MAGNETIC BREAKDOWN IN BERYLLIUM. THE DE HAAS - VAN ALPHEN EFFECT

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We have already reported [1, 2] that the behavior of the magnetoresistance of Be in strong magnetic field, namely the sharp increase of its anisotropy as well as large-amplitude resistance oscillations of the Schubnikov - de Haas type, is due to magnetic breakdown between the first and second bands in the hexagonal plane. It has already been noted by Watts [3], who investigated in detail the de Haas - van Alphen (dHvA) effect in Be, that when $\vec{H}$ is parallel to [0001] that a deviation takes place from the dependence predicted by the Lifshitz and Kosevich formula [4]; this, too was attributed by Watts to magnetic breakdown in the hexagonal plane. We deemed it of interest to experiment with Be in a wider range of magnetic fields.

The dHvA oscillation amplitudes were measured in pulsed magnetic field by a method similar to that described by Shoenberg [5]. The alternating signal from ballistic coils, which were compensated to prevent induction from an external field pulse, were fed directly to the input of a broadband amplifier. To eliminate the induction during the instant of the thyratron firing and at the start of the field pulse, the input to the amplifier was short-circuited at that time. The signal from the amplifier output was fed to the vertical amplifier of an oscilloscope with a long-persistence tube. The image sweep was produced by a signal proportional to the magnetic field. This signal was picked off a 0.1 ohm resistor connected in series with the pulse solenoid, and was fed after suitable amplification to the horizontal plates of the oscilloscope. It was possible to apply to the input of the amplifier, in series with the horizontal signal, a dc bias voltage making it possible to trigger the sweep at any value of the field, and a reference voltage serving either to produce calibration field markers or to measure directly the voltage corresponding to any particular position of the beam on the screen. The reference voltage was measured with a digital voltmeter.

The measurements were made on two hexagonal Be samples. Sample Be-I was cut by the electric spark method from the Be crystallite from which the samples were cut for the earlier measurements [1, 2]. The sample was 1 mm long and 02 x 0.3 mm across. The resistance ratio for all samples from this crystallite was $\rho_{300}/\rho_{4.2} \approx 130$. Sample Be-II was cut (by the same method) from a thin single-crystal[1] whisker, its length was also 1 mm, and its cross section was hexagonal with a distance between opposite faces 0.3 mm; $\rho_{300}/\rho_{4.2} = 1400$.

The intensity of the signal picked off the balistic coil was

$$I \sim \frac{dM}{dt} \sim \frac{\partial M}{\partial H} \frac{dH}{dt}.$$

For the case of magnetic fields that are weak compared with the degeneracy field F (F - magnetic frequency of dHvA oscillations) and at not too high temperatures, when

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$$\pi^2 kTm^*/\mu_B Hm_0 \gtrsim 1$$

the following approximate relation

$$IH^{\frac{1}{2}}/f \sim \exp\left(-\frac{\pi^2 k(T+X)m^*}{\mu_B Hm_0}\right)\cos\frac{2\pi E}{H}$$

(which is obtained by differentiating only the cosine term in the Lifshitz-Kosevich formula) is well satisfied. Here I - intensity of the received signal, H - magnetic field, f = $F(dH/dt)/H^2$ - temporal oscillation frequency, k - Boltzmann's constant, μ_B - Bohr magneton, m^*/m_0 - ratio of electron effective and free masses, T - absolute thermodynamic temperature, and X - Dingle "temperature," such that

$$\pi^2 kXm^*/\mu_B Hm_0 = \pi/\omega\tau,$$

where ω - cyclotron frequency and τ - relaxation time. In our case T = 4.2°K and m^*/m_0 for a "cigar" in the [0001] direction is, according to [3], equal to 0.16.

Both samples revealed dHvA oscillations clearly (see Fig. 1). The maximum of the amplitude corresponds to the sum of the amplitudes of the central and noncentral orbits, and the minimum to the difference. The fundamental frequency and the beat frequencies were, according to our measurements, $0.9 \pm 0.3 \times 10^6$ Oe and $2.85 \pm 0.15 \times 10^5$ Oe, respectively, in full agreement with the results of [3]. The results of the amplitude measurements are shown in Fig. 2, in which the values of log $I\sqrt{H}/f$ are plotted against the reciprocal of the magnetic field. The error in the measurement of the amplitude of the dHvA oscillations was 15 - 20% and was due mainly to the inaccuracy in the determination of the derivative dH/dt. It is clearly seen from the measurement results that the slopes of all curves are approximately equal. The Dingle factors for the firstt and second samples were 2.4 and 2.3°K, respectively[2]. Such an agree-
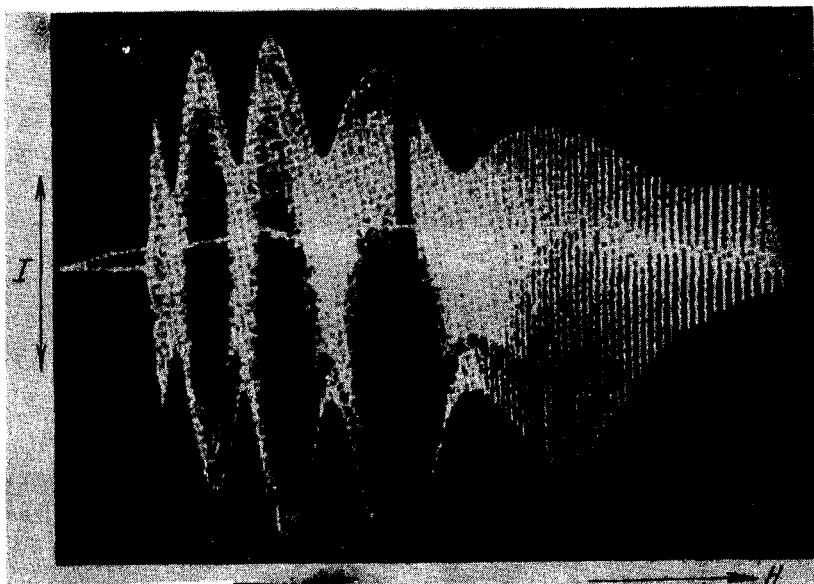

Fig. 1. Oscillogram of signal from ballistic coils, corresponding to dHvA susceptibility oscillations in sample Be-II in H ∥[0001] direction at T = 4.2°K. The beats are due to the presence of two close frequencies from the central and noncentral sections of the cigar.

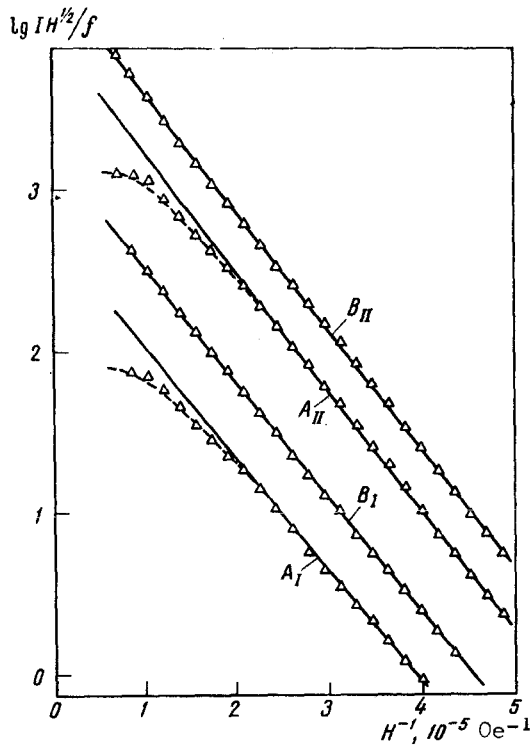[2] The Dingle factor in [3] is apparently twice as large.

Fig. 2. Plot of log $I\sqrt{H}/f$ vs. the reciprocal magnetic field; A_I and B_I - for central and noncentral orbits of sample Be-I, respectively. A_{II} and B_{II} - the same for sample Be-II[3] For convenience, the curves are shifted vertically. The dashed lines correspond to allowance for the magnetic breakdown by means of the Pippard factor $[1 - \exp(-H_0/H)]^{3/2}$, where $H_0 = 130$ kOe.

ment for two samples with such different resistance ratios (130 and 1400) can be ascribed to the fact that the "whisker" has apparently a sort of filamentary structure [4] along the hexagonal axis, which leads to anisotropy of the mean free path. (This circumstance can also be used to explain the fact that the intensity of the dHvA oscillations in the whisker is somewhat larger than that of the Be-I sample.)

Both samples reveal a noticeable difference in the behavior of the dHvA oscillation amplitudes due to the central and noncentral orbits. If we assume, following Pippard [6] (as was indeed observed in pure zinc [7]) that magnetic breakdown leads to an additional factor $[1 - \exp(H_0/H)]^{3/2}$ in the expression for the amplitude, and that the dependence of the amplitude on the field in the absence of magnetic breakdown would be similar to the dependence for the noncentral section, then we can estimate approximately the breakdown parameter H_0. the value $H_0 \sim 130$ kOe (see Fig. 2) agrees well with the magnetic-breakdown picture that follows from the magnetoresistance measurement data[5] [2].

[3]The point for $H = 145$ kOe in A_{II} was obtained from the experimental value of the sum of the amplitudes and the extrapolated value for B_{II}.

[4]This assumption is based both on visual observations and on x-ray diffraction data

[5]As already noted in [2], the azimuthal orientation of the sample was incorrectly indicated in [1]. The minimum resistance is observed when H is parallel to [0001].

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DETERMINATION OF THE CONSTANTS OF HYPERFINE INTERACTION BETWEEN THE DEUTERIUM NUCLEI AND THE INTRAMOLECULAR FIELDS IN THE $N^{14}D_3$ MOLECULE

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The ammonia molecule NH_3 has been investigated by microwave spectroscopy methods more thoroughly and fully than any other polyatomic molecule [1]. The theoretical calculation and observation of the hyperfine structure (hfs) of its inversion spectrum are the subject of [1 - 5]. This molecule is of particular interest in connection with the use of molecular generators as frequency standards [6].

Following the detailed investigation of the "light" ammonia molecule, interest arose in the determination of the character of the hyperfine interactions (determination of the quandrupole and magnetic coupling constants) of deuterium nuclei with the intramolecular fields in the isotopically substituted ND_3 molecule.

The procedure developed in [3] for calculating the hfs of the inversion transitions of the $N^{14}H_3$ molecule was extended to include the case of $N^{14}D_3$ [7] and turned to be exceedingly laborious. By using the data for $N^{14}H_3$ [3 - 5] it was possible to estimate the majority of the hyperfine interaction constants for the $N^{14}D_3$ molecule [7]. This manner, obviously, can not be used to estimate the electric quadrupole interaction of the deuterium nuclei with the intramolecular field eq_JQ_D, since the proton has no quadrupole moment.

An experimental measurement of the hfs of the inversion lines of $N^{14}D_3$ [8] using a spectroscope with Stark modulation (line width larger than 25 kHz) did not yield satisfactory results, owing to the low resolution. On the other hand, the use of a spectroscope based on a molecular generator with a beam of $N^{14}D_3$ molecules [9] (line width ~ 800 Hz) led to a resolution of the hfs of the spectrum near the principal line $J = K = 6$ [10] (K - projection of angular momentum J of the molecule on the molecular symmetry axis).

The calculation of the hfs of the inversion spectrum of ND_3 was greatly simplified in [11] through the use of the mathematical formalism of the theory of three-dimensional rotation groups, but the interpretation of the hfs of the spectrum could not be carried through to conclusion because of its high degree of complexity.

We have investigated the hfs of the inversion transitions $J = 5$, $K = 3$; $J = 3$, $K = 2$, and $J = K = 4$ using a spectroscope similar to that described in [9] (line width ~ 800 Hz, accuracy of frequency measurements ~ 200 Hz). The choice of the inversion line $J = 5$, $K = 3$ (frequency 1509.22 MHz) was dictated by the fact that the matrix elements of the quadrupole