Hall effect and NMR of the compound UBe_{13}

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The Hall voltage, the magnetoresistance, and the NMR of UBe_{13} samples have been measured. It is suggested that the anomalous properties of UBe_{13} stem from a spectrum of a two-band nature.

The compound UBe_{13}, which has the $NaZn_{13}$ structure, has been reported to exhibit several unusual properties.[1] It is interesting to examine the possible reasons for the unusual properties of such compounds. We have recently studied the Hall effect, the magnetoresistance, and the NMR of UBe_{13} samples. The samples were essentially single-phase samples with a lattice constant $a = 10.254$ Å. They were synthesized by the procedure of Ref. 2 and had dimensions of approximately $0.5 \times 1.5 \times 5$ mm. For measurements at temperatures below 1 K, we used an apparatus with adiabatic demagnetization of an erbium-aluminum garnet[3] and also an apparatus with evacuation of helium-3.

Figure 1 shows the Hall voltage versus the magnetic field at three temperatures. The Hall constant is seen to increase with decreasing temperature. The measure-

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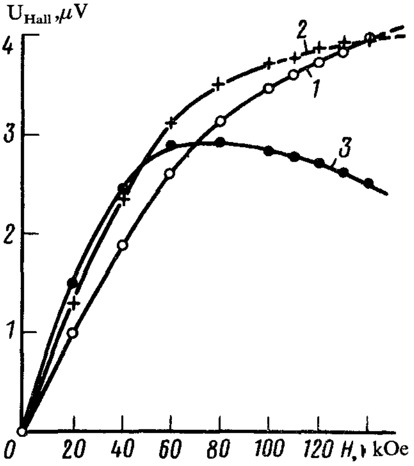

FIG. 1. The Hall voltage versus the magnetic field for a UBe_{13} sample. 1—$T = 4.2$ K; 2—$T = 3$ K; 3—$T = 1.9$ K. The measurement current is 10 mA.

ments yield $(R)_{H=60\text{kOe}} = 1.46 \times 10^{-11}$ $\Omega \cdot \text{cm/Oe}$ at $T = 100$ K and $(R)_{H=60\text{kOe}} = 1.58 \times 10^{-10}$ $\Omega \cdot \text{cm/Oe}$ at $T = 4.2$ K.

Figure 2 shows the resistance versus the magnetic field at several temperatures. The resistance is seen to decrease with increasing field, and the magnitude of the decrease increases with decreasing temperature. There is an inflection point on the

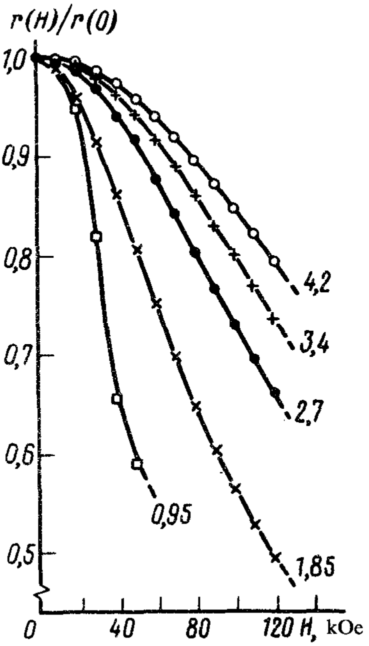

FIG. 2. Reduced magnetoresistance of UBe_{13} versus the magnetic field. The curves are labeled with the Kelvin temperatures.

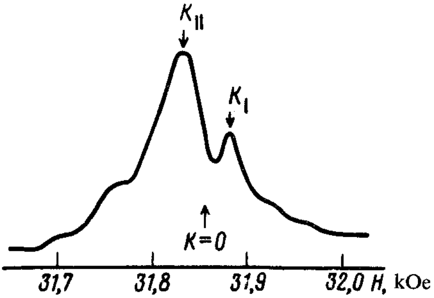

FIG. 3. The NMR spectrum of ^{9}Be in the compound UBe_{13}. $f = 19.06$ MHz, $T = 4.2$ K, $K_I = -0.085 \pm 0.003\%$, $K_{II} = 0.075 \pm 0.003\%$.

$r(H)$ curve at $T \leqslant 2$ K. Evaluating the carrier density n from the Hall constant under the assumption $R = 1/nec$, we find $n = 4.3 \times 10^{21}$ cm^{-3} at $T = 100$ K and $n = 4 \times 10^{20}$ cm^{-3} at $T = 4.2$ K. These estimates of the carrier density are difficult to reconcile with the data from measurements of the specific heat, which yield[1] $\gamma \approx 1$ J/(K^2 · mole). It is thus natural to assume that there are two groups of carriers in the compounds UBe^{13}: heavy and light. This assumption also leads to an explanation of the nonlinear behavior of the Hall voltage as a function of the field, shown in Fig. 1.

Figure 3 shows the NMR spectrum of ^{9}Be in the compound UBe_{13} according to measurements at the frequency 19.06 MHz at 4.2 K. Measurements taken at various values of the magnetic field show that the broad wings to the left and right of the two central components result from a quadrupole interaction. The apparent reason for the two peaks in the spectrum is the existence of two nonequivalent positions for Be in the UBe_{13} lattice.[4] It can be seen from this figure that the Knight shifts for the central components differ in sign. This difference may be due to different signs of the spin polarization in the positions Be I and Be II.

In Ref. 5, Ott *et al.* discussed the unusual properties that they had found in UBe_{13} as a consequence of a superconductivity in this compound due to pairing in a triplet state. This possibility agrees with several experimental data, e.g., the temperature dependence of the specific heat,[5] the extremely high values[1,2] of H_{c2}, and the sharp decrease in T_c during the dissolution in UBe_{13} of isomorphic impurities such as $ZrBe_{13}$ and $CeBe_{13}$ (Ref. 2).

It should be noted, however, that it would become a much more complicated matter to explain the properties of UBe_{13} in terms of a triplet pairing if there are, for example, two types of carriers—heavy and light.$^{1)}$ We might accordingly examine some other plausibe explanations for the unusual properties of UBe_{13}. If it is assumed that heavy and light current carriers do exist in UBe_{13}, then it can also be assumed that the $C_p(T)$ dependence, which is at odds with the Bardeen-Cooper-Schrieffer theory, reflects the presence of two energy gaps, Δ_1 and Δ_2, associated with the two types of carriers. In this case the 5f electrons of U would represent the group of heavy carriers, while the electrons of beryllium would represent the group of light carriers.

The question of a two-band superconductivity has of course been under discussion for a long time.[6] In the case of niobium, two gaps have been discussed: one in an s

band, and another in a *d* band. The specific heat calculated for the two-gap case[6] agrees quite well with experimental data.

Grimberg and Schinkel[7] have discussed a two-band model for rare-earth metals as it would apply to cerium. The magnetic interactions may be determined primarily by heavy carriers. The appearance of a polarization in the system of $5f$ electrons in a magnetic field may lead through the Peter-Jacarino effect[8] to a cancellation of the external magnetic field, thereby causing extremely high critical magnetic fields. The Peter-Jacarino cancellation is a rather rare phenomenon. A clear manifestation of this cancellation effect was apparently observed recently by Meul *et al.*,[9] who observed a superconductivity induced by a magnetic field in the compound $Eu_xSn_{1-x}Mo_6S_8$. A cancellation effect that leads to a magnetic-field-induced superconductivity can occur when the exchange field H_J is above the paramagnetic limit H_p, as was pointed out by Meul *et al.*[9] Fischer *et al.*[10] have determined the exchange integral J for the compound $Eu_xSn_{1-x}Mo_6S_8$: ~ 0.01 eV. If we use our values of the Knight shift of ^9Be and the susceptibility from Ref. 1 for UBe_{13} to estimate the exchange integral, we find $|J| \geqslant 0.01$ eV. In view of the low value of T_c for UBe_{13} (~ 1 K), it may be suggested that the condition $H_J > H_p$ clearly holds for this compound also. This circumstance gives considerable credence to the possibility that the properties of UBe_{13} are influenced by the cancellation effect. Furthermore, we do not rule out the possibility that the high critical magnetic fields may be due, as discussed in Ref. 2, to a covalent instability[11] or the formation of a Kondo lattice.[12]

Further research on the interesting properties of UBe_{13} will probably reveal the actual mechanism for the superconductivity of this system.

[1)] The large spin-orbit interaction in this compound would also make it difficult to use triplet pairing as an explanation.

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