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EFFECT OF HYDROSTATIC PRESSURE ON THE LOW TEMPERATURE PHASE TRANSITION IN ALPHA-URANIUM*

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Measurements of single crystal elastic moduli of uranium at low temperatures and hydrostatic helium pressures to 4 kbar show that $dT_\alpha/dP = -3.4°K/kbar$, where T_α is the temperature of the phase transition that occurs at $42 \pm 1°K$ at 1 bar. Extrapolation of the data indicates that $T_{c,\max}$, for superconductivity in uranium corresponds to T_α at 11.5 kbar. This result supports the concept that $dT_c/dP > 0$ in uranium is a result of the phase transition.

IN 1961 WE reported on the occurrence of a phase transition in uranium, at 43°K, that produced very large and clear anomalies in the temperature dependence of the elastic moduli in single crystals.[1] Subsequent studies of several physical properties[2-4] indicate that the transition from the phase above $T_\alpha \simeq 43°K$ to the state at 4°K occurs in several distinct steps and gives rise to a domain-like structure[5] that is responsible for an increase in neutron intensities as diffracted by the crystal planes.

Correlation of this information with measurements of the transition to superconducting state in uranium suggest that the domain structure contains metastable filaments of the α phase which is the equilibrium phase about T_α.[6,7] These filaments are presumed to account for the superconductivity detected by magnetization measurements at 1 bar pressures[6,7] whereas the bulk or the stable matrix is nonsuperconducting at $T > 0.1°K$, as indicated by heat capacity measurements.[8] The latter also show that uranium at 10 kbar is a bulk superconductor[8] with $T_c \sim 2°K$ whereas recent[9] single crystal magnetization studies show that $dT_c/dP = 0.18°K/kbar$ between 1 bar and 8 kbar, with T_c at 1 bar of 0.20°K. Studies of polycrystalline samples showed T_c increasing with pressure to 2.2°K near 10 kbar and then decreasing slightly from 12 kbar to 20 kbar.[7]

It has been proposed that $dT_c/dP > 0$ arises from a direct relationship between the anomalous negative volume thermal expansion at $T < T_\alpha$ and the number of localized 5*f* electrons, which act to suppress superconductivity.[6] The application of pressure at $T < T_\alpha$ increases T_c by gradually decreasing the number of localized 5*f* electrons in either the bulk phase or in the filaments and the depopulation of the localized states is complete at 10 kbar, thus accounting for the specific heat anomaly associated with T_c and the maximum in measured T_c. The implied effect of this model is that the major difference between the phases above and below T_α is gradually removed by pressure application and that $T_\alpha \to 0°K$ near 10 kbar. This is not, however, consistent with a direct relation between volume and valence, since the compressibility at 4°K suggests that the excess volume due to anomalous thermal expansion is removed by about 4 kbar, or $dT_\alpha/dP \simeq 10°K/kbar$.

The model based on the electron–phonon interaction[10] accounts for dT_c/dP on the basis of a

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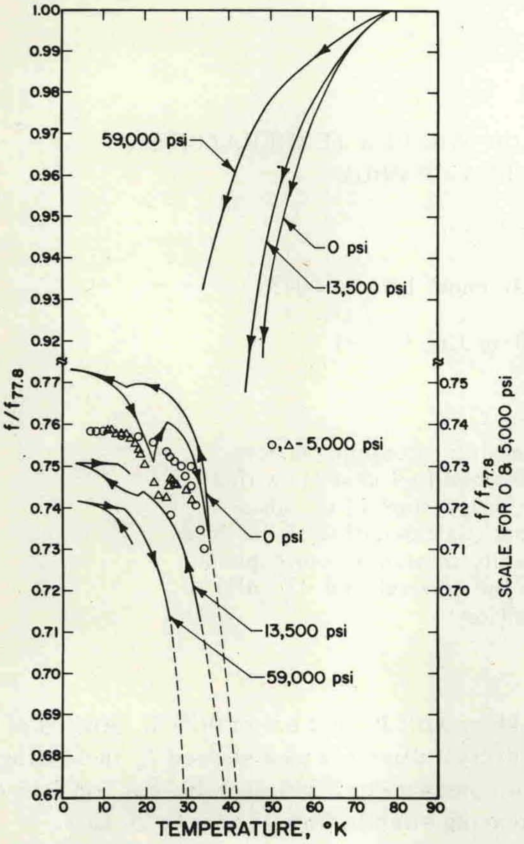

FIG. 1. Effects of pressure on the basic data for C_{11} vs. temperature. ($C_{11} = \rho V_{[100]}$, ρ= density).

shift in energy of an f electron band relative to the Fermi level and an increasing hybridization and density of electronic states at the Fermi level. This model makes no predictions regarding dT_α/dP, since there is no assumed distinction between the superconducting properties above or below T_α , i.e., the filaments are not necessarily associated with the α phase.

The purpose of this paper is to report on the measurements of dT_α/dP from elastic modulus data. The experiments were made with the same pulsed ultrasonic technique and single crystals described in reference 2. The velocity change with temperature of longitudinal waves in the three principal directions of this orthorhombic crystal were measured under several different constant hydrostatic gas and solid helium pressures. The pressure bomb was of CuBe construction manufactured by Harwood Eng., Walpole. Mass.

The data are shown in Figs. 1, 2 and 3 for the [100], [010], and [001] directions, respectively. The ordinates for each figure are

$$\frac{f}{f_{77.8}} = \frac{V}{V_{77.8}} \cdot \frac{t_{77.8}}{t}$$

where f is a critical wave frequency for an

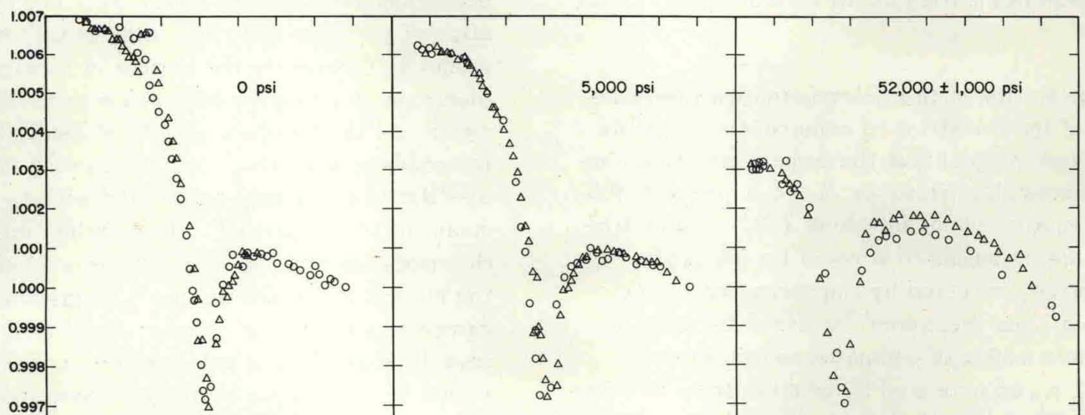

FIG. 2. Pressure effect on T_α as determined from basis data for C_{22} vs. temperature. ($C_{22} = \rho V^2_{[010]}$).