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Lambda-Temperatures of He³—He⁴ Mixtures

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IT has been shown[1] by comparing the isothermal flow of liquid He³ and of liquid He⁴ through a small channel or superleak that no superfluid flow occurs in pure He³, at least down to 1.05°K. These experiments have been extended to mixtures of He³ and He⁴ in order to study the feasibility of concentrating He³ by means of a superleak and to determine the effect of composition on the lambda-temperature.

The first experiment was made in an attempt to separate the He³ from approximately 10 cc of a mixture containing 92.1 percent He³ and 7.9 percent He⁴. Subsequently, experiments were made with 2.4 percent He³ and with mixtures prepared by diluting a portion of the 92.1 percent He³ with He⁴.

The He³—He⁴ mixture was condensed in the capillary tube leading to the platinum-glass superleak used previously,[1] which was immersed in a bath of ordinary liquid helium whose temperature was regulated by pumping. The rate of isothermal flow through the superleak was then determined at successively lower temperatures by observing the rate of pressure rise in a large volume on the exit side of the leak. The starting material, the portion which flowed through the leak during the course of the measurements, and the residuum were analyzed by means of a mass spectrograph.

With the 92.1 percent He³ it was found that the rate of flow decreases monotonically as the temperature is lowered to 1.05°K, and it is therefore concluded that the lambda-temperature of this mixture is lower than 1.05°K. With pure He⁴, as well as with the other mixtures tested, the curve of flow rate *versus* temperature rises sharply below a temperature which is characteristic of the liquid. With pure He⁴ this rise begins at the lambda-point, 2.19°K, and hence the point at which the sharp rise begins is considered to be the lambda-point of the mixture. The breaks in the curves for the mixtures were located with an estimated uncertainty of 0.05°K.

The lambda-temperatures determined in this way and the mass spectrographic analyses are given in Table I. It is believed that there was little change in composition until the temperature was reduced below the lambda-point of the mixture, so that the lambda-temperatures tabulated correspond to the composition of the starting material.
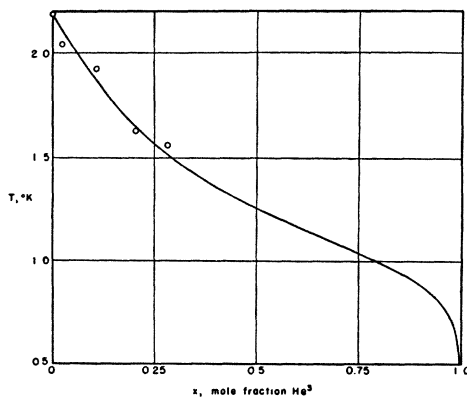

FIG. 1. Lambda-temperatures of He³—He⁴ mixtures. Points determined with a superleak. Curve calculated (see text).

TABLE I. Lambda-temperatures and composition changes of He³—He⁴ mixtures, as observed in superleak experiments.

Starting material	Mole percent He³ Effluent	Residuum	λ-point (°K)
2.4	0.32	8.2	2.04
10.7	2.7	13.8	1.92
20.3	—	—	1.63
28.2	10.9	43.7	1.56
92.1	91.0	93.6	<1.05

In Fig. 1 the experimental lambda-temperatures are plotted against composition, along with a curve calculated by J. W. Stout as described in the following letter.[2] The agreement is within the estimated experimental error.

It is seen from Table I that large changes in He³ concentration can be effected by isothermal flow through a superleak at temperatures below the lambda-point of the mixture. A slight change in concentration will occur above the lambda-point if the amount of gas above the liquid on the entrance side of the leak is appreciable. Since the concentration of He³ is higher in the vapor phase than in the liquid,[3] the liquid flowing through the leak, even without fractionation by superfluid flow of He⁴, has a slightly lower He³ concentration than the starting material. This effect is sufficient to account for the concentration change observed with the 92.1 percent He³ but is far too small to account for the changes observed with the other mixtures.

The limit of He³ concentration attainable by any of the various methods of separation[4,5] which depend on the superfluid flow of liquid He⁴ and the lack of superfluid flow of He³ can be predicted approximately from Fig. 1. Thus, the concentration limit at a temperature of 1.8°K is about 14 percent He³, and the limit at 1.5°K is about 30 percent He³.

It is planned to extend these measurements to lower temperatures obtained by adiabatic demagnetization, and to measure the He³/He⁴ ratio of the material as it issues from the superleak by means of a mass spectrograph directly connected to the apparatus.

[1] Osborne, Weinstock, and Abraham, Phys. Rev. 75, 988 (1949).
[2] J. W. Stout, Phys. Rev. 76, 864 (1949).
[3] Taconis, Beenakker, Nier, and Aldrich, Phys. Rev. 75, 1966 (1949).
[4] Daunt, Probst, and Smith, Phys. Rev. 74, 495 (1948).
[5] Reynolds, Fairbank, Lane, McInteer, and Nier, Phys. Rev. 76, 64 (1949).

Solutions of He³ in He⁴

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IN order to represent their measurements of the liquid-vapor equilibrium in dilute solutions of He³ in He⁴, Taconis, Beenakker, Nier, and Aldrich[1] suggested that below the lambda-point the fugacity of He³ in the solutions is given by Raoult's law counting only that fraction of the He⁴ atoms which on the two-fluid model of liquid helium are in the normal state. From this picture one can calculate thermodynamically the change of the lambda-temperature of He³—He⁴ solutions to compare with the observations of Abraham, Weinstock, and Osborne,[2] reported in the preceding letter.

The number of normal atoms of He⁴ may be approximately represented[3] by $n = n_4(T/T_\lambda)^6$. n_4 is the total number of atoms of He⁴ and T_λ is the temperature of the lambda-transition. Then the fugacity of He³ is given by

$$f_3 = (f_3{}^0 n_3)/[n_3 + n_4(T/T_\lambda)^6] = (f_3{}^0 x)/[x + (1-x)(T/T_\lambda)^6]. \quad (1)$$

$f_3{}^0$ is the fugacity of pure He³ at the same temperature and x is the mole fraction of He³. We shall assume that above the lambda-point the solutions are ideal.

The necessary thermodynamic equations have been given previously;[4] the same notation is used here. If the transition remains