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PRESSURE MEASUREMENTS OF ELECTRICAL TRANSPORT PROPERTIES OF EuB$_6$

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Abstract.– Single crystals of the magnetic semiconducting compound EuB$_6$ have been prepared using the Al flux technique. Resistivity, Hall effect and magnetoresistance measurements have been performed in the 4.2 - 300 K range, under hydrostatic pressure up to 7 kbar. The resistivity peak occurring at $T_p$, correlated to the ferromagnetic ordering temperature is shifted by $dT_p/dP=+0.3$ K/kbar when pressure is applied. The sign and magnitude of the pressure coefficients of resistivity and Hall constant suggest that pressure induces a decrease of the "energy gap" between the 4f and 5d-6s levels of Eu rather than a change from 2+ to 3+ of the cation valence state.

Among the isostructural series of rare-earth hexaborides, with the general formula LnB$_6$, which crystallize in the CaB$_6$-type structure, the Europium compound EuB$_6$ (along with YbB$_6$) is one where the metallic ion exhibits a +2 valence state. This conclusion may be drawn out from the lattice parameter value /1/ and Mössbauer effect experiments /2/,/3/, and is supported by the experimental evidence of EuB$_6$ being a semiconductor. EuB$_6$ moreover exhibits ferromagnetic ordering at $T_c\approx 15K$. According to /3/ the Curie temperature is $T_c\approx 12.5$ K.

Experimental.– Single crystals were prepared by the Al flux technique described in /6/. Electrical transport measurements have been performed using an a.c. bridge method. Hydrostatic pressure was produced in a Be-Cu bomb, using He as a pressure transmitting medium. Helium inside the bomb is "frozen" under controlled constant pressure conditions: the bomb is fed by a helium reservoir, kept at room temperature, pressure of which is monitored by a manganine gauge, thus ensuring a correct measurement of the pressure inside the experimental volume.

The lattice constant of the samples used in this work was measured equal to 4.187 $\pm$ 0.001 Å, to be compared to 4.1855 Å /7/, 4.1843 Å /8/ and 4.1850 Å/9/ for crystals grown in similar conditions. The temperature dependence of resistivity at normal pressure (Fig.1) is quite similar to that reported in /7/. The insert in figure 1 displays the values of resistivity and Hall coefficient at normal pressure for 4.2 K, 77 K and 290 K.

The sharp resistivity variation at...
low temperature is related to the onset of magnetic ordering: the strong negative magnetoresistance in this temperature region suggests that spin-disorder scattering of current carriers should play an important role in the paramagnetic region, and, in such conditions the temperature of the resistivity peak: \( T_p \), might be closely related (if not identified) to the Curie temperature.

Fig.1: Resistivity versus temperature at normal pressure. Insert: resistivity and Hall coefficient at fixed \( T \).

**Pressure measurements.**—In the whole range of temperatures the pressure coefficient of resistivity is negative, its absolute value is maximum around 77 K and becomes quite small at low temperature, in the region where magnetic ordering prevails. The resistivity versus temperature variation is given on figure 2. It can be seen that the maximum of resistivity is shifted towards higher temperature when pressure is applied with a rate \( AT_p/\Delta P = 0.31 \text{ K/kbar} \).

The pressure coefficients of resistivity and Hall coefficient measured at 4.2, 77 and 290 K are reported in table I. It must be noted that for room and liquid \( \text{N}_2 \) temperatures, the Hall coefficient is a "good" Hall constant in that sense that it is essentially field independent. At 4.2 K however, the measured Hall voltage is not a linear function of \( B \), though not typical of the extraordinary Hall effect in magnetic semiconductors, thus at this temperature, Hall coefficient and carrier concentration cannot be correlated in a simple way.

Fig.2: Resistivity versus temperature at different pressure values. Insert: Temperature of the resistivity maximum versus pressure.

As can be seen from table I, the mobility of current carriers is essentially insensitive to pressure at room temperature and only slightly sensitive to pressure at 77 K. Magnetoresistance measurements are illustrated by figures 3 and 4. For clarity, only the measurements at 6 kbar have been reported on figure 3 but the behaviour of magnetoresistance is quite similar for all values of pressure. Only the magnitude of the effect is dependent on pressure as can be seen on figure 4. One can notice that the magnetoresistance: \( \delta \rho/\rho \) changes its sign at low temperature: at 4.2 K \( \delta \rho/\rho \) is positive, goes through zero at 5.5 K and becomes negative at higher temperature its absolute value exhibiting a sharp maximum at the magnetic ordering temperature, as is usual in magnetic semiconductors.
Table I

<table>
<thead>
<tr>
<th>T (K)</th>
<th>d log ρ/dP (10^{-6} bar^{-1})</th>
<th>d log R_H/dP (10^{-6} bar^{-1})</th>
<th>d logμ/dP (10^{-6} bar^{-1})</th>
<th>μ_H (1bar) (cm^2/Vs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>-13 ± 2</td>
<td>-25 ± 2</td>
<td>+10 ± 4</td>
<td>2000</td>
</tr>
<tr>
<td>77</td>
<td>-90 ± 5</td>
<td>-65 ± 10</td>
<td>+25 ± 15</td>
<td>325</td>
</tr>
<tr>
<td>290</td>
<td>-45</td>
<td>-45x10^{-6}</td>
<td>≠ 0</td>
<td>100</td>
</tr>
</tbody>
</table>

* μ_H=R_H/ρ is not representative of the carrier mobility at T^*=4.2 K due to the non-classical behaviour of R_H at that temperature.

At 77K, |δρ/ρ| is essentially a quadratic function of magnetic field and decreases with pressure. Conclusions. - The pressure measurements at room and liquid N_2 temperature indicate that pressure induces an increase of the carrier concentration and only slightly changes mobility; this result can be interpreted in terms of a decrease of the energy interval between the 4f levels, and the 5d - 6s conduction band states. This is consistent with the observed pressure shift of the Curie temperature. A detailed quantitative analysis of the low temperature results - especially Hall effect and magneto resistance - remains to be done, along with measurements in the region of higher magnetic fields, but it seems that hydrostatic pressure gives rise to effects different from those obtained by substituting a trivalent rare earth ion to the divalent Eu.
References


