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JUMP OF SPECIFIC HEAT OF LIQUID He³ AT 2.65×10^{-3} °K

V.L. Vvedenskii

Institute of Physics Problems, USSR Academy of Sciences

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Osheroff, Richardson, and Lee [1] traced the cooling of He³ by adiabatic crystallization to infralow temperatures near 0.001°K. A kink with a change of slope by a factor 1.8 was observed on the plot of the pressure against time at a temperature ~ 0.0027 °K (point A). This was explained by the authors as the production of a new solid phase via a first-order phase transition. The explanation given in [1], however, is debatable.

First, the behavior of a platinum NMR thermometer is characteristic of the superheat due to the Kapitza jump, in view of the constant heat release, and does not require the formation of a new solid phase for its explanation.

Second, the transition at A is very abrupt (pressure interval 3×10^{-4} atm); under the condition of fast passage of the pressure interval to the maximum (less than 15 minutes), it is reproducible under compression and expansion, and does not depend on the rate of change of the volume and on the amount of solid He³ in the chamber. Furthermore, in view of the large relaxation times in solid He³, as found from crystallization studies, the main cooled reservoir is the liquid He³. This indicates that the solid helium in the chamber is far from temperature equilibrium, and at the same time all the features of the transition are completely independent of the degree of non-equilibrium of the solid.

It can be more readily assumed that the phenomenon at point A occurs in the liquid He³, which has a short thermal-relaxation time. At 0.003°K we have

$$\tau = \frac{\ell^2 C_p}{\kappa V} = 0.3 \text{ sec,}$$

where $\ell = 2$ mm is the mean distance to nearest liquid-solid He³ interface, $C_p = 10^{-1}$ J/mole-°K is the molar specific heat [3], $\kappa = 5 \times 10^{-4}$ W/cm-°K is the thermal conductivity [4], and $V = 25$ cm³/mole is the molar volume. At the indicated cooling rate and at the temperature interval 10^{-5} °K given in [1], in which the transition takes place, the transition time is ~ 2 sec, which coincides with the relaxation time in the liquid.

The assumptions that (i) the transition occurs in the liquid, and (ii) the solid is strongly thermally insulated in the fast process, in view of the low thermal conductivity, lead to the following conclusion: at a constant rate of volume change, i.e., at a constant rate of heat absorption, the kink on the time dependence of the pressure $P(t)$, meaning on the time dependence of the temperature, corresponds to a jump in the specific heat of the liquid.

It must be recognized that owing to the pressure dependence of the molar volumes of the liquid and solid He³, a change in the temperature causes an additional change in the volume of the solid phase. A temperature rise corresponds to absorption of heat, and the liquid-solid He³ interface represents an additional specific heat

$$C = T(S_s - S_l) \frac{dx_s}{dT} = -T \left(\frac{dP}{dT} \right) \left(\frac{dV}{dP} \right),$$

where x_s is the relative amount of the solid phase, $dP/dT = 35 \text{ atm}/^\circ\text{K}$ and $dV/dP = 0.13 \text{ cm}^3/\text{mole-atm}$ are taken from the melting curve [2]. At 0.0027°K this specific heat amounts to $4.3 \times 10^{-2} \text{ J/mole-}^\circ\text{K}$, whereas the specific heat of liquid He^3 is $10^{-1} \text{ J/mole-}^\circ\text{K}$ [3]. A change of the slope of the pressure curve by a factor 1.8 corresponds to a specific-heat jump $C_-/C_+ \approx 2.4$ if account is taken of the additional specific heat of the boundary and that the liquid content is $\sim 60\%$. The transition temperature is $2.65 \times 10^{-3}^\circ\text{K}$ according to the melting curve of [2].

The proposed interpretation of the transition in A enables us to describe also the process occurring following slow heating without a change of volume. The molar specific heat of solid He^3 at 0.0027°K is approximately 20 times larger than that of the liquid, and its content in the chamber is about 40%.

Therefore, if the heating occurs with a stationary distribution of the temperature in the solid He^3 , then the jump of the specific heat of the liquid causes an insignificant change in the heating rate. After a short time interval, however, the temperature distribution in the solid He^3 will not be able to follow the temperature on the boundary, and the jump of the specific heat of the liquid will cause a change in the heating rate of the solid-liquid interface, as is revealed by the pressure. After 10 - 15 minutes, when a new stationary temperature distribution is established in the solid He^3 , the heating rate resumes its initial value.

In the slow heating process, the platinum thermometer, although hotter than the helium, registered a jump in the heating rate. This indicates that the "jacket" of solid He^3 on the thermometer was much thinner than on the chamber wall.

A jump of specific heat of He^3 at zero pressure was observed by Peshkov [5] at $T = 0.0055^\circ\text{K}$, corresponding to 0.003°K [6] on the cerium-magnesium-nitrate scale used by the authors of [1, 2]. According to theoretical estimates [7], the jump C_-/C_+ of the specific heat in the superfluid transition is equal to 1.7 or 2.06.

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