*Adv. Space Res.* Vol.5, No.9, pp.145-156, 1985
Printed in Great Britain. 
0273-1177/85 $0.00 + .50


# ON THE PROPERTIES AND ORIGIN OF THE VENUS IONOSPHERE

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## ABSTRACT

The brief review of the properties of dayside and nightside ionosphere of Venus is given, and some possible origins of ionization are discussed. There are arguments in favour of the impact ionization by electrons from magnetotail as the source of main ionization peak of the nightside ionosphere.

The discrepancies in the results obtained by the different in-situ experimental techniques, as well as the discrepancies between the in-situ experimental results and radio occultation results, do not allow the Venus ionosphere to be described quantitatively (although the qualitative description seems to be possible).

After Venera-9,-10 and Pioneer-Venus experiments, a great number of publications followed which dealt with experimental data, hypotheses and theoretical models. They described some properties of Venus' ionosphere as well as its origin. Measurements of the same properties made by different methods often gave inconsistent results. Models based on various preconditions had both common and different features. Finally hypotheses of ionization sources, especially in the night ionosphere, are still under discussion.

It is of interest to analyze the available publications about the properties and origin of Venus' ionosphere emphasizing the inconsistent and debatable results in order to argue for the necessity of statistically processing the available information, its averaging and tabulation for VIRA.

## SOURCES OF EXPERIMENTAL DATA

Experimental data on the Venus' ionosphere were acquired as a result of experiments performed on board the Soviet Venera-4,-9,-10 and the American Mariner-5,-10 and Pioneer-Venus spacecrafts. According to the techniques used for their acquisition, these data can be divided into two groups:

1. Remote sensing data obtained by radio occultations of the spacecrafts. The Mariner-5,-10 radio occultations were observed during their single pass near Venus /1-3/. Numerous radio occultations of Venera-9,-10 and Pioneer-Venus yielded rich statistical material /4-7/.

2. In the Venus ionosphere in-situ measurements of density, temperature and composition of charged particles were obtained with various plasma experiments made by means of retarding potential analyzers, electrostatic analyzers, mass spectrometers and Langmuir probes /8-13/.

Since not only the wave ionizing solar radiation but also the solar wind and the electron fluxes precipitating into the ionosphere affect the Venus ionosphere formation, their measurements are of interest for the Venus ionosphere physics /14,15/.

It should be noted that certain parameters of the ionosphere obtained by various techniques even from the same space probe differ significantly. The causes may be: methodical uncertainties in determining ionospheric parameters from the results of satellite measurements in the actual atmosphere of Venus, different spatial resolutions of instruments, and different criteria used for identifying the structural features of any event. These causes have not yet been analyzed completely. Therefore, the Venus ionosphere more readily lends itself to an accurate qualitative rather than quantitative description in spite of many attempts made to do the latter. The other reason why the Venus ionosphere, in particular its nightside part, cannot be described quantitatively is the inherent non-stationary state of the Venus ionosphere. Hence, to describe the Venus ionosphere qualitatively, it is necessary to have a lot of measurements with controlled external conditions. Therefore, we put our emphasis on the qualitative description of the Venus ionosphere features and of the processes occurring there.

Figures 1 and 2 present the electron density profiles $n_e(h)$ in the Venus ionosphere over the dayside (Figure 1) and nightside (Figure 2) of the planet obtained during the Venera-9,10 radio occultations /4,5,16,17/. Of interest is the regular character of the dayside $n_e(h)$ -profiles and their variability in the night side ionosphere. Parallel with the main peak of the electron number-density, the lower peak of the ionization is also seen on many profiles. The latter peak is well resolved against the main one (or absent) in the night side ionosphere and observed in the day side ionosphere as a characteristic break on the $n_e(h)$ profile (Figures 1,2). The upper boundary of the ionosphere, the ionopause, manifests itself as a pronounced drop of the electron number-density (Figure 1).

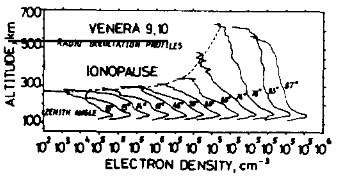


Fig. 1. Height profiles of the electron number-density in the day side ionosphere of Venus obtained from the Venera-9,10 radio occultation measurements in the dm- ($\lambda_1$=32 cm) and cm- ($\lambda_2$=$\lambda_1$/4=8 cm) ranges

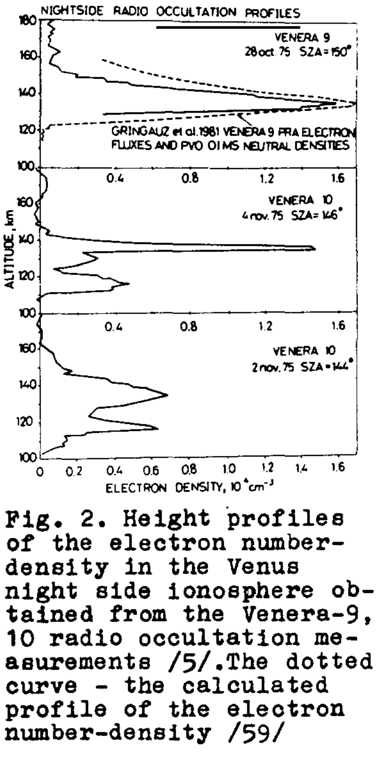


Fig. 2. Height profiles of the electron number-density in the Venus night side ionosphere obtained from the Venera-9, 10 radio occultation measurements /5/.The dotted curve - the calculated profile of the electron number-density /59/

Conventionally, the Venus ionosphere can be divided into three regions: the main and low peaks of the ionization; the ionopause; the intermediate region where the character of the electron number-density distribution is strongly dependent on the solar zenith angle.

## MAIN AND LOWER PEAKS OF IONIZATION

Statistically reliable data on the main and lower peaks of the ionization in the Venus ionosphere were gathered in radio occultation experiments. The pericenter altitude of the Pioneer-Venus orbit was always 150 km and only in 8 cases in the night ionosphere the probe altitude was lower than ~145 km. This did not allow systematic measurements of the main peak region in situ.

Electron density in the ionization peaks. Figure 3 gives the information available about the electron number-density in the main, $n_{em}$, and lower, $n_{el}$, peaks of the ionization determined from the Veneras' radio occultation data. The information about $n_{em}$ and $n_{el}$ in the dayside ionosphere was taken from the papers /16-18/, the data about the night side ionosphere from /5,7,19/. As is seen from Figure 3, $n_{em}$ in the day ionosphere is gradually decreasing with increasing the zenith angle, SZA, from $n_e$=(5 to 7)x$10^5$ $cm^{-3}$ for SZA=$0^o$ to $10^5$ $cm^{-3}$ for SZA=$90^o$. The relative value of $n_{em}$ - decrease is well described by the simple layer theory. This fact shows that the main peak of the ionization, due to UV-radiation of the Sun, is formed under the photochemical equilibrium conditions. The lower values of $n_e$ =5x$10^5$ $cm^{-3}$ obtained from the Venera-9,10 radio occultation data as compared with $n_e$ =7.4x$10^5$ $cm^{-3}$ obtained from the Pioneer-Venus data can be understood from the fact that the latter radio occultation experiment was performed under higher solar activity conditions ($F_{10.7}$=(175 to 215)x$10^{-22}$W $m^{-2}Hz^{-1}$) than the Venera-9, 10 experiments ($F_{10.7}$=(70 to 80)x$10^{-22}$W $m^{-2}Hz^{-1}$). The electron density

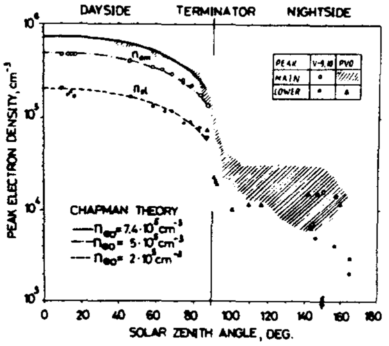


Fig. 3. Solar-zenith-angle dependence of the electron number-density in the main, $n_{em}$, and low, $n_{el}$, ionization maxima in the Venus ionosphere. The shaded zone illustrates the interval of the uncertainty in the Pioneer-Venus data. The solid and dotted lines show the zenith-angle dependences of the electron number-density plotted for the theory of Chapman's simple layer

dependence on solar zenith angle in the lower peak of the ionization, $n_{el}$, in the day side ionosphere is also well described by Chapman's theory. This peak is also formed under the photochemical equilibrium conditions but by the solar soft X-ray radiation.

In the Venus night side ionosphere, $n_{em}$ and $n_{el}$ are 1.5 to 2 orders of magnitude less than in the day side ionosphere. Over the night side of the planet the electron number-density in both peaks is subject to significant variations (Figure 3), in case of the lower peak $n_{el}$ being frequently smaller than several hundreds of electrons in $cm^3$, which is the radio occultation experiment sensitivity threshold.

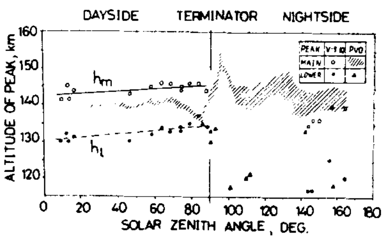


Fig. 4. Solar-zenith-angle dependence of the height of the main $h_m$ and low $h_l$ maxima of the ionization.The designations are the same as in Fig. 3

Altitudes of the ionization peaks. Figure 4, plotted from the same experimental data as Figure 3, shows the solar zenith angle dependence of the height of the main $h_m$ and lower $h_l$ peaks of the ionization in the Venus ionosphere. The heights of both peaks remains practically identical for SZA$\lesssim$70° at the day side of the planet. But according to Chapman's theory in the case of the neutral atmosphere (independent of SZA) $h_m$ and $h_l$ must be gradually increasing with growing SZA due to the fact that for larger SZA's the solar wave radiation must cover a greater path in the atmosphere to reach the corresponding height. Invariability of $h_m$ and $h_l$ is due to decreasing temperature in the upper atmosphere for larger SZA's that results in reducing the number-density of neutral particles and this, in turn, compensates the radiation path length increase in the atmosphere /17,18/ . Both factors that affect the electron number-density peak height are not completely balanced, and the Pioneer-Venus data about $h_m$ given in Figure 4 illustrate the $h_m$ decrease for SZA$\gg$70° followed by the $h_m$ growth for SZA$\gtrsim$82°. Thus, the predominant effect of the neutral number-density decrease on the $h_m$ height for SZA$\gtrsim$70° changed into the growth of $h_m$ for SZA$\gg$82° predicted by Chapman's theory /20/.

In the night side ionosphere for SZA$\gtrsim$110° the average height $h_m$ is practically constant, i.e.$\approx$143 km, but its pass to pass variations are significantly larger than those in the day ionosphere. The average height of the lower peak of the Venus ionosphere at night $h_l$ equals $\approx$118 km /20/ and thus the distance between the main and lower peaks is $\approx$25 km. At this time, that $(h_m-h_l)$ is approximately two times higher than in the day side ionosphere (see Figure 4).

Location and dynamics of the ionopause. The effect of the solar-wind dynamic pressure on the Venus ionosphere restricts its day side extent. In the radio occultation profiles $n_e(h)$ the upper boundary of the ionosphere, i.e. the ionopause, manifests itself as an abrupt decrease of the electron density (see Figure 1).

That the ionopause exists became known from the Mariner-5 radio occultation experiment /1/ . Its systematic observations by Venera-9 and Venera-10 have led Ivanov-Kholodny et al. /16/ to the conclusion of a monotonically increasing dependence of the ionopause height, $h_i$ , on the solar zenith angle, when SZA$\leq 80^{\circ}$ . However, far more numerous direct measurements of the ionopause location made by the Pioneer-Venus probe have revealed its considerable variability, in addition to the general trend of the height $h_i$ increase with increasing SZA. Variations of the solar wind dynamic pressure is the general reason of the variability of the ionopause height for a fixed SZA. The day side ionosphere, however, does not directly interact with the solar plasma. The region of the intense magnetic field, the magnetic barrier, separates the solar wind heated at the Venusian shock front from the ionosphere. This region serves as a 'membrane' that transfers the solar wind pressure to the ionosphere.

The pressure in the magnetic barrier and the pressure due to the solar wind are approximately equal. When these pressures increase the ionopause height is decreasing but dependence is non-linear. The ionospheric plasma pressure and the magnetic field pressure in the magnetic barrier are also approximately equal /21/. Even if the dynamic pressure of the solar wind is high the day side ionopause is not observed below $\approx$ 200 km.

Brace et al./12,13/ pointed out that there is also the ionopause on the Venus night side. In this ionospheric region the ionopause location is more variable than at the day side of the planet: sometimes the night ionopause was observed at very low heights, 200 km , and sometime above 3500 km. Note that the Mariner-5 radio occultation experiment observed the night side ionosphere boundary at $\sim$3700 km /1/. Physical processes causing the existence of the ionopause at the planetary night side have not been obvious yet and it is not clear whether this boundary is of a quasi-stationary (as the day ionopause) or a dynamical formation.

THE IONOSPHERE BETWEEN THE MAIN IONIZATION PEAK AND THE IONOPAUSE

The systematic direct measurements of Pioneer-Venus are the basic source of information about the ionosphere between the main ionization peak and the ionopause. Only the upper limit of the ion number-density on the planetary night side (Venera-4, /8/) and the data on the electron number-density (obtained by radio techniques) were known before the Pioneer-Venus measurements were made.

Diurnal variation of the ion composition. The Pioneer-Venus spacecraft performed measurements of the ion composition using the radio frequency ion mass spectrometer (OIMS) /11,22,23/. The distribution and the temperature of the major ionospheric components could also be measured by means of a wide-angle retarding-potential analyzer /9,10,24/. Figure 5 shows the diurnal variation of the densities of different ions obtained at 200 km: $CO_2^+$ , $O_2^+$, $NO^+$, $CO^+$+$N_2^+$, $O^+$, $N^+$, $C^+$, $He^+$ and $H^+$ . The plotted curves are based on the OIMS data acquired during first two Venerian years of the probe operation. The data shown here were taken from the paper Taylor et al. /23/ but they were ordered in a decreasing sequence of molecular weights of the ions.

A typical feature of the diurnal variation of the densities of heavy molecular ions is its abrupt fall at the terminator when passing to the night side ionosphere; this fall is 2 to 3 orders of magnitude (Figure 5). This fall is less in case of light ions $O^+$, $N^+$, $C^+$; their density in the nightside upper ionosphere decreases by 1 to 2 orders of magnitude. An asymmetric bulge occurs in the density of light ions $H^+$ and $He^+$ at dawn (Figure 5). The asymmetry in the diurnal distribution of $H^+$ is balanced by the distribution of the $O^+$ ion and of molecular ions concentrating in the dusk ionosphere generally so that the total density of ions has not a considerable dawn-dusk asymmetry. The densities of all measured ions have the well-defined fluctuations in the night side ionosphere and near the terminator (Figure 5). They are apparently connected with the non-regular character of the solar wind and the interplanetary magnetic field geometry. Because of this the behavior of the night side ionosphere is unpredictable to a great extent /23/.

Height distribution of the ion densities. Figures 6, 7 show the "height-profiles" of the density of various ions, $n_i(h)$ , in the day and night ionosphere respectively, which are characteristic for the morphology of

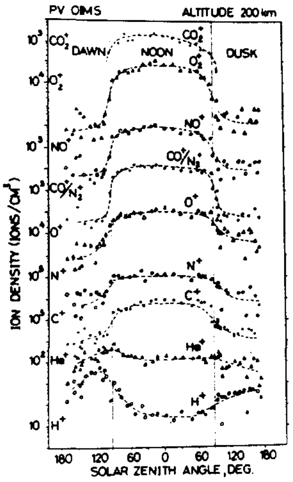


**Fig. 5.** Solar-zenith-angle dependence of the ion composition in the Venus ionosphere from the Pioneer-Venus data /23/

these regions to some extent /23/ . In the rigorous sense the given $n_i(h)$ dependences are not the height profiles since they were measured only along the Pioneer-Venus very flat trajectory near the pericenter and are distorted due to the effects of spatial inhomogeneities and time variations of different scales. These effects may cause the $O_2^+$ - density maximum seen in Figure 6 (this ion is predominant in the main peak of the ionospheric ionization) and observed at ~175 km whereas according to radio occultation data the ionization peak has never been observed at such heights in the day time (see Figure 4 taken from the paper /18/ ). Of interest is also the $O^+$ - density value in the main peak of the night side ionosphere which was determined from the mass spectrometer data as equal to about $1.5x10^{+5}cm^{-3}$. In this regions the maximum values of $n_{em}$ in radio occultation experiments are approximately by 5 times lower (see Figure 3). Such a discrepancy is not the only one in the experimental data obtained by the Pioneer-Venus instruments. For example, the neutral atmosphere model (which is significant for ionosphere physics) constructed upon the neutral particle mass spectrometer (ONMS) data used the 1.63-fold increase in the density values /25/. It is evident that it is necessary to treat very carefully the quantitative conclusions drawn from the measurements in the Venus vicinity, and to analyze thoroughly the discrepancies in the data of various experiments, as it has been mentioned in Section I.

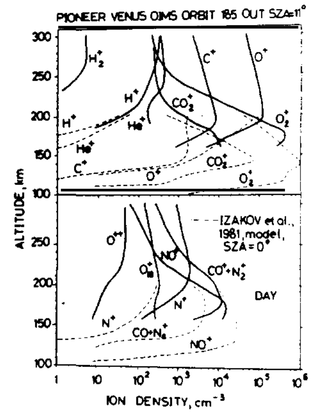


**Fig. 6.** Ion composition in the day side ionosphere of Venus from the Pioneer-Venus data. The dotted lines show the height distributions of ion components in Izakov et al.'s model /42/

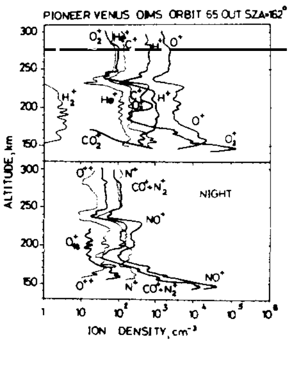


**Fig. 7.** Height distributions of ions in the night side ionosphere of Venus from the Pioneer-Venus mass-spectrometric data /23/

The qualitative analysis of mass-spectrometric observations shows the prevalence of the $O_2^+$-ion in the lower ionosphere. At larger heights the $O^+$ ion becomes predominant. It is essential that the night ionosphere consists of the same ions as the day side one (cf. Figures 6,7). The irregularity mentioned above manifests itself for the most part in measurements in the night ionosphere; its example is the trough in $n_i$ observed near 230 km (see Figure 7) /23/.

~~Plasma transport from~~ <u>the day side ionosphere</u>. The data of two experiments: OIMS /23/ and ORPA /24/ indicate the presence of the horizontal plasma transport in the Venus ionosphere. According to these data the plasma convective transport velocity $V_c$ can be considerably high: from 1 km/sec at the heights 200 km to several kilometers per second at larger altitudes. The following factors obviously cause the plasma transport from the day side ionosphere at different altitudes:

- the viscous-like interaction with the solar wind in the ionopause vicinity /26/;
- the ion density gradient near the terminator /27/ and

- the winds in the neutral atmosphere involving ions at lower heights.

At present it is difficult to judge about the reliability of the determination of the plasma transport velocity $V_c$ from the data of both experiments because the method of determination and the primary experimental data have not yet been published (in principle). It is not clear whether the satellite potential was taken into account in determining $V_c$ from the OIMS data. Knudsen et al. /24/ state that this value was known with an accuracy of ±0.1V which seems to be rather optimistic. Besides, the satellite potential was determined in the other mode of ORPA operation, not simultaneously with measurements of the ion retardation curves. These curves were measured for every $V_c$ at three points of the satellite trajectory spaced by ~200 km. For the fastly and unpredictably changing night side ionosphere such measurements become uncertain /28/. Nevertheless, the existence of the convective plasma motions in the ionosphere with speeds of an order of ~1 km raises no doubts.

The plasma convection velocities and the ionopause heights in the vicinity of the terminator are usually used in estimating the flux of $O^+$ ions transported to the night ionosphere of Venus. The estimates of the transported flux of ions are then used to calculate the diffusive flux of $O^+$ ions downward over the night side of Venus /23,24/. However, the further destiny of ions transported from the day side of the planet is not known, and the assumption that a significant part of convecting ions should diffuse downward across the whole night side of the planet seems to be some oversimplification.

## NON-STATIONARY AND SMALL-SCALE EVENTS IN THE VENUS IONOSPHERE

Above we discussed mainly the large-scale events characterizing the ionosphere as a whole. However, direct measurements in the ionosphere revealed a number of certain interesting small-scale events. Some of them undoubtedly affect the global structure of the ionosphere.

The wave-type irregularities of the ionosphere plasma, which were interpreted by Brace et al. /29,30/ as surface waves of the ionopause, were often observed in the vicinity of the day side ionopause. The clouds of the ionosphere type plasma observed above the ionopause can be also associated with these waves /10,29/. As a rule these plasma clouds are observed downstream of the wave-type structures and obviously are the next stage of the processes of the losses of ionospheric plasma due to its interaction with the solar wind /30/. The magnetic field envelopes the plasma clouds and contributes to their acceleration /31/. Flux ropes observed in the day side ionosphere of Venus may be another result of these wave processes in the vicinity of the magnetopause /32/.

One more structure - the magnetic belt - was sometimes observed in the day side ionosphere of Venus in connection with measurements of the magnetic field /33/. The magnetic belt is a horizontal large-scale steady magnetic field with a strength frequently higher than 100 $\gamma$ that sometimes can be observed in the lower ionosphere for SZA $\lesssim 50^\circ$ /34/. The appearance of these large-scale fields correlates with the periods of high dynamic pressure in the solar wind. In contrast to Cloutier et al. /35/ the magnetic experiment authors believe that the magnetic belt is not a steady-state structure but the remainder (slowly decaying at low heights) of the intense magnetic fields which formed during periods of extremely high solar wind dynamic pressure and survived for some time after its decrease /33,36/. Thus, we can suggest that across the day side of Venus two layers of strong magnetic field sometimes exist simultaneously - in the magnetic barrier and in the magnetic belt. However events of the intense magnetic fields sometimes observed in the ionosphere can possibly be explained in a more traditional way. Perhaps they are the result of the non-monotonous change in a distance between the magnetic barrier and a space probe during its motion through the ionosphere. Such a non-monotonous change in the satellite position relative to the ionopause can be caused, for example, by variations of the dynamic pressure in the solar wind, by the specific shape of the ionopause for high dynamical pressures, large-scale wave changes in its shape under these conditions and so on.

In the night side ionosphere the non-stationary events are more pronounced than in the day side ionosphere. The first measurements in the night side ionosphere revealed that sometimes it disappears completely up to a height of 170 km /22/. At this time the ion number-density in the night side upper ionosphere is by 3-4 orders of magnitude less than in the case of the established night side ionosphere. However, the radio occultation data (but obtained at the different latitude) showed that during times of depleted ionosphere there are only minor density changes in the vicinity of the ionization peak. For example, in case of observations of the depleted ionosphere /22/ in the vicinity of the main and lower peaks of the ionization the electron number-density was $n_{em}=10^4 cm^{-3}$, $n_{el}=7\cdot10^3 cm^{-3}$ , respectively, i.e., close to the usual data obtained for this region (see Figure 3) /28/. The observed "independence" of the plasma density variations in the upper and lower ionosphere apparently indicates that their formation is provided by different sources of the ionization and occurs under different physical conditions: in the upper night side ionosphere the dynamical processes of the plasma transport from the day side of the planet are essential, but in the vicinity of $h_m$ it is the collision ionization by precipitating electrons (see also Section IV).

During some passages of Pioneer-Venus in the night side ionosphere its spatial inhomogeneity was detected which is associated with the presence in this region of the global horizontal plasma layers and the troughs in the plasma density, the so-called holes /29/. Holes in the night ionosphere are obviously the most stable small scale structures /37/. They are apparently the regions of the intense escape of ionospheric plasma and the regions where accelerated electrons penetrating from the magnetic tail heat electron gas up to high temperatures /38/.

## ON THE MODELING OF IONOSPHERIC PROCESSES

The theoretical models of the Venus ionosphere published until recently are one-dimensional except calculations made by Whitten et al. /39/ and Cravens et al. /40/ who tried to include the effect of horizontal gradients of ionospheric parameters on the ionization height profiles. General processes in the day side ionosphere were defined as a result of in situ measurements of the Venus atmosphere and ionosphere composition /41/. The solar UV-radiation is the dominant source of ions on the day side. Ions formed due to photoionization (and due to secondary ionization by photoelectrons) take part in some ion-molecular reactions and finally recombine with electrons.

Above 180 to 200 km the photochemical equilibrium conditions are violated in the day ionosphere. The non-local processes of diffusion become significant due to increase of the free path lengths for ions, and hence height profiles for different ions are usually calculated in a diffusion approximation /41,45,43,46,47/. The comparison of the estimated $n_i(h)$ - profiles and the experimental data (see e.g. Fig. 6) indicates that in general we understand now the character of physical and chemical processes that control a height distribution of ions in the day ionosphere of Venus below the ionopause though many significant details need further refinement /42,43/. Notice, however, that increasing the density values used in the neutral atmosphere model /25/ by a factor of 1.63 (see Section III) we can obtain better agreement between the calculated and experimental data (estimates obtained by /42/ and /43/).

Until recently all model calculations of the night side ionosphere have been performed practically identically to the procedure adopted for the day ionosphere, i.e., including only chemical processes and diffusion. Such an approximation is not obviously valid for the regions above several tens of kilometers over the main ionization peak, $h_m$, where the non-stationary processes and the convective transport of plasma become essential. To describe globally the supersonic plasma flow plasma in the upper night side ionosphere the other equations are necessary. Studies of this kind are not performed and good grounds hardly exist for making any physical conclusions based on a comparison of the variable (especially in this region) results of plasma experiments with the calculations carried out in a diffusion approximation.

In the vicinity of $h_m$, model calculations of the night ionosphere become more valid from the physical viewpoint. The ionization source nature differs them from the similar calculations in the day ionosphere. However, in this region a quantitative comparison of the model and experimental data carries little information content since almost always the agreement between experimental data about the night side ionosphere (alternating widely) and the Venus atmosphere (see Sections 2 to 4) can be reached by choosing parameters of the ionization sources to be variable too. Therefore, for example, a "good agreement" of model distributions /61/ with some experimental $n_e(h)$ profiles resulting from specially chosen, for such calculations, exotic distributions of electron and neutral temperature is not informative.

It is premature now to speak about the availability of the model that describes reliably physical processes in the night side ionosphere of Venus. Below we will pay our attention generally to the role of various ionization sources in different regions of the night side ionosphere. Together with the results of measurements in the night side ionosphere we will use only qualitative rather than quantitative results of the model calculations.

The first effective source of the night side ionosphere ionization was detected during the Venera-9, 10 measurements of the fluxes of electrons with the energies of several tens of electronvolts in the optical shadow of the planets /49-50/. The calculations of the electron impact ionization of the Venus atmosphere /51,52/ revealed the correlation between $n_{em}$ and the fluxes $j_e$ of ionizing electrons. This resulted in the conclusion /19,53/ that the fluxes of electrons with energy of several tens of electronvolts detected by Venera-9, 10 play a principal role in forming the ionization peak in the night ionosphere. Points on Figure 8 show all measured values (from Venera-9,10) of the integral electron fluxes $j_e$ in the optical shadow of Venus with four values of a retarding voltage: 20, 40, 80 and 150 V by means of a wide-angle retarding potential analyzer /54/. As seen from the Figure the scatter of $j_e$ values during measurements was 2 orders of magnitude. This scatter qualitatively corresponds to that of $n_{em}$ measurements which was approximately one order of magnitude (Figure 3) since $n_{em} \sim \sqrt{j_e}$ . The thin broken line in Figure 8 gives the energy spectrum of electrons measured on October 28, 1975 from Venera-9 for SZA=142° . The estimated $n_e(h)$-profile formed due to the effect of such electrons on the Venus atmosphere (the data about the night atmosphere were taken from the paper of Nieman et al. /44/)is shown in Figure 2 by a dotted line /55/. The similarity of the estimated and experimental profiles is obvious (the experimental profile was measured 11 minutes later on the same day for SZA=150°).

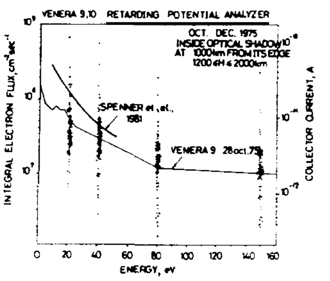


Fig. 8. Electron fluxes for four selected values of the retarding potential measured in the optical shadow of Venus by Venera-9,10 /54,59/

Pioneer-Venus measured the similar (to Venera-9,10 ones) fluxes of electrons with the energy of several tens of electronvolts in the Venus ionosphere in situ by means of two independent instruments /56,57/. The solid line in Figure 8 presents a typical electron spectrum in the night ionosphere (H=244 km, SZA=125°) plotted upon ORPA data /57/. For convenience in a comparison the data of both experiments are presented as the electron downward fluxes per 1 cm$^2$ instead of omnidirectional fluxes (by 4 times more intense) as it has been done in the Gringauz et al.'s paper /54/. The height dependence of the electron fluxes and their considerable anisotropy were not revealed /57/.

Thus, it is established reliably that the electron fluxes precipitating into the night ionosphere are a source of its ionization which can form $n_e(h)$-profile similar to that observed in radiooccultation experiments in the vicinity of $h_m$. Also note that the vertical intensity of the atomic oxygen glow (1304 Å) estimated in the model of Cravens et al. /40/ is equal to 10R. This intensity is determined by electrons precipitating into the night ionosphere and agrees with the typical intensities of the glow obtained from the Pioneer-Venus UV-spectrometer data /58/.

The other source which maintains the night ionosphere of Venus was suggested after the Pioneer-Venus mass-spectrometric measurements /44/. Such a source can be $O^+$-ions transported from the day side of the planet at heights $\gtrsim$ 200 km . Diffusing downward $O^+$-ions take part in ion-molecular reaction with $CO_2$ forming $O_2^+$-ions predominant in the main ionization peak. Spenner et al. /57/ believe that $O^+$ transport is the dominant source of forming the main ionization maximum in the night ionosphere. The model calculations of the night ionosphere considering this source of the ionization are based, however, on the indefinite estimates of the $O^+$ ion fluxes through the terminator. The further behavior of these ions and the value of their downward diffusion flux into the dense night atmosphere, was not determined experimentally. Methodical errors in the paper of Spenner et al. /57/ were analyzed in detail by Gringauz et al./54,59/.

It has been noted in Section IV that in the case of observations of the "depleted" upper ionosphere of Venus the plasma density in this region turned out to be by 3-4 orders less than in the established case. Apparently, within the same or even within the wider limits the diffusive downward flux of $O^+$ ions can vary. Hence, this ionization source becomes "too much variable" to determine the density $n_e$ in the vicinity of $h_{max}$ where its characteristic variations amount to only one order of magnitude (see Fig. 3).

When in the vicinity of $h_m$ the only ionization source dominates, the height profiles of different ions have the following qualitative features. If $O^+$ ions diffusing downward are the only source of $O_2^+$-ions, their height profiles must be rigidly "interconnected"; in this case the maximum of $O_2^+$-density must be observed in the region of abrupt fall of $O^+$ density. Since the scaleheight of carbon dioxide, $H_{CO_2}$=3 km, is characteristic for $O^+$ production, the maxima of the height profiles for both ions should be located at a distance of an order of several scale height for $CO_2$ /54/. It is also obvious that the main ionization peak is formed in this case under the diffusive rather than chemical equilibrium ($F_2$-layer) conditions.

If the fluxes of ionizing electrons are responsible for forming the main maximum of $O_2^+$, the chemical equilibrium conditions ($F_1$-layer) in the vicinity of $h_m$ must result in infinite growth of $O^+$-density with increasing the height h. However, when h is increasing the diffusion processes become predominant and the $O^+$ maximum is formed under the diffusive equilibrium conditions. In such a case the $O^+$ to $O_2^+$ maxima distance is not determined by the height scale for $CO_2$ and can be greater than in the first case. Taylor et al. /28/ published the results of detailed mass-spectrometric measurements of the ion composition in the vicinity of $h_{min}$, the night ionosphere obtained during the Pioneer-Venus two passes across this region. Figure 9 presents the smooth curves plotted over experimental points taken from Figure 5 of the above paper. As is seen, the distance between the maxima of the number-densities for $O_2^+$- and $O^+$ - ions was $\approx$ 15 km, i.e.,$\sim$5 $H_{CO_2}$ . Approximately the same distance was between these maxima in the other example considered by Taylor et al. /28/ (see also Figure 7). Such distances are apparently an argument in favour of a conclusion that the main ionization maximum is formed due to precipitating electrons. The other qualitative feature of the height profiles of ions shown in Figure 9 is the increase of the scale height for $O_2^+$ and $NO^+$ ions at 170-180 km, i.e., in the vicinity of $O^+$-maximum. Such a change in the scale height for $O_2^+$ and $NO^+$ ions indicates evidently the passage from the chemical to diffusive equilibrium in the vicinity of $O^+$-maximum. In this case the $O_2^+$ ionization maximum is under the chemical equilibrium conditions. This fact (as it has been mentioned above) can be a qualitative argument in favour of the predominant role of a mechanism

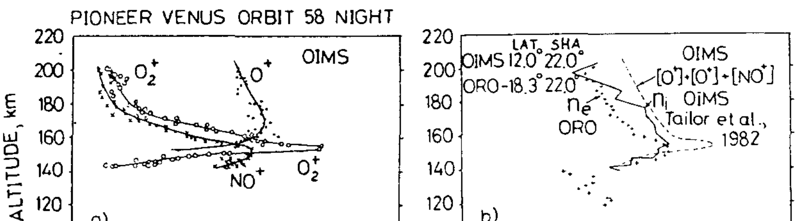


Fig. 9. Distributions of charged particles in the vicinity of the ionization night maximum in the Venus ionosphere. Figure 9a gives the distribution of individual ion components. Figure 9b gives: the total number-density of ions of the OIMS data (solid line) for the same passage, $n_e$ determined from the radio occultation data (crosses), the total number-density of ions plotted from the data of Figure 9a (dotted line)

of the impact ionization by electrons in the vicinity of $h_m$ .

With the height increasing over $h_m$, the non-stationary processes start to be more substantial as well as the convective transport of plasma. Then the contribution of $O^+$ ions transported from the day side of the planet to the night ionosphere formation gets more essential (see Section V). Both ionization sources discussed above refer to the upper maximum. To explain the low maximum it is necessary one should consider the other sources, for example: the fluxes of energetic ions from the plasma layer /55/, the fluxes of more energetic electrons /7,60/ and so on.

To explain the very high number-densities of $O_2^+$ ($10^5$ $cm^{-3}$) and $O^+$($10^4$ $cm^{-3}$) in the vicinity of $h_{max}$ obtained from the OIMS mass-spectrometric measurements (Figure 9a), Taylor et al. /28/ assumed the existence of certain additional ionization mechanisms in the night ionosphere. However, the authors of this paper compared the mass-spectrometric results (the broken line in Figure 9b) with the radio occultation results (crosses in Figure 9b) and made a conclusion about their reasonable agreement. Indeed, as seen from Figure 9b, the mass-spectrometric and radio occultation data differ from each other by 3-4 times (see the dotted line of the total number-density $n_e$ plotted from Taylor et al.'s data /28/). It is evident that first of all the cause of such discrepancies must be cleared up, and before this one should be very careful with quantitative results in developing physical models (it has been already noted in Section III).

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