

curacy. In contrast to Ag, no faster oscillations could be detected in the $\{110\}$ plane although higher purity crystals might well exhibit such oscillations.

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¹D. Shoenberg, *Phil. Trans. Roy. Soc. London* **A255**, 85 (1962).

²See, e.g., *The Fermi Surface*, edited by W. A.

Harrison and M. B. Webb (John Wiley & Sons, Inc., New York, 1960).

³A. S. Joseph and A. C. Thorsen, *Phys. Rev.* **134**, A979 (1964).

⁴A. S. Joseph and W. L. Gordon, *Phys. Rev.* **126**, 489 (1962).

⁵D. Shoenberg, *Progress in Low-Temperature Physics*, edited by J. C. Gorter (North-Holland Publishing Company, Amsterdam, 1957), Vol. II, pp. 226-265.

⁶A. S. Joseph and A. C. Thorsen, *Phys. Rev. Letters* **11**, 554 (1963).

⁷T. G. Berlincourt has pointed out that since the experimental data cannot distinguish between holes and electrons, it is also possible to interpret P_c as arising from first-zone hole pockets at L . This interpretation appears to be inconsistent with present band calculations in the noble metals [see, for example, B. Segall, *Phys. Rev. Letters* **7**, 154 (1961)].

⁸A. H. Wilson, *The Theory of Metals* (Cambridge University Press, London, England, 1958), p. 36.

TEMPERATURE DEPENDENT KNIGHT SHIFT IN A CADMIUM SINGLE CRYSTAL

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Because cadmium metal has a hcp structure, an anisotropy of the Knight shift of the nuclear magnetic resonance line is possible. In measurements by Masuda¹ and Rowland² on polycrystalline material a finite Knight shift (K) and a nine percent anisotropy of the Knight shift (K_{anis}) were observed at room temperature. In the present single-crystal experiments on the Cd^{113} resonance, both K and K_{anis} were found to have an appreciable temperature dependence.

Measurements were made at 4.2°K on a laminar single-crystal sample prepared by slicing a single crystal with an electrolytic saw and spark planing the slices flat and parallel. The sample was assembled using Mylar insulating layers, and an rf coil was wound directly on the resultant sandwich to maximize the filling factor. For higher temperatures, a solid cylinder was used to decrease skin losses and thus oscillator loading. Measurements between 77°K and 300°K were made by permitting the system to warm slowly from the temperature of a liquid nitrogen bath. The results for Knight shift for magnetic field perpendicular to and parallel to the basal plane for all temperatures studied are shown in Fig. 1.

Measurements of linewidth (δ) made at 4.2°K indicate an appreciable anisotropy:

$$\delta(c \parallel H) = 1.5 \text{ kc/sec and } \delta(c \perp H) = 1.0 \text{ kc/sec.}$$

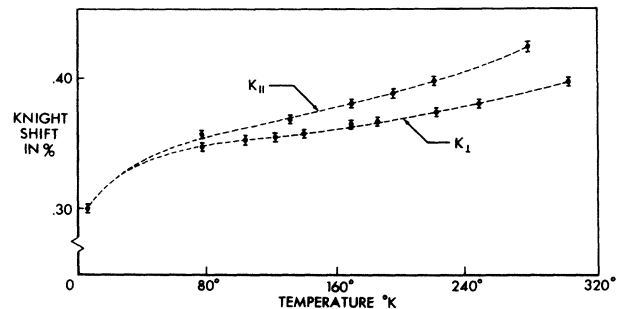


FIG. 1. Cd^{113} Knight shift as a function of temperature for the c axis parallel and perpendicular to the magnetic field.

These measurements were made difficult by a very large magnetoresistance which gave a large angle-dependent loading at 4.2°K. However, the same results have since been obtained at 77°K, where this effect does not exist.

Previous work on cadmium has suggested departures from the simple free-electron picture. Marcus³ observed a large increase in the value of magnetic susceptibility at low temperatures for H parallel to the c axis. The temperature dependence is such as to suggest a correlation with the Knight shift. The anisotropy of the electrical conductivity has also been observed to

change in this temperature range.⁴ Divalent metals, such as cadmium, may be expected to show a low density of states at the Fermi surface and effects due to the Brillouin zone boundaries, such as small pockets of low-effective-mass electrons and holes. The explanation of the temperature dependency will undoubtedly be found in the behavior of these electrons. At present one must consider both the possibility of an explicit temperature dependence of magnetic susceptibility and an indirect temperature dependence through changes in the crystal parameters.

The anisotropy of the temperature coefficient of expansion in cadmium is quite large, so that one might suspect a relation between the c/a ratio and the K values. That is, the effective mass discussed above might change with the c/a ratio due

to changes wrought in the Fermi surface at its intersection with the Brillouin zone boundary. An investigation has thus begun of the effects of decreasing the c/a ratio by adding magnesium.

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²T. J. Rowland, Phys. Rev. **103**, 1670 (1956).

³J. Marcus, Phys. Rev. **76**, 621 (1949). The author would like to thank J. Butterworth for calling attention to this work.

⁴H. H. Landolt and R. Börnstein, Zahlenwerte und Funktionen aus Physik·Chemie·Astronomie·Geophysik und Technik (Springer-Verlag, Berlin, 1955), Vol. 2, Pt. 6, p. 35.

LATTICE VIBRATIONS IN DIAMOND*

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The purpose of this Letter is to report measurements of transverse acoustic (TA) dispersion curves for lattice vibrations propagating in the (100) and (111) directions in diamond. The measurements were made by the method of inelastic scattering of slow neutrons. The observed dispersion curves are in good agreement with those inferred from specific-heat and infrared absorption measurements but disagree with those deduced by assuming that diamond is homologous to silicon and germanium.

The experiment was carried out on a three-axis neutron diffraction spectrometer at the Los Alamos Omega West reactor. A version of the "constant Q " method was used in which the neutron's initial energy was fixed and its energy loss varied.¹ All measurements were carried out at room temperature. The sample was a 242.80-carat brown industrial diamond.² A neutron diffraction study showed it to consist of a large single crystal, with a mosaic spread of $\approx 1^\circ$ full width at half-maximum, plus two small regions misoriented by $3-5^\circ$. The intensity of Bragg reflections from the two misoriented regions was less than 2% of that of corresponding reflections from the main body of the crystal. Infrared and ultraviolet absorption measurements indicated that it was a type-IIa diamond. The experimental data are given in Table I. Uncertainty in the observed frequencies, as estimated from the point-to-point

fluctuations and reproducibility of the data, is $\approx \pm 0.2 \times 10^{13}$ rad/sec. We believe that possible systematic errors should at worst double this figure.

Except at a very high temperature, the specific heat of diamond is completely dominated by the critical point of the lowest dispersion curve, which is the zone boundary point of TA(111). Using this idea, Phillips has fit the specific heat of diamond with a model which gives a value ω

Table I. Frequencies (in units of 10^{13} rad/sec) vs reduced wave number $Z = q/q_{\max}$ for transverse acoustic lattice vibrations in diamond. $q = 2\pi/\lambda$. In the (100) direction $q_{\max} = 1.7614 \times 10^8$ cm⁻¹; in the (111) direction $q_{\max} = 1.5254 \times 10^8$ cm⁻¹. The lattice constant of diamond was taken to be 3.5672 Å.^a

Z	$\omega_{\text{TA}(100)}$	$\omega_{\text{TA}(111)}$
0.3	6.45	5.38
0.4	8.63	6.76
0.5	10.24	7.96
0.6	11.53	8.80
0.7	12.74	9.51
0.8	13.70	9.99
0.9	14.59	10.26
1.0	15.13	10.38

^aInternational Tables for X-Ray Crystallography, edited by J. S. Kasper and K. Lonsdale (The Kynoch Press, Birmingham, England, 1962), Vol. III, Chap. 2, p. 122.