

FIG. 1. Dielectric constant of PbTiO_3 . The dots refer to rising temperature, the crosses to falling temperature.

thermal hysteresis in the transition, the present dielectric measurements with a weak field were carried out in such a way as to take this into account. The temperature dependence of ϵ is shown in Fig. 1. The cooling and heating rates were $0.3^\circ\text{C}/\text{min}$. The measurements were performed by using a disk-shaped sample 0.96 cm in diameter and 0.13 cm thick, the frequency used being 1 Mc/sec. Two small but distinct anomalies in dielectric constant appear at about -100°C and -150°C . The anomaly at -100°C is rather small, but corresponds to the structural change discovered by x-rays. The anomaly at -150°C seems to suggest that a further transition takes place at this lower temperature. This transition, however, has not been confirmed by x-rays, for it is difficult to cool below -150°C in our x-ray camera. The trend of the temperature coefficient of variation of the dielectric constant changes gradually in the vicinity of -60°C .

Up to the present work it has been difficult to find support for antiferroelectricity in PbTiO_3 in the low-temperature region; but the minor changes in ϵ can be clearly observed both at -100°C and at -150°C and seem similar to those at 470°C and 520°C in NaNbO_3 found by Cross and Nicholson.

Considering the present result, it would seem necessary to make further studies on other ferroelectrics, especially on solid solutions with PbTiO_3 , at low temperature.

¹ J. Kobayashi and R. Ueda, Phys. Rev. **99**, 1900 (1955).

² L. F. Cross and B. T. Nicholson, Phil. Mag. **46**, 453 (1955).

Vapor Pressure of the Solution of He^3 in He^4

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RECENTLY, Daunt and Tseng¹ have reported the difference in vapor pressure between a 4% solution of He^3 in liquid He^4 and pure liquid He^4 over a fairly

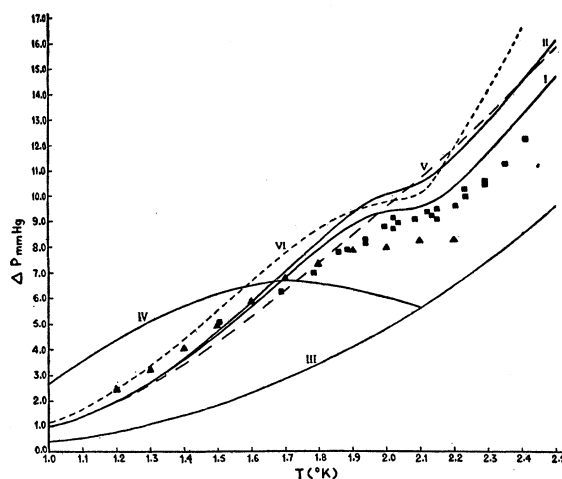


FIG. 1. The vapor pressure difference $\Delta P_{\text{mm Hg}} (=P - p_4^0)$ for a 4% solution of He^3 in He^4 , as a function of absolute temperature $T(^{\circ}\text{K})$. Curve I: present model, linear expression for G_4 . Curve II: present model, quadratic expression for G_4 . Curve III: perfect classical solution theory. Curve IV: de Boer and Gorter's theory.² Curve V: Heer and Daunt's theory.³ Curve VI: Mikura's theory.⁴ \blacktriangle : Smoothed experimental results of Sommers.⁵ \blacksquare : Experimental results of Daunt and Tseng.¹

wide range of temperatures. The experimental results are not in good agreement with the predictions of previous theories.²⁻⁴

According to a model recently proposed by us,^{5,6} the expressions for the partial vapor pressures are

$$p_4 = p_4^0 (1 - X_L)^x \exp \left\{ \frac{1}{RT} [G_4(T, x) - G_4(T, x_0) + x X_L^2 W - (P - p_4^0) B_{44} - P X_V^2 \gamma] - X_L (1 - x) \right\},$$

and

$$p_3 = p_3^0 X_L \exp \left\{ \frac{1}{RT} [x(1 - X_L)^2 W - (P - p_3^0) B_{33} - P(1 - X_V)^2 \gamma] + (1 - X_L)(1 - x) \right\},$$

where X_L and X_V are the concentrations of He^3 in the liquid and the vapor phases respectively, p_4^0 and p_3^0 are the vapor pressures of He^4 and He^3 respectively in the pure phase; $P (= p_3 + p_4)$ is the total pressure, $\gamma = 2B_{34} - B_{33} - B_{44}$, the B 's being the second virial coefficients; G_4 is the Gibbs' function for pure He^4 ; x is the fraction of the total number of atoms of He^4 which constitutes the normal fluid; $w = W/N$ is the interchange energy, and N is Avogadro's number.

Using the experimentally observed⁷ value of $(\partial T_{\lambda X} / \partial X_L)_{X_L \rightarrow 0}$ and following the method outlined in reference 5, W is found to be 1.976 and 2.406 cal mole⁻¹ for the linear and quadratic expressions of G_4 , respectively.⁸ The λ temperature of the solution, $T_{\lambda X}$, calculated by making use of both the expressions for G_4 , is in excellent agreement with the experimental results.⁷

We have calculated the vapor pressure difference $\Delta P (= P - p_4^0)$ for a four percent solution of He³ in He⁴ on the basis of our model by making use of the linear and quadratic expressions for G_4 . The results thus obtained are compared with various theories²⁻⁴ and the experimental results.^{1,9} The vapor imperfection corrections have been applied using the second virial coefficients computed by Kilpatrick *et al.*¹⁰ It is evident from Fig. 1 that the present model, especially with the linear expression for G_4 , describes the observed behavior better than the other theories.

Our grateful thanks are due to Professor D. S. Kothari for his interest in this investigation.

¹ J. G. Daunt and T. P. Tseng, Proceedings of the International Conference on Low Temperature Physics, Paris, 2-8 September, 1955 (National Center of Scientific Research and UNESCO, Paris, 1956).

² J. de Boer and C. J. Gorter, Phys. Rev. **77**, 569 (1950); Physica, **16**, 225 (1950).

³ C. V. Heer and J. G. Daunt, Phys. Rev. **81**, 447 (1951).

⁴ Z. Mikura, Progr. Theoret. Phys. (Japan) **11**, 25 (1954).

⁵ S. K. Trikha and V. S. Nanda, Progr. Theoret. Phys. (Japan) **15**, 178 (1956).

⁶ S. K. Trikha and V. S. Nanda (to be published).

⁷ J. G. Dash and R. D. Taylor, Phys. Rev. **99**, 598 (1955).

⁸ J. G. Daunt, Advances in Physics **1**, 209 (1952).

⁹ H. S. Sommers, Jr., Phys. Rev. **88**, 113 (1952).

¹⁰ Kilpatrick, Keller, Hammel, and Metropolis, Phys. Rev. **94**, 1103 (1954).

Effect of Copper on Ultrasonic Attenuation in Germanium*

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IT has been shown¹ that ultrasonic attenuation in germanium can be attributed to the damped forced oscillation of dislocation segments. Following this idea, an attempt was made to decrease the attenuation by diffusing impurities into the specimen to pin down the dislocations.

Application of dislocation theory² leads to the result that the attenuation for the lower part of the frequency range measured should be given by

$$\alpha = \frac{2\Omega\Delta_0\Lambda L^4 B f^2}{\pi C} (8.7 \times 10^{-6}), \quad (1)$$

where α is the attenuation in decibels per microsecond, Ω is an orientation factor, Δ_0 is a constant for a given material, Λ is the dislocation density, L is the effective loop length, B is a damping constant, f is the frequency, and C is the line tension of the dislocation. Using the values [see references (1) and (2)] $\Omega\Delta_0 = 1/20$, $\Lambda = 2 \times 10^6 \text{ cm}^{-2}$, $L = 10^{-4} \text{ cm}$, $B = 10^{-4} \text{ g sec}^{-1} \text{ cm}^{-1}$, and $C = 1.6 \times 10^{-4} \text{ dynes}$, one obtains $\alpha = 0.3 \text{ db}/\mu\text{sec}$ for $f = 10^8$ cycles/sec which is a typical measured value for this frequency.

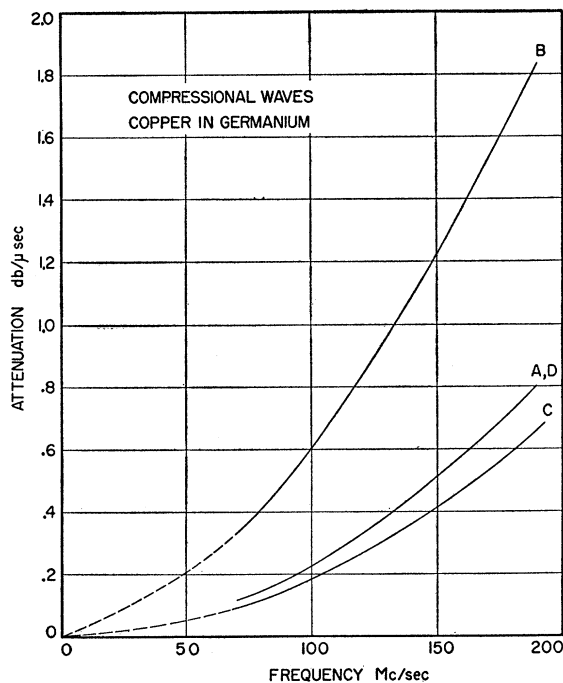


FIG. 1. Attenuation as a function of copper present. Compressional wave attenuation. (A) crystal as originally measured; (B) after heating at 800°C in vacuum; (C) after diffusion of copper into specimen; (D) after reheating in vacuum.

For very pure specimens, the loop length L should be given by the length of the Frank-Read sources, or the network lengths, and as impurities are added, the loop length should be decreased by the pinning action of the impurities. Since the attenuation is determined by the fourth power of the loop length, the attenuation should be very sensitive to impurities.

The attenuation of compressional and transverse waves was measured in a germanium single crystal for waves propagating in the [100] direction. The specimen was first heated at 800°C for fourteen hours in vacuum to drive out impurities.^{3,4} The crystal was then (after making attenuation measurements) plated with copper and heated again to diffuse the copper through the germanium. The attenuation results are shown in Figs. 1 and 2; they are qualitatively as expected. After vacuum heat treatment the attenuation of compressional and transverse waves has increased by factors of approximately $2\frac{1}{2}$ and 4 respectively, and after copper is added the attenuation decreased by factors of $3\frac{1}{2}$ and 9 respectively.

The added copper can affect the dislocation loop lengths in two ways. One way is that of pinning the dislocations by individual copper atoms in solution in the germanium, and the other is by the formation of precipitates along the dislocations. The concentration of copper atoms on the dislocations should be larger than in solid solution because the copper atoms can by their presence reduce the strain at dislocations. It can