

Motion of charges in solid hydrogen

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The velocity of injected charges in solid hydrogen has been measured for the first time. Near T_m , and in weak fields $E \lesssim 10^4$ V/cm, the velocity of charges of both signs falls off exponentially with decreasing temperature. The diffusion coefficient of positive charges, D_+ , is close in magnitude to the self-diffusion coefficient D_s in solid H_2 in the thermal-activation region.

In this letter we report and discuss the results of a study of the temperature and field dependence of the velocity of injected charges in solid hydrogen in the temperature interval 13.8–11 K and in the field interval $E = 5 \times 10^2$ – 1.5×10^4 V/cm. The measurements were carried out in a diode consisting of a radioactive source of charges (a titanium-tritium target) and a collector. The source-collector distance was $L = 0.2$ mm. The diode was inside a cylindrical metal cell in which hydrogen or helium crystals were grown at a constant pressure.

The velocity of the charges was determined from the time of arrival of the charged-particle front at the collector when a step voltage U was applied (a time-of-

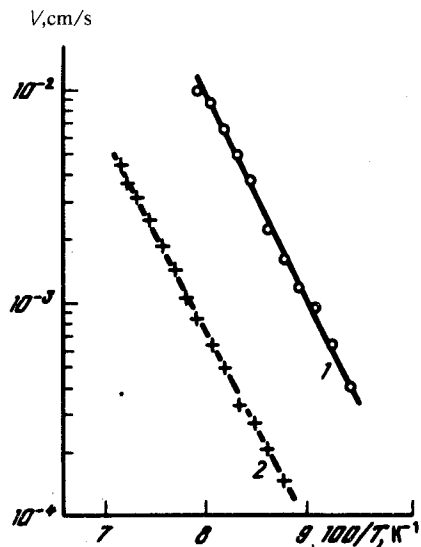


FIG. 1. The velocities v_{\pm} versus the reciprocal temperature at $U = 300$ V. 1—Negative charges; 2—positive charges.

flight method). This method has been used successfully to study the field and temperature dependence of the velocities of injected charges in solid helium.¹ Before we begin the work with solid hydrogen, we tested the operation of the cell in experiments with solid helium over wide ranges of the field and the temperature.

In the present experiments the samples were grown at a constant pressure of 1.5 atm at a velocity of about 1 mm/min. The growth velocity was monitored on the basis of the change in a static current flowing through the diode at a constant voltage and also on the basis of the readings of a thermometer on the cell.

Figure 1 shows the velocity of positive and negative charges vs the reciprocal temperature in one of the samples (sample 2) at a voltage $U = \pm 300$ V. We see that the curves of $v_{\pm}(T)$ are approximately exponential. The activation energies calculated from the slopes of straight lines drawn through these experimental points are $\Delta_{+} = 215 \pm 20$ K and $\Delta_{-} = 230 \pm 20$ K. These figures refer to a sample which was held for about 100 h in the cell. A comparison of the results of measurements taken on different days showed that the velocity of the positive charges decreased systematically, while that of the negative charges increased. The activation energy for the positive charges remained essentially constant, while that for the negative charges fell off by a factor of 1.5 from the value for a freshly grown sample. This effect is not a result of a change in the properties of the sample due to the thermal cycling, since the curves of $v_{\pm}(T)$ are reproducible quite well when the sample is successively cooled and heated. The probable reason for the observed changes is an increase in the concentration of para-molecules in the sample over time.²

Figure 2 shows the field dependence of the velocity $v_{\pm}(U)$ for the same sample. Because of the large difference in the velocities and the pronounced trapping of negative charges in weak fields at $T \ll 12$ K, measurements were carried out at different temperatures. We see from this figure that the velocity of positive charges depends

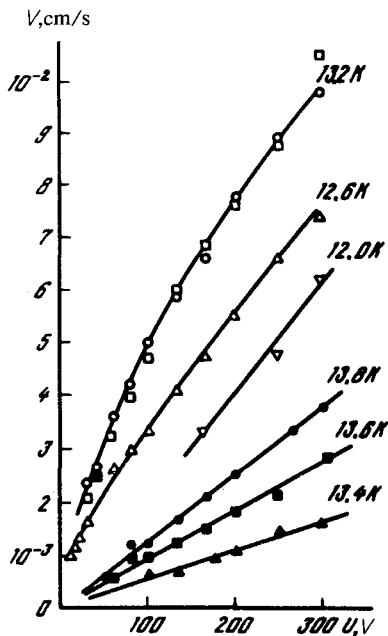


FIG. 2. Field dependence of the velocities $v_{\pm}(U)$. $\circ, \square, \triangle, \nabla$ —Negative charges; $\bullet, \blacksquare, \blacktriangle$ —positive charges.

linearly on the electric field up to $E = U/L = 1.5 \times 10^4$ V/cm. For negative charges, the dependence $v - (U)$ is weaker than linear, even at the weakest working fields, $E = 5 \times 10^2$ V/cm.

The linear dependence of the velocity of the positive charges on the accelerating field makes it possible to work from the measurements of the velocity v_+ to calculate the mobility of positive charges, $\mu_+ = v_+ / E$. When we then use the Einstein relation, we can estimate the diffusion coefficient for the positive charges, $D_+ = \mu_+ kT/e$. In this manner we can transform from the velocity of the positive charges at $U = 300$ V, i.e., $v_+(300)$ (line 2 in Fig. 1), to the diffusion coefficient D_+ : $D_+ = 0.6 \times 10^{-8} v_+(300) T \text{ cm}^2/\text{s}$. It is interesting to compare the values found for $D_+(T)$ with the known values of the self-diffusion coefficient D_s in solid H_2 . According to handbook recommendations,² the self-diffusion coefficient in solid hydrogen can be written in the form $D_s = D_0^s \exp(-\Delta_s/T)$, where $D_0^s = 3 \times 10^{-3} \text{ cm}^2/\text{s}$ and $\Delta_s = 200$ K. A conversion of the results of $v_+(T)$ measurements in Fig. 1 into diffusion coefficients yields values $D_0^+ = 3.7 \times 10^{-3} \text{ cm}^2/\text{s}$ and $\Delta_+ = 228$ K. The approximate equality of D_+ and D_s in the region of a thermally activated motion may indicate that the same diffusion mechanism is playing an important role in the two cases.

¹A. I. Golov, V. B. Efimov, and I. P. Mezhev-Deglin, Zh. Eksp. Teor. Fiz. **94**, 198 (1988) [Sov. Phys. JETP **67**, 325 (1988)].

²Handbook on the Properties of Condensed Phases of Hydrogen and Oxygen, Naukova Dumka, Kiev, 1984.

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