Studying the Hall Effect in a Semiconductor

1. The aim of the laboratory

To observe the Hall voltage generated accross a semiconductor, when a magnetic field $\vec{B}$ is applied perpendicular to an electric current of intensity ***I*** that travels through that semiconductor, and to calculate the Hall constant for this material.

2. Theoretical approach

In 1879, E. H. Hall designed an experiment that allows to determine the sign of the charge carriers in a conductor or a semiconductor such as a flat strip of copper (shown in Fig. 1). It carries an electric current of intensity ***I*** pointing in the direction indicated in the figure. The current arrow indicates the motion of positive charge carriers. The Hall effect, described in the followings, can be used to decide between the two possibilities. A magnetic field with the magnetic induction B is set up at right angles to the strip, by placing the strip between the pole faces of an electromagnet. This field exerts the Lorentz force on charge carriers in motion at velocity *v* (Figure 1):

$$\vec{F} = q \cdot \vec{v} \times \vec{B}. \tag{1}$$

These carriers, whether they are positive or negative will tend to drift toward the left of the figure, as they drift along the strip, producing a transverse Hall potential difference, V_{xy}, between the sides x (left) and y (right) in Fig. 1. The sign of the charge carriers is determined by the sign of this Hall potential difference. If the carriers are positive, the left (x) side will be at a higher, positive potential than the right (y) side. If the charge carriers are negative (such the electrons in metals), the left (x) side becomes negative and the right (y) side remains positively charged. It was thus experimentally confirmed that in metals, the charge carriers are negative.

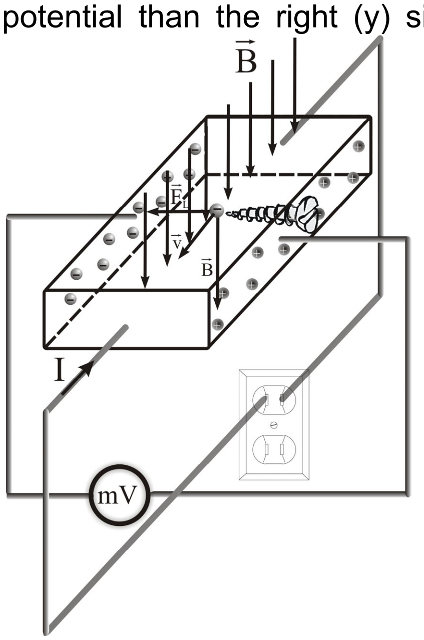

Figure 1

If the potential difference is U_H, the Hall effect produces an electric field of intensity:

$$E_H = \frac{U_H}{d}. \tag{2}$$

The electric charge on the x and y sides will build up, and the Hall voltage U_H will increase up to a value for which the electrostatic force equals the Lorenz force:

$$\frac{eU_H}{d} = evB. \tag{3}$$

The Hall induced voltage can be measured by using the circuit presented in figure 1. The current intensity along the strip is:

$$I = n e v a d, \tag{4}$$

(where ***n*** is the density of the charge carriers, ***a*** and ***d*** are the width and thickness of the strip), and thus the speed of the charge carriers becomes:

$$v = \frac{I}{naed}. \tag{5}$$

The Hall voltage can be deduced as:

$$U_H = vBd = \frac{1}{ne}\frac{IB}{a} = R_H\frac{IB}{a}, \tag{6}$$

where, R_H is the Hall constant for the material studied. This result is valid only in the case that the electrons would be monokinetic, which is actually not true. In fact, $R_H = A/ne$, where A is a constant depending on the charge carriers. The constant R_H is either positive or negative, depending whether the charge carriers are positive (holes) or negative (electrons). If both types of carriers are present, then:

$$R_H = \frac{A}{e}\frac{p\,\mu_p^2 - n\,\mu_n^2}{\left(p\,\mu_p - n\,\mu_n\right)^2}, \tag{7}$$

where $\mu = v/E$ is the mobility of the charge carriers, defined as the speed of the charge carrier under an electric field of intensity E = 1 V/m.

For materials with only one single type of charge carriers, the electric conductivity is $\sigma = n\,e\,\mu$ and the Hall constant is $R_H = A/ne$. In metals, R_H has values between 10^{-11}–10^{-10} m^3/C, while in semiconductors, its values range between 10^{-4}–10^{+2} m^3/C. The mobility of the charge carriers is therefore:

$$\mu = \frac{R_H \cdot \sigma}{A}. \tag{8}$$

In electrical techniques, the Hall Effect is used: (a) to determine the strength (H) and the induction (B) of magnetic field, (b) to determine the losses in Fe, (c) in measuring the electric power and the phase shift in alternative circuits. In automatics and computer science engineering, the Hall-unit performs the summation and the multiplication in numerical computers, it does the automatic protection against short-circuits and it can be used as a current stabilizer.

3. Applications

In the domain of the electronic measurements, the Hall effect is used at the measurement of the magnetic field strength and magnetic induction, at the measurement of the energy losses in iron, at the measurement of very intense currents, at measurement of DC and AC power networks, of diphase shift and power factor.

In the field of electronic computers and automation, the Hall effect is used as in Hall device as a multiplier in numeric computers and is also used for automatic protection circuit installations, contactless switches, power stabilizer, etc.

4. Experimental procedure

The sample studied here is a semiconductive specimen (Ge), placed between the pole face of an electromagnet. A current of intensity I, passes across the Ge strip as indicated in fig. 2b). I_s is the intensity of the electric current through the electromagnetic coils, supplied by a 12V source (Fig 2.b). The Hall potential difference will be measured between the contacts 3 (side x) and 4 (side y), on the Ge strip.

1. Plug in the electromagnet, setting up a magnetic field B, and supply an electric current in the circuit of the Ge sample.
2. Set the current in the electromagnet at an intensity I_S = 1.5 A, then increase the current I along the strip, from 2 to 4; 6; and finally 8 mA, recording the corresponding Hall voltages in the data table. These Hall potential differences will be measured by using an electrometer, calibrated in divisions. The actual values of the measured voltages are to be read on the calibration graph of the electrometer. Care should be taken to find the asymmetry voltage registered by the electrometer even in the absence of any magnetic field. This residual voltage is determined by the current through the semiconductor, and occurs due to the asymmetry between the macroscopic contacts 3 and 4 and has to be subtracted from the total value read on the electrometer, when the magnetic field is applied.
3. Increase the induction of the magnetic field, B, by increasing the I_S current value to 2A, then apply a current through the semiconductor, of 2, 4, 6, 8 mA, and record the corresponding values of the voltage generated by the Hall effect.
4. Repeat (3) for I_S = 2.5 A, change the current through the semiconductor strip from 2, 4, 6, 8 mA, and record the new set of Hall voltage values generated in each case.

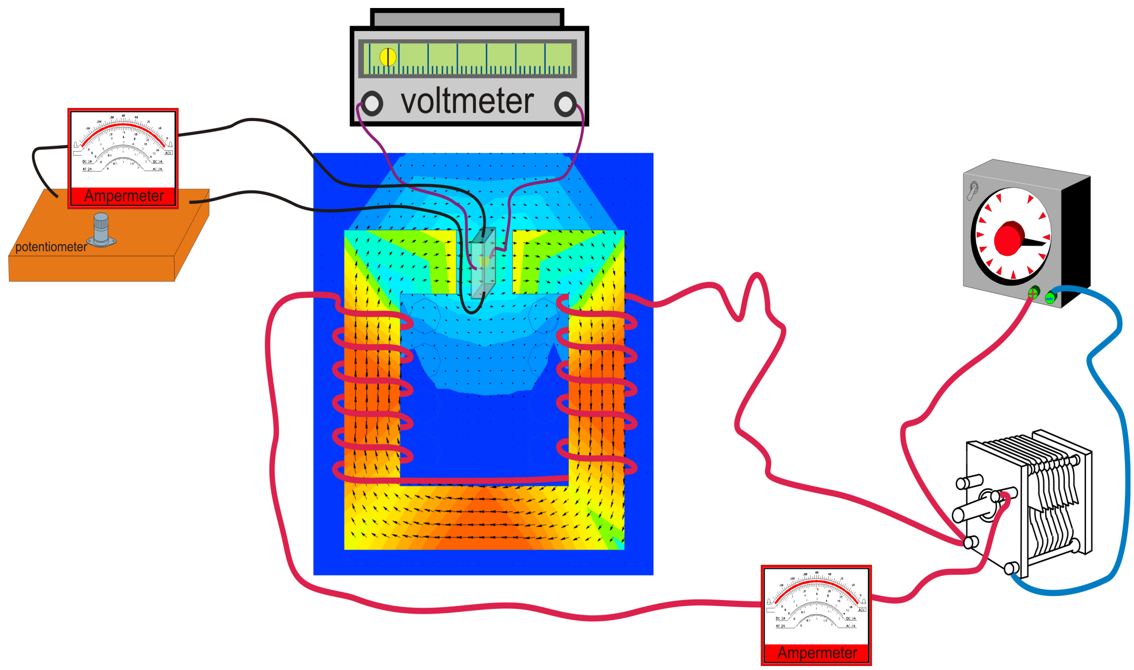

Figure 2.

5. Draw the graph showing the dependence of the Hall voltage U_H (mV) versus the quantity $I_S B/a$ (a total of 12 experimental points).
6. The graph obtained should present a linear dependence, the slope of which gives the Hall constant R_H.
7. The sign of R_H can be found by considering the direction of B and the sign of the voltage U_H, and it indicates the sign of the elementary charge carriers in the strip that was subjected to the Hall effect.
8. Calculate the number of charge carriers in the unit volume: $n = \frac{1}{e R_H}$ (A was assumed to be approximately equal to 1).
9. Calculate the mobility of the charge carriers: $\mu = R_H \sigma$, where: $\sigma = \frac{c}{R a b}$
10. The strip dimensions: a = 1.5 mm; b = 2.0 mm; c = 12 mm; the electrical resistance R = 400 Ω.

Data table

I [A]	B [T]	I_s [mA]	$\frac{I_S B}{a}$ [AT/m]	U [div]	U_H [mv]	R_H [Vm/AT]	n [e^-/m^3]	σ $[\Omega m]^{-1}$	μ [m^2/Vs]
1.5	0.2	2							
		4							
		6							
		8							
2	0.25	2							
		4							
		6							
		8							
2.5	0.28	2							
		4							
		6							
		8							