THE TECHNIQUE AND RESULTS OF EXPERIMENTS CONDUCTED ON THE COSMOS 2 SATELLITE BY MEANS OF LANGMUIR PROBES AND ION TRAPS OF THE HONEYCOMB TYPE

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Abstract: A description is given of some sensitive elements used in experiments aboard Cosmos 2 satellite. The technique of measurements in the ionosphere of electron density and temperature by means of cylindrical Langmuir probes, and of ion temperature by means of honeycomb ion traps is outlined. As an example some results are given of measurements of these parameters made in the height region from 220 km to 550 km. Considerations are presented concerning the influence of geomagnetic field on electron density measurements. Prospects of the use of the technique of ionospheric investigation described are briefly discussed.

Резюме: В докладе приводится описание зондов Лэнгмюра, ионных ловушек и фотоэмиттеров, использованных в экспериментах на спутнике "Космос-2" и ранее не публиковавшиеся результаты этих экспериментов. Анализ результатов приводит к выводам, относящимся к электронным и ионным температурам в ионосфере и к поглощению ультрафиолетового излучения Солнца (на высотах ниже 500 км.). Кратко обсуждаются перспективы применения описанных методов исследования ионосферы.

1. Introduction

Some data on experiments conducted by means of planar and spherical ion traps as well as by means of photoelectron emitters mounted on the satellite Cosmos 2 have been given in communications at the previous International Space Science Symposium sponsored by COSPAR in Warsaw [1], at the 14th International Astronautical Congress in Paris [2] and in [3]. In the present paper a description is given of experiments in the satellite Cosmos 2 aimed at determining electron and ion temperatures (by means of cylindrical Langmuir probes and ion traps of honeycomb type), their technique is briefly discussed and some results of measurements are given for illustration. We give data on the technique despite the fact that the technique of probe measurements is described by Smith in [4]. We do this because in processing probe results of Cosmos 2 a method has been used

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which was not included in [4]. Measurements by means of ion traps of honeycomb type have not been described before.

On April 6, 1962 Cosmos 2 was placed in an orbit with a perigee of about 212 km, an apogee of about 1546 km and an inclination to the equator of about 49°. In [1] and [3] experiments aimed at measuring positive ion concentration were described. These experiments have been carried out along the entire Cosmos 2 orbit by means of a memory device. The experiments described in the present paper have been performed only in case of direct telemetry radio communication. The appropriate group of instruments was switched on simultaneously with a radio transmitter. This fact increased the area of outer electrodes of sensors on which positive potentials were applied with respect to the satellite's surface. These circumstances seemed to promote an increase of the satellite's negative potential. However, one can note that considerable negative potentials of satellites were observed not only in these experiments, but also in Sputnik 3 [5] and in American experiments [6]. Since in the experiments described the memory was not used, their results refer to the height region of the ionosphere from 550 km to 220 km whose boundaries of projection upon the Earth lie comparatively close to the boundaries of the Soviet Union.

2. Description of sensitive elements

In the plane of one of the sections perpendicular to the satellite's longitudinal axis two cylindrical probes were installed near its surface in such a way that the central angle between the points of the installation was equal to 90°. The third cylindrical probe was installed perpendicular to the plane of the first two probes at a distance of 10 cm from the satellite's surface and formed with the first two probes central angles of 180° and 90° respectively. Each probe was made of a silvered brass tube 20 cm long and 1 cm in diameter. Probes were located in such a way in order to have the opportunity of noting the influence of the Earth's magnetic field on measurements. However, one of the probes (the third one) did not function for reasons which were not clear. Identical voltages with respect to the satellite's body were applied to all Langmuir probes. They varied in accordance with the law indicated in fig. 1.

Ion traps of honeycomb type were briefly described for the first time by Gringauz [7]. In a three-electrode trap consisting of a plane collector, a plane antiphotoelectron grid and an outer grid, the latter is made from nickel foil as a group of hexahedral tubes adjacent to each other. Such a configuration of the trap makes it possible to obtain high sensitivity to its

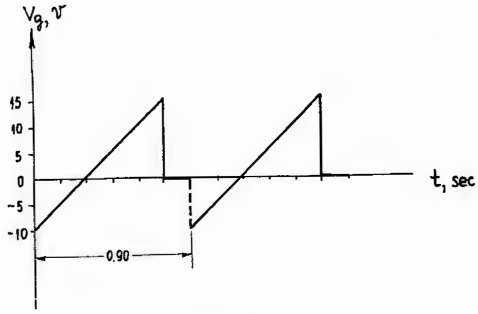

Fig. 1.

orientation with respect to the velocity vector. The height of each tube is 3 cm and distance between opposite sides 0.6 cm. A photograph of the trap is given in fig. 2. The voltage with respect to the satellite's body on the collector was -60 V, on the inner grid -100 V; the outer grid was under the body potential. Two such traps have been installed on a boom 20 cm long perpendicular to the satellite's longitudinal axis in such a way that the planes of the input holes of traps were parallel to the longitudinal axis of the satellite and the holes themselves were directed diametrically opposite to each other.

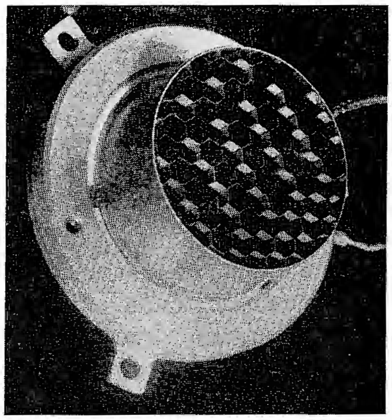

Fig. 2.

In their design the photoelectron emitters were similar to a three-electrode trap of charged particles with a hemispherical outer grid (fig. 3). The two remaining electrodes were plane. Some preliminary data on the experiments with photoelectron emitters were reported at the 14th International

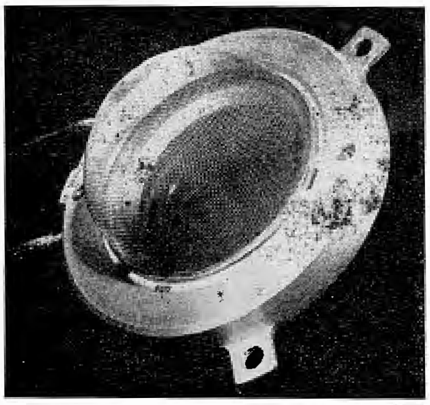

Fig. 3.

Astronautical Congress in Paris in 1963 [2]. More detailed results of this experiment will be published subsequently. Photoelectron emitters formed the same group of instruments switched on simultaneously with a radio-telemetry transmitter as Langmuir probes and ion traps of honeycomb type. At the satellite's surface three identical photoelectron emitters were situated; positive potentials +36 V were applied to their outer grids which, as has been already pointed out, was conducive to an increase of the satellite's negative potential.

3. Measurements by means of Langmuir probes

Fig. 4 shows envelopes of maximum electron probe currents recorded during each period of sawtooth voltage applied to the probe. Such envelopes have been given for the three time intervals indicated on the graphs. As is evident from the graphs, maximum probe currents vary periodically, falling to magnitudes below the sensitivity level of probe current amplifiers. In some cases electron current maxima of both probes coincide in time (4a), and in other time intervals the current maximum in one probe corresponds to the minimum in the other (4b). There are cases when indications of one of the probes are very low during relatively long time intervals (4c). An analysis of simultaneously recorded ion currents in a system consisting of eight planar ion traps installed on the satellite (see [1]) has demonstrated that minimum current values of each probe do not always correspond to a time interval when the probe is in the ion shadow formed behind the satellite (i.e. in the direction opposite to the direction of its velocity), although the period of changes in probe currents, as is seen, for instance,

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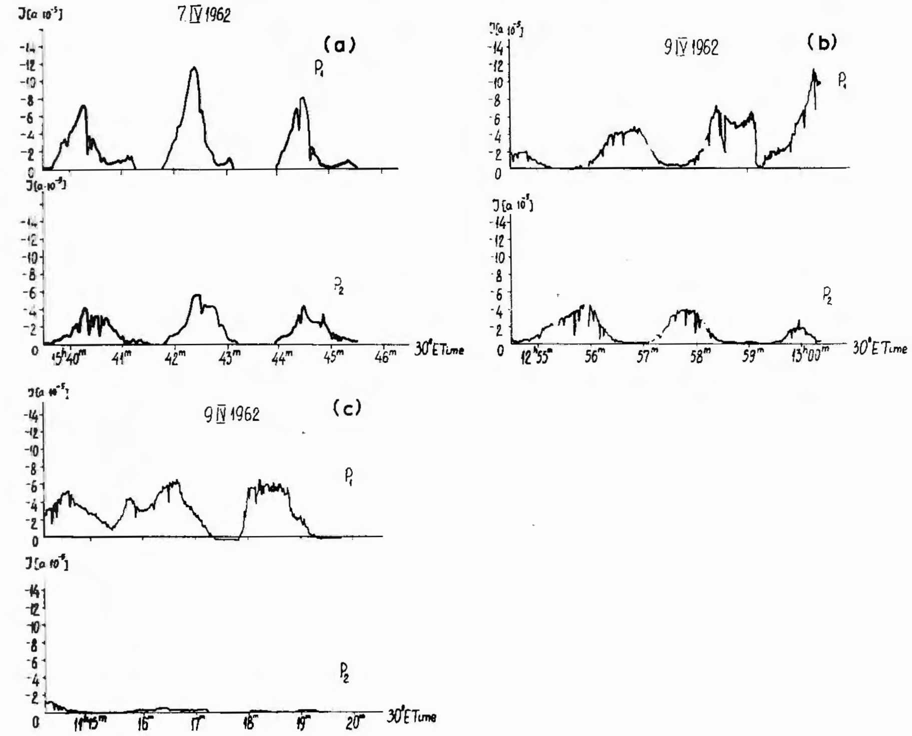


Fig. 4.

in fig. 4, is determined by the satellite's rotation. In our opinion, these changes in probe currents are in the main connected with changes in the orientation of the probes with respect to the geomagnetic field. Depending on this orientation the probe's effective area collecting electrons changes considerably, being a maximum when the probe's axis is perpendicular to the magnetic field and being a minimum when the probe's axis coincides with the direction of the magnetic field.

As is known, in the case of the Langmuir cylindrical probe, plasma parameters can be determined by two methods, in the absence of the magnetic field and with satisfaction of the following conditions in the region of positive potentials of the probe with respect to plasma:

$$\frac{r_s^2}{r_p^2} \gg 1 \quad \text{(A)} \qquad \text{and} \qquad V_p > \frac{kT_e}{e} \quad \text{(B)},$$

where r_p is the probe's radius, r_s is the radius of the space charge sheath, V_p is the potential of the probe with respect to the plasma, e is the electron charge, T_e is the electron temperature, k is Boltzman's constant. Let us note that conditions (A) and (B) are easily satisfied in the ionosphere. These two methods are described in an early paper by Langmuir and Mott–Smith [8]. The first method is based on the use of the portion of the electron branch of the probe characteristics corresponding to low retarding potentials (let us call it the "steep" portion) and is ordinarily used in processing the data of probes of any configuration. The second method is based on the use of the portion of the electron branch of the probe characteristics corresponding to positive potentials of the probe (the "flat" portion). Let us note that probe measurements by means of this method have recently been successfully conducted in a gas discharge plasma by Verweij [9]. The value of electron density (n_e) is determined in the case of a cylindrical probe by means of formulas (1) and (2) (see, for instance, [9]). With the use of the steep portion

$$n'_e = \frac{4.03 \times 10^{13}\, I_{e0}}{S\sqrt{T_e}}\ \text{cm}^{-3}, \tag{1}$$

where I_{e0} is the probe's current in amperes corresponding to its zero potential with respect to plasma, S is the surface of the probe in cm^2, T_e is the electron temperature in degrees Kelvin. Using the "flat" portion, we have

$$n_e'' = 3.22 \times 10^{11}\, \frac{1}{S} \sqrt{\frac{\mathrm{d}I_e^2}{\mathrm{d}V_p}}\ \text{cm}^{-3}, \tag{2}$$

where $(dI_e^2/\mathrm{d}V_p)a^2/v$ is the $I_e^2(V_p)$ curve slope corresponding to the "flat" portion. Correspondingly electron temperature is determined from the data of the indicated portions of the electron branch of the probe characteristic

$$T_e' = \frac{5040}{\mathrm{d}\lg I_e/\mathrm{d}V_p} \tag{3}$$

and

$$T_e'' = 1.16 \times 10^4 (V_p^A - V_p^B), \tag{4}$$

where V_p^B is the voltage applied to the probe corresponding to zero potential of the probe with respect to the plasma, V_p^A is the voltage on the probe corresponding to intersection of the extension of the straight-line section of the curve $I_e^2(V_p)$ with the voltage axis. (According to Langmuir and Mott–Smith, in case of Maxwellian distribution of electron velocities and of satisfaction of conditions (A) and (B), the curve $I_e^2(V_p)$, corresponding to the "flat" portion of the electron branch should be linear [8].) As has been pointed out, the possibility of such use of the data of the "flat" portion was considered in [8] without taking account of a magnetic field.

Phenomena in plasma near the Langmuir probe in the presence of a magnetic field are very complicated, and their complete theory has not yet been developed. In the work by Bohm, Burhop and Massey [10] considerations are given (referring to collection of positive ions by the probe) on the basis of which it has been concluded that when the probe is smaller than the Larmor radius for ions, collection of particles by the probe in the presence of the magnetic field takes place in the same way as in its absence. Apparently this conclusion is applicable also to the case of collecting electrons by a probe whose characteristic size is smaller than the Larmor radius for electrons. The latter condition, which is not satisfied in measurements in a gas discharge plasma considered in [10], can be easily fulfilled in the ionosphere.

When the cylindrical probe is perpendicular to the magnetic field, then the decrease in electron mobility due to the Larmor rotation has a little influence on the collection of charged particles on its side surface. In our case the probe's radius is less than the Larmor radius for electrons. The same applies to the radius of the space charge sheath around the probe in the region where measurements were performed ($h = 200$–550 km). Therefore it was supposed that in this case it is possible to apply not only the method in which the steep portion of probe characteristic is used, but also the method in which the "flat" one is used. It was assumed that the probe characteristics in which electron currents on "flat" portions are maximum (during their changes in the process of the satellite's rotation – see fig. 4) correspond to perpendicularity of the probe with respect to the magnetic field.

It has been found that, in processing the probe's characteristics with maximum currents, the determination of the plasma parameters from the steep and "flat" portions in the majority of cases gives practically the same results. In other cases when these two methods of processing are used, considerable discrepancies usually occur. In our opinion, this circumstance speaks in favour of the correctness of the assumptions used.

Fig. 5 gives typical variations of lg $I_e(V_p)$ and $I_e^2(V_p)$ obtained simultaneously by means of two mutually perpendicular probes (7.04.62, 15h 42m 28s, 30° E.T., $h \sim 280$ km). Upon using formulas (1) and (3), one can obtain from the first characteristic (for P_2) that $n'_e = 1.4 \times 10^5$ cm^{-3}, $T'_e = 3000°$ K; and from formulas (2) and (4) it follows that $n''_e = 1.2 \times 10^5$ cm^{-3}, $T''_e = 2900°$ K. Using the second characteristic (for P_1) one can correspondingly obtain $n'_e = 2.5 \times 10^5$ cm^{-3}, $T'_e = 3200°$, and $n''_e = 2.1 \times 10^5$ cm^{-3}, $T''_e = 2900°$. Thus:

a) values of the plasma parameters determined from data of the same probe by two methods (using the steep and "flat" portion of the electron branch of the probe characteristics) are close to each other;

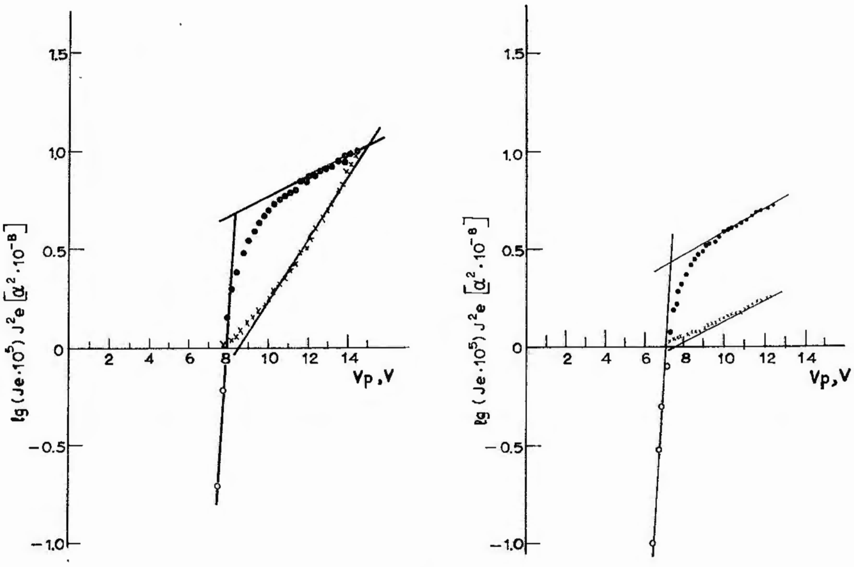


Fig. 5.

b) values of electron temperature from the data of both probes are practically identical;
c) n_e-values from the data of different probes show an essential (approximately twofold) difference from each other.

Let us note once more that, in our opinion, (a) and (b) confirm that the great changes of probe currents during the satellite's rotation are connected with the influence of the geomagnetic field (taking into account that when probe currents decrease, the correspondence between the data obtained from the steep and "flat" portions is violated). However, it is not excluded that different positions of probes at the satellite to some extent affect the determination of n_e even when their orientation with respect to the magnetic field is identical, due to disturbance of the axial symmetry of the space charge sheath around the satellite during its motion. Perhaps this explains the difference of n_e-values determined from the data of fig. 5 in the case when maxima of the greatest currents of two probes are reached simultaneously. Probe characteristics given in fig. 5 were obtained during a magnetic disturbance ($K_p = 6$).

Fig. 6 gives a probe characteristic obtained on 8.04.62 at a height of 259 km at 15h 36m (30° E.T.). It corresponds to the time interval when $K_p = 3$ (in the next three-hour interval $K_p = 6$). This characteristic is of interest since simultaneously with it in the ion trap of honeycomb type currents were recorded for determining ion temperature (see the next section). Using this characteristic, one can obtain from the steep portion from formulas (1) and (3) $n'_e = 3.2 \times 10^5$ cm^{-3}, $T'_e = 3100°$; and from the "flat" portion from formulas (2) and (4) $n_e'' = 3.5 \times 10^5$ cm^{-3}, $T_e'' = 2900°$.

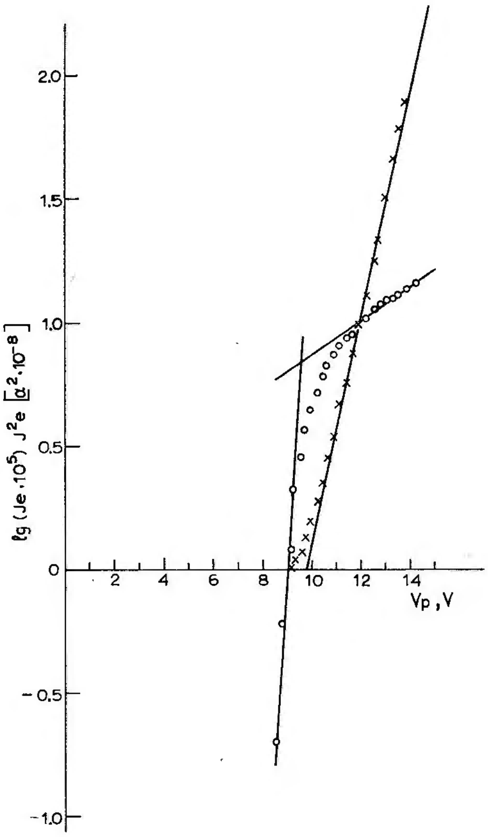


Fig. 6.

4. An estimate of positive ion temperature by means of ion traps of honeycomb type

An attempt at determining positive ion temperature was made by means of ion traps of honeycomb type used in the satellite Cosmos 2. As has been pointed out in the section 2, the cells of "honeycomb" (that is, hexahedral tubes), of which the trap outer grid consists, are parallel to each other.

Obviously the directional properties of such a trap remain the same as those of one tube, and the collector current increases in proportion to the number of tubes. It is also obvious that collector current determined by ions which passed through one tube depends on the angle between the flow and the tube's axis. The type of this dependence is determined chiefly by the tube's geometry. Besides, with a given shape of tube, the ion temperature T_i in the incident flux has an important influence on the form of such a dependence. The current of the trap of honeycomb type can be presented in the form

$$I_c = I_0 \cdot F\left[\psi, \frac{R}{L}, T_i\right],$$

where $I_0 = eSVn_i$ is the current of the trap at the ion temperature $T_i = 0$ and with the vector of the incident ion flux velocity coincident with the tube's axis,

- e is the electron charge (ions are assumed singly-charged),
- V is the velocity of the ion flux (equal to the satellite's velocity),
- S is the sum of cross-sectional areas of all tubes,
- F is a function determining directional properties of the trap,
- ψ is the angle between the axis of the tube and the flux vector velocity,
- R/L is the ratio of the cross section of the tube to the longitudinal section.

To determine the character of the function F, let us substitute a real hexahedral tube for a circular cylindrical one with the radius R, the length L (fig. 7) and with the same cross-sectional area. Not taking into account the influence of the electrical potential of the tube and electrical fields produced by the inner electrodes of the trap, one can state that at $T_i = 0$ the function F is a relative dependence on the angle ψ of the area hatched in fig. 7 which is expressed as follows:

$$F\left(\psi, \frac{R}{L}\right) = \frac{2}{\pi}\left(\arccos \alpha - 2\alpha\sqrt{1-\alpha^2}\right), \qquad (5)$$

where

$$\alpha = \frac{L \operatorname{tg} \psi}{2R}, \quad \operatorname{tg} \psi \leqslant \frac{2R}{L}.$$

In reality, at $T_i \neq 0$, ions have velocity components perpendicular to the satellite's velocity vector, as a result of which the function F will change its form. To determine the form of the function in this case let us consider the passage of ions through an element of the input section of the tube dS which has coordinates r and θ in the polar coordinate system (fig. 8a). Let

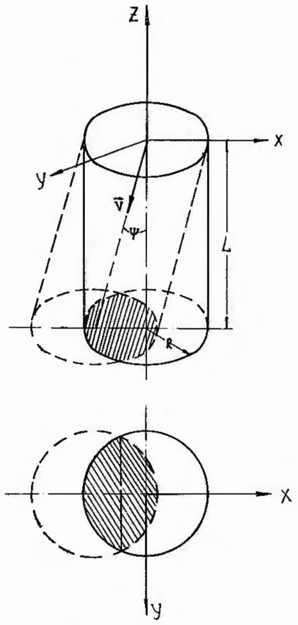


Fig. 7.

us assume that a particle has velocity $\boldsymbol{v}$ (v_z, v_r) with respect to the tube (fig. 8b). This particle will get on the collector if the following conditions are satisfied:

$$0 < v_z \leqslant \infty,$$
$$0 \leqslant \varphi \leqslant 2\pi,$$
$$0 \leqslant v_r \leqslant A/\tau,$$

where $\tau = L/v_z$ is the time of the particle's flight from the upper base to the lower one and A (see fig. 8a) is equal to the distance from the element $\mathrm{d}S$ to the point of intersection of the line passing through $\mathrm{d}S$ parallel to $\boldsymbol{v}_r$ with the boundary of the cylinder's base, and depends on the position of the element $\mathrm{d}S$ at the upper base.

The number of particles which get on the collector through the element $\mathrm{d}S$ is equal to

$$\Delta n = \int_0^{2\pi} \mathrm{d}\varphi \int_0^{\infty} v_z \,\mathrm{d}v_z \int_0^{Av_z/L} f(v_z, v_r, \varphi)\,\mathrm{d}v_r,$$

where $f(v_z, v_r, \varphi)$ is the velocity distribution function of ions in the cylindrical coordinate system. Upon integrating Δn with respect to the area of the

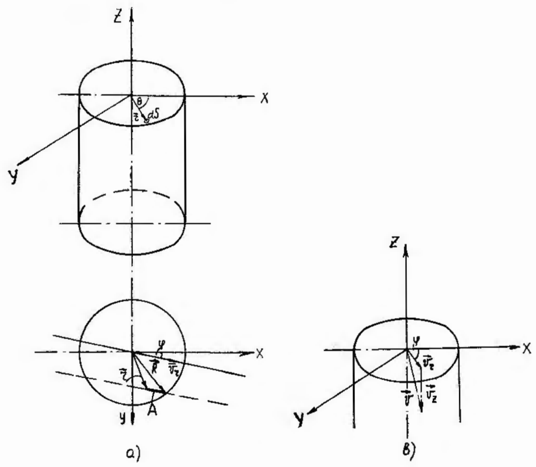


Fig. 8.

upper base, we shall obtain the total number of ions getting on the collector through the tube

$$N = \iint \Delta n \,\mathrm{d}S = \int_0^R \int_0^{2\pi} \Delta n r \,\mathrm{d}r \,\mathrm{d}\theta .$$

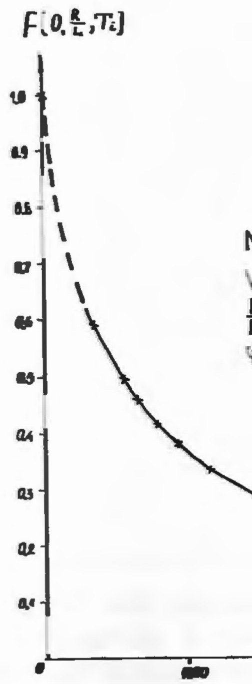
Having introduced dimensionless coordinates

$$x_1 = \varphi/2\pi,\ x_2 = \theta/2\pi,\ x_3 = r/R,\ x_4 = v_z/V,\ x_5 = v_r/V,$$

one obtains the following expression for the function F

$$\left.\begin{aligned} F\left(\psi, \frac{R}{L}, T_\mathrm{i}\right) &= \frac{4\pi V^2}{n_\mathrm{i}} \int_0^1 \int_0^1 \int_0^1 \int_0^\infty \int_0^{A(x_1, x_2, x_3)\, Rx_4/L} x_3\, x_4\, f(x_1, x_4, x_5)\, \mathrm{d}x_1\, \mathrm{d}x_2\, \mathrm{d}x_3\, \mathrm{d}x_4\, \mathrm{d}x_5, \\ A(x_1, x_2, x_3) &= \sqrt{1 - x_3^2 \sin^2 2\pi(x_1 - x_2)} - x_3 \cos 2\pi(x_1 - x_2). \end{aligned}\right\} \quad (6)$$

Assuming a Maxwellian distribution of ion thermal velocities, $F(\psi$ dependences were calculated according to (6) at the value R/L corresponding to honeycomb traps used in Cosmos 2 and at different values of the parameter $mV^2/2kT_\mathrm{i}$. The results of calculations for values $mV^2/2kT_\mathrm{i}$ corresponding to temperatures of 1000° K, 1500° K and 2000° K for atomic oxygen ions ($M = 16$) and for $V = 7500$ m/sec are given in fig. 9. In the same figure $F(\psi)$ is shown for $T_\mathrm{i} = 0$. In fig. 10 changes of $F(\psi = 0)$ are shown depending on T_i with the same M, V and R/L values. From fig. 9 it is seen that, as would have been expected, the curve $F(\psi)$ is extended as T_i increases. From fig. 10 one can see that the collector current of the



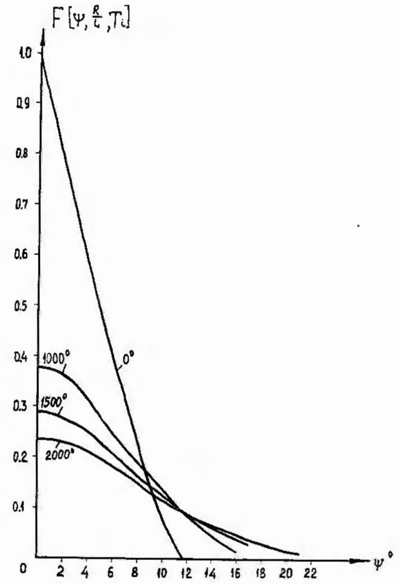

F[ψ, R/L, Ti]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000°
1500°
2000°
0°
2 4 6 8 10 12 14 16 18 20 22
ψ°

Fig. 9.

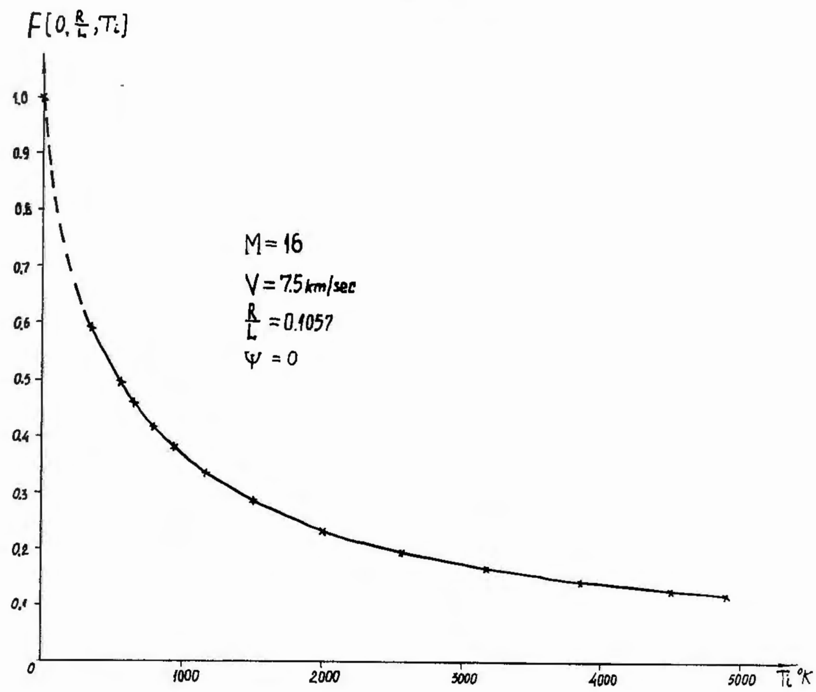

F[0, R/L, Ti]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
M = 16
V = 7.5 km/sec
R/L = 0.1057
Ψ = 0
1000
2000
3000
4000
5000
Ti °K

Fig. 10.

honeycomb trap when the incident flow velocity vector coincides with the direction of the axes of the honeycombs, strongly depends on temperature.

It is clear from the above considerations that experimental data on the $F(\psi)$ dependence can be used for determining T_i (by comparing them with calculated data if the values of M, V and R/L are known). Similarly one can use for determining T_i the experimental values of collector current of the honeycomb trap I_c at $\psi=0$, if the value n_i is determined independently (since it allows one to determine the value $F(\psi=0)$ as a ratio

$$I_{c\ max}/I_0 = I_{c\ max}/eSVn_i).$$

In fig. 11 one of the records of collector current of the honeycomb-type ion trap in Cosmos 2 is presented. It should be noted that due to the fact that the satellite had no fixed orientation, and, due to the sharp directivity of the honeycomb traps, currents in these traps were recorded only during

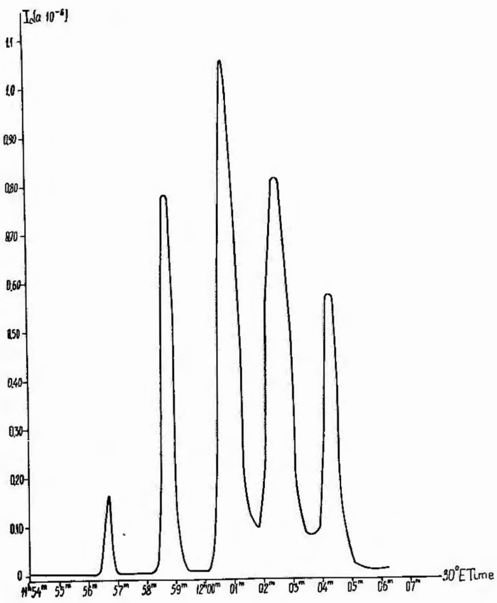


Fig. 11.

a comparatively small portion of the total observational time (when the direction of the ion flow was close to the direction of the axes of the honeycombs). Fig. 12 gives a record of collector current obtained simultaneously with the probe characteristic given earlier, in fig. 6. This record refers to those used in the attempt to estimate ion temperature by means of the theoretical considerations and calculations already outlined.

The angle ψ was determined from the data of the system of eight planar ion traps installed on the satellite. Since the record in fig. 12 refers to a height of 259 km it has been assumed that in the incident flow atomic oxygen ions predominated. An analysis has shown that the record $I_c(t)$ given in fig. 12 differs from the $F(\psi)$ function mainly by a scale factor. In determining T_i both the above-mentioned methods have been used: a comparison of the shapes of curves $F(\psi)$ (experimental and theoretical shown in fig. 9) and from the value $F(\psi=0)$ (with the use of the curve given in fig. 10). In determining T_i by these methods there are the following sources of error:

a) inaccuracy in determining the angle ψ;
b) the influence of the satellite body potential (which was negative in these experiments) on the ion trajectories;
c) leakage of the field of the trap's antiphotoelectron grid inward tubes of the honeycomb, which leads to a decrease of the tube's effective length.

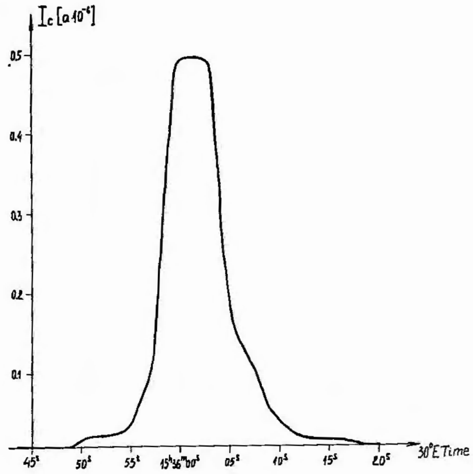


Fig. 12.

Consideration of the influence of these sources of error on determing T_i has shown that due to a) the value T_i is increased and due to b) and c) T_i is decreased. Bearing in mind the above-mentioned errors, the value of ion temperature obtained for the curve indicated in fig. 12 can be estimated as

$$T_i = (1300 \pm 200)\ °K.$$

5. Some considerations on using Langmuir probes and honeycomb ion traps

Despite essential successes achieved over the last five years in using satellite and rocket borne probes shielded by grids (ion and electron traps) [1, 5, 6, 11–13], an attempt at using classic (one-electrode) Langmuir probes for ionospheric investigations is still of interest, due to their simplicity and the opportunity given by them in principle to obtain, from one volt-ampere characteristic, information about the density of particles with charges of both signs and about their energy distributions. The latter opportunity was not used in experiments in the Cosmos 2 satellite (apparently due to insufficient sensitivity of the probe current amplifiers, which accounts for the fact that ion branches of the probe characteristics were not recorded). However this opportunity should be borne in mind. To make a confident estimate of the degree of reliability in determining ionospheric parameters from the electron branch of the probe characteristic, taking into account the influence of the geomagnetic field, some additional experiments and theoretical studies are needed.

Measurements by means of one-electrode probes should not be carried out at daytime in the regions of the ionosphere in which electron density is small and incident charged particle flows are smaller than photoelectron fluxes emitted by the probe. However, near the ionization maximum and/or at nighttime, such measurements seem to be promising.

The use of the planar probe does not allow us to utilize the "flat" portion of the electron branch of the probe characteristic for obtaining information on plasma, since in this region the current of the planar probe should be practically independent of the probe's potential. In cylindrical and spherical probes the electron current in the region of positive potential of the probe with respect to plasma grows with increase of the probe's potential, and the "flat" portion of the probe characteristic corresponding to this region can be used for control of data obtained from the steep portion of the characteristic.

The use of a spherical probe leads to difficulties caused by the fact that to reduce the influence of the magnetic field on the form of the probe characteristic, the probe's radius should be less than the Larmor radius (which in the ionosphere at heights of about 300 km is of the order of 3 cm). The surface of a spherical probe satisfying this condition turns out to be small. Besides, the spherical probe should be mounted on a boom which, taking into account the small radius of the probe, can essentially disturb the structure of the electric field. Despite the small radius a long cylindrical probe can have a large collecting area. In this case the cylindrical boom will not disturb the probe's electrical field, but on the contrary it can serve as a guard-electrode. The use of a boom to separate the cylindrical probe from the satellite or rocket body is expedient also from the standpoint of conducting measurements outside the space charge sheath which surrounds the satellite body. However, to determine the electron density by means of such a probe it is necessary to ensure its orientation in a direction almost perpendicular to the geomagnetic lines of force. Fulfilment of this condition is much less important when determining electron temperature.

Electron temperatures determined in the examples given in section 3 are close to 3000° at heights of about 300 km. Simultaneous measurements of ion temperature gave a magnitude which is less than half the electron temperature (see section 4). The minimum T_e value determined during measurements in Cosmos 2 at the above-mentioned heights is about 1800° K. Increased T_e values obtained from probe characteristics given in figs. 5 and 6 are perhaps due to magnetic perturbations observed during measurements.

In our opinion, the methods of determining ion temperature by means of honeycomb ion traps outlined in section 4 can be used in future experiments. Certainly, instead of the outer grid of the ion trap in the form of a honeycomb, simply a long tube can be used with a sufficient L/R ratio. However the use of honeycombs makes it possible to essentially reduce the trap's geometrical dimensions with a given effective area of the collector and with prescribed sensitivity of the trap to a change in the direction of the incident ion flux (determined by the change in collector current on changing the above-mentioned direction by 1°). For the honeycomb traps used in Cosmos 2 at an ion temperature $T_i = 1500°$ K, and an ion density $n_i \sim 5 \times 10^5$ cm^{-3}, sensitivity in the above-mentioned sense was of order 1.5×10^{-8} per degree. When determining ion temperature by means of honeycomb traps, one should bear in mind the importance of accurately determining changes in the trap's orientation with respect to the incident flow velocity vector (angle ψ), or the moment when the plane of the input holes of honeycomb is perpendicular to this vector ($\psi = 0$).

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