PHYSICAL REVIEW B VOLUME 11, NUMBER 7 1 APRIL 1975

Comment on "Search for the ac Josephson effect in liquid He"

P. W. Anderson
Bell Laboratories, Murray Hill, New Jersey 07974

P. L. Richards*
Department of Physics, University of California, and Inorganic Materials Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720

(Received 21 January 1974)

It has been recently suggested that all experiments which have attempted to show the analog of the ac Josephson effect in superfluid helium can be explained more plausibly by the presence of acoustic resonances in the apparatus. In this addendum we point out that the original experiment by Richards and Anderson differs from all succeeding experiments in such a way that the explanation of it in terms of acoustic resonances is much more difficult.

In a Letter, Musinski and Douglass[1] have given strong arguments that the phenomenon observed by one of us[2] and by others[3,4] and ascribed to the analog of the ac Josephson effect in superfluid He (the "Richards-Anderson effect") is, instead, caused by acoustic resonances of the liquid helium in the coaxial capacitors used for height measurements. Some of their conclusions were reached earlier by Lederer and Pobell.[5] Rudnick[6] has given a theoretical discussion which adds quantitative weight to these conclusions.

The purpose of this comment is to point out that, although these arguments give a plausible explanation of the above-mentioned experiments, they are not obviously relevant to at least one published experiment: The original Letter by Richards and Anderson announcing the effect.[7] The apparatus used there differs in one essential aspect from most succeeding experiments. The first experiment was done in an open bath of He II, which was continually pumped in order to maintain the temperature at, typically, 1.15 °K. As a result, the level of the bath dropped at a rate which varied somewhat (we do not have precise data on it) but which was at least > 2 cm/h. A slower rate would have required an exceptionally good Dewar, which we did not have. Because of this continuous level change, acoustic resonances which lead to a stationary He height in one capacitor could not have caused the stationary height differences which we observed.

To illustrate this we reproduce two figures from the original Letter. The first, while schematic, adequately illustrates that the off-balance signal from the capacitance bridge is a measure of the relative height ΔZ, not of the absolute height Z which varied continuously in the negative direction during the measurement.

Unfortunately the original apparatus was most erratic, occasionally exhibiting violent U-tube oscillations, etc., and the data were never clear or reproducible. On the other hand, most of the data obtained with a variety of capacitors, orifices, transducer frequencies, etc., did show stationary values of ΔZ of the expected type. Because of these difficulties this apparatus was abandoned and most subsequent experiments have been conducted in a closed bath of helium with an essentially constant level. For this apparatus only a single capacitor is required. It is closed at the bottom, except for the orifice and also (usually) at the top. The evidence provided by Musinski and Douglass[1] and by Lederer and Pobell[5] that the stationary heights observed in such apparatus are due to acoustic resonances seems convincing. The same can be said for the open-bath closed-capillary experiments of Lederer and Pobell.[5]

In order to predict the effects of such acoustic resonances on our open-bath open-capacitor experiments we need to know whether the effect of the acoustic resonance is (i) to fix the helium height at the resonant level, or (ii) to plug the orifice. Either hypothesis would explain the experiments in closed-bath closed-capacitor[1,5] and open-bath closed-capillary[5] systems, but they lead to different predictions for the open-bath open-capacitor system used originally.[7] We now consider these hypotheses in turn

(i) If an acoustic resonance in the capacitor with the orifice can fix the height Z at some special value, then the height difference would not remain constant, but rather would change at the rate $\gtrsim 2$ cm/h corresponding to the evaporation of helium from the Dewar. We have drawn a broken line with the minimum slope that would be expected for $\Delta Z(t)$ on the filling curve 2(*c*).

It is possible that we may have seen some acoustic resonances of this type on curve 2(c). Note in particular the region between point numbers 4 and 5 where two smooth regions with

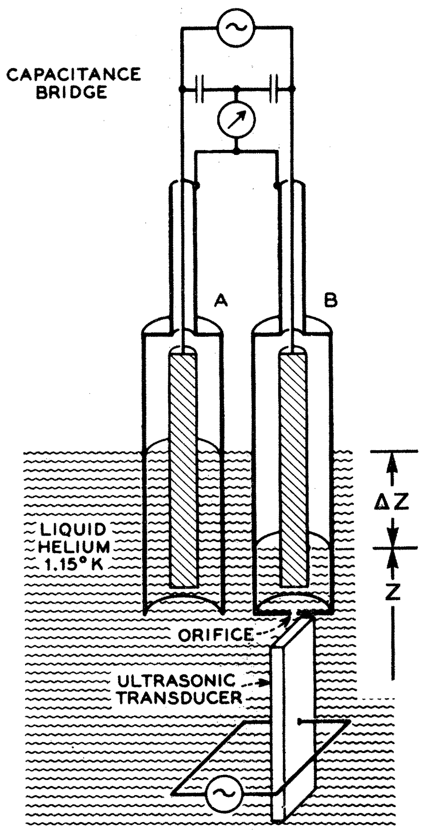

FIG. 1. Schematic diagram of apparatus. The two coaxial capacitors A and B form two arms of a capacitance bridge which measures the helium head difference ΔZ. Helium flow through the orifice is modulated by a quartz ultrasonic transducer.

steep downward slope are observed. (The steep region between points 2 and 4 occurred while the transducer was turned off.) This slope is somewhat larger than the estimated minimum slope given by the broken line. No such evidence for acoustic resonances is seen on the pumping curve 2 (b), where it would appear as a reversal in the general trend of the curve.

In this experiment, acoustic resonances of the assumed type manifest themselves as a rather erratic perturbation of the phenomenon causing stationary values of ΔZ. This might have been one of the influences causing the lack of reproducibility of our data.

It is obvious that the hypothesis of acoustic resonance effects which fix the height Z at special values cannot explain the observed regions of constant ΔZ in the original experiment. This point was made in the original letter.[7] The acoustic mechanisms proposed by Rudnick[6] are both of this type.

(ii) We now consider the suggestion by Lederer and Pobell[5] that the effect of an acoustic resonance is to plug the orifice. If the orifice is plugged, ΔZ will remain constant to the accuracy of our open capacitor experiments. (Estimates suggest that we can neglect the effect of gas viscosity as well as the effects of temperature and height differences on the difference in evapoartion rate per unit area between the two baths.)

Because of the lack of knowledge of the detailed conditions prevailing at the orifice, it may not be possible without further experiments to answer the question of whether or not there is an orifice plugging mechanism with the required properties. One can speculate however, that the sound field near resonance might be sufficiently intense that turbulence would block the orifice. The resonances could occur in both baths, but resonances in the inner bath seem to be required to explain the closed-bath closed-capacitor experiments. Motion of the foil containing the orifice could couple the sound field into the inner bath even if the orifice was blocked.

If we assume that the orifice is plugged whenever the resonant acoustic amplitude exceeds a critical value, then [since the transducer power in Fig. 2(c) is ~ twice that required to observe steps] the fractional length of time with ΔZ = constant is a measure of the Q of the acoustic resonances. The estimated $Q \sim 5$ is orders of magnitude smaller than that expected for first sound resonances with the damping dominated by that which is present in bulk helium. Extra damping must therefore arise from the orifice or the walls

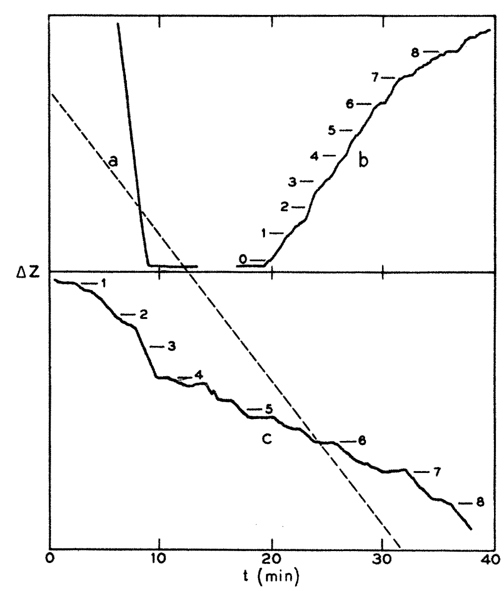

FIG. 2. Chart recordings of head difference vs time. (a) Decay of a head with no ultrasonic modulation; (b) increasing head produced by pumping action of a 69.3-kHz transducer; (c) decay of a head with ultrasonic modulation.

of the capacitor.

If acoustic resonances occur in the orifice capacitor, then the power dissipation and thus the temperature should show resonant effects. The temperature profiles measured by Musinski[1] on a closed-capacitor closed-bath apparatus do show resonant effects with $Q \simeq 5$, but the bath temperature appears to be a minimum at resonance, rather than a maximum as might be expected.

We can conclude that acoustic effects of type (i) which maintain the level constant[6] cannot explain the Richards-Anderson experiment.[7] Unless two mechanisms have been observed, they are not the explanation of the observed step structure in any of the reported experiments. An acoustic resonance effect which plugs the orifice could explain both types of experiments, but the detailed mechanism is not at all clear to us.

Since we have been informed[8] that several attempts to observe an analog of the ac Josephson effect in other ways have failed, we hesitate to ascribe the originally published observations to it. We feel that further study of this question is highly desirable.

We are grateful for discussions with Dr. D. L. Musinski, Dr. I. Rudnik, and Dr. G. Gamota. A portion of this work was performed under the auspices of the U. S. Atomic Energy Commission.

---

*J. S. Guggenheim Foundation Fellow, on leave at the Cavendish Laboratory, Cambridge, England.

[1]D. L. Musinski and D. H. Douglass, Phys. Rev. Lett. 29, 1541 (1972); D. L. Musinski, J. Low Temp. Phys. 13, 287 (1973).

[2]P. L. Richards, Phys. Rev. A 2, 1534 (1970).

[3]B. M. Khorana and B. S. Chandrasekhar, Phys. Rev. Lett. 18, 230 (1967); B. M. Khorana, Phys. Rev. 185, 229 (1969).

[4]J. P. Hulin, C. Laroche, A. Libschaber, and B. Perrin, Phys. Rev. A 5, 1830 (1972).

[5]P. Lederer and F. Pobell, Phys. Rev. A 7, 1130 (1973).

[6]I. Rudnick, report of work prior to publication.

[7]P. L. Richards and P. W. Anderson, Phys. Rev. Lett. 14, 540 (1965).

[8]Discussion at the Boulder ILT-14 Conference, September, 1972; G. Schofield and T. M. Sanders, Jr. (private communication); G. Schofield, thesis (University of Michigan, Ann Arbor, 1972) (unpublished).