the relation

$$\mu = \mu_e P_e + \mu_d P_d. \quad (2)$$

In the high-pressure range $P_d \cong 1$, but as the pressure is decreased P_e increases. In fact in steady state we would have $P_d/P_e = w\tau$, where w is the probability per unit time per free electron for droplet formation and τ the mean lifetime of a droplet. This interpretation then requires that as p (and R) decrease, $w\tau$ must decrease rapidly.

The droplet interpretation of the data discussed above implies the existence of a rather stable state in which an electron is bound to a complex of helium atoms approximately 10 A in radius. It is in fact difficult to see how this is possible. The high zero-point energy of a confined electron, with its associated pressure, has suggested to a number of workers that the electron would tend to expel helium atoms from the region where the electron wave function is greatest. In the present case the "droplet" would then become a "bubble" of inner radius b and outer radius R. The value of the inner radius b is determined by a pressure balance equation and can be estimated either by assuming a surface tension at $r = b$ equal to the bulk value or by the method of Kuper.[8] Both methods predict b values larger than 10 A. Thus we are not at present able to present a consistent model for the wave function of an electron bound to such a complex of helium atoms. We are hopeful that additional study will shed light on the structure of the negative ions observed in both gaseous and liquid helium.

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DETECTION OF THIRD SOUND IN LIQUID HELIUM FILMS

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The present note describes experiments leading to the detection of "third sound" in thin films of liquid helium II. As is well known, Tisza[1] and Landau[2] predicted that for bulk liquid helium II, besides ordinary (or first) sound, in which the normal and superfluid components oscillate in phase, giving a pressure wave, there should also exist another type of wave motion, second sound, in which the normal and superfluid components oscillate out of phase, giving a temperature wave. More recently one of us[3] has suggested that, in the liquid helium film, there might be yet another type of wave motion, termed third sound, in which the superfluid component oscillates but the normal component remains locked to the wall. Detailed analysis suggested that third sound should appear as an oscillation in the thickness of the film. It is therefore somewhat similar to classical waves on shallow water, but the superfluidity of liquid helium is essential to its existence since such a wave would be rapidly attenuated in a thin film of an ordinary viscous liquid. Apart from being an oscillation in thickness rather than pressure or temperature, the most striking characteristic of third sound is that the predicted velocity is much lower than

that of first or second sound (about 50 cm/sec as compared with 2×10^4 cm/sec and 2×10^3 cm/sec). The present investigation was undertaken in the hope that, in addition to its intrinsic interest, third sound would provide a new weapon for attacking the problem of the liquid helium film.

In our apparatus the helium film is formed on a horizontal stainless steel mirror approximately 2 in. long and $\frac{3}{8}$ in. wide, contained in an enclosed experimental chamber. The use of a horizontal mirror provides a film of uniform thickness which can be varied by altering the level of the liquid in the chamber. Third sound is excited by evaporating a narrow strip of the film periodically with pulses of infrared radiation (chopping frequency 2 to 200 cycles/sec). It is detected by a modification of the method of Jackson et al.[4] for measuring the thickness of the static film. A narrow beam of plane-polarized mercury green light is incident on the stainless steel mirror at an angle of $67\frac{1}{2}°$. Upon reflection the beam becomes elliptically polarized and is then converted back into plane-polarized light by a quarter wave plate, with the effect that the plane of polarization becomes tilted through a small angle proportional to the thickness of the film. Therefore when the film thickness oscillates there is an oscillation in space of the plane of polarization, which is converted by passage through an analyzing prism into an oscillation in intensity. This is measured by a photomultiplier, a phase-sensitive detector, and a pen recorder.

In the actual experiments, the detector was kept at a fixed distance from one end of the mirror, and the variation in output was measured as the emitting source was displaced step by step along the mirror. In this way the wavelength of third sound was obtained, since the magnitude of the final signal depends inter alia on the phase difference between emitter and detector. Typical results are presented in Fig. 1. For curve 1, the phase-sensitive detector was adjusted to accept signals exactly in phase with the exciting radiation, and therefore a maximum signal was observed when emitter and detector were superimposed at point A. For curve 2 the detector was set to accept signals 90° out of phase with the exciting radiation so that zero signal was observed at A. Except near point A, each curve gives a sinusoidal variation in output with distance between emitter and detector. We consider the existence of a deflection to imply that there were oscillations in thickness along the film, the sinusoidal variation being due to the variation in the phase of these oscillations relative to the phase-setting of the detector. The large peak on curve 1 at A indicates that the whole film in the neighborhood of the emitter was evaporated and re-formed during each cycle. Detailed analysis of the two curves suggests that we had excited a travelling wave of third sound, rather than a standing wave, with amplitude equal to ±15% of the mean film thickness and attenuation coefficient not greater than 0.3 cm^{-1}. The mean wavelength was 0.97 cm, and since the frequency

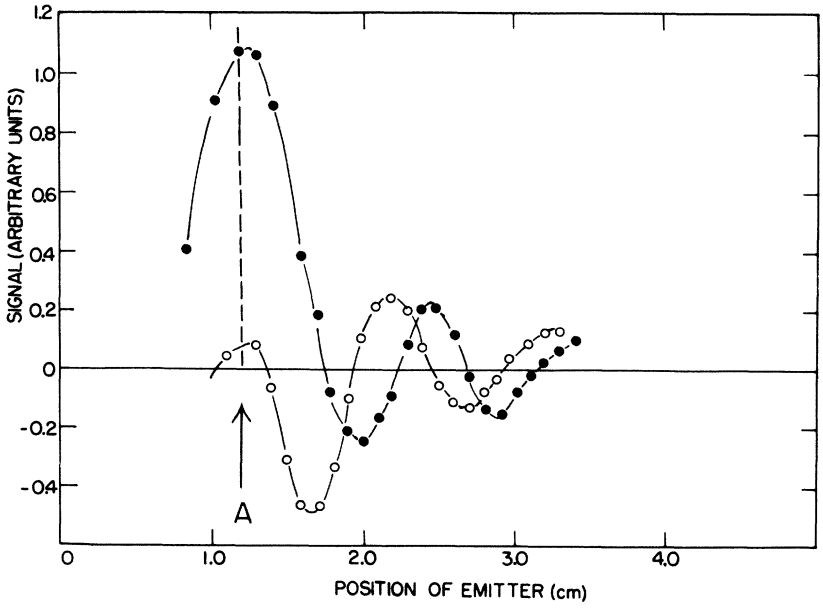

FIG. 1. Typical measurement of third sound. Film height 8.0 cm; temperature 1.1°K; frequency 72.4 cycles/sec. ●Curve 1: detector accepts signals in phase with exciting radiation. o Curve 2: detector accepts signals 90° out of phase with exciting radiation. Point A indicates position of detector.

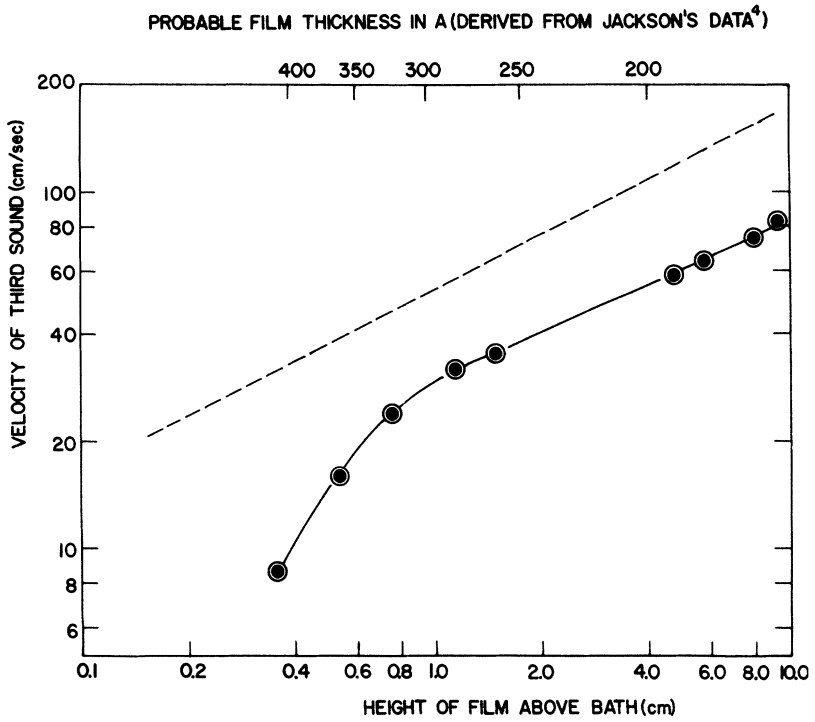

FIG. 2. Variations of velocity of third sound with film height. The broken line shows the variation predicted by assuming that the film is formed solely by van der Waals forces. The film thicknesses are derived from the data of Ham and Jackson.[4]

was 72.4 cycles/sec the wave velocity was 71 cm/sec.

Proof that there was a genuine oscillation in film thickness is supplied by the fact that the signal disappeared: (1) when the emitter was switched off, (2) when detecting light was switched off (this eliminates any possibility of a spurious signal due to scattered radiation from the emitter reaching the photocell), and (3) when the whole film was evaporated by means of an auxiliary radiant heater. Apart from third sound the only likely alternative explanation is that the film was undergoing evaporation from behind by thermal waves propagating in the mirror. Three pieces of evidence indicate that the signal was not due to thermal waves: (1) The observed attenuation was fairly small, whereas thermal waves are always strongly attenuated. (2) The velocity for a given film thickness was independent of frequency (varied by a factor of five), whereas the velocity of thermal waves is proportional to the square root of the frequency. (3) The velocity depended strongly on film thickness, whereas thermal waves would depend solely on the nature of the mirror. Thus the existence of third sound appears established.

In Fig. 2 the variation of velocity with film height is plotted logarithmically, the corresponding film thickness derived from Jackson's[4] data being given on a subsidiary scale. The velocities range between 5 and 80 cm/sec in order-of-magnitude agreement with the theory.[3] The velocity increases with decreasing film thickness also in agreement with theory. However, if the formation of the film were due entirely to van der Waals forces, the velocity of third sound at a height h would be $U_3 = [(\rho_S/\rho)3gh]^{1/2}$. This is shown by the broken line on Fig. 2, and is too large by a factor of about 2. Evidently there are some additional factors which we are investigating further.

Preliminary measurements have been made at higher temperatures up to 2°K. The velocity and amplitude of third sound decrease with increasing temperatures in qualitative agreement with the theory.

Since the velocity of third sound is comparable with the critical velocity of transfer of the film, it is conceivable that the sudden onset of dissipation at the critical velocity arises from the creation of quanta of third sound.

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