

Physics 410/510
Experiment SS-11

Second Sound in Superfluid Helium (He II)

The experiment concerns the propagation of second sound waves (temperature waves) in superfluid helium (He II). The object of the experiment is not only to measure parameters of second sound propagation, but also to give the student experience in the handling of liquid helium and its hardware. This experiment is closely described in an article by Merrill (with Xerox notes SS-11), though important changes have been made as outlined in the "Notes" (SS-11). General information on superfluid helium and handling of liquid helium is described in the general references given below (and in the Xerox Notes SS-II). Familiarize yourself with procedures to transfer liquid helium (see instructions given below) before you start on the low temperature equipment. Be sure to observe the λ -point transition visually.

1. Measure with the "standing wave" method the velocity of second sound as a function of temperature with the simple cavity.
2. Use the pulse propagation method to find the velocity of second sound as a function of temperature. Discuss the pulse shape and resonant Q as functions of various parameters.
3. Measure 4th sound with the special cavity filled with fine powder. Plot velocity of fourth sound against temperature and explain in terms of superfluid component.

References:

- J.R. Merrill, Am. J. Physics, 137 (1968).
K.R. Atkins, "Liquid Helium" (Cambridge Univ. Press, Cambridge, 1959).
C.T. Lane, "Superfluid Physics" (McGraw Hill Book Co., New York, 1962).
K.N. Zinoveva, Soviet Physice--JETP , 4, 36 (1957).
J.R. Pellan, Phys. Rev. 75, 1183 (1949).
Brewer and Edwards, Proc. Roy. Soc. A251, 247 (1959).
Rose-Jnnes, "Low Temperature Techniques".
Jackson, "Low Temperature Physics".

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SS-11: Pump Use

The vacuum pump for this experiment is located behind the cinder block wall. It is best left running throughout the duration of your experiment. The pump may be connected to the cryostat by opening one of the three valves in parallel at the top of the cryostat. If the dewar IS open to atmospheric pressure, please make sure that all these 3 valves are closed (trying to evacuate the room is hard on the pump oil)! After the helium transfer, pumping on the helium bath will lower its temperature. Start pumping the bath slowly, immediately after inserting the rubber stopper into the transfer hole, watching the pressure gauge at the top of the cryostat to make sure that the pressure is dropping slowly. Increase the pumping rate to get down near the operating temperature. You'll use the black pressure gauge mounted on the wall to get your temperature readings.

After you are done for the day, leave the pump pumping on the remaining helium in the dewar. Helium at atmospheric pressure diffuses through glass at room temperature, and will ruin the vacuum insulation of the inner dewar if helium gas is left in the dewar at room temperature.

SS-11: Handling Liquid Helium

CAUTION: Do not fill in liquid N₂ before removing all water from bottom of dewar.

Liquid helium is stored for use in 50 liter moveable dewars located near the experiment. Your instructor will tell you the procedure for signing out these dewars and the method used for determining the liquid level.

The apparatus consists of two dewars: an inner one that holds the liquid helium and your sample and an outer one that holds a liquid nitrogen bath. Before beginning the experiment, pre-cool the outer dewar at the experimental station-by filling with liquid-nitrogen. Access to the outer dewar is at the collar, which is normally plugged with cloth. This should be done at least an hour before transferring liquid helium to give the inner dewar (as well as the specimen and its holder) a chance to equilibrate with the nitrogen bath. At this time one should also evacuate the inner dewar, if this has not already been done, to avoid condensing air and water on the inner walls. To transfer liquid helium from the storage dewar to the inner glass dewar, a U-shaped transfer tube with an insulating jacket is used, and the liquid is forced from the storage dewar by means of modest gas flow from the helium cylinder. Before transferring, it is a good idea to run a little helium gas through the transfer tube to eliminate the possibility of blockages occurring and to backfill the inner dewar with helium gas to atmospheric pressure. With the present dewar arrangement the transfer tube does not extend very far into the inner dewar even when nearly touching the bottom of the storage dewar. Typically about 2 liters of liquid are required to fill the dewar approximately-two-thirds full. Generally, the instructor should be present when transferring. Although the procedure is basically simple, a 'soft' vacuum jacket in the inner dewar or transfer tube could cause a lot of liquid to be wasted. At the present price of about \$4/liter, use of more than just a few liters will be expensive. After finishing the experiment (generally the liquid will last for a number of hours), the vapor pressure of the helium bath should be reduced by means of the vacuum pump located in the utility corridor (the switch is on the wall) and left with the pump operating. After the liquid has evaporated, the dewar is thus left evacuated. If this is not done, helium gas will remain in the dewar, and will diffuse through the glass into the vacuum.jacket, eventually destroying its vacuum.

SS-11: NOTES

You will study second sound propagating in liquid helium in a small cavity. The cavity is a 1 inch long cylinder made of bakelite (an insulator) as shown in Figure 1. At both ends are microphone set-ups consisting of a brass plug and a millipore filter. The millipore filter is simply a plastic film with 2 micron pores that has been aluminized on the side away from the plug. The aluminized side of the millipore filter is connected to ground via a wire soldered to the outside of the cavity. A small hole in the side of the cavity allows the liquid helium to enter.

An audio oscillator or pulse generator drives the microphone. The microphone set-up pushes on the normal liquid alone and produces density waves of normal and superfluid components of liquid helium. The total density is approximately, but not fully, constant so that a little bit of ordinary sound (first sound) is excited also; it should not bother you with your experiment. Because the number density of excitations (or amount of superfluid component) depends on temperature, a density wave of (more or less) superfluid component will correspond to a temperature wave; this temperature wave is called second sound. At the receiver end of the cavity, temperature fluctuations are converted into density fluctuations that push on the microphone, thereby inducing an electrical signal; this goes to an oscilloscope after amplification. Both the microphone and the receiver are operated with a bias voltage of about 130V; you should think about why this is so.

The schematic of the "standing wave" set-up is shown in Figure 2. In this approach, large amplitudes of second sound are excited when "resonances" exist, i.e., standing waves exist in the cavity. Because $v = \lambda \nu$ and $\lambda = 2L/N$ we get $\nu = 2L\nu/N$, the velocity of second sound. As of this writing, the best way to drive the microphone is to use the "Reference" signal from the Lock-in amplifier (see the manual for the Lock-in amplifier to learn more about it), amplified (20 dB) by the Hewlett-Packard 450A amplifier. Also use the lock-in to amplify the signal. The signal size can then be read from the needle indicator or from an AC voltmeter attached to the "monitor" output. Try to measure the "damping" or attenuation constant by measuring the width of the resonance just as in mechanical resonators.

In the "pulse propagation" method, a pulse is fed into the microphone and detected at the receiver. The pulse put out by the pulse generator needs to be amplified. Use the home-built amplifier in the little gray box to do this, providing the necessary -200V with the Heathkit power supply. It should be possible to see the output signal from the cavity directly on the scope. Measure the velocity of second sound and the pulse attenuation as a function of temperature.

Also available is a fourth sound sample. In this case, the cavity is filled with fine powder (rouge). Now the normal fluid is locked in place (cannot swish back and forth), so that the density wave is supported by the superfluid component alone. You get first sound but with a reduced density, namely the superfluid density. Therefore 4th sound measurements measure the superfluid density.

$$v^{4th\ sound} = v^{first} \left(\frac{\rho^{super}}{\rho^{normal} + \rho^{super}} \right)^{1/2}$$

An article by Merrill (below) describes an apparatus very similar to yours. Only the carbon film heaters have been replaced with the microphone set-ups. The standing wave approach seems to work a little better than pulse propagation for fourth sound, but you may have luck with both.

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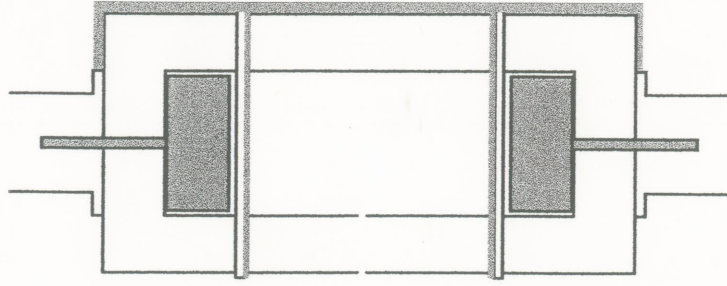


Figure 1. The cavity used to measure second sound.

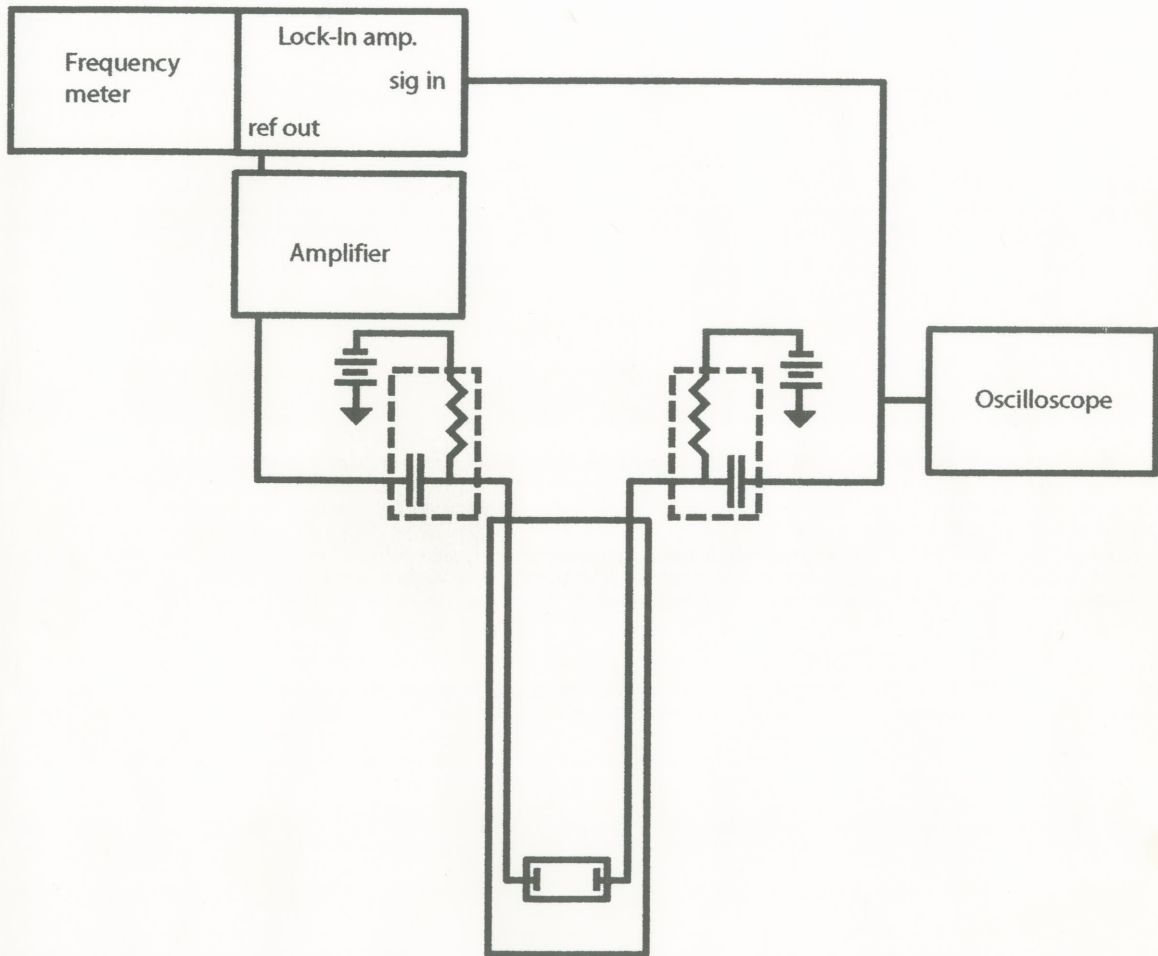


Figure 2. Schematic of apparatus used for standing wave measurements.