Comments and Addenda

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Search for superfluidity in solid ^{4}He

D. S. Greywall
Bell Laboratories, Murray Hill, New Jersey 07974
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A small pressure difference between two sample chambers filled with solid ^{4}He and joined by a capillary was measured as a function of temperature. For temperatures greater than 30 mK and for pressures between 25 and 50 bar there were no indications of "superfluid flow" in the capillary.

In recent years there have been several theoretical speculations[1-9] that superfluidity should exist in solid ^{4}He. The earliest estimates were that the superfluid fraction[3,4] ρ_s/ρ would be less than 10^{-4} and that the transition temperature[4] T_λ would be less than 0.1 mK. In contrast, the most recent calculations[8,9] indicate that ρ_s/ρ and T_λ should be of the order of 10^{-1} and 1 K, respectively. As yet the phenomenon has not been observed experimentally. However, there have been only a few experiments[10-12] performed which were designed specifically to look for this effect and in none of these were measurements made below 0.5 K. In this paper, the results of our search for superfluidity in solid ^{4}He are reported. The method employed was to monitor the pressure difference between two small containers filled with solid helium and joined by a capillary. A sudden relaxation of the small pressure difference as the temperature was lowered would have indicated the onset of "superfluid flow" in the capillary. The experiment was performed at temperatures down to 30 mK and at several pressures in the range from 25 to 50 bar. Although the apparatus was capable of detecting extremely small changes in the pressure difference, in no instance was there evidence that solid was "flowing" through the "superleak."

A cross-sectional drawing of the apparatus is shown in Fig. 1. The two cells were constructed as identically as possible. Each cell consisted of a copper body, into which a 0.6-cm^3 cylindrical sample chamber was machined, and a beryllium-copper capacitance-type pressure gauge.[13] Located midway between the two chambers was the superleak. It was constructed of 25 parallel stainless-steel capillaries which were soldered into a thin-walled brass tube. Each of the capillaries was 1.5 cm long and had a 0.02-cm i.d. The superleak was joined to the cells with 0.1-cm-i.d. brass tubing. One cell was mounted above the second cell which was thermally well anchored to the mixing chamber of a dilution refrigerator. The upper cell was thermally connected to the lower cell with a copper wire of sufficient thermal conductance ($\dot{Q}/\Delta T \approx 8$ mW/K) to eliminate appreciable temperature differences between the two cells in the absence of heat inputs. This thermal link was sufficiently weak, however, to allow small tem-

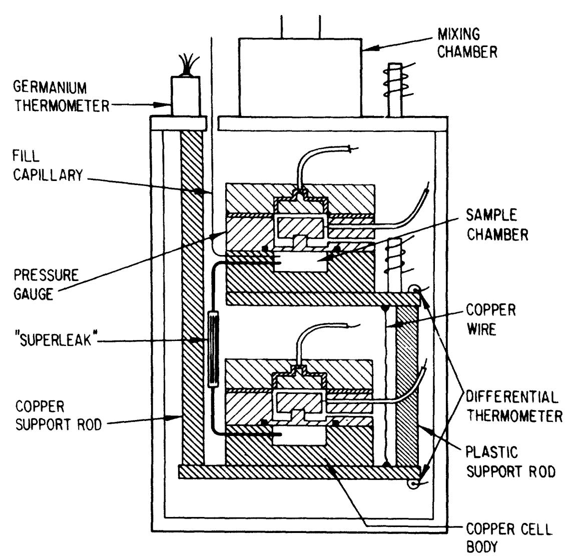

FIG. 1. Sample chambers.

TABLE I. Pressure in the top and bottom cells for each of the five samples.

Sample	P_{bottom} (bar)	$P_{\text{bottom}}-P_{\text{top}}$ (bar)
1	25.77	−1.25
2	27.98	0.24
3	32.79	1.21
4	38.48	1.37
5	49.16	−2.12

perature differences to be developed between the cells during the solidification of the sample. The ^{4}He was admitted to the pair of cells via a 0.01-cm-i.d. Cu-Ni capillary which entered the top sample chamber. This capillary was heat sunk only to a copper block which was normally at 1.3 K but which could be raised above the freezing temperature of the helium sample.

The capacitance of each of the pressure gauges, which had a resolution of about 10^{-5} bar, could be measured separately using a capacitance bridge. There were, however, several advantages in placing the two nearly identical capacitors in opposing arms of the bridge and thus constructing a differential pressure gauge.

The sample chambers were filled with solid using the following procedure: After blocking the fill capillary at the 1.3-K thermal anchor, the temperature of the mixing chamber was allowed to cool below the freezing temperature of the sample. During this process the temperature of the upper cell lagged slightly that of the lower cell. Thus solid began to form first in the lower cell. As a result, when the two cells were completely filled with solid there was a difference in pressure of up to 5 bar. Since the plug in the superleak was some of the first solid to form, the density of the solid confined in the stainless-steel capillaries was presumably much higher than in either of the two sample chambers. To lower the density of the solid helium in the superleak and to reduce the pressure difference between the two chambers, the two cells were warmed quickly until the plug in the superleak was melted. The heater was then immediately turned off and the liquid portion of the sample allowed to resolidify. The final pressure difference between the two cells was typically between 1 and 2 bar.

The temperature T was then slowly lowered in steps of roughly $\frac{1}{10}T$. After each step, the temperature was held fixed for 5–10 min. At the lowest temperature of 30 mK, the pressure difference was monitored for approximately 10 h. Measurements of the pressure difference versus the temperature were made in this manner at each of the five pressures listed in Table I. In no instance was there any evidence that solid helium was moving through the "superleak"; the measured pressure difference changed by less than 3.6×10^{-4} bar in 10 h.

If the transition temperature is indeed greater than 30 mK, the above information can be used to place an upper limit on the product of ρ_s/ρ and the flow velocity v of the superfluid component flowing through the superleak. The change in pressure with time in either cell is given by

$$\frac{dP}{dt}=-\frac{\rho_s}{\rho}\frac{Av}{n}\left(\frac{\partial P}{\partial V}\right)_T, \tag{1}$$

where V is the molar volume, n is the number of moles, and A is the total cross-sectional area of the superleak. Since $(\partial P/\partial V)_T\approx-15$ bar mol cm^{-3}, $A\approx0.008$ cm^2, and $n\approx0.03$ mol, Eq. (1) for this experiment can be written

$$\frac{\rho_s}{\rho}\,v\approx0.25\frac{dP}{dt}. \tag{2}$$

Using $|dP/dt|\lesssim3.6\times10^{-4}$ bar/10 h $=10^{-8}$ bar sec^{-1}, it is concluded that if solid ^{4}He is "superfluid" at 30 mK then

$$(\rho_s/\rho)|v|\lesssim2.5\times10^{-9}\ \text{cm sec}^{-1}. \tag{3}$$

Thus, if $\rho_s/\rho\approx10^{-5}$ then $|v|\lesssim2.5$ μm sec^{-1}; if $\rho_s/\rho\approx10^{-1}$, then $|v|\lesssim2.5$ Å sec^{-1}.

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