Boundary layer (on the order of the correlation length) in ^{3}He-*B*

V. I. Fal'ko
Institute of Solid State Physics, Academy of Sciences of the USSR

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A symmetry classification is offered for the states of the boundary layer in ^{3}He-*B*. The first-order phase transition observed in a gyroscopic experiment by Pekola and Simola [J. Low Temp. Phys. **58**, 555 (1985)] can be explained as a reorientation of a boundary layer. A model is proposed for the dynamics of the transition from the *B* phase to the *A* phase.

Entities with dimensions on the order of the correlation length ξ, such as vortex cores, have recently attracted increased interest in the theory of superfluid ^{3}He. This research has been stimulated by the observation[1,2] of phase transitions in rotating ^{3}He-*B*, which Volovik and Salomaa[3] have interpreted as a change in the structure of a vortex core.

Two transition lines have been found in various experiments (the dashed line in Fig. 1 corresponds to an NMR experiment, and the solid line corresponds to a gyroscopic experiment). The transition observed by the NMR method[2] can be explained only as a change in the structure of a vortex core. The transition detected by the gyroscopic method[1] has not been unambiguously explained. If it is linked with a vortex core, it would be necessary to assume an inordinately large radius, $\sim 30\xi$, for the core in order to reach agreement with the measured heat of transition, q. It was shown in Ref. 3 that near T_c the *B* phase is restored over a distance of 3ξ from the vortex axis, and there is no reason for this region to expand at lower temperatures. The reason for this contradiction is that the angular velocities in the experiments, and thus the number of vortices, are not large. The volume $(\xi^2 L)$ occupied by the vortex cores is less than (ξS) of the boundary layer. In this letter we wish to propose an explanation for the first-order transition which has been observed in the gyroscopic experiment. The explanation is based on a change in the structure of a boundary layer near the wall of the rotating vessel.

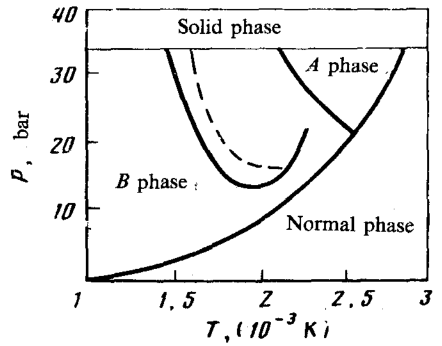

FIG. 1. Phase diagram of ^{3}He at low temperatures. Solid line—Transition observed in a gyroscopic experiment; dashed line—transition observed by an NMR method.

The boundary condition[4]

$$A_{ij} n_j = 0 \tag{1}$$

for the order parameter disrupts the B phase in a layer $\sim\xi$, and various microscopic textures may form in its place. The order parameter in the volume of the B phase, occupying the half-space $z > 0$, is

$$A_{ij} = \Delta\delta_{ij} . \tag{2}$$

These conditions, along with (1), serve as boundary conditions for the wall layer. Their symmetry group, $G = C_{\infty v} \otimes T$, contains rotations around the z axis, reflection in the plane passing through this axis, and time reversal. The free-energy functional is invariant under the wider group $SO_3 \otimes O_3 \otimes T$. Consequently, the highest-symmetry texture with a planar phase at the wall of the vessel is G-invariant. The phases of the lower-symmetry layer are described by the groups $C_{nv} \otimes T$, C_{nv}, $C_{nv}(C_n)$, $C_n \otimes T$, etc. First- and second-order transitions can occur between the textures of different symmetries, and an orientational transition can occur in the asymmetric phases. In order to choose from this variety of possibilities a version that agrees with the experimental observations we make use of the circumstance that the heat evolution q measured in Ref. 1 vanishes linearly in the superfluid current. A transition between microscopic textures of different symmetries cannot satisfy this condition. For a first-order transition this conclusion follows from the circumstance that in the absence of a current the heat of the transition is zero. For a second-order transition, this conclusion can be drawn from Landau's theory. The current leads to either a smearing of the transition or a shift of its temperature T_x, but it does not change its order. The transition can therefore be interpreted as a reorientation of a boundary layer with the broken symmetry of the rotation around the z axis. The heat evolution is linear in the current J_S in those cases in which there is a linear term in the expansion of the free energy in a series in the small current:

$$F = F_0 + \alpha(T - T_x)\mathbf{J}_S \vec{\Psi} .$$

(Here $\vec{\Psi}$ describes the two-dimensional orientation of the layer and has all the symmetry properties of the corresponding phase.) At T_x, there is a "cataclysm" of the microscopic texture, with a heat evolution

$$q = T_x \Delta \frac{\partial F}{\partial T} = 2T_x \alpha \Psi J_S \sim J_S .$$

This effect can occur only in phases with a symmetry which does not exceed that of the superfluid current itself, $C_{2v}(E, \sigma_{Jz})$.

States of this type correspond, in particular, to a microscopic texture with A phase directly at the boundary of the liquid. If we assume that real ^3He has a boundary positioned in this manner, we see why there has been no observation of a superheated B phase. The entire boundary serves as a nucleating region of the A phase, and when T_{AB} is reached the transition layer, which already exists, breaks away from the wall and moves into the interior of the vessel. Some indications of precisely this situation were found in Ref. 5 in calculations on the structure of the boundary layer near the critical temperature.

So far, we have been discussing phenomena associated with systems of large dimensions ($L \gg \xi \sim 10^{-6}$–10^{-5} cm). It is obvious that the effect of a boundary layer is seen most strongly in a bounded geometry. Specifically, its existence leads to a shift

$$\frac{\Delta T}{T_{AB}} = -\frac{2\epsilon}{Rq_{AB}}$$

of the temperature of the A–B transition. This effect has been observed in superfluid ^{3}He in capillaries[6] and in a narrow gap.[7] We can use the data reported here to estimate the surface density of the additional energy due to the boundary layer: $\epsilon \approx (0.5 \times 10^{-5}$ cm$) \times q_{AB} \sim \xi q_{AB}$.

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