in the magnetic equatorial plane with its axis orthogonal to the B vector, then its true rate would be of the order of 10^6 count sec^{-1}; and that even at 65,000 km it would be of the order of 10^4 count sec^{-1}. Thus, it is clear that the radiation environment of Venus is vastly different than that of Earth. However, the nonlinear character of the similitude argument is evident from the precipitous decline in trapped particle intensity at 72,000 km, shown in Fig. 2. If our Mariner II equipment had been flown past Earth at a minimum distance of approach of 75,000 km on the sunward side of the magnetosphere on 5 October 1962, then the results would have been as negative as were those from the Venus fly-by on 14 December.

By means of Explorer XII (*3*) and Explorer XIV (*2*) it has been found that there is often a sharp outer boundary of the magnetosphere (such as exemplified by Fig. 2) as defined by the intensity of electrons of $E > 40$ kev and a nearly coincident discontinuity in the magnitude and direction of the magnetic field. The radial distance to this outer boundary is typically 8 to 11 earth radii. On some occasions, even on the sunward face of the magnetosphere, there is no sharp discontinuity and the intensity of low-energy, trapped electrons dwindles gradually with increasing distance to a radial distance as great as 14 or 15 earth radii.

For the purposes of an exemplary calculation, let it be assumed that the magnetic moment of Venus is perpendicular to the plane of the ecliptic, and that the solar wind which was impinging on the magnetosphere of Venus on 14 December was similar to that responsible for the termination of the magnetosphere of Earth on 5 October (Fig. 2) (the latter assumption is supported by auxiliary geomagnetic data for the two periods in question). If it is further assumed that the magnetospheric boundary occurs at a given value of planetary magnetic field, under given solar wind conditions, then the Mariner II results imply the following upper limit for the ratio of the magnetic moment of Venus M_V to that of Earth M_E.

$$\frac{M_V}{M_E} \leq \left(\frac{41{,}000}{72{,}500}\right)^3 = 0.18$$

We regard this estimate as reasonable but do not regard it as definitive. For example, if the magnetic moment of Venus was in the plane of Mariner II's trajectory and perpendicular to the trajectory at its point of closest approach the fly-by at 41,000 km would have just reached the dipole line of force which crosses the magnetic equator at 106,600 km. This line of force on the sunward side of the earth has never been observed to be populated by a detectable intensity of trapped particles of energy to which our Mariner II detector was sensitive. Hence, in this case M_V/M_E might be equal to or somewhat greater than unity.

It is probable that the heliocentric variation of the dynamic pressure of the solar wind between the orbit of Venus (0.72 astronomical unit) and the orbit of Earth (1.00 A.U.) is less than the day-to-day and week-to-week variations at Earth. Hence no attempt has been made to invoke this consideration, which is in effect buried among other uncertainties previously mentioned.

It may be remarked that our Mariner II detector, though having a wide angle (90°) collimator, was a directional one and was carried past Venus in an oriented vehicle. Since the angular distribution of magnetically trapped particles is always anisotropic, it is of importance to inquire whether the observed null result could have been a false one due simply to the fact that the detector had an unfavorable aspect during its passage through a field of radiation. We examined this possibility for various orientations of the planetary magnetic moment with the help of a model and concluded that such a result was exceedingly unlikely.

The results of the magnetometer observations made with Mariner II may contribute to the determination of an upper limit to M_V, but the interpretation of a null effect on a magnetometer is closely related to the interpretation of the absence of magnetically trapped, charged particles and it is doubtful that anything essentially different can be derived from the magnetic observations. It is assumed implicitly in our interpretation that the processes leading to the development of the radiation belts of Earth also occur in the magnetospheres of other magnetized planets and that the important processes scale in some continuous manner and not discontinuously with the magnitude of the magnetic moment of the planet in question.

In the spirit of the theory of planetary magnetism, our results are consistent with the radar astronomical evidence that the rotational period of Venus is approximately equal to its period of revolution about the sun (*4, 5*).

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References and Notes

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5. This work was supported in part by the Jet Propulsion Laboratory and by our NASA grant NsG-233-62. We are particularly indebted to Conway W. Snyder, Hugh R. Anderson, and Leonard G. Parker (J.P.L.) for essential assistance with many aspects of the work and to C. S. Wang (State University of Iowa) for assistance with data reduction. Two of us (L.A.F. and H.K.H.) are graduate research fellows of the National Aeronautics and Space Administration.

26 February 1963

Infrared Radiometer

The infrared radiometer which was flown on Mariner II in conjunction with the microwave radiometer was designed to measure, with high geographical resolution, the infrared radiation from Venus in two wavelength regions. One of these was centered on the 10.4-μ carbon dioxide band, while the other was selected to correspond to an infrared window centered at 8.4 μ.

The characteristics of the two-channel instrument, which was built by the Barnes Engineering Company, follow: weight, 2.88 lbs; power, 2.4 watts; field of view, 0.9 by 0.9 deg; integration time, 3 seconds between 10 and 90 percent points. The detectors were 0.15- by 15-mm thermistor bolometers immersed in germanium. Channel 1 operated in the spectral region 8.1 to 8.7 microns, channel 2 in the region 10.2 to 10.5 microns. The radiometer, designed to measure radiation temperatures between 200°K and 600°K, chopped the planetary radiation against dark space by means of a mirrored chopper operating at 20 cy/sec. Two essentially identical optical systems looking 45 deg apart were utilized.

The infrared radiometer was mounted

upon and bore-sighted with the microwave radiometer described in the accompanying article. Both instruments therefore executed the same scan pattern caused by the combined effects of the probe motion and a rotation of the radiometers in a plane normal to the probe-sun line. It was originally planned to have approximately 15 scans of the planet, but a failure of the scan reversal system reduced this number to three. Five pairs of radiation temperatures were obtained on the dark side, five on the sunlit side, and eight along the terminator.

The radiometer was calibrated at the Jet Propulsion Laboratory by using two cylindrical black bodies; one was maintained at liquid nitrogen temperature, while the other was variable over the expected planetary temperature range. In addition, a one-point check was obtained during encounter by having the radiometer view a plate, located on the spacecraft structure, whose temperature was independently measured.

The data are consistent with an equality of the 8- and 10-μ radiation temperatures. This apparent equality would indicate that there was little CO_2 absorption in the light path. The implications are that the measured temperatures were cloud temperatures, that the clouds were quite thick, and that essentially no radiation was transmitted from the surface.

A definite limb-darkening was observed in both spectral channels; the radiation temperatures showed a monotonic decrease of approximately 20°K between the central region and the limbs. Central radiation temperatures are estimated to have been on the order of 240°K; an evaluation of the accuracy of the absolute calibration is currently underway. The data do not show any clear-cut evidence of asymmetry in the limb-darkening, except for an anomaly on the southern part of the terminator scan. In particular, the light- and dark-side temperatures were qualitatively the same. The anomaly was about 10°K cooler than expected on the basis of symmetrical limb-darkening (*1*). One obvious interpretation of this temperature anomaly is that the clouds were locally higher or more opaque, or both. An interesting possibility is that this was associated with a surface feature.

A detailed analysis of the data, including a simulation of the Mariner flight equipment, is being carried on in an effort to place realistic limits on the accuracy of the measurements and to understand anomalies which appeared in the science subsystem during calibrations made in flight but before encounter. Until these difficulties are resolved the results must be considered tentative (*2*).

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Notes

1. Cool features have also been reported by Sinton and Strong, *Astrophys. J.* **131**, 470 (1960), and by Murray, Wildey, and Westphal, talk at Am. Geophys. Union meeting, Stanford, Calif., Dec. 1962.
2. We acknowledge the help of Carl Sagan, who was an active participant during the conception and initial planning of this experiment. We thank the engineering staff of the Jet Propulsion Laboratory whose skill and perseverance made the Mariner II spacecraft successful. We especially thank M. Eimer, T. Harrington, K. Heftman, K. Hoyt, J. Martin, and W. Valentine of the Jet Propulsion Laboratory, and F. Schwarz, F. Weeks, and A. Ziolkowski of the Barnes Engineering Corporation for their contributions to this experiment.

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Microwave Radiometers

Earth-based measurements of the radio emission of Venus have indicated that the planet's temperature is approximately 600°K for wavelengths in excess of 3 cm. This temperature may be contrasted with infrared measurements of Venus, which yield values somewhat less than half those obtained by radio. The radio data, which are critical to our understanding of the Venusian environment, rest on terrestrial observations which suffer from lack of resolution and insufficient precision. Fly-by planetary probes offer the possibility of precision and resolution with modest radiometers. Accordingly, the Mariner II spacecraft was instrumented with a two-channel microwave radiometer operating at wavelengths of 13.5 and 19.0 mm (*1*). The radiometer's total weight was 22 lb. Its average power consumption was 4 watts; its peak power consumption was 9 watts.

The radiometers were of the crystal video type; the Dicke switching technique was used. Comparison horns, oriented to avoid pointing toward Venus and the sun, provided reference temperatures. The radiometers operated with a common antenna having a diameter of 48.5 cm. The pertinent equipment performance parameters are given in Table 1. The effective antenna gain was calibrated by using a black disk of known temperature whose angular size was designed to be approximately the size of Venus at encounter. This calibration was performed on Table Mountain near Wrightwood, Calif., in March 1962.

During the 110-day flight 23 noise calibrations were made, and thus the gain, base-level, and time constant performance of the radiometers could be monitored en route.

The radiometers were energized and the antenna scan motion was activated about 6½ hours before encounter. The scan motion had an angular extent of 123.5° and a nominal scan rate of 0.1° per second. The microwave radiometer beams first made contact with the planet Venus at 18:59 GMT (spacecraft time) 14 December 1962. During the next 35 minutes three scans across the planetary disk were obtained. The approximate angular extent of each scan was: scan 1, 10 deg; scan 2, 15 deg; scan 3, 10 deg. The altitudes at mid scan were: scan 1, 40,200 km; scan 2, 37,750 km; scan 3, 35,850 km. Scan 1 was located on the dark side, scan 2 was located near the terminator, and scan 3 was located on the light side.

Telemetered digital data points, presented as voltages as a function of time, are the basic data. The data must be corrected for a number of effects before they may be considered as yielding the microwave temperature distribution across the planet. Among these corrections are the more important effects of the post-detection time constant, and a detailed consideration of the antenna pattern.

The noise tube calibrations obtained en route to Venus have enabled us to determine the in-flight time constant and gain of the radiometers. The gain of both channels decreased during the cruise, and the zero levels had systematic variations. These effects were more serious in the 13.5-mm radiometer, and a more exhaustive analysis must be made before the results from this channel can be reported. Accordingly, we present now only a preliminary analysis of the 19-mm channel (*2*).

Preliminary estimates of the peak brightness temperatures of the three