Lab Report for Physics

The Measurement of Magnetic Field using Hall Effect

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Catalogue

1. Introduction

According to the Hall effect, when charged particles are affected by the magnetic field, it would be fixed on one side of the semiconductor slices, as it is shown in Figure1. With more particles passing, there is a balance between Coulomb force and Lorentz force. It can be calculated with the expression:

$$q(v \times B) = qE \ldots\ldots\ldots\ldots\ldots\text{(1)}$$

In this function (1), E is the Electric field strength, v is the velocity of carrier, q is carrier charge but this expression is independent on q.
The semiconductor's width is set of ω, the thickness is d and the carrier density is p . Consider the current formula and the voltage of parallel-plate capacitor formula can calculate the expression:

$$I_H = pqvwd \ldots\ldots\ldots\ldots\ldots\ldots\text{(2)}$$

$$U_H = E\omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(3)}$$

In the function (2) and (3), I_H is current into the semiconductor and it is the reason for carrier movement. U_H is the voltage in the capacitor. According to (1) (2) and (3), the expression are shown hereinafter:

$$U_H = K_H I_H B \ldots\ldots\ldots\ldots\ldots\ldots\text{(4)}$$

$$K_H = \frac{R_H}{d} = \frac{1}{pqd} \ldots\ldots\ldots\ldots\ldots\text{(5)}$$

For the function (4), K_H is called Hall sensitivity, and it is decided by the carrier density and the thickness. As a consequence, different devices have different Hall sensitivities.

The purposes of this report cover the problems of Hall effect working and measuring the magnetic field B by changing the excitation currents as well as discovering the relationship between U_H and I_H. In addition, measuring whether the magnetic field strength B is evenly distributed.

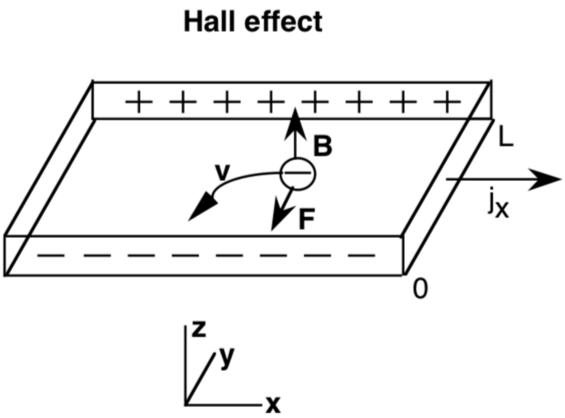


Figure1—Hall Sensor [1]

2.Experiment Setup and Procedure

Apparatus consist of excitation current display, hall voltage display, hall current display, excitation current reversing switch, hall sensor position adjustment, hall current reversing switch, hall sensor and solenoid.

This experiment was conducted on April $24th$, 2018, from 4pm to 6pm.

There were four main steps to conduct this experiment and to measure the data.

2.1 Preparation

Firstly, the wires were connected correctly. Secondly, Hall sensor position adjustment were moved to zero graduation line. Thirdly, the equipment were switched on after being connected to power supplies. Finally, checked the K_H which is $181.1 mV/mA * T$ on the device.

2.2 Measure hall voltage versus hall current

The excitation current I_M was set as 400 mA. Then the Hall current I_H was adjusted from 1 mA to 8 mA with interval 1 mA. The two switches were adjusted from up to down to change the direction of the magnitude. The corresponding Hall voltages were measured and recorded. After changing the position of the Hall strip along the axis of the solenoid to be 10mm,20mm, repeating preceding steps respectively.

2.3 Measure hall voltage versus magnetic field

The hall current I_H was set as 5.00 mA. Then the excitation current I_M was adjusted from 0.05A to 1A. The corresponding Hall voltage U_H were measured and recorded.

3.Results and Discussion

3.1 The relationship between V_H and I_H

The data which the hall strip along axis direction with the distance 0 mm for the V_H and I_H has shown in the Table 1. Table 1 has four parts of voltage, which are respectively positive or negative direction magnetic flux and current I_H. The reason why measuring the positive and negative parts is that decreasing experimental errors. There are four possible influences because of other effects, which are Ettingshausen effect V_E, Nernst effect V_N, Righi-Leduc effect V_R and unequal potential difference V_0[2][3][4].

In order to reduce errors, measuring the positive and negative parts is a good approach to improve the accuracy. The equation can be calculated with the flowing expression:

$$+B \quad +I \quad V_1 = +V_H + V_E + V_N + V_R + V_0 \ldots\ldots\ldots\ldots (6)$$

$$+B \quad -I \quad V_2 = -V_H - V_E + V_N + V_R - V_0 \ldots\ldots\ldots\ldots (7)$$

$$-B \quad -I \quad V_3 = +V_H + V_E - V_N - V_R - V_0 \ldots\ldots\ldots\ldots (8)$$

$$-B \quad +I \quad V_4 = -V_H - V_E - V_N - V_R + V_0 \ldots\ldots\ldots\ldots (9)$$

Then calculate (6) − (7) + (8) − (9), the result can be described the expression (10):

$$V_H = \frac{(V_2 + V_3 - V_1 - V_4)}{4} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

I_H (mA)	V_1 $+B$ $+I_H$	V_2 $-B$ $+I_H$	V_3 $-B$ $-I_H$	V_4 $-B$ $-I_H$	$V_H = \frac{(V_2 + V_3 - V_1 - V_4)}{4}$ (mV)	**B** **(T)**
1.00	32.5	-32.6	-32.8	32.5	-32.675	-0.18042517
2.00	65.6	-65.2	-65.7	65.2	-65.45	-0.18070127
3.00	98.5	-97.7	-98.5	97.7	-98.1	-0.18056322
4.00	131.1	-130.0	-131.1	130.1	-130.575	-0.18025262
5.00	163.7	-162.4	-163.7	162.4	-163.05	-0.18006626
6.00	196.2	-194.5	-196.1	194.6	-195.35	-0.17978096
7.00	228.9	-227.1	-228.8	227.2	-228	-0.17985327
8.00	261.3	-259.2	-261.1	259.3	-260.225	-0.17961416

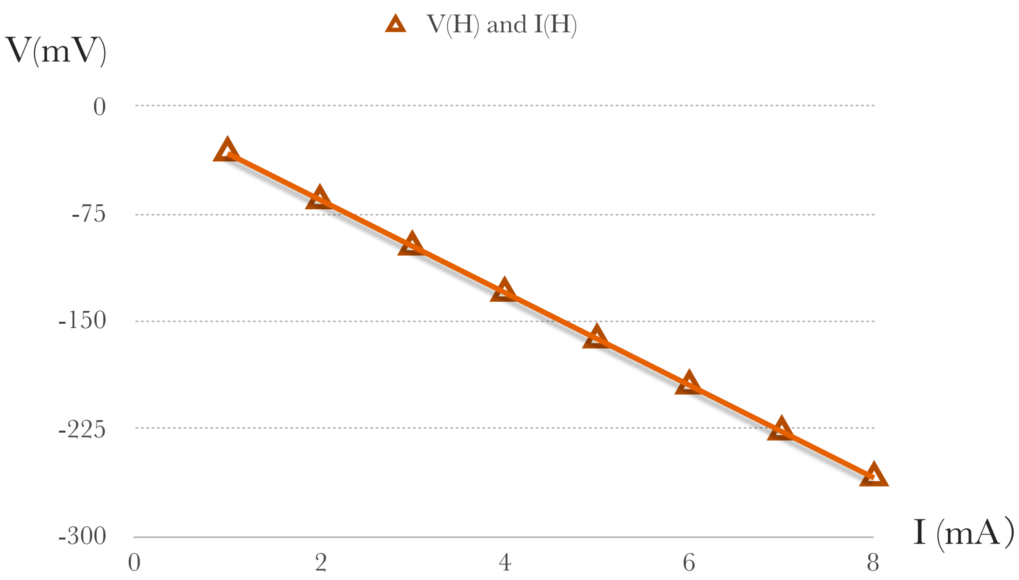
Table1 — The relationship between V_H and I_H ($I_M = 400mA$ distance:0mm)

By using this way, the relationship between V_H and I_H can be described by the Graph 1. The meaning of the Graph 1 is with the I_H increasing and the V_H is decreasing. After the fitting function, the relationship between V_H and I_H is Linear function. The function (4) also proves the result is right.

The Table 2 and Table 3 show that the relationship between V_H and I_H is linear function, the graphs have shown in Graph 2 and Graph 3.

I_H (mA)	V_1 $+B$ $+I_H$	V_2 $-B$ $+I_H$	V_3 $-B$ $-I_H$	V_4 $-B$ $-I_H$	$V_H = \frac{(V_2+V_3-V_1-V_4)}{4}$ (mV)	**B (T)**
1.00	32.5	-32.2	-32.5	32.1	-32.325	-0.178492545
2.00	65.6	-65.0	-65.6	65.0	-65.2	-0.180011043
3.00	98.4	-97.5	-98.5	97.5	-97.975	-0.180333149
4.00	130.8	-129.6	-130.8	129.6	-130.2	-0.179734953
5.00	163.6	-162.0	-163.6	162.1	-162.825	-0.179817780
6.00	195.9	-194.0	-195.8	194.1	-194.95	-0.179412847
7.00	228.0	-226.0	-228.0	226.1	-227.025	-0.179084168
8.00	260.3	-257.8	-260.2	258.0	-259.075	-0.178820403

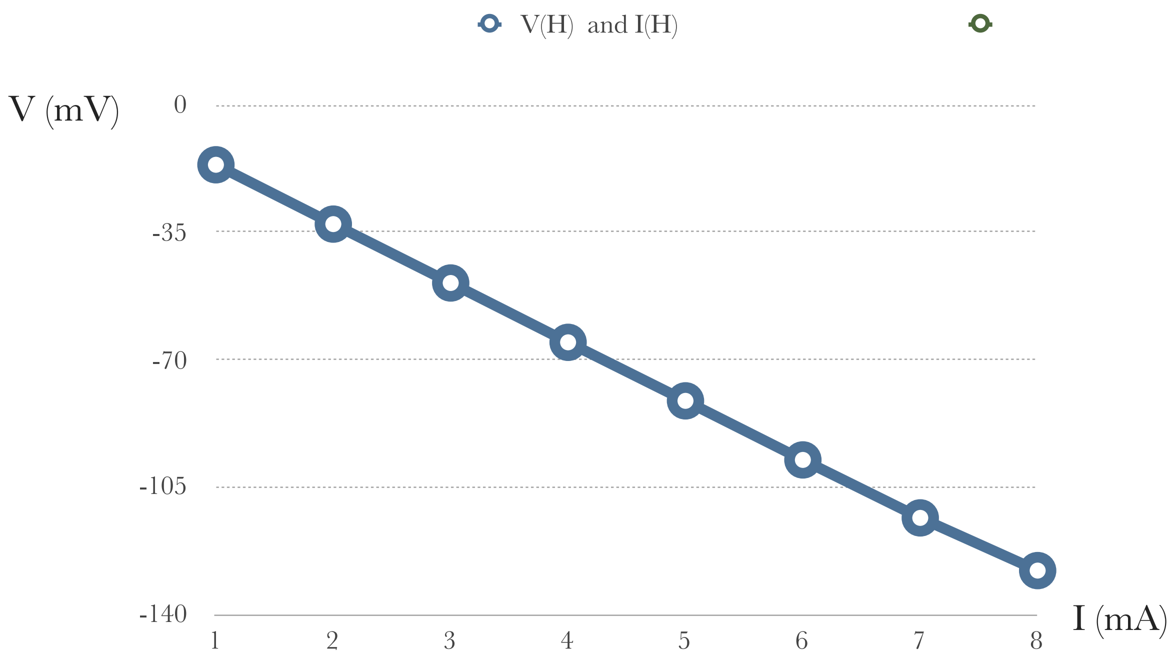
Table2—The relation between V_H and I_H (I_M=400mA,distance:10mm)



Graph2— The relation between V_H and I_H (I_M=400mA,distance:10mm)

I_H (mA)	V_1 $+B$ $+I_H$	V_2 $-B$ $+I_H$	V_3 $-B$ $-I_H$	V_4 $-B$ $-I_H$	$V_H = \frac{(V_2+V_3-V_1-V_4)}{4}$ (mV)	**B (T)**
1.00	16.5	-16.2	-16.5	16.2	-16.35	-0.090281612
2.00	33	-32.3	-33	32.4	-32.675	-0.090212589
3.00	49.3	-48.4	-49.4	48.4	-48.875	-0.089959506
4.00	65.8	-64.6	-65.8	64.6	-65.2	-0.090005521
5.00	82.1	-80.5	-82.0	80.6	-81.3	-0.089784649
6.00	98.5	-96.6	98.4	96.7	-97.55	-0.089775446
7.00	114.6	-112.6	-114.2	112.6	-113.5	-0.089532223
8.00	130.8	-128.5	-128.5	126.5	-128.6	-0.088763114

Table3—The relation between V_H and I_H (I_M=400mA,distance:20mm)



Graph3—The relation between V_H and I_H (I_M=400mA,distance:20mm)

3.2 Uneven magnetic field distribution

By calculating the magnetic field, the results are various in different distance *X*. The reason why various *X* lead to different B is that the magnetic field created by excitation current is not uniform, as is shown in Figure 2. If capacitor moved, magnetic field lines change both in size and direction, so the value of magnetic field changed in the experiment. Because of the function (1) and (3), the V_H changed because of the magnetic field B changed.

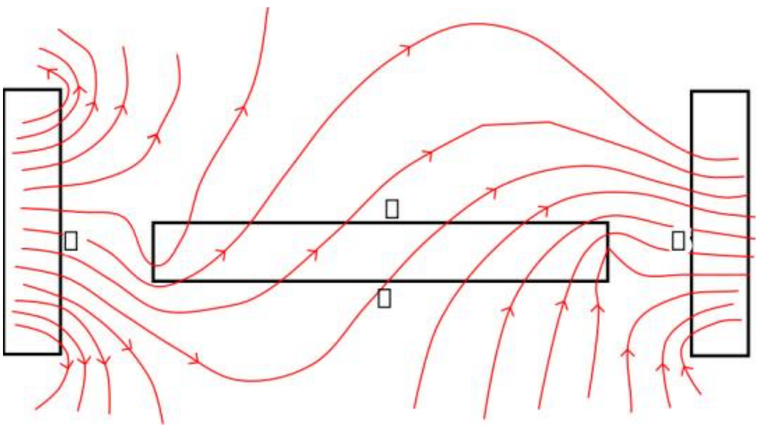
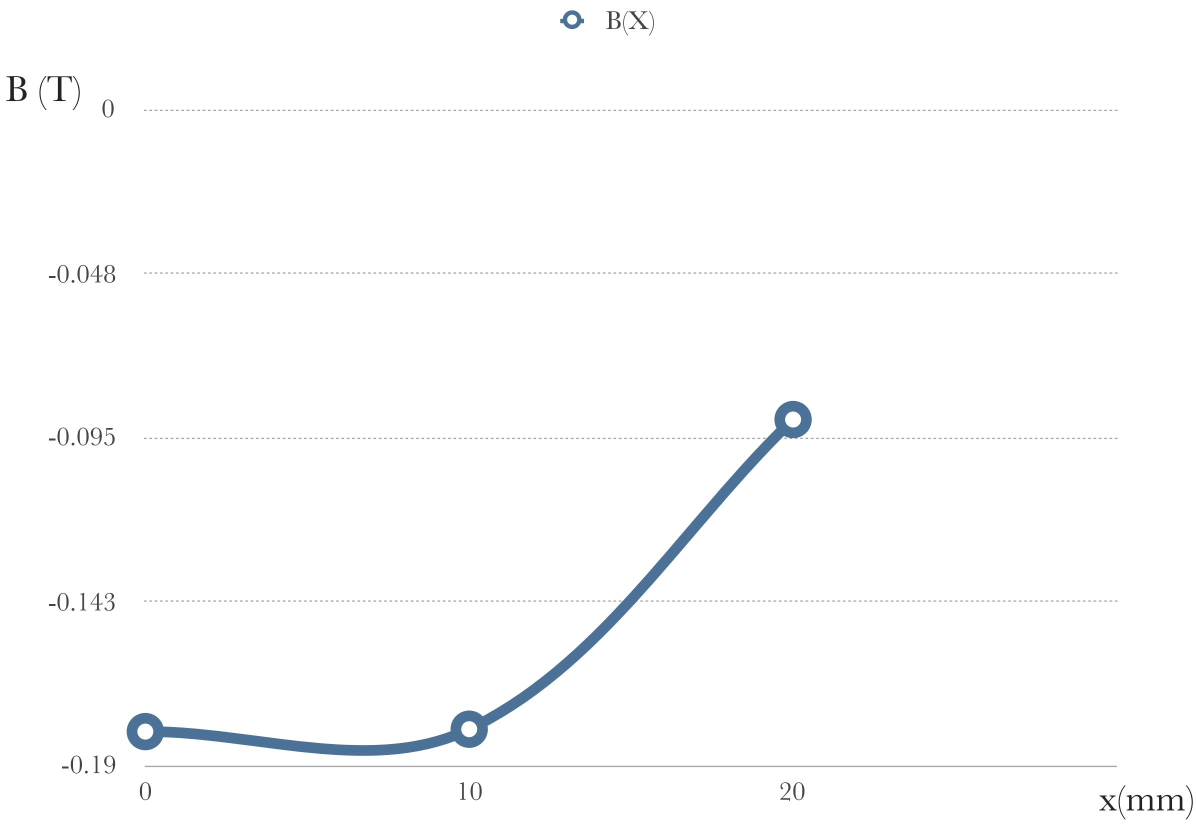


Figure2—Magnetic field line

As Table5 and Graph 4 show, with the increasing of x, B is decreasing slowly when x is from 0 mm to 10 mm and decreasing rapidly from10mm to

20mm. With the increasing of x, the density of the magnitude is decreasing rapidly, which leads to the tangent of the graph is larger.



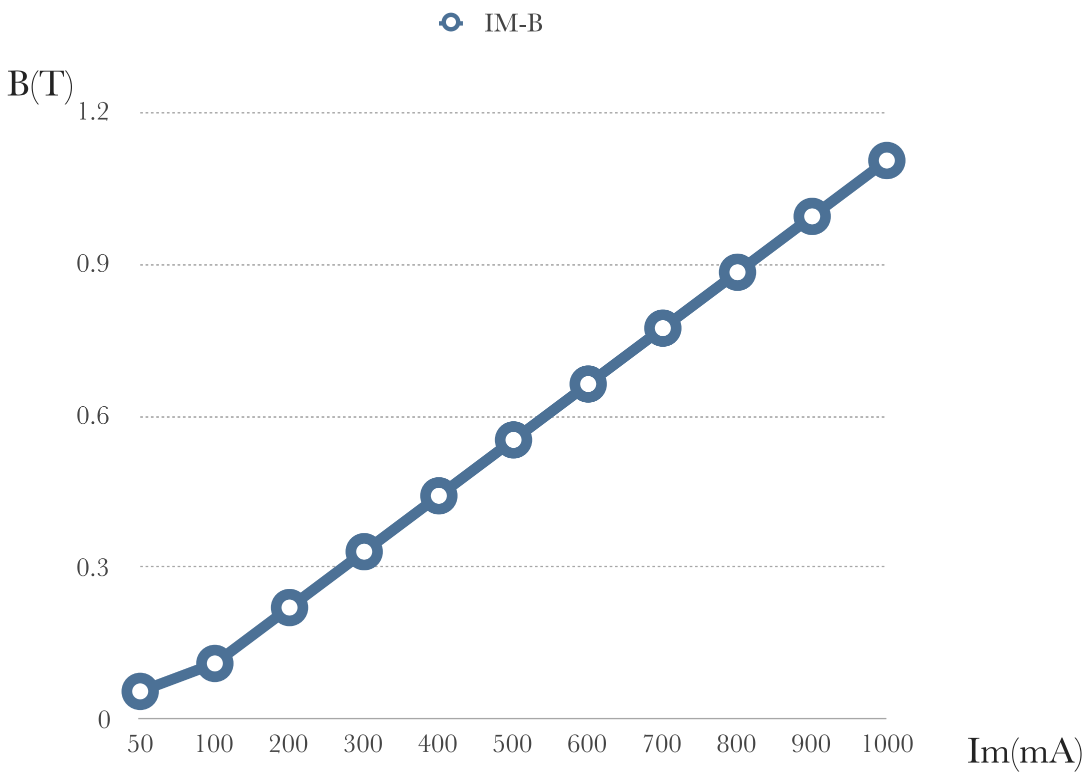
Graph4—The relationship between *x* and ***B***

Distance x	B
0mm	-0.180157120999974
10mm	-0.179463361303936
20mm	-0.089789333044096

Table5—the relationship between *x* and ***B***

3.3 The relationship between B and I_M

As Table6 and Graph6 shows, as I_M is increasing , B is increasing in proportion. The result of I_M and B is a linear function.



Graph6 —The relation between I_M and B (I_H=5.00mA,distance:0mm)

I_M(mA)	V_1 $+B$ $+I_H$	V_2 $-B$ $+I_H$	V_3 $-B$ $-I_H$	V_4 $-B$ $-I_H$	$V_H = \frac{(V_2 + V_3 - V_1 - V_4)}{4}$ (mV)	**B** **(T)**
50	21.8	-20.4	-21.8	20.5	-21.125	552181115405
100	42.5	-40.8	-42.2	40.9	-41.6	104362230811
200	83.0	-81.2	-82.7	81.4	-82.075	208724461623
300	123.7	-121.7	-123.1	121.7	-122.55	313086692435
400	163.9	-162.2	-163.7	162.2	-163.00	417448923246
500	204.8	-202.7	-204.2	202.8	-203.625	521811154058
600	244.8	-242.5	-244.0	242.6	-243.475	626173384870
700	284.0	-281.7	-283.2	281.7	-282.65	730535615681
800	322.3	-319.4	-321.0	319.5	-320.55	834897846493
900	358.7	-355.8	-357.2	355.8	-356.875	939260077305
1000	392.3	-390.8	-392.3	390.9	-391.575	104362230811

Table4—The relation between V_H and B (I_H=5.00mA,distance:0mm)

$I_M(mA)$	$B(T)$
50	0.0552181115405853
100	0.110436223081171
200	0.220872446162341
300	0.331308669243512
400	0.441744892324683
500	0.552181115405853
600	0.662617338487024
700	0.773053561568194
800	0.883489784649365
900	0.993926007730536
1000	1.10436223081171

Table6—the relationship between I_M and B

3.4 Evaluation of errors and methods of improvement

The errors of this experiment are V_E, V_N, V_R and unequal potential difference V_0. The reasons of the errors are numerical readings are not precise and the temperature which is increasing constantly in the period of this experiment will influence V_E, V_N and V_R .

In order to eliminate the influence of above effects, there are two methods to reduce the errors. The first one is reading the number until it reaches stability. The second one is adding water which is through the equipment to decrease the temperature.

4.Conclusions

According to values given in Table1, Table2 and Table3 and the formula B=$V_H/(K_H*I_H)$, after calculating the results of B, the relationship between B and the distance x can be solved, which is shown in Table5 and Graph6. Making I_H be constant, the relationship between I_M and B is shown in Table, which can be approximately expressed as the positive proportional function. The limitations of this project is that the equipment cannot overcome the disadvantage of heat radiation, which will influence V_E, V_N and V_R. The further changes of this experiment is that carrying out a number of tests to reduce errors and adding the flowing water to decrease the temperature.

5.Reference

[1] J. Hirsch, "Spin hall effect," Physical Review Letters, vol. 83, no. 9, p. 1834, 1999.
[2] B. O'Brien and C. Wallace, "Ettingshausen effect and thermomagnetic cooling," Journal of Applied Physics, vol. 29, no. 7, pp. 1010-1012, 1958.
[3] Y. Wang, L. Li, and N. Ong, "Nernst effect in high-T c superconductors," Physical Review B, vol. 73, no. 2, p. 024510, 2006.
[4] E. Sichel and B. Serin, "Righi-Leduc effect in the mixed state of a type-II superconductor," Journal of Low Temperature Physics, vol. 3, no. 6, pp. 635-638, 1970.

6.Appendix

西交利物浦大學
Xi'an Jiaotong-Liverpool University

Name: [illegible] ID: 178128 Partner: 李欣歆 Group: B3 Bench: 2 Date: 4.24

7 实验数据分析 Data Analysis

Study the relationship between U_H and I_H. Measure the magnitude and distribution of magnetic field B.

1. Set $I_M = 400mA$, move the hall strip center in the solenoid interspaces.

I_H (mA)	V_1 +B,+I_H	V_2 -B,+I_H	V_3 +B,-I_H	V_4 -B,-I_H	$V_H=(V_2+V_3-V_1-V_4)/4$ (mV)
1.00	32.8	-32.6	-32.8	32.5	-32.675
2.00	65.7	-65.2	-65.7	65.2	-65.45
3.00	98.5	-97.7	-98.5	97.7	-98.1
4.00	131.1	-130.0	-131.1	130.1	-130.575
5.00	163.7	-162.4	-163.7	162.4	-163.05
6.00	196.2	-194.5	-196.1	194.6	-195.35
7.00	228.9	-227.1	-228.8	227.2	-228
8.00	261.2	-257.2	-261.1	259.3	-260.225
9.00					
10.00					

4.7

2. Set $I_M = 400mA$, move the hall strip along x direction with the distance 10mm.

I_H (mA)	V_1 +B,+I_H	V_2 -B,+I_H	V_3 +B,-I_H	V_4 -B,-I_H	$V_H=(V_2+V_3-V_1-V_4)/4$ (mV)
1.00	32.5	-32.2	-32.5	22.1	-32.325
2.00	65.6	-65.0	-65.6	65.0	-65.3
3.00	98.4	-97.5	-98.5	97.5	-97.975
4.00	130.8	-129.6	-130.8	129.6	-130.2
5.00	163.6	-162.0	-163.6	162.1	-162.825
6.00	195.9	-194.0	-195.8	194.1	-194.95
7.00	228.0	-226.0	-228.0	226.1	-227.025
8.00	260.3	-257.8	-260.3	258.0	-259.075
9.00					
10.00					

3. Set $I_M = 400mA$, move the hall strip along x direction with the distance 20mm.

I_H (mA)	V_1 +B,+I_H	V_2 -B,+I_H	V_3 +B,-I_H	V_4 -B,-I_H	$V_H=(V_2+V_3-V_1-V_4)/4$ (mV)
1.00	16.5	-16.2	-16.5	16.2	-16.35
2.00	33	-32.3	-33	32.4	-32.675
3.00	49.3	-48.4	-49.4	48.4	-48.875
4.00	65.8	-64.6	-65.8	64.6	-65.2

5.00	82.7	-80.5	-82.0	80.6	-81.3
6:00	98.5	-96.6	-98.x	96.7	-97.55
7.00	114.6	-112.6	-116.2	112.6	-113.5
8.00	130.8	-128.5	-128.5	126.5	-128.0
9.00					
10.00					

Study the relationship between U_H and I_M.

Set $I_H = 5.00mA$, adjust the excitation current I_M from 0.05A to 1A.

I_M(mA)	V_1 +B,+I_H	V_2 -B,+I_H	V_3 +B,-I_H	V_4 -B,-I_H	$V_H=(V_2+V_3-V_1-V_4)/4$ (mV)
50	21.8	-20.4	-21.8	20.5	-21.125
100	42.5	-40.8	-42.2	40.9	-41.6
200	83.0	-81.2	-82.7	81.4	-82.075
300	123.7	-121.7	-123.1	121.7	-122.55
400	163.9	-162.2	-163.7	162.2	-163.00
500	204.8	-202.7	-204.2	202.8	-203.625
600	244.8	-242.5	-244.0	242.6	- ~~[illegible]~~ 243.475
700	284.0	-281.7	-283.2	281.7	-282.65
800	322.3	-319.4	-321.0	319.5	-320.55
900	358.7	-355.8	-357.2	355.8	-356.875
1000	392.3	-390.8	-392.3	390.9	-391.575

8 思考题 Questions

1. **What is Hall Effect?**

2. **What are n-type and p-type semiconductors?**

3. **What is the effect of temperature on Hall coefficient of a lightly doped semiconductor?**

4. **Why the Hall voltage should be measured for both the directions of current as well as of magnetic field?**