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MEASUREMENTS OF ELECTRON AND ION PLASMA COMPONENTS ALONG THE MARS 5 SATELLITE ORBIT

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On the spacecraft Mars 5 charged particle traps were installed for measurements of the characteristics of ions with energies $\lesssim 4.1$ keV and electrons $\lesssim 300$ eV. The measurements made have shown that during each revolution around the planet the satellite intersected three zones (undisturbed solar wind, transition region behind the bow shock, and a zone with quasi-isotropic and comparatively cold plasma in the antisolar part of the near-Martian space). The results of simultaneous magnetic measurements have shown that the bow shock positions from the magnetic and plasma data coincide and the boundaries of the quasi-isotropic plasma zone coincide with the boundaries of the Martian magnetosphere created by the intrinsic magnetic field of the planet. The zone of the quasi-isotropic plasma at the antisolar part of the near-Martian space shows some similarity with the plasma sheet in the earth's magnetospheric tail. Variations of the solar wind ram pressure defined from measurements of the solar wind ion component correlate well with changes of the near-Martian bow shock position.

The spacecraft Mars 5 became a satellite of Mars on 13 February 1974. Fig. 1 gives the near planet portions of the Mars 5 orbit on 13 February and 24 February in coordinates X, $(Y^2 + Z^2)^{1/2}$ (the X-axis passes through the planetary centre and is directed towards the sun). Among the scientific instruments installed aboard the spacecraft there were charged particle traps for measurements of the differential energy spectra of ions from 0 to 4.1 keV (acceptance angle $\pm 45°$) and the integral spectra of electrons (retardation curves) from 0 to 300 V (acceptance angle $\pm 40°$).

A detailed description of the devices, their performance, their location on the spacecraft, techniques of processing the data obtained and measurements made are given in [1]; some results are given in [2, 3]. More detailed results on the electron and ion plasma component measurements in the vicinity of the planet for the period from 13 to 26 February are given here.

Fig. 2 gives ion spectra obtained from near-planet satellite passes during which plasma measurements were carried out. Each ion spectrum was measured for ~ 50 sec; the time interval between spectra is 10 min. Near the planet three zones with different plasma properties are observed. Far from Mars the ion spectra are typical for the solar wind undisturbed by the planet (see, for example, spectra 5—9 on 13 February or 1—6 on 21 February). After the satellite crosses the near Martian bow shock front and enters the transition region, the ion spectra are considerably broadened; maximum ion fluxes are registered with lower

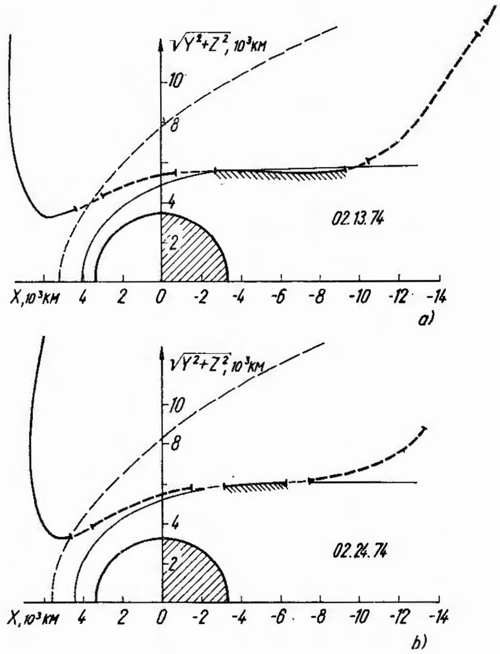

Fig. 1. Mars 5 satellite orbit: a, 13 February 1974; b, 24 February 1974.

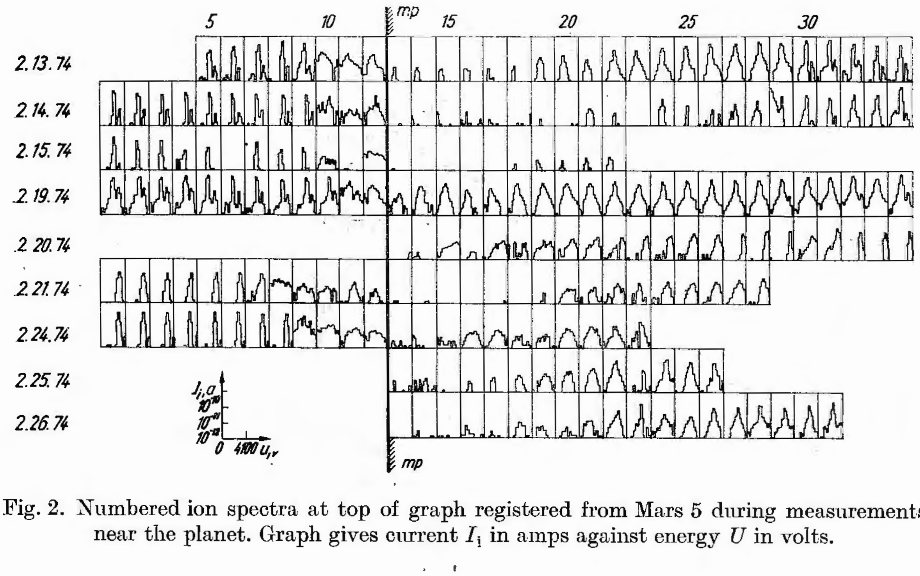

Fig. 2. Numbered ion spectra at top of graph registered from Mars 5 during measurements near the planet. Graph gives current I_i in amps against energy U in volts.

energies (for example, 10—12 spectra on 13 February and 7—12 on 21 February in Fig. 2). This corresponds to a decrease of the ion bulk velocity and thermalization of the ions in the transition region.

After the transition zone a sharp drop of ion fluxes is observed. The decrease of ion currents is so large that in approximately 30% of the measurements carried out in this region ion fluxes are lower than the instrumental sensitivity threshold (empty squares in Fig. 2) and in only 40% of cases are ions registered reliably. Ion energies in this zone are much more variable (but, as a rule, lower) than in the solar wind (for example spectra 18 on 14 February and spectra 13 on 20 February in Fig. 2).

Further along the orbit the satellite again enters the transition layer (for example, spectra 19—30 on 13 February and 20—28 on 21 February) and then leaves for the undisturbed solar wind. Bold lines in Fig. 1 show the portions of the trajectory when Mars 5 was in the solar wind, and dashed bold lines in the transition zone; the region with the least ion fluxes are shown by the line with hatching.

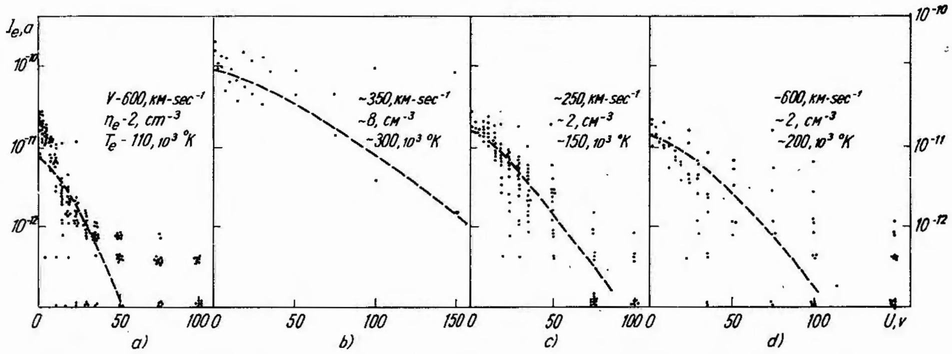

Fig. 3. Electron spectra observed on 21 February 1974 in the regions with different plasma properties: a, in the solar wind; b, in the transition region; c, in the region with least ion fluxes; d, in the transition region. Current I_e in amps against energy U in volts.

The characteristics of the electron plasma component are also different in the regions considered. Fig. 3 gives the measurements on 21 February in the solar wind (Fig. 3a), in the transition zone (with the Sun-Mars-vehicle angles $\varphi \sim 40$ to 90° (Fig. 3b)), in the region with the least ion fluxes (Fig. 3c) and in the transition region (with $\varphi \gtrsim 130°$, Fig. 3d). To give an idea of the characteristic types of electron retardation curves, several separate spectra for each region were placed in one graph. The dashed line shows the curves that have been calculated under the assumption of a Maxwellian electron velocity distribution, with the bulk velocity V, density n_e and temperature T_e, presented in the figure. One can see that, in the transition region (Fig. 3b), the electron fluxes, their temperature and density are increased compared with their values in the solar wind. Fig. 3c corresponds to the region with the least ion fluxes. Here the ion fluxes, T_e and n_e are much less than those in the transition zone, but in contrast to the ions, the electron fluxes are close to (or slightly higher than) the electron fluxes in the solar wind, and are always recorded.

Fig. 4 gives the results of simultaneous measurements of ion components on 13 February (continuous series of spectra) and the magnetic field B_x component taken from [4]. When the spacecraft enters the transition region at 1627 UT the typical change of ion spectra, and the increase of the magnitude of the X-component of the magnetic field and an increase of its fluctuations, are observed. Simultaneously with the sharp decrease of ion fluxes at 1657 UT the magnetic field changes sign and, up to 1757 UT, it remains constant in sign and fluctuates less than in the transition region. At 1757 UT the ion fluxes increase again simultaneously with the magnetic field fluctuation increase (i.e. the satellite enters the transition region). For comparison, the lowest part of the figure gives ion spectra obtained simultaneously in 50 sec from Mars 7 which was on its way to Mars on 13 February at a distance of $\sim 5 \times 10^6$ km from the planet. These

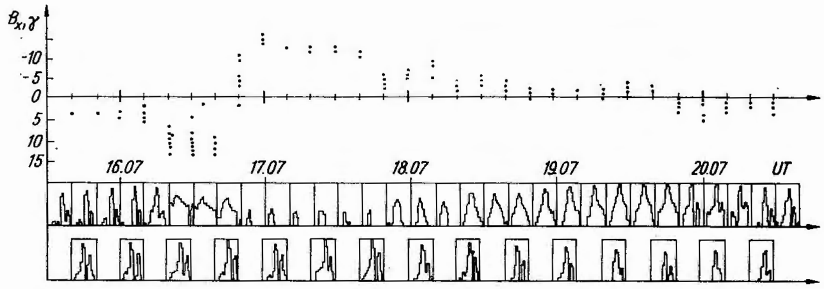

Fig. 4. Comparison of simultaneous data of plasma and magnetic field measurements on 13 February 1974 near Mars.

spectra, as well as ion spectra obtained from this spacecraft earlier or later than the time interval given in Fig. 4, have no typical peculiarities, being similar to those observed in the plasma in the vicinity of the planet.

This region is considered [4] to be the tail of the Martian magnetosphere formed by the interaction of the solar wind with the intrinsic magnetic field of Mars.

We regard the Martian magnetopause as the boundary of the "obstacle" which creates the bow shock. Due to peculiarities of the Mars 5 orbit during a number of its passes near the planet, crossings of the obstacle surface at the antisolar part of the near-Martian space (see Fig. 1) were registered twice during each pass. Using more or less reasonable suppositions one can show that the shape of the Martian magnetopause shown in Fig. 1 can be described by means of the results of gas dynamic calculations [5] corresponding to a parameter $H/r_0 = 0.1$ where H is the height of the shock above the obstacle, of radius r_0 at the subsolar point. H/r_0 for the earth's magnetopause is ~ 0.2. The H_0 values in Fig. 1a is ~ 800 km, and in Fig. 1b ~ 1100 km. From all crossings of the bow shock by Mars 2, Mars 3 and Mars 5 the mean altitude of the obstacle at the sub solarpoint h_0 was evaluated (using $H/r_0 = 0.1$) as 1600 ± 900 km. Comparison of variations of the h_0 values, determined using [5], for different passes of the satellite with variations of solar wind ram pressure (ϱV^2) showed that h_0 decreases when ϱV^2 increaes. For instance on 13 February $\varrho V^2 \sim 3.1$ dyn cm^{-3}, $h_0 \sim 800$ km; on 24 February $\varrho V^2 \sim 1.6$ dyn cm^{-3}, $h_0 \sim 1100$ km.

Simultaneous data on electron and ion characteristics in the antisolar part (tail) of the Martian magnetosphere have been obtained for the first time. When the decrease of ion current occurs the electron trap currents practically do not change, i.e. the plasma density is almost unchanged. Either the ion flux changes its direction rather considerably, since the ion trap acceptance angle is large, or the ion flux becomes quasi-isotropic. The probability of the mean ion energy increasing to values beyond the energy range of the instrument (4.1 keV) is low since the ion spectra in the Martian magnetospheric tail show maximum readings in most cases in the energy interval $\sim 200-500$ eV. Let us note that at the times when there are no readings, the possibility of such an increase of energy cannot be excluded.

If one uses similarities to phenomena in the near earth space, one can suppose that this region can be considered either as a "plasma sheet" in the Martian magnetospheric tail similar to that existing in the central part of the earth's magnetotail [6, 7], or as a "boundary layer" between the transition region behind the bow shock and the Martian magnetosphere similar to that in the tail of the earth's magnetosphere [7, 8].

If it is a "boundary layer" then the direction of plasma motion in it should be mainly antisolar [7, 8]. To explain the observed decrease of currents it is necessary to admit either a considerable decrease of plasma density in the tail compared with that in the undisturbed solar wind (however, then it would be impossible to explain why the electron currents in the magnetospheric tail are even higher than those in the solar wind) or a considerable (by $\sim 30-40°$) turning of the plasma bulk velocity direction at the magnetopause. Since it is rather difficult to explain such a phenomenon it seems to us that this version is not very probable.

If the "plasma sheet" exists in the Martian magnetospheric tail, then small fluxes registered may be explained by the high level of ion isotropy in this zone, similar to that in the earth's magnetotail. In this case there is no contradiction between simultaneous registration of low and high electron currents. In the earth's magnetosphere the energies of plasma sheet isotropic ions (~ 6 keV [8]) exceed the ion energy in the undisturbed solar wind, but in the Martian magnetospheric tail the converse is true. This difference can be caused by the fact that the Martian magnetic field is relatively small and incapable of providing acceleration of the ions.

In [9, 10] it is noted that, at both the day and night sides of Mars, inside the transition zone, a zone with a decrease of plasma bulk velocity is revealed. This zone, according to [9, 10], is a "viscous boundary layer", caused by the dissipating envelope of Mars. Such a region is also observed in the earth's magnetosphere [7, 8, 11], where there is certainly no viscous interaction with dissipating gas.

The data presented in this paper confirm the conclusion made earlier [2, 3] about the magnetic origin of the obstacle creating the near-Martian bow shock. However, one must bear in mind that, in the absence of data on the magnetic field at low altitudes and at the planet's surface, crucial proof of the existence of an intrinsic magnetic field of Mars can only come from a study of simultaneous data on magnetic field variations in interplanetary space and near the planet (see [4]).

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