MAGNETIC FIELD AND PLASMA INSIDE AND OUTSIDE OF THE MARTIAN MAGNETOSPHERE

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INTRODUCTION

The Mars-2, -3, and -5 spacecraft measured the magnetic field and the low-energy plasma near Mars [1 through 18]. Two groups of experimenters carried out the plasma measurements, one of which used wide-angle plasma detectors, retarding potential electron analyzers, and modulated ion traps, that is, Faraday cups [5 through 12]; the other group used narrow-angle electrostatic analyzers [13 through 18]. A review of the data on the magnetic measurements was given by Dolginov et al. [19] while the data on the plasma measurements obtained by means of the wide-angle detectors was reviewed by Gringauz et al. [11] and Gringauz [20].

The present paper deals with the results of a joint consideration of the magnetic and plasma data measured with the wide-angle detectors. The authors of these experiments, even in their first publications, stated a similar point of view about the interpretation of the results obtained. They considered that the magnetosphere formed by the intrinsic magnetic field of Mars [19, 20] is an obstacle that creates the shock wave, detected during all the near-Mars magnetic and plasma measurements.

The possibility of an explanation of the experimental data obtained, from the viewpoint of the various hypotheses previously stated on the nonmagnetic nature of an obstacle producing the near-planetary shock wave (see Michel's review [21]), is discussed in [19] and [20]. It was shown that none of these hypotheses can explain the results of the magnetic and plasma measurements if the information about the Martian ionosphere obtained from the USSR and USA artificial planetary satellites [22, 23, 24] is taken into account. So, for example, the hypothesis that an ionospheric obstacle, limited at the ionopause where the solar-wind pressure is compensated by the ionospheric plasma pressure [25], is not applicable to Mars. This is because the external surface of such an obstacle, according to the Martian ionosphere data, should be much closer to the planetary surface than deduced from the shock-wave positions measured in many cases. Based on the data from different orbits of the Martian satellites, the range of the bow-shock subsolar-point altitude variations was within ~1R♂ [16, 20]. This is in spite of the fact that the properties of the Martian ionosphere observed during a long period of time were quite stable. In addition, the obstacle boundary directly measured during some orbits of the satellites was at altitudes of ~1000 km (for example, on February 8, 1972, see figure 1 [12]) and ~2000 km (on January 21, 1972 [4, 8]), whereas the Martian ionosphere has a much smaller height [22, 23, 24].

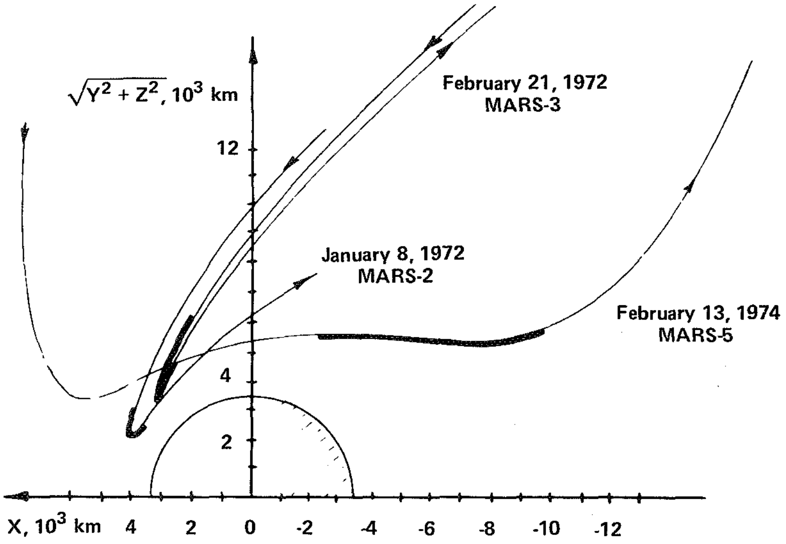


Figure 1. Examples of the near-planetary sections of the Mars-2 (January 8, 1972), -3 (February 21, 1972), and -5 (February 13, 1974) orbits. Blackened portions of the trajectories show the zones of the entry (exit) of these vehicles into (out of) the magnetosphere.

There are two significant arguments against the assumption of Cloutier and Daniell [26]. According to [26], the obstacle is a magnetosphere that is created by currents in the Martian ionosphere, induced by the magnetic field frozen-in to the solar-wind plasma.

The first argument is that the direction of the near-planetary magnetic field in the induced magnetosphere should depend on that of the interplanetary magnetic field. As it has been shown in [4] and [19], and as it will be seen from the present paper, such a dependence was not observed in the Martian magnetosphere.

Secondly, the analysis of the conductivity distribution in the Martian ionosphere and the appropriate calculations of currents induced in the ionosphere carried out by Cloutier and Daniell [26] and Cloutier [27] showed that the maximum height of the obstacle producing a shock wave does not exceed 350 to 425 km, with due allowance for the real characteristics of the Martian ionosphere. This result is not in agreement with the height of the obstacle obtained during some orbits.

At the same time, as it has been shown in [19] and [20], the totality of all the experimental data can be explained quite satisfactorily if Mars possesses an intrinsic magnetic field. At present, there is evidently no alternative for this explanation.

The authors who carried out the experiments using narrow-angle electrostatic analyzers [14 through 18] stated their opinion in some articles that the data they obtained are in good agreement with the hypothesis about the nonmagnetic nature of the obstacle forming the near-Martian shock wave [15, 17]. However, in the report by Vaisberg et al. presented to the 18*th* Session of COSPAR, meeting in Varna, Bulgaria, 1975 [18], this group uses the concept of the Martian intrinsic magnetosphere for interpretation of their results.

If their point of view has not changed, then at present there is agreement between three groups of experimentalists who performed the magnetic and plasma measurements near Mars on the main question: the existence of the Martian intrinsic magnetic field.

The present paper deals with a comprehensive comparison of the results obtained during the simultaneous magnetic and plasma measurements carried out by means of wide-angle plasma detectors in near-Mars space. These comparisons enable us to be certain of the validity of the criteria chosen for each of the given experiments in order to identify, in near-Mars space, regions with significantly different physical properties. They also give additional substantiations of these criteria.

RESULTS OF THE SIMULTANEOUS MEASUREMENTS OF THE PLASMA AND THE MAGNETIC FIELD IN THE NEAR-MARS SPACE

Figure 1 gives examples of the near-Mars orbital sections of Mars-2, -3, and -5 in the coordinate system: X, $\sqrt{Y^2 + Z^2}$, where the X-axis is directed toward the Sun and passes through the planetary center, and Z is perpendicular to ecliptic. Comprehensive information about the instrumentation used and a description of the techniques for the magnetic and plasma measurements were presented by Gringauz et al. [7, 8]. Note here that measurements of ions by the Faraday cup were not carried out onboard Mars-2 and -3 due to a failure of these instruments; Mars-5 yielded the most complete data set, which included the measurements of both ion and electron components. Therefore, these data will be compared first.

Figures 2, 3, and 4 show magnetograms for B_x, B_y, B_z, and spectra obtained by means of wide-angle plasma instruments onboard Mars-5. During approximately 50 s, one ion spectrum (covering 16 energy intervals), one electron retarding curve (over 16 points), and eight readings of each of the three components of the magnetic field were obtained. The readings of B_x, B_y, and B_z are plotted along the vertical axes corresponding to the initial moment of each ion spectrum. UT-time, height above the planetary surface, h, and areographic latitude of the satellite, φ, are plotted along the X-axis.

The increase of fluctuations and of the mean values of magnetic field, B, were used in [1 through 5] as the criteria of the satellite crossing the bow shock while in [9, 10, 11] it was a significant broadening of the ion spectrum (thermalization). In [1 through 5] the increase

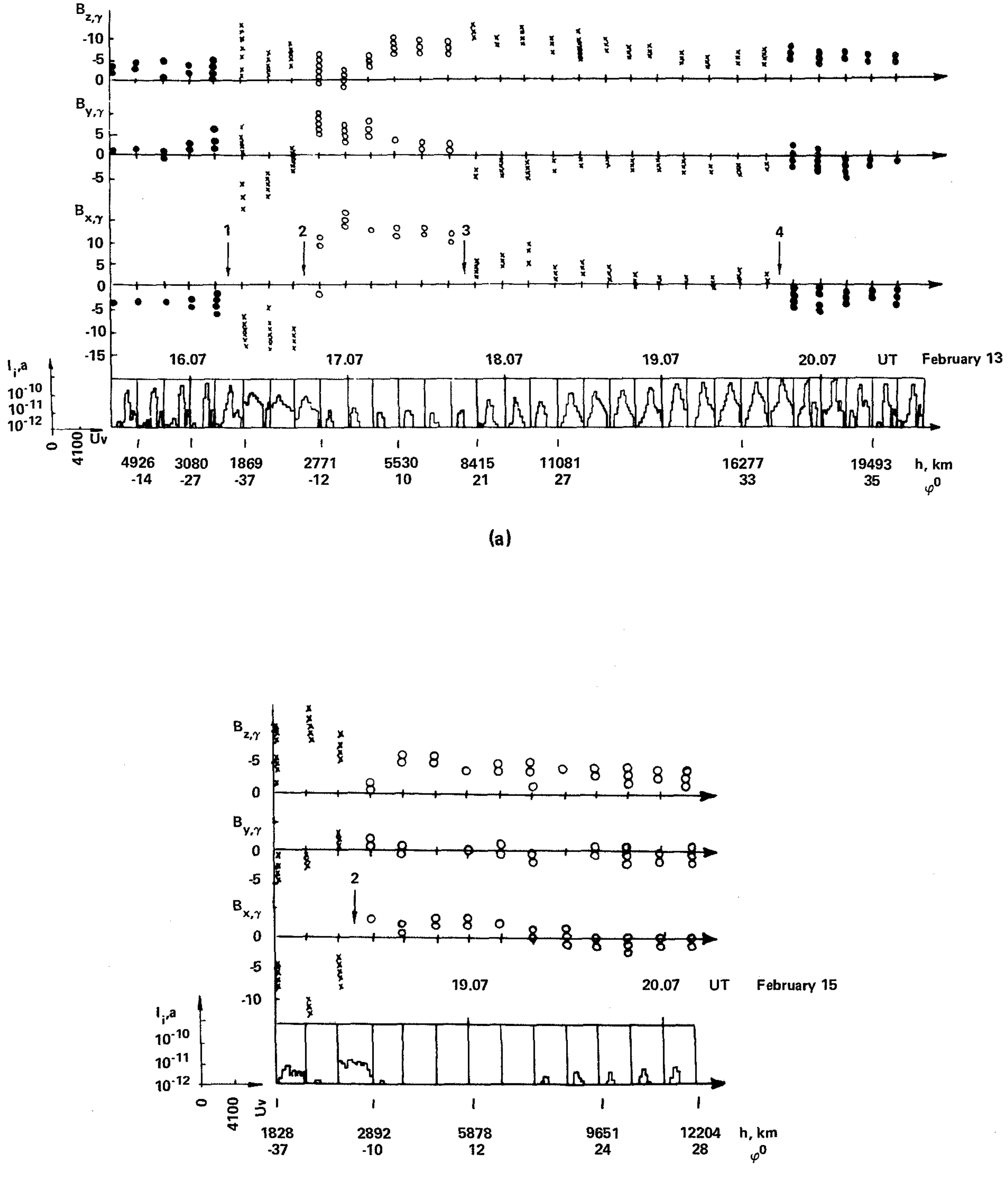


Figure 2. Magnetograms of B_x-, B_y-, and B_z-components of the magnetic field and ion spectra obtained by means of Faraday cup from Mars-5 on February 13, 1974 (a) and February 15, 1974 (b). The B_x-component in the solar wind is directed away from the Sun.

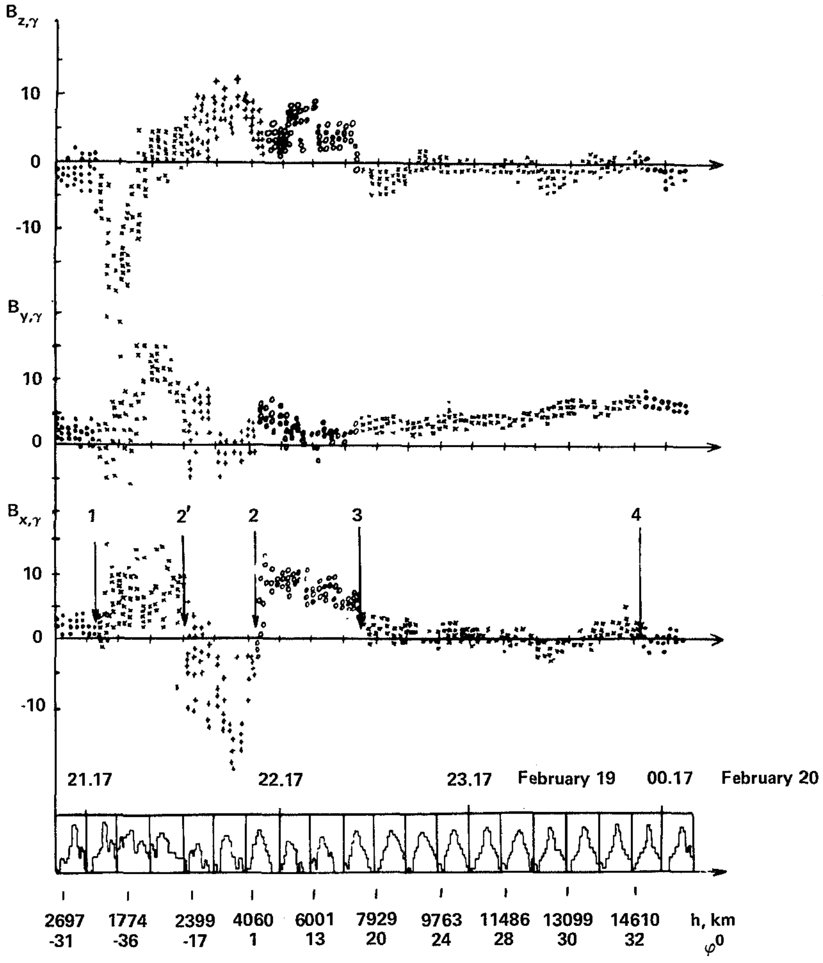
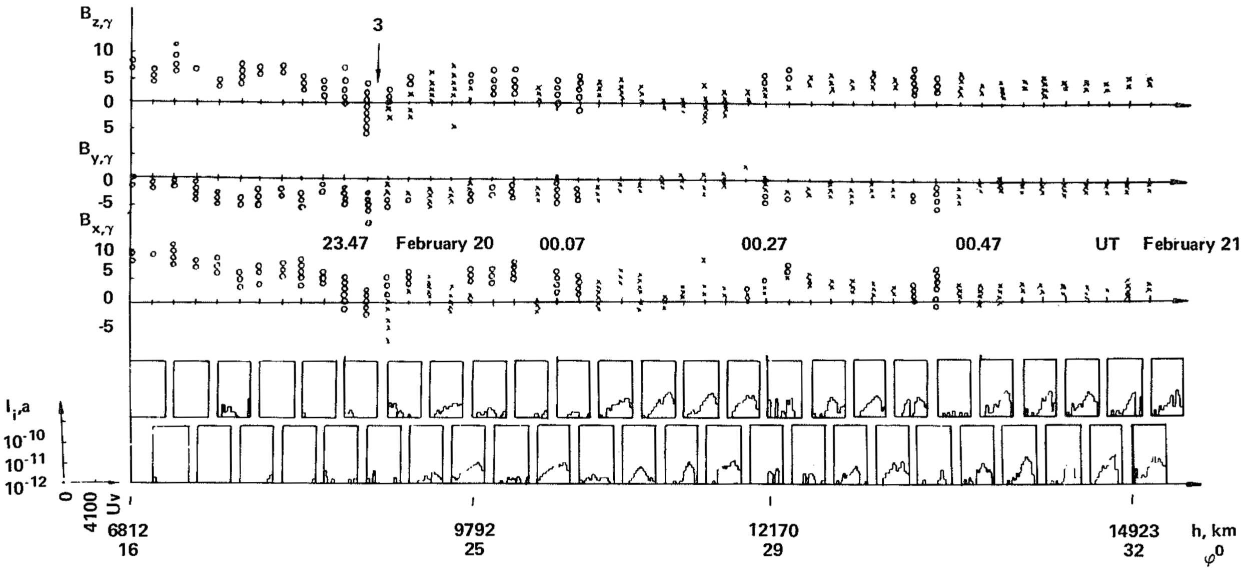


Figure 3(a). Magnetograms of B_x-, B_y-, and B_z-components of the magnetic field and ion spectra obtained by means of Faraday cup for flight on February 19-20, 1974. The B_x-component is directed toward the Sun.

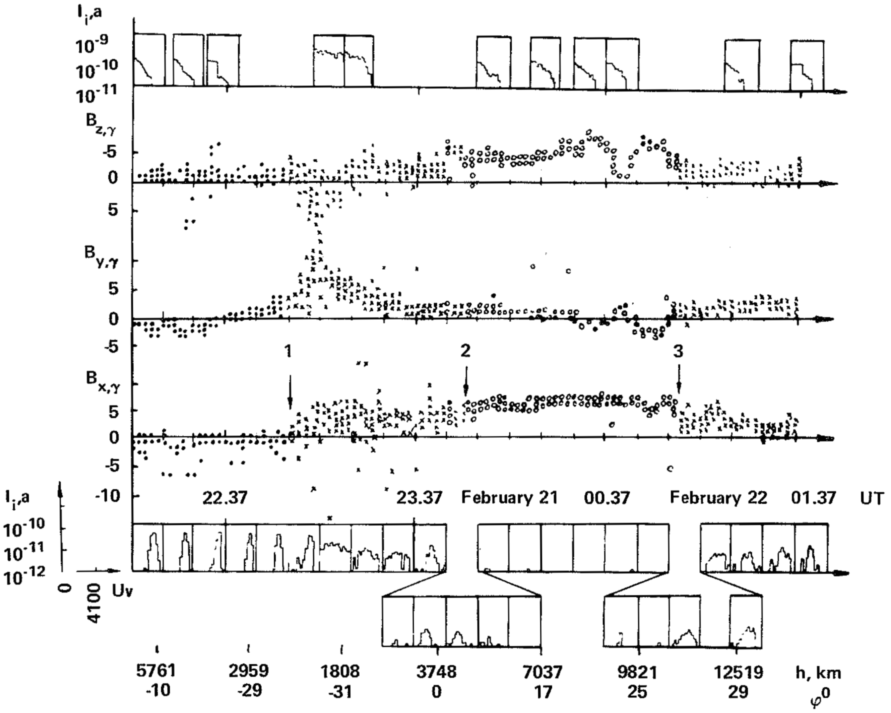
of B and the decrease of its fluctuations were considered to be the criteria of transit into the obstacle region itself (into the magnetosphere) while in [9, 10, 11] there was an appreciable diminution of the ion flux.

The identification of the characteristic regions in the near-Mars space in figures 2, 3, and 4 was carried out based on the joint analysis of the magnetic and plasma data and, in some cases, it differs slightly from those performed earlier in some publications.

For the subsequent discussion, let us divide the available data into two groups consistent with the various directions of the interplanetary magnetic field, defined using the sign of the B_x-component in the magnetosheath (where B_x has the same direction as in the solar wind for a relatively high mean value).

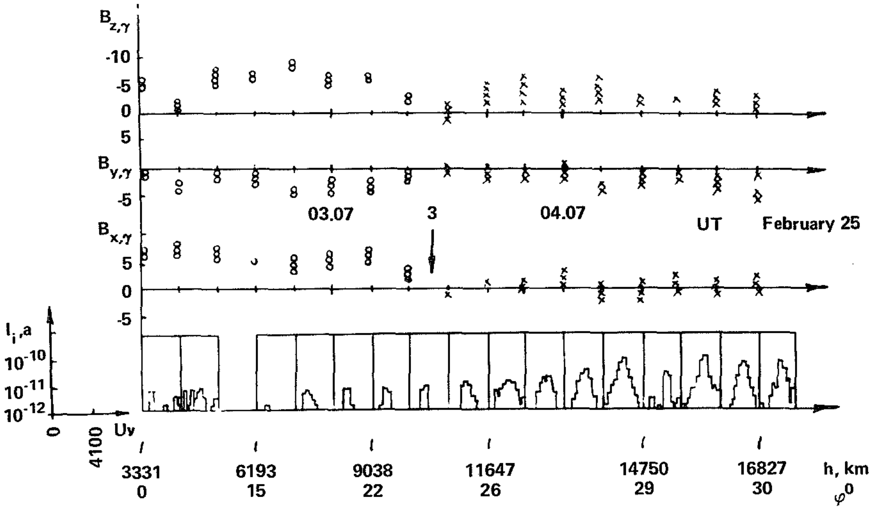


(b)



(c)

Figures 3(b) and 3(c). Magnetograms of B_x-, B_y-, and B_z-components of the magnetic field and ion spectra obtained by means of Faraday cup for flights on February 20-21, 1974 (b) and February 21-22, 1974 (c). The B_x-component is directed toward the Sun. Figure 3(c) gives (top graph) examples of the retarding curves for the electrons.



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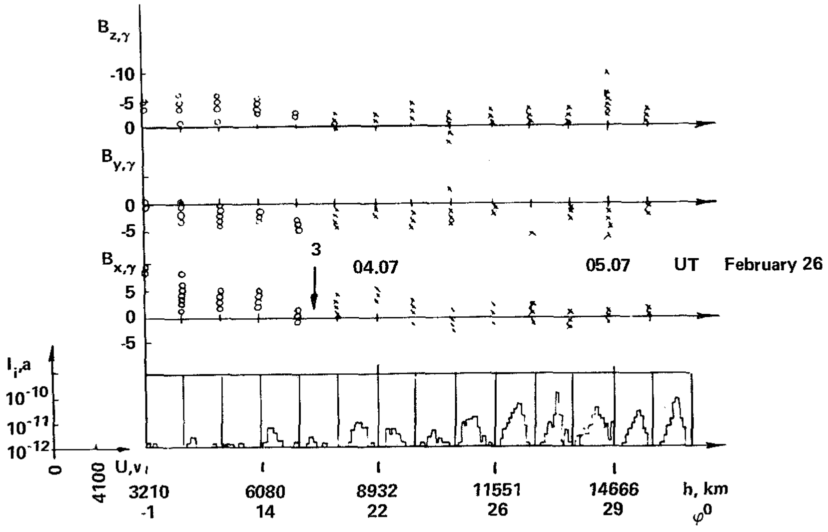
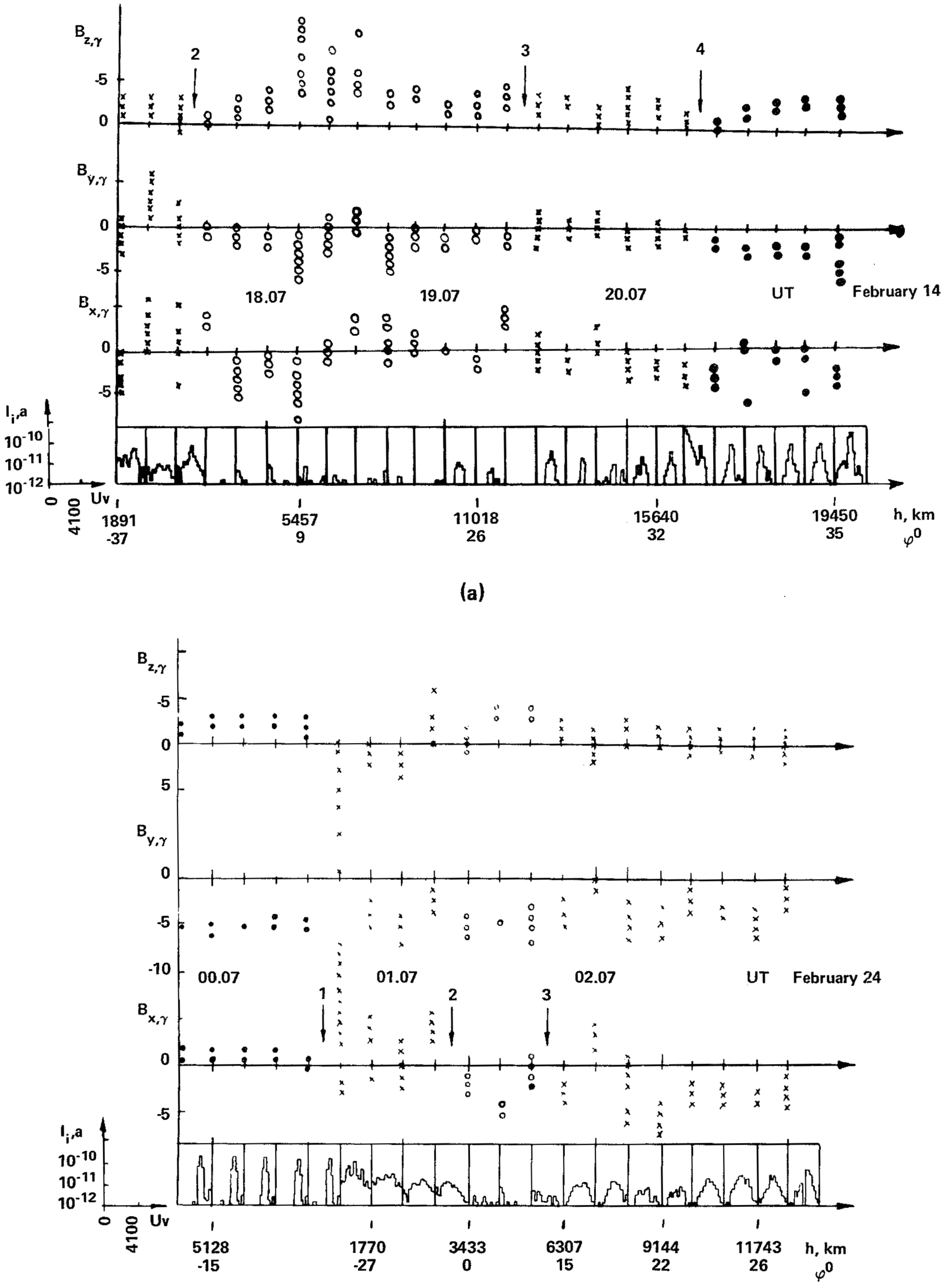


(e)

Figures 3(d) and 3(e). Magnetograms of B_x-, B_y- and B_z-components of the magnetic field and ion spectra obtained by means of Faraday cup for flights on February 25, 1974 (d) and February 26, 1974 (e). The B_x-component is directed toward the Sun.



(a)

Figure 4. Magnetograms of B_x-, B_y-, and B_z-components of the magnetic field and ion spectra obtained by means of Faraday cup for flights on February 14, 1974 (a) and February 24, 1974 (b).

During orbits on February 13 and February 15, 1974 shown in figures 2(a) and (b), the interplanetary magnetic field was directed away from the Sun ($B_x < 0$) and during the orbits on February 19, 21, 22, 25, and 26, 1974 shown in figures 3(a), 3(b), 3(c), 3(d), and 3(e), toward the Sun ($B_x > 0$). Note that the variations of the interplanetary magnetic field direction defined using the Mars-5 data are in good agreement with the data on the variations of the interplanetary field sector structure determined by Mansurov and Mansurova according to the method they suggested in [28].

The moments when the satellite crossed the bow shock and magnetopause, inbound toward and outbound from periapsis, are denoted in figure 3 by the numbers 1 through 4, respectively. Thus, the crossing of the magnetopause, when the satellite entered and went out from the magnetosphere, is denoted by numbers 2 and 3.

During some orbits near Mars, the instruments were switched on when the satellite was already in the magnetosheath (February 15, 1974–figure 2(b) and February 14, 1974–figure 4(a)) or in the magnetosphere (February 21, 25, and 26, 1974–figures 3(b), 3(d), and 3(e)).

As one can see from these figures, both the crossing of the bow shock (1 and 4) and that of the magnetospheric boundary (2 and 3) are simultaneously measured by the magnetometers and plasma detectors according to the criteria discussed above.

The magnetic field in the magnetosphere (2 to 3) is characterized by a noticeable increase in its mean value and the decrease of fluctuations in comparison with the magnetosheath. Note that in all seven cases considered, the B_x-component in region (2 to 3) was directed toward the Sun ($B_x > 0$), in spite of the fact that in two cases (figures 2(a) and (b)), the interplanetary magnetic field was directed away from the Sun ($B_x < 0$). The region (2 to 3) was always measured when the spacecraft were within areographic latitudes 0° to 20°, that is, in the northern hemisphere of the planet. The most noticeable decrease of ion fluxes was recorded in the magnetosphere rather than in the magnetosheath (for example, February 13, 25, and 26, 1974–figures 2(a), 3(d), and 3(e)). During some orbits, the ion fluxes were often lower than the limits of the instrument sensitivity (see figures 2(b), 3(b), and 3(c)–February 15, 21, and 22, 1974).

The examples of the electron retardation curves are also shown in the top graph of figure 3(c), in addition to the magnetic field components and ion spectra. As it is seen from this figure, the fluxes and energy of the electrons in the magnetosphere decrease as compared with the magnetosheath, but they differ slightly from the values in the solar wind. As has been indicated in previous publications [10, 11], electrons were always recorded in the magnetosphere and their properties were similar to those shown in figure 3(c).

The joint analysis of the magnetic and plasma data (figures 2 and 3) indicates that changes in the position of the magnetopause were recorded by plasma and magnetic detectors simultaneously. For example, on February 21, 1974 (figure 3(b)) and February 22, 1974 (figure 3(c)), magnetometers and ion traps measured the alternation of the properties of both plasma and magnetic field typical for the magnetosheath and the magnetosphere associated with multiple crossings of the magnetopause by the satellite.

The value of the magnetic field, the level of its fluctuations, the fluxes and energy spectra of ions and electrons on the flanks of the magnetosheath at the moment when the satellite exited from the magnetosphere, were rather close to the characteristics appropriate to the undisturbed solar wind. The entry to the magnetosheath from the magnetosphere and from the magnetosheath to the solar wind (see figures 2(a), 3(d), and 3(e)) was less distinctly identified on the flanks, according to the data of each experiment, than the entry to these regions that occurred closer to the subsolar part of near-Mars space.

The orbit on February 20, 1974 should be discussed separately because the maximum (for the time period considered) value of the solar-wind dynamical pressure (4.2×10^{-8} dynes/cm^{-2}) was recorded during this orbit. As it is seen from figure 3(c), the ion trap clearly detected entry into the magnetosheath and then a slight decrease of the ion fluxes was observed; at this time, the magnetometers measured a change of sign for the B_x-component (figure 3(a), 2′) and a high level of fluctuations in that part of the zone (2-2′), which borders upon the zone (1-2).

The second change of sign of B_x took place at point 2; after this, the sign of B_x conformed with that of B_x in the magnetosphere typical for the other orbits (figures 2(a), 2(b), 3(c), and so on). Hence, it appears that the satellite has entered into the magnetosphere at point 2.

The magnetosphere is not able to be identified on magnetograms obtained during the two orbits shown in figures 4(a) and (b) on February 14 and 24 (a less intense, widely-fluctuating magnetic field with a large ratio of $\Delta B_x/B_x$ was observed). However, according to the plasma data, the region of the minimum ion flux can be clearly identified.

The Mars-2 and -3 orbits, as seen in figure 1, allowed us in principle to study the magnetic field and the plasma in the subsolar region of the Martian magnetosphere. However, in many cases, the instrumentation for the magnetic and plasma measurements was switched off when the satellite approached the planet (see [4, 8]). Therefore, only a small portion of the data is available that has been obtained inside the magnetosphere in the subsolar region.

Let us consider the Mars-2 orbit on January 8, 1972 (see the orbit in figure 1). The value of the magnetic field modulus, B,* and the currents, I_e, recorded by the electron analyzer, corresponding to three fixed values of retarding voltage, E_R, are shown along the Y-axis in figure 5, and the time (UT) is plotted along the X-axis [12]. The interval denoted as I corresponds to the bow-shock crossing according to data of the electron measurements. It coincides with a noticeable increase of B. The interval denoted as 2 shows a significant decrease of electron flux with energy >50 eV, in particular, and with an increase of B up to its maximum value ~30 γ; the interval 2 can be evidently considered to be equivalent to the satellite crossing of the magnetopause. The interval 3 corresponds to a decrease of B and the growth of electron currents (that is, to the satellite exiting from the Martian magnetosphere).

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*This plot demonstrates the relative variations of its value. The error in B-value can be significant in the interplanetary space due to some uncertainty of the zero reading of the B_x-component.

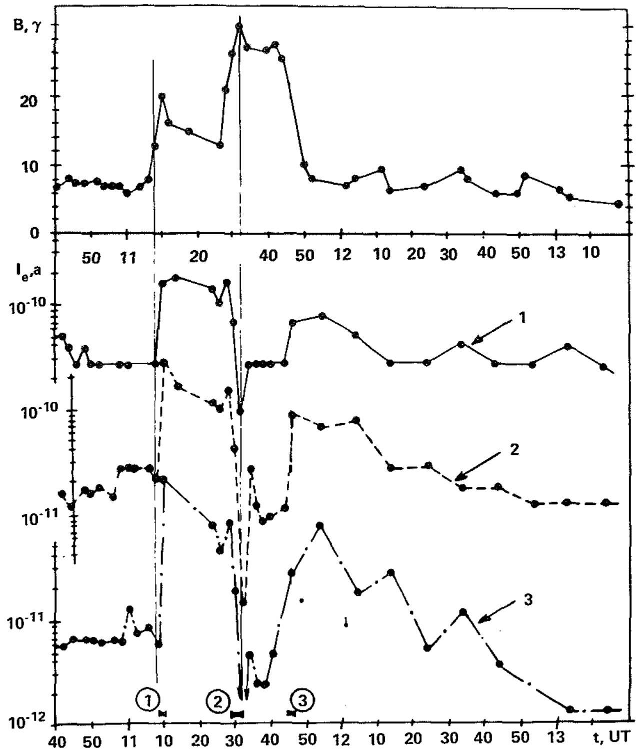

Figure 5. The variations of the magnetic field modulus and currents in the electron traps for the three fixed values of retarding voltage E: 1) 8 V; 2) 20 V; 3) 50 V, during the Mars-2 flight on February 8, 1972.

Figure 6, taken from [29], gives the totality of a projection on the XZ plane of all the B vectors measured from the Mars-3 and -5 spacecraft. Field lines of a magnetic dipole, deformed by the solar wind with the axis normal to the direction to the Sun roughly coinciding with the planet rotation axis, are shown by dotted lines in figure 6.

From this figure, one can see that the projections of the measured vectors $\vec{B}$ are not in agreement with the dotted lines; however, they correspond rather well to the case where the dipole axis is inclined to the rotation axis of the planet at 15° to 20°, and with a polarity opposite to that of the Earth's dipole field.

It should be noted that the variation in dipole orientation related to rotation of the planet must have an influence on the field vector projections. But, for a portion of the measurement data obtained from Mars-5, the influence of this effect is insignificant, since the rotation period of the satellite is close to the diurnal rotation period of the planet. Determining the inclination angle of the Martian dipole as in figure 6 has a purely qualitative character; detailed considerations relating to the dipole inclination problem are given in [19]. The planetary magnetic moment calculated from measurements at the points close to

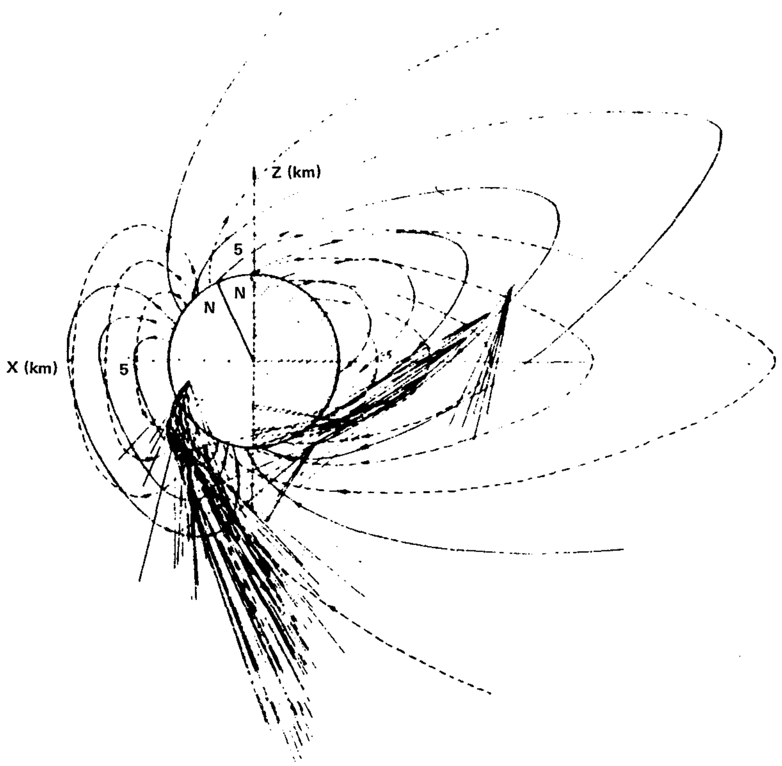

Figure 6. Projections of the magnetic field vectors on the plane normal to the ecliptic according to the data of the Mars-3 and -5 measurements.

the pericenter was 2.4×10^{22} G-cm^3, which corresponds to a field intensity on the equator of 64 γ.

DISCUSSION OF THE RESULTS

As is seen from the previous section discussing the nine cases of the Mars-5 orbits near the planet, in six cases the magnetopause position is in good agreement with the boundary of the minimum ion flux region (figures 2(a), (b), and 3(b), (c), (d), and (e)). In one case, (figure 3(a)—February 20, 1974), the distinct region of the minimum ion flux measurement does not correspond with the distinct magnetosphere in the magnetic field data, as well as in two cases (figures 4(a) and (b)—February 14 and 24, 1974), where the distinct region of the minimum ion flux was observed, but a distinct magnetosphere was absent in the magnetic field data.

At the low, positive, areographic latitudes (<20°) in seven cases when the quiet magnetospheric field was observed, the B_x-component of this field was always directed toward the Sun, independent of the interplanetary field direction.

An understanding of these results involves the following assumptions:

1. The magnetopause near Mars is located much closer to the planetary surface than the magnetopause near Earth, and the intrinsic magnetic field of the planet is much weaker than the Earth's field. This means that the external sources of the magnetic field have a more important effect on the total field (even on the planet's surface) than near Earth. In particular, one can expect that the areomagnetic variations, due to the causes that bring about the geomagnetic variations, are much more significant near Mars than near Earth.

2. The existence of large areomagnetic variations in the Martian magnetosphere thickness can be the reason why the passing of the satellite through the magnetosphere cannot be determined from the magnetic field data shown in figures 4(a) and 4(b). During the flight on February 20, 1974 (figure 3(a)), the sign of the B_x-component at point 2′ could be changed due to the satellite passing through the magnetic equator at the areographic latitude -10°. It is not in agreement with the field topology during the other data intervals, but could be associated with a magnetic equator shift in response to some anomalous current system that arises due to the most intensive solar wind observed during the whole period under consideration ($P = 4.2 \times 10^{-8}$ dynes/cm^2). It is likely that the high dynamic pressure of the solar wind during this orbit resulted in the compression of the magnetosphere. The satellite did not penetrate deeply through the magnetosphere; therefore, only an insignificant decrease of ion fluxes was observed.

3. As was mentioned above and in [8 through 11] and [20], according to the plasma data, a decrease of ion flux was considered to be the criterion of the satellite entry into the magnetosphere. Except for the Mars-5 orbits, when ion fluxes in the Martian magnetosphere turned out to be lower than the limits of the instrumental sensitivity in the vicinity of the magnetopause, a region was observed where the velocity of the ions had an antisolar component similar to that in the transition layer. Earlier, Gringauz et al. [11], Gringauz [20] and Breus and Verigin [12] pointed to the fact that near the magnetopause, but inside the Martian magnetosphere, the phenomena that were observed were similar to the diffuse boundary of the Earth's magnetosphere [30, 31], that is, similar to a boundary layer [32] or plasma mantle [33] in the Earth's magnetosphere.

4. Using analogies with the phenomena near Earth's magnetopause, one can explain the differences in physical characteristics of the regions with less intensive ion fluxes during Mars-5 flights on February 13, 20, 22, and 24, 1974 (figures 2(a), 3(a), 3(c), and 4(b)). The dynamic pressure of the solar wind, P, for these days was 3.1, 4.2, 1.2, and 1.6×10^{-8} dynes/cm^2, respectively. An expansion of the magnetosphere is associated with a decrease in P and Mars-5 could penetrate into the deeper regions of the magnetosphere tail because of the characteristics of its orbit (figure 1).

From figures 2(a), 3(a), 3(c), and 4(b) it is seen that with $P = 1.2 \times 10^{-8}$ dynes/cm^2, when the magnetosphere compression should be the least, the ion fluxes in a long portion of the orbit in the magnetosphere turned out to be lower than the instrument sensitivity level (figure 3(c)). The directed ion flux measured in the diffuse region of the magnetosphere tail on February 13, 1974 (figure 2(a)) was less, relative to the ion flux in the magnetosheath, by 6 to 10 times, and on February 20, 1974 (figure 3(a)) by 2 to 3 times. This is qualitatively in agreement with a relatively deeper penetration of the satellite into the magnetosphere on February 13, 1974.

During some orbits of the satellite inside the magnetosphere, ion fluxes were not measured in general on certain portions of the orbit, that is, they were lower than the instrument threshold sensitivity. In so doing, in the same way as in the diffuse zone, electron fluxes were registered by the electron analyzer without any essential decrease of their value, as compared to that in the undisturbed solar wind.

This discrepancy between the measured fluxes of ions and electrons can be explained if it is realized that, in the region of minimum ion flux inside the Martian magnetosphere, a highly-isotropized plasma may exist which is likely to be similar to the plasma sheet in the Earth's magnetosphere. These concepts are presented in [10, 11].

This quasi-isotropic plasma formation is likely to be surrounded by a diffuse plasma zone near the magnetopause, where the plasma isotropization is much lower than deep in the tail of the Martian magnetosphere.

As mentioned above, the amplitude variations of the Martian bow-shock subsolar point reached 1 R♂ [16] and with the high values of the solar-wind dynamic pressures, the magnetopause could approach the planetary surface at rather small distances. In these individual cases, it is not excluded that the magnetosheath plasma could directly interact with the ionospheric plasma with the exception of the polar cusp regions, where such an interaction is always possible. From the data of our wide-angle detectors, one cannot observe such an interaction.

ON THE DATA OBTAINED BY MEANS OF THE ELECTROSTATIC ANALYZERS

During the preparation of the present paper, the above-mentioned experimental results were compared with the results of simultaneous measurements that have been performed by the authors of experiments using electrostatic analyzers [14 through 18].

It should be noted that the flux, particle concentration, and solar-wind pressure cannot be determined by means of a narrow-angle electrostatic analyzer on a satellite with a fixed orientation. That feature considerably restricts any possibility of correlation of the physical parameters of the plasma obtained from the experimental data. However, with regard to this fact, the comparison of the primary measurement data showed that, as one would expect, the results of measurements which have been performed by all three groups of investigators, are mainly well correlated.

In particular, the moment of occurrence of the bow-shock crossings by the satellite coincides with the limits of the resolution of each instrument. The discrepancy in the calculated coordinates of the stagnation point of the bow shock is associated with the fact that the different authors of the different experiments used different techniques of calculation and assumptions on the shape of the obstacle creating the bow shock.

Due to the electrostatic analyzer data, the obstacle region (magnetosphere) in which the ion fluxes decrease until nothing is measured is distinctly observed during satellite orbits when it is observed by means of a Faraday cup. For example, on February 22, 1974 (figure 7(a)), on the portions of the orbit where the ion trap flux ceases to be measured, ion fluxes with energies $E > 4.1$ keV (upper limit E for the ion trap) are also not measured as a rule. During some orbits, the electrostatic analyzer completely failed to measure any ion flux while the wide-angle detector registered a decrease in the value of the ion flux (figure 7(b)). This can be explained either by the difference in the sensitivity of the two instruments, or by a partial isotropization of the ion fluxes in the specific cases given.

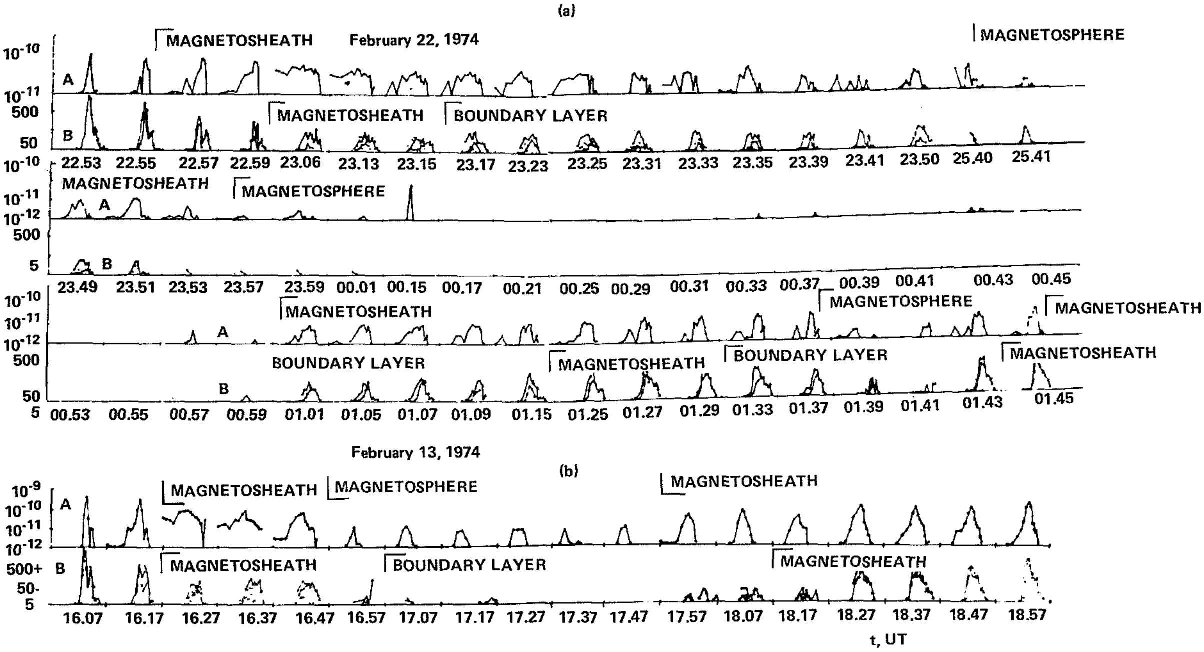

Figure 7. Comparison of ion spectra obtained by means of the Faraday cup (A) (0 to 4 keV) and electrostatic analyzers RIEP (B) onboard Mars-5 on February 22, 1974 (a) and February 13, 1974 (b). The currents in modulation trap and the count rate in the electrostatic analyzers are plotted along the Y-axis. Energies within the 20-eV to 20-keV range are given along the X-axis (logarithmic scale).

We assume that the discrepancy in the conclusions between the authors of the present paper and the authors of the experiments with the electrostatic analyzers is associated not with the difference in the primary results of measurements but with the difference in interpretation of these results.

CONCLUSIONS

Joint consideration of the results of magnetic measurements and plasma measurements performed using wide-angle plasma detectors onboard the Soviet artificial satellites of Mars confirmed the conclusions drawn earlier by the authors of these experiments in separate publications: that the totality of magnetic and plasma measurements performed by the USSR artificial satellites of Mars cannot be explained without a solar-wind interaction with the intrinsic magnetic field of Mars.

Some physical characteristics of the magnetic field and plasma in the Martian magnetosphere (for example, magnetic field topology, diffuse plasma region near the magnetopause, quasi-isotropic region deep in the tail of the Martian magnetosphere) remind us of the corresponding peculiarities of the Earth's magnetosphere, and, to a certain degree, can be explained by the effects of similar mechanisms.

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QUESTIONS

Gringauz/Cloutier: The diffusion time of the magnetic field changes through thë Martian ionosphere is of order ~1 hour. Could this explain some of the magnetic field changes (that is, reversals) seen by the magnetometer close to Mars?

Gringauz: One must remember that the Mars-2, -3, and -5 satellites never entered the Martian ionosphere (the lowest pericenter on the orbit of Mars-5 was 1800 km). Thus the diffusion time of the magnetic field variations through the Martian magnetosphere probably could influence the changes of the magnetometer readings only by means of variations in the induced ionospheric current system during perturbed periods. This possibility must be carefully studied.

Dolginov/Podgorny: Have you compared your long-term measurements of the interplanetary magnetic field with other data? If so, have you seen a change of the X-component direction at the boundaries of the sectors? Such information may provide you with an independent check about the validity of your results.

Dolginov: We have the necessary rate of data sampling during those periods of the special roll maneuvers of Mars-5. During other periods, we have very infrequent data recordings. The information which we received from this data set has not been analyzed completely. Furthermore, I do not think we will have the opportunity to process these data in the near future.

Dolginov/Dessler: How many separate cases of constant magnetospheric-type field have been observed? How many anomalous events?

Dolginov: We have 15 magnetograms from the Mars-2 and -3 spacecraft. Six of these are taken on the dayside at altitudes of 1100 to 2000 km (Mars-2 and -3 in 1972) and nine from the nightside up to an altitude of 9000 km (Mars-5 in 1974).

The Mars-2 satellite tumbled and thus we have the opportunity to determine changes only in the scalar value of the field upon approach to the pericenter (where the field grows to 20 to 25 γ). Only one of the three magnetograms has been published (December 8, 1971).

Mars-3 allowed us to obtain three magnetograms near pericenter. All of the magnetograms served to indicate an intrinsic magnetic field of Mars. The magnetogram taken by Mars-3 on January 21, 1972 proved this. The magnetograms from April 6 and 18 proved that the Martian magnetic field is compressed (limited) on the dayside. Magnetograms from Mars-5 allowed us to trace the field on the nightside up to 9000 km. They proved that there exists a region where the field has a constant sign and also minimum fluctuation, and the field does not change sign with a change in direction of the solar-wind field. The field in this region has a magnetospheric effect on the plasma.

The fields on the night- and daysides agree in orientation. In two instances, (February 14 and 24, 1974) we were not able to demonstrate a characteristic field on the nightside. Hence, in 13 cases we have a magnetospheric-type field. Two cases do not prove this but neither do they contradict that possibility.

The magnetic moment has been determined from direct measurements made on January 21, 1972 and twice by gasdynamic models (1974). These three determinations yield

$$M_M = (2.55 \pm 0.36) \times 10^{22} \text{ G/cm}^3$$

Dolginov/Ness: The principal evidence for an intrinsic magnetic field on the planet is the constant sign of the X-component of the magnetospheric field. But on some occasions, this component is only a few gamma. Unless the accuracy is better than that, you cannot conclude that the sign is constant. What is the accuracy of the X-component measurements and how is that established?

Dolginov: The character of the change in zero levels of the magnetometer axes on Mars-5 was determined from the data of the roll maneuvers performed on September 13, October 12, and December 27, 1973. These data are published in *Space Investigations*, Volume 13, No. 1, 1975. Zero values of the X-sensor turned out to be quite stable. The zero level of the X-axis was initially determined based upon the sign of the interplanetary field as determined from ground-based observations by well-known methods. It was later checked during the roll maneuver and the interplanetary field direction was found to be in agreement with the field sign as determined by ground-based observations.

After entry into orbit, there were no roll maneuvers of the Mars-5 spacecraft. The temperature of the spacecraft, obtained from solar panel sensors, varied little and there was no cause to suspect changes in the zero values which would exceed the accuracy of the telemetry quantization step size of 1 γ. Analysis of the magnetograms from Mars-5 shows just one case

(February 22, 1974) where one can suppose there was a deflection of the zero value. Most of the measurements of the solar wind indicated X = 0 or -1 γ. However, in the transition region, X has a positive value. If we attribute this to an error in zero value and correct it by 2 γ, then this anomaly will be excluded and the magnetosphere field will increase in intensity by 2 γ. In all other cases there are no indications of anomalies.

The criteria for the existence of an intrinsic magnetic field is not only the field strength but the relative fluctuations $\Delta X/X$ and the direction of the field as well. These are the main criteria. They unambiguously demonstrate the existence of a magnetosphere-like region. Its boundaries are also delineated independently by the plasma sensors. These criteria allow us to trust the field measurements from February 15 (3 γ) since they have the direction characteristic of the northern hemisphere while in the transition zone the field has the opposite sign.

It was possible to investigate the stability of the zero level values with the onboard instrumentation, which registered a change in the sector polarity. This was determined from the magnetograms of February 20 by comparison with the preceeding days. This was confirmed with data of Mansurov [28] and Mariner-10.

Hence, all the magnetograms of the nightside presented by us are consistent in their measurements and truly prove a topology which is characteristic for the sheath of the nighttime Martian magnetosphere.

Ness: I want to make a comment about the problems of any comparisons between theoretical (or experimentally-observed at Earth) bow-shock positions and those observed by the magnetometers on the Mars-2, -3, and -5 spacecraft. As is well known from Earth and also to be discussed in my paper tomorrow, there often exist waves upstream from the bow shock. Thus, with the very low data rate on the Mars spacecraft, using the field fluctuations to identify the bow shock automatically biases the shock position further away from the planet than it really exists, and indeed the magnitude jump may be relatively small. These conditions occur when there is a parallel shock. Also, as Spreiter will show in his paper,* for low Alfvénic Mach numbers (less than 6) which are typical of conditions at Mars, the shape of the bow shock is altered from the gasdynamic form causing the flanks to move outward from the obstacle and the nose to move inward toward the obstacle.

These two considerations, upstream waves and low Alfvén Mach numbers, both act in such a way as to lower the stagnation-point height of the obstacle deflecting the solar-wind flow since most of the shock position observations are well away from the nose region. I therefore conclude, based upon a preliminary comparison of the published Mars results, that the height of the obstacle is 600 ± 200 km and this puts it close to the level at which the obstacle could be mainly ionospheric and not an intrinsic field. A more careful comparison of bow-shock identifications, upstream conditions, and theoretical or extrapolated terrestrial bow-shock positions should be made at Mars.

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*See J. R. Spreiter's paper, "Magnetohydrodynamic and Gasdynamic Aspects of Solar-Wind Flow Around Terrestrial Planets: A Critical Review," in this document.