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A B S T R A C T

It was reported [1-4] that the data on ion fluxes measured with the RIEP instrument on-board the Mars-5 satellite could be interpreted as detection of heavy-ion fluxes in the region where the solar wind interacts with Mars. The instrument operation in this experiment is further analyzed in this paper. According to it, all the typical features of the experimental data can be explained, if ions of only one mass are present in this region , and the hypothesis on the existence of heavy-ion fluxes used in [1-4] is not required for their explanation.

It was reported by the group of investigators who had measured the characteristics of low-energy plasma with the RIEP instrument on-board the Mars-5 satellite that the data from measurements of ion fluxes in the region of solar wind interaction with the planet, can be interpreted as detection of heavy-ion fluxes in this region [1-4] . It follows from [1-4] , however, that this conclusion was not a result of an experiment with the main aim to determine the mass of ions recorded, but was a result of the analysis of possible reasons for different readings the two individual RIEP sensors in the region where the planet interacts with the solar wind. Since the detection of heavy-ion fluxes in this region is very essential for understanding of physical processes associated with the interaction of the solar wind with planets that have weak magnetic fields, it seems to be reasonable to analyze once more the operation of the sensors during the experiment discussed. It is shown below that such an analysis leads to interpretation of the effects observed different from that made by the authors of [1-4] .

The experimental procedure and the basic data obtained are briefly discussed below. Two independent narrow-angle electrostatic analyzers A (450 to 4300 eV) and B (280 to 2850 eV) with channel electron multipliers (channeltrons) at their outputs were used as sensors to measure ion spectra in the range from hundreds ev to some kev [2,4] . Ion accelerating voltage U_a of about - 3,6 kev was fed to the channeltrons input [5] . The efficiency of ion counting by the channeltrons operating in counting mode decreased during the flight due to the degradation effect. Both sensors operated in a nonsaturated regime, when the satellite was in the Martian orbit [1,3,4] .

Inside the region of solar wind interaction with the planet, ion spectra obtained with A and B sensors often differed both in shape and signal magnitude. Fig. 1a shows an example of an energy-spectra sequence obtained on February 20, 1974 in this region, at about 6000 km from Sun-Mars line in the antisolar part of the near martian space [1,2,4] . Points on the curves of Fig. 1a show the dependence of the counting rate C_A of A-sensor on the energy E of ions recorded, crosses that of the counting rate C_B of B-sensor (the charge number of ions is taken equal to 1 here and on). To explain the difference observed in the spectra recorded by A and B sensors in the region of solar wind interaction with Mars (Fig. 1a) the authors [1-4] suggested that during the flight the mode of operation of the channeltrons of the A and B sensors, could change in the following way: the B-sensor CEM entered the mode where its efficiency to heavy ions became small relative to its efficiency to light (hydrogen, gelium) ions; the efficiency to light and heavy ions of the A-sensor channeltron remained almost the same. In this case the difference of spectra can be explained by the variation of the ion composition of the surrounding plasma. The upper plot in Fig. 1b shows the estimate of the ratio of heavy N_H to light N_L ion fluxes from [1,3,4] for the spectra given in Fig. 1a. The plot shows that according to those estimates the N_H/N_L ratio reduced at least by about a factor of 200 to 400 during the period of time from 01^h26^m to 01^h48^m.

According to [1-4] laboratory measurements carried out

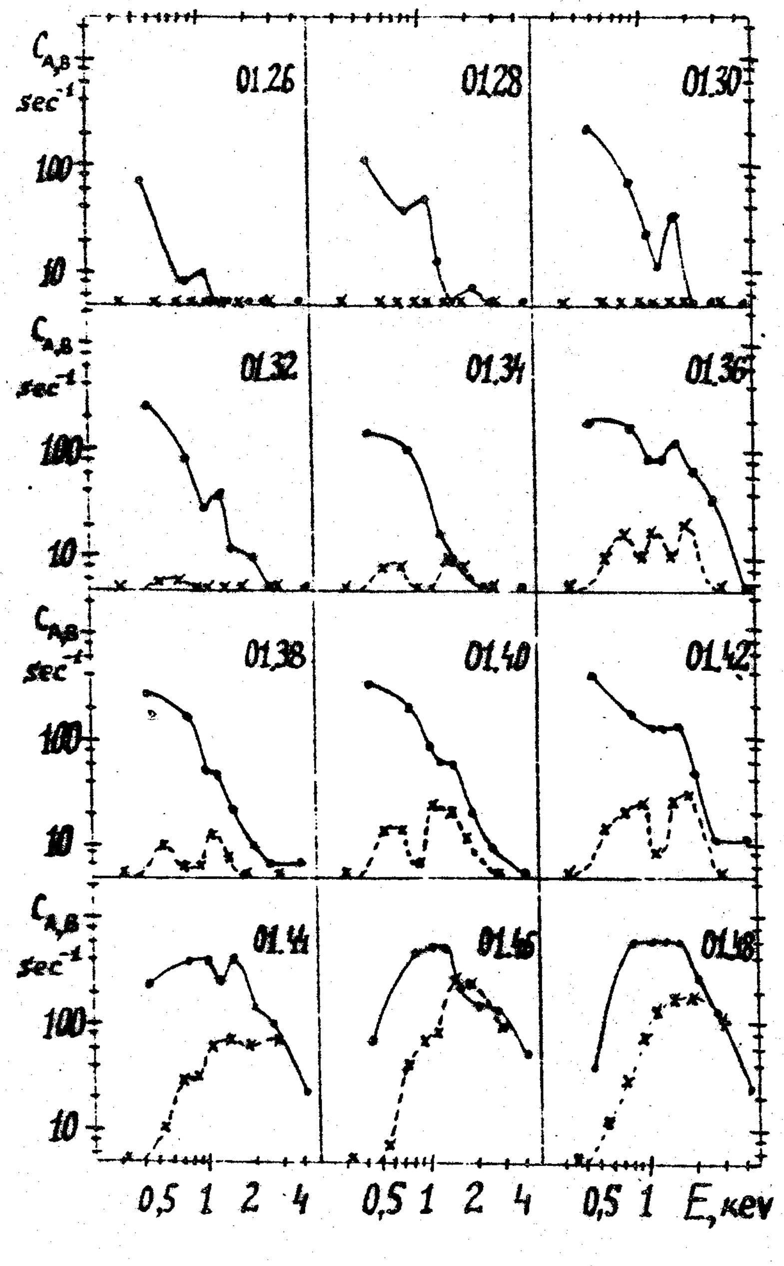

Fig. 1a

The sequence of energy spectra of ions observed on February, 20, 1974 in the region of solar wind interaction with Mars [1,4]. Points show A-analyzer readings, crosses those of B-analyzer.

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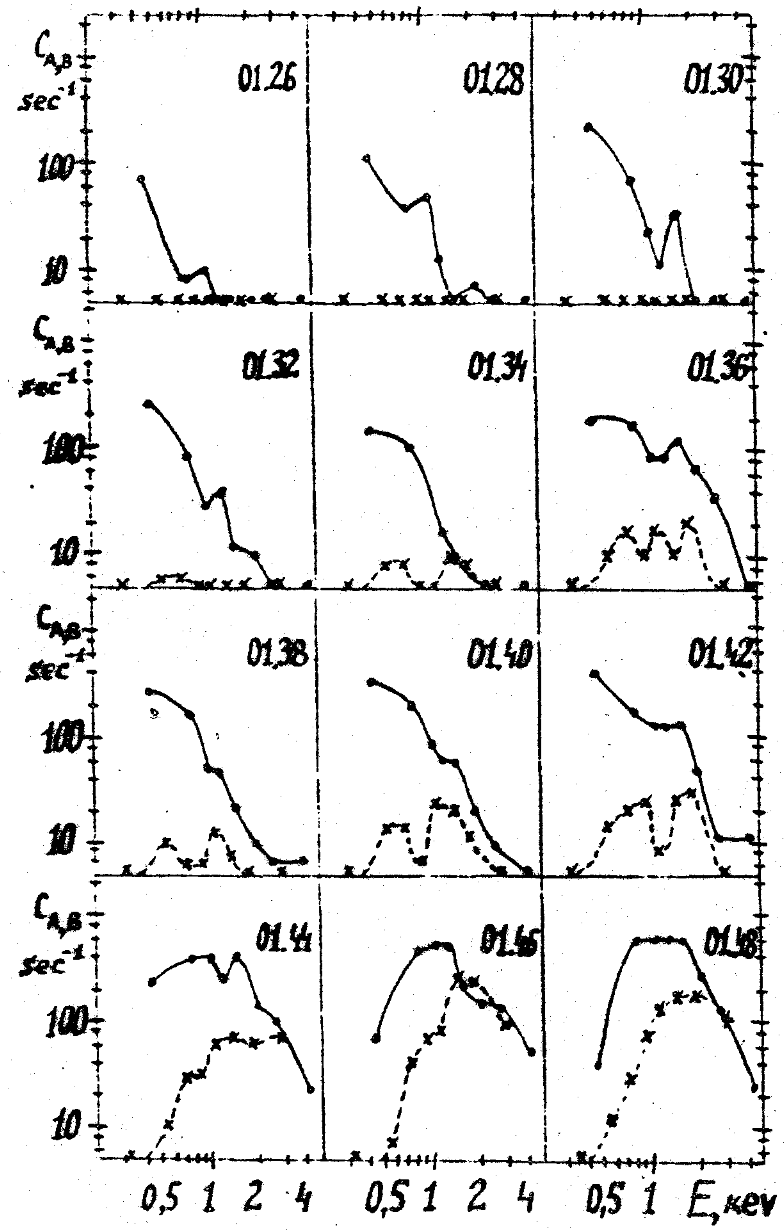

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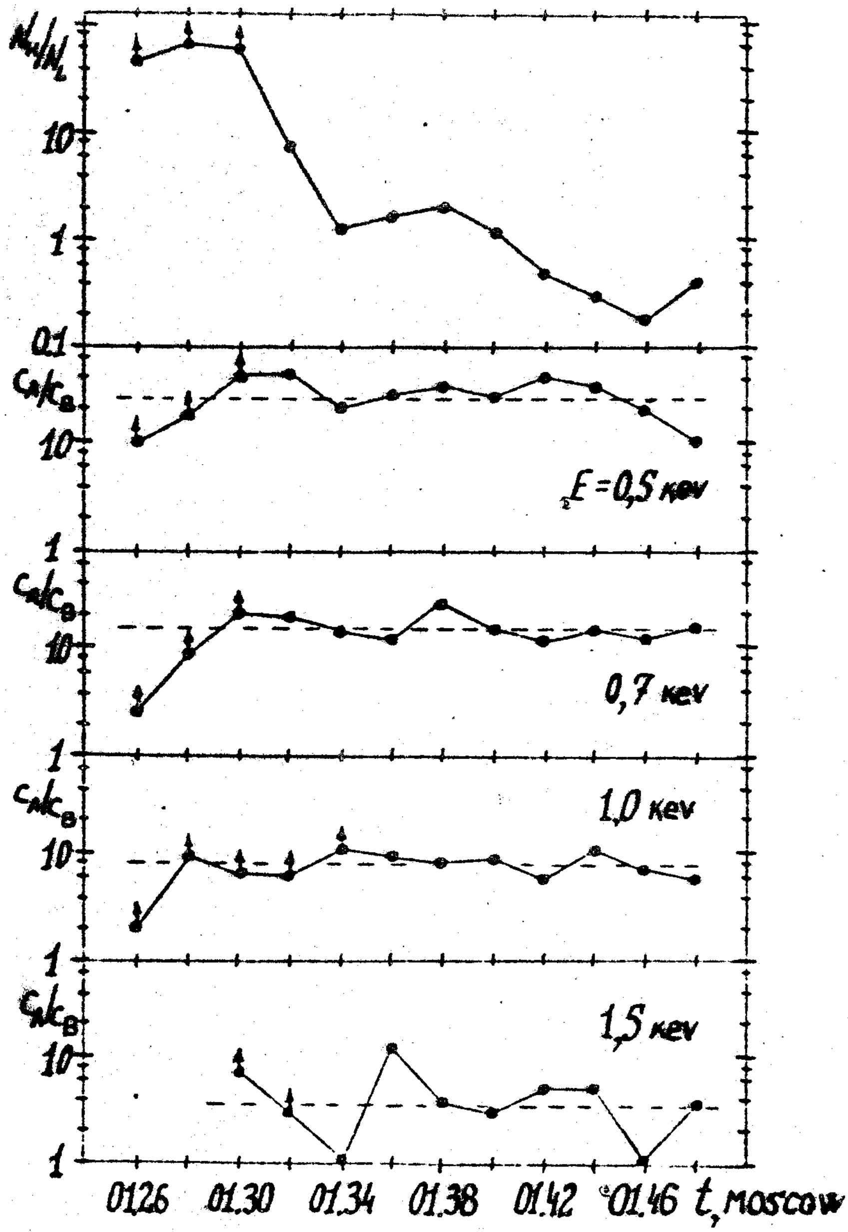

Fig. 1b

Estimate of ratio of heavy ion flux to that of light ions N_H/N_L according to [1,3,4] and ratio of counting rates of C_A/C_B of A- and B-analyzers based on Fig.1a data.

after the flight, and therefore with another channel electron multipliers, showed that in fact the modes of sensor operation described above can be realized. However it is possible to check, using the published on-board RIEP data, had the channeltron operate in the mode assumed in [1-4] in the Martian neighborhood or it had not.

Indeed, if the efficiency to heavy ions of the B-sensor channeltron is low in comparison with that to light ions and if considerable change of the ion composition (heavy ions are substituted with light ions) occur in the time interval from 01^h26^m to 01^h48^m (see Fig.1), then in this interval the ratio C_A/C_B of sensors counting rates at the same energies must decrease. The time dependence of C_A/C_B ratio is plotted in Fig.1b based on the data given in Fig.1a, if counting rates C_A and C_B for any energy E, can be obtained using smooth curves on Fig.1a, for four energies E=0.5; 0.7; 1.0; 1.5 kev. An average C_A/C_B value for each energy E is shown by dotted lines in the Figure. As seen from Fig.1b the C_A/C_B ratio counting rates practically does not change during the time interval from 01^h26^m to 01^h48^m for all chosen values of E. Therefore either plasma ion composition did not changed during this time contrary to the conclusion made in the papers [1-4] and to the estimations of the ratio of heavy and light ion fluxes (the upper plot in Fig.1b), or sensors did not operate as the authors assumed [1-4] . In the latter case the experimental data do not permit any conclusions about the change in plasma ion composition. Thus the conclusion based on the Mars-5 RIEP data that heavy ion fluxes can be detected in the region of solar wind interaction with Mars seems to be unreliable.

At the same time the difference of ion energy spectra observed during the experiment [1-4] in the region of solar wind interaction with Mars can be easily explained by the dependence of relative efficiency of channeltron A and B on ion energy E. As it is seen from Fig.1b the average value of C_A/C_B ratio is decreased with E increased. Using this data the E-dependence of the value reciprocal to C_A/C_B average value is plotted in Fig.2. This dependence can be interpreted as an approximate dependence of B-sensor channeltron efficiency $f_B(E)$ relative to A-sensor channeltron efficiency $f_A(E)$ on ion energy E during channeltron operation in near martian orbit. The decrease of difference of ion energy spectra recorded by A and B sensors from 01^h26^m to 01^h48^m (see Fig.1a) will actually correspond to the dependence $f_B(E)$ / $f_A(E)$ given in Fig.2 as during this time the average ion energy in the plasma around the satellite has increased (see sensor A readings in Fig.1a) and the maximum of their distribution function shifts to the energy range where A and B sensor efficiencies approach each other (Fig.2). Expected energy value $E+eU_a$ ion has at the channeltron input is plotted on the additional axis in Fig.2. It is unlikely that dependence of relative efficiency two channeltrons on $E+eU_a$ in energy range 4 ÷ 5 kev is steep [6,7] . However it should be noted that, first, data given in literature characterize channeltron operation in the saturation mode since the nonsaturated mode is not usually used for pulse recording and, second, f_B/f_A dependence on E is plotted for given instruments under given operating conditions on board the satellite according to the data from the near-martian orbit and hence it is reliable.

The technique of analysis of measurement results that consists in studying character of A and B sensor counting rate

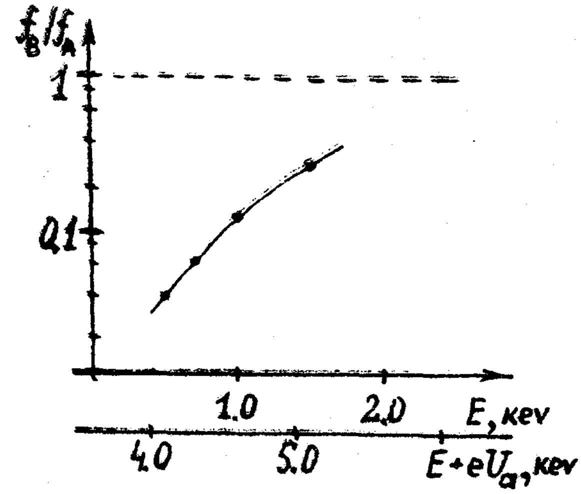

Fig. 2

Dependence of relative efficiency $f_B(E)/f_A(E)$ of A and B sensors on ion energy E.

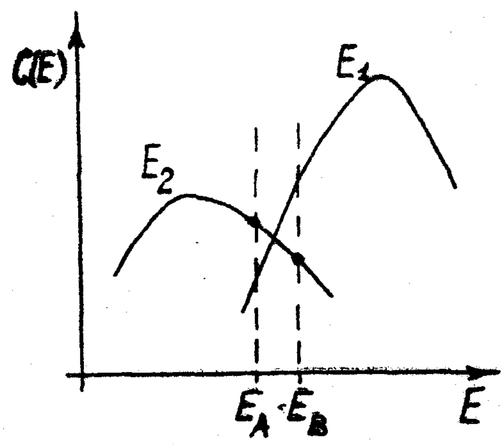

Fig. 4

Decrease of ratio of analyzer counting rates $C(E_B)/C(E_A)$ with the decrease of energy of directional motion of ions $E_2 < E_1$.

ratio at the same ion energy is evident and slightly differs from the procedure previously used [4] . However the conclusions [4] that the average ratio of A, B sensors counting rates depends on the satellite position in the region of Mars interaction with the solar wind and that the difference of spectra recorded by A, B sensors is not due to the changes in the characteristics of channeltrons used when particle energy changes (see Fig.2), contradict the conclusions made above. The reasons for different conclusions are dicussed below in more details.

In contrast to the analysis given above, in [4] C_A and C_B were compared only for ion energy ~1 kev which does not yield any conclusion about energy dependences of channeltrons characteristics; the comparison was made not for A, B sensor counting rates reduced to one energy value but for counting rate, C'_A , of A sensor tuned to $E_A \approx 1.07$ kev and counting rate C'_B of B sensor tuned to $E_B \approx 1.09$ kev [4] . The dependence of C'_B on C'_A according to RIEP data taken near Mars on February, 20, 1974 is given in Fig.3 [4] . As it is seen from the Figure, the average value of sensor counting rate ratio in the solar wind $(C'_A / C'_B)_1 \approx 1.9$; in the region of solar wind interaction with Mars (the transition region behind the schock front and the regions closer to the planet) this ratio increases to $(C'_A / C'_B)_2 \approx 3 \div 10$ (the points are in the range $1.5 \leq (C'_A/C'_B)_2 \leq 20$) i.e. 1,5 to 5 times for most experimental points. However the mentioned increase of C'_A / C'_B cannot be directly interpreted as the increase in the considered region of sensors counting rate ratio with the same energy. It is such a variation of C'_A / C'_B ratio of sensors tuned to different energies ($\delta E = E_B - E_A > 0$) which should be expected near the planet, since the energy of the directional motion of ions is descreased. Fig.4 qualitati-

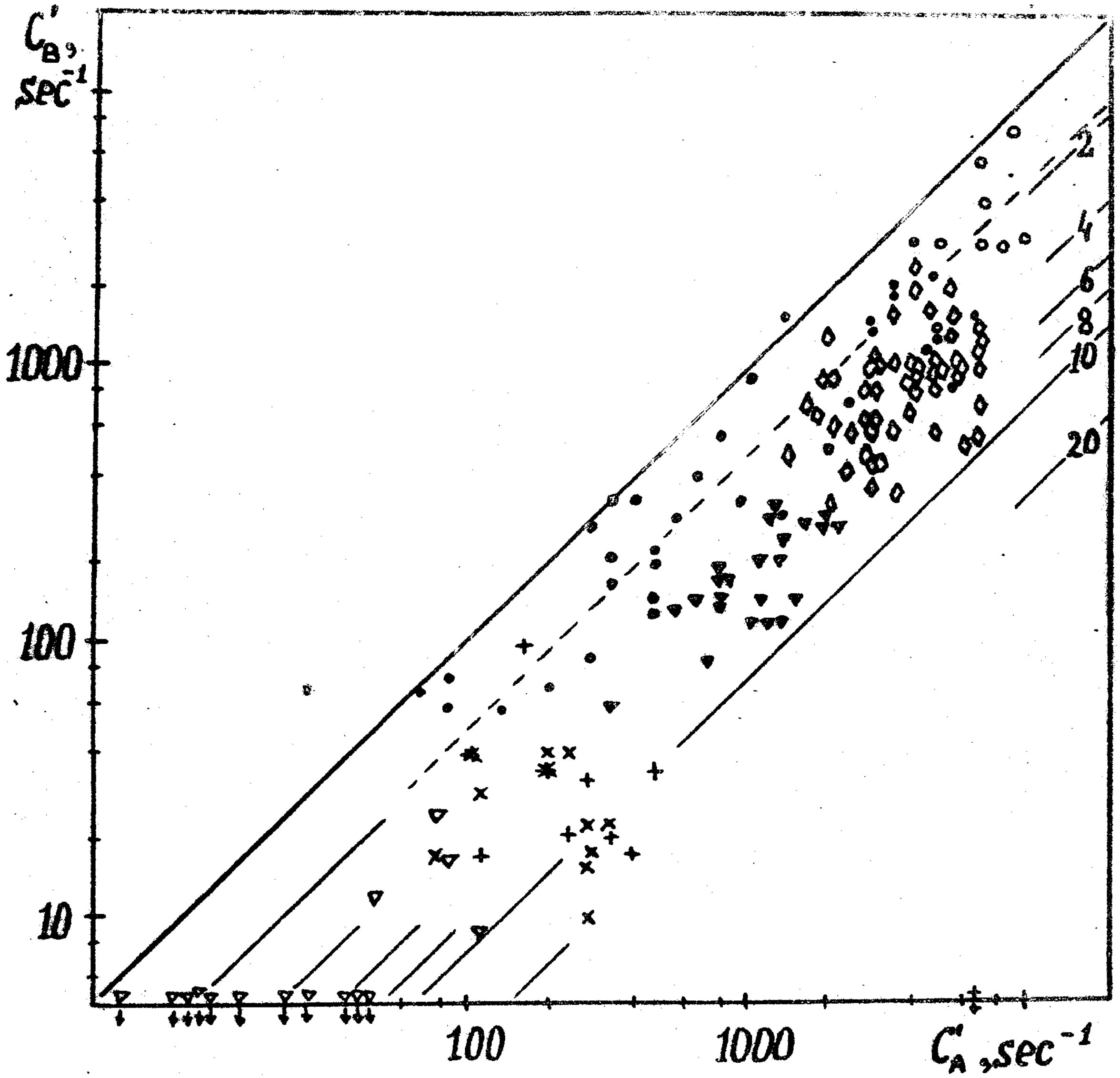

Fig. 3

Dependence of counting rate of C'_B of B-sensor tuned to energy E_B on counting rate of C'_A of A-sensor tuned to energy E_A close to E_B; $E_B < E_A$ [4] . Points and circles are the counting rates of sensors in the solar wind, other marks are the sensors counting rates in the region of solar wind interaction with Mars. A dotted line is the average value of C'_A/C'_B ratio in the solar wind [4] .

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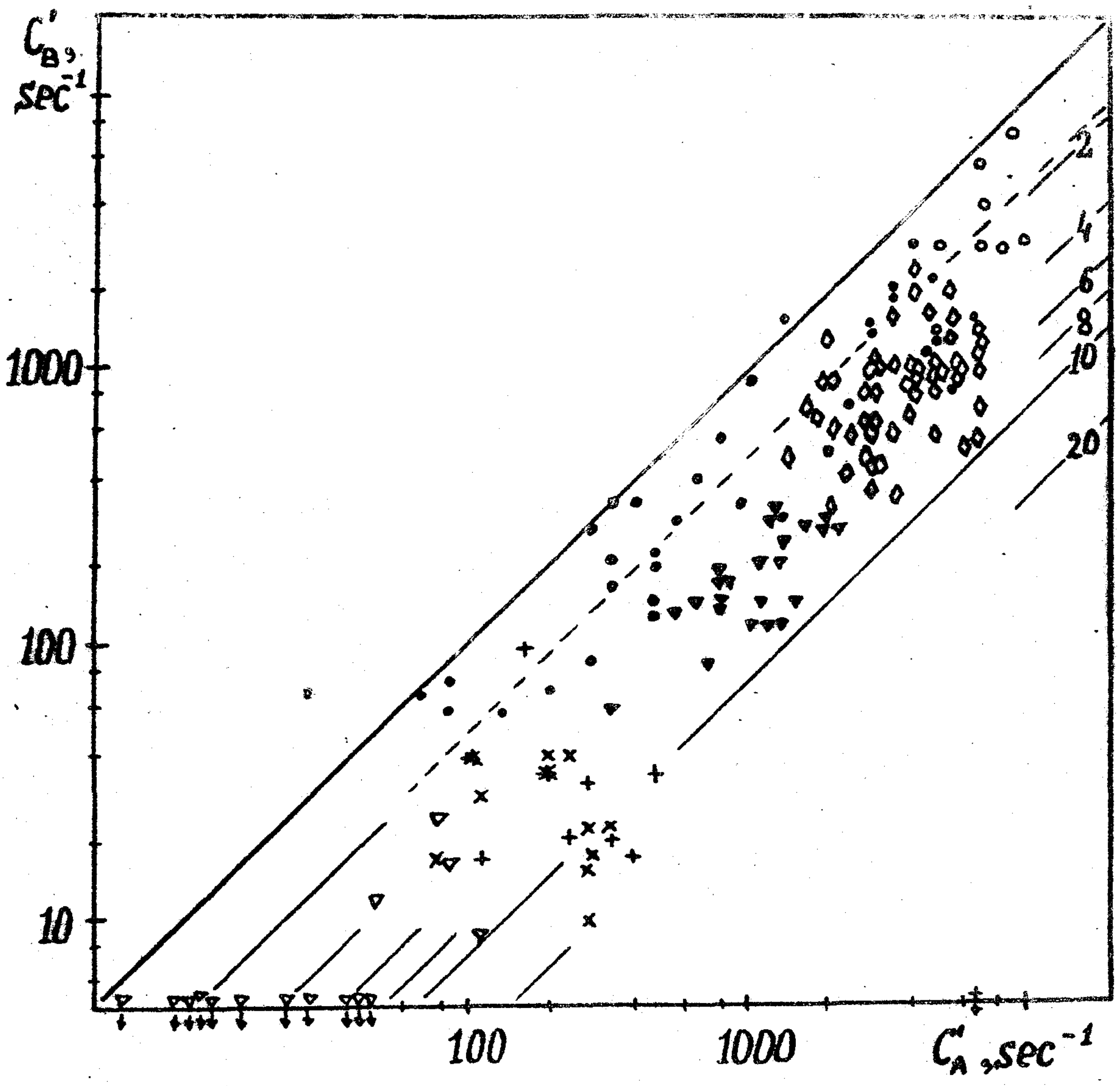

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vely illustrates energy dependence of counting rate C(E) of the sensor with efficiency equal to 1 for two values of the energy of the directional motion of ions $E_2 < E_1$ (solid lines). The increase of ratio $C'_A/C'_B = (f_A(E_A)/f_B(E_B)) \cdot (C(E_A)/C(E_B))$ with the decrease of the energy of the directional motion of ions is evident from this Figure. The value of this effect will be estimated below.

Counting rate ratio $(C'_A/C'_B)_1$ in the solar wind with temperature of ions T_1 and energy of their directional motion E_1 can be written as:

$$(C'_A/C'_B)_1 = f_A(E_A)/f_B(E_B) \cdot (E_A/E_B)^2 \cdot EXP(((\sqrt{E_A}-\sqrt{E_1})^2-(\sqrt{E_B}-\sqrt{E_1})^2)/T_1). \quad (1)$$

Expression (1) is written provided that a vector of ion directional velocity is perpendicular to the sensor aperture. Neglecting the change of efficiency of sensors in the energy range δE and assuming that $\delta E \ll E = (E_A+E_B)/2 \approx 1.08$ kev we obtain from (1)

$$(C'_A/C'_B)_1 = f_A(E)/f_B(E) \cdot (1-2\delta E/E) \cdot EXP(\delta E(1-\sqrt{E_1/E})/T_1). \quad (2)$$

With (2) and similar expression for ratio $(C'_A/C'_B)_2$ in the region of solar wind interaction with Mars where the appropriate parameters of ions are T_2 and E_2 we obtain that C'_A/C'_B increases by

$$(C'_A/C'_B)_2/(C'_A/C'_B)_1 = EXP(\delta E \cdot ((\sqrt{E_1/E}-1)/T_1+(1-\sqrt{E_2/E})/T_2)) \quad (3)$$

as the satellite enters the region discussed.

In Fig.5 horizontal hatching in the plane E, T shows the region of E_1, T_1 values, oblique hatching shows the region of E_2, T_2 values observed on February 19, 20, 1974 in the solar wind and in the region of its interaction with Mars, respectively. The regions are hached according to the estimates of E, T parameters from the RIEP data (see Fig.1 in [2]). Further $T_1 \approx 7$ ev and $E_1 \approx 1300$ ev will be used; these values are shown by

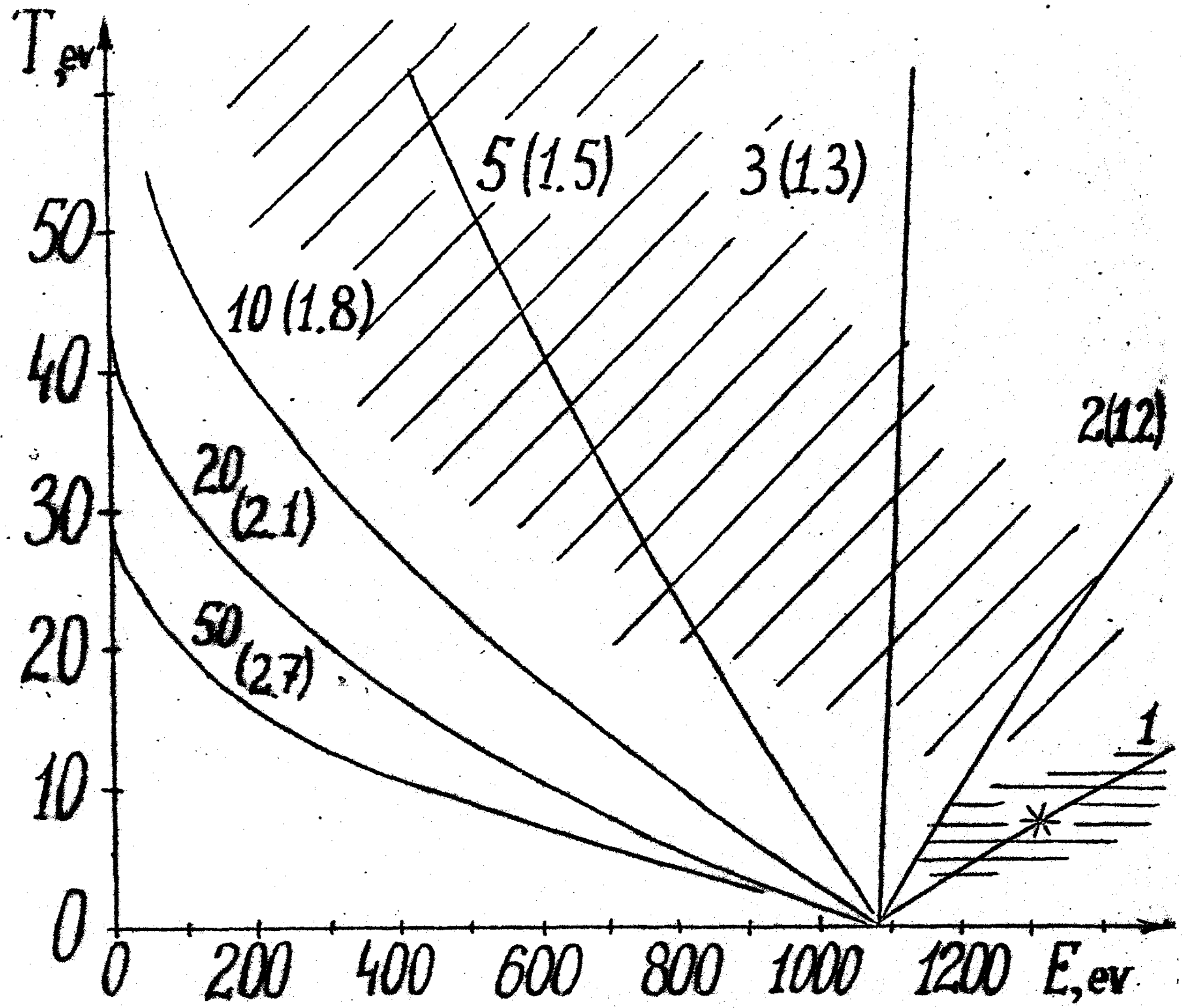

Fig. 5

The regions of values of ion directional motion energy E and ion temperature T observed on February 19 ÷ 20, 1974 in the solar wind (horizontal hatching) and in the range of its interaction with Mars (oblique hatching) according to the estimates [2] . Solid curves are the lines of constant value of counting rates ratio C'_A / C'_B .

an asterisk in Fig.5. Low value δE in Eq.(3) is difference of two large values of energies E_B and E_A and hence δE value realizing in experiment can differ from $\delta E \approx 20$ ev obtained by subtraction of values E_B and E_A given in [4] . Value δE during the experiment can be estimated from relation (2) substituting there the average value of $(C'_A/C'_B)_1$ in the solar wind and the appoximate value of channeltrons relative efficiency $f_B(E) / f_A(E) \approx 0.14$ with $E \approx 1.08$ kev (Fig.2). In this case it follows from (2) that $\delta E \approx 80$ ev.

Solid curves in Fig.5 correspond to the constant values of ratio (3) with the change of parameters E_2 and T_2. Figures without parantheses show the value of ratio (3) for the given curve with $\delta E \approx 80$ ev, as well as figures in parantheses - with $\delta E \approx 20$ ev. As seen from the figure increase of C'_A/ C'_B by about 1.5 to 5 times observed on February, 20, 1974 in the region of solar wind interaction with Mars corresponds to that of this ratio estimated from (3) with $\delta E \approx 80$ ev.

Let us show that $\delta E \approx 80$ ev value estimated above can not be regarded as impossible for the Mars-5 RIEP experiment. Indeed, ion energy to which the electrostatic analyzer A is tuned when voltage U is supplied to its deflector plates is determined from the following equation $E_A = \mu U$ where $\mu = (2 \cdot \ln(R_2/R_1))^{-1}$, $R_1 = 39$ mm and $R_2 = 41$ mm are the curvature radii of the internal and external analyzer plates. The adjustment accuracy of R_1 and R_2 was $\delta R \approx \pm 0.03$ mm [5] hence, the accuracy of $\delta\mu$ did not exceed $\delta\mu/\mu = \sqrt{2} \cdot \delta R(R_2 - R_1) \approx 2\%$. Assuming as an estimation the accuracy of voltage measurement on the deflector plates, when calibrated, equal to $\delta U/U \approx 1\%$, we have $\delta E_A/E_A \approx 3\%$, i.e. the accuracy to which the energy recorded by analyzer A is known is $\delta E_A \approx \pm 30$ ev. Since

$\delta E_B \approx \delta E_A$, then the possibility that A and B analyzers were tuned to energies differing to $\delta E \approx 80$ ev is not contrary to E_A and E_B values given in [4] .

Thus, self-consistent explanation can be given to all the typical features of the experimental data obtained by means of Mars-5 RIEP in the region of solar wind interaction with Mars if in this region there are ions of only one mass with the directional velocity lower than in the solar wind and the hypothesis on the existence of heavy ion fluxes is not required for their explanation. Direct experimental data confirming the presence of ions with heavier mass than that of solar wind ions in the region dicussed are not available at present.

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