ATTEMPT AT OBSERVING VACANCIONS IN He^4 CRYSTALS

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The large amplitude of the zero-point oscillations of atoms in helium crystals makes it

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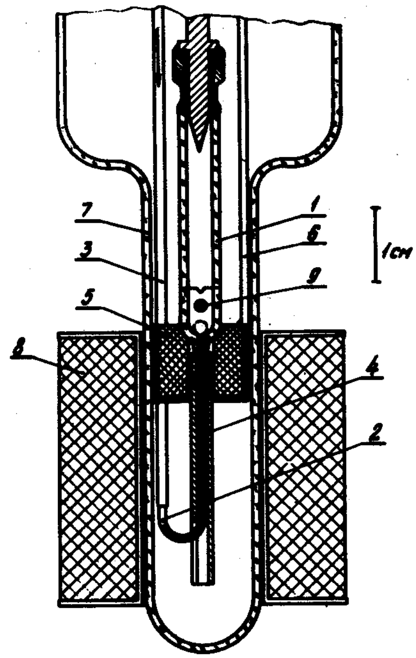
necessary at low temperatures to regard defects of any nature, particularly **vacancies, as non-localized quasi**-particles (see [1]). Moreover, if the width of the energy band for the vacancions turns out to be sufficiently large, then zero-point vacnacions may exist, i.e., those existing also at zero temperature. Under such conditions, the crystal should have an anomalously large ductility.



We have attempted to observe effects connected with the presence of vacancions and their motion.

The idea of our experiment was to measure the velocity of a body frozen into the helium crystal grown under the same conditions in which we have previously [2] prepared crystals of high degree of perfection.

Figure 1 shows the instrument employed by us. The helium crystals were grown in a downward direction in a vertically oriented ampoule (1) with inside diameter ~3 mm, gradually filling its entire volume. A platinum capillary (2), 0.9 (dia) x 0.4 mm, subsequently joined to a tube of stainless steel (3), was sealed into the bottom of the ampoule. A core (4) of Armco iron, 3 mm in diameter, was placed over the platinum capillary. A short lead cylinder (5) in a copper frame, connected with a copper cold finger (6) to the outer helium bath is placed over the core, near the bottom of the ampoule. The ampoule was located inside a vacuum jacket (7), over which a superconducting coil (8) equipped with a thermal switch was placed.

The working body was a highly polished ball (9) of 1.57 mm diameter, made of high-coercivity alloy of platinum with cobalt (25% Co, 75% Pt) and magnetized in a field of 25 kOe. Before the start of the experiment, the sphere was lying on the bottom of the ampoule. After the lead cylinder is cooled, the ball floats over the cylinder at a height ~2 mm and assumes a position at the center of the ampoule, so that its magnetic axis is directed vertically as a result of the action of the core. It was thus possible, after first freezing-in the "weightless" ball into the growing crystal, to subject the ball to the action of artificial gravity produced by the superconducting coil with the ferromagnetic core.

The force with which the ball was drawn into the caoil at a current of 10 A was measured in special model experiments with the aid of spring balances and reached 7.5 g, i.e., it exceeded its weight by 250 times.

The position of the ball was determined with a cathetometer. We measured the distance from the shadow edge of the ball to a reference marker on the surface of the ampoule. The optical distortions due to the observation through six glass walls did not make it possible to attain the rated accuracy of the measuring instrument (10 μ).

We were likewise unable to lower the temperature of the crystal below 0.5°K. We observed no displacement of the ball during $\sim 10^4$ sec, i.e., its velocity was less than 2×10^{-7}

cm/sec.

The ball velocity was determined by two factors - the concentration of the vacancions c and their mobility b. Under the influence of the force applied to the ball, normal stresses σ_{nn} and the associated change in the vacancion concentration are produced on its surface; this is equivalent to a deviation μ' of the chemical potential from its equlibrium value. Just as in the case of ordinary vacancies (see [3]), $\mu' = -\Omega\sigma_{nn}$, where Ω is the atomic volume.

To calculate σ_{nn} it is necessary to determine the deformation of the helium under the influence of the force $\vec{F}$ applied to the ball. The lattice displacement vector equals

$$\mathbf{u} = \frac{1+\sigma}{8\pi E(1-\sigma)r}\left\{(3-4\sigma)\mathbf{F} + \mathbf{n}(\mathbf{n}\mathbf{F}) + \frac{R^2}{r^2}[\mathbf{F} - 3(\mathbf{F}\mathbf{n})\mathbf{n}]\right\}. \quad (1)$$

Here E and σ are the Young's modulus and the Poisson coefficient of helium, R is the radius of the ball, r is the distance from the center $(r > R)$, and $\vec{n} = \vec{r}/r$. As $r \to \infty$, Eq. (1) goes over into the solution corresponding to a δ-function force (see [4]). When $r = R$ we have $\vec{u} = \text{const}$, as should be the case, inasmuch as the ball is assumed to be undeformable. With the aid of (1) we can calculate the normal stresses on the surface of the ball:

$$\sigma_{nn} = \sigma_{ik} n_i n_k = -(\mathbf{F}\mathbf{n})/4\pi R^2.$$

When $r > R$, the chemical potential satisfies the stationary diffusion equation $\Delta\mu' = 0$. The solution satisfying the obtained boundary conditions is given by

$$\mu' = -\left(\frac{\Omega}{4\pi}\right)\mathbf{F}\nabla\frac{1}{r}.$$

The gradient of μ' determines the diffusion flux of the vacancions and the associated normal velocity of the points on the surface of the ball: $v_n = -cb\partial\mu'/\partial n = cb\Omega(F\cdot n)/4\pi R^3$. If we introduce the force $f = 3\Omega F/4\pi R^3$ per helium particle in the volume of the ball, then the rate of displacement of the ball as a whole is $v = (2/3)cbf$.

In our case $f = 1.2 \times 10^{-16}$ dyne and $v < 2 \times 10^{-7}$ cm/sec. Thus, $cb < 2.5 \times 10^9$ sec/g. This condition should be satisfied, in any case, by the mobility due to the quantum tunneling of the vacancies from site to site, which is connected with the width $\Delta\epsilon$ of the energy band of the vacancions by the relation $b \sim a^2\Delta\epsilon/\hbar T \sim 10^{12}\Delta\epsilon/T$, where a is the interatomic distance. From this we get $\Delta\epsilon < 2 \times 10^{-3}$ T/c.

In order for zero-point vacancions to exist, it is necessary that $\Delta\epsilon$ be comparable with the vacancy formation energy, which, one might assume, is of the order of several degrees. It is thus possible to state that if zero-point vacancions do exist in He^4, their concentration does not exceed 0.1%.

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