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

Table 1. Radiometer characteristics.

Item and unit	Channel 1	Channel 2
Center wavelength (mm)	19	13.5
Center frequency (Gcy/sec)*	15.8	22.2
Predetection bandwidth (Gcy/sec)*	1.5	2.0
Sensitivity, rms (°K)	15	15
Calibration signals (°K)	1500	800
Time constant (sec)	40	40
Beamwidth (deg)	2.5	2.2
Side lobes (db)	−23	−23
Reference frequency (Cy/sec)	950	1050

* 1 Gcy = 1 gigacycle = 10^9 cycles.

scans follow. (The temperatures are based on calculations which account for the effects of the antenna beam and the post-detection time constant.) For scan 1 (dark side), 460°K; for scan 2 (near terminator), 570°K; for scan 3 (light side), 400°K. The errors of the quoted temperatures are estimated to be 15 percent.

The possibility of interference between the Mariner radiometer data channels is being investigated. This effect is not expected to alter significantly the tentative conclusions we have given. To date, the analysis of the preliminary results suggests that there is no significant difference in the microwave temperatures on the light and dark sides of the planet. In addition, the results suggest a limb darkening, an effect which presents cooler temperatures near the edge of the planetary disk. The ionosphere model of Venus, which permits earth-like temperatures, appears to be ruled out by these observations. On the other hand, the observed limb darkening is consistent with a model of the Venusian environment which has high temperatures originating deep in the atmosphere or at the surface of the planet.

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1. The radiometer was designed and built at the Jet Propulsion Laboratory. It was based on a larger, four-channel flight instrument developed by the Ewen Knight Corp.
2. A detailed report is in preparation.

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Magnetic Field

Abstract. *Mariner II magnetometer data gave no indication of a Venusian magnetic field. This implies, by comparison with spacecraft measurements near Earth and with theoretical models, that the magnetic dipole moment of Venus is at most 1/10 to 1/20 that of the earth.*

Magnetometer data, obtained as Mariner II passed Venus, gave no evidence of a Venusian magnetic field at any point on the trajectory. No rise in the average value of the magnetic field above the value of the interplanetary field was detected which could be attributed to the planet. The sensitivity of the magnetometer is such that a field change as large as about 4 gamma on any axis would have been detected. (One gamma is 10^{-5} gauss. The magnitude of the earth's field at the equator is about 30,000 gamma.) During encounter, a slow change no larger than about 10 gamma was observed. However, this change should be attributed to a temporal change in the interplanetary magnetic field because it did not have the character of a planetary field. We did not detect the continuous fluctuations with periods from 1 second to 1 minute and amplitudes of the order of 3 gamma, that seem characteristic of the interplanetary region just outside the geomagnetic field. Simultaneous measurements by other Mariner experiments also failed to reveal any effect associated with a planetary field such as trapped particles or a modification in the flow of solar plasma (*1*).

These results do not necessarily mean that Venus has no magnetic field, for the solar wind would confine a weak field to a limited region close to the planet (*2*). The observations indicate that the field does not extend out to the Mariner trajectory, for which the distance of closest approach from the center of Venus was approximately 41,000 kilometers. The results are consistent, however, with the possibility that Venus has no magnetic field.

Since the planetary field does not extend out to the Mariner trajectory, an upper limit for the magnetic dipole moment of Venus can be estimated. Theoretical models of the interaction of the solar wind with a dipole magnetic field, including a crude estimate of the extent of the disturbed region outside the magnetosphere, indicate that the dipole moment of Venus, if it is approximately perpendicular to the Sun-Venus line, is less than 1/10 that of the earth. Comparison of the measurements made near Venus with those made by other spacecraft near the earth leads us to the conclusion that the dipole moment of Venus is less than 1/10, or perhaps 1/20, that of the earth. If the dipole moment of Venus is the dominant field source, the magnitude of the surface field is less than 5 to 10 percent of the geomagnetic surface field. If Venus has a more complicated magnetic structure than the earth, so that higher-order multipoles are important, the surface field in places could be larger than the earth's field without increasing the strength of the field along the Mariner trajectory to an observable value.

Phenomena associated with the geomagnetic field, such as the trapping of particles in radiation belts and the aurora, are likely to be greatly modified, less important, or completely absent on Venus because of its weaker field. The cosmic ray flux at the top of the Venus atmosphere may everywhere correspond to the high level found on earth only in the polar regions.

The Mariner data now add Venus to the other members of the solar system whose magnetic properties are partially known. Recent interpretations of the polarized radio noise from Jupiter indicate that the magnetic field of the surface is 5 gauss (*3*). The Lunik II magnetometer showed that the surface field of the moon, on the sunlit hemisphere, is less than 100 gamma (see *4*).

Jupiter rotates rapidly, twice in an earth day, and is 10 times as large as the earth. The moon rotates once each 28 days, and astronomical observations indicate that Venus, too, may be rotating slowly. These observations suggest that planets and satellites that rotate much less rapidly than the earth have small magnetic fields. This is consistent with theories (*5*) which ascribe planetary magnetic fields to a dynamo action inside the molten core of a rotating planet (*6*).

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