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PHYS307 Applied Modern Physics

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Exp. MP-HE The Hall Effect

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Sample Current - I_p (mA)	Hall Voltage - U_H (mV)
-30	-39.6
-25	-32.1
-20	-23.7
-15	-15.2
-10	-8.3
-5	0.7
0	7.7
5	15.7
10	24.8
15	32.4
20	39.7
25	48
30	55.6

Table 1: Hall Voltage as a function of Sample Current

Slope m=1.6 mV/mA

•The charge carrier concentration from (U_H versus I_p) $=8.1 \times 10^{20}$ m^{-3}
•Type of Germanium semiconductor used = *p-type*

Flux Denstiy - B (mT)	Hall Voltage - U_H (mV)	Sample Voltage - U_p (mV)
0	-1.3	1.80
15	2.5	1.80
30	6.0	1.80
45	10.2	1.81
60	13.4	1.81
75	17.0	1.81
90	20.6	1.81
105	24.3	1.81
120	27.4	1.81
135	30.6	1.81
150	34.7	1.82
165	37.9	1.82
180	41.5	1.83
195	44.3	1.83
210	48.0	1.83
225	50.7	1.83
240	54.0	1.84
255	57.3	1.84
270	60.3	1.84
285	63.4	1.85
300	66.1	1.85

Table 2: Hall Voltage and the Sample Voltage as a function of Flux Density

Slope m=0.2 mV/mT

	x	y	$(x-\bar{x})$	$(x-\bar{x})^2$	x^2	y^2	$\hat{y}$	xy	$(y-\hat{y})$	$(y-\hat{y})^2$
	0	-1,3	-150	22500	0	1,69	0	0	-1,3	1,69
	15	2,5	-135	18225	225	6,25	3,3	37,5	-0,8	0,64
	30	6	-120	14400	900	36	6,6	180	-0,6	0,36
	45	10,2	-105	11025	2025	104,04	9,9	459	0,3	0,09
	60	13,4	-90	8100	3600	179,56	13,2	804	0,2	0,04
	75	17	-75	5625	5625	289	16,5	1275	0,5	0,25
	90	20,6	-60	3600	8100	424,36	19,8	1854	0,8	0,64
	105	24,3	-45	2025	11025	590,49	23,2	2551,5	1,1	1,21
	120	27,4	-30	900	14400	750,76	26,5	3288	0,9	0,81
	135	30,6	-15	225	18225	936,36	29,8	4131	0,8	0,64
	150	34,7	0	0	22500	1204,1	33,1	5205	1,6	2,56
	165	37,9	15	225	27225	1436,4	36,4	6253,5	1,5	2,25
	180	41,5	30	900	32400	1722,3	39,7	7470	1,8	3,24
	195	44,3	45	2025	38025	1962,5	43,1	8638,5	1,2	1,44
	210	48	60	3600	44100	2304	46,4	10080	1,6	2,56
	225	50,7	75	5625	50625	2570,5	49,7	11408	1	1
	240	54	90	8100	57600	2916	53	12960	1	1
	255	57,3	105	11025	65025	3283,3	56,3	14612	1	1
	270	60,3	120	14400	72900	3636,1	59,6	16281	0,7	0,49
	285	63,4	135	18225	81225	4019,6	63	18069	0,4	0,16
	300	66,1	150	22500	90000	4369,2	66,3	19830	-0,2	0,04
Σ	3150	708,9	0	173250	645750	32742	695,4	145386	13,5	22,11

Figure 1: Terms calculate the slope and error in the slope of Hall Voltage versus Field Strength ($x = B$, $y = U_H$)

Sum of some important values:
$\sum x = 3150$
$\sum y = 708.9$
$\sum x^2 = 645750$
$\sum y^2 = 32742$
$\sum xy = 145386$
$\sum (y - \hat{y})^2 = 22.11$
$\sum (x - \bar{x})^2 = 173250$

e. Find slope by the use of following formula

$$m = \frac{145386 - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{1}$$

$$m = \frac{\sum xy - \frac{3150 \times 708.9}{21}}{645750 - \frac{(3150)^2}{21}} \tag{2}$$

$$m = \frac{39051}{173250} \tag{3}$$

$$\boxed{\text{m=0.225}}$$

Then find the charge carrier concentration n by the use of following formula

$$n = \frac{I}{mqd} \tag{4}$$

where I=0.03 A, d=0.001 m and q=1.602×10^{-19}

$$n = \frac{0.03}{0.001 \cdot 1.602 \times 10^{-19} \cdot 0.225} \tag{5}$$

$$\boxed{n = 8.32 \times 10^{20}}$$

f. Find Δm (standard error in the original slope) by the use of following formula

$$\Delta m = \sqrt{\frac{\frac{1}{n-2} \sum (y - \hat{y})^2}{\sum (x - \bar{x})^2}} \tag{6}$$

$$\Delta m = \sqrt{\frac{\frac{1}{19} 22.11}{173250}} \tag{7}$$

$$\boxed{\Delta m = 0.00259}$$

The standard error in carrier concentration is

$$\Delta n = \frac{n^2}{K} \times \Delta m \tag{8}$$

where $K = \frac{I}{qd}$ which is equal to 1.87×10^{20} in this case

$$\Delta n = \frac{(8.32 \times 10^{20})^2}{1.87 \times 10^{20}} \times 0.00259 \tag{9}$$

$$\boxed{\Delta n = 9.58 \times 10^{18}}$$

So,

$$\boxed{\mathrm{n} = 8.32 \times 10^{20} \pm 9.58 \times 10^{18}\ \mathrm{m}^{-3}}$$

1. Explain how did you find out the type of semiconductor.

As we can see in Table 1, slope is positive (m=1.6). Since slope is positive, we can say that this is a p-type semiconductor.

2. a) A piece of semiconductor with the Hall coefficient 6.3×10^{-4} m^{3}C^{-1} is used to make a Hall probe. A current of 2.0 mA is passed along the 10 mm length of the probe. The width of the face to be placed perpendicular to the uniform magnetic field measures 5 mm and the thickness is 1 mm. Estimate the Hall potential difference which would be obtained when B is 0.3 T.

As we know, Hall coefficient R_H is equal to $\frac{1}{nq}$. Hall potential V_H

$$V_H = \frac{1}{nq}\frac{IB}{d} \tag{10}$$

Therefore Hall potential V_H will be

$$V_H = 6.3 \times 10^{-4}\frac{0.3 \cdot 2.0 \times 10^{-3}}{1.0 \times 10^{-3}} \tag{11}$$

$$\boxed{V_H = 3.78 \times 10^{-4}\ \mathrm{V}}$$

b) Find the speed of the charge carriers in the semiconductor given above.

$$v = \frac{1}{nq}\frac{I}{A} \tag{12}$$

where A is cross-sectional area of semiconductor

$$v = 6.3 \times 10^{-4}\frac{2.0 \times 10^{-3}}{5 \times 10^{-5}} \tag{13}$$

$$\boxed{v = 0.0252\ \mathrm{m/s}}$$

3. Explain how and why does the sample voltage change with magnetic field strength ($U_P - B$).

The resistance of the sample increases with the increase of magnetic. Ohm's Law stated the relation between resistance and voltage clearly as

$$V = IR \tag{14}$$

Since resistance R increase, voltage V also increases. This phenomenon is known as magnetoresistance which is due to the fact that the drift velocity of all carriers is not the same.

4. Explain how and why does the Hall voltage change with magnetic field strength ($V_H - B$).

The Hall Voltage is a linear function of the applied magnetic field. This relation can be expressed mathematically as

$$V_H = -wvB \tag{15}$$

where B is the magnetic field strength. When a magnetic field is applied to across the semiconductor or any material which is perpendicular to the current path, Lorentz forces cause a slight shift in the current path because they do in traditional Hall effect. This is causes a voltage differential. As we mentioned above, Hall voltage is proportional to the magnetic field and also related with the drift velocity. In a known magnetic field, drift velocity can be calculated by using Hall voltage.

Discussion and Conclusion

In this experiment we carried out a crucial topic in physics which is Hall Effect. Hall effect is widely using in some like Solid State Physics. When we put a conductor in a magnetic field then a voltage difference can be observed across the conductor. By using Hall Effect, today, we can detect the type of a semiconductor wheter is a p-type or n-type. While talking about Hall effect, we should explain the Hall Coefficient R_H which is equal to $1/nq$. In this experiment we used a Germanium semiconductor which is the intrinsic semiconductor. We applied different voltage and current to our semiconductor and we observed that each one can effect the magnetic field stregth. Obviously, changing in magnetic field stregth also effect voltage and current. There is one issue that we did not studied in the experiment that is the behaviour of voltage and current in different temperature. As we state in Table 2, slope is 0.2 mV/mT. After calculations whose are stated in Figure 1 we can see that slope m is equal to 0.225 mV/mT. In Figure 3 and 4 we stated theoretical and experimental values for Hall Voltage. Since there is a small difference between them we can calculate a percentage error as follows

$$PercentageError = \frac{|0.22 - 0.23|}{0.22} \times 100\% = 4.5\% \tag{16}$$

To sum up, we can say that this experiment was successful and data that we took in experiment is acceptable.

Plots

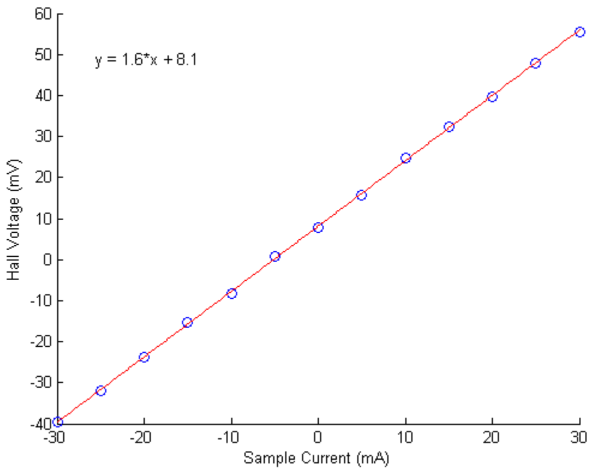

Figure 2: Hall Voltage versus Sample Current

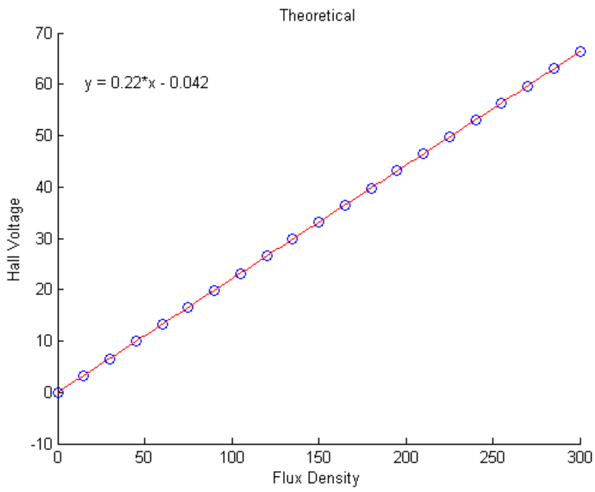

Figure 3: Hall Voltage versus Flux Density Theoretical Value

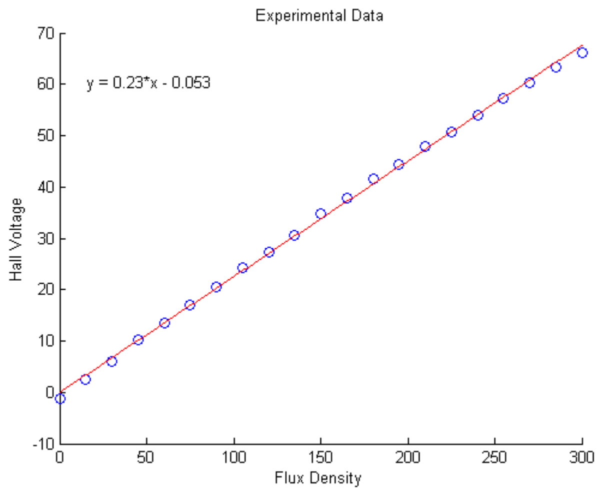

Figure 4: Hall Voltage versus Flux Density Experimental Value