negative field-effect mobility, which requires only that the effective surface mobility vary more strongly than Q^{-1}.

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CRYSTAL STRUCTURE OF PARA-ENRICHED SOLID DEUTERIUM BELOW THE λ TRANSITION*

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(Received 14 March 1966)

It has recently been reported by Mills and Schuch[1] that the crystal structure of solid normal hydrogen undergoes a change below the temperature of the λ anomaly observed in the heat capacity.[2] Above the λ anomaly the solid is reported to exhibit a hexagonal close-packed structure, and below the λ transition this hexagonal phase changes to a face-centered cubic lattice. These results are in accord with deductions concerning the crystal structure of the solid from the infrared spectrum of normal hydrogen.[3]

In an earlier communication[4] we reported the results of neutron-diffraction studies of solid ortho and normal deuterium at 13°K. The structure of both solids is hexagonal close-packed, $a = 3.63$ Å and $c/a = 1.61$. We have now extended our neutron-diffraction measurements to lower temperatures and to para-enriched solids which, like normal hydrogen, exhibit anomalies in the nuclear magnetic resonance[5] and λ transitions in the heat capacities.[6] The neutron diffraction patterns for the para-enriched solids (para content >80%) above the λ-transition temperatures of the heat capacities are, within experimental error, the same as those for ortho and normal deuterium with respect to both line positions and intensities. The high-temperature form of solid deuterium is, therefore, hexagonal close-packed irrespective of the para content.

The neutron diffraction pattern of a solid deuterium sample containing 83% para species at 1.9°K is shown in Fig. 1. The experimental apparatus used in these measurements was similar to that previously used,[4] the deuterium being rapidly solidified in an aluminum-magnesium sponge. The enrichment in para content was accomplished by fractional desorption from a column packed with γ-Al_2O_3. The three diffraction patterns of Fig. 1 correspond to the background counts N_B for the cryostat at 4.2°K, trace C; the total counts N_T at 1.9°K for the cell filled with 83% para-deuterium, trace B; and the difference pattern $N_T - pN_B$, trace A, where p is a constant equal to 0.8 which corrects for removal of neutrons from the incident beam by the deuterium sample. The three most intense lines can be identified as the 111, 200, and 220 reflections of cubic phase. While these obey the extinction requirements of a fcc lattice with $a = 5.084 \pm 0.004$ Å, the two weak lines of pattern A in Fig. 1 appear to be real. These two lines cannot be discounted as due to random statistics or an arbitrary choice of the constant p. A calculation of p using the total cross section of deuterium yields a value of $p \geq 0.75$. These two weak lines have been identified as the 210 and 211 reflections of the above cubic cell, which do not obey the

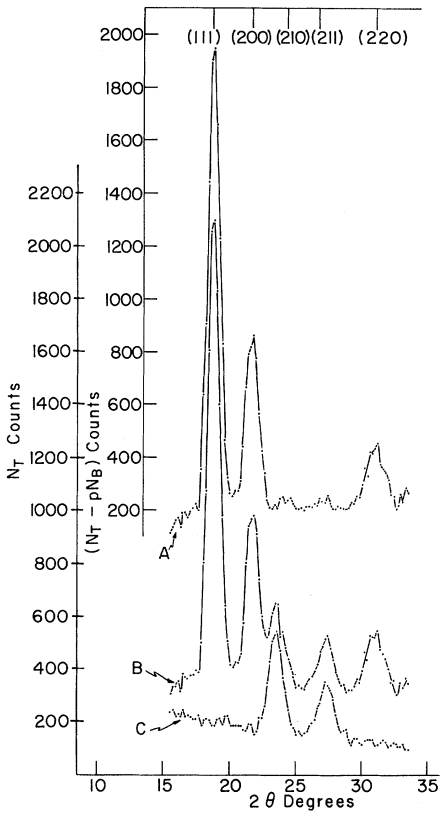

FIG. 1. Trace A, diffraction pattern of solid deuterium, 83% para, at 1.9°K. Trace B, total counts, N_T, for sample plus cryostat. Trace C, total counts, N_B, for empty cell and cryostat. $p = 0.8$ is background correction for deuterium.

face-centered extinction requirements. However, all the observed reflections are in accordance with a structure having a space group symmetry $Pa3$[7] as suggested for the low-temperature modification of hydrogen by Raich and James.[8]

Table I summarizes the data and gives a comparison between the observed relative integrated intensities and those calculated for the $Pa3$ symmetry on the assumption that the molecular scattering length can be replaced by that for a pair of bound deuterons separated by the internuclear distance of the molecule. Preliminary calculations of absolute line intensities show a similar agreement with the observed values.

The transformation from the hexagonal close-packed form to the cubic exhibits a hysteresis. In Fig. 2 the intensity of the 10·1 reflection of the hcp form plus background is shown as a function of temperature. The arrows indicate

Table I. Reflections and relative intensities of cubic phase, 83% para-deuterium at 1.9°K. λ(neutrons) = 0.963 Å.

Reflections	2θ (deg)	a (Å)	$\frac{I_{hkl}}{I_{200}}$(obs)	$\frac{I_{hkl}}{I_{200}}$ (calc)
111	18.91	5.077	2.30	2.15
200	21.82	5.088	1	1
210	24.5[a]	5.08	0.05	0.03
211	27.2[a]	5.02	0.05	0.04
220	31.08	5.083	0.50	0.47
		5.083 ± 0.005[b]		

[a]These weak reflections were not used in obtaining the average cell edge.

[b]$\overline{V} = 19.8$ cc/mole [$\overline{V}(n\text{-}D_2) = 19.5$ cc/mole: H. W. Wooley, R. B. Scott, and F. G. Brickwedde, J. Res. Natl. Bur. Stds. 41, 379 (1948)].

the directions of paths along which the transformation can occur. These preliminary results suggest that the only reversible paths are those parallel to the temperature axis. Futhermore, the rate of transformation on cooling (hcp → cubic) seems to be extremely large, whereas the reverse process on heating requires a few minutes before a steady-state concentration of the mixed phases is obtained.

An interesting feature of Fig. 2 is that the transformation (hcp → cubic) on cooling the sample has clearly set in at 2.82°K. This is very near the temperature corresponding to the maximum heat capacity of the λ anomaly, 2.95°K,[6] for a deuterium sample containing 83% para

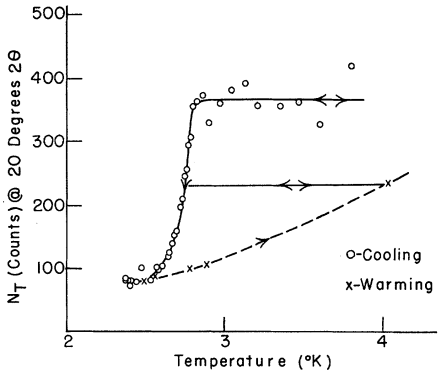

FIG. 2. Variation of total counts at fixed angle, $2\theta = 20.0$ deg, corresponding to 10·1 reflection of hexagonal close-packed phase, as a function of temperature for 83% para-deuterium. Dashed line shows approximate temperature dependence.

species. It should be pointed out, however, that the heat-capacity data were obtained on a sample which had been first cooled well below the transformation temperature (approximately 1.3°K), the data being collected as the temperature was increased. Figure 2 clearly shows that a cubic phase must have been present during the measurements above and below the observed λ anomaly. It thus appears that the λ anomaly which is associated with the disordering of the $J=1$ rotational species is not a consequence of the lattice transformation. Yet the lattice transformation on cooling is probably a consequence of the rotational ordering.

*This work was supported in part by the U. S. Atomic Energy Commission, Chemistry Branch, Division of Research, Washington, D. C.

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GALVANOMAGNETIC AND RELATED EFFECTS IN TYPE-II SUPERCONDUCTORS*

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(Received 30 March 1966)

Recently, galvanomagnetic and thermomagnetic effects have been observed in the mixed state of type-II superconductors. Fiory and Serin[1] measured the heat absorbed and emitted at a junction in a superconductor on one side of which $H>H_{c1}$ and on the other side $H<H_{c1}$. This is similar to the Peltier effect in a normal metal. Otter and Solomon[2] have observed the analogs of the Ettingshausen and Nernst-Ettingshausen effects.[3] Firstly, they measured the transverse temperature gradient produced by a current and, secondly, the transverse voltage produced by a thermal gradient. In all cases the applied magnetic field was perpendicular to the voltages, temperature gradients, etc. The magnitude of these latter effects is about three orders of magnitude larger than those found for normal metals, and they vanished if the current in the specimen did not exceed the critical value for depinning. Both groups of authors have interpreted their results in terms of the entropy carried by moving vortex lines. It is the purpose of this note to examine these effects somewhat further.

Consider a type-II superconductor in the mixed state. The applied magnetic field is taken to be along the z direction and all voltages, thermal gradients, etc., are in the x,y plane. The effects of pinning of the vortex lines will be disregarded. To obtain the effective force on a vortex line in a thermal gradient, consider the situation where a thermal gradient exists and at the same time a current is passed through the superconductor to prevent the vortex lines from moving. If $F=F_{SH}-F_{S0}$, where F_{SH} and F_{S0} are the free-energy density of the superconductor in a field H and zero field, respectively, the entropy and field associated with the vortex lines are determined from

$$dF(T,B)=-SdT+(1/4\pi)HdB. \qquad (1)$$

The number of vortex lines per unit area, n, is related to B by $B=n\varphi_0$ where $\varphi_0=hc/2e$ is the flux quantum. Thus from (1), $H\varphi_0/4\pi$ plays the role of the chemical potential for vortex lines. The condition of mechanical equilibrium of the lines is that the "pressure," $-G(T,H)$, be constant where

$$G(T,H)=F-(1/4\pi)HB. \qquad (2)$$