Unit 8 Hall Effect

**Keywords:**
The Hall Effect, The Magnetic Field, Lorentz Force

**Objective:**
Investigate the deflection of the carriers in the conductor under the function of the magnetic field due to Lorentz force. Based on this measurement, we can know the density of the carriers and the sign of the charges in the conductor.

**Apparatus:**
n-type & p-type germanium Hall Effect wafers, microvoltmeter, magnetic assembly, the power supply (contains two outputs), the digital voltmeter, several wires
Fig. 1 The apparatus of Hall Effect experiment
**Principle:**

We know that when a charge \( q \) moves in the vacuum with the magnetic field \( \vec{B} \), the moving direction of the charge would deflect due to the deflected force originated from the magnetic field. If the velocity of the charge is \( \vec{v} \), then the deflected force originated from the magnetic field is \( q\vec{v} \times \vec{B} \), and the maximum deflected effect occurs when \( \vec{v} \) is perpendicular to \( \vec{B} \).

Based on the above comprehension, Hall (Edwin Hall 1855-1938) brought an interesting question: Would the current in the conductor deflect due to the influence of the magnetic field? What is the effect? He thought that the current would gather mostly in one side of the conductor, and then the effective area of the cross-section of the current would decrease and the resistance increases. Although this thought is good, the sensitivity of his apparatus wasn't good enough to let him measure the change of the resistance. Therefore, Hall changed his thought: Since the current deflects, there should be a stress in the lateral side. Henry Rowland, Hall's advisor, had found that there was weak potential difference in the lateral side (the y axis) of the conductor; therefore, he suggested that Hall repeated the experiment. At this time, Hall used thin gold foil to accomplish the experiment. Finally, in October, 1879, Hall measured the lateral potential difference successfully. This effect is the famous Hall Effect.

![Fig. 2 the diagram of Hall Effect (the carriers are positive charges)](image)

The diagram of Hall Effect is shown in Fig. 2. In the conductor, along the x axis is current \( I_d \), and the current is uniformly distributed. The density of the current is \( j_d = I_d/A \). \( A = wt \) is the area of the cross-section of the conductor; \( w \) is the width; \( t \) is the thickness. If there is only one kind of carriers in the conductor, the charge of the carrier is \( e \) (For convenience, we consider the condition that the carrier is with positive charge \( e > 0 \)), and then

\[
j_d = I_d/A = nev_d \tag{1}
\]
n is the density of the carriers, \( v_d \) is the drift velocity of the carriers along the \( x \) axis. Without a magnetic field, there are no accumulated carriers at the two sides of the conductor and no lateral potential difference. (For example, in Fig. 2, the potential of points O and A is the same.) When a uniformly distributed magnetic field \( \vec{B} = B\hat{z} \) is given, the carriers deflect towards \(-y\) direction due to the magnetic force; therefore, it causes the accumulated positive charges at the side of point O. At the same time, because the conductor is neutral, there are correspondingly accumulated negative charges at the side of point A. The direction of the charges which induces lateral electric field is along \(+y\) direction and the electric field would weaken the deflected tendency of the following carriers. Finally, when the attracted force towards carriers from the lateral electric field \( E_H \) increases until the attracted force is large enough to balance the magnetic force:

\[
ev_d B = eE_H \tag{2}
\]

At this moment, the potential difference of point O and point A \( V_{Hi} = E_{Hi} w = v_d B w \) doesn't change anymore. \( V_{Hi} \) is the Hall potential difference. Simplify Eq. 1, we can get the relationship between \( V_{Hi} \) and \( I_d \), that is,

\[
V_{Hi} = \frac{I_d B}{net} \tag{3}
\]

Eq. 3 represents that \( V_{Hi} \) and \( I_d \) or \( B \) is linear. We can get the density \( n \) from the slope. Besides, from the sign of \( V_{Hi} \) we can get the sign of the carriers. What is worth emphasizing is that the relationship between \( V_{Hi} \) and the thickness \( t \) is an inverse ratio. Therefore, the key point of his successive experiment is that he utilized the thin gold foil. In ideal condition, if we want to measure \( V_{Hi} \), we should connect the microvoltmeter with point O and A in Fig. 2. Before the measurement, if we find that \( I_d \) isn't zero when \( B \) is zero, (Of course, before connecting the microvoltmeter with wires, we should complete zero process.) we should have a fine tuning design to solve the nonideal condition, so that the correctness of the experiment wouldn't be disturbed.

**Q1: What is possible reason that the nonideal condition occurs?**

The fine tuning design in the experiment is the fine tuning voltage divider (Fig. 3). In the procedure of regulation, we can make the microvoltmeter reading to be zero by adjusting the fine tuning voltage divider.

**Q2: Can you figure out the principle of the fine tuning voltage divider?**
**Instructions:**

1. **Set range:** Before connecting any wires, set the operation range of the apparatuses.
   
   The microvoltmeter is around 30mV; the current sent to n-type & p-type germanium Hall effect wafers is around 1~50mA, and the magnetic field is around 1k~4kG.

2. **Zero process:** Before connecting any wires, begin the zeroing process for the microvoltmeter.

3. **Connect wires:** Connect the wires with the n-type germanium Hall effect wafer (Fig. 1), and notice that don’t turn on the power at first. Because there is current output from the power supply and difference between the current outputs is very large, therefore, we must check the circuit again and again. Make sure there is no fault before we turn on the power.

1. **Measurement:**

   A. Record the current $I_d$ of the sample. Make sure the magnetic field is zero at this moment.

   B. Check if the microvoltmeter reading is zero or not. If it is not zero, adjust the fine tuning voltage divider so that the microvoltmeter reading is zero.

   C. Vary the intensity of the magnetic field by adjusting the distance between two magnets. (Make sure that the wafer is set between two magnets.) Measure the magnetic field by the Tesla Meter and record it. (The manual of the Tesla Meter is in the appendix of Unit 3-Current Balance.)
D. Record the Hall potential difference $V_H$ and the sign of carriers.
E. Fix the current $I_d$ of the sample, vary the magnetic field 5 times (1kG~4kG) and record the Hall potential difference $V_H$ respectively.
F. Keep the magnetic field $B$ fixed, vary the current $I_d$ 5 times and record the Hall potential difference $V_H$ respectively.
G. Plot the figure of $B$ versus $V_H$ and calculate the density $n$ of carriers.

2. Utilize p-type germanium Hall effect wafers:
   Utilize p-type germanium Hall Effect wafers and repeat step 3~4.

Q3: What is the application of the Hall Effect?
Q4: Why did Hall utilize the thin gold foil to do the experiment? However, the sample we utilize in this experiment isn't necessarily thin?
Q5: Based on your experimental result, what is difference between n-type & p-type germanium Hall effect wafers?
Q6: What do the red and black inks on the samples represent? n-type or p-type germanium Hall Effect wafers? Explain how you can make the conclusion.

**Remark:**

1. The current flowing in the sample can't exceed 50mA.
2. Be careful to utilize the n-type & p-type germanium Hall effect wafers and avoid impact.
3. Conversion of the magnetic field: 1 Gauss = 10$^{-4}$ T
4. The density of the carriers for intrinsic germanium is around $2.4 \times 10^{-13} / \text{cm}^3$.
5. The probe of the Tesla Meter is easily broken and is very expensive. Please be careful to use it. If it is broken, you should pay for it.