Daunt · Edwards
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(Part A)

LOW TEMPERATURE PHYSICS

LT 9

Part A

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on Low Temperature Physics
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Edited by
J. G. Daunt, D. O. Edwards,
F. J. Milford, M. Yaqub

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# THE MELTING CURVE SLOPE OF $^4$He AND $^3$He–$^4$He MIXTURES*

**George O. Zimmerman**†

*Yale University*
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Since the apparatus and experimental procedure are important in establishing the validity of these data, a detailed description of the technique follows. The apparatus used in this measurement was similar to that of Strongin *et al.*,[1] with the low temperature section shown in Fig. 1. Temperatures below 1°K were obtained by adiabatic demagnetization from a $^3$He cryostat, and the temperature was monitored by means of a 200 Ω $\frac{1}{4}$ W IRC carbon resistor which had been previously calibrated against a cerium magnesium nitrate thermometer salt. The experimental cavity contained 10,000 0.003-in.-OD copper wires which were silver soldered to it for good thermal contact between it and the helium. The cavity contained no pressure-sensing element.

The pressure apparatus consisted of a U-tube containing mercury. One arm of the U-tube contained a reservoir of 500 cm$^3$ in volume located 2 m above the bottom of the U-tube. This reservoir served as a helium container and was connected to the experimental cavity by means of a capillary tube. The other arm had a reservoir of 1000 cm$^3$ in volume about 30 cm above the bottom of the U-tube. This reservoir served as a mercury container which could be pressurized by means of a compressed nitrogen tank. It also contained a provision for pressure release, and a Heise–Bourdon gauge to monitor the pressure. The pressure read on the Heise–Bourdon gauge corrected for the hydrostatic pressure of the mercury whose level could be constantly monitored, gave the pressure in the helium container and also the experimental cavity when the helium was in gaseous or liquid state. Once the capillary line was blocked, the pressure inside the cavity could not be determined.

The following procedure was used to grow the solid: The helium gas was condensed under pressure into the experimental cavity, while the cavity was held at a temperature of $\frac{1}{2}$° above the solidification temperature of pure $^4$He at the particular pressure by holding the temperature of the liquid $^4$He bath constant. Since exchange gas was used only for temperature calibration purposes, thermal contact between the liquid $^4$He bath and the apparatus inside the isolation can (which is shown in Fig. 1) was effected by means of a $^3$He gas column inside the $^3$He cryostat. Once condensation, evident by the stabilization of pressure, occurred within the experimental cavity, the temperature of the $^4$He bath was lowered gradually, care being taken that the pressure on the experimental helium mixture was constant. As further helium condensed into the cavity, the level of the mercury in the pressure apparatus changed. The formation of a block in the capillary was indicated by the stabilization of the mercury level. The block developed first in the capillary above

* Work supported by the U.S. Office of Army Research, Durham, N.C.
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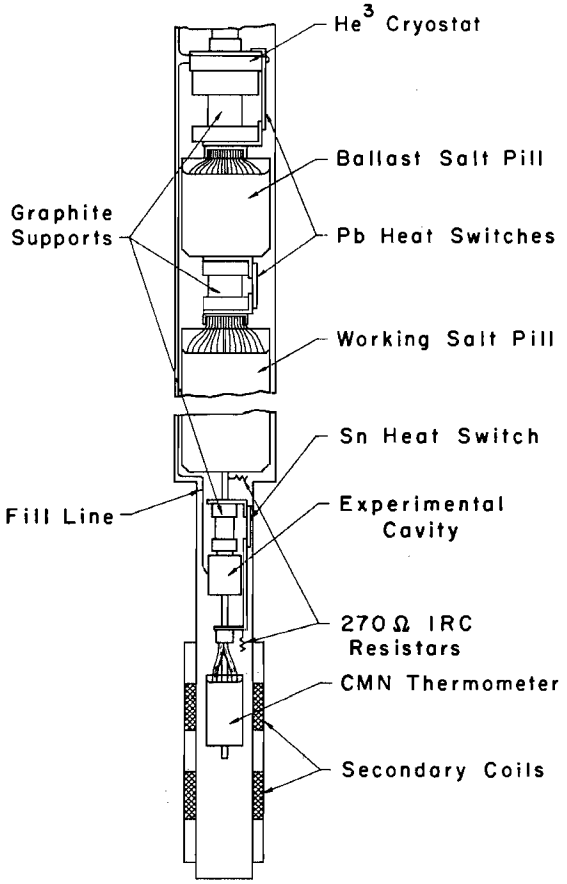


Fig. 1. The low temperature part of the apparatus used in this experiment.

the isolation can, since that was the coldest spot. However, since at that point the capillary was 0.01 in. ID, there were indications of block slippage. It took about an hour to lower the temperature sufficiently for a solid block to develop. The sample was then cooled to the lowest temperature by the method described by Strongin *et al.*,[1] and specific heat determinations (described by Zimmerman[2]) made on it. After the specific heat determinations the sample was again cooled and thermally isolated by means of the tin heat switch. Its temperature was then monitored while the pressure was released at a rate of about 2 atm/min. At a certain pressure, denoted in Table I, a sudden dramatic heating was observed which indicated the melting of the solid in the cavity. Within a second of the observation of the heating effect, the release of pressure was stopped and the temperature was again monitored.

The results are shown in Table I. The percent column gives the atomic fraction of $^3$He in the mixture, $P_{in}$ gives the solidification pressure of the particular run, $P_{min}$ gives the pressure at which the block gave way as measured by the Heise–Bourdon gauge, with corrections for the mercury level, $T_{low}$ and $T_{high}$ give the temperature at the beginning and end of the sudden heating, respectively, and $\Delta T$ gives the rise in temperature at the release of the block. It should be pointed out

**Table I**

| $\%^3$He | $P_{in}$, atm | $P_{min}$, atm | $T_{low}$, °K | $T_{high}$, °K | $\Delta T$ |
|---|---|---|---|---|---|
| 3.2 | 48 | 25 | 0.613 | 0.855 | 0.242 |
| 3.2 | 63.2 | | 0.435 | 0.942 | 0.507 |
| | Positive slope above 1.6°K* | | | | |
| 2.6 | 48 | 24.6 | 0.145 | 0.300 | 0.155 |
| 2.6 | 26.5 | | 0.320 | 0.625 | 0.305 |
| | Positive slope above 1.4°K* | | | | |
| 1.2 | 48 | 24.5 | 0.145 | 0.425 | 0.280 |
| 1.2 | 48 | 24.75 | 0.382 | 0.891 | 0.509 |
| | Positive slope above 0.9°K* | | | | |
| 0.58 | 48 | 25.1 | 0.100 | 0.308 | 0.208 |
| 0.58 | 48 | 24.75 | 0.534 | 1.25 | 0.716 |
| 0.58 | 26.6 | | 0.650 | 1.100 | 0.450 |
| 0 | 48 | 25.4 | 0.147 | 0.630 | 0.483 |

* These were the temperatures at which positive slopes were actually observed. This does not preclude a positive slope below these temperatures.

that there is no apparent correlation between the temperature jump and the initial pressure. This would indicate a negligible contribution due to irreversible heating. These results are in qualitative agreement with the measurements of Weinstock *et al.*,[3] who showed the existence of a negative slope in the melting curve of $^3$He–$^4$He mixtures.

A very interesting result was obtained when pure $^4$He was subjected to the above procedure. Goldstein[4] suggested that the melting curve of pure $^4$He might have a negative slope below a certain temperature. When the pressure was released in pure $^4$He, a heating was observed when the pressure reached 25.4 atm. Figure 2 shows the warming upon melting of the block, and subsequent cooling due to the working salt's being at a lower temperature than the experimental cavity.

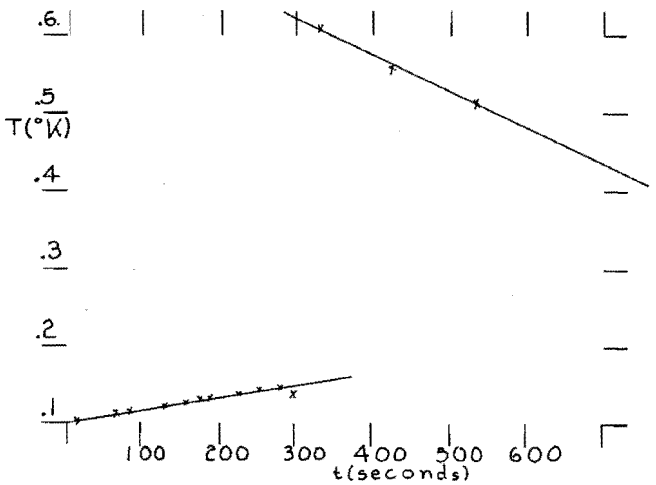


Fig. 2. Warmup of pure $^4$He upon release of pressure.

From the temperature jump, and the assumption that all the helium in the cavity is in the liquid phase after the temperature jump, one can calculate the average slope of the melting curve between 0.147° and 0.630°K, by using the Clapeyron equation. By inserting the specific heat values obtained from the sound velocity measurements of Atkins and Stasior,[5] and the change in volume upon solidification data of Swenson,[6] one obtains as an average slope between the two above-mentioned temperatures

$$\frac{dP}{dT} = -0.2 \text{ atm/deg K}$$

This value is greater than the determination of the negative slope in the melting curve of pure $^4$He of le Pair *et al.*[7] and Wiebes and Kramers,[8] and gives a change in pressure between the minimum and 0°K greater by a factor of 2 than that calculated by Goldstein,[4] when added to the change in pressure reported by Sydoriak and Mills.[9]

A similar calculation of the average slopes of the melting curve for mixtures could not be carried out since the data for specific heat and change in volume upon solidification are not yet available.

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