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Melting Properties of He^3 and He^4 up to 3500 kg/cm^2*

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For He^3 and He^4 the volume change on melting, ΔV_m, the molar volume of fluid, V_f, and the fluid thermal expansion coefficient, $\alpha_f[\equiv(1/V_f)(\partial V_f/\partial T)_P]$, were measured along the melting curve from 1.3 to 31°K at pressures up to 3500 kg/cm^2. These are the first such measurements to be reported for He^3; for He^4 they are the first measurements, consistent with melting curve determinations, which cover this pressure range accurately. Detailed studies of all the melting parameters were made at pressures below 250 kg/cm^2 for both isotopes. Two solid forms of He^3 were found with a transition line which intersects the melting curve at 3.15°K and 141 kg/cm^2. For He^4 an indirect determination was made of the intersection of the lambda line with the melting curve.

I. INTRODUCTION

Although the melting curves of He^3 and He^4 have been traced in considerable detail from a few tenths of a degree absolute up to 30 and 50°K, respectively, (*1–12*) there exist no measurements of the corresponding volume change on melting, ΔV_m, for He^3 and no direct measurements for He^4 above 4°K. Such data in combination with slopes of the melting curves are useful in deriving the various thermodynamic quantities of melting. For He^4, ΔV_m measurements have been made by Swenson (*6*, *7*, *13*) in the region 1.2 to 4.0°K. In addition there are indirect measurements by Keesom and Keesom (*9*) in the region 2.2 to 4.0°K, and by Dugdale and Simon (*3*) in the region 4 to 26°K. The most precise of these measurements occur below 4°K where the quoted (*6*, *7*) error is 3 percent. For He^3 and He^4, ΔV_m data consistent with the melting curve determinations in accuracy and extent (*1*) are especially desirable.

Reported here are final determinations of the volume change on melting of He^3 and He^4 up to 3500 kg/cm^2. It should be noted that some preliminary data have already been presented (*14*). This study is part of a continuing program to measure the melting parameters for all the low boiling gases; in the past measurements for N_2 were reported (*15*).

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II. EXPERIMENTAL

A. Apparatus

The apparatus was similar to that which has been described elsewhere (*15*). It consisted of an oil hydraulic system in equilibrium with a high-pressure gas system through a mercury U-tube. Gas from the high-pressure system was metered in a low-pressure volume manometer

Incorporated in the hydraulic system were a hand pump, intensifier, oil injector, and free-piston gauge. Two different piston gauges were required to cover the full pressure range. Pressures from 5 to 125 kg/cm^2 were read on a commercial[1] free-piston gauge, whose effective area was determined by balancing the gauge against the known vapor pressure of CO_2 at 0°C (*16*). In the range 50–3500 kg/cm^2, pressures were measured with a controlled-clearance free-piston gauge, previously described in some detail (*1*). At pressures above 200 kg/cm^2, the weights were suspended below the piston by a yoke, rods, and pan. The piston was rotated by the method of Myers and Jessup (*17*). Below 200 kg/cm^2 the weights were placed on a pan above the piston and rotated by hand. Over the region of mutual accessibility, 50 to 125 kg/cm^2, both piston gauges were in agreement. Movement of the pistons was measured either with a height indicator gauge of calibrated spring constant or with a traveling telescope. Readings were reproducible to about 0.01 mm.

In the U-tube which separated the oil system from the gas system, mercury levels were indicated by external magnetic coils which sensed the position of ferritic steel balls floating on the mercury surface inside the nonmagnetic steel columns of the U. The levels could be read to 0.5 mm, and differences in mercury level between the two arms were applied as corrections to the piston pressures.

The gas system was identical to that shown previously (see Fig. 1, Ref. 15) with the exception that in most of the runs below 200 kg/cm^2 Valve 2 was removed and the manganin gauge was relocated between Valves 3 and 4. For all runs, Valves 1 and 3 were replaced by shop-made valves (*18*) which featured unsupported area packings and nonrising spindles for constancy of volume during operation.

Many of the determinations below 250 kg/cm^2 were made in a cell different from that already described (*15*). The new low-pressure cell had a nominal volume of 0.4 cm^3 and was made of thin-walled AISI No. 304 stainless steel. Both cells were equipped with inlet capillaries which were vacuum-jacketed. Electrical heaters and thermocouples were spaced along the capillary so that room temperature could be maintained to within several millimeters of the cell opening.

A special gas handling system was required for the rare isotope He^3. The gas

[1] Ashcroft Gauge Tester 1300-25, Manning, Maxwell, and Moore, Inc., Stratford, Connecticut.