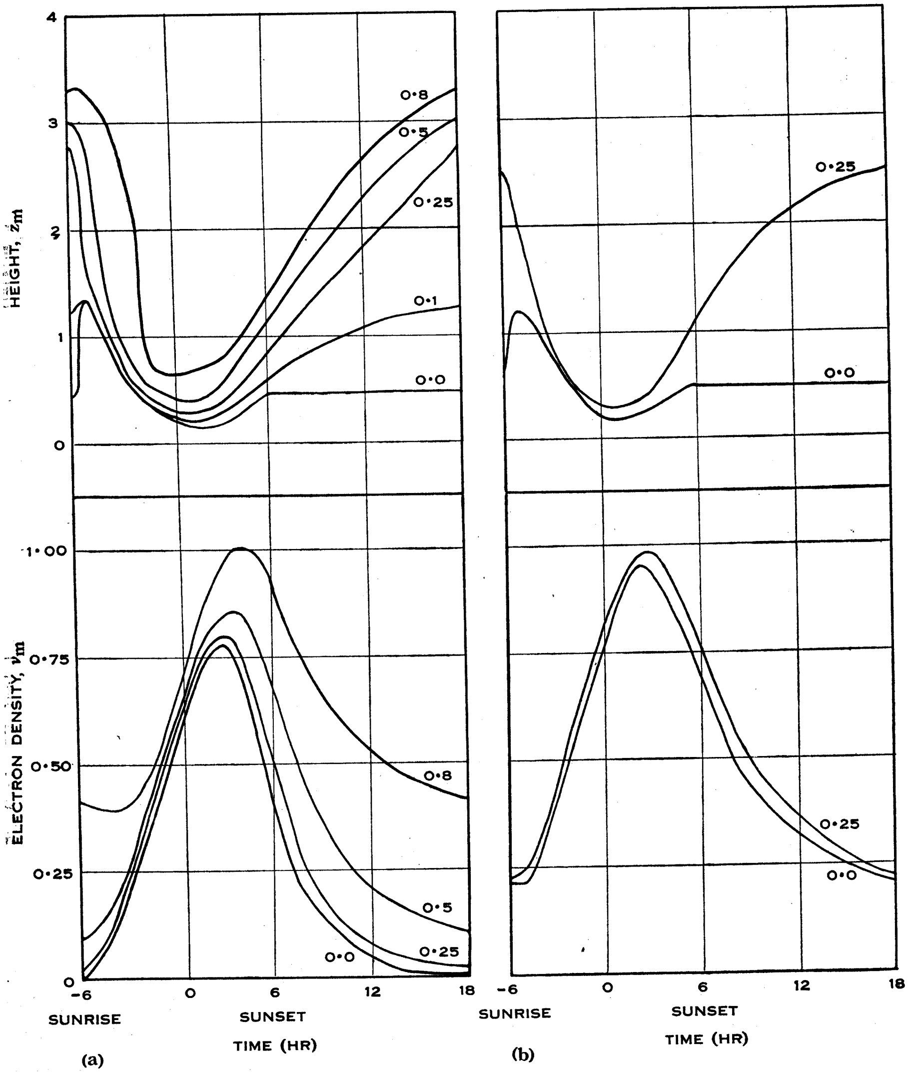

Fig. 4.—Region parameters, z_m and ν_m, when decay decreases with height. The numbers on the curves are the values of γ. (a) Attachment, (b) recombination.

(d) For the intermediate value of a chosen for the integrations $\nu_{\mathrm{attach}} \sim (\nu_{\mathrm{recomb}})^2$. During the middle part of the day $d\nu/d\varphi \rightarrow 0$ quite closely at low levels, whilst at higher levels the equilibrium condition is simulated (Section III). Further confirmation of this relation lies in Figure 3, with $a\pi = 5$, for which $K_{\mathrm{attach}} = 2K_{\mathrm{recomb}}$ gives approximately equal night-time rises of z_m.

(e) Sunrise values of ν_{attach} are much less than the corresponding values of ν_{recomb}, smaller even than implied by (d) above. If N_s is the sunset value of N_m, then with decay by recombination $N/N_s=(1+N_s\alpha t)^{-1}$, whilst for decay by attachment, with $\beta=N_s\alpha$, $N/N_s=\exp(-N_s\alpha t)$. These two laws give equal rates of decay only if $N_s\alpha t<\frac{1}{2}$, or, for a 12-hr period, $N_s\alpha<10^{-5}$ if N_s is measured in cm^{-3}, α in cm^3 sec^{-1}. Now, for the conditions under which these integrations were performed, $N_s\alpha\sim 4\times 10^{-5}$ and the more rapid decay following the attachment law is not unexpected. Values of α approaching 10^{-11} are necessary before the two laws lead to equal rates of decay over a period as long as 12 hr, and under such conditions N/N_s remains quite large, $N/N_s>\frac{1}{2}$.

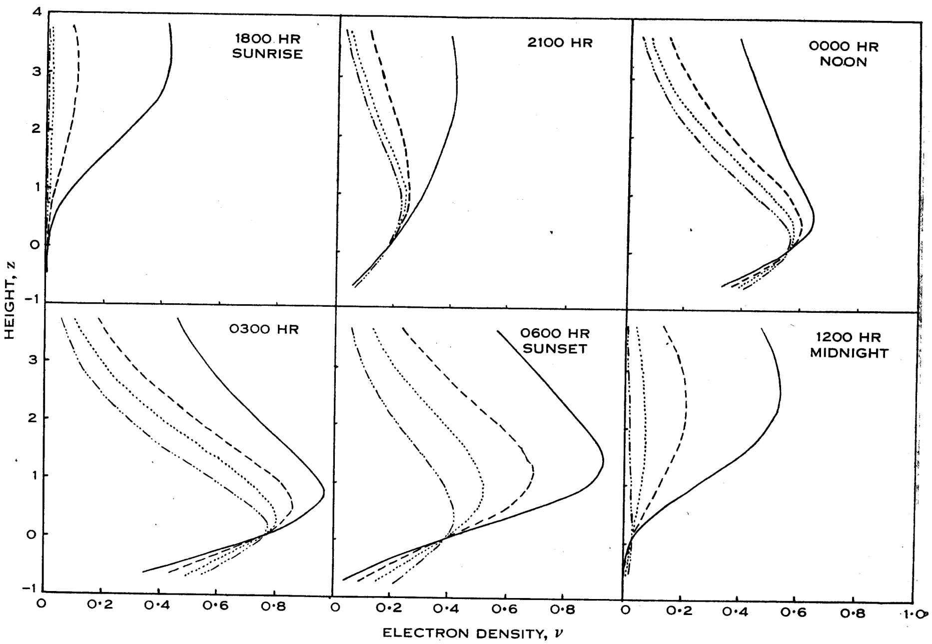

Fig. 5.—Electron density profiles when decay proceeds by attachment.
——— $\gamma=0\cdot8$. · · · · · $\gamma=0\cdot25$.
- - - - $\gamma=0\cdot5$. —··—··— $\gamma=0\cdot0$.

VI. Discussion of Height Variations

Height data for the F_2 region have been summarized by Appleton (1950). The idealized annual variation of height as a function of latitude relates to noon h'_{F_2} and, if a vertical tidal drift with height gradient contributes to these variations, noon $h^m_{F_2}$ may not vary with season and latitude in exactly the same manner as noon h'_{F_2}. However, in examining how far these annual variations in height can be explained by vertical tides acting on a simple (isothermal) Chapman region, we may assume that the two heights are directly comparable.

According to Martyn (1948) and Mitra (1952), the tidal drift at any station may be represented as the sum of two terms, one annual and the other seasonal. Since Weiss (1953) has shown that even a considerable height gradient in the vertical tidal drift velocity has little influence on z_m, and in any case the available data indicate that tidal drift velocities at the F_2 level are not large ($\sim$10 km/hr) it is sufficient to consider a semi-diurnal tide uniform with height, which is directly additive. If v_a and v_s are the amplitudes of the annual and seasonal components of the total vertical tidal drift and λ_a and λ_s the respective phase angles, the total tidal drift velocity is

$$v=v_a(\theta) \sin (2\varphi+\lambda_a)+v_s(\delta, \theta) \sin (2\varphi+\lambda_s+\Omega t), \quad \ldots . \quad (\mathbf{15})$$

where θ=co-latitude, δ=solar declination, and $\Omega t=30°$/month.

The seasonal variation of noon z_m is then found, after integration of (**15**) and incorporating the control of region height by zenith angle (second term), to be

$$w_{\text{noon}}=-\tfrac{1}{2}[v_a(\theta) \cos \lambda_a+v_s (\delta, \theta) \cos (\lambda_s+\Omega t)]+\ln \operatorname{cosec} (\theta+\delta).$$

The terms in δ will introduce a semi-annual variation at latitudes $<23\frac{1}{2}°$ and an annual variation at higher latitudes, whilst the term in Ωt produces an annual variation at all latitudes. Close to the equator the seasonal tidal term $v_s(\delta, \theta)$ should be small and the zenith angle term is in phase quadrature with the actual variation of noon height. At high latitudes one would expect the zenith angle term to dominate, and this is in phase opposition with the observed variations.

The conclusion that the seasonal height variations of the F_2 region cannot be satisfactorily explained by vertical tides acting on an isothermal Chapman region is strengthened by consideration of the diurnal cycle in $h^m_{F_2}$ for a station such as Washington. Here the seasonal variation is well developed, and is related to the radical change in $h^m_{F_2}$ from Chapman-like behaviour in winter months to high day-time values in summer. It does not admit of ready explanation in terms of a seasonal cycle in the amplitude, or phase, or both, of a tidal drift. It is pertinent to mention here that Martyn (1948) has shown that the height variations of the F_1 region are consistent with small tidal displacements, which at this level do not necessarily imply small tidal drift velocities, of an isothermal Chapman region.

Apart from influencing tidal drifts and displacements of the level of the maximum rate of ion production, the seasonal cycle in the solar zenith angle may alter region heights through an annual temperature cycle. Increased summer temperatures at the level of the F region are substantiated in several different ways. It has already been shown that a combination of diurnal temperature cycle and tidal drift, with a decay coefficient independent of height, appears adequate to account for the diurnal $h^m_{F_2}$ variations in summer months; from Section IV it is clear that this explanation only holds provided the decay coefficient remains essentially independent of height. Further, according to Lepechinsky (1951), two regions, produced in two distinct ionizing processes, have smaller noon separation in winter than in summer owing to the smaller diurnal temperature cycle in winter. However, so long as temperature cycles alone are invoked, difficulties which cannot be resolved by appeals to tidal theory may still arise in connection with the bifurcation of the summer night F region into separate F_1 and F_2 regions just after sunrise and with the failure of evidence of the temperature changes to appear in the diurnal and seasonal cycles of $h^m_{F_1}$.

The origin of the F_1 and F_2 regions in a single ionizing process has been considered qualitatively by Martyn (1948) and Bates (1949); the former has also stressed the importance of tidal phenomena to the structure of the composite region. Mitra (1952) has drawn profiles for a region with $\gamma=1\cdot5$, but as already mentioned this result has not been confirmed by the present investigation. The behaviour of z_m for $\gamma<1$ (Fig. 4) bears no resemblance to the diurnal cycles found for $h^m_{F_2}$, nor does it admit of sufficient separation between z_m and the level of maximum ion production for bifurcation on the scale found in summer months. The night-time profiles for $\gamma\geqslant\frac{1}{2}$ (Fig. 5) can scarcely be described as parabolic, but Ratcliffe (1951) has found for the three stations he analysed that the profiles, if not parabolic at sunset, rapidly become so and retain this shape during the night. These observed profiles of course apply only to the underside of the region, below $h^m_{F_2}$.

Although region formation is not directly possible for $\gamma\geqslant1$, two maxima of electron density may arise in a single ionizing process if there is a double discontinuity in the height gradient of the decay coefficient, with $\gamma\sim0$ below a lower level (giving rise to an F_1 region essentially similar to the simple Chapman region) and above an upper level (giving rise to the upper portion of the F_2 region, above $h^m_{F_2}$), with $\gamma>1$ between these two levels. It is readily seen that for large values of a (Section III), values of γ not very much greater than unity will suffice to produce the observed ratio of $N^m_{F_2}$ to $N^m_{F_1}$ of from 2 to 4, whether decay proceeds by recombination or by attachment. During the summer night-time the upper discontinuity in the decay coefficient will act as an effective barrier preventing any rise of $h^m_{F_2}$ above the sunset level, other than that due to tidal drift. During winter in high latitudes the contraction of the atmosphere as a whole will lower both discontinuities in the decay coefficient, and this, coupled with the relative elevation of the region consequent upon reduced solar zenith angle, may well result in the complete absorption of the effective solar radiation above the level of the upper discontinuity, where decay is not strongly dependent upon height, with a normal Chapman region and failure of bifurcation to appear. Some additional mechanism, such as tides, would probably be necessary to account for the major seasonal alterations in the distribution of electrons within the F_2 region, as reported by Ratcliffe (1951).

This explanation is consistent with the results of Smith (1952), who from studies of the refraction of radio stars at Cambridge has found that the integrated electron density above $h^m_{F_2}$ is normal for a Chapman region in winter and whilst somewhat above the Chapman norm during summer is certainly not excessively so.

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