HALL EFFECT IN METALS

1 Objectives

- Study and understand the Hall Effect.
- To measure the Hall voltage as a function of the electric current and the magnetic field.
- To find out the Hall coefficient.
- To identify the charge carriers sign in term of the polarity of the Hall voltage.

2 Theorethical background

Hall effects was discovered by Edwin Herbert in 1879. In consists of the appearance of an electric field **E**, that is perpendicular to the direction of the electric current **I** that is flowing through a material, when a magnetic field **B** is applied in a direction that is perpendicular to the electric current **I**.

2.1 Effect Hall in metals.

Let us consider the metallic material of the Figure 1a, with length L, width W and high h. Along the length, the ends are connected to a battery and electric current I flows through the material.

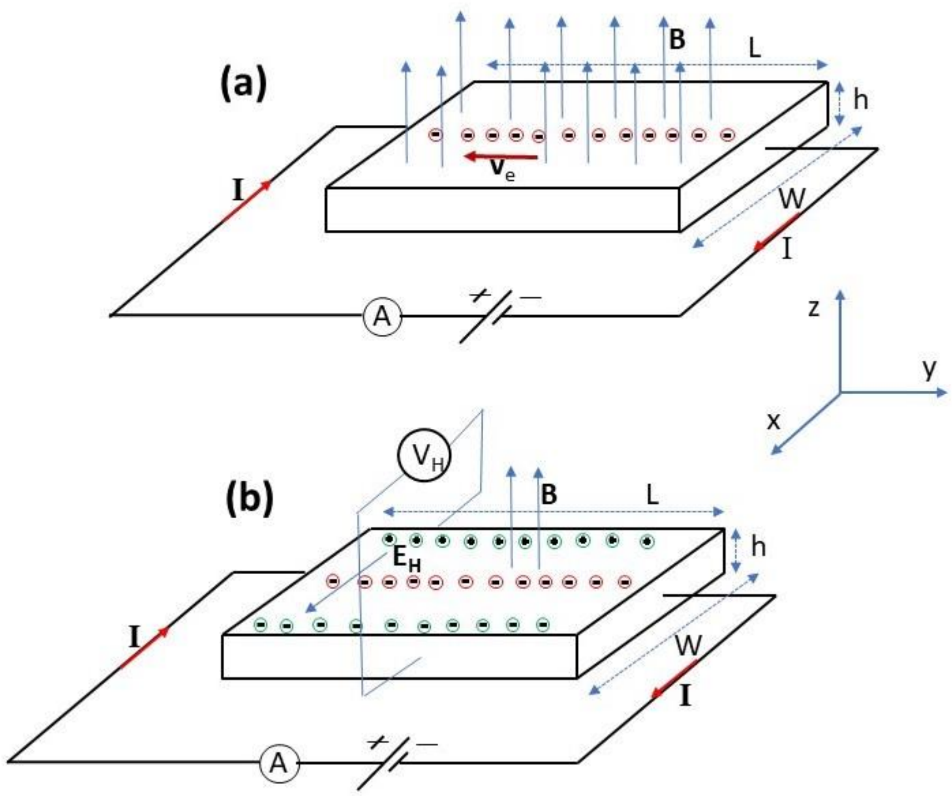

Figure 1. Schematic view of the Hall effect in metals.

The electrons move from the positive pole of the battery to the negative pole with a average drift velocity **V_e**. A magnetic field is established along the z-direction which is perpendicular to the electric current I. The magnetic force acting on the electrons is:

$\vec{F}_{mag} = -e\vec{V}_e \wedge \vec{B}$ (1)

Then, some of the electrons deviate towards the x-direction and some of them arrives to one side of the material. Since the electrons are not collected by a wire, they accumulated in this side of the material. As it is shown in Figure 1b, on the opposite side of the material, the positive ions are not compensated by a negative charge, and then a positive charge is accumulated in this part of the material. Due to this fact, a potential difference appears between both sides what originate an electric field along the x-direction. This electric field, which is called Hall field, exerts a force on the electrons that try to balance the effect of the magnetic force. The electric force on the charge carriers is:

$\vec{F}_e = -e\vec{E}_H$ (2)

At the equilibrium:

$\vec{F}_{mag} + \vec{F}_e = 0 \Rightarrow eV_eB = eE_H \Rightarrow E_H = V_eB$ (3)

The average drift velocity of the electrons can be expressed in terms of the electric current I, since:

$\vec{J} = -en\vec{V}_e$ (4)

$I = \int \vec{J} \cdot d\vec{S}$ (5)

Where n is the density of electrons in the metal. Therefore:

$I = JS = neV_ewh \Rightarrow V_e = \dfrac{I}{newh}$ (6)

On the other hand, the Hall field E_H is related to the Hall potential V_H by the expression:

$V_H = E_H w$ (7)

Finally, the expression for the Hall potential is

$V_H = V_eBw = \dfrac{IBw}{newh} = \dfrac{IB}{neh}$ (8)

If it is taken into consideration that the Hall coefficient is defined as

$R_H = \dfrac{1}{ne}$ (9)

The Hall potential can be written like

$V_H = R_H \dfrac{IB}{h}$ (10)

The type of charge carrier can be deduced from the sign of the Hall coefficient. In case the sign is negative, it means that the charge carries are electrons and the Hall effect is called "Normal Hall effect". On the other hand, if the sign of the Hall coefficient is positive, the charge carriers are holes and the Hall effect is called "Anomalous Hall effect".

3 Bibliography

- **C. Kittel, Introduction to Solid State Physics, 8th edition, pp.153-156**
- **N.W: Ashcroft, N.D. Mermin, Solid State Physics, (1976), pp. 6-15.**

In the WEB

https://www.tf.uni-kiel.de/matwis/amat/mw2_ge/kap_2/backbone/r2_1_3.html

https://courses.lumenlearning.com/physics/chapter/22-6-the-hall-effect

4 Equipment

1. Power supply (for the magnetic field)
2. Power supply 0-30 VDC/ 20 A (for the Hall effect carrier board, Cu and Zn)
3. Universal measuring amplifier
4. Teslameter, digital
5. Probe for measuring the tangential component of the magnetic field
6. Hall effect, carrier board (Cu and Zn). Dimensions for Cu: d = h = $18\cdot10^{-6}$ m
7. Electromagnet
8. Polymer voltimeter
9. Connection cables
10. Screwdriver

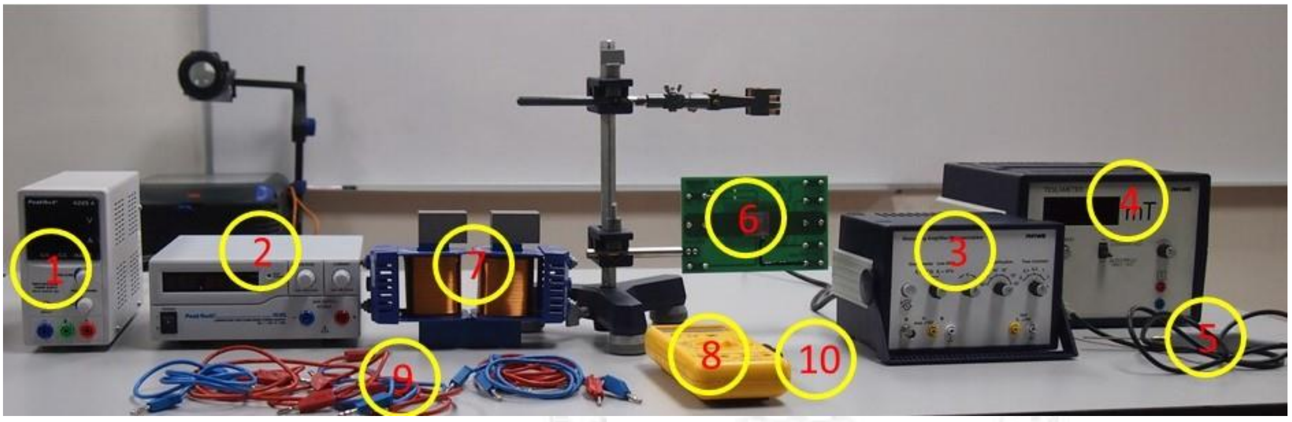

Figure 2.Equipement for measuring the hall effect in metals

5 Experimental procedure

5.1 Instructions for connecting the different devices. These tasks must be done with all the devices off.

5.1.1 Connect the power supply (PeakTech 6225 A) to the electromagnet to originate the magnetic field.

- Connect with a cable the negative pole of the power supply, point (1), to the point (6) of the electromagnet. Connect the point (7) of the electromagnet to the point (8) of the electromagnet with a cable. Connect the point (9) of the electromagnet to the positive pole of the power supply, point (2) (see figure 3).

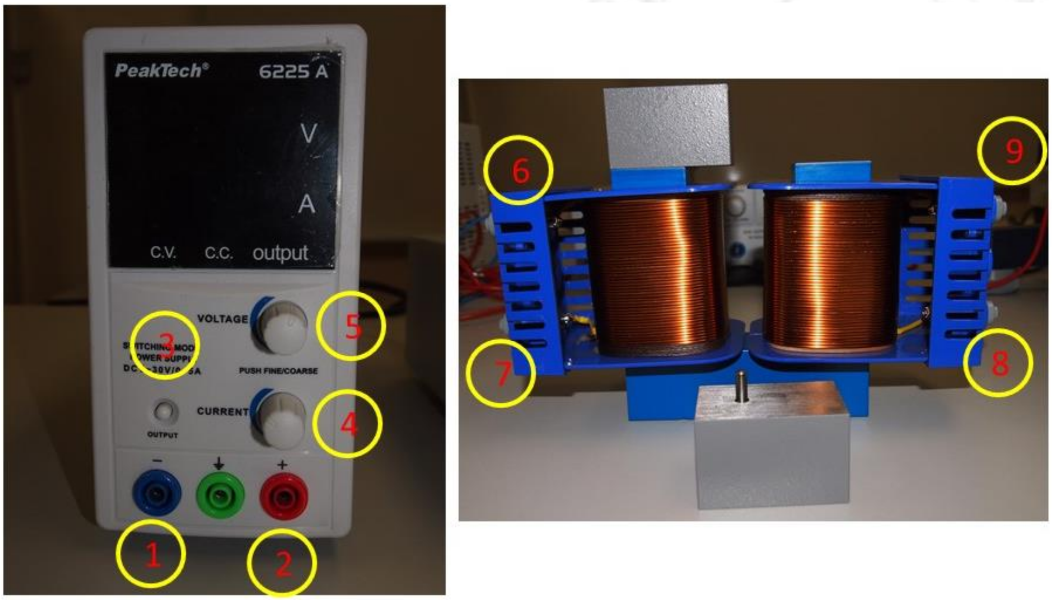

Figure 3. Connections between the power supply and the electromagnet.

5.1.2 You will usually find the magnetic field probe mounted. Check that the position is the indicated in the figure: the handwriting must be looking to the front part of the metal which is in the Hall effect carrier board (see Figure 4).

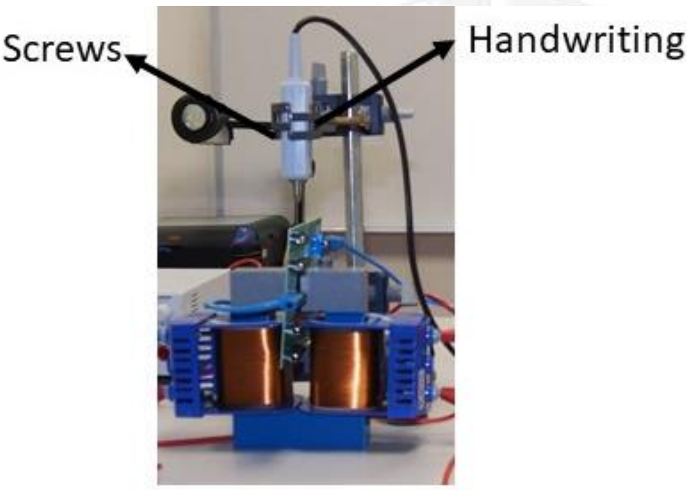

Figure 4. Magnetic field probe mounted in the Hall effect carrier board.

5.1.3 Connect the negative pole of the power supply (Peak Tech 1535), point (15) to the point (11) of the back part of the Hall effect carrier board. Connect the positive pole of the power supply, point (16), to the point (10) of the Hall effect carrier board (see figure 5).

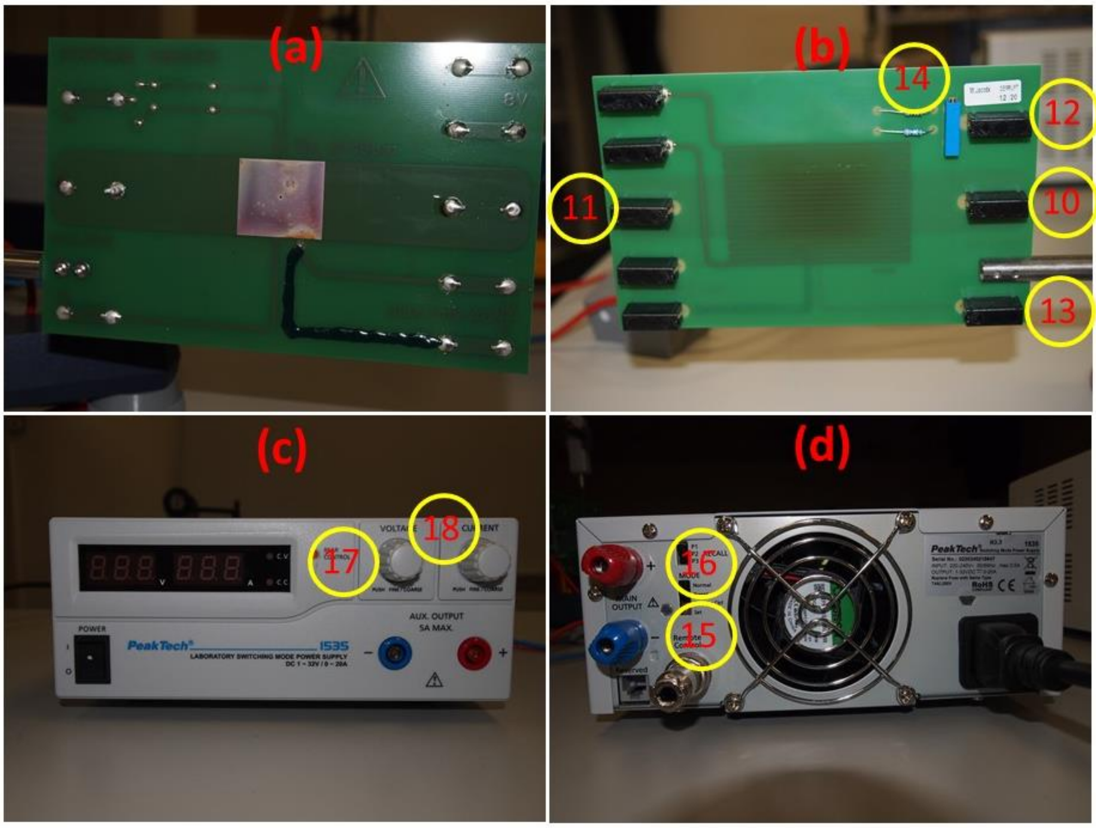

Figure 5. (a) Front part of the Hall Carrier board. (b) Back part of the Hall carrier board. (c) Front part of the power supply. (d) Back part of the power supply

.

5.1.4 It is necessary to perform the following connections for measuring the hall potential.
Connect the point (12) of the Hall carrier board to the point (20) of the measuring amplifier. Connect the point (13) of the Hall carrier board to the point (19) of the measuring amplifier.
Connect the polymeter as voltimeter to the measuring amplifier. For it connect point (22) of the measuring amplifier to the point 23 of the polymeter. Later connect the point (21) of the measuring amplifier to the point (24) of the voltimeter (see figure 6).

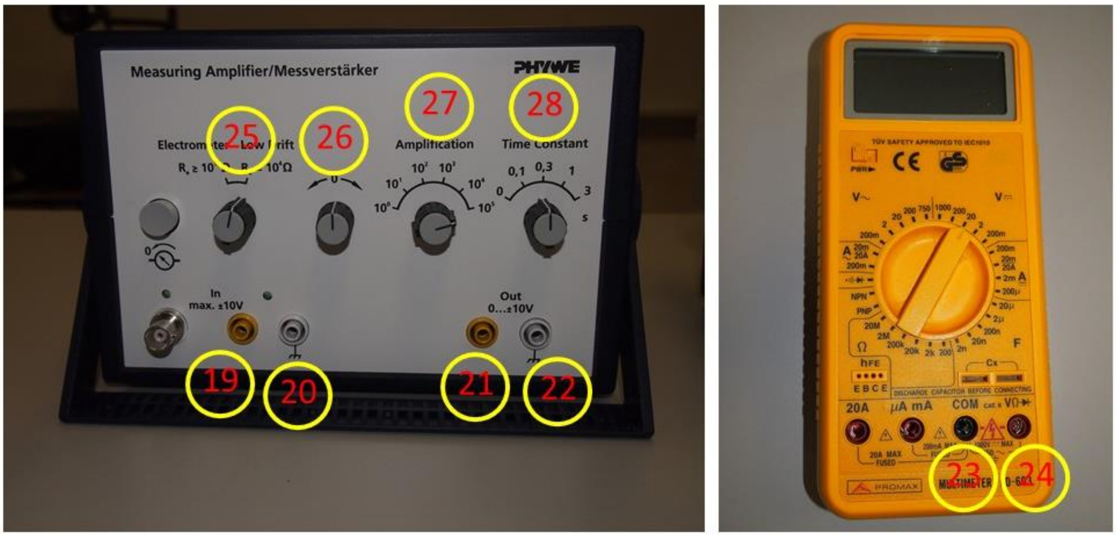

Figure 6. Measuring amplifier and digital polymeter as voltimeter.

If all the connections are alright, he experimental set-up must be that of the figure 7.

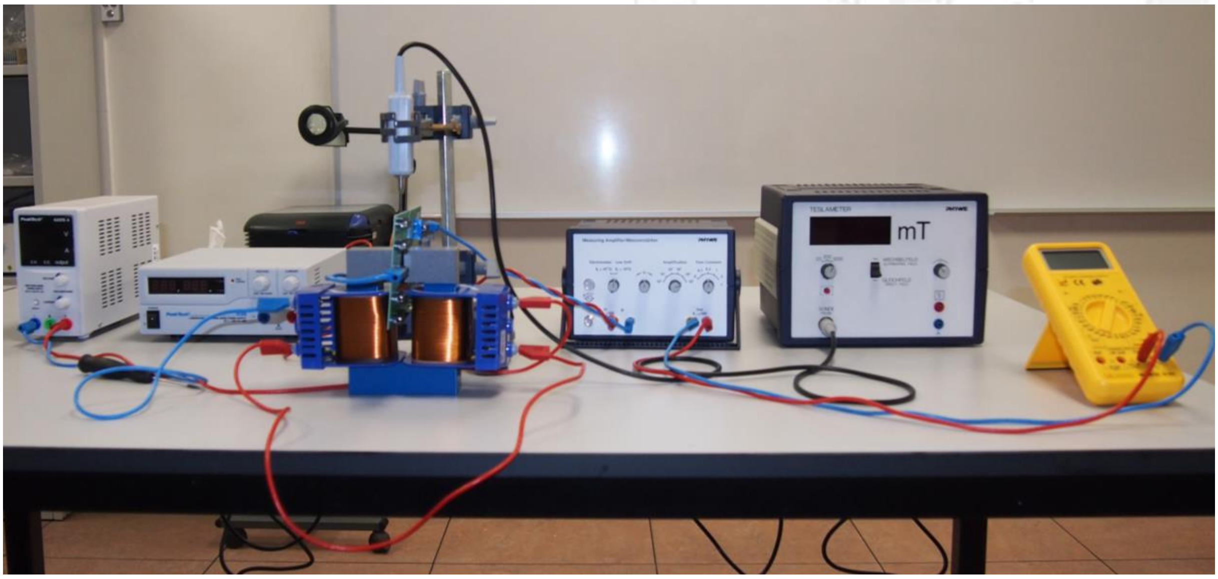

Figure 7. Experimental set-up for measuring the Hall effect in metals.

Points to check before start to measure

- Check all the connections are alright
- The teslameter must be switch on 15 min. before start the measurements
- The measuring amplifiers takes about 15 min. to settle down free from drift and should therefore be switched on correspondingly earlier.
- The measuring amplifier: control (25), low drift R $=10^4$; control (27), amplification: 105; control (28), time constant, t = 0.3. Be careful: the signal of the hall volatage measured in the voltimeter is multiplied by 10^5.
- The maximum current for the Hall carrier board is 20 A. it is the current given by the power supply Peak Tech 1535. The maximum current cannot be greater than 15 A, and this current can only be established for short periods.
- The digital multimeter must be in mode direct current for measuring the voltage. The suitable scale is 20 V.

5.1.5 Switch on both power supplies and the voltimeter. In the power supplies the intensity must be zero.

5.1.6 In the power supply for the magnetic field. Fix a potential of 5 V; for it, the control (3), output, must be off, (in the screen the red lights that are labelled as CC and output are off), then, move the control (5) up to obtain 5 V in the screen. This will be the maximum voltage given by the power supply. It is enough for getting a field of 250 mT.

5.1.7 The magnetic field measured by the teslameter must be 0. First, it is a direct field, so control (28) must be in mode direct field. The scale, control (25), must be in 1000. If there is a magnetic field different from zero, with the control (26) (it is very sensitive) makes that the magnetic field in the screen is 0. If it is not possible, then use the control (27) and put the magnetic field to zero.

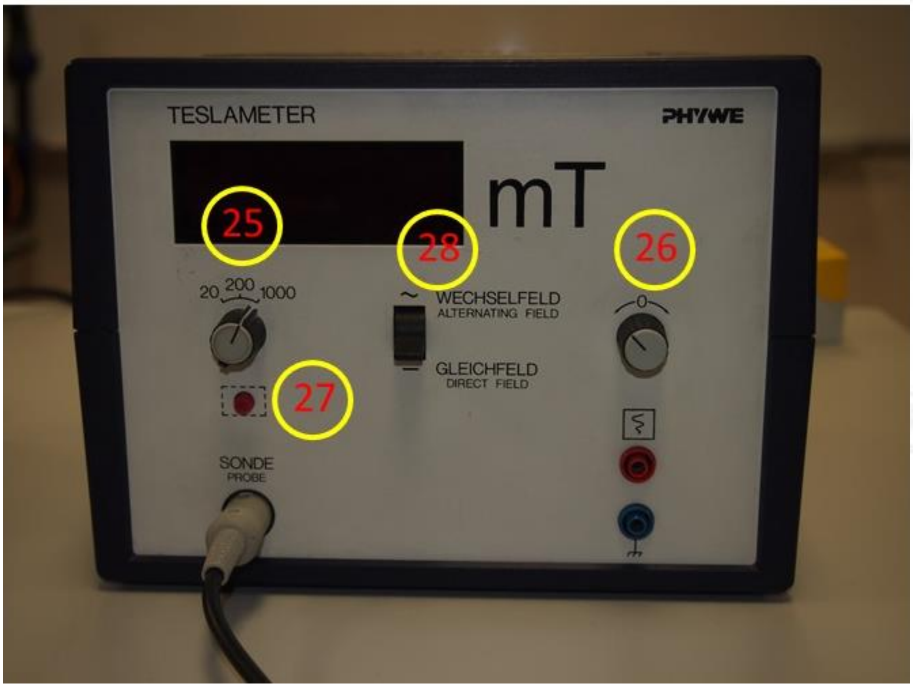

Figure 8. Teslameter

5.1.8 **Adjust the Hall voltage to zero**. The Hall probe will show a voltage at the Hall contacts (the reading in the voltimeter is different from zero) even in the absence of a magnetic field, because these contacts are never exactly one above the other but only within the manufacturing tolerances. Before measurements are made this voltage must be compensated. For it, you must use the compensation-voltage of the measuring amplifier, control (27) (figure 6) and the compensating potentiometer, control (14) of the Hall carrier board (figure 5b). The method for performing the compensation is this one:

- Disconnect the transverse current of the Hall effect carrier board (the current supplied by the power supply Peak Tech 1535)
- By using the compensation-voltage, control (27), try to obtain a reading of 0 V in the volitimeter (The control is very sensitive!!!).
- Connect the transverse current.
- Twist the connecting cords between hall voltage sockets and amplifier input in order to avoid as much as possible stray voltages.
- Adjust the compensating potentiometer, control (14) of the Hall carrier board, with a screw driver up to obtaining a reading of 0 V in the voltimeter. It is also very sensitive. Be careful and do not damage the screw.

- Repeat this operation several times to obtain a precise adjustment.

Measurements of the Hall voltage versus the transverse electric current

5.1.9 First it is necessary to put a magnetic on the sample. In the power supply Peak tech 6225 A put the output in position on, control (3) (figure 3). With the control of the intensity, point (4), increase its value up to get a magnetic field of 250 mT. The power supply is delivering electric current if the red lights on CC and output are on.

5.1.10 You must vary the transverse current through the sample by using the control (18) of the power supply PeakTech 1535. Increase the intensity from zero up to 15 A instep of 1 A. For each value of the current you must note the Hall voltage. Later put the current to 0 A, change the polarity of the cables in the power supply, exchanging the connections of the cables: swap the connections (15) and (16). Then change the intensity of the transverse current from -1 A up to -15 A in steps of -1 A. Make a table with the intensity versus Hall voltage.

Remark: On finishing the measurements exchange the cables of the position (15) and (16) in order to put the original polarity!!!!!

5.1.11 Plot the Hall voltage (y-axis) versus the intensity (x-axis). Perform a least square fitting of the curve.

5.1.12 By using the expression [10], interpret the values of the adjustment parameters. Indicate the type of charge carriers. Obtain the value of the Hall coefficient R_H and the concentration of carriers n or p from the adjustment parameters.

Measurements of the Hall voltage versus the transverse electric current

5.2 Measurements of the Hall voltage versus the magnetic field.

5.2.1 Fix the value of the transverse electric current to 10 A by using the control (18) of the power supply PeakTech 1535.

5.2.2 In the power supply Peak Tech 6225 A put the output in position on, control (3) (figure 3). With the control of the intensity, point (4), change the value of the magnetic field from 0 mT up to 250 mT in steps of 25 mT and measure the corresponding value of the Hall voltage. Subsequently put the electric current of the power supply Peak Tech6225 to 0. Change the polarity for the magnetic field: exchange the cables of the power supply between the positions (1) and (2). Vary the magnetic field from 0 up to -250 mT in steps of -25 mT and measure the corresponding value of the Hall voltage. Make a table with the magnetic field versus the hall voltage.

Remark: On finishing the measurements exchange the cables of the position (1) and (2) in order to put the original polarity!!!!!

5.2.4 Make a graphic with the Hall voltage (y-axis) versus B (x-axis). Perform a least square adjustment

5.2.5 Interpret the different parameters of the fitting by using the expresión [10]. Obtain the value of the concentration of charge carriers n or p from the fitting parameters. Compare the results with those obtained in section 5.1.12. Discuss the results.