This summer one of the most versatile scientific experiments ever assembled will be flown as the Mariner P-37 and P-38 spacecraft in

Venus Mission—1962

BY ROBERT C. WYCKOFF

JET PROPULSION LABORATORY, PASADENA, CALIF.

THIS SUMMER, under NASA sponsorship, the Jet Propulsion Laboratory plans to send the first of a series of scientifically instrumented spacecraft to the planet Venus. For reliability and coverage, this Venus-probe mission will comprise two identical spacecraft—Mariners P-37 and P-38—which will be capable of making a close approach to the planet. The mission has three primary objectives:

- Launching a spacecraft to the vicinity of Venus.
- Communication with the spacecraft in the vicinity of this planet.
- Performing a Venus-oriented scientific experiment and others oriented toward interplanetary space.

Experiments fall into three areas:

1. Close to Venus, to give information about it and its atmosphere.
2. In the vicinity of Venus, to give information on its environment out to about 10 or 20 planetary radii.
3. Between earth and Venus.

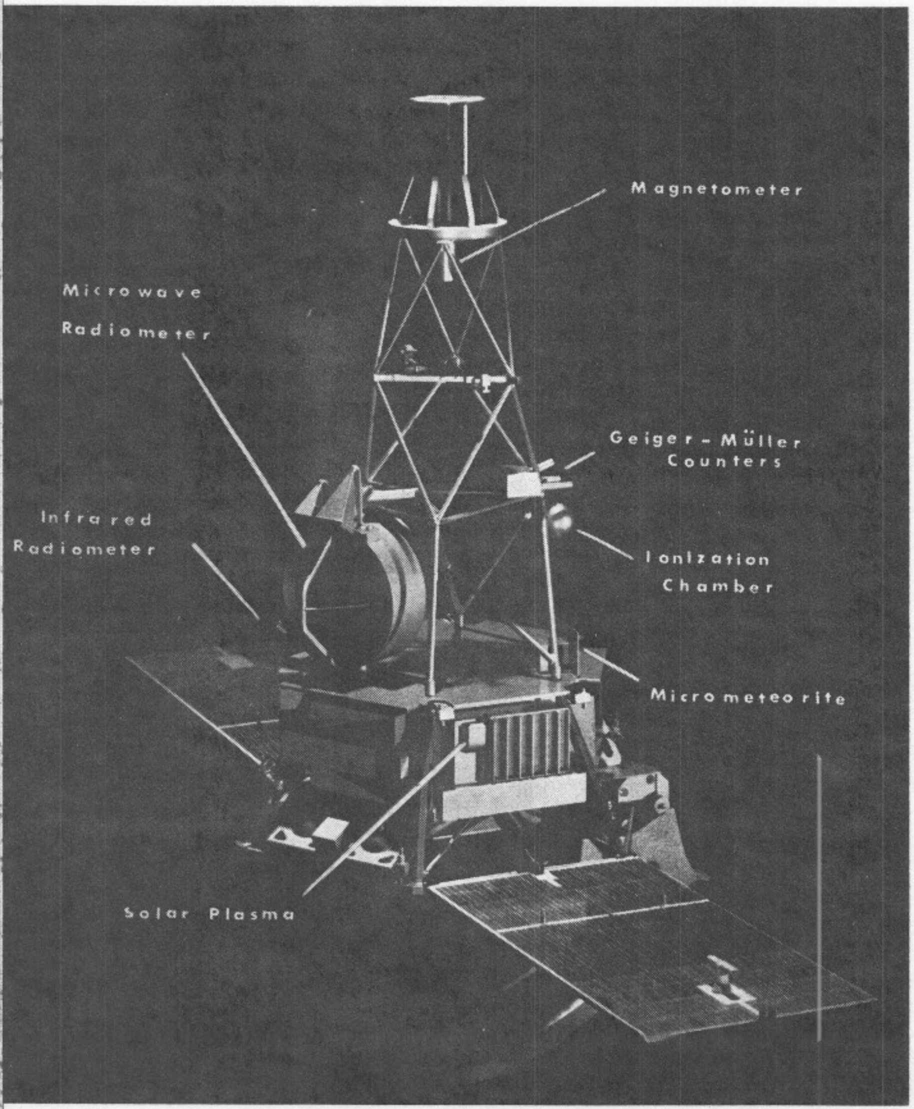
Area 1 experiments involve a microwave and an infrared (IR) radiometer. Areas 2 and 3 involve a magnetometer and various instruments to measure the flux of charged particles and the spatial and temporal density of cosmic dust.

Dynamic range of the interplanetary experiments will permit investigation of phenomena caused by solar disturbances, besides the quiescent interplanetary environment.

In addition, since the mission will extend over a radial distance of some 0.3 A. U., there will be the opportunity to measure any radial variation of the interplanetary magnetic field and charged-particle flux. The possibility of making simultaneous measurements of these quantities on two spacecraft widely separated in space, and at varying distances from the sun and at different solar longitudes, is extremely interesting scientifically. The results of such measurements may well play a crucial part in understanding the origin of these phenomena, the mechanism of their propagation, and their spatial and temporal variations.

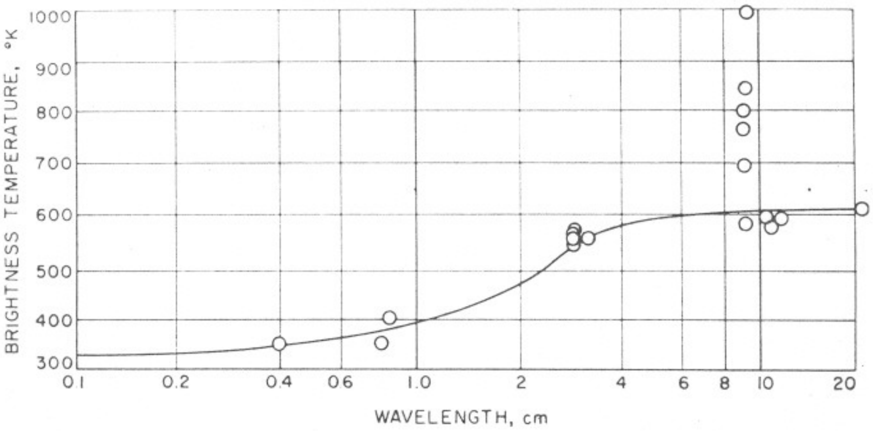
Seven distinct scientific experiments will be flown in the mission, as called out on the Mariner model on this page. They have been proposed by and are under the direction of scientists from the Army Ordnance Missile Command, the Univ. of California-Berkeley, CalTech, NASA Goddard SFC, Harvard Observatory, State Univ. of Iowa, JPL, MIT, State Univ. of Nevada, and NASA Headquarters.

Placement of experiments on Mariner for this summer's Venus flyby.



MICROWAVE BRIGHTNESS-TEMPERATURE MEASUREMENTS OF VENUS

Wavelength, cm	Brightness Temp., K	Date of Observation	Reference
3.15	560 ± 73	May 5–June 23, 1956	1, 2
9.4	580 ± 160	June 24–July 27, 1956	1, 2
0.86	410 ± 160	Jan. 29–Feb. 5, 6, 11, 1958	3
3.4	575 ± 60	Feb. 12–March 5, 1958	4
3.37	575 ± 58	April 18–April 19, 1958	5, 6
0.80	3.5 ± 70	Sept. 18, 1959	7
3.75	573 ± 28	July 7–Oct. 4, 1959	8
10.2	600 ± 65	Sept. 17–Oct. 10, 1959	4
0.4	350 ± 50	1961	9
3.15	550 to 620	April–June 1961	10
9.6	850 ± 50	April 3, 1961	11
—	1000 ± 150	April 4, 1961	11
—	700 ± 100	April 5, 1961	11
—	775 ± 70	April 21, 1961	11
—	800 ± 50	April 22, 1961	11
10.2	580 ± 636	April–July 1961	12
12.5	590 ± 200	1961	13
21	630 ± 130	March 8, 9, 10, 13, 1961	14



As might be imagined, the most important are the radiometric experiments, designed to give data on the planet and its atmosphere.

Microwave Radiometer. Venus' surface temperature and the nature of its atmosphere stand high among the most interesting and puzzling questions in the entire field of planetary astronomy. Direct experimental evidence bearing on them is meager and in certain respects contradictory. Experiments that may resolve these questions were considered first.

Temperature measurements of Venus have been made from earth by both IR and microwave techniques. The microwave measurements give consistently higher values. The combined graph and table at the right summarize results of these observations over the wavelength range 0.4 to 21 cm.[1-14]

The IR radiometric observations of Petit and Nicholson,[15] in the 8- to 13-micron terrestrial window, and of Sinton and Strong[16] indicate a temperature near 235 K, which presumably refers to a region near the top of Venus' cloud layer.

The temperature from the spectroscopic rotational band analysis of the 7820 Å CO_2 band is about 285 K, based on Chandrasekhar's radiation-transfer theory.[17] A direct application of the Boltzmann theory gives a temperature of over 300 K.[18] These temperatures probably refer to the top of the visible cloud layer or below. The microwave data, which give temperatures hundreds of degrees higher, obviously refer to quite a different region, most probably Venus' surface.

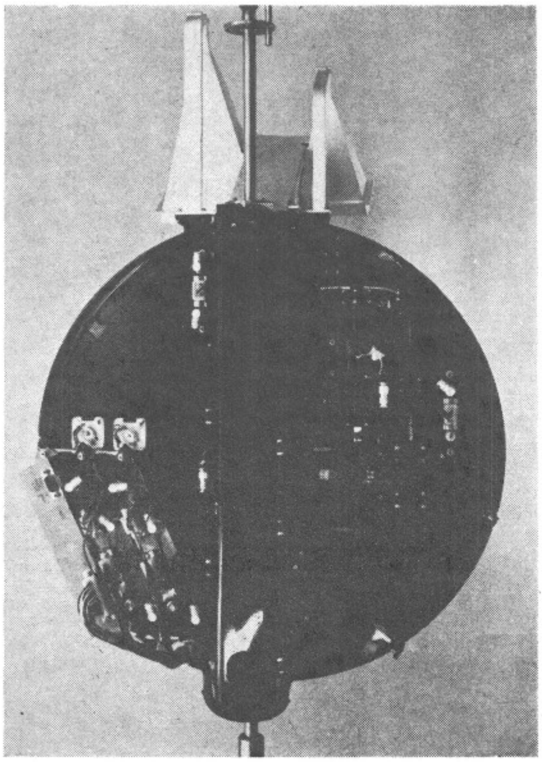
The IR temperature measurements indicate a very small difference between the dark and light portions of the planetary disk, but there is strong evidence that this does not hold for microwave measurements. At the same inferior conjunction, some investigators have found a distinct phase effect, while others have not. Even more puzzling, the same investigators have found a phase effect at one conjunction but not at another. Moreover, the Russians find a day-to-day variation of as much as 100 to 150 K.[11]

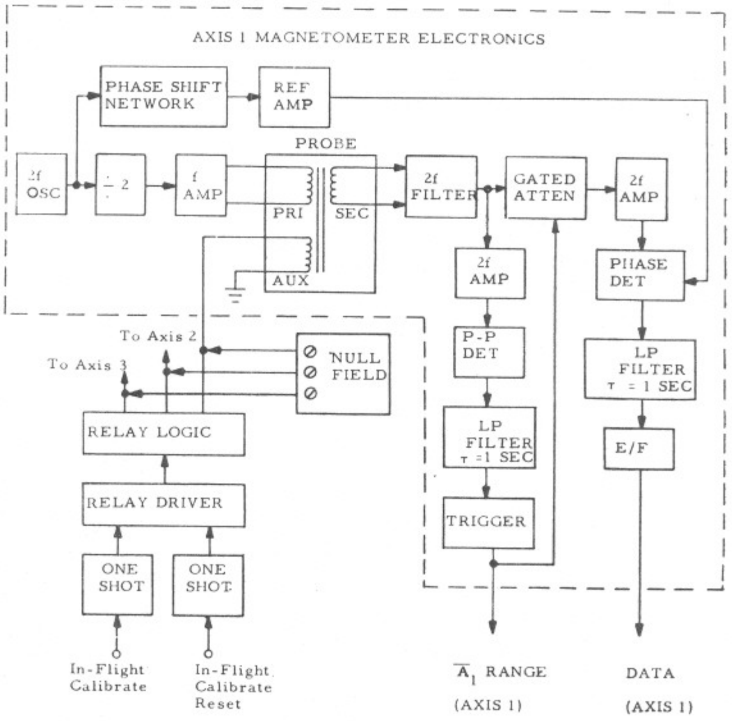
All-in-all, the question of Venus' surface temperature and atmospheric composition is in great turmoil; and a number of atmospheric models have been formulated. The Mariner microwave and IR radiometric experiments should allow either a distinction among existing atmospheric models or formulation of the correct one. The surface temperature of Venus is of most popular interest. It is hoped that this, in addition to other knowledge of the nature of our mysterious neighbor, will be gained.

Ideally we should make microwave measurements at as many wavelengths as possible, so as to determine the form of the wavelength-vs.-temperature curve in the transition region from short-mm to short-cm wavelengths (see graph with table at top here). Sufficiently small angular resolution, coupled with an appropriate scan pattern, will allow the planetary disc to be scanned across the terminator. Thus any phase effect can be determined, as well as any changes in temperature and emissivity over the surface. It is expected that the longer of two wavelengths selected—13.5 and 19 mm—will get through the atmosphere from the surface. Weight and power limitations do not allow the inclusion of more than these two wavelengths.

The photo on page 56 shows a rear view of the microwave radiometer, a crystal video type, which does not tie up weight in RF mixers or IF amplifiers. This instrument should give an rms noise level less than 3% of the expected antenna temperature.

One antenna will operate simultaneously at both wavelengths. It will be calibrated through a secondary standard in the form of a noise discharge tube, combined with a cold space reading. The antenna beam widths are 2.2 and 2.5 deg, respectively, at the 13.5- and 19-mm wavelengths. Sidelobe power due to energy from the sun will be negligibly low compared with the planet's. The output signal can range between +1 and +6 v DC with the zero temperature level set at +1 v and the +6-v level corresponding to a temperature of 1000 K. The voltage fluctuations





NOTE: Functions in phantom are triplicated.

If all goes well, results from the spacecraft's microwave and infrared radiometer experiments will give the true surface temperature of Venus and allow a sounder hypothetical description of the planet. Left, the microwave radiometer as seen from the rear; and right, a block diagram of its electronics.

at the output correspond to about 50 K peak to peak.

This radiometer will begin to operate a few hours before the spacecraft's closest approach to Venus. It will first run a searching pattern 60 deg above and 60 deg below a plane defined by the earth, spacecraft, and the sun—a plane approximately parallel to the ecliptic and perpendicular to the spacecraft-sun vector. The initial scan rate will be a degree a second. As the spacecraft approaches the planet, the microwave-radiometer antenna beam will contact the near planetary limb. Then the scan rate will drop to 0.1 deg/sec; and when the antenna beam has passed 5 deg off the limb, the scan direction will reverse. This reduced and "locked-on" scan pattern then continues until the planetary disc is lost through the motion of the spacecraft.

If the planetary disc is accidently lost during this slow scan mode, provision is made for a return to the initial fast scan-search mode until the disc is again acquired. Thus a sinusoidal-like path will be scanned on both the light and dark parts of the planetary disc, the number of periods of which will depend on the distance the spacecraft passes the planet.

IR Radiometer. This completes the experimental package designed to obtain information on Venus' radiation. IR radiation can come from the planetary surface, clouds in the atmosphere, or a combination of both. Two wavelength regions will be investigated—8 to 9 microns and 10 to 10.8 microns. A higher angular resolution will be possible with this experiment than with earth-based ones, and this should help detect any fine cloud-layer structure above a certain minimum.

Earth-based measurements indicate a Venus temperature in the 8- to 13-micron region of about 235 K, with a short-term (daily) fluctuation.[16,19] In the 8- to 9-micron region, the common gases are fairly transparent at temperatures of 200–300 K. A CO_2 absorption band that has been detected in Venus' spectrum centers at 10.4 microns.

The two wavelength channels observe the same area on the planet.

If radiation comes entirely from the cloud tops, the effective temperatures derived from the two channels will be the same, after appropriate corrections for any CO_2 above the cloud layer. A 1% break in a 235-K cloud cover over a 600-K surface will change the energy in the 8- to 9-micron channel by a factor of 2, while the CO_2 absorption in the 10- to 10.8-micron channel will lead to a smaller energy change.

The IR radiometer attaches rigidly to the microwave radiometer antenna, with optic and antenna axes aligned parallel, and so follows the scan pattern of the microwave radiometer. It will be turned on at the same time as the microwave radiometer. Its angular field of view is a 0.9-deg square. The detectors are uncooled, germanium-immersed thermistor bolometers with a sensitive area of 0.15 by 0.15 mm. The $f/2.4$ optical system utilizes a germanium objective. The incident beam is chopped at a frequency of 20 cps, which alternately allows the detectors to see the planet and free space through a similar optical system but with its axis displaced 45 deg from the other.

After being chopped, the beam is split into two perpendicular beams by a dichroic filter. Appropriate filters then define the two wavelength regions. A schematic diagram of the instrumentation appears on page 57. At the end of each complete fast-scan sweep, the IR detectors view a plate at a known temperature on the spacecraft superstructure and thus can be calibrated.

Magnetometer. There is practically no direct experimental evidence of a magnetic field for the planet Venus. The most commonly accepted explanation of the origin of a planetary magnetic field involves fluid motion in a fluid planetary core. Detecting a magnetic field for Venus would play an important part in determining the origin and nature of the planetary interior. Moreover, the properties and dynamics of the atmosphere in relation to charged particles, magnetic storms, and auroras depend heavily on knowledge of any magnetic field.

Whether Venus has a magnetic field can be established by observing a transition region from interplanetary space to the immediate vicinity of the planet. This transition, called the magnetopause, separates a planetary magnetic field from the ionized component of the interplanetary medium. It is thought that a planetry magnetic field, owing to the so-called "solar wind," will be distorted in the radial direction to the sun, being compressed toward the sun and elongated away from it.[20-23] Thus a planetary magnetic field appears to be confined to a sort of streamlined cavity inside the interplanetary gas. Observation of such a boundary would constitute evidence of a planetary magnetic field. In addition, the magnitude inside such a boundary and the distance from the planet would permit an estimate of the magnetic field at the surface, assuming a known origin.

The Venus-probe magnetometer will allow direct measurements to be made of the interplanetary magnetic field, its variations with distance from the sun, short-term variations caused by solar activity.

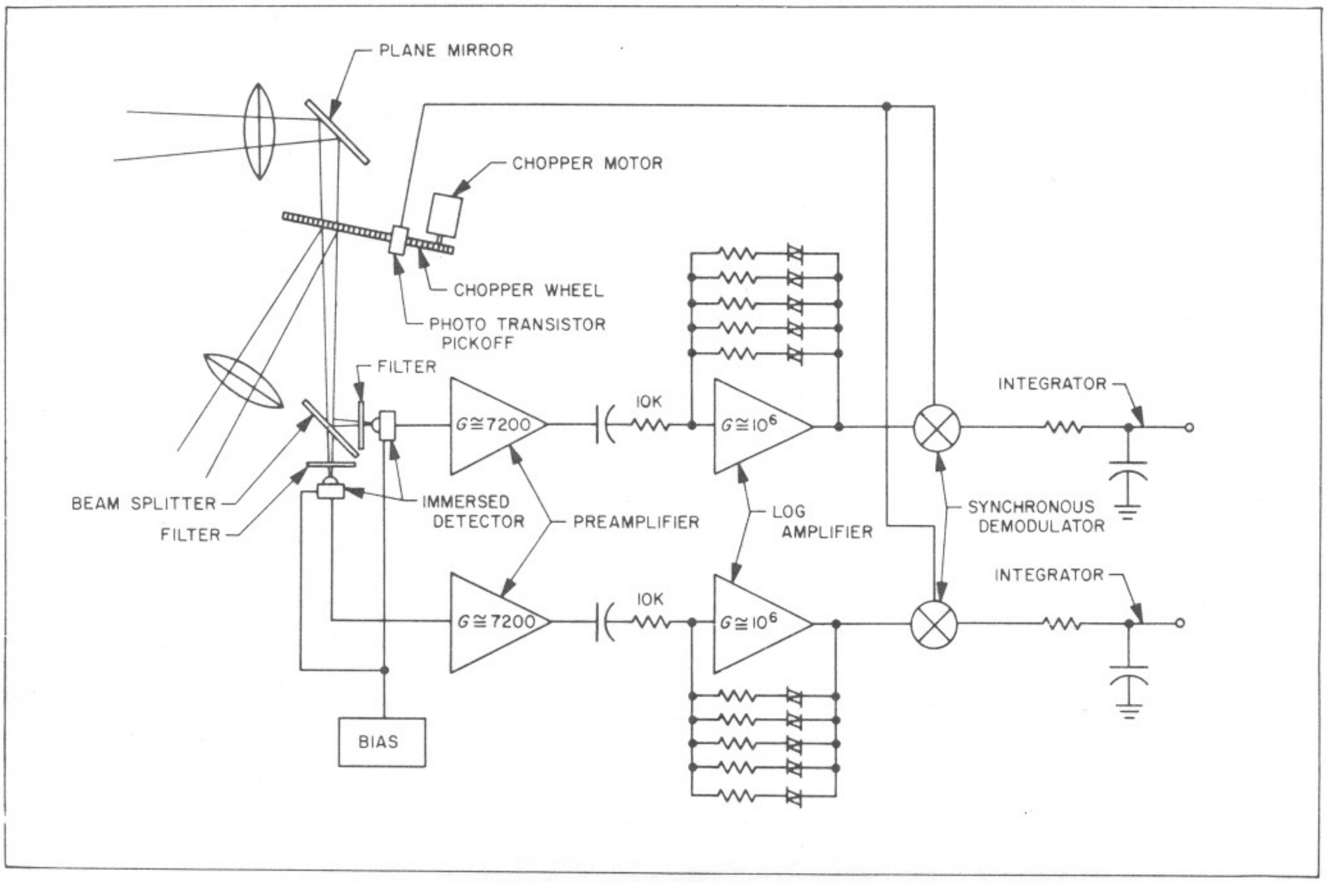
SHOWN DIAGRAMMATICALLY on page 56, magnetometer, is a triaxial fluxgate type. The sensing element is a magnetic core containing primary and secondary windings. An alternating current of 20 kc/s is applied to the primary winding sufficient to saturate the core material. Any external magnetic field with a component parallel to the axis of the core then induces a signal in the secondary winding, which contains the second harmonic of the signal impressed on the primary winding. The amplitude of this second harmonic component is proportional to the magnitude of the external magnetic-field component.

The noise appearing in the magnetometer is equivalent to a fluctuating magnetic field of approximately 0.25 gamma (1 gamma = 10^{-5} oersted). There are two scale ranges, 0 to ±64 gamma and 0 to ±320 gamma. On the low range the sensitivity is about 0.6 gamma. A system of coils surrounds each sensor, by which the component of any induced or permanent field of the spacecraft can be counteracted. These coils can "compensate" for a magnetic field component up to 100 gamma.

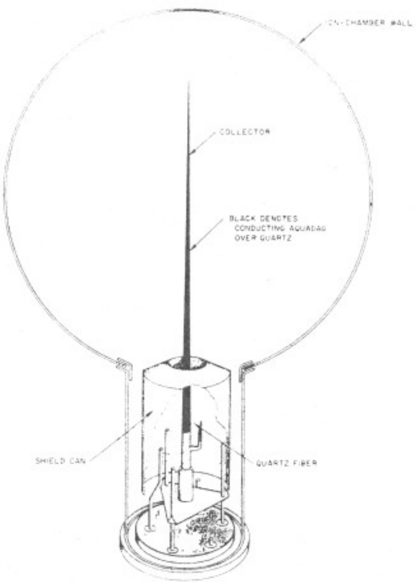
Charged-Particle-Flux Experiments. These experiments will allow measuring high-energy radiation for a long time over a significantly varying distance from the sun. They will be helpful in understanding the nature, origin, and behavior of this radiation. Three specific areas of interest will be investigated.

1. Variation with distance. This spatial variation of cosmic rays depends on the mechanism by which the sun's activity modulates both the frequency and intensity of this radiation

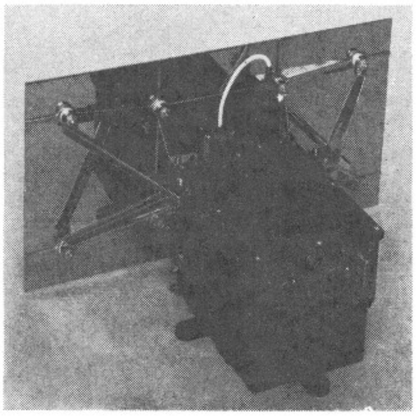
SCHEMATIC DIAGRAM OF THE INFRARED RADIOMETER



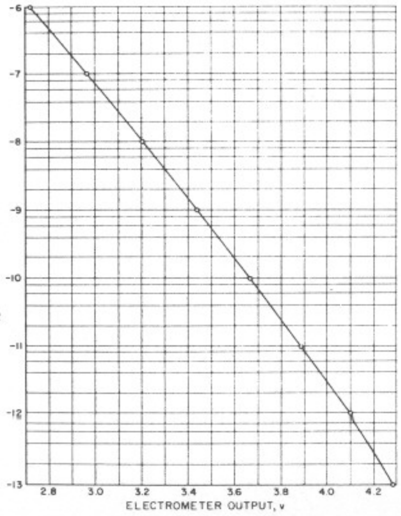
IONIZATION CHAMBER



MICROMETEORITE DETECTOR



ELECTROMETER CALIBRATION CURVE FOR SOLAR-PLASMA EXPERIMENT



and condition of the interplanetary medium.

2. Variation with time. The cosmic-ray intensity will vary at the spacecraft and at the earth during the same period of observation. This variation and the energies of the particles depend on the distribution of the magnetic field and plasma between the earth, the spacecraft, and the sun.

3. Any radiation trapped near Venus. This would depend on origin of the radiation and magnitude of any magnetic field of Venus.

A. *Ionization Chamber.* This instrument is of the Neher type and consists of a volume of argon gas considered in a spherical metal shell. An insulated collector extends into the gas as shown in the figure at top left. A potential is established between this collector and the shell. Any radiation penetrating into the gas produces ionization in the argon gas. Ions collect at the insulated collector and the shell, gradually reducing their potential difference. When the collector has been discharged to a certain level, it is automatically recharged.

Thus the number of times the collector recharges in any specified interval measures the rate of ionization of the argon gas. The collector is recharged after about 10^{-10} coulombs have been collected from the gas. The shell can be penetrated by protons of 10-Mev energy or greater and by electrons with energy greater than 0.5 Mev. For alpha particles the value is about 40 Mev. Electrons with less energy may still be detected through the bremsstrahlung process, with an efficiency depending on their energy.

The ionization of the gas is related to the recharging pulse frequency by the equation $I = k/\Delta t$ where k is a constant and Δt is the time between pulses. The instrument obeys this equation for a time region $5 \times 10^4 > \Delta t > 0.05$ sec to within about 2%.

The instrument will give measurements with the Δt as small as 0.01 sec. Ionization due to galactic cosmic rays probably lies between 100 and 1500 ion pairs $\text{cm}^{-3}\text{sec}^{-1}\text{atm}^{-1}$. The ionization may rise to more than 400,000 ion pairs during a solar flare. Corresponding values of Δt are 3600, 240, and 0.9 sec.

B. *Geiger-Mueller Counters.* In contrast to the ionization chamber, these well-known devices produce a current pulse every time a charged particle traverses any part of their sensitive volume. The pulse rate is thus proportional to the number of charged particles encountered. Triggering the counters will be primary particles that penetrate its walls, secondary particles produced in its walls and gas, and secondary particles produced in the adjacent material of the spacecraft.

Two RCL 10311 G-M counters and one Anton 213 are being flown on this mission. The RCL 10311's are shielded so as to detect protons with energies of 10 Mev and 0.5 Mev for electrons. Differently shielded, these two counters will allow a distinction to be made between protons and electrons through the bremsstrahlung effect in each tube. It is expected that the galactic cosmic-ray background will produce about 15 counts/sec. The RCL counters have a maximum counting rate of 45,000 sec^{-1}.

The Anton 213 G-M counter, an end-window type, admits electrons with energies greater than 40 Kev and protons with energies greater than 0.5 Mev. A shield defines the solid angle of entrance to the window. The remainder of the tube is shielded so as to admit electrons with energies greater than 1 Mev and protons with energies greater than 20 Mev. The normal galactic cosmic-ray count with this tube should be about one count every 5 sec. Its maximum counting rate is 20,000 sec^{-1}, which corresponds to a maximum resolvable rate of about 10^7 true counts per sec. This tube is mounted so that the window cannot view the sun.

Cosmic Dust Experiment. A knowledge of spatial and temporal density of cosmic dust between earth and Venus will be of great importance both for design of future manned and unmanned spacecraft and for understanding the sources and dynamics of these interplanetary particles. This experiment aims to measure cosmic dust as a function of direction, distance from the sun, and momentum with respect to the spacecraft. In addition, it is desired to investigate any concentration of these particles into streams. Pronounced time variations of the particle flux near the earth have been reported.[24,25] Concentrations of cosmic dust are thought to be dispersed by the Poynting-Robertson and other drag effects, as well as by the cumulative effects of small differences in the orbital elements of the individual particles. Thus any large concentration of particles will probably be of relatively recent origin.

The instrumentation consists of a crystal-transducer microphone attached to the center of a flat rectangular plate. The microphone is tuned to 100 kc/s, with an over-all gain of 100 db. A binary counter records this amplifier's pulse rate. A second binary counter receives its input from a point in the amplifier of 20-db-less gain. The threshold sensitivity of the detector varies as a function of the impact location on the plate, and lies between 0.9×10^{-4} and 1.1×10^{-4} dyne sec over 99% of the exposed area of the plate, with the heater sensitivity at the center over the microphone. The flux values measurable lie betwen 1.5 and 2.8 impacts m^{-2} sec^{-1}.

Solar Plasma. This experiment is designed to measure the flux and energy spectrum of the *positively charged* component of streams of solar plasma which may be moving radially outward from the sun. The existence of this solar plasma, or "wind," has been of course a fairly recent discovery and the mechanism of its origin and the dynamics of its movement are of the greatest importance. The results from the magnetometer experiment must be considered in the analysis and interpretation of this experiment.

The instrument is a charged-particle spectrometer with a logarithmic response covering the range of energies from 240 to 8400 ev for protons.

The plasma analyzer consists of a pair of curved plates, electrically charged with respect to each other, that selects the charged particles of desired energy, a Faraday cup which collects the charge of the particles traversing the electrostatic field between the plates, an electrometer circuit for measuring the current due to this collected charge, and a high-voltage generating system which applies voltages in sequence to the analyzer plates. The plates have an angular length of 120 deg with radii of curvature of 3.97 and 4.50 in.

The analyzer has, effectively, a 10-deg angular resolution and a 12% energy resolution. The high-voltage supply is programmed to apply 10 progressively greater deflecting voltages to the plates. The electrometer circuit, utilizing logarithmic feedback, can measure currents from 10^{-6} to 10^{-13} amp—a fair dynamic range.

A typical calibration curve appears on page 58. The linearity of the response over this dynamic range is remarkable. Provision is made for a "zero current" measurement by holding both collecting plates at zero voltage, as well as for a calibrating current of 10^{-10} amp fed directly to the electrometer input through a constant-current source.

We will always want to fly more equipment, and more complex equipment, than circumstances permit. For the Mariner mission to Venus this year we have designed a logical, integrated payload with the emphasis allocated according to the importance of the scientific questions to be asked, and the expectation of getting the answers. Mariners P-37 and P-38 represent one of the most versatile scientific experiments ever assembled.

References

1. Mayer, C. H., McCullough, T. P., and Sloanaker, R. M.; *A. J.*, Vol. 127, p. 1 (1958).
2. Mayer, C. H., *A. J.*, Vol. 64, p. 43 (1959).
3. Gibson, J. F. and McEwan, R. J., Paris Symposium on Radio Astronomy, editor Bracewell, R. N. p. 50, Stanford Univ. Press (1959).
4. Mayer, C. H., McCullough, T. P., and Sloanaker, R. M., Paper presented to the XIII General Assembly, URSI, London Sept. 5-15 (1960).
5. Alsop, L. E., Giordmaine, J. A., Mayer, C. H., and Townes, C. H., *A. J.*, Vol. 63, p. 301 (1958).
6. Alsop, L. E., Giordmaine, J. A., Mayer, C. H., and Townes, C. H., Paris Symposium on Radio Astronomy, editor, Bracewell, R. N. p. 69, Stanford Univ. Press (1959).
7. Kuzmin, A. D. and Salomonovitch, A. E., *Astr. Zhir.* Vol. 37, p. 297 (1960).
8. Drake, F. D., *Publ. Natl. Radio Astr. Obs.*, No. 11, Vol. 165 (1962).
9. Grant, C. R., Private Communication.
10. Mayer, C. H., Private Communication.
11. Kuzmin, A. D. and Salomonovitch, A. E., *Astron. Tsirkulyar*, No. 22, -3,-5 (1961),
12. Drake, F. D., Private Communication.
13. Stevens, R., Victor, W. K., and Golomb, S. W., JPL Tech Report 32-132, Aug. 1, 1961.
14. Lilley, A. E., *A. J.* (in print).
15. Petit, E. and Nicholson, S. B., *Pub., A.S.P.*, pp. 67-293 (1955).
16. Sinton, W. M. and Strong, J., *Ap. J.* pp. 131-470 (1960).
17. Chamberlain, J. W., Kuiper, G. P., *Ap. J.*, Vol. 124, p. 399 (1956).
18. Spinrad, H., Private Communication.
19. Sinton, W. M., Private Communication.
20. Axford, W. I. and Hines, C. O., *Can. J. Phy.*, Vol. 6 (1961).
21. Piddington, J. H., *Geophy, J.*, Vol. 3 (1960).
22. Piddington, J. H., *J. Geophy. Res., Vol.* 65 (1960).
23. Johnson, F. S., *J. Geophy. Res.*, Vol. 65 (1960).
24. Nazarova, T. N., Proceedings of the Ist International Space Science Symposium, Nice Jan. 11-16, 1960 editor, Kallmann-Bijl, H., North Holland Publishing Co., Amsterdam.
25. Alexander W. M. McCracken, C. W., and LaGow, H. E., *J. Geophy. Res.*, Vol. 66 (1961).

Acknowledgment

This paper presents the work of one phase of work conducted at the Jet Propulsion Laboratory and sponsored by the National Aeronautics and Space Administration under contract NAS 7-100.

◆◆