

the value of  $\alpha$  is negative, corresponding to a positive 'internal pressure'. For  $^3\text{He}$ , on the other hand, the value of  $\alpha$  is positive and this corresponds to a negative internal pressure. It is of interest to see how this result fits in with the theoretical treatment of solid helium.

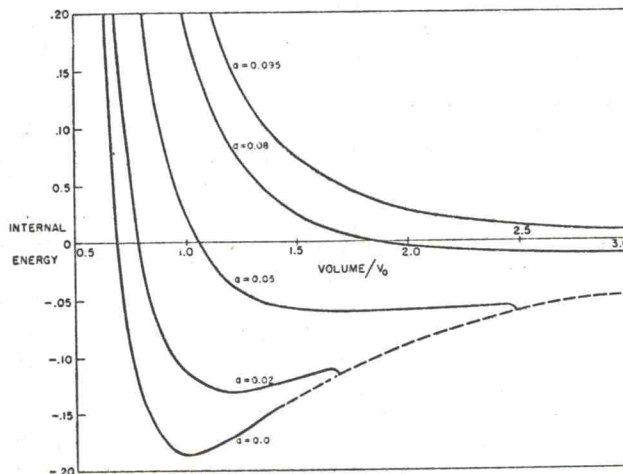
In an attempt to account for the properties of substances in which the role of zero-point energy is important, the present writer put forward the following differential equation for the Debye  $\Theta$  value (Domb 1952):

$$\Theta = 0.4109 \frac{h}{k} \left[ \frac{\phi''(r)}{m} + \frac{9R}{8m} \frac{d^2\Theta}{dr^2} \right]^{1/2} \dots\dots(2)$$

where  $\phi(r)$  is the lattice energy per particle, and  $m$  the mass of the particles. This equation was rewritten by Dugdale and MacDonald (1954) as an equation for the internal energy at absolute zero  $E_0$  in the form

$$E_0 = \phi(r) + a \left( \frac{d^2E_0}{dr^2} \right)^{1/2} \dots\dots(3)$$

where  $a$  is a constant inversely proportional to  $m^{1/2}$  which represents the effect of zero-point energy. Dugdale and MacDonald put forward an approximate solution in closed form when  $\phi(r)$  is a Mie-Lennard-Jones 6-10 potential, and this solution has a number of interesting physical properties.



The internal energy  $E_0$  at absolute zero plotted as a function of volume, for various values of  $a$  (see equation (3)).

The form of  $E_0$  as a function of volume for varying  $a$  is shown in the figure. As  $a$  increases the minimum is pushed out and the potential well becomes shallower until, for a particular critical value  $a_c$ ,  $E_0$  ceases to have a minimum. It seems that  $^4\text{He}$  with a positive internal pressure corresponds to a value of  $a < a_c$ , whereas  $^3\text{He}$  corresponds to  $a > a_c$ . For  $^4\text{He}$  the solid phase could exist under atmospheric pressure, but the liquid phase is more stable; for  $^3\text{He}$ , however, the solid phase could not exist.

The accuracy of the solution of Dugdale and MacDonald in the region of applicability to  $^4\text{He}$  and  $^3\text{He}$ , and the dependence of the solution on the form of intermolecular potential are being investigated by M. E. Fisher and I. J. Zucker at King's College.

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