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MAGNETIC PHASES OF SUPERFLUID ^{3}He IN ^{3}He–He II SOLUTIONS

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The superfluid phases of ^{3}He in ^{3}He–^{4}He solutions in the presence of a magnetic field are discussed. The most interesting one is the spatially inhomogeneous phase. Observation of this phase seems to be possible.

^{3}He–^{4}He solutions exhibit considerable magnetic effects [1,2]. This letter is intended to point out that the superfluid transition of ^{3}He dissolved in ^{4}He in the presence of an external magnetic field has some peculiar properties which are accessible to observation. The intensity of the field dictates the type of superfluid phase. The properties of these essentially different phases appear to be as interesting as the properties of superfluid pure ^{3}He.

In not very high fields the superfluidity of ^{3}He in solutions is brought about as in the zero field case [3,4] by s-wave pairing of ^{3}He quasiparticles. In the presence of a field H the Fermi momenta of the coupling particles p_+, p_- are not equal to each other. This fact prevents the formation of BCS pairs with zero momentum. As a result the temperature of the transition becomes lower with increasing field, and in some range of H pairing with non-zero momentum is efficient. The corresponding superfluid phase is spatially inhomogeneous, and the liquid mixture of ^{3}He–^{4}He obtains some sort of "crystalline" structure. A subsequent increase of the field forbids the s-wave pairing of fermions, and the superfluidity is due to BCS pairing with a higher orbital moment.

This situation is somewhat analogous to the case of superconductivity. The thermodynamics of superfluid ^{3}He in ^{3}He–He II mixtures is described by the equations of the BCS theory of superconductivity if out of all magnetic phenomena one takes into account only spin paramagnetism. For superconductors this model is rather rough because it does not consider the influence of the vector potential, considerable spin–orbit interaction and the presence of impurities. For the same reasons the detection of the spatially inhomogeneous superconducting phase is impeded [5]. These difficulties are absent in the case of ^{3}He–^{4}He solutions, and the observation of the inhomogeneous superfluid phase seems to be probable.

The transition temperature T_{cH} can be derived from the Bethe–Salpeter equation for pairing with momentum Q and low coupling energy (cf. refs. [5,6]):

$$\ln\frac{T_{cH}}{T_{c0}} - 2\ln 2 = -C + \frac{\mathrm{i}\pi}{2q}\ln\frac{\Gamma[(1+\mathrm{i}q+\mathrm{i}h)/2]\,\Gamma[(1+\mathrm{i}q-\mathrm{i}h)/2]}{\Gamma[(1-\mathrm{i}q-\mathrm{i}h)/2]\,\Gamma[(1-\mathrm{i}q+\mathrm{i}h)/2]}$$

$$\equiv (\pi/q)\sum_{n=1}^{\infty}\{\operatorname{arctg} x_n + \operatorname{arctg} y_n - (2q/\pi n)\}, \qquad (1)$$

where C is the Euler constant,

$$q = Qv_0/(2T_{cH}), \quad h = \beta H/T_{cH},$$

$$x_n = q_n + h_n, \quad y_n = q_n - h_n,$$

$$q_n = (q/\pi)/(2n-1), \quad h_n = (h/\pi)/(2n-1),$$

β is the ^{3}He nuclear magnetic moment, v_0 is the Fermi velocity. The divergent integrals were cut so that the transition temperature (1) is equal to that of ref. [4] T_{c0} when $H = 0$. The equation in Q is the condition