EXPERIMENT 22

HALL EFFECT IN P-GERMANIUM

PURPOSE

- To study the Hall effect in the semiconductor (p-type germanium).
- To determine the sign of the charge carriers, Hall's constant and the mobility, and density of charge carriers.

APPARATUS

Sample board. Electromagnet with the sample holder. Universal AC/DC voltage power supply; rectifier, potentiometer and capacitor boards. Teslameter with probe. Digital multimeters.

DESCRIPTION OF THE EXPERIMENT

Charge carriers in the conducting flat stripe (length - ***l***, width - ***a,*** thickness - ***d***) with the established steady current ***I*** and placed in the external magnetic field ***B*** normal to the direction of the current are deflected by the Lorentz force. The charge separation results in development of the voltage across the sample (Hall voltage - U_H) - see Fig.1. The type of the charge carrier causing the flow of the current can be determined from the polarity of the Hall voltage, knowing the direction of the current and the direction and sense of the magnetic field.

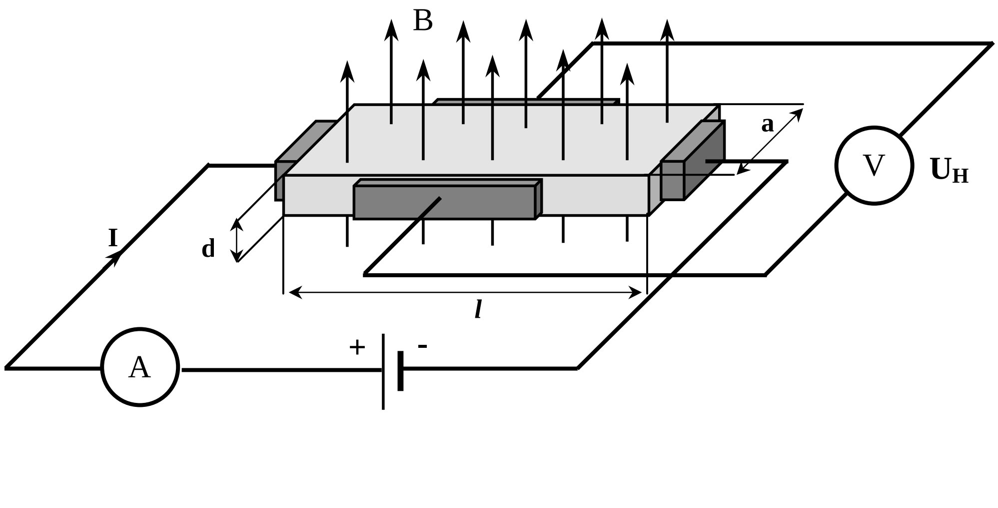

Fig.1. Ideogram of the observation of the Hall effect

The Hall voltage is proportional to the flowing current, apart from the very low temperatures where the quantized Hall effect is seen.

$$U_H = i \cdot \frac{B}{e \cdot d \cdot n} \qquad (1)$$

where ***n*** is the charge carriers density.

The charge carriers mobility μ_H, conductivity σ and the charge carriers density ***n*** are related through the Hall constant C_H :

$$C_H = \frac{U_H}{B} \cdot \frac{d}{I} = \frac{1}{n \cdot e} \qquad (2)$$

$$n = \frac{B \cdot I}{U_H \cdot d \cdot e} = \frac{1}{C_H \cdot e} \qquad (3)$$

$$\mu_H = \frac{v_D}{E} = \frac{v_D \cdot \sigma}{j} = \frac{j \cdot \sigma}{j \cdot n \cdot e} = \frac{\sigma}{n \cdot e} = C_H \cdot \sigma \qquad (4)$$

Conductivity σ of the material can be calculated from the sample resistance ***R*** and sample dimensions ***d, a, l***:

$$\sigma = \frac{l}{R \cdot d \cdot a} \qquad (5)$$

The sign of the charge carriers predominant in the conductivity of the examined material can be established from the polarity of the observed Hall voltage.
If the directions of the magnetic field and current are as given at the Fig.1. and the front edge of the strip becomes negative then the negative charge carriers are responsible for the conductivity of the material. The reversed polarity stands for the p-type conductivity of the material.

EXPERIMENTAL SETUP

Figure 2. presents the circuit diagram for observation of the Hall effect.
Flat strip of the examined material is assembled on the **board** together with the electrical heater and thermocouple enabling control and measurement of the sample temperature (not used in the present experiment). The sample board is to be put in the gap of the **electromagnet**. The magnetic induction in the gap is set up by the steady current flowing through the coils. This current is provided by the **power supply**. Induction ***B*** is measured by the use of the **magnetic field probe** (hallotron) connected to the **teslameter**.

The **power supply** provides the alternating current which is converted into the DC by means of the **rectifier** with the electrolytic capacitor filter ***C***. **Potentiometer P** controls the magnitude of the current ***I*** which is measured by the **ammeter**. Additional **serial resistor** (330 Ω) limits the magnitude of the current through the sample.
The Hall voltage U_H is measured by the **voltmeter**.

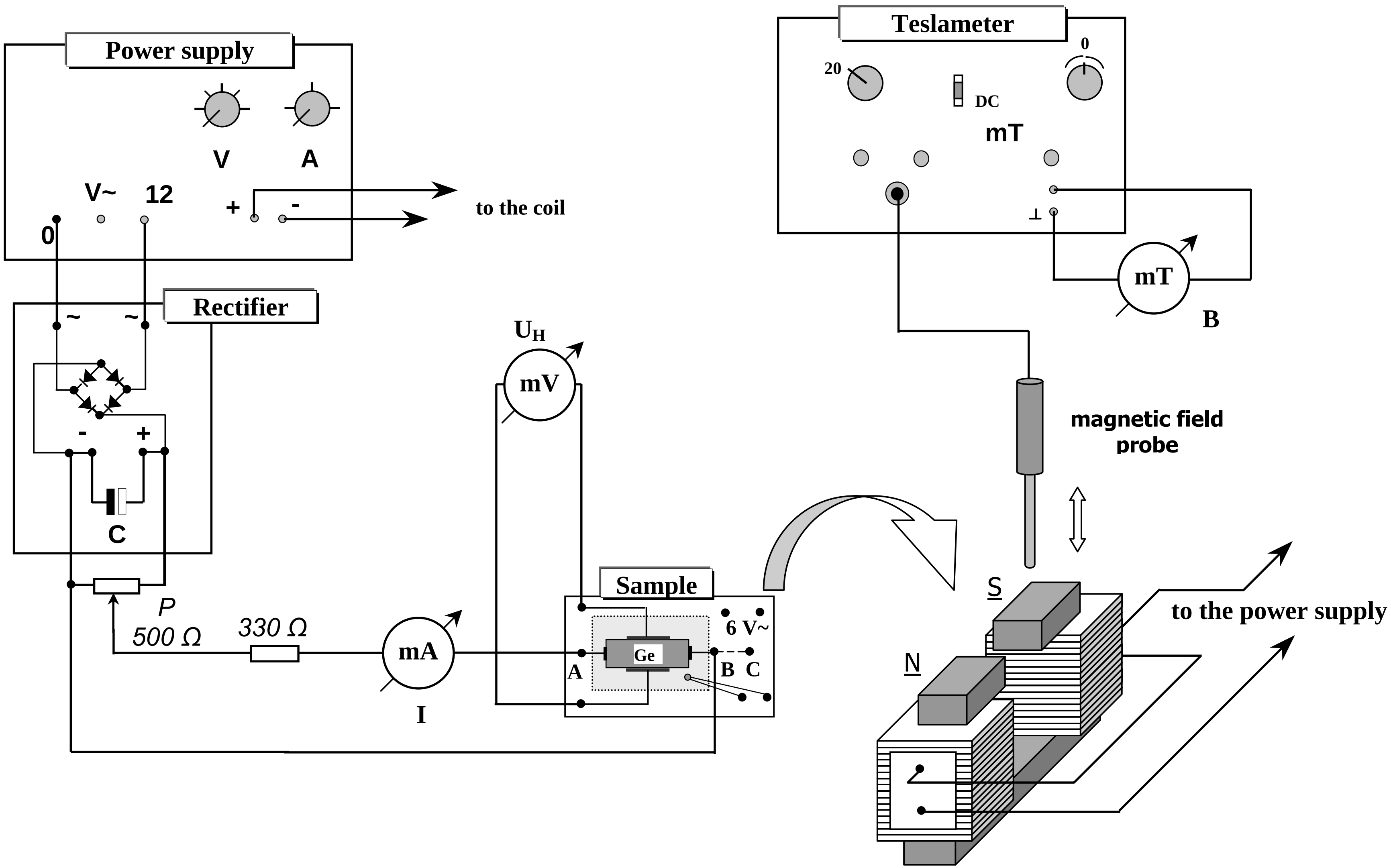

Fig.2. Experimental setup

EXPERIMENTAL PROCEDURE

Preparation of the experimental setup (to be made by the laboratory staff):

1. Check out connections according to the diagram given in the Fig.2.
2. Assembly the sample board on the tripod base holder and fit it in the gap of the electromagnet.
3. Assembly the magnetic field probe in the central part of the gap between the sample board and the pole of the electromagnet.
4. Set the potentiometer ***P*** in the most left position.
5. Set the current and voltage control knobs of the power supply in the most left positions.

Measurements:

Part I. Examining the $U_H\ (I)_{B=const,\ T=const}$

1. Check out the position of the voltage and current controls (at the minimum).
2. Check the connections between the power supply and the rectifier and connections between rectifier and the sample board (check the node ***B***).
   Ask instructor for approval of the connections!!
3. Turn on the teslameter.
4. Set the magnetic field in the gap of the electromagnet:
   a. adjust the power supply voltage at the ***12 V***.
   b. slightly increase the current through the coil by means of the current control at the power supply. Observe the indications of the teslameter. Adjust the magnetic induction at the 10 mT level.
5. Using the potentiometer ***P*** set the current ***I*** through the sample at the ***2 mA***.
6. Record the Hall voltage U_H from the voltmeter. Note the polarity of the voltage.
7. Repeat the steps 5 and 6 for at least 16 current values from ***0*** up to ***38 mA***.
   Record current ***I*** and voltage U_H values in the data table.
8. Turn off the current through the sample (put the potentiometer ***P*** control in the ***O*** position).
9. Reverse the direction of the current flowing through the sample by changing the connections to the terminals of the electrolytic capacitor ***C***.
10. Repeat measurements of steps 5 to 8.
11. Record all results on the data sheet.

Part II. Examining the $U_H\ (B)_{T=const}$

1. Check out the position of the voltage and current controls (at the minimum).
2. Change the connection between the sample board and the rectifier.
   The potentiometer should be connected to the nodes ***A*** and ***C***.
   Ask instructor for approval of the connections !!
3. Turn on the teslameter.
4. Using the potentiometer ***P*** set the current ***I*** through the sample at the chosen value (ask supervisor) e.g. ***20 mA***. Record this value.
5. Adjust the power supply voltage at the ***12 V***.
6. By the current control knob on the power supply set the magnetic induction in the gap at the 1mT level (check the indications of the teslameter).
7. Record the Hall voltage U_H from the voltmeter. Note the polarity of the voltage.

8. Repeat the steps 6 and 7 for at least 10 induction values from ***1mT*** up to ***10 mT***. Each time check and if necessary adjust the constant values of the current $\boldsymbol{I}$.
9. Record both $\boldsymbol{U_H}$ and $\boldsymbol{B}$ values in the data table.
10. Turn off the current through the coil.
11. Reverse the direction of the current flowing through the coil by changing the connections to the terminals of the power supply.
12. Repeat measurements of steps 5 to 9.
13. Record all results on the data sheet.

Closing the measurements:

1. Turn off the current through the sample (adjust the potentiometer $\boldsymbol{P}$ at the most left position).
2. Turn off the magnetic field by adjusting the current and voltage controls at the '0' positions.
3. Turn of the power supply and the teslameter.

CALCULATIONS AND PRESENTATION OF RESULTS

1. Make plots of $U_H(I)_{B=const,\ T=const}$ dependences for both directions of the current.
2. Calculate for each $U_H(I)$ plot the slope R_H (Hall resistance) from the linear regression.
3. Put the established regression lines on the plots.
4. Make plots of $U_H(B)_{I=const,\ T=const}$ for both direction of the magnetic field.
5. Calculate for each $U_H(B)$ plot the slope b from the linear regression - see Eq.1.
6. Calculate the Hall constant C_H from the b value. Take $d= 1\cdot 10^{-3}[m]$ as the thickness of the strip - see Eq.2.
7. Calculate the charge carriers density n from the Hall constant - see Eq.3.
8. Calculate the conductivity σ from the Eq. 5. Use $l= 2\cdot 10^{-2}[m]$ as the length and $a=5\cdot 10^{-3}[m]$ as the width of the strip. Use $R=57\ [\Omega]$ for the sample resistance.
9. Calculate the carriers mobility μ_H from Eq. 4.

ANALYSIS AND INTERPRETATION

1. Discuss the linearity of the established $U_H(I)$ and $U_H(B)$ approximations.
2. Discuss the polarity of the Hall voltage in all examined configurations.
3. Discuss the nature of conductivity of the examined material.

DATA TABLES

I [mA]	U_H [mV]

B [mT]	U_H [mV]

REQUIREMENTS

1. Hall effect.
2. Electrical conductivity in the metals and semiconductors.
3. Description of the experimental method.