MAGNETOACOUSTIC OSCILLATIONS IN TUNGSTEN

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(Received February 5, 1962)

There is relatively little detailed information, apart from magnetoresistance data,[1] concerning the band structure of the cubic transition metals. In this paper we report the observation, for the first time, of the magnetoacoustic effect in such a metal, viz., tungsten.

The single crystal of tungsten used in the present investigation was grown by one of us using electron bombardment techniques. An acoustic specimen, one inch in length and 0.2 inch in diameter and having its axis approximately along [001], was cut from the resulting ingot. The residual resistance ratio $\rho_{300}/\rho_{4.2}$ was approximately 9000. Magnetoacoustic measurements were made by the usual pulse technique at 274 Mc/sec using longitudinal waves. Automatic recording of the data as a function of $1/H$ was accomplished by suitable circuitry.

A typical recorder trace for $q \sim [001], H \sim [110]$ is shown in Fig. 1. As shown by the full and broken arrows, there are two distinct sets of oscillations which are periodic in $1/H$. The momenta corresponding to these oscillations were computed from the formula

$$\hbar k = \frac{e}{2c}\frac{\lambda}{\Delta(1/H)}, \qquad (1)$$

where λ, the sound wavelength, was calculated from the data of Bolef[2] extrapolated to 0°K and $\Delta(1/H)$ is the appropriate period in $1/H$. The resulting wave vectors are

$$k_1 = 4.7\times10^7\ \text{cm}^{-1}, \quad k_2 = 1.7\times10^7\ \text{cm}^{-1}.$$

Lacking a definite model for the band structure of a transition metal, it is difficult to compare these values with theory. The work of Fawcett[1] seems to indicate that metals such as tungsten and molybdenum, of even atomic number, may have an even number of valence electrons and that the mobilities of the carriers in the *s* and *d* bands are approximately equal. It is therefore tempting to apply the free-electron model[3] to predict the Fermi surface of tungsten, assuming that all six electrons outside a closed subshell can be treated as equivalent charge carriers. The resulting Fermi surface is one in which the first zone is completely full, the second zone a small dodecahedron with concave faces, and the third and fourth zones

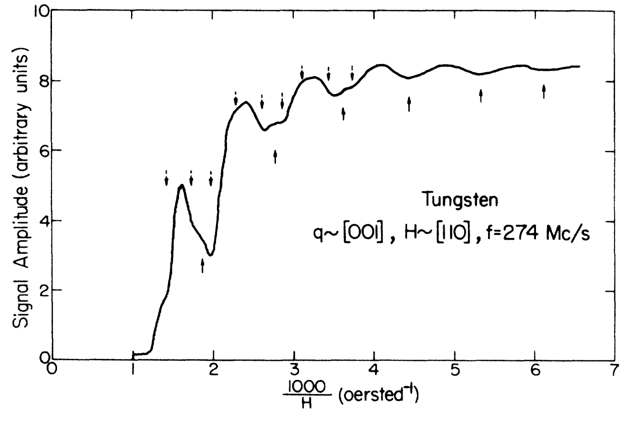

FIG. 1. Oscillatory attenuation of longitudinal 274-Mc/sec sound wave in tungsten as a function of $1/H$. The propagation direction is approximately [001], while H is approximately along [110].

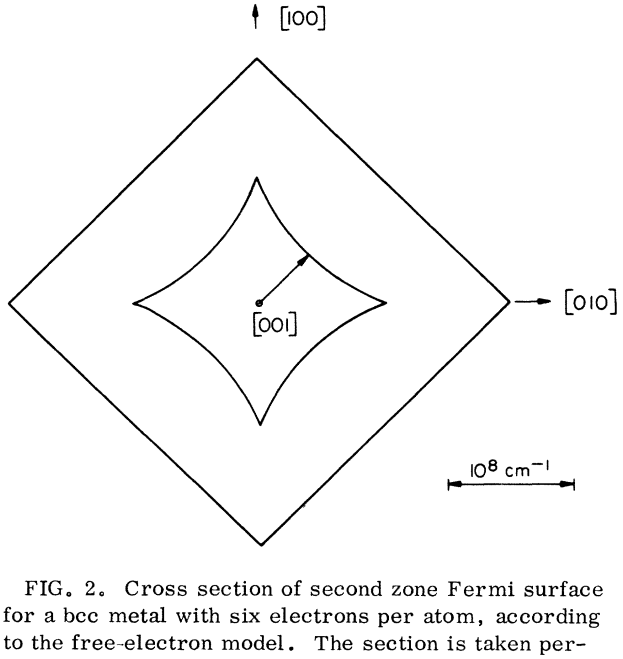

FIG. 2. Cross section of second zone Fermi surface for a bcc metal with six electrons per atom, according to the free-electron model. The section is taken perpendicular to [001].

the usual pathological "monsters" associated with the free-electron model. A cross section of the second zone surface, taken perpendicular to [001], is shown in Fig. 2.

According to the theory of the magnetoacoustic effect,[4] the oscillations for a propagation direction $\vec{q}$ and field direction $\vec{H}$ measure the extremal dimensions in the direction $\vec{q}\times\vec{H}$ of the cross sections of the Fermi surface perpendicular to $\vec{H}$. For the configuration corresponding to Fig. 1, one would thus expect an extremal momentum in the second zone corresponding to the indicated dimension. This has the value

$$k_{\text{theory}} = 5.5\times10^{7}\ \text{cm}^{-1},$$

which must be considered to be quite reasonable agreement with the larger of the two experimental values. Presumably the smaller dimension corresponds to an extremal dimension for one of the higher zone surfaces. It thus appears that the free-electron model might have even greater application than previously envisioned.

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[1] E. Fawcett, Phys. Rev. Letters 7, 370 (1961).

[2] D. Bolef (private communication).

[3] W. Harrison, Phys. Rev. 118, 1190 (1960).

[4] A. B. Pippard, Proc. Roy. Soc. (London) A257, 165 (1960).

SCATTERING OF PHONONS BY SPINS AT LOW TEMPERATURES

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(Received January 23, 1962)

One method of studying the interaction of spins and phonons is to investigate the lattice thermal conductivity of crystals containing paramagnetic ions. If a paramagnetic ion has a low-lying excited level at an energy kT' above the ground state, then one might expect that, at temperatures of the order of T', the phonons will induce transitions to the higher state and will themselves be scattered. This will give rise to an extra thermal resistivity. Some experiments have already been reported[1,2] in which this effect was thought to have been observed. These showed that the low-temperature heat conductivity of mixed crystals of $ZnSO_4$ and $FeSO_4$ was much smaller than that of pure $ZnSO_4$. The decrease was much more than could be ascribed to ordinary impurity scattering. Nevertheless, these experiments were unsatisfactory in that the energy levels of the paramagnetic ion were determined by the internal field of the crystal and could not be changed to any appreciable extent by the application of an external magnetic field.

In the present experiments the heat conductivity of holmium ethyl sulfate has been measured and for this material the application of a magnetic field parallel to the hexagonal axis of the crystal has a marked effect on the thermal conductivity. Due to the magnetic anisotropy of the crystal there is hardly any effect when the field is perpendicular to the hexagonal axis.

Figure 1 shows the field dependence of the relative change in the thermal resistance $\Delta W/W_0$, where W_0 is the thermal resistance in zero field, at a series of temperatures in the liquid helium region. At the lower temperatures $\Delta W/W_0$ has a

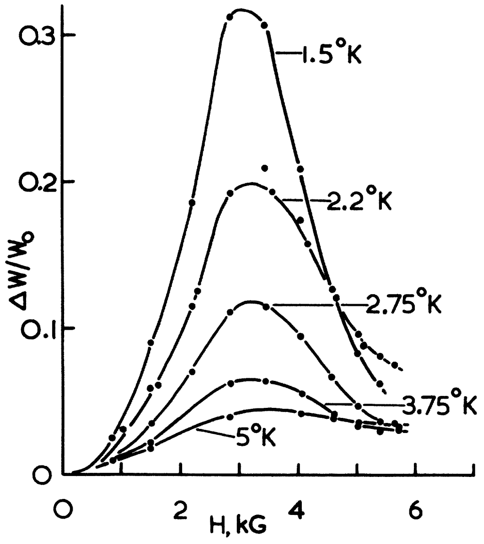

FIG. 1. The relative change in the thermal resistance, $\Delta W/W_0$, of holmium ethyl sulfate, as a function of the magnetic field, H, parallel to the hexagonal axis of the crystal.