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λ-POINTS OF CONCENTRATED $He^3 - He^4$ MIXTURES

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λ-transition temperatures have been measured in helium isotope mixtures with He^3 concentrations of 50.0, 59.6, and 62.4%; the values obtained are 1.31, 1.05, and 1.02°K, respectively. No λ-transition was observed in a mixture containing 66.1% He^3.

THE dependence of the temperature of the helium II phase transition (T_λ) upon the He^3 concentration (X) in mixtures of the helium isotopes has previously been investigated in our laboratory[1-4] by a variety of methods. These experiments have covered a range of He^3 concentrations up to 40%. Similar data subsequently obtained by other authors[5-18] show good agreement with these results.

Studies in the region of higher He^3 concentrations are of especial interest, since analysis of the λ-point curve near the phase separation region may provide information concerning the superfluidity of separated mixtures. The available data in this concentration range, however, do not as yet permit this question to be resolved unambiguously, especially if one takes into account the T_λ measurements obtained by the visual method.[19]

In view of this, our measurements of $T_\lambda(X)$ have been extended to mixtures rich in the lighter helium isotope (50—60%). In these experiments T_λ was determined for a mixture of given He^3 concentration from the singularities which appeared in the curves showing the rate of heating or cooling in the liquid, resulting from a change in the thermal transport mechanism at the transition.

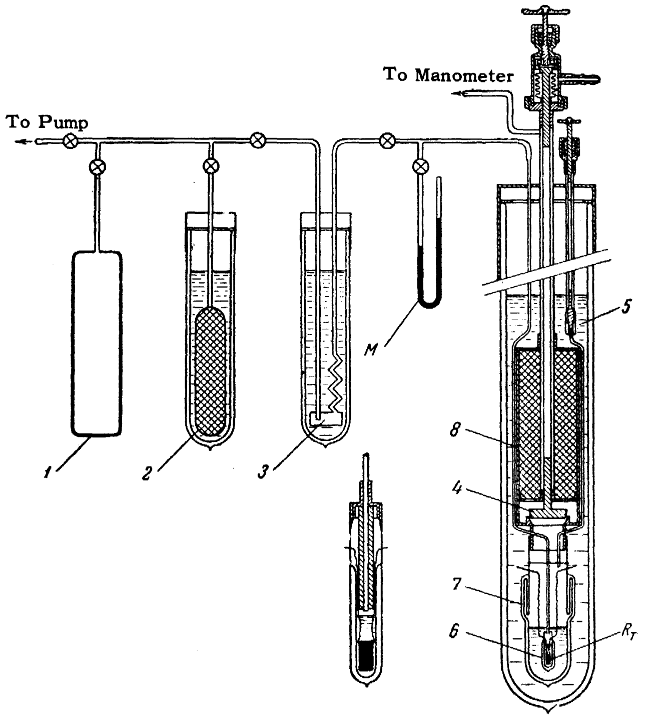

FIG. 1. Diagram of system and apparatus for determination of T_λ (see description in text).

The measurements were carried out with apparatus (Fig. 1) in which temperatures below 1°K could be reached by pumping out the vapor over liquid He^4 with an adsorption pump.[20] At an outer bath temperature of ~ 1.3°K, a mixture containing known proportions of the helium isotopes was condensed from the flask 1 into the small glass Dewar 6, passing on its way through a coil 3 cooled with liquid hydrogen, for removal of possible impurities. The small Dewar 6, containing a carbon thermometer (R_T), had an internal diameter of 5 mm and a length of 30 mm. The height of the liquid column generally amounted to 14—15 mm, and a Plexiglas cylinder was placed above the liquid to reduce the volume of the gaseous phase. This Dewar is shown on the left in Fig. 1, on an enlarged scale.

Following condensation of the mixture, the Dewar 7 was filled with liquid helium from the outer bath through the valve 5. The helium in the Dewar 7 (and, as a result, in the Dewar 6 containing the mixture) was cooled below 1.3°K with the aid of a charcoal pump 8, the pumping rate being controlled by means of the larger-aperture valve 4.*

Following cooling of the mixture below T_λ, the valve 4 was closed, leaving the helium iso-

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*After completion of a run, most of the mixture was recovered from the system into the flask 1, and the balance in the liquid hydrogen-cooled charcoal pump 2.

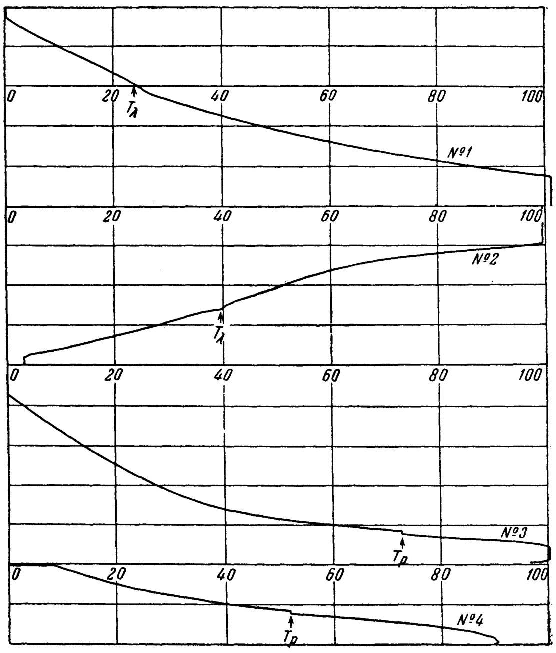

FIG. 2. Typical heating (1) and cooling (2) curves as recorded by the EPP-09 potentiometer. The breaks correspond to T_λ. Curve 1 refers to a mixture having a He^3 concentration of 59.6%, curve 2, to a 50.0% mixture. Phase separation of the mixtures is recorded on curves 3 (66.1% He^3) and 4 (62.4% He^3).

tope mixture to warm up gradually. By means of an ÉPP-09 electronic potentiometer, connected with the carbon resistance thermometer through a cathode follower, a continuous trace was obtained representing the warming curve. Naturally, by beginning the run at a temperature higher than T_λ, cooling curves might also be obtained by an analogous procedure. It should be stated that in these experiments the power dissipated in the thermometer never exceeded 10^{-4} W. In the majority of cases it was considerably less.

The procedure thus described made it possible to obtain during the course of a single experiment several curves, on which a break in slope is found at $T = T_\lambda$ (Fig. 2). The temperature corresponding to this break could be determined with the aid of a previously obtained resistance-temperature curve for the thermometer (measured against the vapor pressure of He^3 [21]), and from reference marks impressed upon the recording chart at the end of the experiment. Each such mark corresponded to a definite thermometer resistance, as measured with a PPTV potentiometer. It is necessary to point out that in these experiments the full width of the recording chart (275 mm) corresponded to a temperature range of no more than 0.2°. In a number of cases, this range was even smaller (0.1°).

The experiments were carried out with mixtures having He^3 concentrations of 50.0, 59.6, 62.4, and 66.1%; the 50.0% and 66.1% mixtures were prepared by dilution of pure He^3, the other two, by dilution of the 66.1% mixture. As a control, the vapor pressures of these liquid mixtures were measured as a function of temperature, from which it was possible to determine their He^3 content by means of the liquid-vapor phase diagram for the He^3—He^4 system. [22,17] From all of the foregoing, we may regard the concentrations of the mixtures as known to an accuracy of at least 0.5%.

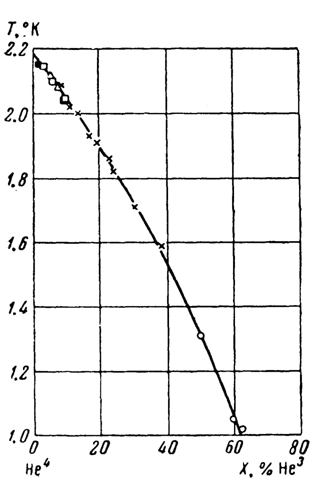

FIG. 3. T_λ (X), from data obtained at the Physico-Technical Institute, Academy of Sciences, Ukr. S. S. R.

For the indicated mixtures, the following values of T_λ were obtained.

X(% He^3):	50,0	59,6	62.4	66.
T_λ (°K):	1.31±0.01	1,05±0.01	1,02±0,03	—

No λ-point was observed for the mixture containing 66.1% He^3. The T_λ(X) diagram derived from data obtained in our laboratory, [1-4] and including the measurements just described (○), is presented in Fig. 3.

Data on the displacement of the transition temperature as a function of the He^3 content of the mixtures has also been obtained by other authors, using a variety of methods for determining T_λ. All of the data available at present are presented in Fig. 4, in which curve 2 has been constructed according to the results of a number of papers, [1-12,16-18]* while curve 1 has been taken from the data of Zinov'eva and Peshkov. [19] The results of the present experiments agree well with curve 2; they are also shown in Fig. 4. The same figure

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*Sydoriak and Roberts reported [9,11] a T_λ measurement which they made on a mixture containing 80% He^3; in a later paper,[17] however, these authors reached the conclusion that for mixtures containing more than 68% He^3, T_λ could not be distinguished from the phase separation temperature (T_p). According to the data of Taconis et al,[18] T_λ (X) follows curve 2, but with the junction point of curves 2 and 3 located at $T = 0.8$°K, $X = 73\%$ He^3.

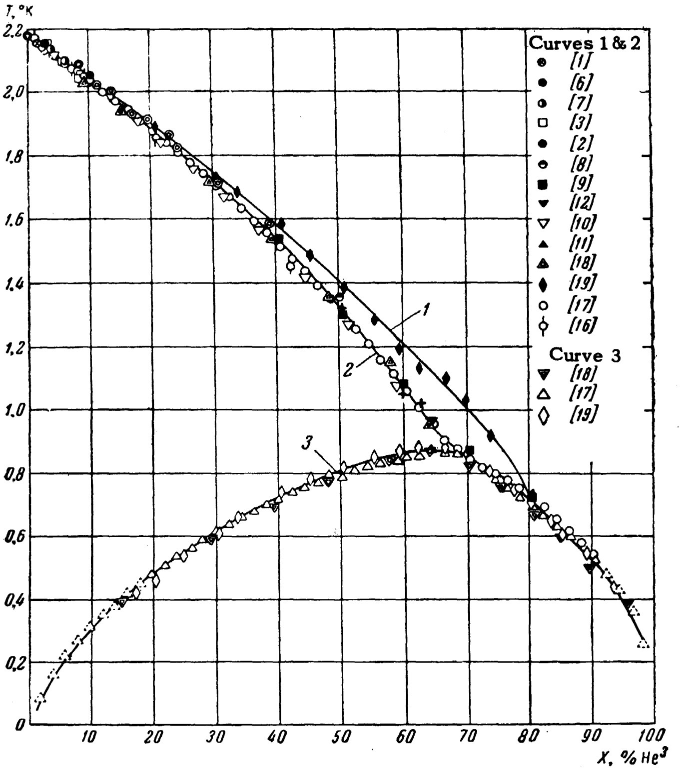

FIG. 4. T_λ (X) (curves 1 and 2) and T_p(X) (curve 3); data from the present paper are indicated by crosses (+).

also contains the curve 3, which defines the boundary of the phase separation region. This latter curve has been constructed from published data [17-19] which agree well with one another.* It can be see from Fig. 4 that the λ-point curve meets the curve $T_p(X)$ near its maximum, indicating that for He^3—He^4 mixtures within the phase separation region, the upper phase is non-superfluid. If, in fact, these mixtures do show superfluidity, it must occur only within the extremely small range in temperature between the maximum of the $T_p(X)$ curve and its point of intersection with curve 2.

It should be noted that direct experiments for determination of the properties of the upper phase in separated mixtures, involving studies of film flow,[22] second sound,[10,12] and changes in thermal transfer characteristics, have led to contradictory results, providing as yet no definite answer to the question of its superfluidity.

In conclusion, we take this opportunity to thank Professor B. G. Lazarev for discussing our results, and to V. D. Krasnikov for his assistance in the measurements.

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*The technique described in the present paper permitted determination not only of T_λ, but also of the mixture phase separation temperature (Fig. 2); the values obtained agree well with those found in the literature.[17-19]

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