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ZERO SOUND IN LIQUID He^3*

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In the article that follows this note Abel, Anderson, and Wheatley report the discovery of zero sound in liquid He^3, the non-superfluid isotope of liquid helium. This interesting phenomenon was predicted by L. D. Landau in 1957 on the basis of his general theory of Fermi liquids, which consist of particles obeying Fermi statistics.[1]† A review of this theory by Abrikosov and Khalatnikov has already been published in Uspekhi.[3] In the present short note we recall certain theoretical aspects of sound propagation in liquid He^3.

Ordinary sound propagates in liquid He^3, as in any other liquid or gas, subject to the condition

$$\lambda \gg l, \tag{1}$$

where λ is the wavelength of sound and l is the mean free path of liquid particles. The velocity of sound propagation is here related to the compressibility of the liquid by the customary formula

$$c^2 = \frac{\partial p}{\partial \rho}. \tag{2}$$

Fermi liquids are distinguished by the fact that the mean free path of elementary excitations within them increases with decreasing temperature:

$$l \sim \frac{1}{T^2}. \tag{3}$$

Therefore (1) ceases to be valid for any wavelength λ at sufficiently low temperatures. This leads to the damping of ordinary sound, which ultimately cannot be propagated. At absolute zero, when collisions do not occur, ordinary sound could not be propagated at all in a Fermi liquid. However, Landau established however that when interactions between elementary excitations are of a certain type a different kind of sound, called zero sound, can propagate in a Fermi liquid. The condition for the existence of this sound is found in an inequality that represents the reverse of the relationship in (3); zero sound propagates at very low temperatures. The frequency and wave vector of zero sound are related by the customary equation

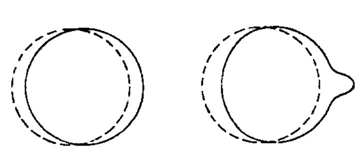
$$\omega = kc_0,$$

where the velocity c_0 is independent of k and is not determined by the simple formula (2), but depends on the interaction between elementary excitations in the liquid. The value of c_0 can be calculated from experimental data on the heat capacity and compressibility of the liquid. Calculations show that in liquid He^3 we have

$$\frac{\Delta c}{c} = \frac{c_0 - c}{c} \approx 0.032. \tag{4}$$

Therefore the overall picture of sound propagation in He^3 exhibits the following properties. At sufficiently high temperatures ordinary sound is propagated; its damping is proportional to ω^2/T^2 and is enhanced with decreasing temperature. At low temperatures corresponding to $\lambda \sim l$ the damping becomes so extremely large that sound propagation becomes actually impossible. At still lower temperatures we enter the zero-sound region, where damping is reduced and the sound velocity changes by the amount Δc. The damping of zero sound is proportional to T^2 and is independent of frequency. All the described singularities of propagation were observed experimentally and were reported in the work whose translation follows this note. The results leave no room for doubt that the Fermi liquid theory is in excellent quantitative agreement with experiment.

To attain a better understanding of the difference between ordinary sound and zero sound it is useful to consider how the momentum distribution of elementary excitations changes in a Fermi liquid through which sound is propagating. When the liquid is in equilibrium its elementary excitations, like electrons in a metal, fill the Fermi sphere in momentum space; the radius p_0 of the sphere depends on the density of the liquid. When ordinary sound is propagated thermodynamic equilibrium exists at each point of the liquid, whose density is variable, however, and all its particles move together with a certain velocity. Therefore the momentum distribution of the particles can here be represented by a Fermi sphere, of altered radius, that



a) Ordinary sound b) Zero sound

*In connection with the article, "Propagation of Zero Sound in Liquid He^3 at Low Temperatures," by W. R. Abel, A. C. Anderson, and J. C. Wheatley, Phys. Rev. Letts. 17, 74 (1966).

†V. P. Silin had previously established theoretically that the oscillations corresponding to zero sound can exist in a Fermi gas with weak interatomic repulsion.[2]

is displaced in momentum space. The picture becomes extremely more complicated in the case of zero sound; thermodynamic equilibrium cannot be established. The Fermi surface ceases to be spherical, but is deformed in a complex manner and is entrained in the direction of sound propagation. The accompanying figure shows schematically how a Fermi sphere is affected by the propagation of ordinary and zero sound.

[1] L. D. Landau, JETP **32**, 59 (1957), Soviet Phys. JETP **5**, 101 (1957).

[2] V. P. Silin, JETP **23**, 641 (1952).

[3] A. A. Abrikosov and I. M. Khalatnikov, UFN **66**, 177 (1958), Soviet Phys. Uspekhi **1**, 68 (1959).

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