Plastic flow of crystalline He^4

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Plastic flow of crystalline helium was investigated in the temperature range 0.6–2.1°K at pressures 25.7–40 atm and at absolute deformation rates $5\cdot 10^{-10}$–10^6 cm/sec. The dependences of the deformation rate on the applied force and on the temperature were measured. It is concluded on the basis of tl obtained data that the plastic deformation is of dislocation origin.

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In view of the large amplitude of the zero-point oscillations of the atoms in the helium crystals, the defects, particularly vacancies, should be regarded at low temperatures as quasiparticles.[1] Under these conditions the crystal should have anomalously high ductility. No displacement of a sphere of 1.3 m diameter by a force of 7.5 g, with velocity greater than $2\cdot 10^{-7}$ cm/sec, was observed in [2]. In [3], where plastic flow of polycrystalline helium at rates

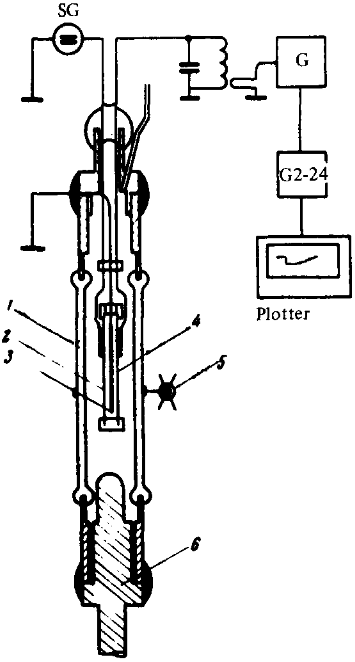
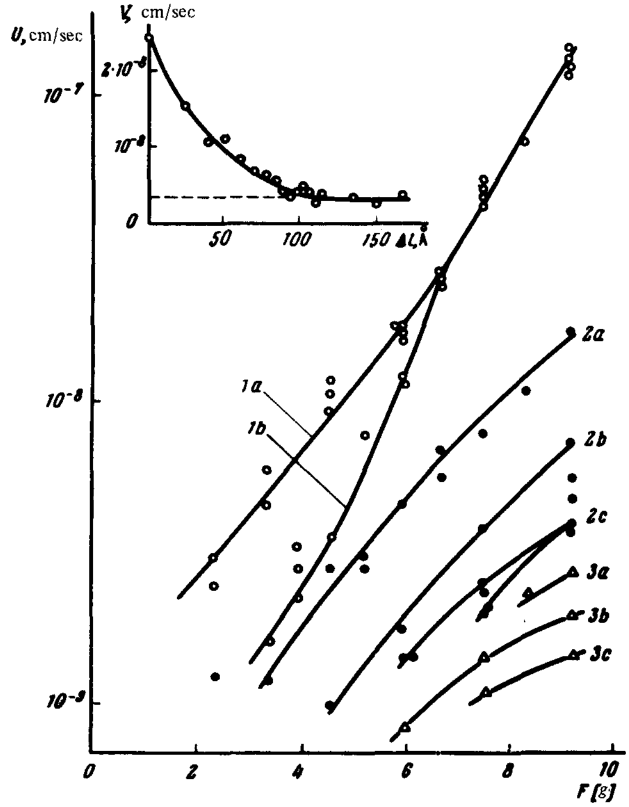


Fig. 1. Overall view of the apparatus: 1—glass container, 2,4—stationary plates, 3—movable plate, 5—resistance thermometer, 6—copper cold finger.



g. 2. Dependence of the rate of plastic deformation on the force (32.2 atm): $T=1.76$ °K. 1a) without deformation, 1b) deformation 700 Å; ●) $T=1.67$ °K;) without deformation, 2b) deformation 50 Å, 2c) deformation 200 Å; Δ) T .64 °K, 3a) without deformation, 3b) deformation 50 Å, 3c) deformation 80 Å. p—typical plot of the deformation rate against the deformation.

$^{-4}$—10^{-1} cm/sec was investigated, it was concluded that the main mechanism
the plastic deformation is dislocation motion.

This paper is devoted to the study of plastic deformation of He^4 crystals at
tremely low loads and rates.

Figure 1 shows the apparatus used for this purpose. The helium crystals
re grown under conditions of a small temperature gradient in an upward di-
ction in a vertically placed ampule, at a rate 10^{-4} cm/sec. A double capacitor
th plates of stainless steel 0.3 mm thick was situated at the center of the am-
le. The outer plates 2 and 4, measuring 14×4 mm, were rigidly fastened to
ch other, and the central plate 3, with dimensions 10×4 mm was mounted
a highly pliable suspension. The gaps were maintained accurate to 0.04 mm
d were equal to 0.35 mm. The capacitor made up of plates 3 and 4 was part

of the tank circuit of a highly stabilized oscillator, the frequency of which was measured with an electron-counting frequency meter and recorded on an x-y plotter. The error in the absolute average displacement of the plate 3 was $\sim 10^{-8}$ cm, and owing to the small intrinsic drift of the oscillator the velocitie could be measured accurate to $(2-5)\cdot 10^{-10}$ cm/sec. A potential difference of 10 kV between plates 2 and 3 produced a force of ~55 g. The temperature wa measured with a resistance thermometer and was maintained constant during the experiment within 0.002 °K.

We have performed experiments with He^4 crystals grown at pressures 25.7-40 atm in the temperature range 2.1—0.6 °K. The most thoroughly studied wa the plastic flow of crystals grown at 32.2 atm. Figure 2 shows plots of the vel city of the central plate against the applied force. It is seen that the drift velo city depends on the force in nonlinear fashion at all temperatures. It was impossible to fit the data to a universal law, but each individual curve could be approximated, within the limits of experimental error, by a power law formul $v \sim F^{\alpha}$ with an exponent $\alpha = 3-5$. With increasing deformation, the plate drift velocity decreases, leveling off to a constant value (Fig. 2, top), that is, the crystal "becomes more rigid." The same phenomenon is illustrated by the families of curves plotted at constant temperatures but at different total deformations (Fig. 2, curves 2a,b,c). After removing the load, near the meltin temperature ($T_m - T = 0.05$ °K), a return motion amounting to ~3% of the prior deformation was observed.

Qualitatively similar relations were observed for all the investigated pressures both in the HCP phase and the BCC phase. Figure 3 shows the temperature dependences of the steady-state drift velocity at a constant force for thre pressures: 40, 32.2, and 25.7 atm. By approximating the experimental point by the relation $v \sim \exp(-\Delta/T)$, we obtain for the parameter Δ the values 210, 110, and 250 °K, respectively. We have replaced the central solid plate by a

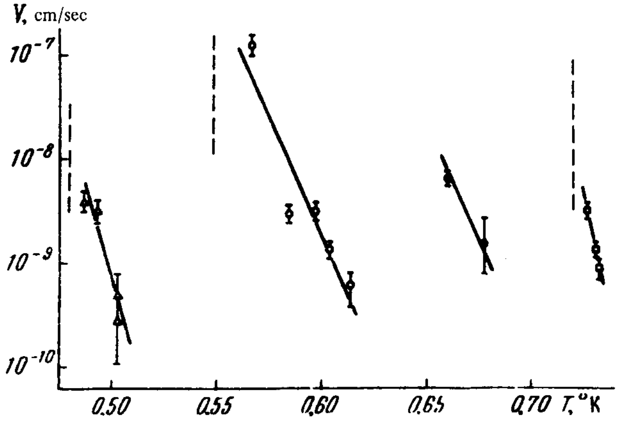


Fig. 3. Dependence of the rate of plastic deformation on the temperature at a constant force 9.2 g. The vertical dashed lines to the left of the experiment points are the corresponding melting temperatures: Δ) $P = 40$ atm, solid plate o) $P = 32.2$ atm, solid plate, ●) $P = 32.2$ atm, grid, □) $P = 25.7$ atm, solid pla

essed flat grid made of nickel wires of 0.1 mm diameter with a square mesh 25×0.25 mm. The absolute drift velocities in this case increase by two or-rs of magnitude, but the qualitative similarity remained (Fig. 3). Several periments were performed with crystals cooled to 1.3 and 0.6 °K without ior deformation. The rates of plastic flow in these experiments were under sensitivity limits.

At temperatures ~ 1.3 °K, a noticeable displacement of the central plate uld be caused by applying a force ~ 25 g. A force threshold had to be over-me to start the motion, and the velocity was not constant with a value $\cdot 10^{-6}$ cm/sec. The threshold force increased with decreasing temperature. e rigidity of the crystal could be increased by successive deformations. ter removing the load, relaxation was observed—a nonmonotonic return tion of the plate with a characteristic settling time ~ 3 min.

Comparing the results with the analogous relations for ordinary single crys-s, it seems possible to propose that in the investigated temperature and essure range the plastic flow of crystalline helium, with velocities $\gtrsim 5\cdot 10^{-10}$ /sec, is effected by a dislocation motion. This yields for the rate of plastic formation due to vacancy motion a value of $v < 5\cdot 10^{-10}$ cm/sec. Using the re-lts of [4], we can calculate for the mean free path of the vacancies near the lting temperature the value $l < 7$ Å, which depends on the temperature like $a(T_0/T)^9$ (a is the average interatomic distance), for which it follows that < 1.85 °K.

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