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THE POMERANCHUK EFFECT AND INFRALOW TEMPERATURES

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IN "JETP Letters" (Vol. 1, No. 6, Russ. p. 1, transl. p. 155), Yu. D. Anufriev reported attainment of infralow temperatures with the aid of the Pomeranchuk effect. This effect, predicted by Pomeranchuk back in 1950, consists in the following. As is well known, all bodies release heat upon solidification. Therefore, if crystallization is effected under conditions of thermal insulation (for example, by increasing the pressure), the substance becomes heated. This is normally the case, but not for He^3 below a certain critical temperature. If He^3 is made to crystallize at $T < 0.3°K$, it will absorb heat, meaning that it will become cooled under adiabatic conditions. The melting curve of He^3 can be drawn as shown in Fig. 1. It is seen from this figure that below the point T_0 the melting curve exhibits unusual behavior. This is the Pomeranchuk effect.[2] It can be explained theoretically as follows.

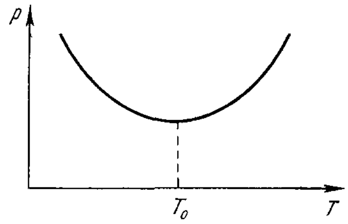

FIG. 1.

It is known that the heat of melting at a specified temperature is given by[3]

$$Q = T\,(S_2 - S_1); \tag{1}$$

the subscript 2 denotes the solid phase and 1 the liquid phase. If $Q > 0$, this means that on going from the liquid to the solid state heat is absorbed. For ordinary bodies $S_2 < S_1$, and therefore $Q < 0$; for He^3 $S_2 > S_1$ at temperatures below T_0 and therefore $Q > 0$. Why then is $S_2 > S_1$ for He^3 under these conditions?

It is known that the entropy of any system under specified conditions (specified energy and volume) is determined by the formula

$$S = k \ln N, \tag{2}$$

where N is the number of possible states at the given temperature. When the temperature tends to zero the system goes over into the ground state, which is not degenerate and therefore $N = 1$, i.e., $S = 0$ —the well-known Nernst theorem. But different systems go into the ground state at different rates. Let us consider He^3. Its atoms consist of three nucleons and have spins $\frac{1}{2}$. Since the spin of each atom can have two orientations, if the spins were not to interact with one another they would form 2^n possible orientations, where n is the number of atoms, i.e., the entropy should be not less than $kn \ln 2$ or $R \ln 2$ per gram-atom of helium. However, there are two types of interaction between the spins:

1) exchange—quantum-mechanical, and

2) magnetic, since the atoms have magnetic moments oriented along the spin.

Both interactions are quite weak and exert practically no influence on the random orientation of the spins. At very low temperatures, however, they go into action. The first to operate are the exchange forces. Even at $T \sim 1°K$ they begin to align the spins antiparallel to one another, so that we obtain in lieu of the 2^N possible states only one state, i.e., the entropy starts to tend to zero already at $T \sim 1°K$. It is interesting, however, that in the crystalline state these exchange forces do not come into play at all. The magnitude of the exchange forces is determined by the zero-point oscillations of the atoms, in other words, by the smearing of the wave functions. Whereas in the liquid state this smearing is large, in the solid, crystalline state at low temperature the atoms of He III have clearly fixed positions and the amplitude of their zero-point oscillations about the equilibrium position is much smaller than the distances between the atoms. Consequently, the entropy will tend to zero in the liquid, but in the solid phase it will remain not smaller than $R \times \ln 2$ per gram atom. This can be represented as in Fig. 2.

The temperature variation of the entropy is repre-

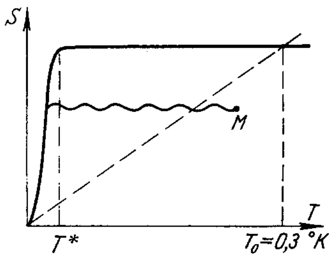

FIG. 2.

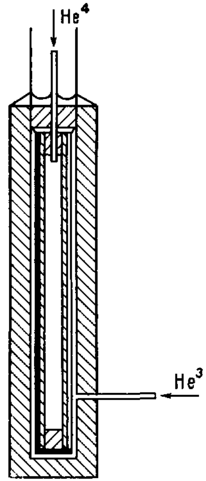

FIG. 3.

sented by the dashed curve for the liquid and by the solid curve for the solid phase. We see that these curves cross at the point T_0, below which $S_{sol} > S_{liq}$, meaning that the Pomeranchuk effect will be observed. It is seen from Fig. 2 that the entropy of the solid also begins to tend to zero ultimately, but this is already due to the magnetic interaction of the atoms, which is so weak that it comes into play at $T = T^* \sim 10^{-7}$ deg K. Theoretically, the adiabatic transition from a certain state M along the wavy curve should lead to temperatures $\sim 10^{-7}$ deg K, but so far only $T \sim 0.02$°K has been attained in practice.

The instrument described in Anufriev's letter consists of a bronze chamber, in which is placed another chamber with membrane walls (Fig. 3). He^3 at a pressure of 30 atm, cooled by adiabatic demagnetization to a temperature below 0.3°K, is contained between the chambers. He^4 under pressure is fed into the inner chamber. The pressure of the He^4 was raised to 24 atm, at which a temperature of the order of 0.02°K was obtained.

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