REPRINTED FROM:

SPACE RESEARCH II

PROCEEDINGS

OF THE SECOND INTERNATIONAL SPACE SCIENCE SYMPOSIUM
FLORENCE, APRIL 10-14, 1961

EDITED BY

H. C. VAN DE HULST, C. DE JAGER
and
A. F. MOORE

N·H
P C

1961
NORTH-HOLLAND PUBLISHING COMPANY—AMSTERDAM

THE STRUCTURE OF THE EARTH'S IONIZED GAS ENVELOPE BASED ON LOCAL CHARGED PARTICLE CONCENTRATIONS MEASURED IN THE USSR

K. I. GRINGAUZ

Radiotechnical Institute of Academy of Sciences of USSR, Moscow, USSR

Abstract: This paper contains results of local electron and ion concentration measurements which were made in the Soviet Union in 1958 and 1959 by vertically launched geophysical rockets, Sputnik III and space probes ("Luniks") I, II and III. Some data on the variability of the outer ionosphere are given.

At heights from about 1700 km to 15 000 km an ionized gas exists with ion concentration $n_i \approx 10^3$ cm^{-3}. At heights from about 15 000 to 20 000 km there is a region with high negative vertical gradients of ion concentrations; at 20 000 km $n_e \approx 10^2$ cm^{-3}. These experimental results make it possible to present a composite curve showing the approximate vertical distribution of charged particles in the gaseous envelope of the Earth for the period close to solar maximum activity.

Резюме: Представлены результаты измерений локальной концентрации электронов и ионов, проведенных в Советском Союзе в 1958 и 1959 гг. при помощи вертикальных запусков геофизических ракет, при помощи третьего советского искусственного спутника Земли и космических ракет ("Лунников") I, II и III. Приводятся некоторые данные об изменчивости внешней ионосферы. На высотах около 1700—15000 км ионизированный газ характеризуется ионной концентрацией $n_i \approx 10^3$ см$^{-3}$. На ыысотах около 15000—20000 км имеется область с высокими отрицательными вертикальными градиентами ионной концентрации, на высоте 20000 км $n_e \approx 10^2$ см$^{-3}$. Эти экспериментальные результаты позволяют построить сложную кривую, показывающую ориентировочное вертикальное распределение заряженных частиц в газовой оболочке Земли для периода близкого к периоду максимальной солнечной активности.

For the last three years in the Soviet Union measurements of local electron and ion concentrations have been made in the ionosphere (above the maximum of ionization of the F region) during vertical launchings of the geophysical rockets of the USSR Academy of Sciences, on Sputnik III and on soviet space probes I, II and III ("Luniks" I, II and III).

Speaking of "local" concentration measurements we mean measurements which have the following characteristics. They include a number of determinations of charged particle concentrations each of which refers to a definitely known altitude and does not require any laws chosen or assumed a priori for the distributions of charged particle concentration with height and in a horizontal plane; they do not use measurements of ionospheric stations; and they are not a result of statistical processing of measurements which were not taken simultaneously. In other words, each determination of concentration is completely localized in space and time.

A combination of results of the said experiments makes it possible to compose a pattern of the height distribution of charged particles in the Earth's ionized gaseous envelope, to determine its boundary and to draw some conclusions about the degree of its variability at different altitudes.

1. Results of measurements made by means of radio waves radiated from geophysical rockets

Aboard the USSR Academy of Sciences geophysical rockets which are launched almost vertically up to altitudes of 450–470 km transmitters of coherent radio waves with frequencies of 24×10^6 cycles per second, 48×10^6 cycles per second and 144×10^6 cycles per second are mounted. During the reception of these radio waves in a number of points on the earth's surface (including points near the projection of the rocket trajectory's apex) determinations of free electron concentrations at different altitudes are made. Two methods are used. One is based on the determination of radio wave dispersion (at frequences $144 \times 10^6 - 48 \times 10^6$ per second cycles and $144 \times 10^6 - 24 \times 10^6$ cycles per second), and the other on observations of Faraday rotation.

To determine the height distribution of free electron concentration from observations of the rotation of the plane of polarization of radio waves it sufficies to make these observations at one frequency as the rockets used are fully stabilized during free flight (i.e. during flight three mutually perpendicular axes which are rigidly connected with the rocket do not change their orientation with respect to the earthbound reference system). Therefore, difficulties connected with the separation of the Faraday rotation from the rotation of radiating antennae are not encountered and measurements of the turning of the plane of polarization of radio waves at any frequency radiated while the rocket passes some altitude interval makes it possible to determine the mean electron concentration at this interval.

The detailed description of the instrumentation used in these experiments has recently been published [1].

The height distribution of electron concentration determined from phase measurements of radio wave dispersion during the launching of a geophysical rocket up to an altitude of 470 km on February 21, 1958, was published [2] and reported at the Fifth IGY General Assembly in Moscow in August 1958. It is interesting, however, to compare the results obtained on February 21, 1958, with those obtained during the launchings of two similar rockets on August 27, 1958, and October 31, 1958. All three rockets were launched over the same geographical point (in middle latitudes of the European part of the USSR); measurements of electron concentration were made with the same instrumentation and the same technique.

During each launching radio sounding of the ionosphere from the Earth was made by the ionospheric station located near the rocket launching pad. In all cases maximum electron concentrations measured by rockets agreed well with the F layer critical frequencies.

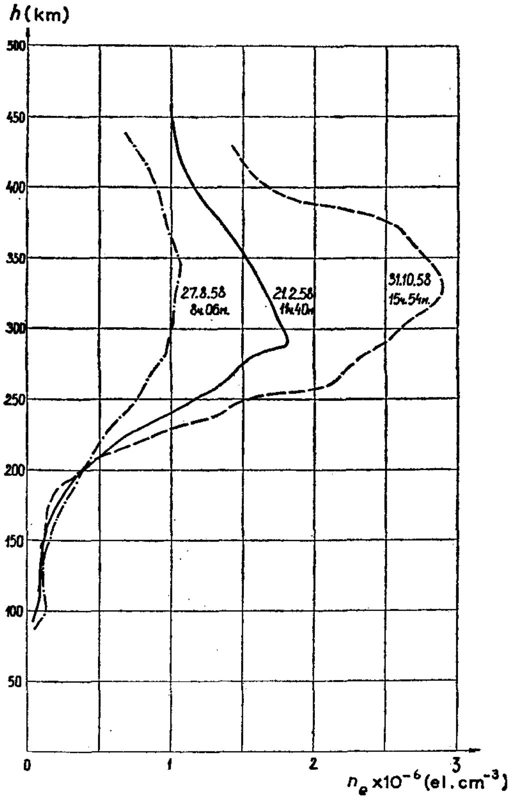

Fig. 1.

Fig. 1 shows three distributions of electron concentration with height which were obtained from measurements of radio wave dispersion during the said rocket firings. The times of these rocket launchings were February 21, 11^h 40^m; August 27, 8^h 06^m; and October 31, 15^h 54^m (everywhere local time is given).

Simultaneously with these radio wave dispersion measurements in all cases the rotations of the plane of polarization of the radio waves were recorded. For comparison, values of electron concentrations at different heights, obtained from phase measurements of radio wave dispersion (dashed curve) and from measurements of Faraday rotation at $f = 48 \times 10^6$ cycles per second are given in fig. 2 for August 27, 1958. The lengths of vertical segments correspond to altitude intervals when the plane of polarization of radio waves turns by the angle $\theta = \pi$.

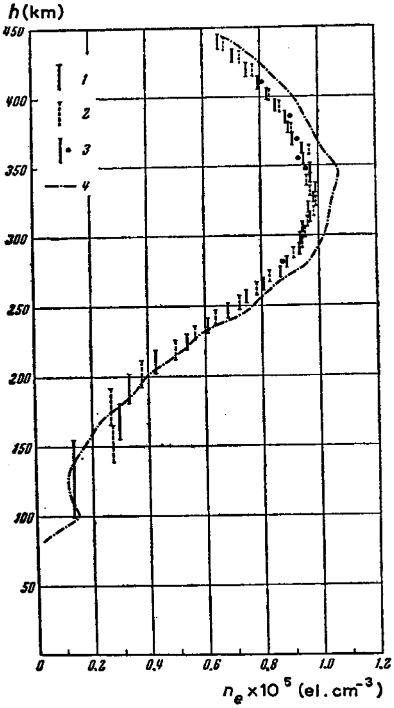

Fig. 2.

Fig. 1 strikingly illustrates the fact that vertical gradients of electron concentration in the region of the outer ionosphere lying immediately above the maximum of the F layer strongly vary with the time of the day and the season.

To characterize the variability of the ionosphere in this region we have summarized in table 1 values of $n_{e,\,\max}$ and $\Delta n_e/n_{e,\,\max}$, where $\Delta n_e = n_{e,\,\max} - n_e(h_m + 100 \text{ km})$; h_m is the height of maximum of electron concentration. The magnitude of the mean gradient of n_e in the 100 km above the maximum of n_e then is $\overline{|\text{grad } n_e|} = \Delta n_e/100$ (expressed in cm^{-3} km^{-1}).

TABLE 1

Data and time (Moscow time) 1958	$n_{e,\max} \times 10^{-6}$ (cm^{-3})	$\dfrac{\Delta n_e}{n_{e,\max}}$	$\overline{\lvert \text{grad } n_e \rvert} \times 10^{-3}$ (cm^{-3} km^{-1})
21.2 $11^h\,40^m$	1.83	−0.126	−2.3
27.8 $8^h\,06^m$	1.08	−0.134	−1.45
31.8 $15^h\,54^m$	2.92	−0.161	−4.7

The frame of the present report does not permit consideration of the problems connected with the errors in our measurements based on the observations of radio waves radiated from high altitude rockets. These problems are discussed in papers [1] and [3]. I wish only to point out that it is essential that the rocket trajectories be nearly vertical so that in interpreting the results of the measurements any suppositions on the magnitude of the horizontal gradients of n_e and on refraction effects are superfluous.

2. Results of measurements of positive ion concentration n_2 by spherical ion traps on Sputnik III

Experiments on measuring positive ion concentration along the Sputnik III orbit were carried out from May 15 to June 3, 1958. All further data which refer to these experiments were received at the daytime hours (from 5 to 17.00 h Moscow time) from the ionospheric region with heights up to 1 000 km which lies over the part of the earth's surface confined by geographical co-ordinates from 30° East to 175° East and from 25° North to 65° North.

The description of the experiment was published before its realization in 1957 [4] and was repeatedly reproduced [5, 6]. Therefore, let us recall only that measurements of positive ion concentration were carried out by taking ion current-voltage characteristics from the spherical two-electrode ion traps mounted on long rods over the satellite surface (fig. 3). The ion current-voltage characteristic, or retardation curve, shows the way in which the current in the circuit of the trap collector depends on the voltage supplied to the trap cover grid with respect to the satellite body.

Telemetry information on this experiment received during Sputnik III's flight contained the data for more than 10 000 ion current-voltage characteristics. One of these characteristics (based on results of preliminary treatment) was presented at the IGY Moscow Assembly in 1958. Referring to a height of 795 km it demonstrated the existence of the concentration $n_i \sim 1.8 \times 10^5$ cm^{-3} at this altitude.

The complete reduction of all information obtained has turned out to be

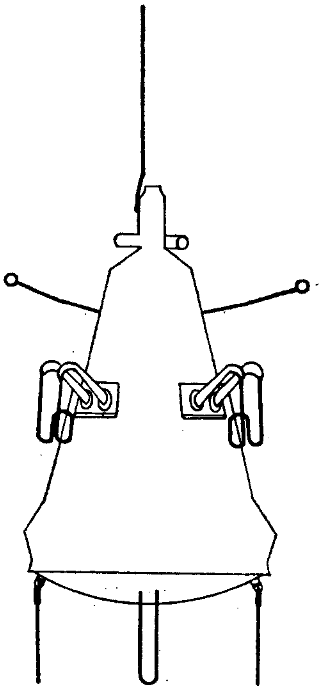

Fig. 3.

a time-consuming job and has come only recently to a close. In the present paper we have no occasion to discuss problems connected with the technique of determining positive ion concentration in the undisturbed ionosphere n_i from the current-voltage characteristic and, in particular, with the influence of ion thermal velocities on the results of processing. These problems are considered in a special paper [6]. I may only mention that the main method was based on the use of the slope of the linear portion of the ion current-voltage characteristic in the region of positive ion retardation by the aid of:

$$n_{i_0} = \frac{\mathrm{d}I_k}{\mathrm{d}\varphi} \frac{m_i V_{sat}}{2\alpha S e^2} \tag{1}$$

Here $\mathrm{d}I_k/\mathrm{d}\varphi$ is the slope of the said portion of the characteristic, V_{sat} is the velocity of the satellite, α a grid transparency coefficient, S is a trap diametral sectional area, e is the electron charge, and m_i the mass of the ion.

According to data obtained by means of the ion mass-spectrometer on board Sputnik III at altitudes from 250 km to 1000 km atmospheric oxygen ions do not constitute less than 90 % of total number of ions [7].

In several cases comparisons were made of the values n_{i_0} determined by means of Sputnik III's ion traps while it passed the ionization maximum of the F layer with the results of simultaneous measurements of critical frequencies by terrestrial ionospheric stations located near the satellite path.

Data on the F layer critical frequencies when the satellite passed altitudes about 300 km were determined (for the satellite's northern altitudes) by interpolation of the data received by ionospheric stations in Murmansk, Salehard, Tiksi bay, and Providence bay, and for satellite positions farther south than 40° North by extrapolation of the data obtained by the Ashkhabad ionospheric station (the most southern station in the USSR) and the network of stations the world over.

TABLE 2

Date (May 1958)	Moscow time	Satellite co-ordinates			Critical frequency $f_{crit.}$ (Mc/sec)	Electron concentration n_e (cm^{-3})	Positive ion concentration n_{i_0} (cm^{-3})
		Height above the earth	Northern latitude (degrees)	Eastern longitude (degrees)	(from ionospheric stations)		
15	$10^h\,12^m$	288 km	64.5	107.6	7.8	7.5×10^5	9.6×10^5
18	$10^h\,39^m$	356 km	65.1	114.6	8.3	8.5×10^5	7.5×10^5
21	$9^h\,00^m$	311 km	27.5	43.9	12.2	1.8×10^6	1.4×10^6

Examples of such a comparison are listed in table 2. From these examples it is seen that the value of the ion concentration n_{i_0} determined from data obtained by the satellite ion traps agrees closely (with a precision up to 25 %) with the value of the electron concentration determined from simultaneous observations of the ionosphere by ionospheric stations in the same geographical region. As local concentrations are determined by means of traps and average concentrations over a large region of the ionosphere (which is defined by the first Fresnel zone for the wavelength which corresponds to f_{crit}) are determined from the data obtained by ionospheric stations, the agreement of these results can be considered as satisfactory.

The following conclusions may be drawn:

1. Any negative ions in the F region of the ionosphere are present only in insignificant quantities, since the measured electron concentrations are approximately equal to the positive ion concentrations.

2. The ionization of the neutral air particles by the satellite motion does not significantly influence the results of n_i measured by ion traps.

The absence of significant quantities of negative ions in the outer ionosphere means *that the measured magnitudes of positive ion concentration can be regarded as magnitudes of electron concentration as well.*

As a result of the experimental data processing, a significant number of distributions of positive ion concentration was obtained along the parts of the satellite orbit in the above mentioned ionospheric region. Since the vertical velocity component of the satellite is considerably lower than the horizontal one, it is impossible to show the altitude dependence in a pure from from the distributions of positive ion concentrations obtained along the sections of the satellite orbit. The results obtained near the perigee, where the satellite vertical velocity is especially low, reveal the existence of considerable horizontal gradients of charged particle concentrations. However, despite the horizontal variations in n_i a presentation of the results of the measurements in a co-ordinate system (h, n_i) where h is a height over the earth is undoubtedly of interest. Although considerable horizontal variations are imposed on the height variations, these graphs (with due smoothing) should correctly reflect height variations in n_i since (with height changes by hundreds

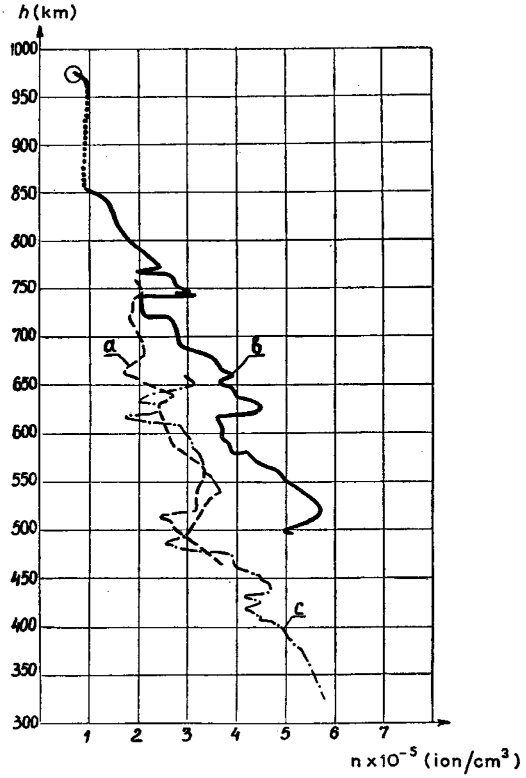

Fig. 4.

of kilometers) the n_i concentration is changed by an order of magnitude while horizontal variations are much lower. Small height variations in n_i cannot be separated from horizontal variations during measurements by the satellite-borne traps.

Fig. 4 presents graphs of changes of positive ion concentrations n_i with height referring to Sputnik III (a) 5th revolution (May 15, 1958, 17.00 h Moscow time, (b) 56th revolution (May 19, 1958, 11.00 h Moscow time, (c) 68th revolution (May 20, 1958, 9.00 h Moscow time. A number of other $n_i(h)$ graphs referring to different heights and different passes of the satellite around the Earth was published in [6], the remaining part of the material is ready for publication.

To characterize the degree of the variability of the ionosphere at altitudes above 500 km a table is presented in which for two altitude intervals (from $h_0 = 500$ km to $h_0 + \Delta h = 600$ km and from $h_0 = 600$ km to $h_0 + \Delta h = 700$ km) the following values are given (determined from data obtained during different passes of the satellite:

1) $n_i(h_0)$ – ion concentration at an altitude h_0,

2) relative decrease n_i with an increase of height by 100 km, i.e.

$$\frac{\Delta n_i}{n_i(h_0)} = \frac{n_i(h_0) - n_i(h_0 + \Delta h)}{n_i(h_0)},$$

3) the mean value of the ion concentration gradient with an increase of height by 100 km, expressed in cm^{-3} km, i.e.

$$\overline{|\text{grad } n_i|} = n_i(h_0) - n_i(h_0 + \Delta h).$$

TABLE 3

Altitude interval	Date and time (Moscow time)	Number of passes	$n_i(h_0)$ (cm^{-3})	$\frac{\Delta n_i}{n_i(h_0)}$	grad 10^{-3} (cm^{-3}/km)
From 500 km to 600 km	20.V.58 8 h 30 min	68	5.9×10^5	-0.15	-0.88
	31.V.58 5 h 30 min	216	4×10^5	-0.45	-1.7
	3.VI.58 5 h	256	2×10^5	-0.30	-0.56
From 600 km to 700 km	15.V.58 17 h	5	2.5×10^5	-0.27	-0.545
	18.V.58 10 h 30 min	42	2.6×10^5	-0.32	-0.636
	19.V.58 11 h	56	4.2×10^5	-0.33	-1.33

3. Data on charged particle concentration in the outermost part of the ionized gaseous envelope of the earth based on results of charged particle traps experiments on Soviet space probes

The collector current of each ion trap aboard Sputnik III was the sum of two components I_i created by atmospheric "thermal" ions and I_0 dependent on the action of solar ultraviolet radiation and energetic charged particles on the collector. With the decrease of ion concentration with height the ratio I_i/I_0 drops and n_i determination becomes difficult. With sufficiently small I_i the determination of n_i can become impossible.

In order to measure small ion concentrations, (for instance $n_i < 10^3$ cm^{-3}), the necessity thus arises to change the trap design to introduce a third electrode – an additional grid located between the collector and the outer grid. A sufficiently large negative potential of this additional grid with respect to the collector creates an electric field which suppresses the photoelectron emission from the collector as well as the secondary electron emission under the action of energetic charged particles.

Traps of such design were mounted aboard Soviet space probes and made it possible to register the low currents created by different streams of charged particles at different parts of the trajectories, including currents caused by the positive ions of the earth's ionized gas envelope.

In the present paper I shall consider only the results of experiments with three-electrode traps which were obtained in the immediate vicinity of the earth ($h \lesssim 4R_E$). Results obtained at larger distances from the Earth will be considered in a separate paper.

Since statistically the most valuable results were obtained with three-electrode traps at the near-the-earth section of the trajectory during the flight of Lunik II launched on September 12, 1959, data of this experiment are mainly discussed, though I shall use also results obtained with Luniks I and III [8, 9, 10].

On the surface of the spheroid container with scientific instrumentation, which was separated from the rocket of Lunik II, four three-electrode traps were located on the apexes of a tetrahedron described into the sphere. Each trap consisted of a semispherical outer nickel grid (with radius of 30 mm) inside of which a flat nickel collector was situated. A flat tungsten inner grid (fig. 5) was located between the collector and the outer grid. The trap electrode potentials relative to the container body were the following. On the collectors $\varphi_k = -60$ to -40 volts; on the inner grids $\varphi_{g1} = -200$ volts. The outer grids of the four traps had different potentials:

$$\varphi_{g2} = -10, \ -5, \ 0 \text{ and } +15 \text{ volts.}$$

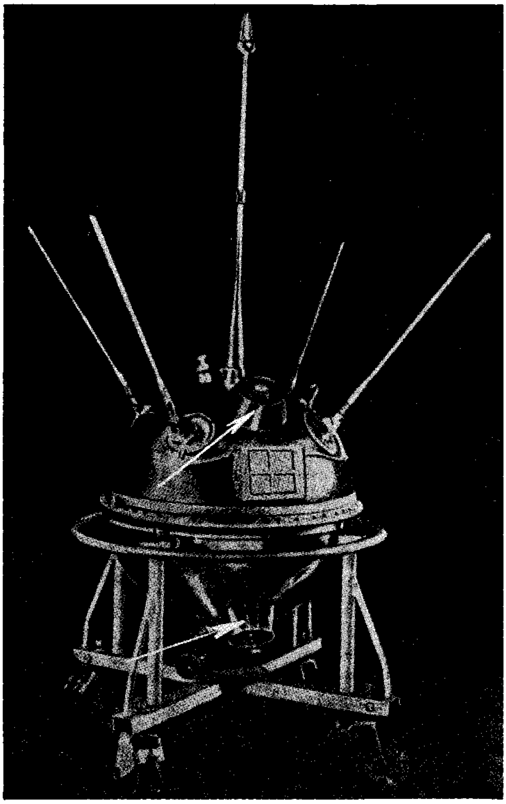

Fig. 3.

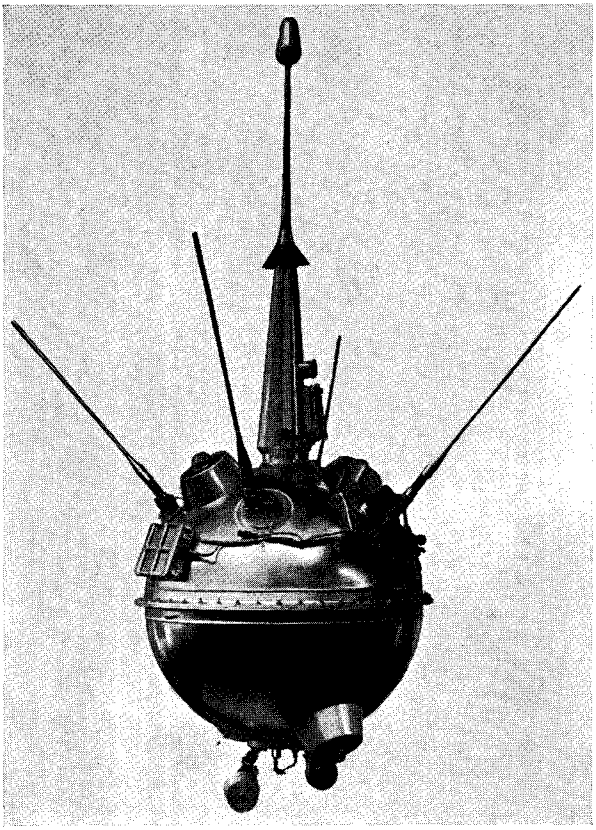

Fig. 4.

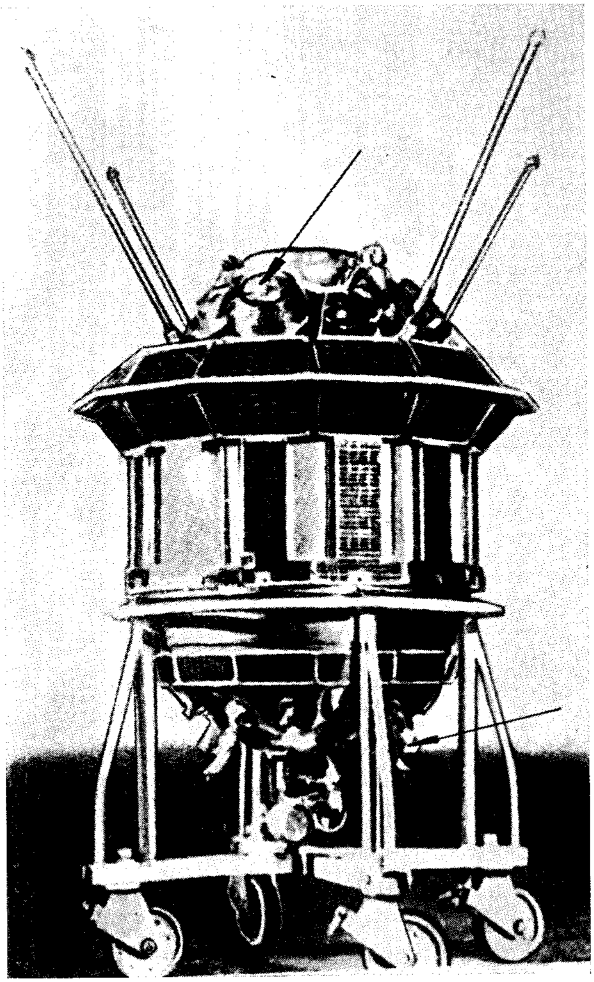

Fig. 5.

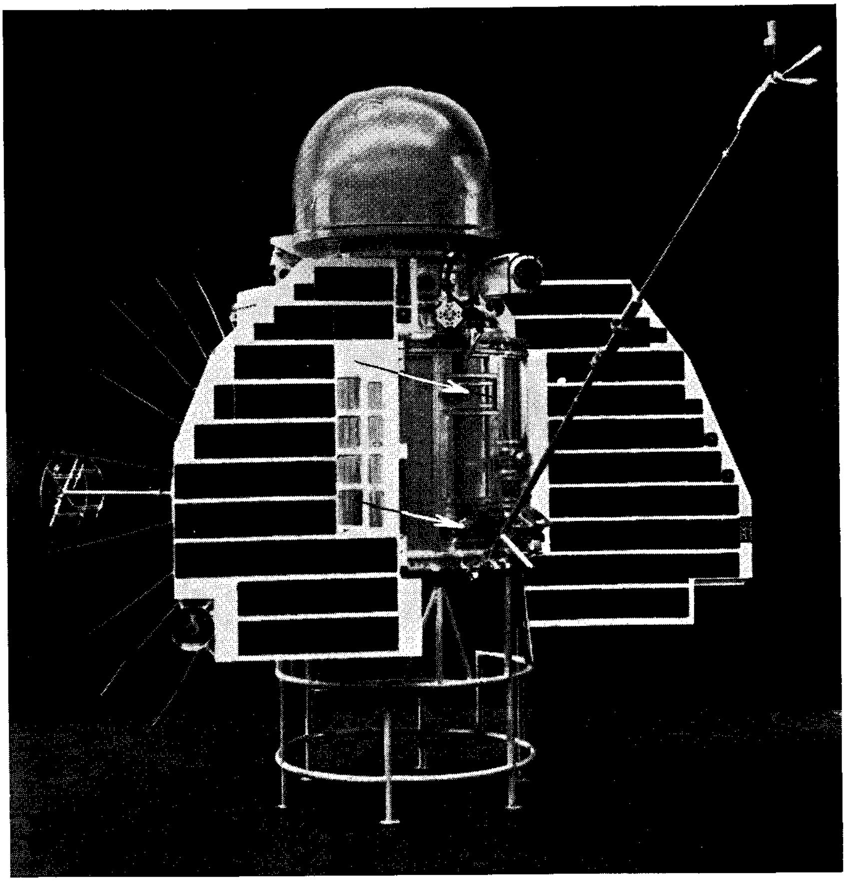

Fig. 6.

The values of the electrical currents created by the trapped charged particles were amplified and transmitted to the earth by means of a radiotelemetry system which made it possible to record positive collector currents I_k in the range from 10^{-10} to 50×10^{-10} amperes and negative collector currents from 10^{-10} to 15×10^{-10} amperes. The instantaneous magnitudes of each collector current were recorded two times per minute.

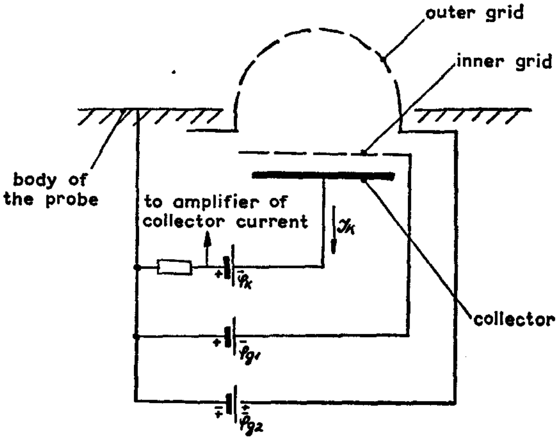

Fig. 5.

The first fact which attracted out attention while examining the rough material was that at distances from the earth's surface lower than $h \approx 20\,000$ km in all traps (except for the trap with potential $\varphi_{g2} = +15$ volts which retarded positive ions) considerable positive currents were observed which rather sharply dropped off in the region $h = 18\,000$ to $20\,000$ km. Within this region currents of each trap varied rather strongly.

In fig. 6 values of the collector currents in the trap with $\varphi_{g2} = -10$ volts are shown and in fig. 7 values of the currents in the traps with $\varphi_{g2} = 0$ volts (dots) and $\varphi_{g2} = +15$ volts (crosses) are shown.

The observed currents variations are accounted for by the fact that the container with scientific instrumentation while moving along the trajectory at the same time performed complicated rapid rotational movement which caused a continuous changes of the orientation of each trap in regard to the velocity vector and the direction towards the sun.

Maximum current values seem to correspond to container orientations close to the optimum orientation of a given trap when apparently the normal to the trap collector coincides with the velocity vector of the container since the flux of ions trapped is then the greatest. Therefore, the changes of the

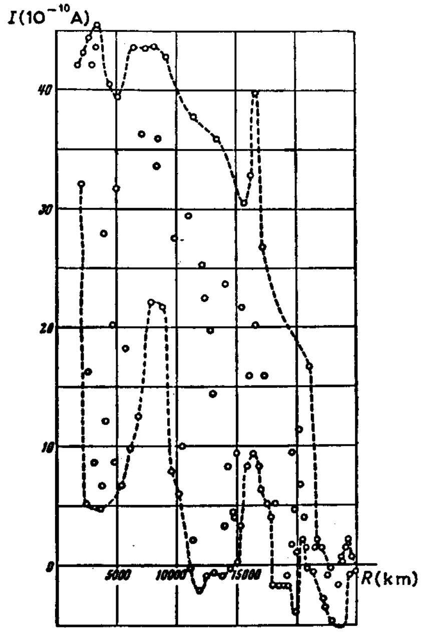

Fig. 6.

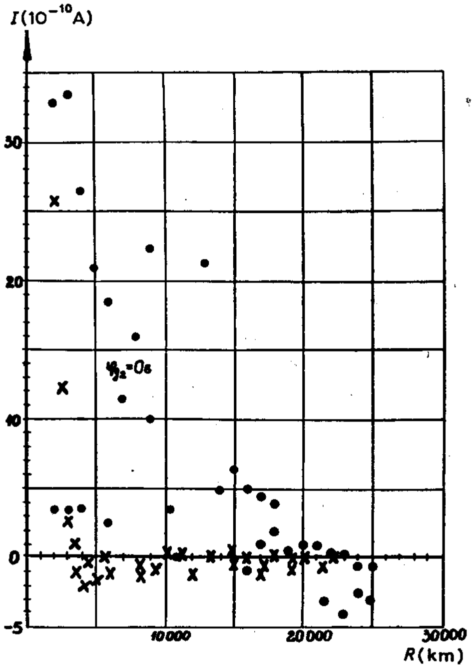

Fig. 7.

I_k values along the trajectory, which depend chiefly on the surrounding medium, can be described by means of curves which envelope the maximum I_k values. The influence of the container rotation on the experimental results can thus be eliminated to a certain degree.

Fig. 8 shows these collector current envelopes for different traps on an analyzed section. Curve 1 indicates the upper limit of currents in the trap with the outer grid potential $\varphi_{g2} = -10$ volts, curve 2 the upper limit of the trap currents with $\varphi_{g2} = -5$ volts, curve 3 the upper limit of the trap currents with $\varphi_{g2} = 0$ volts, curve 4 the upper limit of the trap currents with $\varphi_{g2} = +15$ volts, curve 5 represents the common lower boundary of currents in traps with $\varphi_{g2} = -10$ volts, -5 volts and 0 volts, curve 6 is the lower limit of the trap currents with $\varphi_{g2} = +15$ volts.

The absence of similarity in the shape of the curves in this figure seems to be accounted for by the peculiar changes of orientations of each trap in relation to the container velocity vector, arising from the different locations of the traps on the surface of the container, which rotated in a complicated pattern.

Fig. 9 indicates the upper boundary of the collector currents in traps with

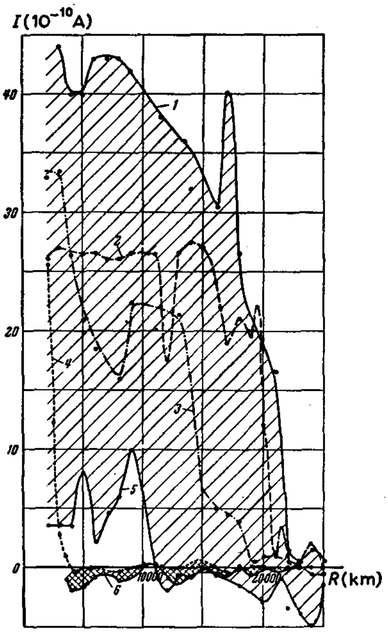

Fig. 8.

$\varphi_{g2} = -10$ volts and 0 volts measured during flight of Soviet space probe I (the first artificial planet) on January 2, 1959.

Fig. 10 shows the collector currents measured in traps with $\varphi_{g2} = -10$ volts and $+25$ volts during the flight of space probe III on October 4, 1959. The measurements in the vicinity of the Earth were made only to $R = 7\ 000$ km, at which distance the first radiocontact with the automatic interplanetary station was discontinued.

It is interesting to note that all three experiments discussed show at altitudes of about 2 000 km considerable systematically in traps with $\varphi_{g2} = \pm 15$ volts whose nature is not clear.

At altitudes above 2 000 km traps with the retarding positive potential on their outer grids showed in all cases only negative currents near the earth, caused by the photoemission of electrons from the inner grid.

Analysis of the above experimental results reveals that at distances of about four earth radii from the earth's surface an ionized gas exists with a temperature the order of magnitude of which is not more than $10^4°$. This follows from the significant influence (clearly seen from the figures referring to Lunik II) on the collector current values of relatively low (5 volts) differences in potentials of the outer grids of the traps.

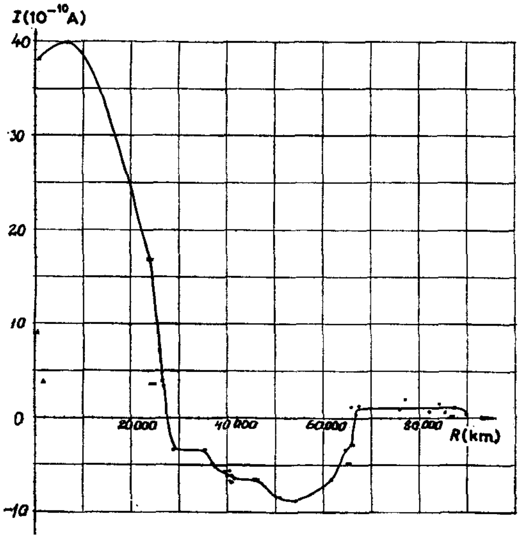
$I(10^{-10}A)$
40
30
20
10
0
-10
20000
40000
60000
80000
R(km)

Fig. 9.

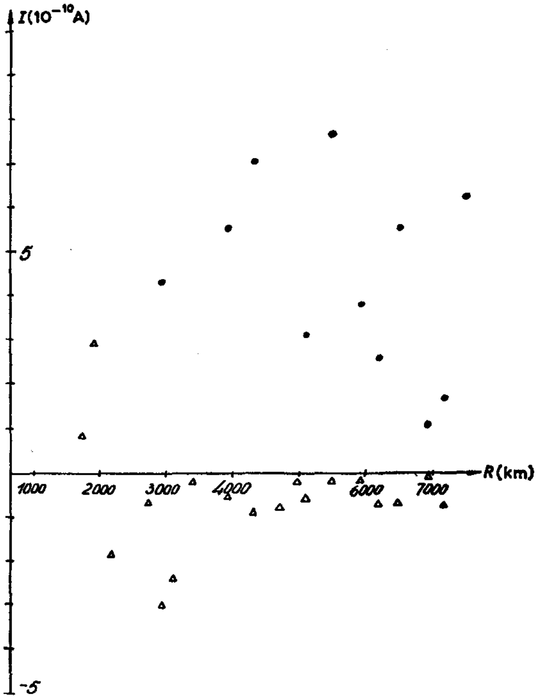
$I(10^{-10}A)$
5
-5
1000
2000
3000
4000
6000
7000
R(km)

Fig. 10.

Quantitative values of positive ion concentrations at the section of space probe II's trajectory with $h \lesssim 4R_E$ (where R_E is the earth's radius) were obtained from the values of the currents of the trap, the outer grid of the trap being connected with the container body ($\varphi_{g2} = 0$).

The following assumptions were made: 1) the recorded maximum current values correspond to the trap optimum orientation (in the sense indicated above). It is clear that this assumption can lead to an error in determining the current corresponding to the trap optimum orientation. In each case it is quite possible that the current registered is lower than that which corresponds to the optimum position of the trap, for example, by a factor two.

2) With the optimum orientation of the trap the flux of ions trapped can be calculated as a current collected by an infinite flat probe which moves with the container velocity V_{sat} in the plasma with Maxwellian distribution of ion velocities, with ion concentration n_i and temperature T_i. This assumption is based on the fact that the radius of the trap is small in comparison with that of the container and the surface of the trap discussed (its outer grid) is equipotential with the surrounding container surface. It may be added that the ion current density on the section of the spherical container surface normal to the velocity vector of the sphere, when it moves in a surrounding plasma with a velocity exceeding the ion thermal velocity, depends less strongly on the sphere potential than the ion current density on other sections of the surface.

Ratios by means of which the ion concentration is determined from measured currents are considered in [10]. In this report we have no possibility of considering them. I may only note that in the vicinity of the Earth the container velocity unquestionably exceeds the ion thermal velocity. That is why the current which corresponds to the optimum orientation of the trap should depend only in an insignificant degree on thermal velocities and, therefore, on ion masses and ion temperatures.

If one considers that hydrogen ions with the temperature $T = 2\,000°$ K are trapped, it is possible on the basis of data obtained on October 12, 1959, to construct a graph of the variations of ion concentration with height shown in fig. 11.

The dependence of these results on the assumed temperature is very weak. With $T = 50\,000°$ the curve drops only in an insignificant degree. The assumption that at the altitudes analysed, as well as at altitudes lower than 1 000 km, ions of atomic oxygen dominate also causes only insignificant changes in the results (the region of small gradients can be explained if the temperature is increased up to 15 000°). A theoretical relative distribution of hydrogen concentration was constructed in accordance with the barometric formula taking account of the curvature of the layers of equal density (the dotted line in fig. 11). The comparison of this curve with the observed curve shows that the region corresponding to $h < 15\,000$ km is easily explained while the sharp change in gradients with height in the region $h > 15\,000$ km requires special analysis.

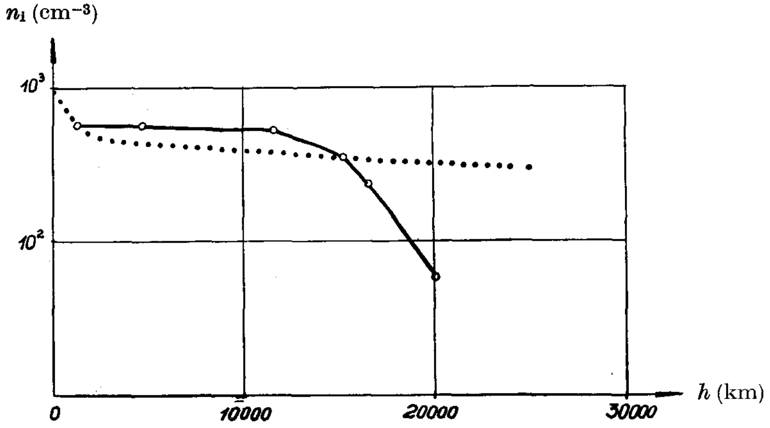

Fig. 11.

It should be emphasized that the existence of this region of increased negative gradients of n_i is beyond doubt since decrease of collector currents is observed in three traps with $\varphi_{g2} \leqslant 0$ which are oriented differently and therefore cannot be explained by unfavourable changes of the container orientation.

The comparison of the curves in fig. 11 gives reasons to believe that beginning with $h \approx 1\,400$ km (the minimum height at which registration of currents in traps began) up to $h \approx 20\,000$ or $22\,000$ km the earth is surrounded by ionized hydrogen, and, hence, that at altitudes between $h = 1\,000$ km and $1\,400$ km the transition from the "oxygen" ionosphere to the "hydrogen" ionosphere occurs.

The experiments expounded have proved that the earth is surrounded by an ionized gas envelope with a thickness up to $4R_E$ and with ion concentrations of the order of 10^3 cm^{-3} which considerably exceed the concentration in the interplanetary medium.

The problem of evaluating the ion concentration in the interplanetary medium will be discussed in more detail in our report on the results of experiments with charged particle traps at greater distances from the earth.

4. Conclusion

The results of experiments in the outer ionosphere expounded in the preceding section of the report make it possible to compose an approximate vertical distribution of free electron concentration (or of positive ion concentration, which is numerically equal to it above the F-region maximum) in the gas envelope of the earth, *which is fully based on experimental data.* Such a distribution is shown in fig. 12. Since it is based on measurements carried out during the period from February 1958 to September 1959 it naturally reflects the state of the ionosphere for the period close to maximum solar activity.

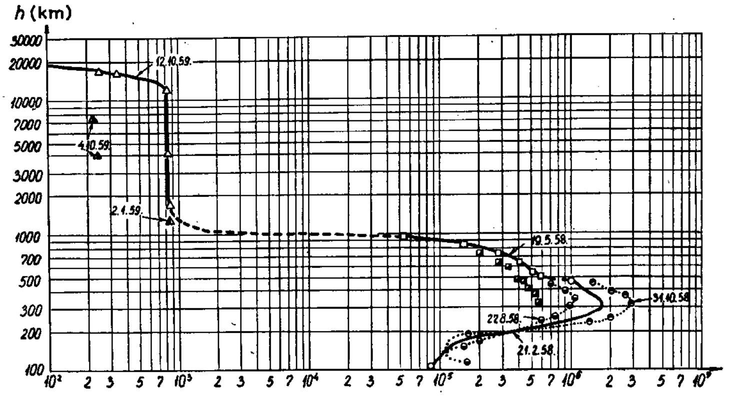

Fig. 12.

In constructing the lower part of the graph, data of one of the vertical launchings of geophysical rockets are used (on 21 February 1958); the middle part (from $h = 500$ to $h = 1\,000$ km) is constructed from data of measurements in the section of the orbit of Sputnik III during its 56th pass around the earth; the part of the graph from $h = 1\,400$ km to $h \approx 20\,000$ km is constructed on the basis of measurements performed on Lunik II. Near the curve some points are shown obtained during the measurements made at the indicated altitudes at different time (on other geophysical rockets or other passes of Sputnik III, on Luniks I and III). These points to a certain degree characterize the variability of the ionosphere.

Concerning the points for Lunik III it should be pointed out that on the near-the-earth portion of the trajectory of the automatic interplanetary station put into orbit by space probe III two traps were included with potentials on outer grids $\varphi_{g2} = +25$ volts and $\varphi_{g2} = -10$ volts, respectively. The currents registered in the trap with $\varphi_{g2} = -10$ volts turned out to be approximately four times lower than in the traps with the same φ_{g2} on the containers of Lunik I and II. This can be explained by the decrease of ion concentration at altitudes of the order of thousands kilometers, but at the same time it is possible that decreased values of the current are due to adverse orientation of the trap (this assumption cannot be checked since there were no other traps switched on with $\varphi_{g2} \leqslant 0$ with different orientation on the container surface at this portion of the trajectory).

The measurements on the basis of which the upper part of the graph in fig. 12 was constructed are the first direct experiments in the exploration of the earth's ionized gas envelope and represent only the beginning of the investigation of this region. In the nearest future multiple measurements of ion concentration in the outermost part of the earth's gas envelope should be made. The stability of its height and dependence of height on geographical latitude should be verified. Such measurements will make it possible to check the stability of characteristics of this region.

In a period when the single source of information about the structure of the earth's ionized gas envelope was radio sounding by means of ionospheric stations, theories of ionosphere formation were derived which adequately explained the experimental data then available. Experiments on board of the artificial satellites and space probes compel us now to seek paths for creating a new theory which would adequately explain the facts we have acquired of late. Among these facts is the significant increase of negative gradients of concentration revealed in the range of altitudes 15 000–20 000 km near the boundary of the earth's gas envelope.

The experiments described in the paper were performed by a group of radiophysicists, collaborators of the Radiotechnical Institute of the USSR Academy of Sciences. Besides the author of the report, the following persons participated in the work: V. A. Rudakov and A. V. Kaporsky (the design of instrumentation, carrying out of experiments with the dispersion interferometer and interpretation of results obtained), V. V. Bezrukikh and V. D. Ozerov (the design of instrumentation, performance of experiments with spherical ion traps on board Sputnik III and interpretation of experimental results), V. V. Bezrukikh, V. D. Ozerov and R. E. Rybchinsky (the working out of the experimental technique with three-electrode traps and instruments for these experiments, and treatment of experimental results). A group of collaborators of the Sternberg Astronomical Institute—Prof. I. S. Shlovsky, V. G. Kurt and V. I. Moroz took part in the interpretation of some experimental results obtained by three-electrode traps carried by space probes.

References

1. K. I. Gringauz, V. A. Rudakov, A. V. Kaporsky, Artificial Earth Satellites, issue 6, (1961) 33
2. K. I. Gringauz, Doklady Akademii Nauk SSSR, 180 (1958) 1234
3. K. I. Gringauz, V. A. Rudakov, Artificial Earth Satellites, issue 6 (1961) 48
4. K. I. Gringauz, M. H. Zelikman, Advances of Physical Sciences (Uspekhi Fiz. Nauk) 63 (1957) 239
5. V. I. Krassovsky, Proceedings of the IRE, 47, N 2, (1959) 289
6. K. I. Gringauz, V. V. Bezrukikh, V. D. Ozerov, Artificial Earth Satellites, issue 6 (1961) 63
7. V. G. Istomin, Artificial Earth Satellites, issue 4 (1960) 171
8. K. I. Gringauz, V. V. Bezrukikh, V. D. Ozerov, R. E. Rybchinsky, Dok. Akad. Nauk, 13 (1960) 1301
9. K. I. Gringauz, V. G. Kurt, V. I. Moroz, I. S. Shklovsky, Dokl. Akad. Nauk SSSR issue 5, (1960) 1062
10. K. I. Gringauz, V. G. Kurt, V. I. Moroz, I. S. Shklovsky, Astronomichesky Zhurnal, 37 (1960) 716