the axis. (iv) The highly irregular magnetic field in the magnetosheath region contributes an additional pressure that is not included in the usual gas-dynamic analysis. Until further analysis, and perhaps further observations, have been made, these suggestions must be regarded as speculative, and the dynamic soundness of our model must be regarded as uncertain.

Other models are possible but unattractive. Most of the features seen near Venus could be regarded individually as features of the interplanetary medium even though some of them are very unusual. However, it seems extremely unlikely that all these features would have been observed during the short period in which Mariner was near the planet and that they would have been organized purely by coincidence into the observed pattern.

The magnetopause and bow shock observed around Earth can be scaled so that the shock passes through point 1 and very near to point 5. The scaled magnetopause is then in the upper atmosphere at the subsolar point, and the trajectory would be inside the magnetosphere between points 2 and 4. The corresponding scaling of the dipole moment gives a value for Venus about 1/700 that of Earth. Although the presence and position of the shock is an attractive feature of this model, the presence of solar wind inside the scaled magnetopause and the very low value of $|B|$ near event 3 seem to rule out the model completely.

An upper bound can be placed on the magnetic moment of Venus, but it depends for its precise value on the details of the model used. The unsuitability of the scaled geomagnetic analogue summarized above requires that the actual ratio of dipole moments be significantly smaller than that derived from the model. We estimate a reasonable limit to be within a factor of two of 10^{-3} times that of Earth. Obviously, there is no way to tell from such analyses whether or not Venus has an intrinsic field smaller than the upper bound. Nothing that we report here is inconsistent with the available information on the recent Russian observations which appear to give an even lower limit.

The interaction of the solar wind with Venus differs from its interaction with either Earth or Moon. In the case of Moon, the plasma ions are absorbed by the lunar surface, and no shock develops (*10*). Moreover, Moon appears to be a sufficiently good insulator to allow the interplanetary field to be convected nearly unchanged through it (*11*). Except for a region close to or inside the lunar shadow, the plasma flow near Moon is unaffected by its presence. In contrast, the plasma flow near Venus is bounded by an anemopause. The shock around Venus resembles that around Earth except in scale, but conditions inside are quite different because the anemopause around Venus is probably supported by the ionosphere, whereas that around Earth is supported by the geomagnetic field. The plasma appears to expand into the cavity on the downwind side of Venus, whereas, behind Earth, inward expansion is prevented by the magnetic field in the geomagnetic tail.

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Venus: An Upper Limit on Intrinsic Magnetic Dipole Moment Based on Absence of a Radiation Belt

Abstract. *On the basis of the absence of energetic electrons* ($E_e > 45$ *kiloelectron volts) and protons* ($E_p > 320$ *kiloelectron volts) associated with Venus to within a radial distance of 10,150 kilometers from the center of the planet and using a physical similitude argument and the observational and theoretical knowledge of the magnetosphere of Earth, we conclude that the intrinsic magnetic dipole moment of Venus is almost certainly less than 0.01 and probably less than 0.001 of that of Earth. Corresponding upper limits on the magnetic field at the equatorial surface of Venus are about 350 and* 35×10^{-5} *gauss, respectively.*

The University of Iowa apparatus on Mariner V comprises three Geiger tubes and a 32-μm thick, totally depleted, surface-barrier silicon detector with four electronic discrimination levels. The data obtained during Mariner V's encounter with Venus on 19 October 1967 establish a complete, or nearly complete, absence of energetic electrons and protons associated with the planet, in to the minimum radial distance of approach of 10,150 km (*1*). These results are consistent with earlier ones from the 41,000-km approach of Mariner II to Venus in 1962 (*2*), but they are much more definitive by virtue of the closer approach.

Specific upper limits on the average

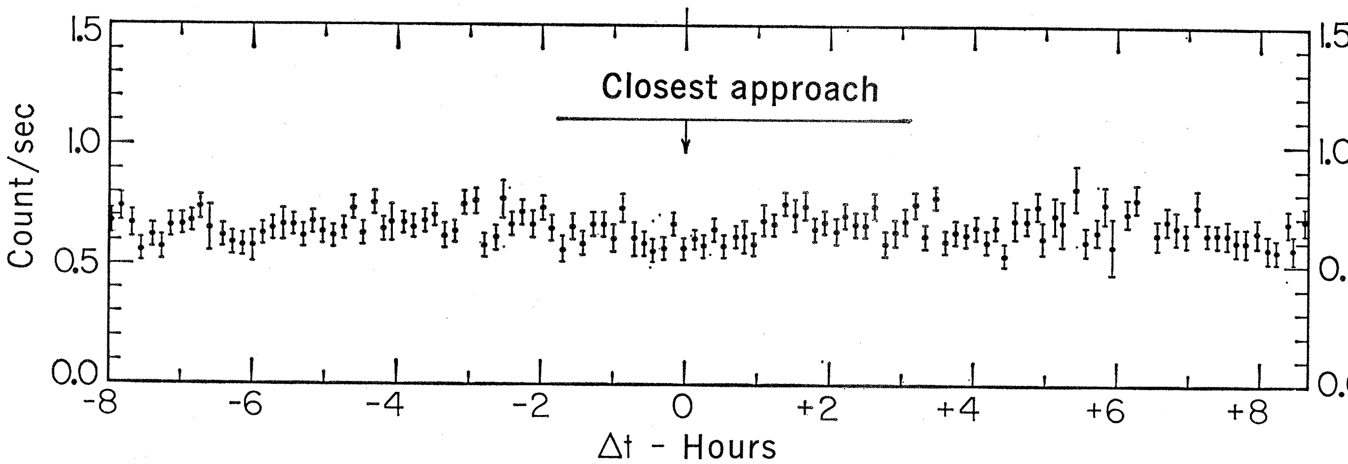

Fig. 1. Counting rate of the electron detector ($E_e > 45$ kev). Each point represents the average counting rate for a 216-second sampling period. Error bars show the statistical standard error of each point. The lowest daily average rate of this detector which has been observed during its flight to Venus is 0.59 ± 0.01 count/sec (due primarily to galactic cosmic rays).

unidirectional intensities of planet-associated particles during any 216-second interval of the encounter period are 3.0 (cm^2 sec steradian)$^{-1}$ for electrons ($E_e > 45$ kev) and 1.0 (cm^2 sec steradian)$^{-1}$ for protons ($0.32 < E_p < 12$ Mev).

Figure 1 shows a plot of the 216-second averaged counting rate of the most sensitive of our electron detectors ($E_e > 45$ kev) for a 16-hour period centered on the time of closest approach. The counting rate at points remote from the planet is due principally to galactic cosmic rays that penetrate the sidewalls of the detector. There is also a small contribution from solar particles.

By contrast, the same apparatus observed maximum unidirectional intensities of 1×10^6 (cm^2 sec steradian)$^{-1}$ of electrons ($E_e > 45$ kev) and 3.5×10^6 (cm^2 sec steradian)$^{-1}$ of protons ($E_p > 320$ kev) during its outbound traversal of Earth's magnetosphere on 14 June 1967. The spacecraft passed through the outer portion of Earth's magnetosphere on its sunward side. A major, precipitous decline of the intensities of geomagnetically trapped particles occurred during the period 0935 to 0943 U.T. on 14 June at a geocentric radial distance of about 10 Earth radii and a Sun-Earth-spacecraft angle of 59° (*2*).

However, "spikes" of electron and proton intensity were observed in the "transition region" for several hours thereafter. The last such spike occurred at 1225 to 1227 U.T. at a radial distance of 16.8 Earth radii and a Sun-Earth-spacecraft angle of 62°, in almost exact coincidence with the last magnetometer indication of the presence of Earth, a discontinuous drop from 25 to 8×10^{-5} gauss (*3*).

The flow of the solar wind is arrested on the sunward side of a planet at a radial distance R such that the dynamic pressure of the wind is equal to the opposing pressure of the (compressed) magnetic field B of the planet (*4*).

$$k\, n\, m\, v^2 = B^2/8\pi \qquad (1)$$

In Eq. 1, n is the number density of protons each of mass m and directed velocity v in the solar wind, and k is a numerical factor between 1 and 2. A necessary condition for the existence of a radiation belt of trapped particles is that the "stagnation point" given by condition 1 is sufficiently far above the surface that the atmospheric density is adequately small (see *5* for a more quantitative statement of this condition). For Venus, it appears safe to take an altitude of several thousand kilometers or a radial distance of ~ 2 planetary radii as being a generous value. If one takes n as inversely proportional to the square of the distance from Sun and v as independent of this distance, and notes that $B \propto M/R^3$, physical similitude with the known

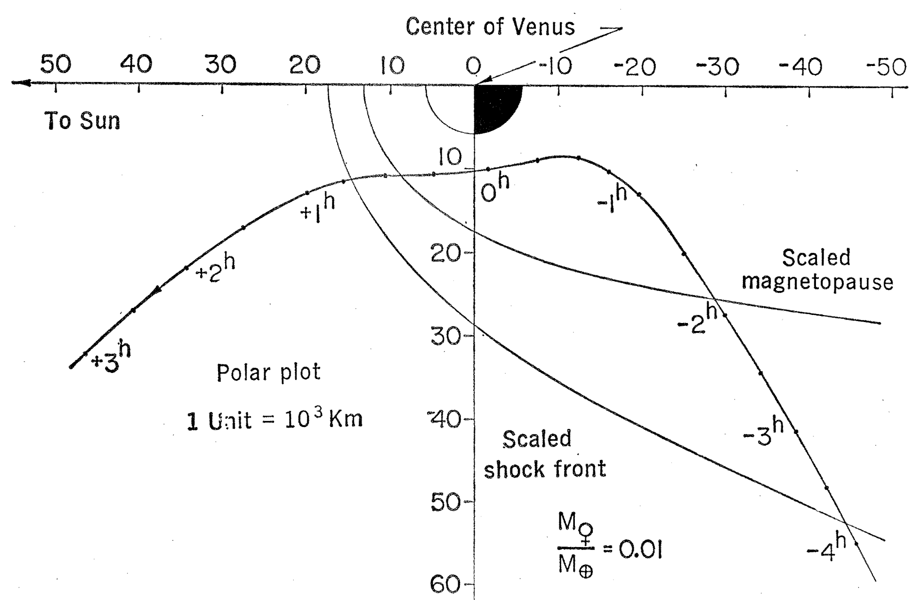

Fig. 2. Encounter trajectory of Mariner V with Venus in the rotating plane which contains Sun, the center of the planet, and the spacecraft. The coordinates are the Sun-Venus-spacecraft angle and the radial distance from the center of the planet to the spacecraft. Blackened circles on the trajectory are at 15-minute intervals from -1 hour to $+1$ hour, and at 30-minute intervals elsewhere. One unit equals 10^3 km. Also shown are traces of the magnetopause and shock front to be expected if the intrinsic magnetic dipole moment of Venus were 0.01 of that of Earth.

properties of Earth's magnetosphere entitles one to derive a scaling law from Eq. 1, namely

$$R_V/R_E = 0.9\ (M_V/M_E)^{\frac{1}{3}} \qquad (2)$$

wherein R_V and R_E are the radial distances from the centers of Venus and Earth to corresponding points on their respective magnetospheric boundaries, and M_V and M_E are their respective magnetic dipole moments.

In Fig. 2 is a sketch of the magnetopause and shock front to be expected for M_V/M_E equal to 0.01, as scaled from the observed boundaries for Earth (*6*) with use of Eq. 2. Also shown is a portion of the encounter trajectory of Mariner V plotted in polar coordinates in the (rotating) plane which passes through Sun, the center of the planet, and the spacecraft. The interpretative use of such a plot includes the assumption of approximate axial symmetry about the Sun-planet line, as is established adequately for the present purpose by both theory and experiment. It is clear that Mariner V penetrated deeply into such a scaled magnetosphere.

Although the foregoing discussion is believed to be reliable in establishing a necessary condition for the existence of a radiation belt of durably trapped particles, it is less clear that such a condition is sufficient to assure the existence of a trapped particle population which would be detectable by our apparatus. We argue that it would be sufficient on the following grounds:

1) The magnetic and magneto-fluid dynamical conditions at the shock front and between the shock front and the magnetopause would be essentially identical with those of Earth's physical system.

2) The existence of easily observable patches or "spikes" of electrons ($E_e > 45$ kev) is characteristic of these regions around Earth (*7*) (as confirmed by the Mariner V apparatus) as well as of distances as great as 500,000 km "downstream" from Earth (*8*).

3) The frictional interaction between the solar wind and the magnetic field and ionized gas of the exosphere of Venus (*9*) would result in a system of polarization electric fields (or magnetic convection) that would accelerate particles and deliver them into the inner magnetosphere with an average increase of energy of some tens of kilovolts.

On these grounds we conclude that the absence of a detectable population of electrons ($E_e > 45$ kev) (Fig. 1) near Venus establishes M_V/M_E equal to 0.01 as a generous upper limit.

A diagram similar to Fig. 2 for M_V/M_E equal to 0.001 shows that the sunward magnetopause would then lie at the surface of the planet and that durable trapping of charged particles would be impossible. But, even in this case, shock-generated energetic electrons, or protons, or both, might be expected. No such "spikes" are evident in our data.

Nonetheless, both the magnetometer and the solar-wind detector (*3*) on Mariner V observed clear and significant, though weak, "signatures" of the planet. These effects have been attributed to the magneto-fluid dynamical interaction of the solar wind with the conducting ionosphere of the planet, the latter being clearly established by other experiments on Mariner V (*10*).

Since Venus has about the same size and average density as Earth and probably has a metallic core and an internal temperature similar to or greater than that of Earth (*11*) the very small (or perhaps zero) value of its intrinsic magnetic dipole moment is presumably attributable to its very slow rotation—a sidereal period of 245.1 ± 2 days (*12*) —and the consequent weakness of dynamo electromotive forces.

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Ultraviolet Emissions Observed near Venus from Mariner V

Abstract. *A Lyman-alpha airglow of atomic hydrogen measured in the outer atmosphere of Venus showed that atomic hydrogen is present. The variation as a function of height indicates that the temperature of the upper atmosphere of Venus is lower than that of Earth. An ultraviolet airglow of atomic oxygen was not found. An ultraviolet nightglow was observed on the dark limb.*

The Mariner V flyby mission past Venus presented the opportunity to measure ultraviolet emissions from the upper atmosphere of Venus with a small instrument. The atmospheric species atomic hydrogen and atomic oxygen have resonance lines at 1216 and 1304 Å that may be measured with a simple ultraviolet photometer. The measurement of the ultraviolet emissions from resonance scattering of solar radiation by these atoms is a method of determining their density. The variation of the density as a function of height above the surface is a measure of the temperature of the outermost region of the atmosphere. Our experiment provides one part of a systematic study of the structure of the atmosphere of Venus. This is a report of the first preliminary results from the ultraviolet photometer experiment.

The ultraviolet photometer consists of three photomultiplier tubes, each with a different filter to isolate different regions of the vacuum ultraviolet spectrum. The photomultipliers, which have cesium iodide photocathodes and lithium fluoride windows, respond to ultraviolet radiation between 1050 and 2200 Å and have greatly decreased sensitivity at longer wavelengths. The three filters are the lithium fluoride window of the first tube and additional filters of calcium fluoride and barium fluoride for the other two tubes. The effective passbands for the three channels are: