ACADEMY OF SCIENCES OF THE USSR

INSTITUTE FOR SPACE RESEARCH

Пр-I92

K.I. Gringauz, B.B. Bezrukikh, M.I. Verigin,
A.P. Remizov

STUDY OF SOLAR PLASMA NEAR MARS AND ALONG THE EARTH TO MARS PATH BY MEANS OF CHARGED PARTICLE TRAPS ABOARD THE SOVIET SPACECRAFTS LAUNCHED in 1971-1973

III. Characteristics of ion and electron plasma components in antisolar part of the near-Martian space as measured aboard the satellite "Mars-5".

MOSCOW

INSTITUTE FOR SPACE RESEARCH
ACADEMY OF SCIENCES OF THE USSR

Пр-I92

K.I. Gringauz, B.B. Bezrukikh, M.I. Verigin,
A.P. Remizov

STUDY OF SOLAR PLASMA NEAR MARS AND ALONG THE EARTH TO MARS PATH BY MEANS OF CHARGED PARTICLE TRAPS ABOARD THE SOVIET SPACECRAFTS LAUNCHED in 1971-1973

III. Characteristics of ion and electron plasma components in antisolar part of the near-Martian space as measured aboard the satellite "Mars-5".

Moscow, 1974

SUMMARY

Results of measurements of boundary positions and characteristics of transition layer behind the martian bow shock are presented. For the first time measured characteristics of the plasma formation located behind the inner boundary of the transition layer at the antisolar part of near-martian space are considered. A possible nature of this formation is discussed and some considerations in favour of its interpretation as the plasma sheet in the martian magnitospheric tail are presented.

At the spacecraft "Mars-5" that become the satellite of Mars on 13.2.1974 (the pericenter ~1800 km, the apocenter ~32 000 km, the inclination to the ecliptic plane ~60°, the rotation period ~25 hours) wide-angle charged particle traps were installed for measuring of ion and electron component characteristics of the low-energy plasma. Characteristics of instruments, the description of their arrangement at the spacecraft and regimes of measurements are given in [1] . Below the data are presented of new measurements of the location of boundaries and characteristics of the transition layer - the Martian magnetosheath (see, for example, [2-8]) and the data of first measurements of characteristics of a plasma formation located behind the inner boundary of the transition layer at the anti-solar part of the near-Martian space. A preliminary information on that plasma formation are given in [9] .

Fig. 1a shows the orbit of "Mars-5" on 14.2.74 in solar-areoecliptic coordinates X, Y, Z. The axis X is directed to the Sun, Y is in the orbital plane of Mars and makes a blunt angle with the velocity vector of the planet, the axis Z supplements the coordinate system to the right one. In fig. 1b a part of the same orbit is presented in coordinates $X, \sqrt{Y^2+Z^2}$. The analysis of ion and electron energy spectra obtained during all available communication sessions showed that near the planet the satellite crossed three zones (I-III) with substantially different characteristics of the plasma. Typical primary ion spectra and electron retardation curves corresponding to these three zones are showed in fig. 2. In zone I ion and electron spectra are typical to the undisturbed solar wind (fig. 2a). The criterion of the crossing of the bow shock front and the entering the transition layer II is the characteristic change of charged particle spectra (fig. 2b): ions are thermalized and their fluxes increase; I_{max} at electron retardation curves increases too (I_{max} - the current corresponding to zero retarding potential and proportional to $n_e \sqrt{T_e}$, where n_e - - the electron density, T_e - the electron temperature (see [8]). In zone II the retarding potential, which characterizes the energy of electrons also increases.

Characteristics of these two zones are similar to those observed in 1971-72 aboard the "Mars-2" and "Mars-3". Results of electron [2, 3] and ion [4, 5] plasma measurements and magnetic measurements [6, 7] from these two spacecrafts allowed to establish the existence of the bow shock. Characteristics of the plasma in the zone III at the angle Sun-Mars-satellite more than 90° are measured for the first time. An abrupt fall of ion currents is typical to the zone III compared to zones I and II (fig. 2b). The decrease of measured ion currents is so great that along approximately 30% of parts of the orbit inside the zone III the ion fluxes are below the limit of the sensitivity of the instrument and only along 40% of the path the ions are registered quite reliably (the level of signal exceeds the minimum telemetric signal by factor of three or even more). Values of electron currents in the zone III also decrease compared to those in the zone II (fig. 2c). However, they are higher than in the undisturbed solar wind (the zone I, fig. 2a) and are always registered.

Let us consider in detail the results of plasma measurements. At four revolutions of "Mars-5" satellite (see table 1) the instrument was not switched during the crossing of the bow shock front and the entering the transition layer. From values of areocentric distances r, angles Sun-Mars-satellite φ at which the spacecraft crossed the bow shock front and gas-dynamic calculations [10] of a flow past an obstacle having a form of the Earth's magnetosphere at $M_\infty = 8$, $\gamma = 5/3$ one can estimate the altitude of the obstacle h_{obst} (at the subsolar point) stopping the solar wind in a similar way as it was made in [8]. In table 1 values of the density n, the bulk velocity V and dynamical pressure of solar wind protons ρV^2 are also given before the crossing of the shock wave front (in sessions with two-minutes intervals between successive electron and ion spectra the values averaged over 10-min intervals are given). Values of the density and velocity of solar wind ions were estimated from three readings close to maximum ones under the assumption of the Maxwellian distribution in the coordinate system moving with the velocity V. The proton and electron temperatures at moments of time under consideration were within $(80 \div 200) \times 10^{3}\,^{\circ}K$ and $(70 \div 230) \times 10^{3}\,^{\circ}K$ respectively. At the entering the transition layer the charged particle density (estimated from the electron trap data) increased by a factor of 1.5-3, the electron temperature reached $(0.3 \div 1) \times 10^{6}\,^{\circ}K$.

When comparing values of the altitude of the obstacle at the stagnation point (table 1) with the solar wind dynamical pressure in "two-minutes" session of measurements on 20.02 and

22.02 one can see that the altitude of the obstacle decreases with the increase of ρV^2. On 13.02 and 24.02 a high scatter in estimations of h_{obst} is related to the fact that measurements were performed rather seldom (electron and ion spectra are measured within ~1 min with intervals of 9 min) but as the solar wind dynamical pressure in these sessions was less than on 20.02 (see table 1) the obstacle altitude seemed to be not less than in the latter session (although this altitude varied within the range mentioned in table). Therefore, a minimum estimation of the obstacle altitude from the "Mars-5" data can be $h_{obst} \sim 500$ km which was made from the data of the crossing of the bow shock front on 20.02.74. Note that according to the data from "Mars-2" and "Mars-3" the minimum estimation of h_{obst} was ~600 km (from the crossing of the bow shock front by the "Mars-2" satellite on 12.05.72) and this estimation is close to mentioned one. It should be noted that the estimation of the obstacle altitude $h_{obst} \sim 500$ km is obtained at the value of solar wind density $n \sim 11$ cm^{-3} and velocity $V \sim 480$ km·sec^{-1} and these values substantially exceed an average value of n and somewhat exceed an average value of V even near the Earth's orbit.

Let us estimate obstacle dimensions from all crossings of the bow shock front by "Mars-2", "Mars-3" and "Mars-5" satellites similar to that as it was made in [8]. Fig. 3 shows parts of orbits of these satellites at which the shockwave front was crossed. Characteristics of the plasma measured at near-planet points and shown in this picture are typical to the magnetosheath (fig. 2b) and at distant points - to the undisturbed solar wind (fig. 2a). Areocentric distances to the subsolar point of the obstacle and bow shock front (choose in such a way [8] that the sum of square of distances from both ends of orbit parts at which the bow shock front was crossed to the bow shock front would be minimum) are $(4.6 \pm 0.8) \cdot 10^3$ km and $(5.7 \pm 1) \cdot 10^3$ km respectively, i.e. from all crossings of the bow shock front the estimation of an average obstacle altitude h_{obst} is $\sim 1200 \pm 800$ km.

Let us consider in detail physical characteristics of the zone III the data of which are obtained for the first time. One can see from fig. 1b that the part of the orbit crossing the zone III on 14.02.74 corresponded to $\sqrt{Y^2+Z^2}$ from ~ 5800 km to ~ [illegible]00 km, i.e. to the interval of distances from the Sun-Mars line exceeding 2000 km. The extent of this part of orbit along the axis X is not less than several radii of the Mars.

As it was mentioned above ion currents registered in this zone are substantially less and electron currents are higher than those in the undisturbed solar wind. Ion energies are more changeable (as a rule they are lower but sometimes higher than in the zone I - see fig. 4). From retardation curves obtained by means of the electron trap in the zone III one can estimate the electron temperature and charged particle density in this zone. Typical values of electron temperatures are $T_e \sim 100 \times 10^{3}$ °K. However, there were observed values of $T_e \sim (70 \div 250) \times 10^{3}$ °K. Note that a possible bulk velocity of electrons (it is less than that in the solar wind) slightly influences upon the accuracy of the determination of T_e [8]. According to [8] estimations of n_e are $\sim 2 \div 8$ cm^{-3}, i.e. approximately the same as in the solar wind.

Under these conditions a sharp decrease of ion currents in the modulating trap compared to that in the solar wind (compare fig. 1a to fig. 1c and 4) can occur in two cases: either a bulk ion flux considerably changes its direction (the ion

trap has wide-angle response - [1]) **of this flux becomes quazi-isotropic** one. Note that the change of the direction of the plasma motion or its isotropisation should be revealed only in ion current but not electron ones as the electron flux is quazi-isotropic even in the undisturbed solar wind. The isotropisation of the ion flux should decrease the ion current approximately by a factor of 20 compared to the cold ion flux normal to the trap apperture (see characteristics of the instrument in [1]). An increase an average energy $\bar{E}$ of protons near the satellite up to values exceeding the upper energy limit of the instrument ($\bar{E} \lesssim 4000$ ev) is unlikely as all changes of ion spectra in the zone III when these spectra are registered are mainly observed with the maximum currents within energy range ~200 ÷ 500 ev.

The comparison of results of plasma measurements under consideration with the simultaneous magnetic data from "Mars-5" [11] showed that:

1) the magnetic data also give an evidence of the existence of three different zones along the near-planet part of the satellite orbit.

2) According to both sorts of measurements boundaries between the zones coincide at all revolutions of the satellite around the planet.

3) The zone III is characterized by a substantial decrease of magnetic field fluctuations (they are highly considerable in the zone II) and a considerable increase of a regular magnetic field strength. This point gave a ground to attribute the zone III to the tail of the Martian magnetosphere [1].

Generally speaking, two suppositions are possible about the nature of the plasma zone III. It may be related either to"the plasma sheet" similar to that in the central part of the Earth's magnetospheric tail (see, for example, [12] and [13]), or to the boundary layer between the transition layer (the Martian magnetosheath) and Martian magnetosphere similar to that observed in the Earth's magnetospheric tail [13, 14].

If it is a boundary layer the direction of the plasma motion should be primarily antisolar there [13, 14], although in the boundary layer of the Earth's magnetosphere there were observed deviations of the ion bulk velocity from the antisolar direction by ~ ±20° [15]. Though from changeable ion spectra in the zone III one can see some decrease of the average ion velocity in this case it is necessary to assume (for an explanation of the observed decrease of ion fluxes) either a considerable decrease of the plasma density in the zone III compared to that in the undisturbed solar wind (however, if it would be the case, it would be impossible to explain why electron currents registered in the zone III are higher than those in the zone I), <u>or</u> an essential (by 30°-40°) turn of the plasma bulk velocity vector at the boundary between zones II and III. It is also extremely difficult to explain the cause of such a turn of plasma flow.

If the zone III is the plasma sheet of the Martian magnetospheric tail the values of low ion currents can be explained by the high isotropy of ion fluxes in this zone similar to that in the plasma sheet of the Earth's magnetospheric tail. In this case a contradiction between a simultaneous registration of low ion currents and high electron ones is removed. In the Earth's magnetosphere energies of isotropic ions of the plasma sheet $\bar{E} > E_0$, where E_0 - energies of ions in the undisturbed solar wind ($\bar{E} \sim 6$ kev - see [14]). In the zone III

$\bar{E} < E_0$. This difference from the Earth's magnetosphere may be related to the fact that the Martian magnetic field is relatively weak and therefore is not able to cause the ion acceleration.

The totality of the plasma data pertaining to the zone III and data of magnetic measurements in this zone (the increase of the regular component of the magnetic field and the decrease of magnetic field fluctuations with the simultaneous decrease of the plasma density compared to that in the transition layer - the zone II) gives an evidence in favour of a magnetic nature of the obstacle. Solar wind flow past this obstacle creates near-martian bow shock. However, in the absence of magnetic field data at bow altitudes and on surface of the Mars the decisive proof of the existance of planetary intrinsic magnetic field may give, in our opinion, only a joint study of simultaneous data on magnetic field variations in the interplanetary space and in the vicinity of the planet [16] .

Table 1

Date	Time, hr, min	r, 10^3 km	$\varphi°$	n, cm^{-3}	V, $km.sec^{-1}$	h_{obst}, km	ρV , 10^{-8} dyn.cm^{-2}
13.02. 74	19.17- 19.27	5.6- 5.2	40- 55	9	455	750-100	3.1
20.02. 74	00.19- 00.21	5.5- 5.4	44- 48	11	480	650-450	4.2
22.02. 74	01.53- 01.55	5.8- 5.65	39- 42	1[illegible]	640	900-800	1.2
24.02. 74	03.37- 03.47	5.85- 5.3	35- 47	2.5	620	1050-400	1.6

REFERENCES

1. K.I. Gringauz, V.V. Bezrukikh et al., Kosmitcheskie Issled., 12, N 3, 1974.
2. K.I. Gringauz. V.V. Bezrukikh et al., Ikarus, 18, 54, 1973.
3. K.I. Gringauz, V.V. Bezrukikh et al., Journ. Geophys. Res., 78, 5802, 1973.
4. O.L. Vaisberg, A.V. Bogdanov et al., Ikarus, 18, 59, 1973.
5. O.L. Vaisberg, A.V. Bogdanov. Kosmitcheskie Issled., 12, N 2, 279, 1974.
6. Sh.Sh. Dolginov, E.G. Yeroshenko, L.N. Zhouzgov, DAN SSSR, 207, 6, 1973.
7. Sh.Sh. Dolginov, Ye.G. Yeroshenko, L.N. Zhuzgov, Journ. Geophys. Res., 78, 4779, 1973.
8. K.I. Gringauz, V.V. Bezrukikh et al., Kosmitchesk. Issled., 12, N 4, 1974.
9. K.I. Gringauz, V.V. Bezrukikh et al., DAN SSSR, 1, 197 (in press).
10. J.R. Spreiter, A.I. Alksne, in book "Magnetospheric Physics", ed. by D.J. Williams and G.D. Mead, 1968.
11. Sh.Sh. Dolginov, E.G. Yeroshenko et al., DAN SSSR, 1974 (in press).
12. K.I. Gringauz, Rev. of Geophys., 1-2, 339, 1969.
13. E.W. Hones, Jr., J.R. Asbrige et al., Journ. Geophys. Res., 77, 5503, 1972.
14. S.I. Akasofu, E.W. Hones, Jr., et al., Journ. Geophys. Res., 78, 7257, 1973.
15. D.S. Intrilligator, J.H. Wolfe, Journ. Geophys. Res., 77, 5480, 1972.
16. Sh.Sh. Dolginov, E.G. Yeroshenko et al., Kosmitchesk. Issled., 1974, (in press).

FIGURE CAPTIONS

Fig. 1 Trajectory of the spacecraft "Mars-5" on 14.02.74

——— - the undisturbed solar wind (I)

– – – - the transition region (II)

//////// - the zone III

— — — - no measurements

Fig. 2 Ion spectra and electron retardation curves typical to zones I-III.

Fig. 3 Crossings of bow shocs by satellites of the Mars

"Mars-2" 1 - 17.02.71
2 - 08.01.72
3 - 12.05.72
"Mars-3" 4 - 15.12.71 5 - 09.01.72
6 - 21.01.72 7 - 21.01.72

"Mars-5" 8 - 13.02.74 9 - 20.02.74
10 - 22.02.74 11 - 24.02.74

Average position:

——— - obstacle

– – – - bow shock front

Fig. 4 Samples of ion spectra registered in the zone III.

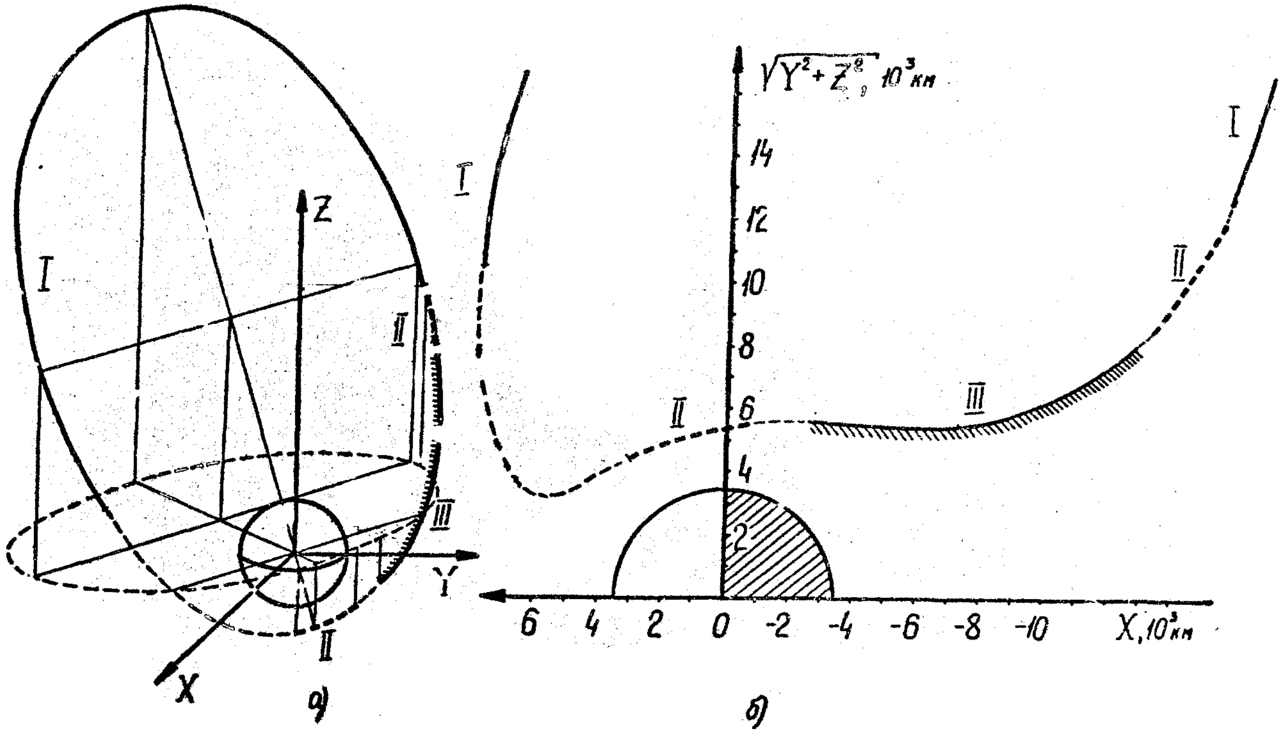
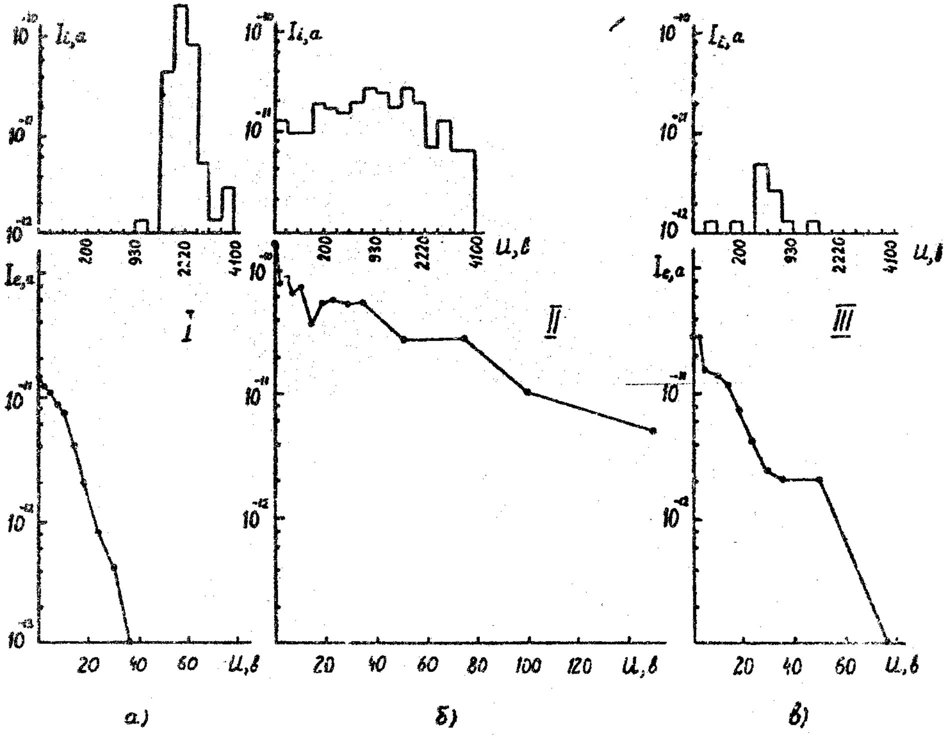

Z
Y
X
I
II
III
a)
$\sqrt{Y^2+Z^2}$, 10^3км
14
12
10
8
6
4
2
0
2
4
6
-2
-4
-6
-8
-10
X, 10^3км
I
II
III
б)

Fig.


10^{-10}
I_i, a
10^{-11}
10^{-12}
200
930
2220
4100
$U, в$
I_e, a
10^{-10}
10^{-11}
10^{-12}
10^{-13}
20
40
60
80
100
120
I
II
III

a)

б)

в)

Fig. 2

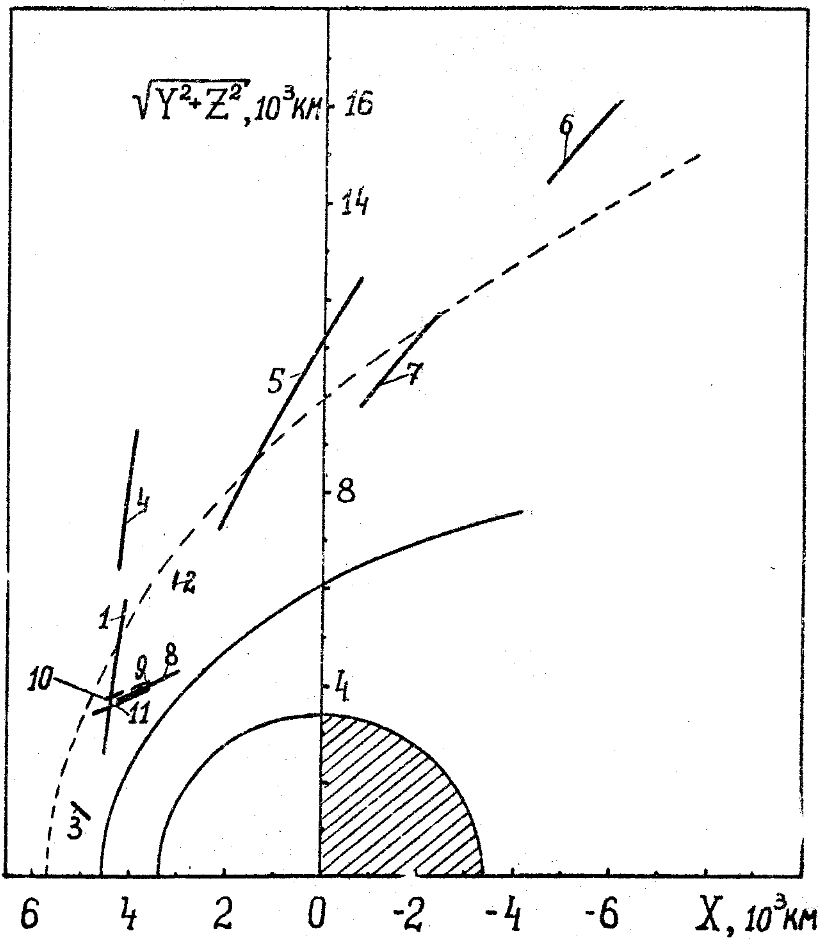
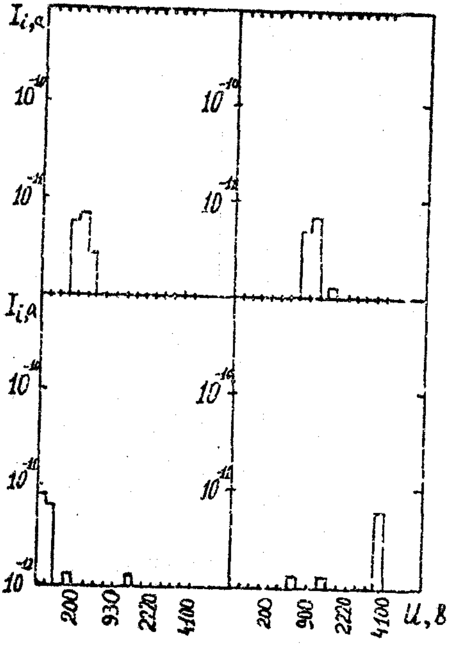


Fig. 3



I_i, a
10^{-10}
10^{-11}
10^{-10}
10^{-11}
I_i, A
10^{-10}
10^{-11}
10^{-12}
10^{-10}
10^{-11}
200
930
2220
4100
200
900
2220
4100
U, В

Fig. 4

055(02) 2 Отпечатано в ИКИ АН СССР

Т - I482I Подписано к печати 9.8.74

Заказ 2126 Тираж I25 Объем 0,7 уч.-изд.л.