scattering by small dust particles, steeper slopes for flux-mass distributions are obtained with $\beta \approx -0.9 \pm 0.1$ for much smaller particles (1 to 10 μ diameter). In addition, most of the analyses of flux distributions based on ground-based observations follow the assumption that decrease of flux is a function of increasing heliocentric distance. The measurement from Mariner IV shows a variation in the flux-mass distribution with the steepest slope of the distribution occurring between the planets. The measurement also yields a flux which increases with heliocentric distance from the sun. Neither of these results have been included in the analyses of ground-based photometric observations.

The experiment has been resumed after the playback of the pictures of the planet, and data are being obtained. Additional information concerning the apparent enhancement of flux near the perihelion distance of Mars may be obtained whenever there are communications with the spacecraft.

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Magnetic Field Measurements near Mars

Abstract. *During the encounter between Mariner IV and Mars on 14–15 July, no magnetic effect that could be definitely associated with the planet was evident in the magnetometer data. This observation implies that the Martian magnetic dipole moment is, at most, 3×10^{-4} times that of the earth.*

This is a preliminary report of the magnetic field measurements that were made near Mars on 14–15 July by the Mariner IV magnetometer. No effects definitely attributable to the presence of the planet were observed. This conclusion is based on a comparison of the encounter data with the measurements recorded by the same instrument within the region of interaction between the earth's magnetic field and the solar wind, as well as in interplanetary space during the 7-month interval between launch and encounter. It is assumed that the interaction of the solar wind with a significant Martian dipole moment would have produced effects geometrically similar to those observed near the earth, but with a scale determined by the magnitude of the dipole moment. This assumption is used to establish an upper limit for the Martian dipole moment. Since the bow shock (*1*) is the feature of a planet's interaction with the solar wind that occurs farthest from the planet (except possibly for the magnetic tail, which we were never in a position to detect because of the nature of the trajectory), the ability to detect such a shock forms the basis for our discussion. The ability of the Mariner magnetometer to detect a planetary shock front depended on the spatial resolution and sensitivity of the measurements, on the character of the interplanetary field fluctuations during encounter, and on the nature of the encounter trajectory.

The resolution of the telemetered magnetic data was 0.35 gamma per axis (1 gamma = 10^{-5} gauss), a limit imposed by the uncertainty inherent in converting the magnetometer output analog signals to digital numbers before transmission to Earth. The noise threshold of the Mariner's vector helium magnetometer was significantly smaller, being equivalent to only 0.1 gamma rms per axis. Measurements were made in a 50.4-second cycle in which the intervals between consecutive simultaneous triaxial observations were 6.0, 3.6, 9.6, and 31.2 seconds after which the cycle repeated. During passage through the earth's bow shock, the sensitivity was the same, but each interval was only one quarter as long. Data obtained slightly behind the extended dawn line showed clear evidence of the geomagnetic bow shock as it repeatedly surged back and forth past the spacecraft (*2*). The region behind the shock front was characterized mainly by fluctuations about the mean with amplitudes of the order of 2 gamma and with prominent frequencies, as judged by the amount of change over the various lengths of the sampling intervals, of the general order of 0.1 cy/sec and lower. There were also changes of several gammas across the bow shock in the average components of the field. The bow shock around Mars should occur at a position where the field strength has a value determined by the solar-wind pressure (that is, its momentum flux), and hence the characteristics of the shock should be largely independent of the Martian magnetic moment and quite similar to what is observed at the earth.

Throughout the 7-month period in interplanetary space the Mariner magnetometer data show a pattern of alternating disturbed and quiet intervals which has come to be expected of these kinds of data and which is related to daily changes in solar activity. Fortunately the time interval before, and during, encounter was one of relative magnetic calm, even though the Mariner's energetic particle detectors were recording a solar proton event that began about 23 hours prior to encounter (*3*). During the interval from 1800 on 14 July to 0123 Universal Time, 22 minutes after closest approach, the field was unmistakably interplanetary in character, having fluctuations roughly an order of magnitude smaller than those behind the earth's bow shock. At 0123 U.T., a period of disturbance began abruptly with a 5-gamma jump in the field and an approximate doubling of the amplitude of the fluctuations. This condition continued for about 3 hours, after which the components returned to near their previous values. This disturbance could be interpreted as evidence for a weak bow shock associated with Mars, but our preliminary analysis does not exclude the possibility that it is just one of many similar disturbances seen in the 7-month period.

The Mariner flight path approached Mars from a direction 13° above the equatorial plane and at 0940 local time. It crossed the noon meridian at a latitude of −50° and an areocentric distance of 14,500 km or 4.3 r_M (Martian radii); it dipped down 21 minutes later to a latitude of −67° at closest approach, where the local time was 1435 and the areocentric distance 13,200 km or 3.9 r_M. Mariner did not pass into the shadow of the planet, but moved away in a direction making an angle with the Sun-Mars line of about

145°, the local time being 2150 and the latitude being −3°. Beginning at 0219 U.T. (about 1 hour after closest approach), Mariner IV was occulted by Mars for 54 minutes, and no telemetry data were received. However, this gap in the record does not significantly affect our estimate of the Martian dipole moment, since a moment large enough to cause a significant effect during this interval would have caused detectable effects before occultation.

Satellite and space probe measurements made near the earth must be scaled in order to make them applicable to a planet having a different dipole moment. We use essentially the same approach here that we applied to the Mariner II data obtained near Venus (*4*). We assume that the locations and shapes of the magnetopause and the shock front are approximate surfaces of revolution about the solar direction and are reasonably insensitive to orientations of the magnetic dipole. Then the dipole moment of Mars (M_M) can be expressed in terms of the earth's dipole moment (M_E), the typical solar wind pressure at earth (P_E), the actual wind pressure at the planet (P_M), the areocentric distance to a point on the encounter trajectory at which an effect such as the magnetopause or shock occurs (R_M), and the geocentric distance (R_E) to the corresponding feature near earth at the same sun-planet-spacecraft angle:

$$M_M/M_E = (R_M/R_E)^3\,(P_M/P_E)^{\frac{1}{2}}$$

In this report, we use this equation to derive an upper limit for M_M from the observation that no magnetic disturbance was seen before 0123 U.T. when Mariner was 14,700 km from the center of Mars at a Sun-Mars-spacecraft angle of 110°. Near Earth at a Sun-Earth-spacecraft angle of 110°, the Mariner IV data showed that the position of the shock front varied between 233,000 and 246,000 km at a time when the velocity of the solar wind was 400 km sec^{-1} and the density was about 6 cm^{-3} (*5*). These data, when combined with the IMP-1 (interplanetary monitoring platform) shock front data (*6*), lead to a reasonable, smooth contour for the average shock front location.

The typical value for R_E at an angle of 110° is 240,000 km ($\sim$37.5 r_E). Average values for the solar wind parameters during the IMP-1 observations (8 cm^{-3} and 340 km sec^{-1}) (*5*) correspond to an average pressure (P_E) of 2.10^{-8} dyne cm^{-2} in good agreement with the above Mariner IV plasma measurements. During encounter, the preliminary values for the velocity and density of the solar wind are 330 km sec^{-1} and 2 cm^{-3} (*5*), respectively, so that P_M is approximately 0.5×10^{-8} dyne cm^{-2}. Substituting these values into the equation above gives $M_M \leqq 10^{-4}\ M_E$. These results could be changed somewhat if allowance were made for the possibility that the dipole axis of Mars may not be parallel to the rotation axis and for the fact that the earth's bow shock has not been completely explored and will deviate somewhat from a surface of revolution. However, we are confident that the maximum uncertainty is a factor of 3 and that the upper limit to M_M lies between 3×10^{-4} and 10^{-4} M_E.

If the disturbance that started at 0123 U.T. is regarded as interplanetary because the amplitude of the fluctuations appears to resemble other interplanetary disturbances more than the earth's bow shock, the actual value of M_M must be smaller than the upper limit given above, and it may well be zero. If the disturbance is regarded as a weak bow shock, then the above values should be regarded as giving the range within which the actual magnetic moment of Mars must lie.

Some of the consequences of this small upper limit for M_M are immediately apparent. Any field-producing dynamo must be nearly inactive. Since the rotation rates of Mars and the earth are nearly the same, a very small fluid core is suggested for Mars, in agreement with earlier proposals (*7*). The Martian interior now appears definitely to be more like the interior of the moon than that of the earth. A moment of $3 \times 10^{-4}\ M_E$ implies a surface field at the magnetic equator of only 100 gamma. It also means that the flux of cosmic rays above the atmosphere should everywhere be comparable to what is observed at earth only over the polar regions. The elevation of the magnetopause in the subsolar region is, at most, 5000 km or 1.5 r_M. The very weak fields and low L value for the magnetopause imply that any belts of trapped radiation on Mars must be very small and weak. If the dipole moment is zero, there can be no trapped radiation.

If there is no intrinsic dipole moment due to interior sources, the solar wind, with its embedded interplanetary magnetic field, must press in against the Martian atmosphere to the level at which the ion pressure balances the stagnation pressure of the solar wind. The energy and momentum fluxes of the solar wind are large enough that if they interact with the Martian atmosphere at this level with moderate efficiency, they will remove it at a rate that is significant in any treatment of its evolution. As suggested by Gold (*8*) with regard to the moon, some of the interplanetary field lines should diffuse into Mars. The field lines will tend to pile up at the subsolar point and to be swept around the planet by the solar wind. It seems probable that in this case there would be a weak bow shock outside the stagnation region; and it may be that the disturbance seen at 0123 is associated with this tentative model (*9*).

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