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Abstract

The different crystallographic phases of two stable isotopes of solid helium are analyzed by means of a law of corresponding states. From this analysis it follows that new phase transitions should occur, in particular solid· He3 should undergo a transition from a h. c. p. lattice to a f. c. c. lattice circa 1800 atm. and 18°K.

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AMES LABORATORY
RESEARCH AND DEVELOPMENT REPORT
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Research and Development Report

ON THE DIFFERENT CRYSTALLOGRAPHIC PHASES OF SOLID HELIUM

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Abstract -- The different crystallographic phases of two
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law of corresponding states. From this analysis it follows
that new phase transitions should occur, in particular
solid He^3 should undergo a transition from a h.c.p. lattice
to a f.c.c. lattice circa 1800 atm. and 18°K.

The results of a simple model are also presented, and
they indicate the possibility of a new phase for solid He^3
below circa 1°K and 50 atm.

This communication, which deals with the several
crystallographic phases of solid He^3 and He^4, is divided
into three parts. In the first two we present an argument
based on a law of corresponding states which: (1) makes
plausible the existence of a low pressure b.c.c. phase
for solid He^4, and (2) predicts a new phase (f.c.c.) for
solid He^3 at pressures above circa 1800 atm and 18°K.

The last part presents (3) theoretical results derived on the basis of a specific model (to be published) which indicate the possibility of other, not yet found, low pressure phases for solid helium (in particular, one for solid He^3 circa 1°K and 50 atm). A more quantitative account of these ideas will be published elsewhere.

(1) The melting curves[1] of solid He^3 and He^4 are shown in Fig. 1 by the full lines. Solid He^3 is known[1] to undergo a transition (point B on the line AB in Fig. 1) from a hexagonal close packed lattice to a b.c.c. lattice when the molar volume along the melting curve is increased above 18.6 cm^3/mole (point B, circa 150 atm and 3.2°K). Presumably the He^3 nuclear spins (i.e. statistics) have only a negligible effect on this transition. Zero point motion and thermal effects should play a moderate role. For He^3 these effects will be larger than for He^4, but in a first approximation we may assume them to be the same for both isotopes. Hence in a first approximation we may use a classical law of corresponding states (which describes the transition as purely a volume effect) and be led to expect that also solid He^4 should undergo a transition to a b.c.c. phase when its volume along the melting curve is increased above 18.6 cm^3/mole; i.e. in the neighborhood of the same line
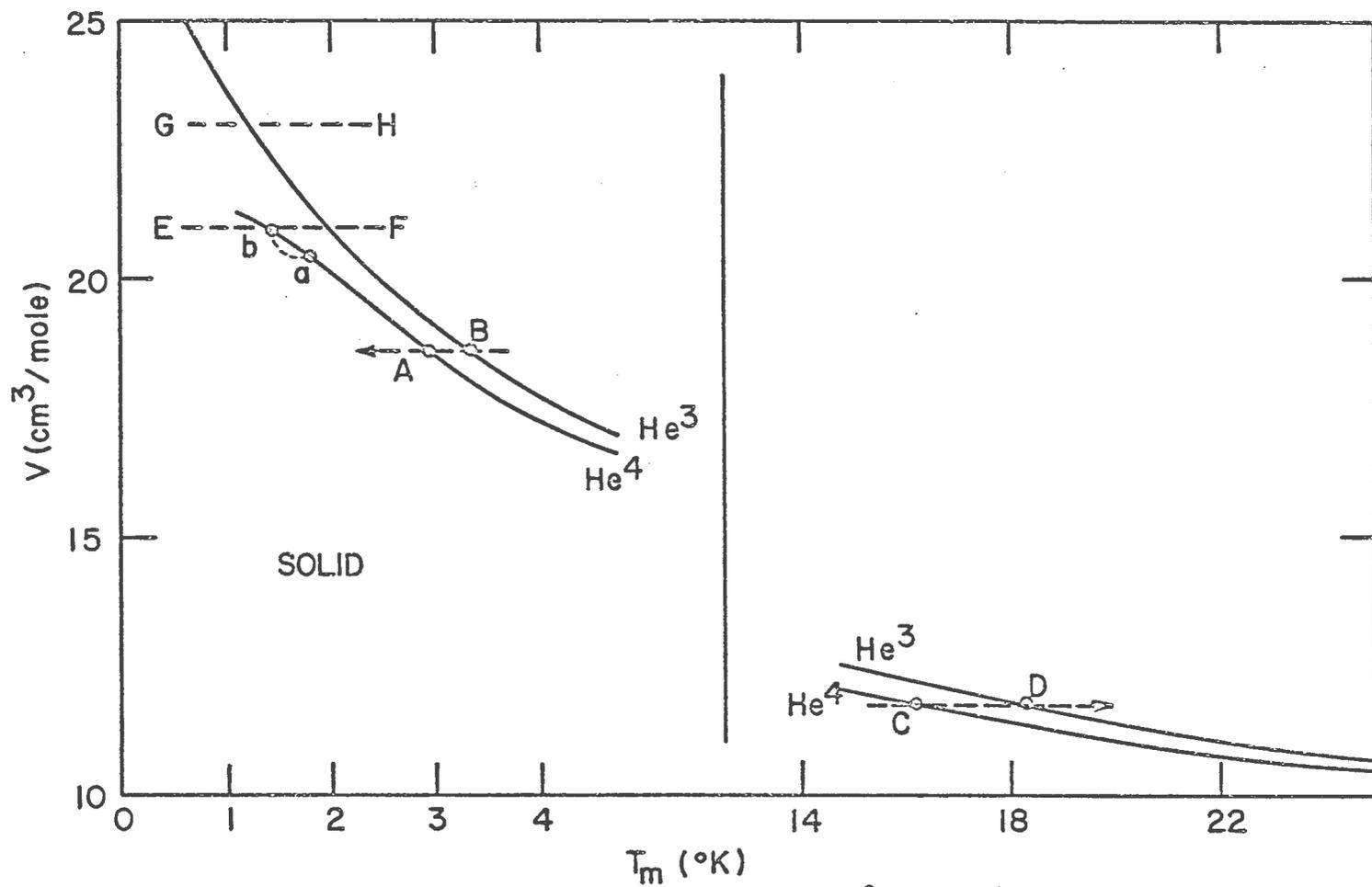
Fig. 1 The full lines represent the melting curves of solid He[3] and He[4]. Points C, B, a and b represent phase transitions which have been observed experimentally.[1-4] A law of corresponding states predicts phase transitions in the neighborhood of points A and D. The experimental point a may correspond to the theoretical point A, while no experiments have been reported for $\overline{He}^3$ in the neighborhood of point D. Lines EF and GH represent volumes for which, in a simple model (to be published), a close packed lattice and a b.c.c. lattice, respectively, should become unstable.

AB in Fig. 1. From the experimental melting curve[1] of solid He^4 the point A should lie *circa* 2.8°K and 70 atm. Recently a new phase transition has been reported[2] for solid He^4 along the line ab of Fig. 1, the point a corresponding to 1.78°K, 30.3 atm and 20.8 cm^3/mole. Even though the lattice structure of this new low pressure phase is not known, one may expect[2] it to be b.c.c., and in this case its existence could have been predicted solely by the argument above based on a law of corresponding states.

(2) Conversely at high pressures a different phase transition is known to occur[3,4] in solid He^4 when its volume is decreased below 11.8 cm^3/mole, corresponding to a transition from a h.c.p. to a f.c.c. lattice[3,4] (point C, on the line CD in Fig. 1, *circa* 16°K and 1300 atm). A similar high pressure transition for solid He^3 has not yet been investigated. However, the same argument based on a law of corresponding states predicts a transition (from h.c.p. to f.c.c.) for solid He^3 when its volume along the melting curve is decreased below 11.8 cm^3/mole; i.e. point D, on the line CD, *circa* 18.5°K and 1800 atm. We may expect this last prediction to be rather accurate since at such small molar volumes zero point motion effects are relatively small, and

both solid He^3 and He^4 are very nearly classical solids.

Notice that all the results under (1) and (2) are based solely on the use of a law of corresponding states in conjunction with experimental data, and no specific models for the transition were either assumed or offered.

(3) A detailed theoretical analysis (based on first principles) of the low pressure phase transitions is difficult due to large zero point motion effects. On the other hand the analysis of the high pressure transition (h. c. p. to f. c. c.) is difficult due to the smallness of the energy changes involved. Nevertheless, a semi-quantitative theoretical analysis (to be published) of the relative stability of different lattices at low pressures shows (independent of any known experimental facts) that in a first approximation a close packed lattice of solid helium should become unstable with respect to a b. c. c. lattice for volumes larger than 21 cm^3/mole (line EF in Fig. 1), and the b. c. c. lattice, in turn, should become unstable (with respect to some more open structure) for volumes larger than 23 cm^3/mole (line GH in Fig. 1). From Fig. 1 we see it is possible that solid He^3 may undergo a new phase transition at low pressures (circa 1°K and 50 atm) when the known b. c. c. lattice should become unstable. This possibility is appealing especially in view of the complex results for the nuclear magnetic

susceptibility[5] and thermal conductivity[6] of solid He^3 at low temperatures and pressures.

In view of all these possible phase transitions it would be desirable to introduce a uniform and systematic nomenclature for the different crystallographic phases of solid helium. A compromise between flexibility and a minimum amount of change can be achieved by labeling the phases $\alpha, \beta, \gamma \ldots$ starting from low pressures for both He^3 and He^4. In this case no change would be required for He^3, while the so-called α, β and γ [2,3] phases of He^4 would be relabeled β, γ and α, respectively. This would be particularly convenient if the so-called γ phase[2] of solid He^4 proves to be a b. c. c. lattice, and if the new f. c. c. phase of solid He^3 is found at high pressures as predicted.

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