Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics, USSR Academy of Sciences (25–26 February 1976)

Usp. Fiz. Nauk 120, 134–135 (September 1976)

A scientific session of the Division of General Physics and Astronomy was held on February 25 and 26, 1976 at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. *I. M. Kopylov*, The Large Azimuth Telescope: Technical Parameters and Scientific Prospects.

2. *Yu. N. Pariĭskiĭ*, First Observing Results from the RATAN-600 Radio Telescope.

3. *A. F. Andreev*, Diffusion in Quantum Crystals.

4. *B. N. Esel'son, V. N. Grigor'ev and V. A. Mikheev*, Experimental Observation and Investigation of Quantum Diffusion in Solid Helium.

Andreev's paper was based on a review article published in Usp. Fiz. Nauk 118, 251 (1976) [Sov. Phys. Usp. 19, 137 (1976) and is therefore not summarized here.

We publish below the brief content of the fourth paper.

B. N. Esel'son, V. N. Grigor'ev, and V. A. Mikheev. *Experimental Observation and Investigation of Quantum Diffusion in Solid Helium.* By virtue of the importance of its zero-point vibrations and low interatomic-interaction energy, solid helium occupies a special position among other crystalline substances. This circumstance give rise to a whole series of unusual phenomena, among which the behavior of impurities and defects in the crystals is found to be especially interesting.

A theoretical analysis by Andreev and Lifshitz[1] showed that the manner in which impurity particles and point defects move changes radically in quantum crystals, of which solid helium is a typical representative. The strong overlapping of the wave functions of neighboring atoms results in transformation of the impurities and defects into impuritons—unique quasiparticles that move with practically complete freedom through the crystal lattice. This phenomenon, which has come to be known as quantum diffusion, is accompanied by anomalous behavior of the diffusion coefficient D of the impurity—instead of the usual exponential dropoff as the temperature is lowered, we observe an increase of $D \propto T^{-9}$[1] or find it to be independent of temperature and to vary in inverse proportion to the concentration x.[2,3] The former is the case when collisions with phonons have a definite role in the motion of the impuritons, and the latter when the impuritons interact with one another.

To detect the phenomenon of quantum diffusion, the spin-echo method was used to measure D in the hcp phase of solid solutions of He^3–He^4 isotope solutions in the He^3 concentration range from 0.25 to 2.17% down to 0.4 °K. (Improvement of the measuring technique made it possible to broaden the range of measured D values significantly, to $\sim 10^{-10}$ cm²/sec). Under the conditions of these experiments, the measured spin-diffusion coefficients practically agree with the values of the mutual diffusion coefficients.

It was shown as a result of the measurements that the diffusion coefficient is independent of temperature at $T < 1$ °K and $x \lesssim 2\%$ He^3 (Fig. 1) and varies in inverse proportion to x (Fig. 2). A continuous transition was registered from vacancion diffusion to impuriton diffusion, and D was found to depend strongly on the density ρ of the crystal. The impuriton diffusion coefficient varied approximately 3 times more strongly than the spin diffusion coefficient in pure He^3 in response to the same change in ρ.

The relationships found here indicate a definite contribution of quantum effects to the diffusion of He^3 impurities and are consistent with a situation in which the mobility of the impurity excitations is limited by their collisions with one another. The strong $D(\rho)$ dependence confirms the nonlinearity of the impuriton diffusion coefficient as a function of the exchange integral I_3.

Studies of diffusion in the bcc phase established that D decreases exponentially with decreasing temperature in solutions containing $\lesssim 2\%$ He^3, indicating a vacancion diffusion mechanism. In the vacancion diffusion range, the values of D in the bcc phase are several tens of times larger than the corresponding values of D in the hcp phase.[7] This made it possible to construct phase diagrams in the neighborhood of the bcc–hcp transition of dilute He^3–He^4 solid solutions.

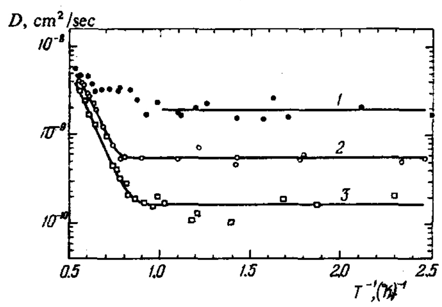

FIG. 1. Temperature dependence of the coefficient of diffusion of He^3 in the hcp phase of solutions at a molar volume of 20.7 cm³/mole and various He^3 concentrations: 0.25% (1), 0.75% (2), and 2.17% (3).

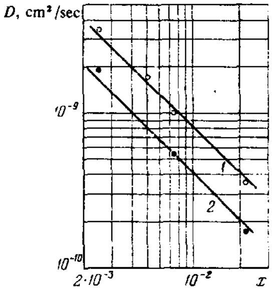

FIG. 2. Impuriton diffusion coefficient vs He^3 concentration at different molar volumes: 21.0 cm^3/mole (1) and 20.7 cm^3/mole (2).

In more concentrated solutions, for which the bcc phase exists down to $T \approx 0.4$ °K, studies made up to $x = 1$ indicated a number of additional features in the behavior of D. A smooth transition from an exponential decrease at high temperatures to a plateau at $T < 0.7$ °K was observed.[8] In the range of the plateau at $x < 19\%$ He^3, D depends very weakly on x and is of the same order of magnitude as the impuriton diffusion coefficient in the hcp at $x \approx 2\%$ He^3. This fact indicates the existence of a new mechanism of He^3 diffusion in the intermediate concentration range. At $x \approx 20\%$ He^3, it was found that D increases sharply and becomes dependent on the diffusion path time t: the diffusion coefficient decreases by approximately half as t increases from 0.1 to 50 sec. These last features can be explained by the appearance, in this concentration range, of continuous chains of He^3 atoms with dimensions on the order of the diffusion length, which support spin diffusion, and by a decrease in the number of the chains as their length increases.[9]

Thus, experiments conducted in the hcp phase of He^3–He^4 solutions have made it possible to observe quantum diffusion of He^3 impurities and to estimate the basic parameters characterizing this phenomenon, and have indicated that the interaction of the impurities with one another is a decisive factor. The results obtained for the bcc phase indicate the existence of new features that characterize the diffusion in this complex system.

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[8]V. N. Grigor'ev, B. N. Esel'son and V. A. Mikheev, *ibid.* **66**, 321 (1974) [**39**, 153 (1974)].
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Translated by R. W. Bowers