SPECULAR REFLECTION OF PHONONS IN SUPERFLUID HELIUM AT 0.33°K*

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Specular reflection of phonons is observed in superfluid helium at 0.33°K. The phonons are generated at a small carbon transmitter and travel along various directions in the experimental chamber without colliding with other phonons.[1] Some phonons go directly to a concave fused quartz mirror shown in Fig. 1, where they are specularly reflected; and, when the mirror is sharply focused[2] so that the carbon receiver is conjugate to the carbon transmitter, an enhanced signal 14 times greater than the unfocused phonon background signal is recorded. Thus, phonons are directly "manipulated" simply by means of a spherical mirror to form the heater image at the carbon detector.

The carbon transmitter and receiver are two opposite 90° arcs of Dag 154 carbon. Each arc has an inner radius of 0.050 inch and an outer radius of 0.065 inch. They are about 0.002 inch thick, 0.015 inch wide, and 1.4×10^{-3} square inch in area. One expects that the phonon beam has a cross section similar in shape and close in size to the transmitter. Since the focused signal is as much as 14 times larger than the phonon background, it would appear that most of the phonons proceed from the heater in the forward direction, keeping the width of the phonon beam close to or smaller than the dimensions of the electrode. The narrowness of the focusing (about 12 minutes of arc) indicates that the beam is probably smaller in cross section than the electrode. Figure 2 is one of the seven observations made of phonon signal strength vs mirror angle.

There have been experiments conducted by Whitworth[3] and Fairbank and Wilks[4] whose results have been explained in terms of specular reflection of phonons. In these experiments, however, the reflection was that of phonons from the walls of the containing vessel. In Whitworth's paper specular reflection was deduced from ob-

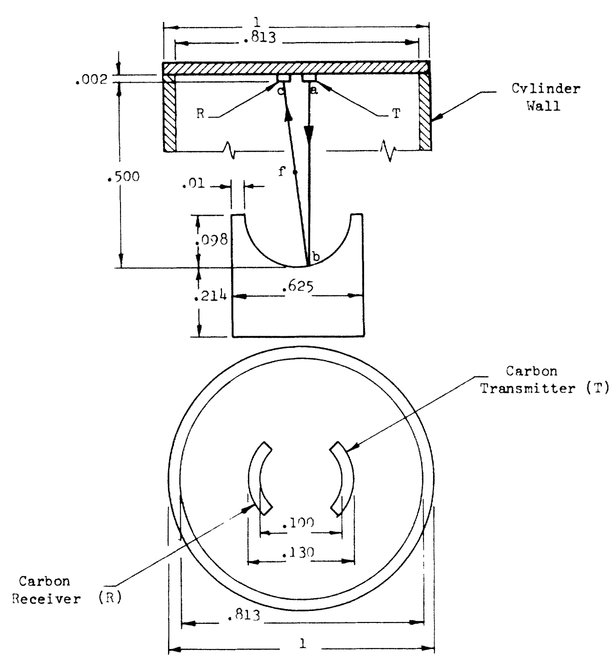

FIG. 1. Geometry of fused quartz mirror and carbon electrodes. *abc* is a possible path traveled by a longitudinal phonon from transmitter to mirror to receiver. The fused quartz mirror has a $\frac{1}{2}$-inch radius of curvature. The inside diameter of the brass cylinder is $\frac{13}{16}$ inch. All dimensions given here are in inches.

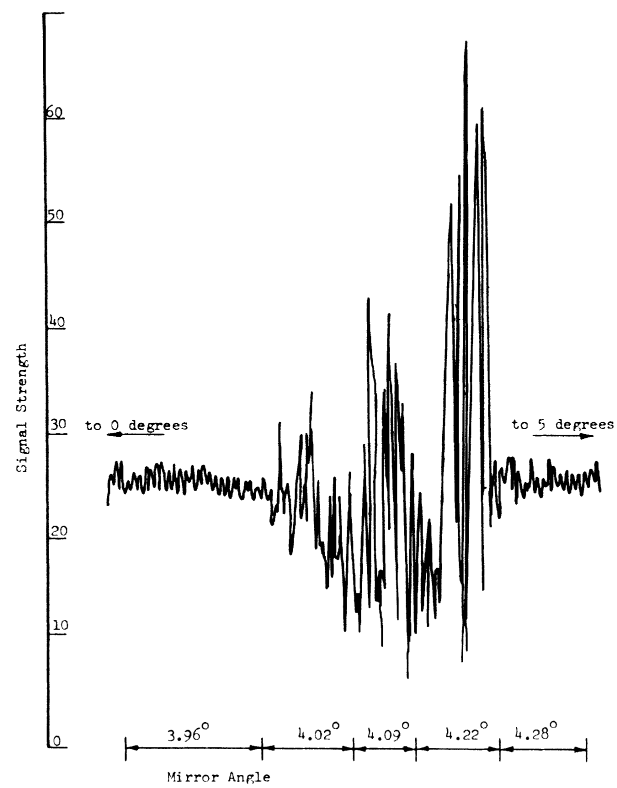

FIG. 2. Signal strength vs angle. Recorder rate = 0.917 inch per minute.

served values of the thermal conductivity of liquid helium below 0.6°K. In the present experiment the specular reflection from the walls serves only to contribute to the background signal.

A Model 50-A Min A tron impulse generator is used to produce two signals, one at 155 cps and the other at 310.4 cps. The lower frequency is filtered of all harmonics and sent into the carbon transmitter where it generates 310-cps local Joule heating of the liquid helium. The wavelength of the second sound arising from the Joule heat is 48 cm. Since this wavelength is much greater than the dimensions of the experimental chamber, it is clear that the observed enhancement of the received 310-cps signal could not be due to the specular reflection of thermal waves. After the received 310-cps signal is amplified, it is mixed with the higher 310.4-cps signal and a rectified signal of 0.4 cps is displayed on a strip chart recorder. The 0.33°K temperature was attained by means of a He^3 refrigerating system.[5]

The ability to focus and diffract phonons would make available a powerful new method for studying phonon spectra of solids.[6] The construction of a very high-frequency (10^{10}-10^{11} cps) phonon "monochromator," i.e., source of monoenergetic phonons analogous to optical monochromators, would become feasible. Phonon spectroscopy of solids would make it possible to study phonon-phonon, phonon-photon, phonon-electron, and phonon-imperfection interactions which play important roles in electrical and heat conduction, x-ray and neutron scattering, and other solid-state phenomena.

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[1]L. D. Landau and I. M. Khalatnikov, Zh. Eksperim. i Teor. Fiz. 19, 637, 709 (1949); I. M. Khalatnikov, Zh. Eksperim. i Teor. Fiz. 20, 243 (1950). On the basis of Landau-Khalatnikov theory, the longitudinal mean free path is greater than 50 cm at 0.33°K; furthermore, at this low temperature only longitudinal phonons propagate in liquid He II. Experimentally, according to A. C. Kramer et al. [Physica 20, 743 (1954)], the mean free path at 0.33°K is 6.4 cm, which is still greater than the dimensions of the apparatus.

[2]An electromagnet set outside the cryostat moves the mirror.

[3]R. W. Whitworth, in Proceedings of the Fifth International Conference on Low-Temperature Physics and Chemistry, Madison, Wisconsin, August 30, 1957, edited by J. R. Dillinger (University of Wisconsin Press, Madison, Wisconsin, 1958), p. 33.

[4]H. A. Fairbank and J. Wilks, Proc. Roy. Soc. (London) A231, 545 (1955).

[5]H. A. Reich and R. L. Garwin, Rev. Sci. Instr. 30, 7 (1959).

[6]E. T. Kornhauser, J. Phys. Chem. Solids 21, 228 (1961).

THEORY OF COHERENCE OF LASER LIGHT

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In a recent Letter to this journal Jordan and Ghielmetti[1] have concluded from the analysis of interference and beat experiments[2,3] with two independent laser beams that the expectation value $\langle b^\dagger(t)\rangle$ of the field operator does not vanish for laser light whereas it does for light from thermal sources. In our present note we wish to show how this result can be derived from first principles. For this end we use a fully nonlinear theory of laser noise in contrast to the hitherto published theories which are basically linear.[4-11]

For our treatment we assume a homogeneously broadened Lorentzian line of width γ and resonance between atoms and the cavity mode under consideration. We describe the mode by a running wave in order to avoid an otherwise spatially inhomogeneous inversion of the atomic system. After splitting off the main time dependence $\exp(i\omega t)$, and after elimination of the atomic coordinates, the steady-state equation for the creation operator $b^\dagger$ of the cavity mode reads[12]

$$[\ddot{b}^\dagger + (\kappa+\gamma)\dot{b}^\dagger - Gb^\dagger + 2|g|^2 b^\dagger b b^\dagger] = i\sum_{t_{\mu\nu}} g\delta(t-t_{\mu\nu})\delta\alpha_\mu^\dagger(t_{\mu\nu}), \qquad (1)$$

where $G = 2|g|^2 G_0 - \kappa\gamma$. κ denotes the cavity linewidth. G_0 is the time average over the total number of the excited atoms and photons present, g is the coupling constant between the cavity mode