# EP11 Measurement of the Magnetic Field by Hall Effect

## OBJECTIVE

1. To understand the principle of the Hall Effect.
2. To learn to the out put character of the Hall Effect sensors.
3. To measure the magnitude of the magnetic field along the axis of a solenoid using a Hall Effect sensors.

## THEORY

In general the Hall effect refers to the fact that a voltage can develop in a direction transverse to the current flow in a system of charged particles in a magnetic field, owing to the Lorentz force q(v x B).

Consider a conducting rectangular bar of material carrying a current or stream of changed particles moving along the axis of the bar (x axis). The same current could be caused by positive carries moving one way or by negative charges moving oppositely. The bar is placed in a uniform magnetic field that is perpendicular to the direction of motion of the charged particles creating the current (the direction of the magnetic field is parallel z axis), as shown in Fig1

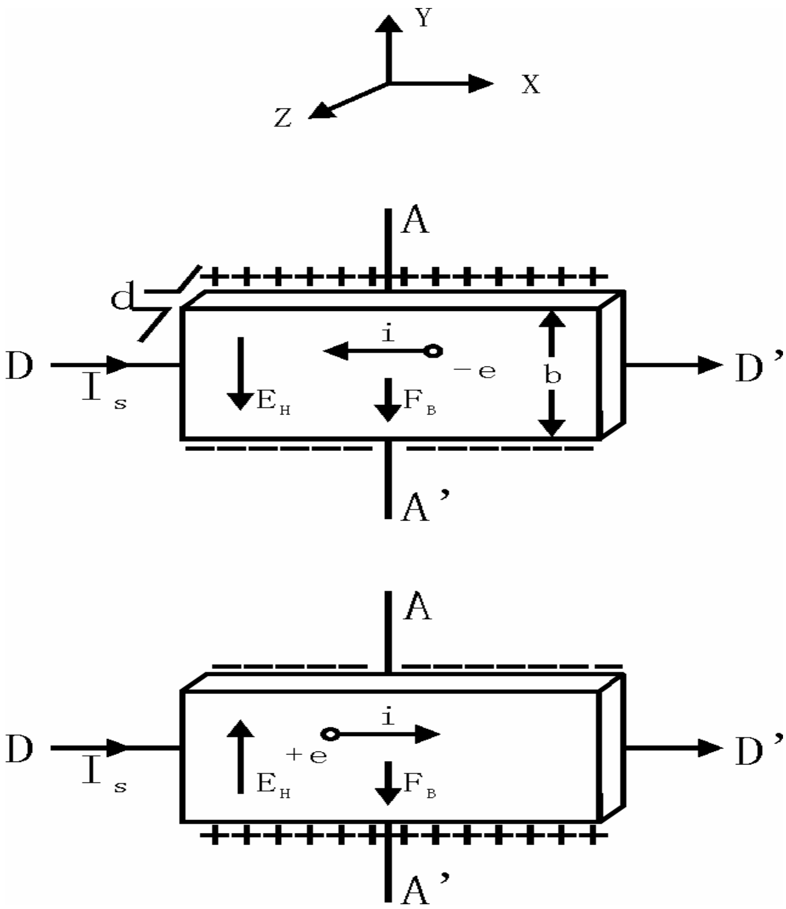


Figure1. Negative and positive charges moving in a material in a magnetic field.

Say the current in the bar arises from positive charge carriers, each with charge q(C).

They each experience a magnetic force (Lorentz force) given by following equation:

$$\vec{F}_{magnet} = q\vec{v} \times \vec{B} \qquad (1)$$

The quantity $\vec{v}$ is the average drift velocity of the charge carriers. Under the influence of the magnetic force, the positive charges move downward and accumulate near the lower edge of the material, leaving behind an equivalent amount of negative charge near the upper edge of the rectangular bar. The charge separation produces an electric field transverse to the current, that is, the direction of the electric field is parallel y axis, directed as in Fig1.

As the charge accumulates, this electric field increase in magnitude and produces an electrical force on the positive charge carriers as well:

$$\vec{F}_{electric} = q\vec{E} \qquad (2)$$

The accumulate cease when the magnitude of the opposing electrical force has the same magnitude as that of the magnetic force on each charge carrier. That is:

$$qE_H = qvB \qquad (3)$$

Where $E_H$ is the magnitude of Hall electric field; $v$ is the magnitude of the average drift velocity of the charge carriers. The direction of the electric field (toward y axis) indicates that the lower edge of the bar is a higher electric potential than the upper edge.

If the current in the bar arises from negative charge carriers the direction of the electric field is reverse.

The potential difference between the edges of the bar is $V_{A'}$-$V_A$. Let $V_{Hall}$= $V_{A'}$-$V_A$ be the Hall voltage. Thus:

$$V_{Hall} = E_H b \qquad (4)$$

where b is the separation of the edges of the bar.

Substituting equation (4) into (3), then equation (3) becomes:

$$V_{Hall} = vBb \qquad (5)$$

This can be put in a more useful form by eliminating the drift speed via its relation to the current:

$$I_s = nqvbd \qquad (6)$$

where $n$ is the number of charge carriers per unit volume and $bd$ is the cross-sectional area of the wire (here the bar). Solving Equation (6) for $v$

$$v = \frac{I_s}{nqbd}$$

Substituting for $v$ into Equation (5), we find the Hall voltage is:

$$V_{Hall} = \frac{1}{ne}\frac{I_s B}{d} = R_H \frac{I_s B}{d} \qquad (7)$$

$R_H$ is Hall coefficient. It is a very important parameter that reflects the degree of the Hall effect of a material.

Hall device is electromagnetism conversion component made using Hall effect. For finished product, $R_H$ and $d$ is known, so Hall voltage can be expressed by:

$$V_{Hall} = K_H I_s B \qquad (8)$$

where $K_H = \frac{R_H}{d}$, is called the sensibility of Hall effect. A measurement of the Hall voltage $V_{Hall}$ permits a determination of the magnitude of the magnetic field $B$:

$$B = \frac{V_H}{K_H I_s} \qquad (9)$$

There are side effects that company Hall effect when it generated, so we measure the Hall voltage $V_{Hall}$ using symmetrical measurement method that the current and the magnetic field change direction regularly to eliminate the side effects. Keep $I_s$ and $I_M$ fixedness, change the direction of the current and magnetic field, we can obtain 4 Hall voltage ($V_1$, $V_2$ , $V_3$ , $V_4$) from following groups:

| | | |
|---|---|---|
| $+I_s$ | $+B$ | $V_1$ |
| $+I_s$ | $-B$ | $V_2$ |
| $-I_s$ | $+B$ | $V_3$ |
| $-I_s$ | $-B$ | $V_4$ |

Hall voltage can be obtained from:

$$V_{Hall} = \frac{1}{4}\left(|V_1| + |V_2| + |V_3| + |V_4|\right) \qquad (10)$$

Substituting $V_{Hall}$ into (9), B can be calculated.

In this lab we will measure the magnetic field of a solenoid. A solenoid is constructed by winding wire in a helix around the surface of a cylindrical form, usually of circular cross section. The turns of the winding are ordinarily closely spaced and may consist of more layers.

If the length of the solenoid is large compared with its cross-sectional diameter, the internal field near its center is very nearly uniform and parallel to the axis, and the external field near the center is very small. Inside a long solenoid having N turns per meter of its length, each carrying current $I_M$, far from its ends:

$$B = \mu_0 N I_M \qquad (11)$$

near its end:

$$B = \frac{1}{2}\mu_0 N I_M \qquad (12)$$

where $\mu_0$ is a scalar constant. The sectional view of solenoid is shown in Fig2.

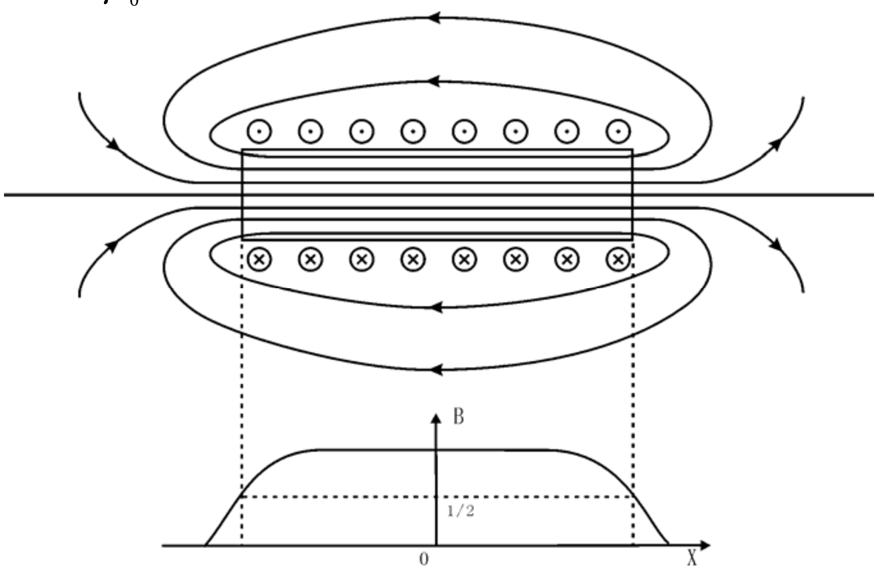


Fig2.the magnetic field in a solenoid.

**PROCEDURE**

(A) Measure the out put character of the Hall Effect device

(1) Connect the appropriate cables between the measurement device and the experimental

device as shown in Fig3

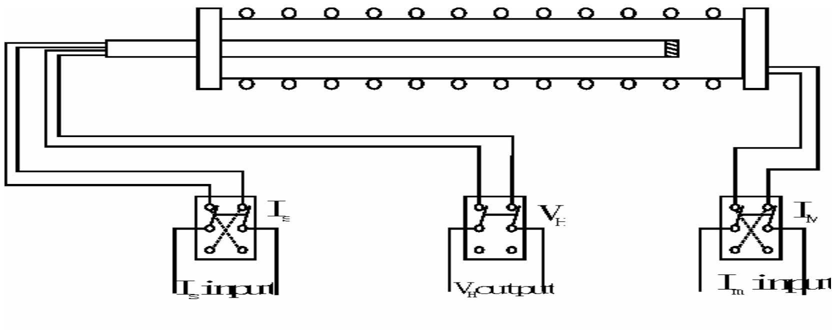


Fig3.Experimental setup

(2) Rotate the "$I_M$ adjust" and "$I_s$ adjust" knob until it is fully counterclockwise.

(3) Turn on the power of the measurement device, now, the readings on the amperemeter screen or the voltmeter screen should be "0.00" or "0.000", if not, adjust the resistor for zero.

(4) Carefully rotate the knob $X_1$ and $X_2$ attached to the probe of the Hall effect until $X_1$ =14.00cm, $X_2$ =0.00cm, here the probe of the Hall effect is in the center of the solenoid.

(5) Plot the $V_H$ - $I_s$ curve.

Keep $I_M$ =0.500A, and adjust $I_s$ =1.00mA, $I_s$ =2.00mA, $I_s$ =3.00mA, $I_s$ =4.00mA, $I_s$ =5.00mA, $I_s$ =6.00mA. Using symmetrical measurement method measure $V_1$, $V_2$ , $V_3$ , $V_4$, record them in table 1.

(6) Plot the $V_H - I_M$ curve.

Keep $I_s$ =5mA, and adjust $I_M$ =0.100A, $I_M$ =0.200A, $I_M$ =0.300A, $I_M$ =0.400A, $I_M$ =0.500A, $I_M$ =0.600A, $I_M$ =0.700A. Using symmetrical measurement method measure $V_1$, $V_2$ , $V_3$ , $V_4$, record them in table 2.

(B) Measure the magnitude of the magnetic field along the axis of a solenoid

Keep $I_M$ =0.500A and $I_s$ =5mA, adjust $X_1$ and $X_2$ as shown in table 3, Using symmetrical measurement method measure $V_1$, $V_2$ , $V_3$ , $V_4$, record them in table 3.

**CAUTION**

You must not connect the $I_M$ out put of the measurement device to the $I_s$ input of the experimental device, otherwise the Hall Effect will be destroyed; the switch of the $V_H$ output must keep shut.

**DATA RECORDING AND PROCESSING**

*Table 1 $I_M$ =0.500A*

| $I_s$ (mA) | $V_1$ (mv) | $V_2$ (mv) | $V_3$ (mv) | $V_4$ (mv) | $V_{Hall}=\frac{1}{4}(\lvert V_1\rvert+\lvert V_2\rvert+\lvert V_3\rvert+\lvert V_4\rvert)$ |
|---|---|---|---|---|---|
| | + $I_s$ +$B$ | + $I_s$ -$B$ | - $I_s$ +$B$ | - $I_s$ -$B$ | |
| 1.00 | | | | | |
| 2.00 | | | | | |
| 3.00 | | | | | |
| 4.00 | | | | | |
| 5.00 | | | | | |
| 6.00 | | | | | |

Plot the $V_H$ - $I_s$ curve

*Table 2* $\quad I_s$ *=5.00mA*

| $I_M$ (A) | $V_1$ (mv) | $V_2$ (mv) | $V_3$ (mv) | $V_4$ (mv) | $V_{Hall} = \frac{1}{4}\left(\lvert V_1\rvert + \lvert V_2\rvert + \lvert V_3\rvert + \lvert V_4\rvert\right)$ |
|---|---|---|---|---|---|
| | + $I_s$ **+B** | + $I_s$ **-B** | **-** $I_s$ **+B** | **-** $I_s$ **-B** | |
| 0.100 | | | | | |
| 0.200 | | | | | |
| 0.300 | | | | | |
| 0.400 | | | | | |
| 0.500 | | | | | |
| 0.600 | | | | | |
| 0.700 | | | | | |

Plot the $V_H$ – $I_M$ curve

*Table 3* $\quad I_M$ *=0.500A,* $I_s$ *=5.00mA*

| $X_1$ (cm) | $X_2$ (cm) | $X$ (cm) | $V_1$ (mv) | $V_2$ (mv) | $V_3$ (mv) | $V_4$ (mv) | $V_H$ (mv) | B(KGS) |
|---|---|---|---|---|---|---|---|---|
| | | | +$I_s$ **+B** | +$I_s$ **-B** | **-**$I_s$ **+B** | **-**$I_s$ **-B** | | |
| 0.00 | 0.00 | | | | | | | |
| 0.50 | 0.00 | | | | | | | |
| 1.00 | 0.00 | | | | | | | |
| 1.50 | 0.00 | | | | | | | |
| 2.00 | 0.00 | | | | | | | |
| 5.00 | 0.00 | | | | | | | |
| 8.00 | 0.00 | | | | | | | |
| 11.00 | 0.00 | | | | | | | |
| 14.00 | 0.00 | | | | | | | |
| 14.00 | 3.00 | | | | | | | |
| 14.00 | 6.00 | | | | | | | |
| 14.00 | 9.00 | | | | | | | |
| 14.00 | 12.00 | | | | | | | |
| 14.00 | 12.50 | | | | | | | |
| 14.00 | 13.00 | | | | | | | |
| 14.00 | 13.50 | | | | | | | |
| 14.00 | 14.00 | | | | | | | |

$x = 14.00 - x_1 - x_2$

Plot the B-X curve, and the magnetic field on the axis of a solenoid can be getted,

$B_m$=

We can calculate the magnitude of the magnetic field on the axis of the solenoid according to equation (11), $B = \mu_0 N I_M$ ,then compare $B_m$ and B.