Thermodynamic properties and melting of solid helium

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The melting properties and thermodynamic functions of solid helium have been determined at temperatures from 4 to 26° K and at pressures up to 3000 atm. The upper temperature corresponds to about five times the critical temperature of helium; it was therefore possible to measure properties of the solid state in a range which has not yet been attained for any other substance. The melting curve shows no signs of an approach to a solid-fluid critical point; in fact, the difference between the phases becomes more pronounced at higher melting temperatures.

The internal energy at 0° K was calculated from the experimental data and was found to be in good agreement with the theoretical values based on the Slater-Kirkwood potential, using $\frac{9}{8}R\theta$ as an estimate of the zero-point energy (θ being the Debye characteristic temperature).

A first-order transition in the solid was revealed; its equilibrium line cuts the melting curve at 14·9° K and moves to higher temperatures at higher densities. The heat of transition is very small, about 0·08 cal/mole. The transition is assumed to correspond to a change of crystal structure from hexagonal to cubic close-packed.

At the highest pressure solid helium is compressed to less than half its volume under equilibrium conditions at absolute zero, and the Debye θ is increased five times. It was hence possible to test the Lindemann melting formula for a single substance over a very wide range. The formula was found to fit the experimental data satisfactorily, although the value of the constant in it differed somewhat from the classical value.

Introduction

Because its interatomic forces are so weak, solid helium is the most compressible of all solids, and quite moderate pressures give rise to changes in volume far in excess of those obtained with ordinary substances. Measurements of the thermal properties of solid helium over a relatively small pressure range can therefore provide data on the solid state over a wide range of volumes, and this data may help to elucidate a number of questions arising in the theory of the solid state. Of course, it must be remembered that quantum effects, such as zero-point energy (Simon 1934), play a major part in determining the properties of helium at low temperatures, and therefore helium cannot be regarded as a perfect model substance. Nevertheless, for some purposes these quantum effects can be adequately taken into account and general conclusions drawn; in other cases an analysis of the differences between the behaviour of classical substances and helium can be illuminating.

One problem in which helium can, at least in some respects, serve as a model substance is the behaviour of the melting curve at high pressures. The equilibrium curve between liquid and vapour ends in a critical point above which the discontinuity between these phases disappears, and a good deal of discussion has centred around the question whether the equilibrium curve between solid and fluid behaves similarly or not. Much of the earlier speculation on the problem was

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