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The data available on the night-side ionosphere of Venus have been obtained during radio-occultation observations made once by each of the Mariner-5 [1] and -10 [2] spacecrafts and several times by the Venera-9 and -10 satellites [3] . The results of these observations substantially differed which might be explained by variability of the night-side ionosphere of Venus. In the height profiles of electron density $n_e(h)$ there were one or two maxima with almost equal densities in the range of heights from about 120 to about 140 km. According to the evaluations maximum electron densities n_{em} varied from $\sim 6 \cdot 10^3$ to $\sim 2 \cdot 10^4 cm^{-3}$.

It is rather difficult to explain comparatively high electron densities in the night-side maximum and variability of $n_e(h)$-profiles [4 to 7] . In fact, the rotation period of Venus' upper atmosphere is about 4 days [8] and the characteristic recombination time is $\tau_R \approx (\alpha n_{em})^{-1} \approx 100 \div 500$ sec for the above given n_{em} and for $\alpha \approx 3.8 \cdot 10^{-7} cm^3 sec^{-1}$; α is the coefficient of dissociative recombination of CO_2^+ with electrons which dominates over recombination processes [9] ; therefore the night-side ionosphere of Venus should be sustained by a permanent ionization source of fairly high intensity.

It was assumed in 1968 [4] that turbulized solar-wind plasma fluxes in the transition region behind the near-planet bow-shock front, partially precipitate in the Venus' night-side atmosphere and can act as a source of night-side ionosphere ionization. At that time there were no data (on fluxes and energies of ionizing particles) which could have made it possible to quantitatively evaluate how that source affected Venus' atmosphere [4] ; however as has been mentioned in [5,7] , about 2 to 10% of the energy flux of the undisturbed solar wind is quite sufficient to produce the observed maximum of the night-side ionization.

Cosmic rays, scattered L_α radiation, inter-charging of CO_2 with He^+ ions transported from the day-side of the planet [1,5,7] , meteoric ionization [5,10] were discussed as possible sources of night-side ionization. All the discussed hypotheses either did not yield a satisfactory explanation to the n_e-values observed or were not based on the direct experimental data on the sources of ionization.

Venera-9 and -10 measured an electron plasma-component (Venera-9 also measured an ion component) at heights of about 1500-2000 km in the optical umbra of Venus. Below the estimations are given showing that electron fluxes measured are sufficient to ionize Venus' neutral atmosphere with the n_{em} - value coinciding with the observational data.

The electron plasma component was measured with a wide-angle (±40°) sensors; energy distribution of electrons was analyzed by means of 16 retarding potential values, in the 0 to 300 v range applied to analyzing grid. The ion plasma-component was also measured with a wide-angle (±45°) sensor (but with a modulation technique) in 16 energy bands, the energy range being 0 to 4400 ev. Currents from each sensor were measured once per second, it took 160 sec to get the whole energy spectra, integral for electrons and differential for ions. The devices slightly differed from those used earlier in plasma experiments near Mars [11].

A series of plasma measurements was carried out in the optical umbra of the Venus, up to date only part of the data related to the first month of the satellite operations has been processed.

Ion fluxes with very intensive fluctuations were recorded in Venus' optical umbra: in about 70% of cases these fluxes were lower that the sensitivity threshold of the sensor, while in about 30% of cases fluxes chaotically distributed over all the energy intervals were recorded. The integral energy spectra of electrons (retardation curves) were always recorded in the optical umbra of the planet (at all values of retarding potential U_R). Samples are given in Fig.1 (a) for Venera-9 and (b) for Venera-10; vertical bars show within which limits electron currents fluctuated during 10 sec for fixed values of U_R. Shown on the ordinate are the values of electron sensor currents, I_e, and of the omnidirectional electron flux, j_{eo}, with $E \geqslant eU_R$, calculated with use of angular characteristics of a trap (see [11]) under the assumption of an isotropic electron distribution function.

The portions of satellite orbits over which the spectra of Fig.1 were obtained are shown by a solid lines with appropriate letters, in Fig.2. The latter gives near-Venus parts of Venera-9 (a), Venera-10 (b) orbits in X, $\sqrt{Y^2+Z^2}$ - coordinates (X -axis directed towards the Sun passes through the center of Venus).

According to Fig.1, these measurements in Venus optical umbra (Fig.2) yield $j_{eo}(E \geqslant 40\ \text{eV}) \approx (1\ \text{to}\ 2)\cdot 10^{8}\,\text{cm}^{-2}\text{sec}^{-1}$, most electrons have energy equal to tens of eV. In the umbra of the planet the ion sensor looked downwards (towards the planet) while the electron one upwards, therefore it recorded planetward electron fluxes.

Processes of electron flux interaction with the neutral atmosphere of the Earth have often been discussed (e.g. the review given in [12]); however, this has been done only for electrons the energy of which is of the order of kev (or tens of keV) when their scattering can be neglected and the average energy required for an ionization event E_1 ($\sim$ 35 eV in the terrestrial atmosphere [12]) is low as compared with the energy of ionizing electrons. In the case under consideration both these conditions are not met and a special treatment is needed.

A kinetic equation [13] is used:

$$\frac{\partial F}{\partial t} + \vec{v}\frac{\partial F}{\partial \vec{r}} - \frac{e}{m_e}\left(\vec{E} + \frac{1}{c}[\vec{v}, \vec{B}]\right)\frac{\partial F}{\partial \vec{v}} = \left(\frac{\partial F}{\partial t}\right)_c \quad (1)$$

where F ($\vec{v}, \vec{r}$) - is the electron distribution function, $\left(\frac{\partial F}{\partial t}\right)_c$ is the collision integral. If a steady-state case is considered and the effects of electric $\vec{E}$ and magnetic $\vec{B}$ fields are neglected then only the second addend is retained in the right side of Eq.(1). CO_2 is the basic component of the neutral atmosphere at altitudes corresponding to the maximum ionization. The cross-section of the elastic scattering of electrons, σ_c , in CO_2 in the 20 to 50 eV energy-range, is about (1.2 to 1.6)$\cdot 10^{-15}$ cm^2 [14] . The ionization of CO_2 as a result of collisions with electrons is regarded here as the basic non-elastic process. The ionization cross-section, σ_i , rapidly grows with electron energy from about $6\cdot 10^{-17}$ cm^{-2} for $E \approx 20$ eV to $\sim 2\cdot 10^{-16}$ cm^{-2} for $E \approx 40$ eV, and up to $\sim 3\cdot 10^{-16}$ cm^{-2} for $E \approx 100$ eV, then it decreases down to $\sim 10^{-16}$ cm^{-2} for $E \approx 1000$ eV [15] . Further the collision cross-sections are assumed to be independent of energy and, with [14,15] taken into account, taken equal to $\sigma_c \approx 10^{-15}$ cm^{-2},

$\sigma_i \approx 2\cdot 10^{-16}\,\mathrm{cm}^{-2}$ for $E \geqslant 40$ eV, $\sigma_i = 0$ for $E \leqslant 40$ eV. Thus, when electrons with energy of several tens of eV collide with CO_2-molecules elastic electron scattering is a dominant process ($\frac{\sigma_c}{\sigma_i} \simeq 5$) which leads to isotropization of electron distribution function $F(\vec{v}, \vec{r})$. Hence, if $F(\vec{v}, \vec{r})$ is given as a series in terms of spheric functions $Y_{\ell m}(\frac{\vec{v}}{v})$:

$$F(\vec{v}) = F_0(v) + \frac{\vec{v}}{v}\vec{F}_1(v) + \sum_{\ell \geqslant 2;m} F_{\ell m}(v) Y_{\ell m}\left(\frac{\vec{v}}{v}\right), \qquad (2)$$

where $F_0(v)$, $\vec{F}_1(v)$, $F_{\ell m}(v)$ are the functions of the absolute value of particle velocity, then it should be expected that $F_0(v)$ - term will have the largest value.

With only two first addends in Eq.(2) and Eq.(2) substituted into Eq.(1), equations can be written to determine F_0 and F_1 (see e.g. [13]):

$$1/3\, v\nabla\vec{F}_1 - J_0 = 0, \quad v\nabla F_0 - \vec{J}_1 = 0, \qquad (3)$$

where $J_0 = \int\left(\frac{\partial F}{\partial t}\right)_c \frac{d\Omega}{4\pi}$, $\vec{J}_1 = 3\int\left(\frac{\partial F}{\partial t}\right)_c \frac{\vec{v}}{v}\frac{d\Omega}{4\pi}$ are the zero and first moments of the collision integral.

Due to collisions the number of electrons the velocities of which are in the interval ($\vec{v}$, $\vec{v} + d\vec{v}$) will change during the time dt by

$$\left(\frac{\partial F}{\partial t}\right)_c v^2 dv\,dt\,d\Omega = n_n v\left(-\sigma_c F(\vec{v}) + \sigma_c F_0(v) - \sigma_i F(\vec{v}) + \sigma_i F_0\left(\sqrt{v^2 + 2E_i/m_e}\right)\left(1 + 2E_i/m_e v^2\right)\right) v^2 dv\,d\Omega\,dt \qquad (4)$$

where n_n - is the neutral concentration. The first and the third addends in Eq.(4) describe the electron out-flow over the velocity interval mentioned, as a result of elastic and inelastic collisions, respectively; the second is the inflow of electrons which underwent elastic scattering, to the interval ($\vec{v}$, $\vec{v} + d\vec{v}$), while the last addend is the inflow of electrons which lost energy E_i through ionization. It was assumed in deriving Eq.(4) that the electron energy suffers no changes in case of elastic scattering while that of inelastic scattering decreases by E_i, and that all the directions of electron velocities after collisions of both types are equally probable. Further on we shall assume that the electron-energy spectrum is falling down rapidly enough with growing energy so that:

$$F_o(v) \gg F_o\left(\sqrt{v^2+2E_i/m_e}\right) \qquad (5)$$

hence, the last addend in Eq.(4) may be neglected. It means that when ion production is considered the ionization can be neglected which is produced by electrons which have already underwent an inelastic collision; how this assumption affects our estimations is discussed below.

With Eq.(4) and Eq.(5) taken into account $\vec{F}_1(v)$ may be eliminated from the simultaneous equations (3):

$$\Delta F_o - \frac{1}{n_n}(\nabla n_n \cdot \nabla F_o) - 3n_n^2\sigma_i(\sigma_i+\sigma_c)F_o = 0. \qquad (6)$$

For the one-dimensional atmosphere where n_n and F_o depend only on altitude h, ion production rate q can be derived at h, based on the solution of Eq.(6) which is monotonically falling with decreasing h:

$$q(h) = j_{eo}(E \geq 40eV)\cdot\sigma_i\cdot n_n(h)\cdot\exp\left(-\sqrt{3\sigma_i(\sigma_i+\sigma_c)}\int_h^\infty n_n(h)dh\right). \qquad (7)$$

Electron density in the ionosphere, $n_e(h)$, will be estimated from the condition of local equilibrium between ion production and recombination processes: $q(h) - \alpha n_e^2(h) = 0$, hence $n_e(h) = \sqrt{\frac{q(h)}{\alpha}}$. The height of maximum ionization, h_m, is obtained from the condition $dn_e(h_m)/dh = 0$, hence, with Eq.(7)

$$\frac{dn_n(h_m)}{dh} = -\sqrt{3\sigma_i(\sigma_i+\sigma_c)}\,n_n^2(h_m) \qquad (8)$$

Since in the vicinity of this h_m-value $n_n(h) = n_n(h_m)\cdot\exp(-(h-h_m)/H(h_m))$ where $n_n(h_m)$ and $H(h_m)$ are the density and scale height of neutrals if $h = h_m$, then from Eq.(8) it follows that:

$$\sqrt{3\sigma_i(\sigma_i+\sigma_c)}\,n_n(h_m)H(h_m) = 1. \qquad (9)$$

Eq.(9), if the model of neutral atmosphere is used, can give the height of ionization maximum as well as $n_n(h_m)$ and $H(h_m)$.

Three versions of neutral atmosphere models are given in [16], and in the so-called maximum model (most appropriate for the conditions of our measurements: 1975 - approximately minimum solar activity and night) the temperature of the upper atmosphere, T_∞ is given as 430°K. According to this model $h_m \approx 180$ km, at which $n_n(h_m) \approx 9 \cdot 10^8 \text{cm}^{-3}$, $H(h_m) \approx 11$ km, fits to the Eq.(9). Discrepancies between the h_m -value thus determined and the heights of ionospheric ionization maximum on the nightside observed by radio occultation technique [1 to 3] may be attributed to the insufficient knowledge of the nightside parameters of Venus' neutral upper atmosphere.

In fact, according to [17,18] where night-to-day-time temperature variations in the upper atmosphere are considered T_∞ varies from about 700° to 800°K during the day time down to about 300°K at night, for the mean solar activity. Measurements made on Venera-9 and Venera-10 correspond to the minimum solar activity, hence, if the night-time temperature T_∞ is assumed to be ~ 250°K and the maximum model [16] is exstrapolated starting from a height of 100 km (for which this model parameters are sufficiently reliable [16]) by the barometric formula then in this case $h_m \approx 150$ km fits Eq.(9), the one that agrees better with the observational results in [1 to 3]. At this height $n_n(h_m) \approx 2 \cdot 10^9 \text{cm}^{-3}$, $H(h_m) \approx 6$ km. Another possible explanation of the discrepancy in h_m based on the above mentioned model [16] and the observed values of h_m is the fact that the model [16] is static and does not take into account dynamic effects which undoubtedly occur in the upper atmosphere of Venus and which can cause the deviation of parameters from model values.

The equation for an electron density profile if $n_n(h)$ is assumed to be described for all heights by the above relation valid in the vicinity of h_m, can be given in the following form:

$$n_e(h)=\sqrt{\frac{n_n(h_m)\sigma_i j_{e0}}{\alpha}}\cdot\exp\left(-\tfrac{1}{2}(h-h_m)/H(h_m)-\tfrac{1}{2}\exp\left(-(h-h_m)/H(h_m)\right)\right) \quad (11)$$

Eq.(11) can yield ionospheric electron density in the electron density maximum of the night-time ionosphere $n_{em}=\sqrt{\frac{n_n(h_m)\sigma_i j_{e0}}{\alpha e}}\approx(5\div 8)\cdot 10^3\,cm^{-3}$. Therefore electron fluxes in the planet's optical umbra, measured in the experiments on board Venera-9 and Venera-10 may, in fact, create n_e-values observed in the night ionosphere of Venus. Fig.3 is a height profile $n_e(h)$ corresponding to the estimations given.

In the above said some factors that affect n_{em} and h_m values have not been accounted for. They include ionizing action of ion fluxes which come to the night-side ionosphere from the optical umbra of the planet and the real distribution function of ionizing electrons. The latter can decrease with increasing energy slower than according to the condition in Eq.(5). Due to this, however, high-energy electrons which have brought about CO_2 ionization events at h, will diffuse to lower height again causing ionization; this, in turn, will result in higher n_{em} and lower h_m. Thus the approximations mentioned cannot affect the basic conclusion that electron fluxes in the optical umbra of the planet are sufficient to produce its night ionosphere. It has already been mentioned that the knowledge of parameters of the neutral upper atmosphere of Venus is somewhat ambiguous. With this in mind, hardly is it reasonable now to refine the above given numerical calculations of n_{em} and h_m, experimental data about charged-particle fluxes in Venus' optical umbra and the simultaneous observational data about its night-time ionosphere from the same satellites, Venera-9 and -10, will be discussed in details elsewhere.

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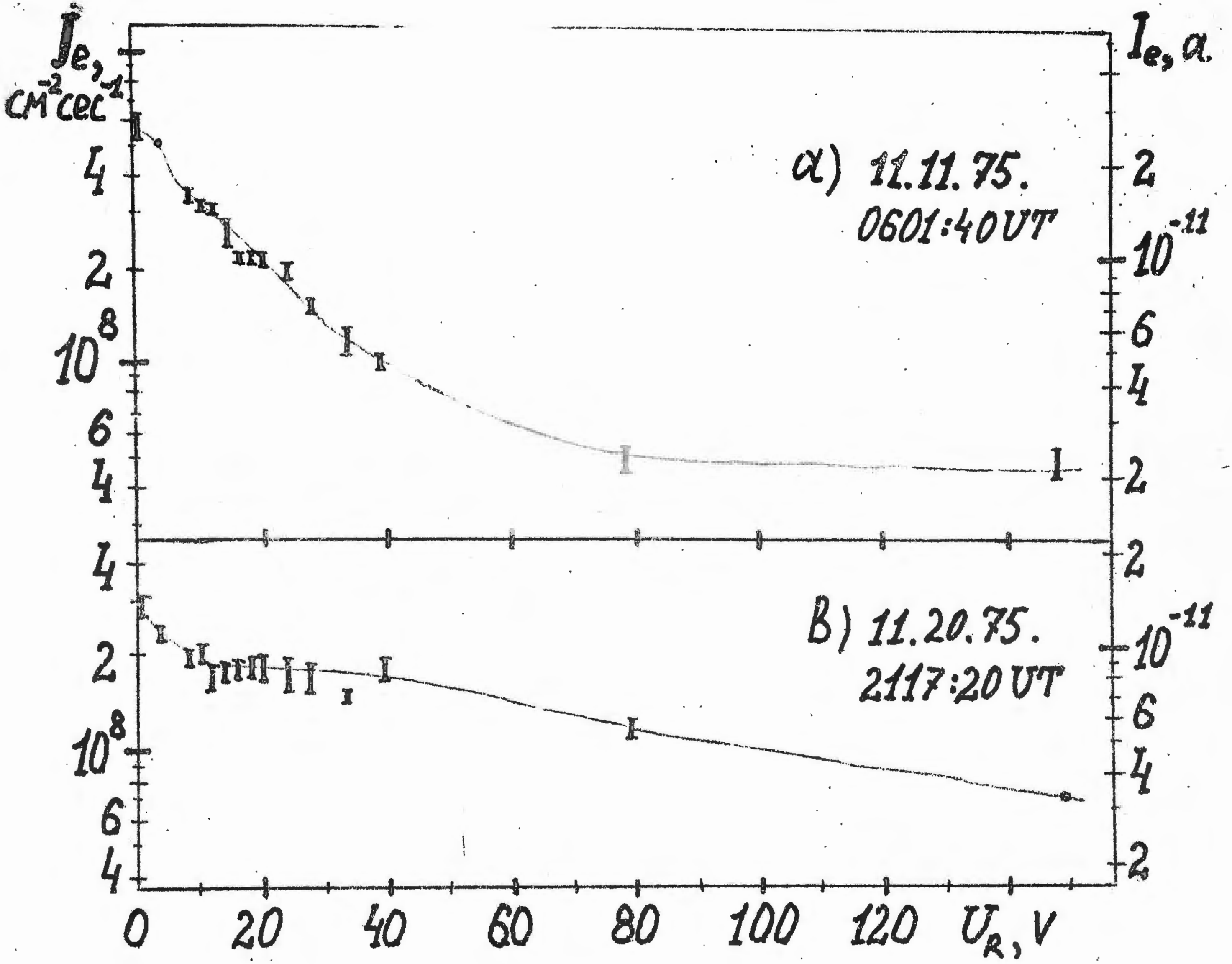
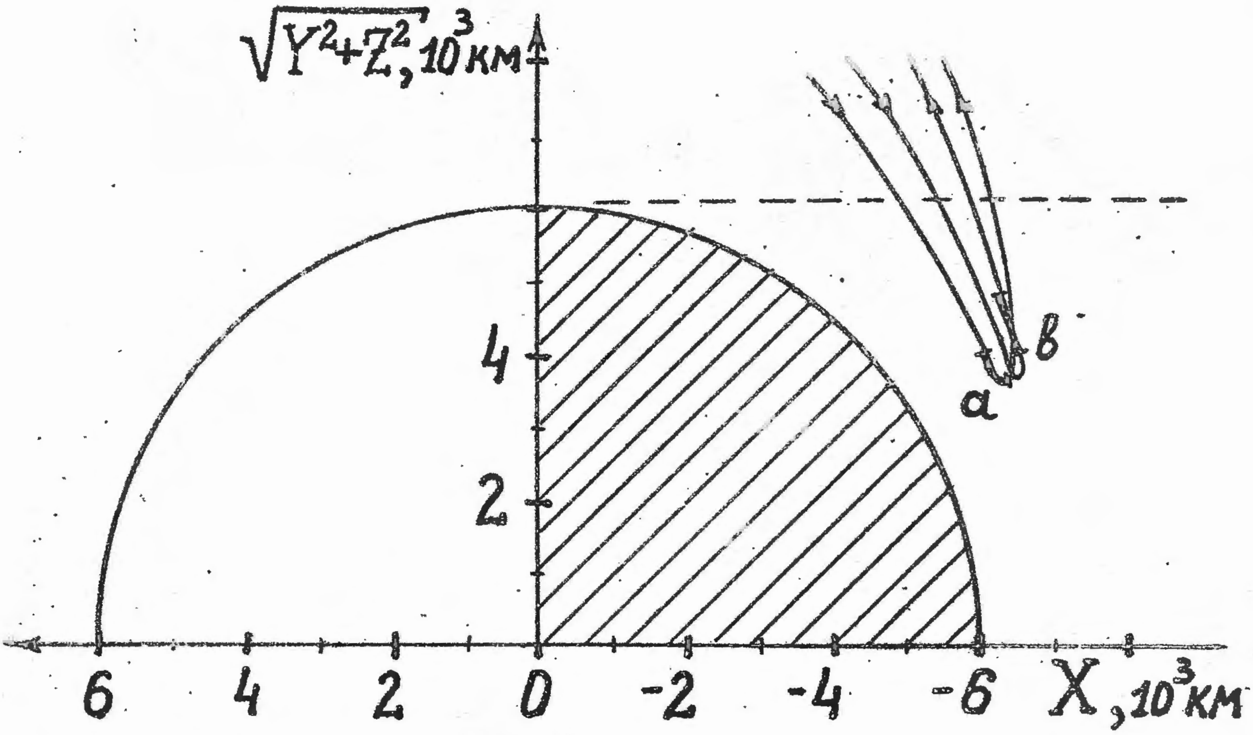

Je, cm⁻²сек⁻¹
Ie, a.
a) 11.11.75.
0601:40UT
B) 11.20.75.
2117:20UT
4
2
10⁸
6
4
4
2
10⁸
6
4
2
10⁻¹¹
6
4
2
2
10⁻¹¹
6
4
2
0
20
40
60
80
100
120
U_R, V

Fig. 1


$\sqrt{Y^2+Z^2}$, 10^3км
4
2
6
4
2
0
-2
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-6
X, 10^3км
в
a

Fig. 2

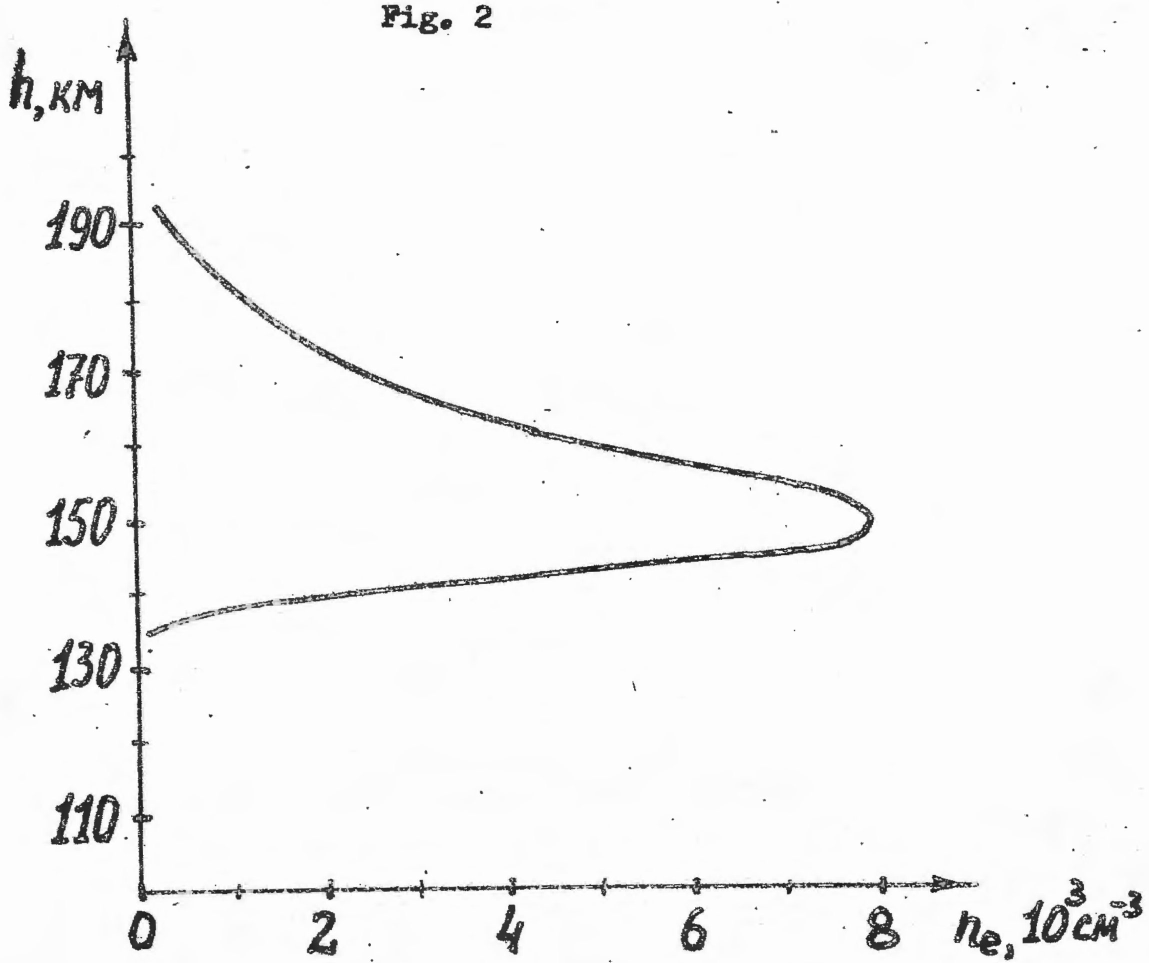
h, км
190
170
150
130
110
0
2
4
6
8
n_e, 10^3см$^{-3}$

Fig. 3

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