(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 Sis 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 $T_2 \approx 180^{\circ}$ 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 3.4mm 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.

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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 usec; 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.

tive power input to the cavity was estimated at 3 mw maximum; with such input, the power delivered to the receiver is not greater than 10^{-11} watts because of piezoelectric reconversion of a portion of the sonic energy into microwave energy each time the sound wave is reflected at the ends of the quartz.

This figure assumes no attenuation of the sound wave within the quartz rod and that the end surfaces are perfectly flat and parallel and normal to the x-axis. Because of the short sonic wavelength ($\lambda \simeq 500$ Å), such conditions are virtually impossible to satisfy even approximately with present methods of sample preparation. Thus the power input to the receiver is probably more nearly of the order of 10^{-12}



Fig. 2. Echo-train output for longitudinal waves in quartz at 114 Gc/sec, as detected by superheterodyne phase-sensitive receiver. Initial pulse is direct feed-through from transmitter (klystron) to receiver. First echo is missing because of transient saturation of receiver: subsequent echoes out to No. 5 are visible. Temperature, 4.2°K; pulse width, 1 μ sec; time interval between adjacent echoes, about 1.4 μ sec; recorder output in arbitrary units.

watts or less, making necessary employment of superheterodyne phase-sensitive detector. The output of this instrument was then fed to a recorder; Fig. 2 is a typical record.

The first large deflection is the direct feed-through of the klystron pulse to the receiver. The first echo pulse is missing, as indicated, because of receiver saturation produced by the direct klystron pulse, but subsequent echo pulses up to No. 5 are visible. The time between individual pulses is the time required for sound to travel one length of the rod. Sound-wave packets are generated at both ends simultaneously by the initial klystron pulse. Subsequent reflection and detection of the sound pulses occur at both ends simultaneously at time intervals of ℓ/ν , where l is the rod length (0.85 cm) and v is the velocity of sound for compressional wave along the x-axis of quartz.

Assuming perfect crystal structure and ideal end surfaces, one could determine the attenuation constant, in decibels per centimeter, directly from the recorder trace. This information is of interest because it describes the anharmonic forces between atoms. However, for the reasons mentioned earlier, such direct interpretation of the data in Fig. 2 is not justified; thus we cannot now give a value of the attenuation per unit length with any certainty. Recent experiments in this laboratory at lower frequencies (for example, at 10 Gc/sec), where accurate measurements are possible, give attenuation values of less than 5 \times 10⁻³ db/cm for longitudinal waves in quartz at 4°K (3). On this basis one may expect the true attenuation in quartz at 114 Gc/ sec to be not greater than 0.1 db/cm at the same temperature, but more work is required to establish a reliable value.

Figure 3 shows the change in attenuation versus temperature; data at 114 Gc/sec are compared with similar measurements by Thaxter and Tannewald (4) at 70 Gc/sec and by one of us (E.H.J.) at 24 Gc/sec (5). In all instances the minimum attenuation, assumed to be less than 0.1 db/cm, is normalized to zero in the graph. Existing theoretical treatments (6) of the attenuation versus temperature-based on Akhiezer's concept that the generated acoustic wave irreversibly disturbs the distribution of thermal phononsproclaim that the attenuation should vary as ωT^4 , where ω is the angular frequency of the exciting wave and T



Fig. 3. Attenuation of longitudinal waves in quartz at various frequencies versus temperature; minimum attenuation is set equal to zero in the graph. Data at 70 Gc/sec, from Thaxter and Tannenwald (4); at 24 Gc/sec, from Jacobsen (5).

is the sample temperature. Our preliminary data give an initial rise that is faster than ωT^4 .

We are not yet certain to what extent our data at 114 Gc/sec reflect scattering of the sound wave by various imperfections-as distinct from anharmonic scattering by the thermal-phonon spectrum. These measurements are being refined and will be extended to transverse waves and to higher temperatures.

In spite of the somewhat tentative nature of our data, we feel that these preliminary results are significant in that they suggest the feasibility of similar experiments with piezoelectric transducers at much higher frequencies and with other materials. Such techniques could be of great interest, for example, in the eventual study of interatomic forces, electron-phonon interactions, and elementary excitations in condensed systems.

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