References and Notes

1. D. Atlas, K. R. Hardy, T. G. Konrad, *Proc. Weather Radar Conf. 12th* (Amer. Meteorol. Soc., Boston, in preparation).
2. K. S. Zhupakhin, *Glavnaia Geofiz. Observ. Tr. No. 177*, p. 129 (1965) [*Res. transl. TR-629* (Air Force Cambridge Res. Labs., Bedford, Mass., 1966)].
3. K. R. Hardy, D. Atlas, K. M. Glover, *J. Geophys. Res.* **71**, 1537 (1966).
4. V. I. Tatarski, *Wave Propagation in a Turbulent Medium* (McGraw-Hill, New York, 1961).
5. D. Atlas, K. R. Hardy, K. Naito, *J. Appl. Meteorol.*, in press.
6. P. B. MacCready, Jr., R. E. Williamson, S. Berman, A. Webster, "Operational application of a universal turbulence measuring system," *NASA Rept. CR-62025* (Meteorology Research, Inc., Altadena, Calif., 1965).
7. D. Atlas and K. Naito, *Proc. Weather Radar Conf. 12th* (Amer. Meteorol. Soc., Boston, in preparation).

8. Work supported by the laboratory director's fund, Air Force Cambridge Research Laboratories, and by NASA. We thank Jack Howard, Wallops Island, and his staff for their assistance.

22 June 1966

Mercury: Infrared Evidence for Nonsynchronous Rotation

Abstract. *An infrared observation of the dark side of Mercury made by Pettit and Nicholson in 1923 led them to suggest that the planet rotates nonsynchronously. Their early measurements, if taken at face value, would imply a brightness temperature of about 180°K for the dark side. The asymmetry of the infrared phase curve is further interpreted as suggesting direct rotation.*

Radar observations at the Arecibo Ionospheric Observatory by Pettengill and Dyce (*1*) indicate that Mercury rotates with a direct nonsynchronous period of 59 ± 5 days. Peale and Gold (*2*) showed that this could have been theoretically expected as a consequence of solar tidal torque acting along an eccentric orbit.

Pettit and Nicholson (*3*) reported an observation of Mercury which they correctly interpreted as indicating nonsynchronous rotation. The observation was probably made on 21 June 1923, with an infrared-sensitive (*8–14* μ) thermocouple receiver at the focus of the 100-inch (2.5 m) Mt. Wilson reflector. The phase angle i (the planetocentric angle between Earth and Sun) and fractional illumination k of the planet were about 110°W and 0.32, respectively. The diameter of the planetary image was 0.55 mm, while that of the thermocouple receiver was 0.40 mm.

The authors had no absolute calibration at the time, but measured only a deflection from the thermocouple. The receiver was centered on the illuminated crescent, giving a maximum free deflection of 132.2 mm, the crescent intersecting 50 percent of the receiver. The receiver was moved close to the convex limb of the crescent (position A in Figure 1) and a deflection of 1.5 mm was obtained as a dark sky reading. But when the receiver was brought to the same distance from the terminator, approaching from the darkened side (position B), a deflection of 4.0 mm was obtained.

However, if the rotation of Mercury were synchronous, the thermal emission from the dark side would have been near the detection threshold of the thermocouple and should have caused about the same deflection as the dark sky reading at position A. But in fact the deflection for position B was greater, and the investigators suggested that "any radiation from the dark side of Mercury is an indication of a short rotation period. . . ."

Subsequently, Antoniadi (*4*) and others, using extensive optical observations of Mercury, reestablished the older view that the planet rotated in synchronism with the sun, and the scientific community was generally convinced. Apparently no one thereafter sought thermocouple data for the dark-side of Mercury.

Pettit and Nicholson (*5*) later developed a system of absolute calibration, from which it could be determined that the total energy (E) radiated from Mercury and arriving outside Earth's atmosphere on 21 June 1923, was $E = 218 \times 10^{-12}$ cal cm^{-2} min^{-1}, normalized for the planet at mean distance from the sun and at one astronomical unit from the earth. This value was based on observations with a larger thermocouple receiver that covered the entire disk of Mercury, but it can be used here to derive an approximate value for the brightness temperature of the dark side. First, recalling the 1.5-mm dark-sky reading, we define an "effective deflection"

$$D = (d - 1.5)/f$$

where d is the observed deflection in millimeters and f is the fraction of the thermocouple receiver actually used to measure the region of interest. The illuminated crescent, the dark portion, and the entire disk of the planet may be designated by subscripts 1, 2, and 3, respectively. We then have $d_1 = 132.2$, $d_2 = 4.0$, $f_1 = 0.50$, and

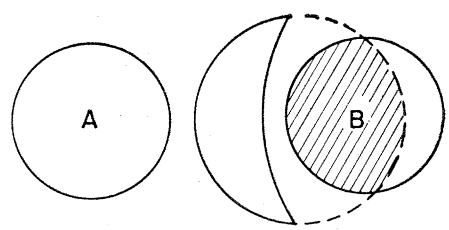

Fig. 1. Positioning of infrared receiver with respect to crescent of Mercury by Pettit and Nicholson (*3*). Dark sky observed at A and portion (*shaded*) of unilluminated hemisphere at B.

(as may be shown, with $k = 0.32$ together with the relative areas of the planetary and thermocouple disks) $f_2 \approx 0.75$ (that is, the shaded portion of region B in Fig. 1). Therefore $D_1 = 261.4$ and $D_2 \approx 3.3$. The effective deflection corresponding to the entire disk is

$$D_3 = kD_1 + (1 - k)D_2 = 85.8$$

The surface brightness temperature T_3, which corresponds to this deflection, can be computed from the normalized radiant energy E received from the entire planet according to

$$E = \sigma R^2 T_3^4$$

where σ is the Stefan-Boltzmann constant and R is the radius of Mercury in astronomical units. With unit emissivity, the result is $T_3 = 316$°K.

Knowledge of the mean temperature corresponding to D_3 now allows a determination of the dark side surface temperature responsible for D_2. The effective deflection is proportional to that part of the blackbody energy which penetrates the earth's atmosphere, and thus depends upon the temperature of the radiating surface according to

$$D(T) = S \int_{3\mu}^{24\mu} B_\lambda(T)\, E_\lambda \, d\lambda$$

where $B_\lambda(T)$ and E_λ are, respectively, the blackbody intensity due to a surface at temperature T and the atmospheric transmissivity at wavelength λ. The constant S is characteristic of the detecting apparatus; its response is assumed to be uniform over the relevant range of wavelengths. The integration need not be over all wavelengths since B_λ (316°K) essentially vanishes for $\lambda < 3\mu$.

The major part of planetary thermal radiation comes through the 8 to 14 μ window, and the E_λ curve used for this range is that of Sinton and Strong

(*6*). For small amounts at shorter wavelengths, E_λ is taken from Pettit and Nicholson (*7*), while data from the much weaker window at 16 to 24 μ are from Adel (*8*). After several numerical integrations, a curve of $D(T)$ plotted against T is obtained and S is normalized so that D (316°K) $= D_3 = 85.8$. Then the brightness temperature of the portion of Mercury's unilluminated hemisphere observed in 1923 is simply the T coordinate of the curve where $D(T) = D_2 \approx 3.3$. The result, which depends slightly on the probable value assumed for the unspecified fraction f_2 of the thermocouple receiver used to measure the dark side, is $T_2 \approx 180$°K. If we take as probable bounds $0.95 > f_2 > 0.33$, the limiting results for this observation become 170°K $< T_2 <$ 205°K. However, the unobserved predawn portion of the dark side should have a yet lower temperature. The 180°K value already mentioned will undoubtedly be revised as further infrared observations are reported.

Epstein (*9*) derived a brightness temperature of about 200°K from 3.4-mm radio observations of Mercury when it was near inferior conjunction. The dark side temperature clearly exceeds 28°K, the maximum for the antisolar point computed by Walker (*10*) assuming synchronous rotation.

There is older evidence indicating the direction of Mercury's rotation. When the thermal energy received from the whole disk of the planet was plotted against phase angle *i*, the curve was markedly asymmetrical (*4*). Pettit (*11*) estimated that Mercury when west of the sun radiates 20 percent more energy than when east of the sun. Assuming synchronous rotation, he suggested that the side of the planet always toward the earth soon after western elongation was a more efficient blackbody, perhaps by being less mountainous. But this would require different polarizations and albedos between western and eastern phases, an effect which is not observed. Such an asymmetrical phase curve may perhaps be explained in terms of the direct rotation of Mercury, because the dark portion of the planet observed in western phases has recently rotated out of sunlight and is warmer than the corresponding dark portion in eastern phases.

STEVEN L. SOTER
Center for Radiophysics and Space Research, Cornell University, Ithaca, New York

References and Notes

1. G. H. Pettengill and R. B. Dyce, *Nature* **206**, 1240 (1965).
2. S. J. Peale and T. Gold, *ibid.*
3. E. Pettit and S. B. Nicholson, *Publ. Astron. Soc. Pacific* **35**, 194 (1923).
4. E. M. Antoniadi, *La Planète Mercure* (Villars, Paris, 1934).
5. E. Pettit and S. B. Nicholson, *Astrophys. J.* **83**, 84 (1936).
6. W. M. Sinton and J. Strong, ibid. **131**, 459 (1960).
7 E. Pettit and S. B. Nicholson, *ibid.* **71**, 102 (1930).
8. A. Adel, *J. Opt. Soc. Amer.* **37**, 769 (1947); *Infrared Phys.* **2**, 31 (1962).
9. E. E. Epstein, *Science* **151**, 445 (1966). Similar results have been obtained at more recent inferior conjunctions.
10. J. C. G. Walker, *Astrophys. J.* **133**, 274 (1961).
11. E. Pettit, in *Planets and Satellites*, G. P. Kuiper and B. M. Middlehurst, Eds. (Univ. Chicago Press, Chicago, 1961), p. 400.
12. I thank Professor F. D. Drake for reading and discussing the manuscript. The Arecibo Ionospheric Observatory is operated by Cornell University with the support of ARPA under a research contract with the Air Force Office of Scientific Research.

30 June 1966

Generation and Detection of Coherent Elastic Waves at 114,000 Mc/sec

Abstract. *Coherent elastic waves were generated and detected at 114,000 megacycles per second in quartz at liquid-helium temperatures. Effective input power was approximately 3 milliwatts. The results suggest that the piezoelectric method may be applicable to similar experiments at much higher frequencies.*

We report generation and detection of coherent elastic waves in quartz at 114,000 Mc/sec; the apparatus is outlined in Fig. 1. Longitudinal elastic waves were generated at the ends of a quartz rod measuring 0.323 by 0.425 by 0.85 cm and completely filling a TE_{215}-mode microwave cavity (*1*). The *x*-axis of the quartz crystal was parallel with the long dimension of the cavity; the end surfaces were polished flat and parallel to within 1000 Å, and normal to the *x*-axis within 3 minutes of arc. In this arrangement the electric field configuration at each end is such as to excite a predominately longitudinal wave by piezoelectric conversion of electromagnetic energy into sound. (See *2*).

The cavity and quartz were held at low temperatures in a liquid helium Dewar flask, and the cavity was excited by pulses of microwave power from a 20-mw klystron tuned to the cavity resonant frequency (114,000 Mc/sec). The pulse width was nominally 1 μsec; pulse repetition frequency, approximately 1000 cy/sec. Because of the severe losses in the waveguide components at these frequencies, the effec-

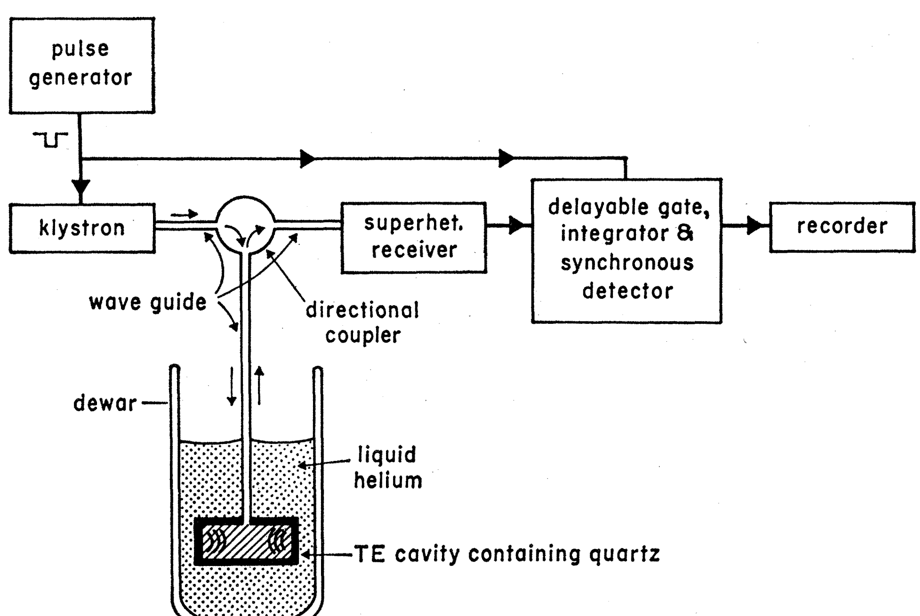

Fig. 1. Block diagram of "single-ended" ultrasonic pulse-echo apparatus. Sound pulses are generated and detected simultaneously at both ends of a quartz rod which completely fills a rectangular TE_{215} cavity. For any given echo, synchronous detector compares output (of superheterodyne receiver) containing noise-plus-signal with noise only.