



**EXERCISE**  
**57C**

**INVESTIGATION OF THE HALL EFFECT**

**Measurement Procedure**

**I. List of equipment**

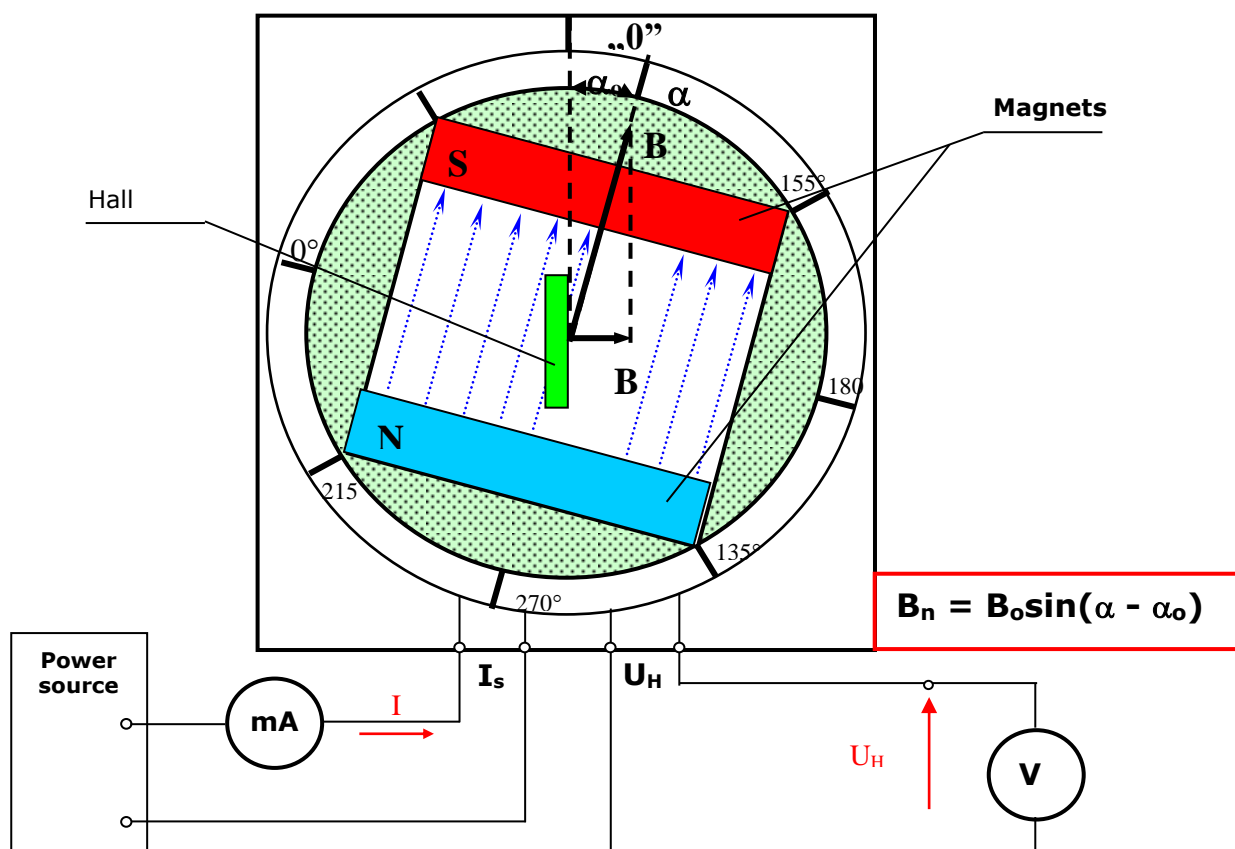
1. Hall Effect sensor placed in a magnetic field of permanent magnets. The magnets are mounted in a way which allows the change the orientation of the magnetic field.
2. Hall sensor power supply.
3. Milliampmeter for measuring the current on the sensor  $I_S$ .
4. Voltmeter for measuring the Hall voltage  $U_H$ .
5. Electrical cables.

**II. Goals**

1. Measuring the static characteristics of the Hall sensor:
  - a.  $U_H = f(\alpha)$  i  $U_H = f(B_n)$  – basic version of the exercise.
  - b.  $U_H = f(I_S)$  – extended version of the exercise.
2. Determination of the current sensitivity  $\gamma_I = \Delta U_H / \Delta I$  and field sensitivity  $\gamma_B = \Delta U_H / \Delta B$  of the Hall sensor.
3. Determination of the free charge carriers' concentration  $n$ .
4. Determination of the maximum angle sensitivity  $\gamma_\alpha = \Delta U_H / \Delta \alpha$  of the Hall sensor.

**III. Measurement setup**

1. Schematic picture of the measurement setup:





- Calculate the values of the normal component of the magnetic induction  $B_n = B_o \sin(\alpha - \alpha_o)$  and their uncertainties, using  $B_o = (0.500 \pm 0.05)$  T. **Note:** while calculating the uncertainty  $u_c(B_n)$ , the uncertainties of  $u(\alpha)$  i  $u(\alpha_o)$  should be expressed in radians
- Create point plots of  $U_H = f(B_n)$ . For  $I_S = \text{const}$  this graph should show a straight line (if it is not, you have to slightly change  $\alpha_o$ ).
- Using linear regression, determine the coefficients of the line (lines) of the best fit for the measured  $U_H = f(B_n)$  dependences, their uncertainties and the correlation coefficients  $R_K$ . Use the provided computer software (see: "Pomoce dydaktyczne" on the LPF website). Using the values of the linear regression coefficients to plot the trend lines  $y = ax + b$  over the point plots, producing a family of field characteristics of the Hall sensor. Discuss the graphical result.
- Add the uncertainty rectangles to three points and discuss the trends or their changes. Choose the points (one from the beginning, one from the middle and one from the end of the range) that diverge from the linear regression the most.
- To one of these points, with coordinates  $U_{Hi}$  and  $B_{ni}(\alpha_i)$ , calculate an exemplary value of  $\gamma$  using the equation  $U_H = \gamma I_S B_n$ . Taking into account the accuracy of the meters, estimate the uncertainty of the Hall sensor sensitivity. Compare and discuss the role of partial uncertainties. Remember to use proper units for each of the components of the equation.
- Calculate the final current sensitivity  $\gamma_B \equiv \gamma$ , using the slope coefficients of the trend lines ( $a = \gamma I_S$ ) and calculate the uncertainty of the parameter
- Calculate the free charge carrier concentration  $n$  and calculate their uncertainty. Use the expression  $n = \frac{1}{e \gamma d}$  where  $d$  is the thickness of the Hall sensor plate ( $d = 2 \mu\text{m}$ ,  $u_r(d) = 5\%$ ) and  $e$  is the elemental charge ( $e = 1.602 \times 10^{-19}$  C)
- Repeat the analysis for all the values of  $I_S$ .
- Compare the obtained values of the parameters  $\gamma_B$  and  $n$  with literature data and determine the type of material from which the Hall sensor was made.

## Extended version

$U_H = f(I_S)$  CHARACTERISTICS

### VI. Measurement procedure

- Connect the setup as shown on the schematic picture. Turn on the voltmeter and Hall sensor power supply.
- Set the angle of the Hall probe magnets to the value specified by the instructor. Write down this angle and the precision of the angle dial,  $\Delta\alpha = \Delta\alpha_o$
- Measure the dependence  $U_H = f(I_S)$  for  $B_n = \text{const}$ , i.e. the dependence of the Hall voltage  $U_H$  on the current  $I_S$  at a set value of the magnetic induction  $B_n$ . Conduct these measurements for  $I_S$  within the range 1 mA to 15 mA every 1 mA. Then change the value of  $B_n$  and repeat the measurements of  $U_H = f(I_S)$  in the same way.
- Write down the classes of accuracy of the used electric meters and their range. Use this values to calculate the measurement uncertainties of voltage  $U_H$  and current  $I_S$ .
- After finishing the measurements, set the  $I_S$  back to zero.

### VII. Analysis of the results:

- Create point plots of the measured dependences  $U_H = f(I_S)$  at  $B_n = \text{const}$ .
- Calculate the values of the normal component of the magnetic induction  $B_n = B_o \sin(\alpha - \alpha_o)$  and their uncertainties, using  $B_o = (0.500 \pm 0.05)$  T. The value of the  $\alpha_o$  determine based on the results from the basic version of the exercise (§V.1). **Note:** measurement uncertainties of  $u(\alpha)$  i  $u(\alpha_o)$  should be expressed in radians
- Using linear regression, determine the coefficients of the line (lines) of the best fit for the measured  $U_H = f(I_S)$  dependences, their uncertainties and the correlation coefficients  $R_K$ . Use the provided computer software (see: "Pomoce dydaktyczne" on the LPF website). Using the values of the linear regression coefficients to plot the trend

lines  $y = ax + b$  over the point plots, producing a family of current characteristics of the Hall sensor. Discuss the graphical result.

4. Add the uncertainty rectangles to three points and discuss the trends or their changes. Choose the points (one from the beginning, one from the middle and one from the end of the range) that diverge from the linear regression the most.
5. To one of these points, with coordinates  $U_{Hi}$  and  $I_{Si}$ , calculate an exemplary value of  $\gamma$  using the equation  $U_H = \gamma I_S B_n$ . Taking into account the accuracy of the meters, estimate the uncertainty of the Hall sensor sensitivity. Compare and discuss the role of partial uncertainties. Remember to use proper units for each of the components of the equation.
6. Calculate the final current sensitivity  $\gamma_I \equiv \gamma$ , using the slope coefficients of the trend lines ( $a = \gamma B_n$ ) and calculate the uncertainty of the parameter.
7. Calculate the free charge carrier concentration  $n$  and calculate their uncertainty. Use the expression  $n = \frac{1}{e\gamma d}$  where  $d$  is the thickness of the Hall sensor plate ( $d = 2 \mu\text{m}$ ,  $u_r(d) = 5\%$ ) and  $e$  is the elementary charge ( $e = 1.602 \times 10^{-19} \text{ C}$ )
8. Repeat the analysis for all the values of  $B_n$ .
9. Compare the obtained values of the parameters  $\gamma$  and  $n$  with literature data and determine the type of material from which the Hall sensor was made. Compare the results of calculations from point 6 and 7 to the corresponding results from the basic version of the exercise and draw conclusions about the accuracy of the methods

**Exemplary tables (to be accepted by the instructor)**

1. Basic version:  $U_H = f(\alpha)$  for  $I_S = \text{const}$

$B_n$	$u_c(B_n)$	$I_S$	$u(I_S)$	$U_H$	$u(U_H)$	$\alpha$	$u(\alpha)$	$\gamma_\alpha$	$u_c(\gamma_\alpha)$
[T]	[T]	[A]	[A]	[V]	[V]	[°]	[°]	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$
...	...	...	...	...	...	...			

2. Basic version:  $U_H = f(B_n)$  for  $I_S = \text{const}$

$B_n$	$u_c(B_n)$	$I_S$	$u(I_S)$	$U_H$	$u(U_H)$	$\alpha$	$u(\alpha)$	$\gamma_B$	$u_c(\gamma_B)$	$n$	$u_c(n)$
[T]	[T]	[A]	[A]	[V]	[V]	[°]	[°]	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$	$\left[\frac{1}{\text{m}^3}\right]$	$\left[\frac{1}{\text{m}^3}\right]$
...	...	...	...	...	...	...					

3. Extended version:  $U_H = f(I_S)$  for  $B_n = \text{const}$

$I_S$	$u(I_S)$	$\alpha$	$u_c(\alpha)$	$U_H$	$u(U_H)$	$B_n$	$u_c(B_n)$	$\gamma_I$	$u_c(\gamma_I)$	$n$	$u_c(n)$
[A]	[A]	[°]	[°]	[V]	[V]	[T]	[T]	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$	$\left[\frac{\text{V}}{\text{A}\cdot\text{T}}\right]$	$\left[\frac{1}{\text{m}^3}\right]$	$\left[\frac{1}{\text{m}^3}\right]$
...		...		...	...	...	...				