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Investigations on the Diurnal Variation of the Ionosphere F_2 in Winter and in Summer

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1. Introduction.

Observations of ionosphere at intermediate latitudes prove remarkable differences between diurnal variation curves of penetration frequency and virtual height of F_2 in winter and those in summer as shown in Fig. 1. The daytime electron density is greater and the night electron density is smaller in winter than in summer, and, as seen in general, from the time of sunrise, some phase lag is observed in summer behind the curves in winter. The source of ionosphere is obviously the absorption of radiation from the sun. Then the daytime electron density of F_2 in summer smaller than that in winter,

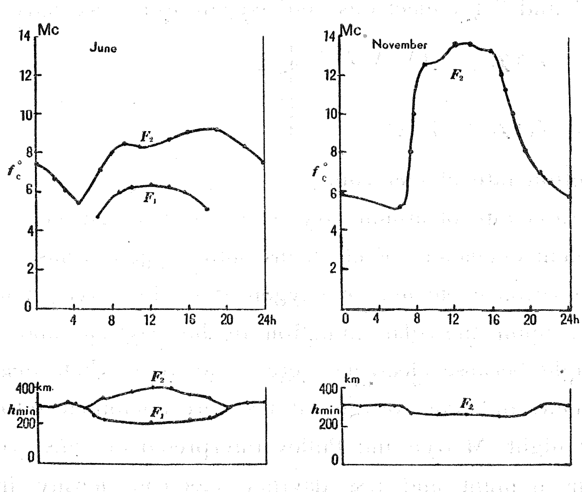

Fig. 1

decreasing rate of night electron density in summer much less than that in winter and the night electron density greater in summer are all rather hard to understand.

Some authors tried to interpret these variations of F_2 in summer and winter :

Appleton and Naismith[1] assumed the atmosphere in F_2 not to be identical in its temperature in summer and in winter and to suffer thermal expansion in summer, and started from the Chapman's equation of electron density variation

$$\frac{dN}{dt}=I-\alpha N^2 \tag{1}$$

where I= Ion production rate in a unit volume

N= Electron density,

α= Recombination coefficient.

Putting $\frac{dN}{dt}=0$ we have for a stationary state assumed at noon

$$N=\sqrt{I/a} \tag{2}$$

and at the maximum of ion production

$$N_{max}=\sqrt{I_0\cos\chi/a}=\sqrt{S_\infty\beta\cos\chi/eHa}$$

where $H=kT/mg$,

$a\propto T_e^{-\frac{1}{2}}$, T_e = electron temperature.

With suffixes s and w for summer and winter, respectively, we have

$$\frac{(N_{max})_s}{(N_{max})_w}=\sqrt{\frac{\sin(\theta+23.°5)\,a_w T_w}{\sin(\theta-23.°5)\,a_s T_s}}=\sqrt{\frac{\sin(\theta+23.°5)\,T_w}{\sin(\theta-23.°5)\,T_s}}\sqrt{\frac{T_{es}}{T_{ew}}} \tag{3}$$

From this expression, Appleton and Naismith concluded, assuming T_e identical in summer and in winter, that the temperature at noon would be in summer 4 times as high as in winter. If the electron temperature is assumed to change with molecular temperature, the above value should be over 10 times greater. Martyn and Pulley[2] adopted the theory of attachment and assumed that the electrons attach only to oxygen in atomic state. With suffixes 1 and 2 for electrons and oxygen atoms, we have

$$\left.\begin{aligned}\frac{dN_1}{dt}&=I_1(\chi,z)-\beta N_1N_2T_e^{\frac{1}{2}},\\ \frac{dN_2}{dt}&=I_2(\chi,z)-\gamma N_2^2,\end{aligned}\right\} \tag{4}$$

where I_1 = production rate of electron,

I_2 = production rate of atomic oxygen by solar radiation,

β = attachment coefficient of electrons onto oxygen atoms,

γ = recombination coefficient of oxygen atoms into oxygen molecules.

I_1 mainly depends upon the solar radiation in the daytime and was also supposed not to be zero at night because electrons were made free when negative oxygen ions produced by attachment and other oxygen atoms were combined into oxygen molecules while I_2 vanished at night. Martyn and Pulley interpreted on this basis the decreasing tendency of electrons at night and less daytime electron density in summer than in winter. But, for this purpose, they had to take into consideration the influences of ozone and water vapor and to assume expansion and contraction of atmosphere between the layers E and F_2.

Taro Tsukata's research[3] of recombination and attachment in various cases is also not likely to interpret the difference in summer and winter without taking to some extent the expansion and contraction into consideration and, in the daytime, the negative ions produced by attachment will probably isolate their electrons by visible rays from the sun and will not be able to exist as negative ions so that the daytime electron density in summer seems unable to be less than in winter. No interpretations were given to the level of F_2 higher in summer than in winter.

The writer[4] considered the expansion of the upper atomsphere after an ellipsoidal distribution model to give a qualitative interpretation to the noon electron density in the regions of intermediate latitudes less in summer than in winter, and constructed a qualitative theory of observed latitudinal and seasonal variations of the layer height. Nothing, however, has been stated on the difference of diurnal variation curves of winter and summer types.

In the present paper, with the observed data at Shanghai by the writer himself, Paramushiro, Hiratsuka, Rangoon and Palau, not only the diurnal variation curves of penetration frequency or the maximum electron density and the minimum virtual layer height but also the $h'-f$ curves in winter and in summer shall be directly compared with each other, from which the true height h_{max} of the maximum electron density and the layer thickness Z_d up to there will be calculated and the seasonal and latitudinal differences of their diurnal variations will be investigated to clarify the meaning of the diurnal variation curves and to consider from various points of view how their differences in summer and in winter are given rise to.

2. Observed Facts.

All-night observations of the ionosphere were made by the writer since October, 1939. As an example of the observations in winter, the diurnal variation curves of the penetration frequency and minimum virtual height on November 19, 1940 and, as an example in summer, those on June 11, 1940 are shown in Fig. 2. The observations on

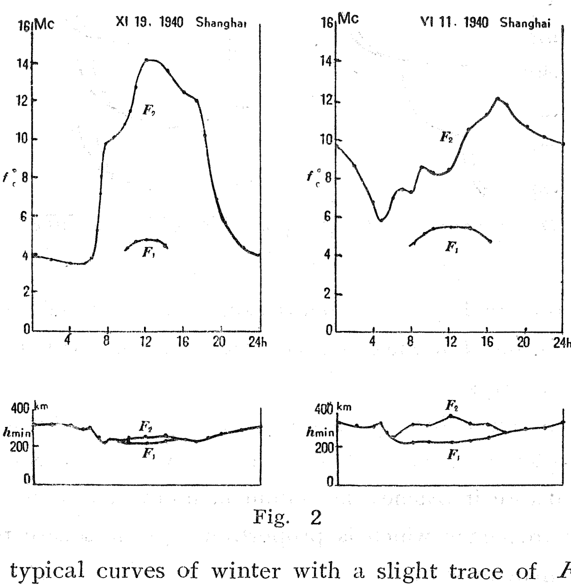

Fig. 2

November 19 show typical curves of winter with a slight trace of F_1 for some hours in the daytime. The curves, however, show distinctly the effect of superposition and splitting of F_1 and F_2 as previously discussed in one of the writer's reports(5). The characteristics of summer type seem to be well represented, with all a shade of magnetic storm, by the curves on June 11, except some ups and downs and a too slow rate of electron density increase.

The $h'-f$ curves of these two days in winter and in summer observed at every two

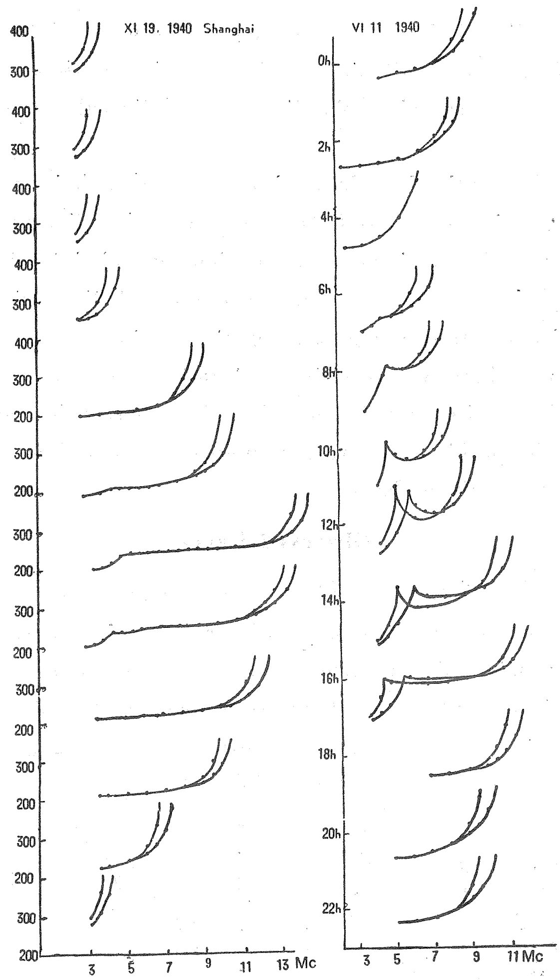

Fig. 3

hours from 0^h are shown in Fig. 3. A comparison of the left and right groups of the curves reveals a remarkable difference between the curves of winter and summer types at the same time of the days.

The penetration frequency decrease is comparatively rapid after sunset in winter but rather slow and flat after midnight, while rather slow after sunset in summer at an almost constant rate before it reaches the minimum point just before the dawn keeping the night penetration frequency which is proportional to the square root of the electron density much higher than in winter.

Comparing the two $h'-f$ curves a and b in Fig. 4, the gradient of the curve of b is found steeper than that of a, which means that the electron density varies with height more slowly in b than in a and, followingly, that the layer thickness up to the height of the maximum electron density Z_d of b is greater. Comparing the curves of summer night in Fig. 3 with those of winter night from the above point of view, the former are found steeper suggesting a greater thickness of F_2, and the greatest thickness take place at about 20^h to decrease gradually toward dawn.

In the daytime, on the other hand, the penetration frequency in winter increases rapidly after sunrise, a little less rapidly when F_1 and F_2 are supposed to split away from each other, again rapidly until it attains its maximum a short time after the noon to decrease rapidly except for a short time period of less decreasing rate observed when the superposition of F_1 and F_2 are supposed to take place again ; while, in summer, though the case of June 11 is a particular example, penetration frequency increases rather slowly, and very slowly, perhaps affected by the splitting of F_1 and F_2, around midday to give the maximum electron density at $16 \sim 17^h$ in the evening. The waves are to suffer retardation by F_1 when it is present and the h'–f curve of F_2 is greatly distorted giving rise to difficulties mentioned above. The layer has a considerable thickness increasing gradually after sunrise.

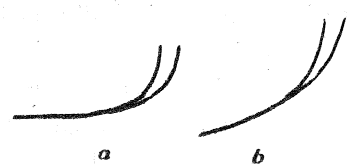

Fig. 4

The calculation of electron density distribution with respect to true height from given h'–f curves is theoretically possible when the layer is a single one. Putting

z_1 = true height corresponding to the electron density N_1,

f_1 = frequency of waves reflected at the height z_1,

z_0 = true height of the lowest level of the ionosphere,

the real height z_1 can be obtained by the numerical integration of

$$z_1 = \frac{1}{\pi} \int_0^{N_1} \frac{h(N) - z_0}{\sqrt{N_1 - N}} \frac{dN}{\sqrt{N}} \tag{5}$$

or

$$z_1 = \frac{1}{\pi} \int_0^{f_1} \frac{h(f) - z_0}{\sqrt{f_1^2 - f^2}} df. \tag{6}$$

The numerical calculation, however, is too laborious in practice and, when F_1 is present, impossible because of the discontinuity on the h'–f curves.

By assuming an approximate parabolical distributon of electron density introduced by Booker and Seaton[6], the true height of the maximum electron density h_{max} and the thickness up to the maximum electron density Z_d may be obtained in an easier way. An

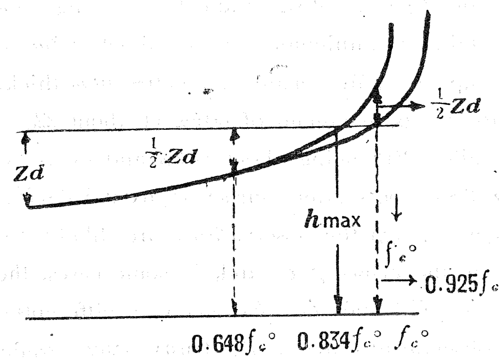

Fig. 5

approximate parabolical distribution as shown in Fig. 5 gives the desired values in such a way that

f_c° = penetration frequency of ordinary waves,

h_{max} = true height of maximum electron density N_{max}

= virtual layer height at the frequency $0.834 f_c^{\circ}$

and, h' (0.925) = virtual layer height at $0.925 f_c^{\circ}$,

h' (0.648) = virtual layer height at $0.648 f_c^{\circ}$,

$$\left.\begin{aligned} Z_d &= h'(0.925) - h'(0.648) \\ &= 2\{h'(0.925) - h_{max}\} \\ &= 2\{h_{max} - h'(0.648)\}, \end{aligned}\right\} \qquad (7)$$

or, by means of the minimum virtual layer height h'_{min}, we have approximately

$$Z_d \fallingdotseq h_{max} - h'_{min}. \qquad (8)$$

This method, however, still leaves us an inevitable fear of estimating h_{max} somewhat too great and Z_d somewhat too small as an influence of retardation by F_1 when it is highly developed in the daytime.

Fig. 6 shows the monthly mean values of h_{max} and Z_d in November and June, 1940, which depicts the general variations of h_{max} and Z_d. In winter, h_{max} is highest at midnight, decreases gradually, lowest at about 8^h in the morning, increases gradually before

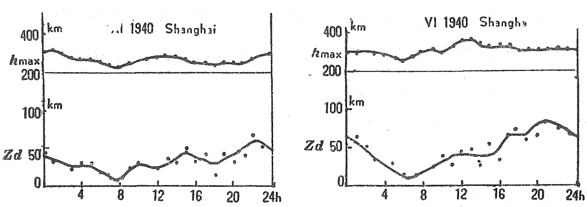

Fig. 6

it attains its second maximum after the noon, decreases gradually toward evening to have its second minimum and then increases toward midnight. In summer, though the general tendency is identical to that of winter the maximum in the afternoon is greater than that at night, the decreasing rate in the afternoon is smaller and some time lag in the phase is observed. In winter, Z_d is greatest at about 22^h being about 60*km* in thickness, decreases gradually and attains its minimum value of about 10*km* around $7 \sim 8^h$ or $2 \sim 3$ hours after sunrise, grows up gradually getting some $30 \sim 40$*km* thick, and goes on steadily after the sunset until it attains its maximum of 60*km* at about 22^h. The maximum of Z_d in summer takes place at about 21^h being about 85*km* and decreases gradually before it attains its minimum 13*km* $2 \sim 3$ hours after sunrise or around $6 \sim 7^h$. It seems to increase gradually after its minimum, though the observations are likely to give values smaller than really it is affected by the growing F_1 and, in some cases, the observation itself is impossible. After 16^h, as f_c° (F_1) and f_c° (F_2) become differentiable from each other and F_1 gets weaker, the observations are more trustworthy, gradually increasing until about 21^h. The daily variation amplitude of Z_d in summer is about 1.5 times as much as in winter. The decrease of Z_d after midnight seems to be due to the contraction of the atmosphere, while the increase of Z_d with increasing h_{max} from the minimum in the morning may be a result of layer expansion.

Beside the observations at Shanghai, those at Paramushiro, Hiratsuka, Rangoon, and Palau with values of $h'(0.834) = h_{max}$ recorded were available[7], from which the diurnal variations of penetration frequency f_c°, h_{min}, h_{max} and Z_d were estimated. Figs. 7, 8, 9 and 10 show their monthly average curves in November and June.

At Paramushiro (50. 1°N), very little diurnal variation in h_{max} is observed in winter as well as in summer but a slight lowerinng in the daytime. Z_d is about $25 km$ at night

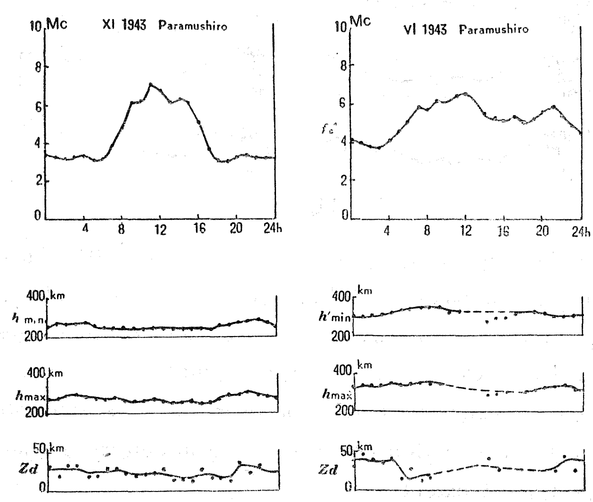

Fig. 7

and about $15 km$ in the daytime in winter, while in summer it is $35 km$ at night and, not a many observations being available affected by the sporadic E, some $15 \sim 20 km$ in the daytime. The amplitude of layer thickness variation is $1.5 \sim 2$ times greater in summer.

Fig. 8 shows the observations at Hiratsuka (35.3°N). Both h_{max} and Z_d vary more greatly than at Paramushiro, but still a little less than at Shanghai. In winter, Z_d is $35 \sim 40 km$ at night and $10 \sim 20 km$ in the daytime, while in summer $70 km$ at about 23^h is the maximum of Z_a, which decreases suddenly at sunrise attaining its minimum $15 km$, and increases gradually in the daytime. The amplitude of Z_d variation in summer is about 2 times as great as in winter.

Fig. 9 shows the curves obtained at Rangoon (19. 8°N). In the tropical zone the contrast of penetration frequency is not so remarkable as in the regions of intermediate latitudes and no great differences are observed between the curves in winter and in summer. Considerable distinctions, however, exist between the diurnal variation curves of h_{max} and Z_d in winter and those in summer. The behaviors of h_{max} and Z_d in winter are identical to those observed in summer at Hiratsuka and Shanghai in the intermediate zone. But, in summer, h_{max} is lowest $3 \sim 4$ hours after sunrise or around $7 \sim 8^h$,

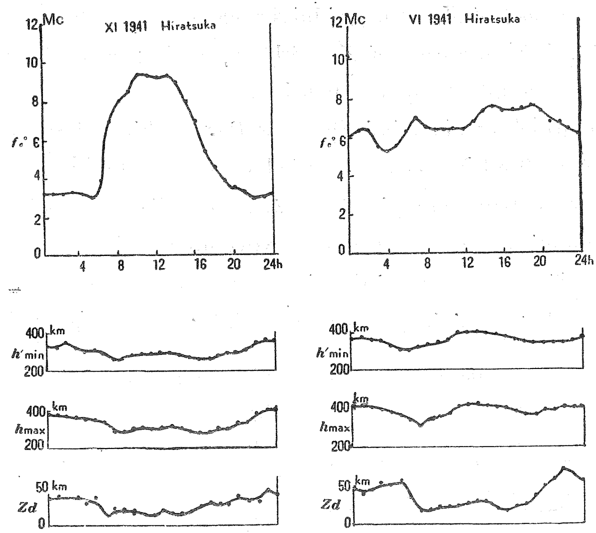

Fig. 8

gets then suddenly higher and lowers gradually until after 20^h. This diurnal variation seems to prove a considerable phase lag behind the solar altitude. The amplitude of remarkable Z_d variation is as great as $150km$ at its maximum. Z_d is greatest in the evening, starts decreasing and decreases rapidly in $3\sim4^h$ hours after sunrise. The ratio of Z_d variation in winter and in summer seems to be over 2. It is interesting that, with all little difference between the variation curves of electron density in summer and in winter, h_{max} and Z_d vary to a great extent.

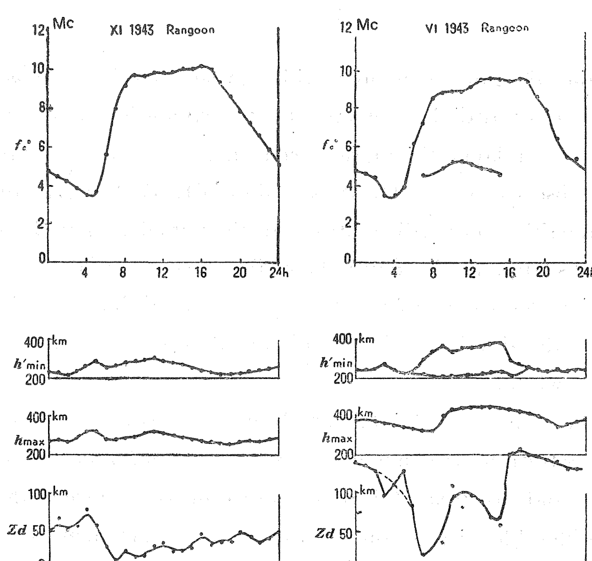

Fig. 9

Fig. 10 was recorded in 1941 at Palau (7. 3°N). The penetration frequency curves in

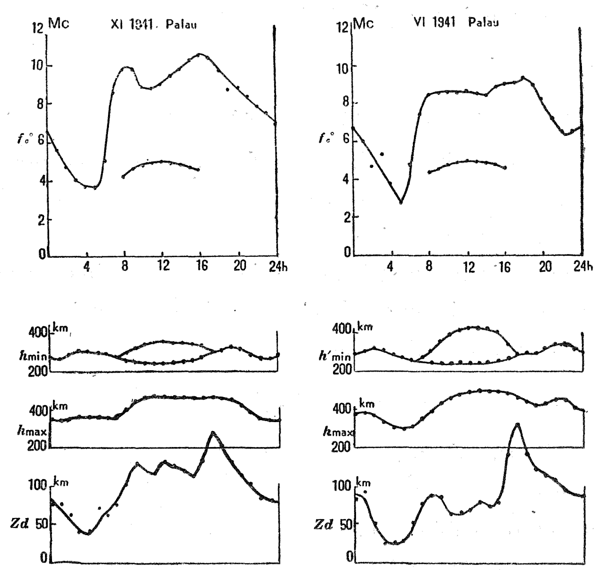

Fig. 10

winter and in summer are very similar to each other in their shapes but a little smaller in their values in summer. The behavior of h_{max} is similar to that at Rangoon in summer, being very high in the daytime and starting to lower from $20\sim22^h$. Z_d variation curves in winter and in summer also show little difference both in their shapes and amplitudes, being as thick as $170\sim180km$ at its maximum at about 17^h in the evening to decrease rapidly toward dawn. Then it gets thicker again and rapidly in the evening. Z_d in the daytime greater in winter than in summer may be an effect of highly developed F_1.

3. Considerations on the Observations.

The difference between the winter and summer types has been hitherto discussed on the basis of diurnal variation and, on the electron extinction mechanism in the process of electron density decrease observed after sunset, we have two theories submitted, that it is due to the recombination of the electrons and positive ions and that the extinction is a result of attachment of the electrons on neutral atoms or molecules, both of which have not yet been assured. The bases of these discussions are confined to the diurnal variation curves of penetration frequency f_c° which is proportional to the square root of the electron density.

Let us then consider what the diurnal variation of penetration frequency means. The penetration frequency means, as seen from its definition, the penetration frequency of ordinary waves f_c°, whose relationship with the electron density is expressed by

$$\mu^2 = 1 - \frac{e^2}{\pi m} \frac{N}{f^2} \tag{9}$$

and, in case of vertical transmission, the radio waves are reflected downward at the level where the refractive index μ is equal to zero. Therefore, the maximum electron density

N_{max} of the layer corresponding to f_c° is given by

$$N_{max}=\frac{\pi m}{e^2} f_c^{\circ 2}. \tag{10}$$

The diurnal variation of the above N_{max} or f_c° is what is observed as the penetration frequency curve. The level height of N_{max} or f_c°, however, does not necessarily remain constant all the time in a day but, as a matter of fact, its level as well as the electron density distribution itself vary from time to time.

Therefore, exists some discrepancy between the observed time variation of N_{max} and the time variation of electron density N at a fixed level, which is derived as many authors did after Chapman's model[8] from

$$\begin{aligned}\frac{dN}{dt}&=I-\alpha N^2 \quad \text{for recombination}\\ &=I-\beta N_0 N \quad \text{for attachment,}\end{aligned} \tag{11}$$

where I= electron production rate,

α= coefficient of recombination,

β= coefficinet of attachment,

N_0= number of neutral atoms in a unit volume.

Therefore, for the purpose of putting theory in accordance with observation, the level height $(h_{max})_0$ of the maxium electron density $(N_{max})_0$ at $t=t_0$ should be obtained, where N is in general a function of height and time $N(h, t)$, from

$$\left(\frac{dN}{dh}\right)_0=0 \quad \text{at} \quad t=t_0$$

and then the behavior of N_{max} is to be discussed. That is, as h_{max} is also a function of time, $N_{max}\{h_{max}(t), t\}$ is to be studied. It is a lot of trouble. In the equations (11) are included only the electron production and the recombination or attachment, beside which the expansion and contraction of the atomosphere, convection of the atmosphere, diffusion of the electrons and other factors may come into problem. The theory then becomes more and more complicated. A glance over the diurnal variation curves of penetration frequency gives us the impressions that the contrast of electron density variation at night and in the daytime is more remarkable in winter, that daytime variation seems to follow the solar zenith distance χ without any discernible lag of equilibrium phase and that the electron extinction after sunset is rapid. On the other hand, in summer, the contrast of electron density variation at night and in the daytime is much weaker and the variation has a considerable phase lag after solar altitude.

Putting $t=86400\phi/2\pi=1.37\times10^4\phi$,

$$\nu=N/N_0, \qquad N_0=(I_0/\alpha)^{\frac{1}{2}} \tag{12}$$

and $1/\sigma_0=1.37\times10^4(I_0/\alpha)^{\frac{1}{2}}=1.37\times10^4\alpha N_0$,

Chapman[9] transformed (11) into

$$\begin{aligned}\sigma_0\frac{d\nu}{d\phi}+\nu^2&=\exp(1-z-e^{-z}\sec\chi) \quad \text{(daytime)},\\ &=0 \quad \text{(night)},\end{aligned} \tag{13}$$

where $z=\frac{h-h_0}{H}$, $I_0=\beta' S_\infty/He$, $h_0=H\log A\rho_0 H$.

Comparing σ_0 with unity, which is taken as a criterion of diurnal variation, we find

(I) If $\sigma_0 < 1$, equilibrium is realized at every moment of diurnal variation of solar zenith distance because of the high reaction rate,

(II) If $\sigma_0 > 1$, the greater the value of σ_0, the greater the phase lag of the equilibrium behind the diurnal solar variation,

(III) If $\sigma_0 \gg 1$, no diurnal variation takes place.

According to Masataro Miyamoto,[10] in the case of attachment,

$$\sigma_0 = 1/1.37\times 10^4 \beta N_0. \tag{14}$$

Therefore, for σ_0 in winter σ_{0w} and that in summer σ_{0s} in our case, we have

$$\sigma_{0s} > \sigma_{0w}. \tag{15}$$

$$\therefore \quad \alpha_s N_{0s} < \alpha_w N_{0w},\ I_{0s}\alpha_s < I_{0w}\alpha_w \quad \text{for recombination} \tag{16}$$

$$\beta_s N_{0s} < \beta_w N_{0w} \quad \text{for attachment,} \tag{17}$$

where $\alpha = Q_\alpha v$, $\beta = Q_\beta v$,

Q_α, Q_β = effective cross sections of collision,

v = electron velocity

T_e = electron temperature.

As a result of quantum mechanics, we have for the oxygen atoms

$$Q_\alpha = 2.3\times 10^{-21}/\varepsilon^{(11)(12)(13)}, \tag{18}$$

$$Q_\beta = 6\times 10^{-23}/\varepsilon^{\frac{1}{2}(14)(15)}, \tag{19}$$

where ε = energy of an electron.

$$\text{Therefore,}\quad \left.\begin{array}{l} \alpha \propto T_e^{-\frac{1}{2}} \\ \beta : \text{independent of } T_e. \end{array}\right\} \tag{20}$$

From $I_0=\beta' S_\infty/He$, $H=kT/mg$, we find $I_0 \propto T^{-1}$.

Therefore, (16) and (17) are transformed into

$$T_{es}^{\frac{1}{2}}\, T_s > T_{ew}^{\frac{1}{2}}\, T_w, \tag{21}$$

$$N_{0s} < N_{0w}, \tag{22}$$

and further, as $N_0 \propto T^{-1}$, (22) becomes

$$T_s > T_w. \tag{23}$$

When the atomosphere is expanded by its raised temperature, σ_0 gets greater regardless the case of recombination or attachment and the time lag of diurnal variation behind the solar diurnal motion gets more prominent reducing the difference of night and day. The observed results seem to be interpreted by assuming higher temperature, expansion of atomsphere and greater value of σ_0 in summer.

From (21) and (22) and from (12) and (14), we have

$$\left.\begin{array}{ll} \sigma_0 \propto T_e^{\frac{1}{4}}\, T^{\frac{1}{2}} & \text{for recombination} \\ \text{and}\quad \sigma_0 \propto T & \text{for attachment.} \end{array}\right. \tag{24}$$

The above descriptions are, however, based solely on (11) or (13) and there exist as stated above some discrepancies between the theory and the observations, which shall be further considered.

The penetration frequency is supposed, as already described, to represent the curve of N_{max}. The level height h_{max} of N_{max} is now desirable, but it is not usually reported. What is usually reported and observed is the minimum virtual height. As the desired exact value of h_{max} is rather troublesome to obtain and impossible when F_1 is present, we shall be satisfied, as the first approximation, with h_{max} obtained from $h'-f$ curve by Booker and Seaton's method of approximate parabolical distribution.

This method is accompanied by small errors when the penetration frequency of F_2 is much higher than that of F_1 giving rise to smaller retardation, while when the penetration frequencies of F_2 and F_1 are close to each other good heed has to be paid to the fact that the observed height is much higher than the real one affected by the retardation of the group velocity passing through F_1. When F_1 is not present, this method of approximate parabolical distribution gives a very high approximation being most accurate from evening to early morning. The curves of h_{max} show that h_{max} is higher in the daytime at intermediate and lower latitudes not only in summer but also in winter when F_1 is less developed. If the atmosphere stays at a standstill and no expansion, convection or other change takes place, the solar radiation is to penetrate deeper to ionize the lower level of the atmosphere reducing h_{max} in the daytime. That is, the result of Chapman's distribution will be as shown in Fig. 11 and h_{max} in the daytime will be represented by

$$h_{max} = H\log(\sec\chi A\rho_0 H) \qquad (25)$$

being lowest at noon. Any other assumption than Chapman's distribution also necessarily gives the lowest value at noon if the atmosphere stands still.

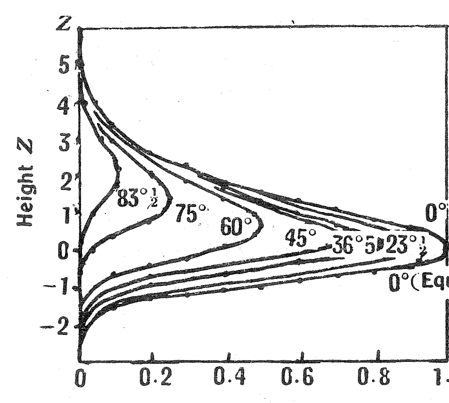

Fig. 11

Therefore, the fact that h_{max} is higher in the daytime in winter and especially in summer at the intermediate and lower latitudes seems to suggest expansion, convection or some other changes in the atmosphere. It is true that the presence of F_1 makes h_{max} observed as if it were higher than it really is, but higher values of h_{max} observed in the winter daytime when F_1 is supposed to be very weak and in the late summer evening when F_1 supposed to be already vanished is understood to prove the abovementioned atmospheric motion. It is clearly observed at Hiratsuka, Shanghai, Rangoon and Palau in summer that h_{max} gets lower and lower after midnight and lowest after sunrise, which seems to mean the expansion of the atmosphere in the daytime and its contraction at night. During usual observations of $h'-f$ curves, the existance of this kind of phenomena is frequently noticed. The minimum of h_{max} is supposed to take place 2∼3 hours after sunrise in the upper air because the solar radiation penetrates deeper and deeper through the atmosphere as the sun rises higher, ionizing the lower level of the atmosphere in the most contracted state at dawn when the expansion has not yet started. Then, as the atmosphere starts to expand prevailing in its effect over the deepening penetration of solar radiation.

The less rapid decrease of h_{max} in the afternoon toward evening and the consequent asymmetry of the daytime h_{max} curves are supposed to be due to the decrease of the penetration of solar radiation through the atmosphere with decreasing altitude of the sun after its maximum of expansion. Anyway, the variation rate of penetration of the solar radiation and the atmospheric expansion and contraction rates have time lags behind the followed solar height variation, being very likely to be the cause of asymmety of h_{max} curves. This is an interesting contrast to the comparatively symmetric curves of h'_{min}. Now let us go into the diurnal variation of Z_d. At Paramushiro in the northern region, the diurnal variation is as small as to show very little difference between night and day but it is in summer about 1.5 times as thick as in winter. At Hiratsuka and Shanghai in the zone of intermediate latitude, Z_d is considerably greater than at Paramushiro and Z_d in summer is $1.5\sim2$ times as thick as in winter. At Shanghai, its diurnal variation is fairly clear ; Z_d is minimum $2\sim3$ hours after sunrise, increases gradually to its maximum about 2 hours after sunset and decreases toward dawn. At Rangoon in summer and at Palau, the variation amplitude is much greater.

These behaviors of Z_d seem to accord with the abovementioned variation of h_{max} ; a reasonable interpretation for such great variations of Z_d in the regions of intermediate and lower latitudes may be the expansion and contraction of the upper atmosphere. Z_d decreases by contraction at night to attain its minimum at dawn, and the deeper penetration of solar radiation prevents Z_d from increasing as in the case of h_{max} giving rise to a phase lag of Z_d variation, and as the solar radiation penetrates less deep in the evening because of its oblique incidence through the expanded atmosphere the maximum of Z_d is realized because of the atmospheric expansion and higher h_{max} as seen from Fig. 11. No other interpretations are likely to avail with these great diurnal variations of Z_d in the tropics.

In Fig. 12 are plotted the daily maxima of Z_d versus the latitudes of the observatories. Z_d varies to a great extent with latitude and gets much greater near the Equator ; being at Palau over 5 times as great as at Paramushiro. The above curves in November and June are similar in their shapes except a translation by 15° of latitudes, which is far less than the variation of daily maximum solar altitude $23°.5\times2=47°$. Nevertheless, at other places than Palau near the Equator, Z_d in summer is found $1.5\sim2$ times as thick as in winter.

The zenith distances of the sun at noon in November and June are tabulated in Table 1 with the latitudes of each place of observation. A survey of latitudinal and seasonal variations of Z_d with the tabulated latitudes readily reveals that Z_d is not only a function of χ but depends to a considerable degree upon the latitude itself : χ at Paramushiro in summer is nearly equal to that in winter at Palau, while Z_d at Palau in winter is definitely greater ; Z_d at Hiratsuka in summer never gets so great as at Palau in summer. These facts are due to the translation of Z_d not more than 15° northward in summer despite the solar altitude variation as much as 47° and Z_d is likely to depend not only upon the solar zenith distance χ but also upon some latitudinal factors such as annual average of the daily solar illumination.

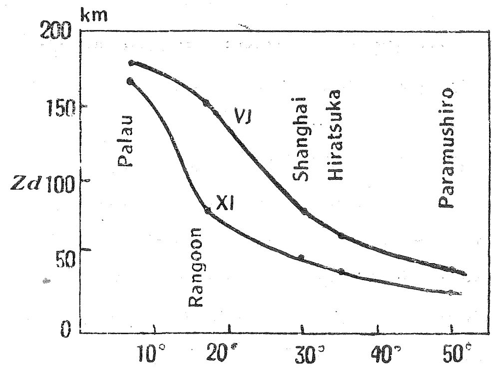

Fig. 12

Table. 1

	Solar zenith distance χ	
	XI	VI
Paramushiro (50.°1N)	73°	27°
Hiratsuka (35.°3N)	58°	12°
Shonghai (31.°1N)	53°	7°
Rangoon (16.°8N)	40°	6°
Palau (7.°3N)	30°	16°

Now let us consider how the atmospheric expansion possibly take place as the cause of the daytime increase of h_{max} and Z_d. The atmoshphere is not ionized only by a monochromatic solar radiation of a certain wave length but by the absorption of energy quanta $h\nu$ of the radiations shorter in wave length than that corresponding to the ionization potential $E=h\nu_m$ of the atoms or molecules. Therefore, the energy excess

$$h\nu-h\nu_m=\frac{1}{2}mv^2 \tag{26}$$

is liberated as the kinetic energy given to the electrons, whose mean velocity is related to the electron temperature T_e by

$$v=\sqrt{3kT_e/m.} \tag{27}$$

Stronger ionization causes higher electron temperature and it is supposed to be higher than the gas temperature. When the electrons and atoms or molecules collide elastically or non-elastically, the energy is passed over from the electrons to the atoms or molecules resulting in the gas temperature rise of the atmosphre and its expansion. This may be a possible process of the atmospheric expansion, while the accumulation of the radiation energy in the F_2, as M. Miyamoto opines(16), by its scattering atmosphere may be another.

The number of electrons in a unit volume of the atmosphere is reduced by expansion when the other factors remain unchanged. How the recombination and attachment coefficients will be then ? Denoting the effective cross sections of recombination and attachment by Q_α and Q_β respectively, we have

$$\alpha=Q_\alpha v, \qquad \beta=Q_\beta v \tag{28}$$

and, from (18) and (19), $Q_\alpha \propto 1/\varepsilon$, $Q_\beta \propto 1/\varepsilon^{\frac{1}{2}}$

where $$\varepsilon=\frac{1}{2}mv^2=\frac{3}{2}kT_e.$$

Therefore, $$\alpha\propto 1/v\propto T_e^{-\frac{1}{2}},$$

and $$\beta : \text{independent of } T_e. \qquad (29)$$

In the case of attachment, it is not only β that must be taken into consideration but the number of neutral atoms or molecules in a unit volume N_0 and βN_0 becomes the effective factor, of which N_0 is inversely proportional to the gas temperature T and β is independent of the electron temperature T_e.

Therefore, the expression $\beta N_0 \propto T^{-1}$ is found closer to the fact than the assumption of Martyn and Pulley that the attachment coefficient is proportional to $T_e^{\frac{1}{2}}$.

Both α and βN_0 are thus concluded from the variation of h_{max} and Z_d, not only when compared in summer and in winter but from time to time in a day, to vary with the electron temperature, the gas temperature, the atmospheric expansion and contraction etc. The only possible case of constant α and βN_0 is the motionless atmosphere without any temperature difference between its upper and lower levels.

The mechanism of electron extinction in F_2 has been discussed in various ways and it has been concluded that α is too small to give rise to the diurnal variation only by means of recombination. Both recombination and attachment are, however, supposed to take place.

Both α and βN_0 do not remain constant during a day as previously guessed from the behaviors of h_{max} and Z_d. But, on the basis of the fact that Z_d is as much as 1.5~2 times thicker in summer than winter, we shall be allowed to consider the states in general, with suffixed s and w for summer and winter respectively, that

$$T_{es}>T_{ew}, \qquad T_s>T_w. \qquad (30)$$

Then, from $\alpha=T_e^{-\frac{1}{2}}$, we have for the case of recombination

$$\alpha_s<\alpha_w. \qquad (31)$$

Chapman's discriminating quantity of diurnal variation

$$\sigma_0=1/1.37\times10^4\alpha N_0=1/1.37\times10^4(\alpha I_0)^{\frac{1}{2}}$$

is proportinal to $T_e^{\frac{1}{4}}\,T^{\frac{1}{2}}$, and consequently

$$\sigma_{0s}>\sigma_{0w}. \qquad (32)$$

In summer, therefore, the diurnal variation of the electron density has more phase lag behind the diurnal motion of the sun, the contrast of the diurnal variation at night and in the daytime is weaker and the variation amplitude is smaller.

Likewise, in the case of attachemnt, we have from (30)

$$N_{0s}<N_{0w}$$

$$\beta N_{0s}<\beta N_{0w}.$$

As $\sigma_0=1/1.37\times10^4\beta N_0$,

$$\sigma_{0s}>\sigma_{0w}.$$

Therefore, as in the case of recombination, it follows that the phase lag of the diurnal variation is greater and the ratio of the electron density of night to that in the daytime is smaller in summer.

If the above obtained value of $Z_{ds}/Z_{dw}=1.5\sim2.0$ is solely due to the atmospheric expansion, the ratio T_s/T_w is also to take $1.5\sim2.0$. Therefore, assuming $T_e \propto T$, we have

$$\sigma_{0s}/\sigma_{0w} = (1,5)^{\frac{3}{4}} \sim (2.0)^{\frac{3}{4}} = 1.3\sim1.7 \text{ for recombination,}$$
$$=1.5\sim2.0 \qquad \text{for attachment.} \qquad (33)$$

A general comparison of summer and winter has been discused above. A more detailed discussion of the diurnal variation necessiates the evaluation of the atmospheric expansion and contraction from the diurnal variations of h_{max} and Z_d, and the decrease and increase and the changes in α and βN_0 from time to time caused by the atmospheric expansion and contraction have to be taken into consideration.

4. Conclusiosns.

It has been the general way of dealing with the variation of F_2 of the summer and winter types to discuss the penetration frequency or the electron density at noon and to compare summer and winter from the equations

$$\frac{dN}{dt}=I(\chi.Z)-\alpha N^2$$
$$=I(\chi.Z)-\beta N_0 N$$

assuming a stationary state at noon. As some discrepancies were expected between this way of treatment and what the obsevations really meant, the writer supplemented the curves f_c° and h'_{min} by the diurnal variation curves of h_{max} and Z_d obtained from the observations at Paramushiro, Hiratsuka, Shanghai, Rangoon and Palau, both of which prove the atmoshperic expansion in the regions of intermediate and lower latitudes $2\sim3$ hours after sunrise. Before this expansion takes place after sunrise the electron density increases rapidly and less rapidly after the beginning of the expansion making the electron density curve rather flat. This lower rate of electron density increase is supposed to be due to the expansion of the atmosphere which is naturally accompanied by smaller recombination and attachment coefficients α and βN_0 and the consequent phase lag of the phenomenon. Smaller decreasing rate of h_{max} in the evening, the asymmetry of h_{max} curves in the morning and afternoon and the minimum and the maximum of Z_d curves $2\sim3$ hours after sunrise and from evening toward night are supposed to be due to the time difference of the penetration of solar radiations into the atmosphere and the atmospheric expansion and contraction which results a phase lag on the variation curves of Z_d. That is, the penetration of the solar radiation into the contracted atmosphere in the morning ionizes lower level of the atmosphere to give the minimum of h_{max} and Z_d and, in the evening, the oblique incidence of solar radiation penetrates less deep to lessen the decreasing rate of h_{max} and to give the maximum of Z_d. Another basis of the supposed restless expansion and contraction of the atmosphere is the going up of h_{max} in the daytime in winter at intermediate latitudes.

The atmospheric expansion and contraction give rise to the changes in the coefficients of recombination and attachment α and βN_0, both of which can no longer be considered to be invariant throughout a day. Their values are to vary from time to time after

$$\alpha \propto T_e^{-\frac{1}{2}} \quad \text{and} \quad \beta N_0 \propto T^{-1}$$

and it is supposed not to fit the fact to represent them as constants independent of time. The Chapman's discrimination quantity of diurnal variation σ_0 is given by

$$\sigma_0 \propto T_e^{\frac{1}{4}} T^{\frac{1}{2}} \text{ for recombination}$$

and $$\sigma_0 \propto T \quad \text{for attachment.}$$

Variations in h_{max} and Z_d are scarecely observed at latitude as high as Paramushiro and the diurnal variation shows the state of atmosphere next to stand-still. The difference of summer and winter is, however, considered to be due to the 1.5~2-fold expansion of Z_a in summer. In the regions of intermediate and lower latitudes, the difference between summer and winter as well as the considerable variations in a day are observed and the diurnal variation curve is a result of the expansion, contraction and other atmospheric changes. From a general point of view, the variation amplitude of Z_d, 1.5~2 times greater in summer than in winter with α and βN_0 assumed to vary with the expansion, gives the evaluation of σ_0 as

$$\sigma_{0s}/\sigma_{0w} = 1.3 \sim 1.7 \quad \text{for recombination}$$

and $$\sigma_{0s}/\sigma_{0w} = 1.5 \sim 2.0 \quad \text{for attachment,}$$

from which is deduced the result answering to the fact that the amplitude of diurnal variation is smaller and the phase lag behind the diurnal motion of the sun is greater in summer than in winter. But a theoretical consideration of the diurnal variation of F_2 will require a closer treatment with h_{max}, Z_d, expansion and contraction and the consequent variation of α and β all taken into consideration.

Z_d does not seem to be a function of the solar altitude only but to have unnegligible factors depending upon the latidude and, with all the solar altitude difference in summer and in winter as much as 47°, the corresponding shift of the latitudinal variation curve of Z_d is no more than 15°.

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