V. I. Panov, A. A. Sobyanin, and V. A. Khvostikov, *Experimental investigation of superfluidity of helium II near the λ point.* The results of precision measurements of the temperature dependence of the density and coefficient of thermal expansion of liquid ^4He in a large volume[1] near the λ transition as well as the difference in the densities of helium contained in a large volume and in a narrow plane-parallel gap[2] are presented in the report. Interest in these investigations is due to the great deal of attention that is currently being directed to the problem of the nature of the anomalous thermodynamic properties of substances near second-order phase transitions (critical effects) and the problem of the effect of various factors on these anomalies, including, the finiteness of the dimensions of the system in one or several directions (critical size effects). In addition, an immediate problem of the investigation was a quantitative check of the predictions of the phenomenological Ψ theory of superfluidity[3-6] ($\Psi = \eta e^{i\varphi}$ is the macroscopic wave function which plays the role of the order parameter) concerning the magnitude of the shift of the λ point under conditions of finite geometry and the determination of the parameter M, entering into this theory,[5,6] depending on the value of which, the phase transition of helium in the gap is either a first- ($M>1$) or second-order ($M<1$) phase transition.

In the first experiments,[1] based on detailed measurement of the temperature dependence of the dielectric permittivity of pure liquid ^4He, the values of the molar volume V, the coefficient of thermal expansion at the saturation vapor pressure β_s, and the isobaric coefficient of thermal expansion β_p were calculated with high accuracy and the form of the divergence of these coefficients near the temperature of the λ transition was also investigated. The measurements were performed with the help of a superconducting uhf resonator, which was placed in the chamber with pure liquid ^4He. In the measurements, the relative variations of the temperature were recorded with an accuracy $\leq 1\cdot 10^{-6}$ K. The variations of the dielectric permittivity of liquid helium were measured to within 10^{-9}. The rate of change of temperature in determining the dependence $\beta_s(T)$ was $1\cdot 10^{-4}$ K/min. The results of the measurements of the molar volume showed that the values of V obtained for ^4He correspond well with the direct dilatometric changes[7] only in the region $T\leq T_\lambda$. For $T>T_\lambda$, there is a significant (~0.3%) disagreement between the results in Ref. 7 and the present measurements.

The coefficient of thermal expansion β_s near the λ transition is described with high accuracy by the logarithmic dependence:

$$10^3\beta_s = (8.21 \pm 0.02) \ln|\tau| + (47.75 \pm 0.15), \quad T > T_\lambda,$$
$$10^3\beta_s = (7.98 \pm 0.02) \ln|\tau| + (11.83 \pm 0.12), \quad T < T_\lambda,$$

where

$$\tau = \frac{T - T_\lambda}{T_\lambda}.$$

The general form of the divergence of $\beta_s(T)$ is shown over a wide temperature range in Fig. 1.

In studying the nature of the divergence of the coefficient β_p near T_λ, the experimental results were likewise compared with a power-law dependence $\beta_p = (A/\alpha)|\tau|^{-2} + B$ and the critical indices α, α' and coefficients A, A' and B, B' were calculated. From the analysis of the experimental data it follows that these quantitites are equal, with a confidence of 0.95, to

$$T > T_\lambda, \quad \alpha = -0.006 \pm 0.0025, \quad A = (7.9 \pm 0.6)\cdot 10^{-3}, \quad B = 1.35 \pm 0.5,$$
$$T < T_\lambda, \quad \alpha' = 0.000 \pm 0.0025, \quad A' = (7.95 \pm 0.5)\cdot 10^{-3}, \quad B' = 4.86 \pm 0.3.$$

The values obtained for the critical indices indicate with high probability that the divergence in the quantities β_p and C_p for ^4He in the region of the λ transition is logarithmic. This result differs from the results ob-

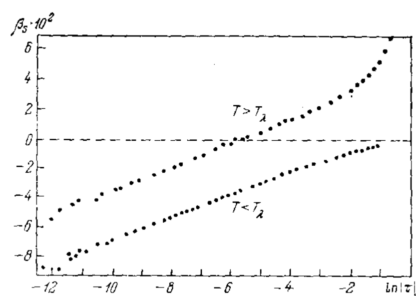

FIG. 1. Temperature dependence of the coefficient of thermal expansion of ^4He at the saturated vapor pressure.

tained in Ref. 8 and 9 (according to which $\alpha = -0.026$), but agrees with recent new measurements of the heat capacity,[10] from which it follows that for ^{4}He the index α is close to zero or could even have a very low positive value.

The shift in the temperature of the λ transition $\Delta T_\lambda = T_\lambda - T_\lambda(d)$ in narrow gaps with $d_3 = 2.85\cdot 10^{-5}$ cm, $d_2 = 3.60\cdot 10^{-5}$ cm, and $d_1 = 5.90\cdot 10^{-5}$ cm was investigated experimentally[2] in order to compare with the theoretical equation[5,6]

$$\Delta T_\lambda = 2.53\cdot 10^{-11}\left(\frac{M+3}{3}\right)^{3/4} d^{-3/2}\mathrm{K}, \quad (1)$$

(where d is measured in cm) and to determine the free parameter M contained in the theory in Ref. 5 and 6.

The shift in the temperature of the λ transition was investigated by the observation of breaks on the curve showing the temperature dependence of the density difference $\Delta\rho(T)$ of liquid ^{4}He in the gap $\rho_d(T)$ and in the bulk $\rho_\infty(T)$. For this, the temperature dependence of the difference in the dielectric permittivity $\Delta\varepsilon(T)$ of helium in wide ($d = 5\cdot 10^{-3}$ cm) and narrow gaps, made in the form of plane electrical capacitors with reliably monitored parallel orientation of the plates, was measured.

The measured values of the shift in the temperature of the λ point for each gap are as follows: $\Delta T_\lambda(d_1) = 0.62\cdot 10^{-4}$ K, $\Delta T_\lambda(d_2) = 1.33\cdot 10^{-4}$ K, $\Delta T_\lambda(d_3) = 1.97\cdot 10^{-4}$ K. It is evident from Fig. 2 that all three experimental points lie on the same straight line, corresponding to a power law dependence $\Delta T_\lambda(d) \sim d^{-n}$ with the index $n = 1.58 \pm 0.09$ practically coinciding with the theoretical value $n = 1.5$. If it is assumed that $n = 1.5$, then the average value of M, calculated from these data, is 0.6 ± 0.3.

In conclusion, we emphasize that in the course of the present experiments neither a jump in density nor any hysteresis effects accompanying the λ transition of helium in narrow gaps was observed with $\Delta\rho/\rho$ measured with an accuracy better than 10^{-7}. This indicates that the λ transition in helium in a gap remains a second-order phase transition and, therefore, the parameter M, in any case, must be less than 1.

We note finally that, as indicated in Ref. 6 and by L. T. Pitaevskii (unpublished), the transition of helium

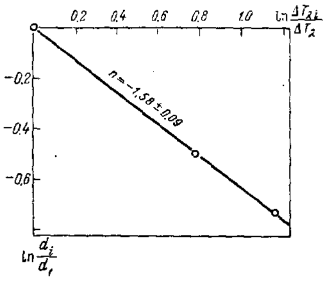

FIG. 2. Dependence of the shift in the temperature of the λ point on the width of the gap.

in gaps into the superfluid state can occur at a temperature lower than the temperature at which, as described above, anomalies are observed in the thermodynamic quantities. To solve this problem experimentally, additional measurements of the thermal conductivity or the rate of propagation of fourth sound in the same gaps are required.

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