**Solid-State Physics**

*Conduction phenomena*

*Hall effect*

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**Investigating the Hall effect in silver**

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### Objects of the experiment

- Validation of the proportionality of the Hall voltage and the magnetic flux density.
- Determining the polarity of the charge carriers.
- Calculating the Hall constant $R_H$ and the charge carrier concentration $n$.

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### Principles

If a current-carrying metallic conductor strip is located in a magnetic field $B$ perpendicular to the direction of the current $I$, a transverse electrical field $E_H$ and a potential difference is produced (Hall effect).

The following equation holds for the Hall voltage $U_H$ (Fig. 1):

$$U_H = \frac{1}{n \cdot e} \cdot \frac{B \cdot I}{d}$$  \hspace{1cm} (I)

- $B$: magnetic flux density
- $I$: current through the metallic conductor
- $d$: thickness of the band-shaped conductor
- $n$: concentration of charge carriers
- $e = 1.602 \cdot 10^{-19}$ C: elementary charge

The Hall voltage $U_H$ is caused by the deflection of the moving charge carriers in the magnetic field due to the Lorentz force, whose direction may predicted by the right hand rule. The factor $\frac{1}{n \cdot e}$ is called Hall constant $R_H$:

$$R_H = \frac{1}{n \cdot e}$$  \hspace{1cm} (II)

The sign of the Hall constant $R_H$ is determined by the polarity of the charge carriers.

The Hall constant depends on the material and the temperature. For metals $R_H$ is very small, however, for semiconductors $R_H$ becomes significantly large (compare experiments P7.2.1.3 and P7.2.1.4).

The polarity of the charge carriers can be determined from the direction of the Hall voltage. The concentration of the charge carriers $n$ can be determined experimentally by measuring the Hall voltage $U_H$ as function of the magnetic field $B$ for various currents $I$. 

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**Fig. 1:** Hall Effect schematically: Inside a charge carrying metallic conductor which is located in the magnetic field $B$ the Lorentz force $F_L$ is causing an electrical field $E_H$ resulting in a Hall voltage $U_H$ (I denotes the transverse current).
**Setup**

The experiment is performed in two steps:

**a) Calibration of the magnetic field**

Set up the U-core with yoke, the pair of bored pole pieces and the coil with 250 turns as shown in Fig 2. Set the pole piece spacing of the electromagnet exactly to the thickness of the support plate of the Hall effect apparatus. To do this loosen the clamping devices and place one edge of the Hall effect apparatus between the pole pieces. Then push the latter as close as possible to the pole pieces.

Connect the coils with 250 turns in series to the extra low-voltage transformer and locate the Combi B-Sensor S between the pole pieces.

**b) Measuring the Hall voltage as function of the magnetic field**

After recording the calibration curve mount the Hall effect apparatus in the electromagnet. The pole pieces have to be pushed as close as possible to the support plate (i.e. the air gap between the pole pieces as narrow as possible and of the same width as for recording the calibration curve).

**Safety notes**

- For transverse currents over 15 A or magnet currents above 5 A, only switch on the device briefly (overheating of leads or overloading of the coils, which are designed for a maximum load of 5 A).
- In the transverse current circuit, use cables which are rated for a maximum load of 20 A (e.g. connecting leads 501 20 ff or safety connecting leads 500 610).
- Protect the experiment setup from drafts while measuring the Hall voltage.
To measure the Hall voltage connect either the Microvoltmeter or the Mobile CASSY with the µV-Box to the support plate of the Hall effect apparatus.

Connect the Hall effect apparatus to the high current power supply as shown in Fig. 3. The B-field direction should be as printed on the support plate. For measuring the current I through the coils the Multimeter LD analog 30 is used.

Carrying out the experiment

Note: For further notes to the experiment see also instruction sheet 586 81 /84.

a) Calibration of the magnetic field
- Demagnetize the iron of the electromagnets before recording the magnetic field as function of the current I by allowing to flow a I = 5 A AC current through the field coils 250 turns for a short time; then steadily reduce the current to zero.
- To measure the current I trough the coils connect the ammeter between the positive pole of the voltage transformer and the coil.
- Measure the magnetic flux density B as function of the current I by increasing the current I in steps of 0.5 A DC.

b) Measuring the Hall voltage as function of the magnetic field
- Mounting the Hall effect apparatus between the pole pieces (Fig. 3.).
- Before exposing the Hall effect apparatus to the magnetic field, adjust the zero point: Apply a transverse current I of e.g. 10 A and set the indicator of the meter for measuring the Hall voltage U_H to zero using the adjusting knob 4 (see instruction sheet 568 81/84). If the display changes after switching off, switch the transverse current back on and repeat the zero-point adjustment.
- Apply a transverse current I = 15 A to the Hall effect apparatus and measure the Hall voltage U_H as function of magnetic field B (Read off the effective field value from the calibration curve of part a)). Carry out several measurements to determine a mean value for the Hall voltage U_H. For further measurement hints see also the instruction sheets 568 81/84 (Hall effect apparatus) and 532 13 (Microvoltmeter).
- Repeat the measurement for a transverse current I = 20 A.

Measuring example

<table>
<thead>
<tr>
<th>I (A)</th>
<th>B (T)</th>
</tr>
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<tbody>
<tr>
<td>0.0</td>
<td>0.000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.118</td>
</tr>
<tr>
<td>1.0</td>
<td>0.200</td>
</tr>
<tr>
<td>1.5</td>
<td>0.295</td>
</tr>
<tr>
<td>2.0</td>
<td>0.374</td>
</tr>
<tr>
<td>2.5</td>
<td>0.455</td>
</tr>
<tr>
<td>3.0</td>
<td>0.520</td>
</tr>
<tr>
<td>3.5</td>
<td>0.585</td>
</tr>
<tr>
<td>4.0</td>
<td>0.630</td>
</tr>
<tr>
<td>4.5</td>
<td>0.665</td>
</tr>
<tr>
<td>5.0</td>
<td>0.695</td>
</tr>
<tr>
<td>5.5</td>
<td>0.715</td>
</tr>
<tr>
<td>6.0</td>
<td>0.735</td>
</tr>
<tr>
<td>6.5</td>
<td>0.748</td>
</tr>
<tr>
<td>7.0</td>
<td>0.760</td>
</tr>
<tr>
<td>7.5</td>
<td>0.780</td>
</tr>
<tr>
<td>8.0</td>
<td>0.790</td>
</tr>
<tr>
<td>8.5</td>
<td>0.800</td>
</tr>
<tr>
<td>9.0</td>
<td>0.810</td>
</tr>
</tbody>
</table>

The data of table 1 are plotted in Fig. 4.

Fig. 4: Calibration curve magnetic field as function of current I.
b) Measuring the Hall voltage as function of the magnetic field

Table 2: Hall voltage \( U_H \) (absolute value) as function of the magnetic field \( B \) for constant transverse currents \( I \).

<table>
<thead>
<tr>
<th>( B ) (T)</th>
<th>( U_H ) (( I = 15 ) A)</th>
<th>( B ) (T)</th>
<th>( U_H ) (( I = 20 ) A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>4.6</td>
<td>0.20</td>
<td>6.25</td>
</tr>
<tr>
<td>0.35</td>
<td>8.2</td>
<td>0.38</td>
<td>11.7</td>
</tr>
<tr>
<td>0.51</td>
<td>12.0</td>
<td>0.50</td>
<td>15.0</td>
</tr>
<tr>
<td>0.62</td>
<td>14.1</td>
<td>0.61</td>
<td>18.1</td>
</tr>
<tr>
<td>0.70</td>
<td>16.1</td>
<td>0.68</td>
<td>20.5</td>
</tr>
<tr>
<td>0.73</td>
<td>17.0</td>
<td>0.70</td>
<td>21.0</td>
</tr>
<tr>
<td>0.76</td>
<td>17.7</td>
<td>0.72</td>
<td>21.6</td>
</tr>
<tr>
<td>0.78</td>
<td>18.1</td>
<td>0.76</td>
<td>22.7</td>
</tr>
<tr>
<td>0.80</td>
<td>18.6</td>
<td>0.80</td>
<td>24.0</td>
</tr>
</tbody>
</table>

The polarity of the Hall voltage \( U_H \) was determined to be negative.

Results

b) Measuring the Hall voltage as function of the magnetic field

The recorded data of Table 2 for the transverse currents \( I = 15 \) A and \( I = 20 \) A are plotted in Fig. 5.

Form Fig. 5 also follows that the Hall voltage \( U_H \) increases with increasing transverse current \( I \):

\[ U_H \sim I \]  \hspace{1cm} \text{(III)}

Note: The proportionality between the Hall voltage \( U_H \) and transverse current \( I \) can be determined experimentally by measuring the Hall voltage \( U_H \) as function of the transverse current \( I \) for a constant magnetic field \( B \).

From the fit of equation (I) to the experimental data is resulting the slope

\[ A_H = \frac{1}{n \cdot e \cdot d} \]

\[ A_H (I = 15 \) A) = 23.2 \ \frac{\mu V}{T} \]

\[ A_H (I = 20 \) A) = 30.4 \ \frac{\mu V}{T} \]

With the thickness \( d = 5 \times 10^{-5} \) m the Hall constant can be determined (absolute value):

\[ R_H (I = 15 \) A) = 7.7 \times 10^{-11} \ \frac{m^3}{C} \]

\[ R_H (I = 20 \) A) = 7.6 \times 10^{-11} \ \frac{m^3}{C} \]

Literature value: \( R_H = 8.9 \times 10^{-11} \ \frac{m^3}{C} \)

The Hall voltage is determined to be negative. This shows that in silver the conduction mechanism is mainly effected by negative charge carriers.

With elementary charge \( e = 1.602 \times 10^{-19} \) C follows the concentration of charge carriers:

\[ n (I = 15 \) A) = 8.1 \times 10^{28} \ \frac{1}{m^3} \]

\[ n (I = 20 \) A) = 8.2 \times 10^{28} \ \frac{1}{m^3} \]

Literature value: \( 6.6 \times 10^{28} \ \frac{1}{m^3} \) (atoms density \( 5.8 \times 10^{-22} \ \frac{1}{m^3} \))

Evaluation

Form Fig. 5 follows that the Hall voltage \( U_H \) is proportional to the magnetic field \( B \):

\[ U_H \sim B \]  \hspace{1cm} \text{(III)}

Supplementary information

In 1916, Tolman obtained certain proof that electrons are the charge carriers in metals.