Experimental Physics Lab
Wave Guides

CNNAUA001

November 2020

Introduction and Theory

The Hall Effect has been observed in many materials since its discovery in 1879. Once studied the Hall effect brought great clarity on how electrons flow in a current, whether it be through solids liquids or gases. A semiconductor is used in this practical to show the effects of this.

Aim

The aim of this report is to obtain the properties of this specific type of germanium, in terms of the Hall coefficient R_H, the conductivity σ, the number density of charges n and the mobility of charges μ.

Apparatus

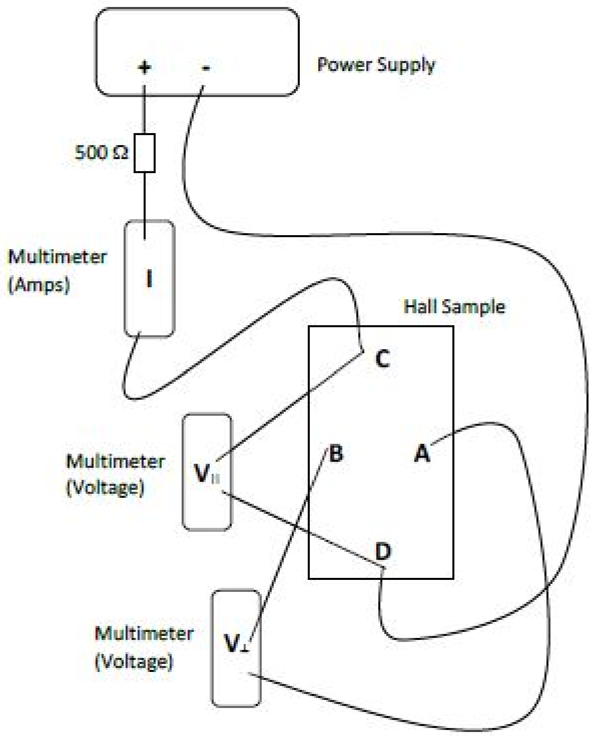

Figure 1: This figure shows the setup of the Hall effect practical

A piece of germanium (p-type) is used to experiment the Hall effect. There are three multimeters, one measures the series current through the germanium piece, one measures the voltage parallel across the germanium, one measures the perpendicular voltage across the piece of germanium, perpendicular to the motion of the current. A DC power supply, with variable voltage is used. A 500Ω resistor is connected in series. A magnet is used later in the experiment to see the effect of a magnetic field on current. A potentiometer was used when the magnet was far away to determine a zero $V_{\perp}$.

Method

The germanium was set up as seen above. Then making sure that the current did not exceed $50mA$, a 500Ω resistor was put in place. The power supply was then turned on and was set to 22V. The current in the sample was set to around

$38mA$. The magnet was placed some distance away and the potentiometer was varied in order to obtain a zero reading for $V_{\perp}$. Then the magnet was put into place and readings were taken of $V_{||}$ and $V_{\perp}$ as a function of I_s. 21 readings were taken with the current in the range 0 to $40mA$. This was done within 10 minutes. After the 10 minutes another measurement of all of the values were taken at a current of $40mA$. Then another 21 readings were taken after this going backwards from $40mA$ to $0mA$. These were captured in an excel spreadsheet and was used to analyse the behaviour of this piece of germanium.

Data

The data captured was put into an excel document
The table on the next page (page 4) shows the readings taken from the experiment multimeters

Reading Type	I_s(mA)	$V_{\|\|}$(V)	$V_{\perp}$(mV)
Forward	0,0	0,00	0,0
	2,0	0,22	2,8
	4,0	0,46	5,8
	6,0	0,68	8,6
	8,0	0,91	11,4
	10,0	1,13	14,3
	12,0	1,36	17,2
	14,0	1,59	20,2
	16,0	1,83	23,3
	18,0	2,06	26,3
	20,0	2,29	29,3
	22,0	2,53	32,5
	24,0	2,76	35,7
	26,0	3,01	39,0
	28,0	3,24	42,3
	30,0	3,49	45,8
	32,0	3,74	49,3
	34,0	3,99	52,9
	36,0	4,23	56,6
	38,0	4,49	60,2
	40,0	4,76	64,4
After 10 Minutes	40,0	4,81	66,1
Reverse (After the 10 minutes)	40,0	4,80	65,9
	38,0	4,55	62,4
	36,0	4,31	58,7
	34,0	4,05	55,1
	32,0	3,80	51,4
	30,0	3,55	47,9
	28,0	3,29	44,2
	26,0	3,05	40,8
	24,0	2,81	37,3
	22,0	2,57	34,1
	20,0	2,32	30,6
	18,0	2,09	27,4
	16,0	1,85	24,1
	14,0	1,61	20,9
	12,0	1,38	17,8
	10,0	1,14	14,7
	8,0	0,91	11,7
	6,0	0,68	8,7
	4,0	0,46	5,8
	2,0	0,22	2,8
	0,0	0,00	0,0

The size of the dimensions a, b and c are:

$$a = 5mm = 5 \times 10^{-3}m$$
$$b = 10mm = 10 \times 10^{-3}m$$
$$c = 1mm = 1 \times 10^{-3}m$$

The magnetic field is: $0.125 \pm 0.005T$

Graphs

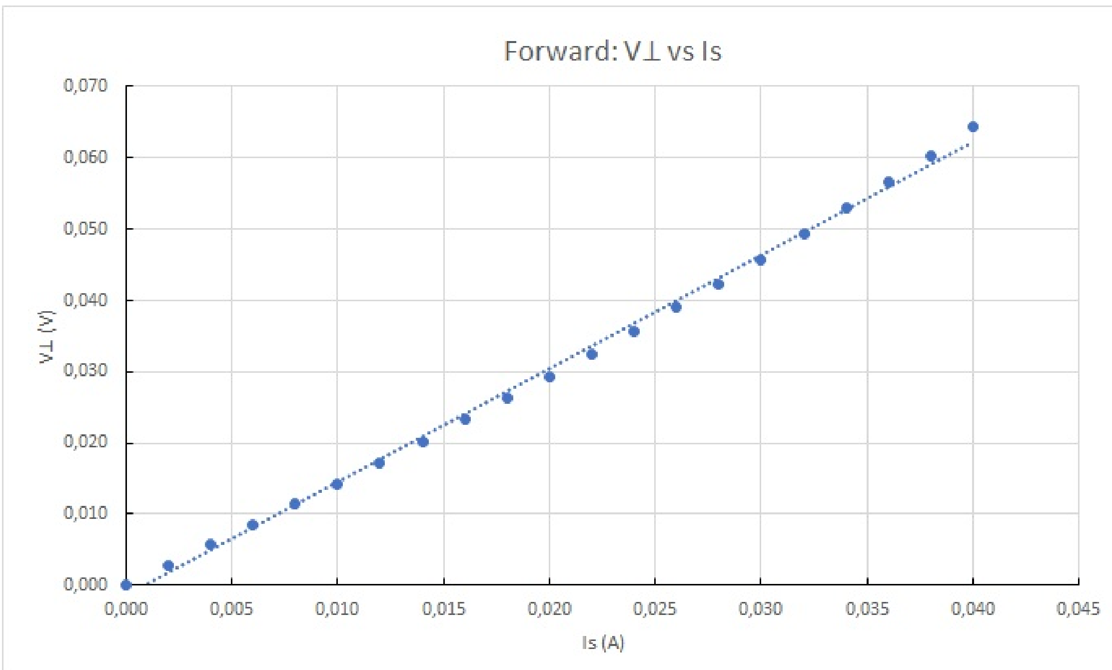

Figure 2: This graph shows the data points for the forward readings of $V_{\perp}$ vs I_s as well as the line of best fit

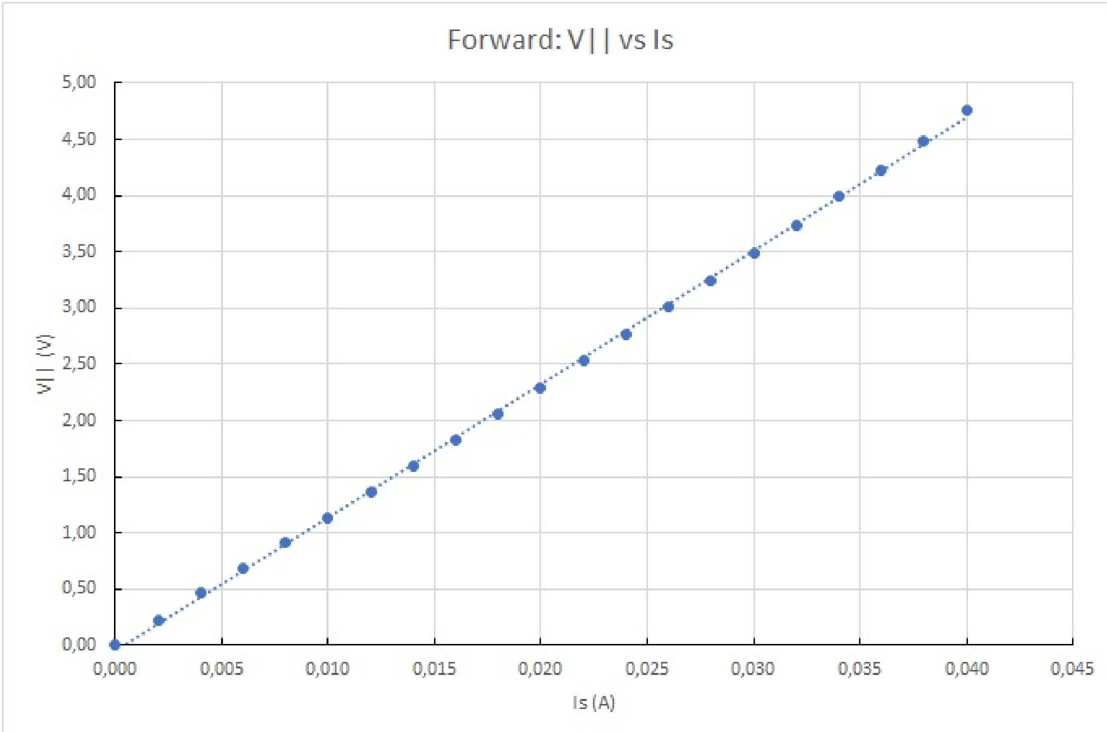

Figure 3: This graph shows the data points for the forward readings of $V_{||}$ vs I_s as well as the line of best fit

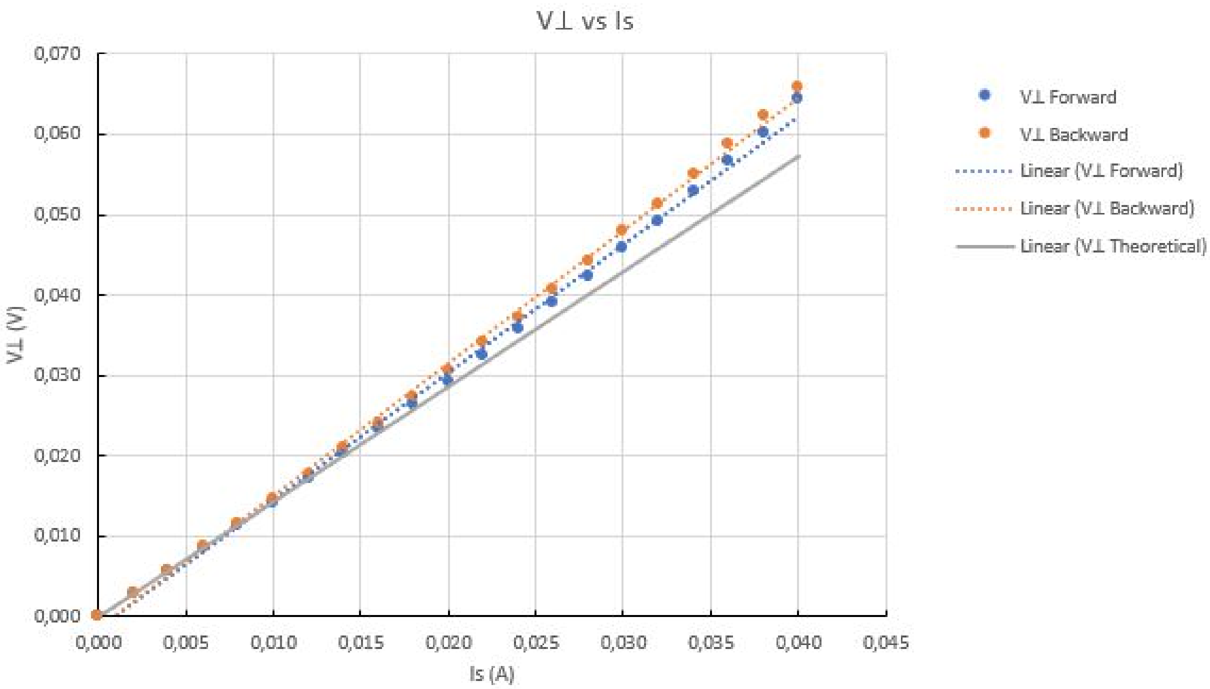

Figure 4: This graph shows the deviation of the data from the theoretical line for $V_\perp$ vs I_s

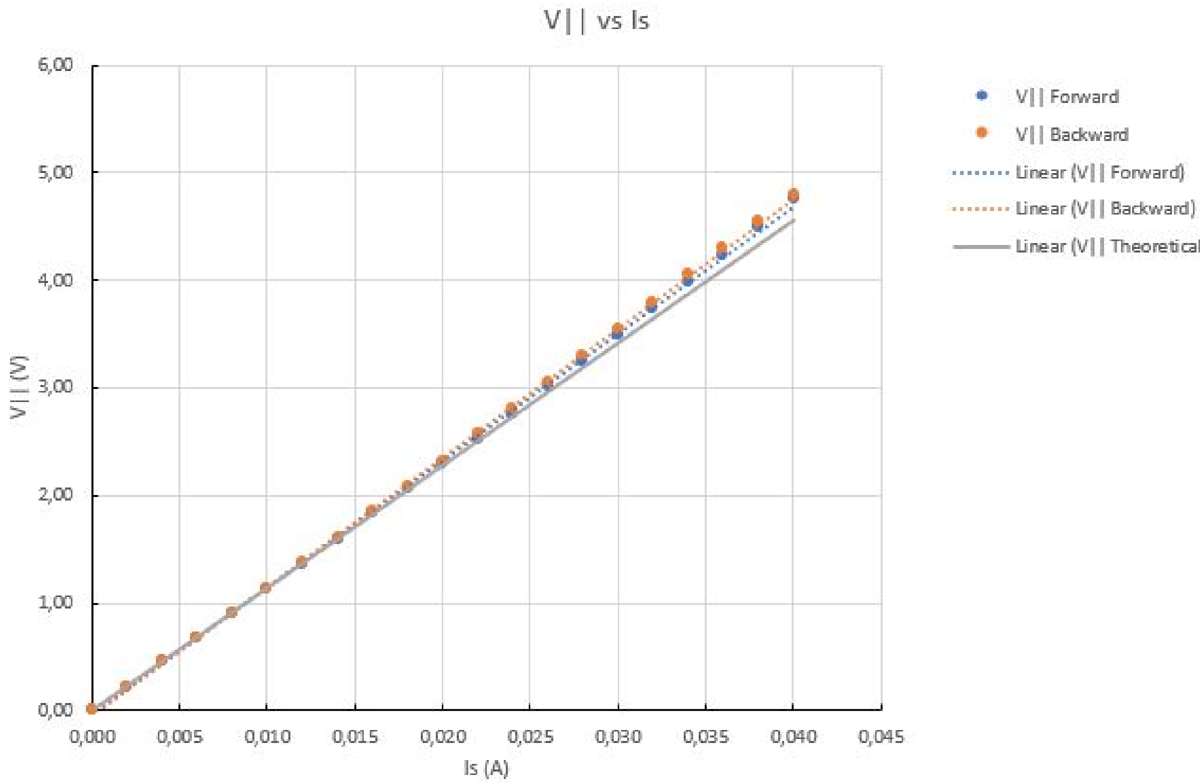

Figure 5: This graph shows the deviation of the data from the theoretical line for $V_{||}$ vs I_s

Calculations

Changing values for graphs

The table on the next page (page 9) shows the changed values as well as calculated values taken from the data in the table on page 4

Reading Type	I_s(A)	$V_{\|\|}$(V)	$V_{\perp}$(V)	$V\perp/Is$	$V_{\|\|}/Is$	$V\perp/V_{\|\|}$
Forward	0,000	0,00	0,0000	N/A	N/A	N/A
	0,002	0,22	0,0028	1,4	110	0,012727
	0,004	0,46	0,0058	1,45	115	0,012609
	0,006	0,68	0,0086	1,433333	113,3333	0,012647
	0,008	0,91	0,0114	1,425	113,75	0,012527
	0,010	1,13	0,0143	1,43	113	0,012655
	0,012	1,36	0,0172	1,433333	113,3333	0,012647
	0,014	1,59	0,0202	1,442857	113,5714	0,012704
	0,016	1,83	0,0233	1,45625	114,375	0,012732
	0,018	2,06	0,0263	1,461111	114,4444	0,012767
	0,020	2,29	0,0293	1,465	114,5	0,012795
	0,022	2,53	0,0325	1,477273	115	0,012846
	0,024	2,76	0,0357	1,4875	115	0,012935
	0,026	3,01	0,0390	1,5	115,7692	0,012957
	0,028	3,24	0,0423	1,510714	115,7143	0,013056
	0,030	3,49	0,0458	1,526667	116,3333	0,013123
	0,032	3,74	0,0493	1,540625	116,875	0,013182
	0,034	3,99	0,0529	1,555882	117,3529	0,013258
	0,036	4,23	0,0566	1,572222	117,5	0,013381
	0,038	4,49	0,0602	1,584211	118,1579	0,013408
	0,040	4,76	0,0644	1,61	119	0,013529
After 10 Minutes	0,040	4,81	0,0661	1,6525	120,25	0,013742
Reverse (After the 10 minutes)	0,040	4,80	0,0659	1,6475	120	0,013729
	0,038	4,55	0,0624	1,642105	119,7368	0,013714
	0,036	4,31	0,0587	1,630556	119,7222	0,013619
	0,034	4,05	0,0551	1,620588	119,1176	0,013605
	0,032	3,80	0,0514	1,60625	118,75	0,013526
	0,030	3,55	0,0479	1,596667	118,3333	0,013493
	0,028	3,29	0,0442	1,578571	117,5	0,013435
	0,026	3,05	0,0408	1,569231	117,3077	0,013377
	0,024	2,81	0,0373	1,554167	117,0833	0,013274
	0,022	2,57	0,0341	1,55	116,8182	0,013268
	0,020	2,32	0,0306	1,53	116	0,01319
	0,018	2,09	0,0274	1,522222	116,1111	0,01311
	0,016	1,85	0,0241	1,50625	115,625	0,013027
	0,014	1,61	0,0209	1,492857	115	0,012981
	0,012	1,38	0,0178	1,483333	115	0,012899
	0,010	1,14	0,0147	1,47	114	0,012895
	0,008	0,91	0,0117	1,4625	113,75	0,012857
	0,006	0,68	0,0087	1,45	113,3333	0,012794
	0,004	0,46	0,0058	1,45	115	0,012609
	0,002	0,22	0,0028	1,4	110	0,012727
	0,000	0,00	0,0000	N/A	N/A	N/A

Calculating R_H

Using equation:

$$V_{\perp} = \frac{R_H I_s B}{c} \tag{1}$$

$$\therefore \frac{V_{\perp}}{I_s} = \frac{R_H B}{c}$$

$$\therefore R_H = \frac{V_{\perp} c}{I_s B} \tag{2}$$

As the germanium normally is at $25^o C$, the best value for $V_{\perp}/I_s$ is the values at the beginning of measurement and the the point that is on the best fit line in graph in Figure (2). Therefore the value chosen comes from table (**??**) is $V_{\perp}/I_s = 1,433(V/A)$. Substituting these values into equation (2):

$$\therefore R_H = (1.433)\Big(\frac{1 \times 10^{-3}}{0.125}\Big)$$
$$\therefore R_H = 11.464 \times 10^{-3} m^3/C$$

And with the uncertainty:

$$R_H = (11.46 \pm 2.35) \times 10^{-3} m^3/C$$

Calculating σ

Using equation:

$$V_{||} = \frac{I_s b}{\sigma a c} \tag{3}$$

$$\therefore \sigma = \frac{b}{\frac{V_{||}}{I_s} a c} \tag{4}$$

Substituting the values for a, b, c and $V_{||}/I_s$ is chosen the same way as before, being the best value from graph in Figure (3) and closest to the beginning, into equation (4):

$$\therefore \sigma = \frac{10 \times 10^{-3}}{(113.75)(5 \times 10^{-3})(1 \times 10^{-3})}$$
$$\therefore \sigma = 17.582 AV^{-1} m^{-1}$$

And A/V is given by Siemens (S) therefore the value of σ with uncertainties is:

$$\sigma = 17.58 \pm 3.68 Sm^{-1}$$

Calculating n

As this piece of germanium is p-type the formula that gives the Hall coefficient:

$$R_H = \frac{1.4}{n_+ e} \tag{5}$$

where e is the charge of an electron which is $e = 1.6 \times 10^{-19}C$. We have calculated R_H above to be $R_H = 11.46 \times 10^{-3}m^3/C$, substituting this into equation (5) gives:

$$\begin{aligned}(11.46 \times 10^{-3}) &= \frac{1.4}{n_+(1.6 \times 10^{-19})} \\ \therefore n &= \frac{1.4}{(11.46 \times 10^{-3})(1.6 \times 10^{-19})} \\ \therefore n &= 7.635 \times 10^{20} m^{-3}\end{aligned}$$

And with uncertainty included is:

$$n = (7.64 \pm 1.57) \times 10^{20} m^{-3}$$

Calculating μ

As we have equation:

$$\mu = \frac{\sigma}{ne} \tag{6}$$

And we have σ, n and e we substitute these into the equation:

$$\begin{aligned}\mu &= \frac{17.582}{(7.635 \times 10^{20})(1.6 \times 10^{-19})} \\ \therefore \mu &= 0.144 m^2 C^{-1}\end{aligned}$$

And with the uncertainty:

$$\mu = (0.14 \pm 0.04) S m^2 C^{-1}$$

Uncertainty Analysis

Uncertainty in calculating R_H

In order to calculate R_H, $V_\perp/I_s$ needs to be calculated, as these values are given by a multimeter there is type B uncertainty. The uncertainty of the multimeter is 1%. Therefore we need the uncertainty of $V_\perp/I_s$ first.

Uncertainty of $V_\perp/I_s$

First there is uncertainty in reading the measurements from the multimeters. This is given by a rectangular pdf:

$$u = \frac{a}{2\sqrt{3}} \tag{7}$$

For the current, choosing $a = 1 \times 10^{-4}A$:

$$\therefore u_1(I_s) = \frac{1 \times 10^{-4}}{2\sqrt{3}}$$
$$\therefore u_1(I_s) = 2.887 \times 10^{-5}A$$

For the potential difference, choosing $a = 1 \times 10^{-4}V$:

$$\therefore u_1(V_\perp) = \frac{1 \times 10^{-4}}{2\sqrt{3}}$$
$$\therefore u_1(V_\perp) = 2.887 \times 10^{-5}V$$

The value of $V_\perp$ chosen is: $8.6 \times 10^{-3}V$
The value of I_s it corresponds to is: $6 \times 10^{-3}A$
$u_2(V_\perp)$:1% of $V_\perp$:1%$(8.6 \times 10^{-3}) = 8.6 \times 10^{-5}V$
$u_2(I_s)$:1% of I_s:1%$(6 \times 10^{-3}) = 6 \times 10^{-5}A$
Then we add these uncertainties:
For current:

$$u(I_s) = \sqrt{u_1(I_s)^2 + u_2(I_s)^2}$$
$$\therefore u(I_s) = \sqrt{(6 \times 10^{-5})^2 + (2.887 \times 10^{-5})^2}$$
$$\therefore u(I_s) = 6.658 \times 10^{-5}A$$

For potential difference:

$$u(V_\perp) = \sqrt{u_1(V_\perp)^2 + u_2(V_\perp)^2}$$
$$\therefore u(V_\perp) = \sqrt{(8.6 \times 10^{-5})^2 + (2.887 \times 10^{-5})^2}$$
$$\therefore u(V_\perp) = 9.072 \times 10^{-5}V$$

In order to calculate this uncertainty the equation below is used:

$$u(R) = R\sqrt{\Big(a\frac{u(A)}{A}\Big)^2 + \Big(b\frac{u(B)}{B}\Big)^2} \tag{8}$$

$$\therefore u(V_\perp/I_s) = (V_\perp/I_s)\sqrt{\Big(\frac{u(V_\perp)}{V_\perp}\Big)^2 + \Big(-1\frac{u(I_s)}{I_s}\Big)^2}$$
$$\therefore u(V_\perp/I_s) = (1.433)\sqrt{\Big(\frac{9.072 \times 10^{-5}}{8.6 \times 10^{-3}}\Big)^2 + \Big(\frac{6.658 \times 10^{-5}}{6 \times 10^{-3}}\Big)^2}$$
$$\therefore u(V_\perp/I_s) = 0.022V/A$$

Calculating uncertainty of c/B

If we look at equation (2) we see that we need the uncertainty of c/B:
The uncertainty of c:
As c is a physical measurement we use the triangular pdf as I am assuming it was measured with an analogue device:

$$u = \frac{a}{2\sqrt{6}} \tag{9}$$

where a is the interval that the value lies between. Therefore $a = 1mm$. Therefore u(c):

$$u(c) = \frac{1 \times 10^{-3}}{2\sqrt{6}}$$
$$\therefore u(c) = 0.204 \times 10^{-3} m$$

The uncertainty of B: $0.005T$ Therefore the uncertainty of c/B using equation (8) is:

$$u(c/B) = (c/B)\sqrt{\Big(\frac{u(c)}{c}\Big)^2 + \Big(-1\frac{u(B)}{B}\Big)^2}$$
$$\therefore u(c/B) = \frac{1 \times 10^{-3}}{0.125}\sqrt{\Big(\frac{0.204 \times 10^{-3}}{1 \times 10^{-3}}\Big)^2 + \Big(\frac{0.005}{0.125}\Big)^2}$$
$$\therefore u(c/B) = 1.663 \times 10^{-3} m/T$$

Calculating the uncertainty of R_H

Using equation (8) we can calculate $u(R_H)$ as it is the multiplication of $V_\perp/I_s$ and c/B:

$$u(R_H) = (R_H)\sqrt{\Big(\frac{u(V_\perp/I_s)}{V_\perp/I_s}\Big)^2 + \Big(\frac{u(c/B)}{c/B}\Big)^2}$$
$$\therefore u(R_H) = (11.46 \times 10^{-3})\sqrt{\Big(\frac{0.022}{1.433}\Big)^2 + \Big(\frac{1.633 \times 10^{-3}}{8 \times 10^{-3}}\Big)^2}$$
$$\therefore u(R_H) = 2.35 \times 10^{-3} m^3/C$$

Uncertainty in calculating σ

Looking at equation (4) we see that we need the uncertainty of $1/(V_{||}/I_s)$, therefore we need the uncertainty of $I_s/V_{||}$. We also need the uncertainty of ac for the uncertainty of b/ac.

Uncertainty of $I_s/V_{||}$

First there is uncertainty in reading the measurements from the multimeters.This is given by equation (7).

For the current, choosing $a = 1 \times 10^{-4}A$:

$$\therefore u_1(I_s) = \frac{1 \times 10^{-4}}{2\sqrt{3}}$$
$$\therefore u_1(I_s) = 2.887 \times 10^{-5}A$$

For the potential difference, choosing $a = 1 \times 10^{-5}V$:

$$\therefore u_1(V_{||}) = \frac{1 \times 10^{-5}}{2\sqrt{3}}$$
$$\therefore u_1(V_{||}) = 2.887 \times 10^{-6}V$$

The value of I_s chosen is: $8 \times 10^{-3}A$
The value of $V_{||}$ it corresponding to is: $0.91V$
$u_2(I_s)$:1% of I_s:$1\%(8 \times 10^{-3}) = 8 \times 10^{-5}A$
$u_2(V_{||})$:1% of $V_{||}$:$1\%(0.91) = 9.1 \times 10^{-3}V$
Then we add these uncertainties:
For current:

$$u(I_s) = \sqrt{u_1(I_s)^2 + u_2(I_s)^2}$$
$$\therefore u(I_s) = \sqrt{(8 \times 10^{-5})^2 + (2.887 \times 10^{-5})^2}$$
$$\therefore u(I_s) = 8.505 \times 10^{-5}A$$

For potential difference:

$$u(V_{\perp}) = \sqrt{u_1(V_{\perp})^2 + u_2(V_{\perp})^2}$$
$$\therefore u(V_{\perp}) = \sqrt{(9.1 \times 10^{-3})^2 + (2.887 \times 10^{-6})^2}$$
$$\therefore u(V_{\perp}) = 9.1 \times 10^{-3}V$$

Using equation (8) and substituting the relevant values:

$$u(I_s/V_{||}) = (I_s/V_{||})\sqrt{\Big(\frac{u(I_s)}{I_s}\Big)^2 + \Big(-1\frac{u(V_{||})}{V_{||}}\Big)^2}$$
$$\therefore u(I_s/V_{||}) = \frac{8 \times 10^{-3}}{0.91}\sqrt{\Big(\frac{8.505 \times 10^{-5}}{8 \times 10^{-3}}\Big)^2 + \Big(\frac{9.1 \times 10^{-3}}{0.91}\Big)^2}$$
$$\therefore u(I_s/V_{||}) = 1.283 \times 10^{-4}A/V$$

Uncertainty of ac

The uncertainty of a and c is the same as the uncertainty of b calculated above as it is the same reading type and used the same piece of equipment to measure it. Therefore:
$u(a) = 0.204 \times 10^-3 = u(c) = u(b)$

The uncertainty using equation (8) is:

$$
\begin{aligned}
u(ac) &= (ac)\sqrt{\Big(\frac{u(a)}{a}\Big)^2 + \Big(\frac{u(c)}{c}\Big)^2} \\
\therefore u(ac) &= (5\times10^{-3})(1\times10^{-3})\sqrt{\Big(\frac{0.204\times10^{-3}}{5\times10^{-3}}\Big)^2 + \Big(\frac{0.204\times10^{-3}}{1\times10^{-3}}\Big)^2} \\
\therefore u(ac) &= 1.040\times10^{-6}m^2
\end{aligned}
$$

Uncertainty of b/ac

Using equation (8):

$$
\begin{aligned}
u(b/ac) &= (b/ac)\sqrt{\Big(\frac{u(b)}{b}\Big)^2 + \Big(-1\frac{u(ac)}{ac}\Big)^2} \\
\therefore u(b/ac) &= \frac{10\times10^{-3}}{5\times10^{-6}}\sqrt{\Big(\frac{0.204\times10^{-3}}{10\times10^{-3}}\Big)^2 + \Big(\frac{1.040\times10^{-6}}{5\times10^{-6}}\Big)^2} \\
\therefore u(b/ac) &= 417.996m^{-1}
\end{aligned}
$$

Calculating the uncertainty of σ

The equation for σ can be rewritten as:

$$
\sigma = \frac{I_s}{V_{||}}\frac{b}{ac} \tag{10}
$$

Therefore the uncertainty of sigma is given by:

$$
\begin{aligned}
u(\sigma) &= (\sigma)\sqrt{\Big(\frac{u(I_s/V_{||})}{I_s/V_{||}}\Big)^2 + \Big(\frac{u(b/ac)}{b/ac}\Big)^2} \\
\therefore u(\sigma) &= (17.582)\sqrt{\Big(\frac{1.283\times10^{-4}}{8.791\times10^{-3}}\Big)^2 + \Big(\frac{417.996}{2000}\Big)^2} \\
\therefore u(\sigma) &= 3.684Sm^{-1}
\end{aligned}
$$

Uncertainty in calculating n

Manipulating equation (5) we get:

$$
n = \frac{1.4}{R_H e} \tag{11}
$$

Therefore the uncertainty, given by equation (8):

$$
\begin{aligned}
u(n) &= (n)\sqrt{\Big(-1\frac{u(R_H)}{R_H}\Big)^2} \\
\therefore u(n) &= (7.635\times10^{20})\frac{2.35\times10^{-3}}{11.46\times10^{-3}} \\
\therefore u(n) &= 1.57\times10^{20}m^{-3}
\end{aligned}
$$

Uncertainty in calculating μ

The equation to calculate μ is given by equation (6), therefore the uncertainty, using equation (8) is:

$$u(\mu) = (\mu)\sqrt{\Big(\frac{u(\sigma)}{\sigma}\Big)^2 + \Big(-1\frac{u(n)}{n}\Big)^2}$$
$$\therefore u(\mu) = (0.144)\sqrt{\Big(\frac{3.684}{17.582}\Big)^2 + \Big(\frac{1.57\times 10^{20}}{7.635\times 10^{20}}\Big)^2}$$
$$\therefore u(\mu) = 0.042Sm^2C^{-1}$$

Interpretation and Discussion

Interpretation of the graphs

It is seen in Figures (2) and (5) that the data points are linear however they are deviated from the theoretical lines the further into the experiment one goes, i.e. the higher the temperatures the more the deviation. and it is seen that the backward data is even more deviated than the forward data and as the backward data was taken at a higher temperature this can be seen once more that indeed higher temperature does deviate the data.

Systematic variation

Systematic variation means the inaccuracy of data due to inaccurate measurement[1]. If we look at the table on page (!!!!!!!!) we see that all of the values for $V_{\perp}/V_{||}$ are around the same value of 0.013. For the values of $V_{\perp}/I_s$ we see the same, that the values are around 1.5. This means that there is not much systematic variation, i.e. the error in reading off the values for current and potential difference is small.

The values obtained

The best values were obtained for $V_{||}/I_s$ and $V_{\perp}/I_s$ by looking at both the values closest to the beginning of the measurement as those are the values at which the germanium piece is at room temperature and also by looking at the value on the linear line in Figures (2) and (3). The values for the Hall coefficient (R_H), the conductivity (σ), the number density of charges (n) and the mobility of charges (μ) are:

$$R_H = (11.46 \pm 2.35)\times 10^{-3}m^3/C$$
$$\sigma = (17.58 \pm 3.68)Sm^{-1}$$
$$n = (7.64 \pm 1.57)\times 10^{20}m^{-3}$$
$$\mu = (0.14 \pm 0.04)Sm^2C^{-1}$$

Conclusion

In conclusion the properties of this piece of germanium was found and is shown above. And as seen in the exercises below that the germanium acts differently to an ordinary semiconductor.

Exercises:

1. Does the conductivity of the sample increase or decrease with temperature? Does your answer to this question agree with what you know about semiconductors

If we look at equation (4) we see that we get the proportionality:

$$\sigma \propto \frac{1}{\frac{V_{||}}{I_s}} \tag{12}$$

Therefore we see that when the gradient of the graph of $V_{||}$ vs I_s increases, the conductivity decreases. If we look at Figure (5) we see that the backward points, the points at a higher temperature as it was taken after 10 minutes when the germanium was measured to be at 31.3^oC from its initial temperature of 25.4^oC, have a larger gradient than the forward readings, at room temperature. Therefore this shows us that as temperature increases, the conductivity decreases. This does not agree with how a semiconductor should act with an increase in temperature, which is that conductivity should increase with temperature[4]. However it is seen here that this is not the case.

2. Does the number density of charges increase or decrease with temperature? Does our answer to this question agree with what you know about semiconductors

If we look at equation (5) and equation (2), with some manipulation, you can get to the following equation:

$$n = \frac{1.4}{\left(\frac{V_{\perp} c}{I_s B}\right) e} \tag{13}$$

Therefore there is a proportionality, which is:

$$n \propto \frac{1}{\frac{V_{\perp}}{I_s}} \tag{14}$$

Wee see that here to n is inversely proportional to the gradient of the graph of $V_{\perp}$ vs I_s. If we look at the graph in Figure (2) we see that the gradient increased in the backward readings taken at a higher temperature, therefore an increase in temperature decreases the number density of charges. This is also different to an ordinary semiconductor in which the concentration of charges increases with energy, or temperature.[3]

3. Does the mobility of charges increase or decrease with temperature? Compare your answer to this question with the information on charge mobilities in pure germanium (at 20^oC)

The value obtained for the mobility of charges in this report is $\mu = (0.14 \pm 0.04)Sm^2C^{-1}$ which by rearranging the units is equal to $\mu = (0.14 \pm 0.04)m^2V^{-1}s^{-1}$. The result in the table is $\mu = 0.18m^2V^{-1}s^{-1}$. It is seen that the tabular result is within the uncertainty of my result. The result I obtained came from a piece of germanium at 25.4^oC whereas the result from the table was from a piece that was 20^oC. As my result is less than the one in the table it can be said that for this piece of germanium, with the increase of temperature there is a decrease in mobility of charges. However including my uncertainty, it cannot be stated conclusively.

References

[1] AlleyDog.com. *Systematic Variation.* URL: `https://www.alleydog.com/glossary/definition.php?term=Systematic+Variation#:~:text=In%5C%20research%5C%20and%5C%20experimental%5C%20situations,are%5C%20not%5C%20under%5C%20statistical%5C%20control.`. (accessed:23.11.2020).

[2] Assoc. Professor Mark Blumenthal. *PHY2004W: PHYLAB 2, Experimental Physics Lab Session, Wave Guides.* UCT, 2020. URL: `https://vula.uct.ac.za/access/content/group/21e34359-1eaa-44b3-a8d8-20da306e1181/PHYLAB%5C%202%5C%20-%5C%20Online%5C%20Manuals/Waves.pdf`.

[3] *How does temperature affect intrinsic carrier concentration?* URL: `http://www.ece.utep.edu/courses/ee3329/ee3329/Studyguide/ToC/Fundamentals/Carriers/explain.html`. (accessed:23.11.2020).

[4] *How Does Temperature Affect the Conductivity of a SemiConductor?* URL: `https://fog.ccsf.edu/~wkaufmyn/ENGN45/Course%5C%20Handouts/15_ElectricalProps/06_TemperatureConductivitySemiConductor.html`. (accessed:23.11.2020).