HALL EFFECT OF SEMICONDUCTORS

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Abstract :

The Hall effect experiment was conducted for 3 semiconductor samples to determine their Hall coefficient at room temperature. Majority charge carriers were identified using the sign of Hall coefficient. For p-type Ge sample, variation of Hall coefficient with temperature was measured and Hall inversion was observed. Results obtained are consistent with two-carrier model of semiconductors. These measurements are used to determine carrier concentration & mobility in semiconductors & Hall sensors used to measure magnetic field.

Aim :-

(I) To determine the Hall coefficient of semiconductors at room temperature

(II) To study the variation of Hall coefficient with Temperature.

Theory :-

When a current carrying material is placed in a magnetic field perpendicular to the direction of current, charge carriers experience a transverse Lorentz force. Due to this, charges accumulate on opposite sides of the sample producing a transverse electric field. This traverse potential is measurable and is called Hall voltage.

Consider a rectangular semiconductor slab with current density $\vec{J}$ along x-direction, magnetic field $\vec{BH}$ along z-direction, due to ~~with~~ which Hall field $\vec{E}_H$ is along y-direction.

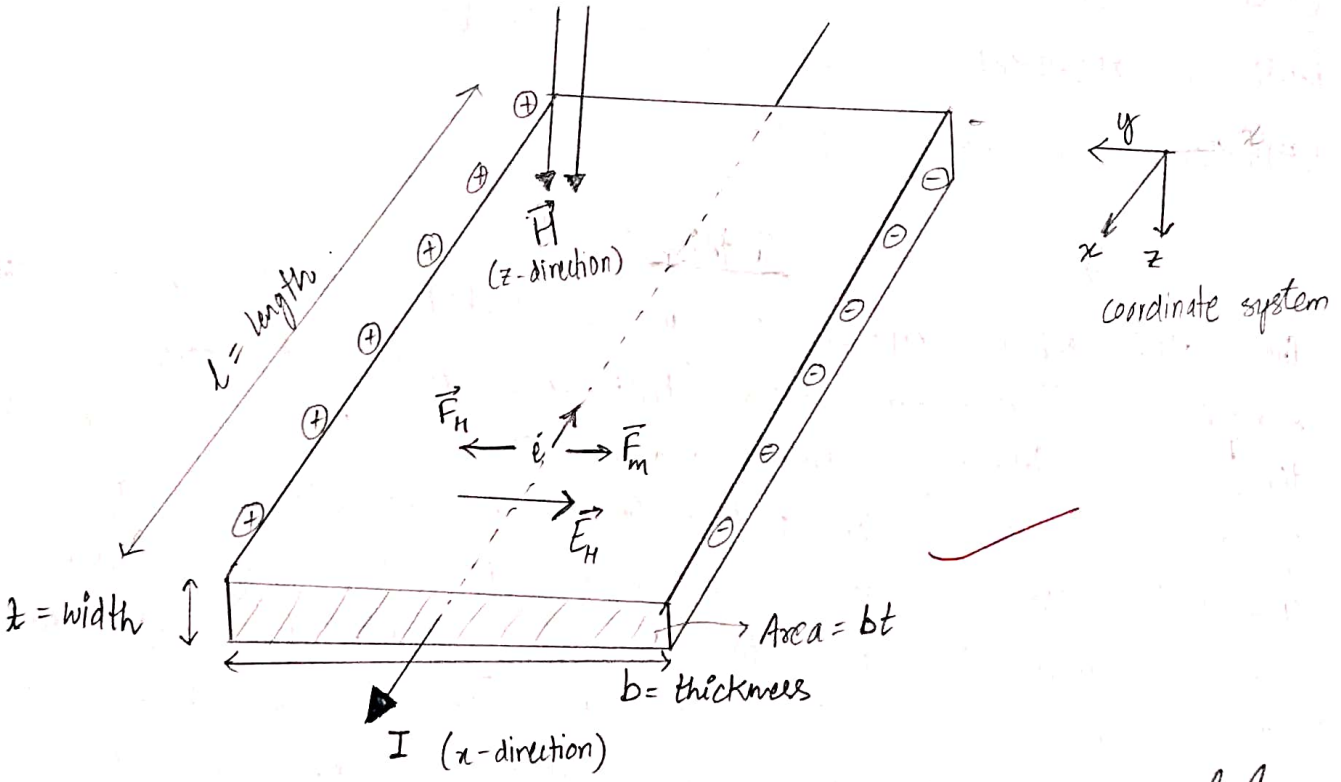

Figure 1 - Schematic illustration of Hall effect of a crystal.

Force on charge carrier with charge 'e',

$$\cancel{\vec{F} = e\vec{E}_m = e} \qquad \vec{F} = e(\vec{E} + \vec{v}_d \times \vec{BH})$$

In steady state, the magnetic force is balanced by the Hall field,

$$|\vec{F}_m| = |\vec{F}_H|$$

$$E_m = vH = \mu E_x H$$

where $\vec{E}_m = \vec{v} \times \vec{BH}$

where μ = carrier mobility $\quad v = \mu E_x \quad$ E_x = applied electric field along x-axis related to current density & conductivity

$$\boxed{\sigma E_x = J_x}$$

The Hall coefficient is defined as,

$$|R_H| = \frac{E_m}{J_x H} = \frac{\mu E_x}{J_x} = \frac{\mu}{\sigma} = \frac{1}{ne} \quad , \text{ using } \sigma = ne\mu$$

$$\Rightarrow \mu = R_H \sigma$$

Experimentally, $\quad R_H = \dfrac{V_y b}{\left(\frac{I_x}{bt}\right) H} \quad$, since $E_m = V_y b$. $J_x = \frac{I_x}{bt}$.

$$\boxed{R_H = \frac{V_y t}{J_x H}}$$

The Hall angle is defined as,

$$\phi = \frac{V_y}{V_x} = \frac{E_m b}{E_x l} = \mu \frac{b}{l} H$$

l = length of the crystal

$\therefore \quad \underline{\phi \propto \mu}$.

* Two types of carriers: For electrons & holes, ~~both~~ present in semiconductors, let

n = electron density $\quad \mu_e$ = electron mobility

p = hole density $\quad \mu_h$ = hole mobility

The Hall potential has opposite signs for holes & electrons. In this case, Hall field E_y doesn't compensate for magnetic force on both types of carriers, leading to a transverse motion of carriers. But, there is no traverse current i.e.

$$e(v_y^+ p - v_y^- n) = 0 \quad \text{— (I)}$$

where v_y^+, v_y^- = transverse velocities of holes & electrons.

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& v_x^+, v_x^- = velocities along $\vec{J}$ for holes & electrons
(Note: v_x^+ has opposite sign from v_x^-)

$$e(v_x^+ p - v_x^- n) = J_x \quad \text{and} \quad e(\mu^+ p + \mu^- n) = \sigma$$

Drift velocity of electron, as defined in Drude Model is,

$$v = \frac{s}{\tau} = \left(\frac{1}{2}\frac{f}{m^*}\tau^2\right)\frac{1}{\tau}$$

τ = relaxation time
s = avg. displacement b/w 2 collisions.

Lorentz force, on holes & electrons,

$$\vec{F}^+ = e[(v_x^+ \times \vec{H}) - \vec{E}_H] \qquad \vec{F}^- = -e[(v_x^- \times \vec{H}) - \vec{E}_H]$$

we have,

$$v_y^+ = \frac{1}{2}\frac{e}{m_h}\tau[\mu^+ E_x H - E_H] = \mu^+(\mu^+ E_x H - E_H) \quad \text{— (II)}$$

$$v_y^- = \frac{1}{2}\frac{e}{m_e}\tau[\mu^- E_x H - E_H] = \mu^-(\mu^- E_x H + E_H) \quad \text{— (III)}$$

where m_h, m_e = effective mass of holes & e^-.

Putting eq. (II) & (III) in (I), we get

$$\mu^+ p(\mu^+ E_x H - E_H) - \mu^- n(\mu^- E_x H + E_H) = 0$$

$$\Rightarrow \quad E_H = E_x H\left(\frac{\mu_h^2 p - \mu_e^2 n}{\mu_h p + \mu_e n}\right)$$

Hall coefficient, $R_H = \dfrac{E_H}{J_x H} = \dfrac{E_H}{\sigma E_x H} = \dfrac{\mu_h^2 p - \mu_e^2 n}{e(\mu_h p + \mu_e n)^2}$

Due to Temperature dependence of μ_h & μ_e, R_H is also temperature dependent. Generally $\mu_e > \mu_h$, so R_H can change sign if $p > n$

∴ "Hall coefficient inversion" happens only in "p-type" semiconductors

@ $R_H = 0$ $\quad \boxed{\dfrac{\mu_e}{\mu_h} = \sqrt{\dfrac{p}{n}}}$

Observations :-

(I) Ambient Temperature :

Coil current = 1.01 A

~~2) n-type Germanium :-~~

~~Probe current~~	~~Hall voltage~~	~~Hall coefficient~~
~~3.90 mA~~	~~-11.6 mV~~	

~~(ii)~~

Offset Thermo e.m.f = 0.91 mV

(I)

Table :- Hall voltage ~ Temperature for fixed probe current measurement

Residual Magnetic field = 138 Gauss. Applied Magnetic field =

Probe current (I) = 3.83 mA Coil current = 1.50 A

S.no.	Heater Current (mA)	Thermo e.m.f. (mV)	Temp. (°C) (with offset correction)	Hall Voltage (mV)	Off-set voltage at residual (mV)	Corrected Hall Voltage (mV)	Hall Coefficient ($cm^3 \cdot C^{-1}$).
1	0	0	22.8	47.0	25.5	21.5	0.012
2	200	0.09	24.9	46.8	25.8	21	0.0117
3.	301	0.289	29.8	52.5	29.4	23.1	0.0128
4.	401	0.58	36.8	52.6	29.8	22.8	0.0127
5.	500	0.94	45.6	47.1	28.2	18.9	0.0105
6.	60.0	1.30	54.3	42.3	28.0	14.3	0.008
7.	653	1.59	61.4	31.7	23.7	8.	0.0044
8.	700	1.80	66.5	24.2	19.9	5.9	0.0027
9.	752	2.06	72.8	18.5	16.7	1.8	0.001
10.	850	2.43	81.8	12.6	13.0	-0.4	-0.0002
11.	996	3.14	99.0	7.1	8.4	-1.3	-0.0007

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Residual Magnetic field = 137 Gauss

Table (II) Calibration of current ~ Magnetic field

S.no.	Current (A)	Magnetic field (Gauss)
1.	0	137
2.	0.30	573
3.	0.60	1041
4.	0.90	1516
5.	1.20	1995
6.	1.51	2490
7.	1.80	2970
8.	2.10	3460
9.	2.58	4210
10.	2.68	4350
11.	2.80	4540
12.	3.00	4850

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Table (III) Hall voltage ~ Magnetic field for constant probe current

S.no.	Coil current (A)	Magnetic field (Gauss)	Hall voltage. (mV)	Corrected Hall voltage (mV)
1.	1.00	1690	-20.1	~~Probe current~~ -6.1
2.	1.21	2023	-21.2	-7.2
3.	1.52	2515	-23.4	-9.4
4.	1.82	2990	-25.2	-11.2
5.	2.18	3561	-27.1	-13.1
6.	2.42	3941	-28.4	-14.4
7.	2.80	4343 14/7/26	-30.3	-16.3
8.	~~3.05~~ 2.97	4813	-31.7	-17.7

Sample - n-type Si

Zero field potential = -14.0 mV

Probe current = 1.69 mA

NOTE :- The magnetic field values here are not including the residual correction.
Refer to table attached with plot for actual values.
(These values are raw observations)

Table :- (IV)

n - type Ge.

Zero field potential = +1.3 mV Probe current = 3.24 mA

S.no.	Coil current (A)	Magnetic field (Gauss)	Hall voltage (mV)	Corrected Hall voltage (mV)
i)	0.30	581	-2.4	-3.7
ii)	0.53	945	-4.6	-5.9
iii)	0.70	1215	-6.5	-7.8
iv)	0.92	1564	-8.8	-10.1
v)	1.21	2023	-12.0	-13.3
vi)	1.46	2420	-14.6	-15.9
vii)	1.62	2673	-16.3	-17.6
viii)	1.82	2990	-18.5	-19.8
ix)	2.02	3307	-20.6	-21.9
x)	2.21	3608	-22.5	-23.8
xi)	2.40	3909	-24.5	-25.8
xii)	2.61	4242	-26.6	-27.9
xiii)	2.81	4559	-28.6	-29.9
xiv)	2.99	4845	-30.3	-31.6

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Table : (V)

p-type Ge.

Probe current = 3.663mA Zero field potential = 25.3 mV

S.no.	Coil current (A)	Magnetic field (Gauss)	Hall voltage (mV)	Corrected Hall voltage (mV)
1.	0.25	502	30.3	5.0
2.	0.42	772	32.7	7.4
3.	0.61	1073	35.5	10.2
4.	0.82	1406	38.7	13.4
5.	1.05	1770	42.4	17.1
6.	1.30	2166	46.2	20.9
7	1.42	2357	48.8	23.5
8.	1.53	2531	50.3	25
9.	1.64	2705	51.9	26.6
10.	1.76	2896	53.6	28.3
11.	1.92	3149	55.8	30.5
12.	2.05	3355	57.6	32.3
13.	2.13	3514	58.9	33.6
14.	2.27	3704	60.3	35
15.	2.52	4100	63.5	38.2
16.	2.71	4401	65.8	40.5
17.	2.85	4623	67.4	42.1
18.	2.97	4813	68.7	43.4

~~Hall~~ Table :- ~~Hall coeffi~~

Apparatus Required :-

i) Hall probe ii) Oven iii) Temperature sensor

iv) Hall Effect setup v) Electromagnet

vi) Constant current power supply

vii) Digital Gaussmeter.

Calculation & Error Analysis of charge carrier density

(this section was added at the end, sorry for the wrong sequence)

i) n-type Si sample.

$$\boxed{n = \frac{1}{Re}}$$

$$n_1 = \frac{1}{R_{H_1} e} = +5.78 \times 10^{20} \ m^{-3}$$

$$\Delta n_1 = \sqrt{\left(\frac{\partial n_1}{\partial R_{H_1}} \cdot \Delta R_{H_1}\right)^2} = \left| \frac{-1}{R_{H_1}^2 e} \Delta R_{H_1} \right| = |n_1| \left| \frac{\Delta R_{H_1}}{R_{H_1}} \right|$$

$$\Delta n_1 = 0.11 \times 10^{20} \ m^{-3}$$

~~The negative sri~~

ii) n-type Ge sample. (similarly)

$$n_2 = \frac{1}{R_{H_2} e} = 6.11 \times 10^{20} \ m^{-3}$$

$$\Delta n_2 = n_2 \left| \frac{\Delta R_{H_2}}{R_{H_2}} \right| = 0.06 \times 10^{20} \ m^{-3}$$

iii) p-type Ge sample.

$$n_3 = \frac{1}{R_{H_3} e} = 5.03 \times 10^{20} \ m^{-3}$$

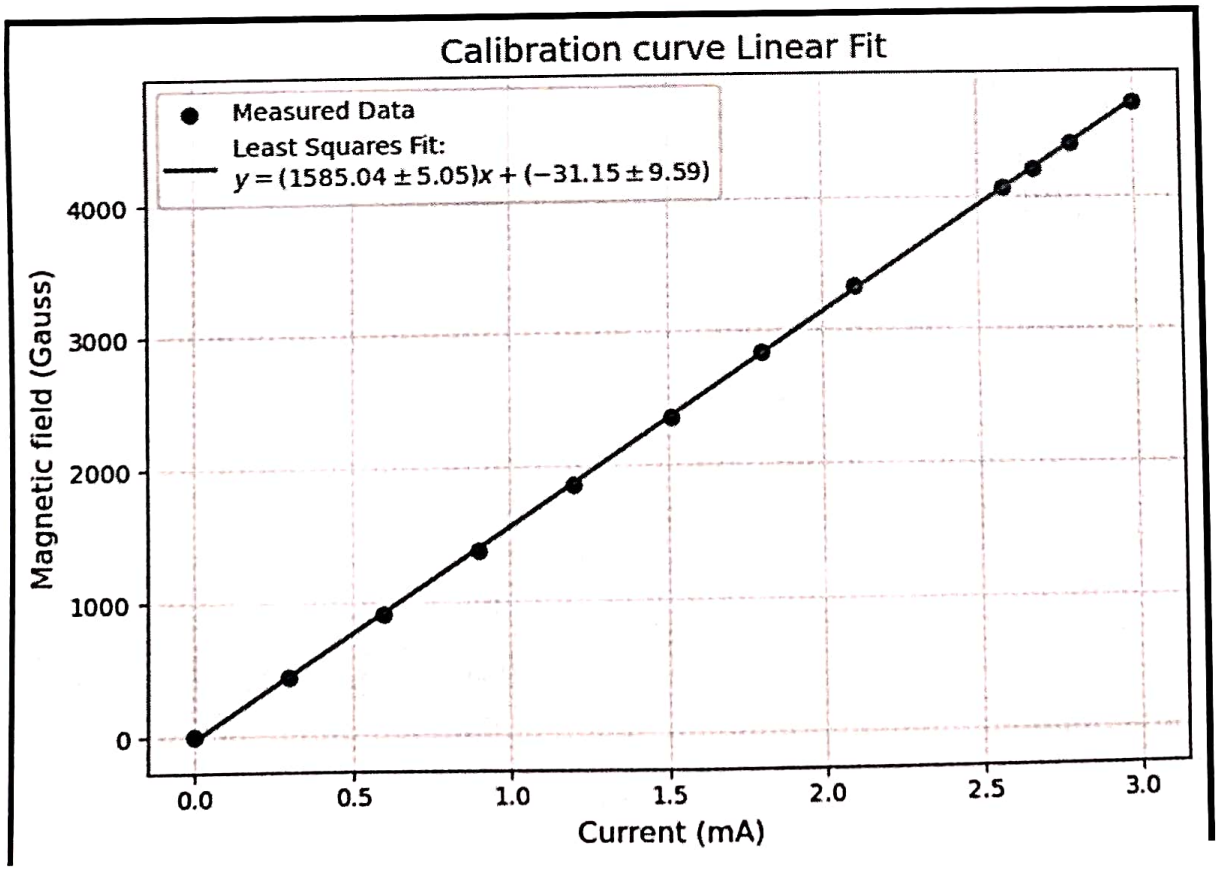
$$\Delta n_3 = n_3 \left| \frac{\Delta R_{H_3}}{R_{H_3}} \right| = 0.08 \times 10^{20} \ m^{-3}$$

For table - II Magnetic field v/s coil current

Input Data				
i	x	y	x^2	xy
1	0.0	0.0	0.0	0.0
2	0.3	436.0	0.09	130.8
3	0.6	904.0	0.36	542.4
4	0.9	1379.0	0.81	1241.1
5	1.2	1857.0	1.44	2228.4
6	1.51	2353.0	2.28	3553.03
7	1.8	2833.0	3.24	5099.4
8	2.1	3323.0	4.41	6978.3
9	2.58	4073.0	6.656	10508.34
10	2.68	4213.0	7.182	11290.84
11	2.8	4403.0	7.84	12328.4
12	3.0	4713.0	9.0	14139.0
Σ	19.47	30487.0	43.309	68040.01

Measured vs Fitted Values		
x	y (measured)	y (fit)
0.0	0.0	-31.15
0.3	436.0	444.363
0.6	904.0	919.876
0.9	1379.0	1395.389
1.2	1857.0	1870.902
1.51	2353.0	2362.266
1.8	2833.0	2821.929
2.1	3323.0	3297.442
2.58	4073.0	4058.263
2.68	4213.0	4216.767
2.8	4403.0	4406.973
3.0	4713.0	4723.981

Fit Results & Statistical Errors		
Parameter	Value	Uncertainty
Slope (a_1)	1585.0439	±5.0458
Intercept (a_0)	-31.1505	±9.5858
σ_y (Std. Error)	17.2731	
Δ (delta)	140.6259	

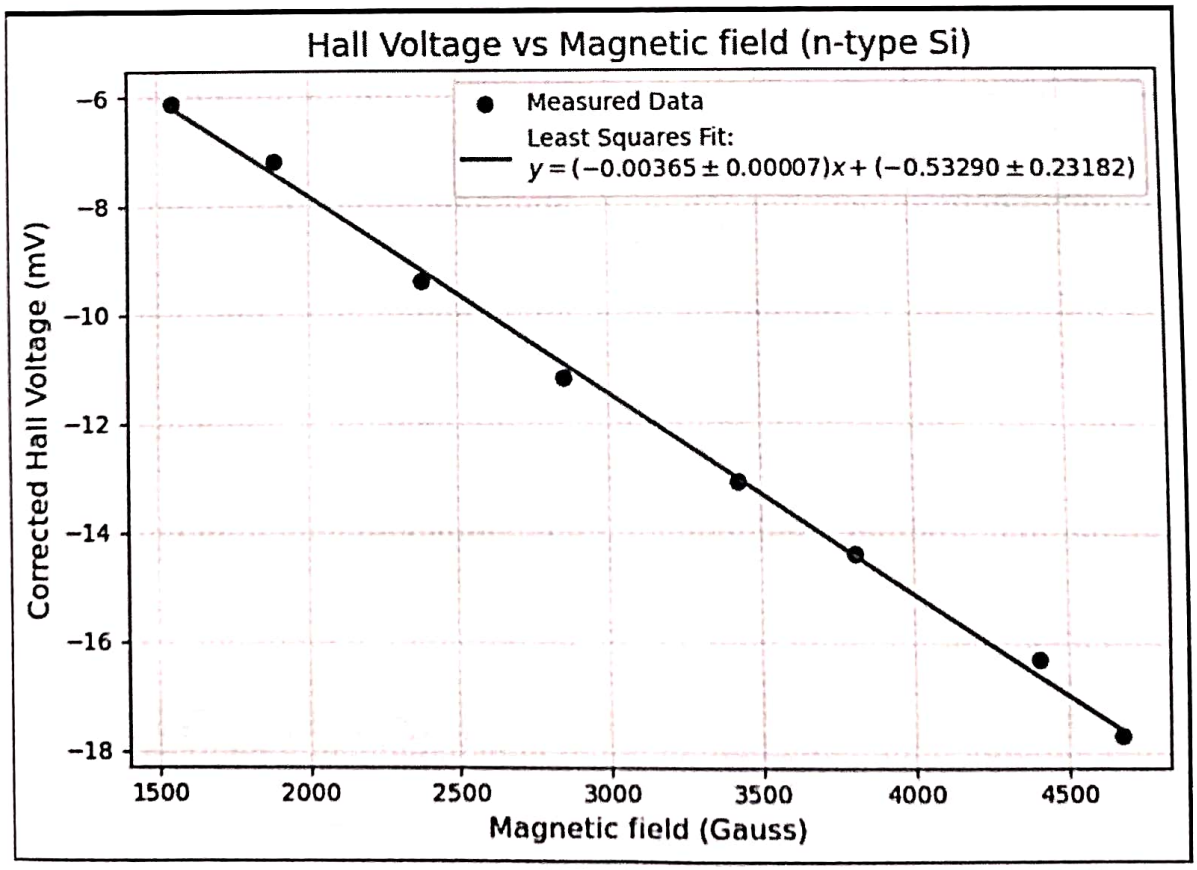


for Table - (III) n-type Si (V_h v/s H)

Input Data				
i	x	y	x^2	xy
1	1554.0	-6.1	2414916.0	-9479.4
2	1887.0	-7.2	3560769.0	-13586.4
3	2379.0	-9.4	5659641.0	-22362.6
4	2854.0	-11.2	8145316.0	-31964.8
5	3425.0	-13.1	11730625.0	-44867.5
6	3806.0	-14.4	14485636.0	-54806.4
7	4408.0	-16.3	19430464.0	-71850.4
8	4677.0	-17.7	21874329.0	-82782.9
Σ	24990.0	-95.4	87301696.0	-331700.4

Measured vs Fitted Values		
x	y (measured)	y (fit)
1554.0	-6.1	-6.2
1887.0	-7.2	-7.415
2379.0	-9.4	-9.209
2854.0	-11.2	-10.941
3425.0	-13.1	-13.024
3806.0	-14.4	-14.413
4408.0	-16.3	-16.609
4677.0	-17.7	-17.59

Fit Results & Statistical Errors		
Parameter	Value	Uncertainty
Slope (a_1)	-0.0036	±0.0001
Intercept (a_0)	-0.5329	±0.2318
σ_y (Std. Error)	0.2133	
Δ (delta)	73913468.0000	

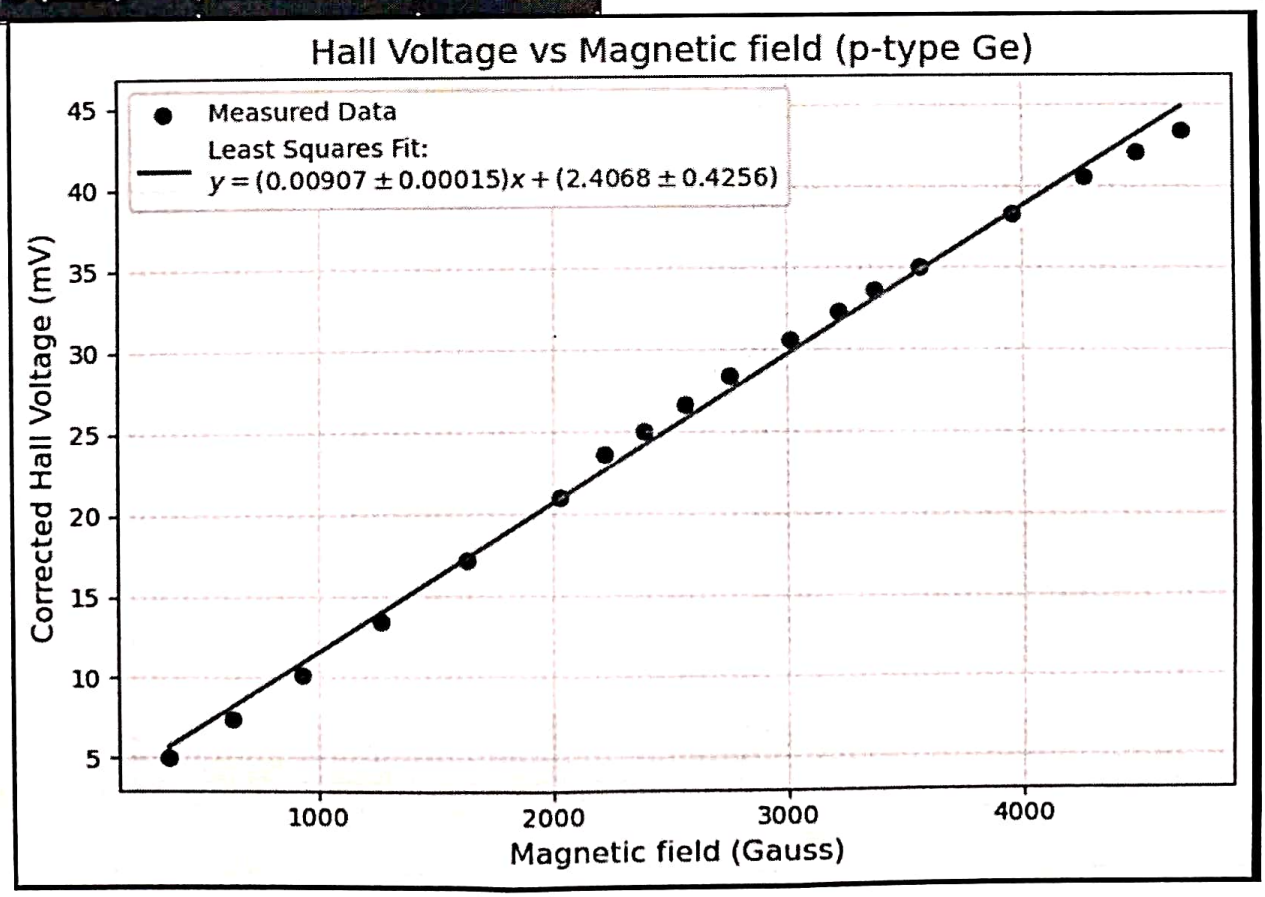


for Table (V) (p-type Ge) (V_n v/s H)

Input Data				
i	x	y	x^2	xy
1	365.0	5.0	133225.0	1825.0
2	635.0	7.4	403225.0	4699.0
3	936.0	10.2	876096.0	9547.2
4	1269.0	13.4	1610361.0	17004.6
5	1634.0	17.1	2669956.0	27941.4
6	2030.0	20.9	4120900.0	42427.0
7	2220.0	23.5	4928400.0	52170.0
8	2395.0	25.0	5736025.0	59875.0
9	2569.0	26.6	6599761.0	68335.4
10	2759.0	28.3	7612081.0	78079.7
11	3013.0	30.5	9078169.0	91896.5
12	3219.0	32.3	10361961.0	103973.7
13	3377.0	33.6	11404129.0	113467.2
14	3568.0	35.0	12730624.0	124880.0
15	3964.0	38.2	15713296.0	151424.8
16	4265.0	40.5	18190225.0	172732.5
17	4487.0	42.1	20133169.0	188902.7
18	4677.0	43.4	21874329.0	202981.8
Σ	47382.0	473.0	154175932.0	1512163.5

Measured vs Fitted Values		
x	y (measured)	y (fit)
365.0	5.0	5.717
635.0	7.4	8.165
936.0	10.2	10.895
1269.0	13.4	13.915
1634.0	17.1	17.225
2030.0	20.9	20.816
2220.0	23.5	22.539
2395.0	25.0	24.126
2569.0	26.6	25.703
2759.0	28.3	27.426
3013.0	30.5	29.73
3219.0	32.3	31.598
3377.0	33.6	33.031
3568.0	35.0	34.763
3964.0	38.2	38.354
4265.0	40.5	41.083
4487.0	42.1	43.097
4677.0	43.4	44.82

Fit Results & Statistical Errors		
Parameter	Value	Uncertainty
Slope (a_1)	0.0091	±0.0001
Intercept (a_0)	2.4068	±0.4256
σ_y (Std. Error)	0.7892	
Δ (delta)	530112852.0000	

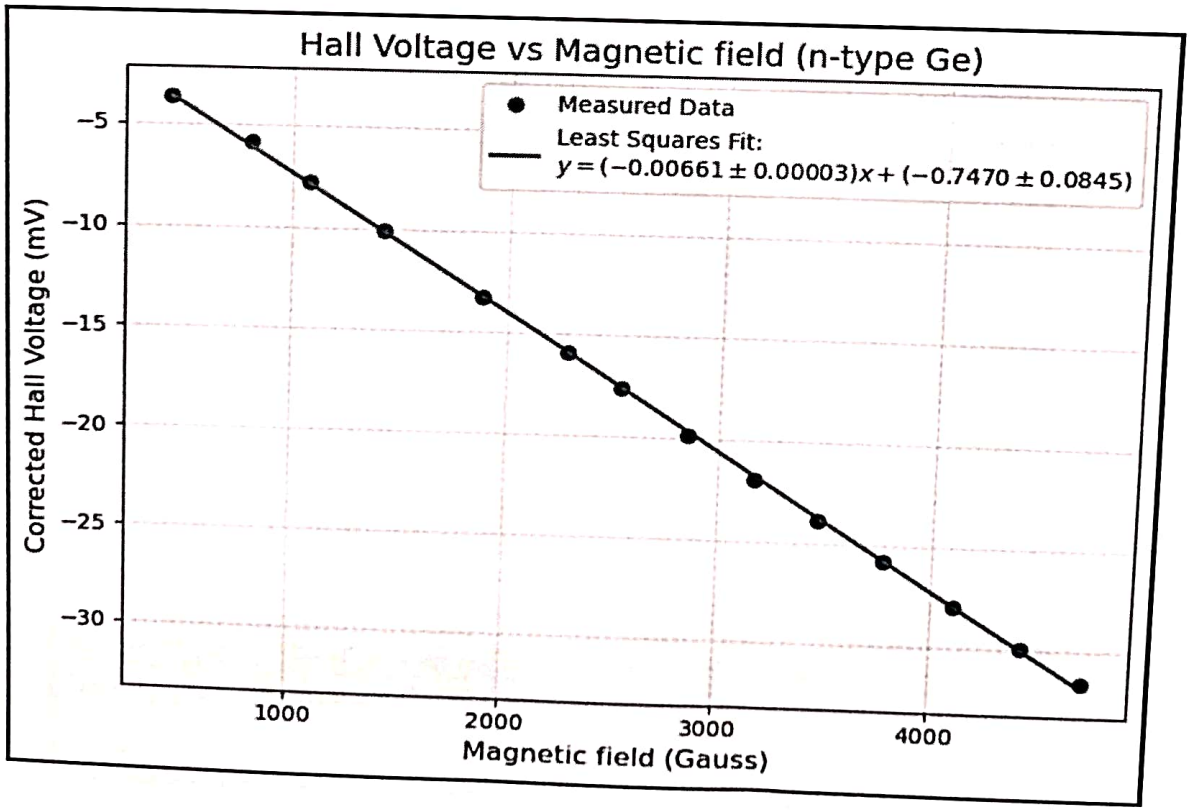


for Table - IV (n-type Ge) (V_H v/s H)

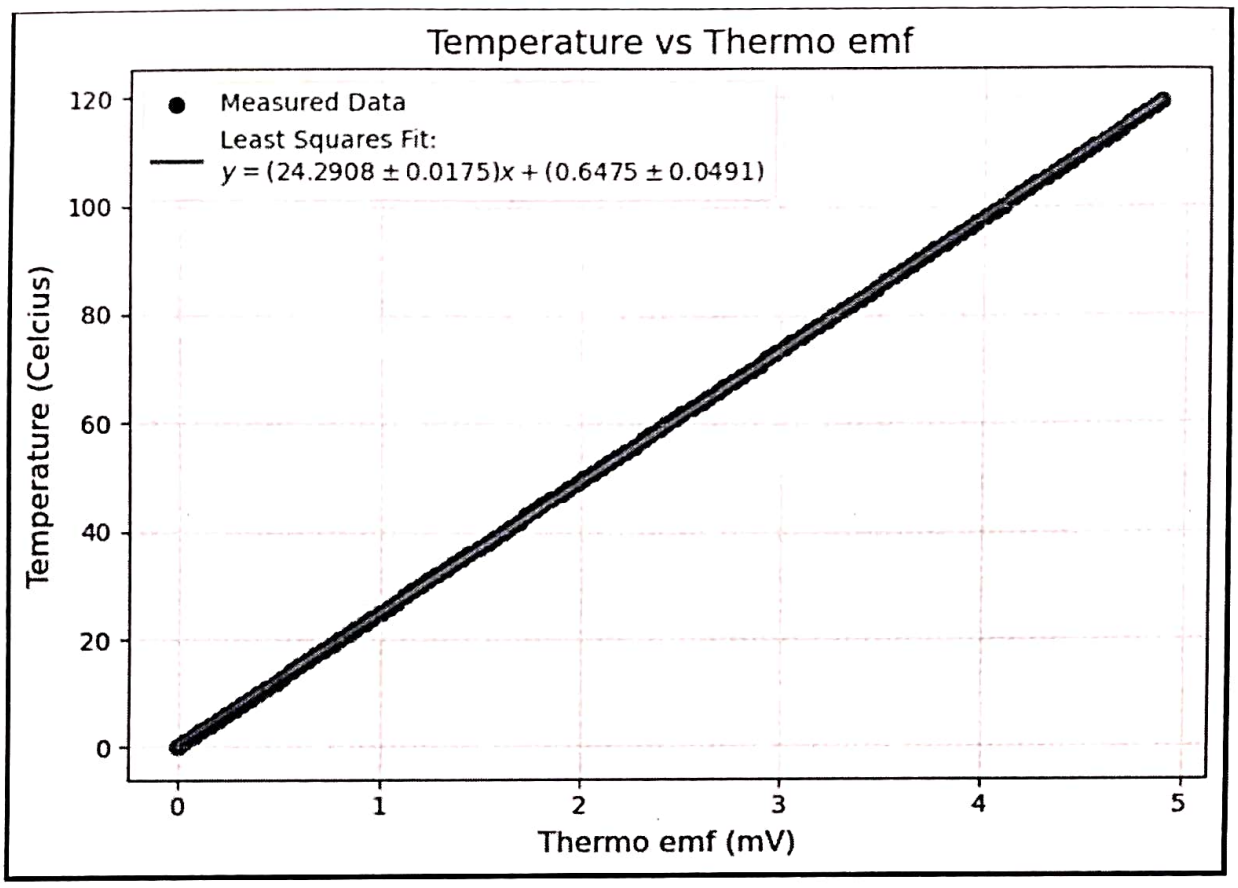
Input Data				
i	x	y	x^2	xy
1	444.0	-3.7	197136.0	-1642.8
2	809.0	-5.9	654481.0	-4773.1
3	1079.0	-7.8	1164241.0	-8416.2
4	1427.0	-10.1	2036329.0	-14412.7
5	1887.0	-13.3	3560769.0	-25097.1
6	2284.0	-15.9	5216656.0	-36315.6
7	2537.0	-17.6	6436369.0	-44651.2
8	2854.0	-19.8	8145316.0	-56509.2
9	3171.0	-21.9	10055241.0	-69444.9
10	3473.0	-23.8	12061729.0	-82657.4
11	3774.0	-25.8	14243076.0	-97369.2
12	4107.0	-27.9	16867449.0	-114585.3
13	4424.0	-29.9	19571776.0	-132277.6
14	4709.0	-31.6	22174681.0	-148804.4
Σ	36979.0	-255.0	122385249.0	-836956.7

Measured vs Fitted Values		
x	y (measured)	y (fit)
444.0	-3.7	-3.683
809.0	-5.9	-6.097
1079.0	-7.8	-7.882
1427.0	-10.1	-10.184
1887.0	-13.3	-13.226
2284.0	-15.9	-15.851
2537.0	-17.6	-17.524
2854.0	-19.8	-19.62
3171.0	-21.9	-21.717
3473.0	-23.8	-23.714
3774.0	-25.8	-25.704
4107.0	-27.9	-27.907
4424.0	-29.9	-30.003
4709.0	-31.6	-31.888

Fit Results & Statistical Errors		
Parameter	Value	Uncertainty
Slope (a_1)	-0.0066	±0.0000
Intercept (a_0)	-0.7470	±0.0845
σ_y (Std. Error)	0.1421	
Δ (delta)	345947045.0000	

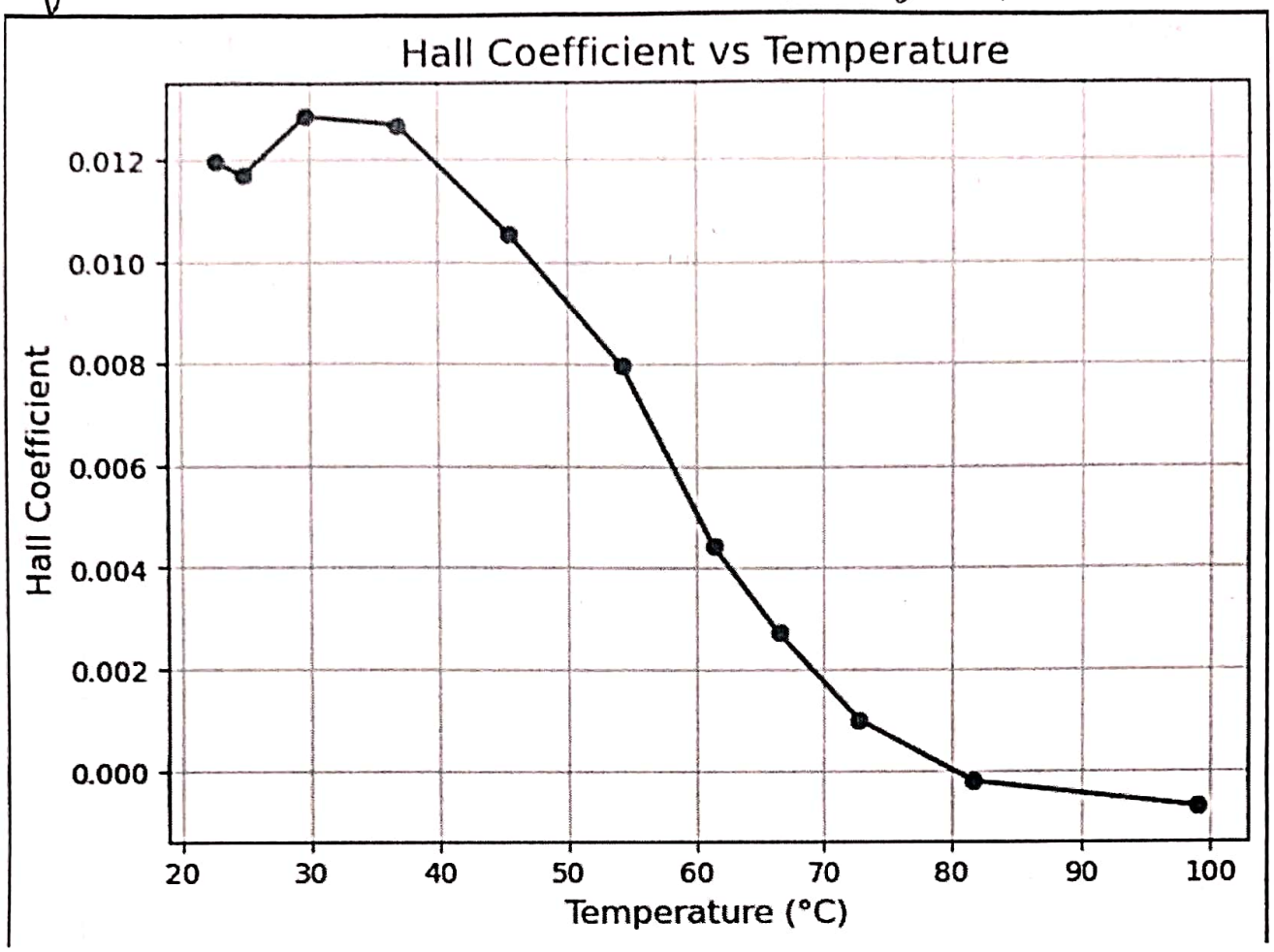


for Table from manual :- Temp v/s Thermo emf



Fit Results & Statistical Errors		
Parameter	Value	Uncertainty
Slope (a_1)	24.2908	±0.0175
Intercept (a_0)	0.6475	±0.0491
σ_y (Std. Error)	0.2729	
Δ (delta)	29282.2124	

for Table (I) :- R_H v/s Temp for (p-type Ge).



Calculations :-

(I) Magnetic field ~ Coil current linear calibration.

From the linear fit of Magnetic field B (Gauss) v/s Coil current I (mA), we obtain the linear relation :

$$B = (1585 \pm 5.05)I + (-31.15 \pm 9.59)$$

This is obtained after incorporating the offset due to residual magnetic field due to previous use of the magnet. This relation is used further in the experiment to calculate B from I and the residual is subtracted. The least squares fit formulae to calculate slope, intercept & their uncertainities are mentioned in Error Analysis section. The figure & error analysis tables for the plot are attached.

(II) Hall voltage ~ Probe current @ room temperature

i) n-Si sample :

we obtain from least squares fit, (tables attached) between Corrected Hall voltage (mV) v/s Magnetic field (Gauss)

slope = (-0.00365 ± 0.00007)

~~intercept = -0.53290 ± 0.23182~~

~~Working~~ Formula for Hall coefficient :-

$$R_H = \frac{V_y t}{I_x H}$$

t = thickness of sample

$t = 0.5$ mm

I_x = probe current

$I_x = 1.69$ mA

$$R_H = \frac{(\text{slope}) \times t}{I_x}$$

$$R_H = \frac{-0.00365 \times 0.5 \times 10}{1.69} = -0.0108 \ \frac{m^3}{C}$$

ii) n-type Ge :-

Similarly, the linear fit plot of Hall voltage (corrected) v/s Magnetic field (Gauss) for n-type Germanium sample (attached) gives a slope = -0.00661 ± 0.00003

$I_x = 3.24$ mA

$t = 0.5$ mm

$$R_H = \frac{(\text{slope}) \times t}{I_x}$$

$$= \frac{-0.00661 \times 0.5 \times 10}{3.24}$$

$$R_H = -0.6102 \ \frac{m^3}{C}.$$

iii) p-type Ge sample :-

Similarly, the linear fit for ~~volt~~ corrected Hall voltage v/s Magnetic field (Gauss) for p-type Germanium sample gave a +ve slope,

slope = 0.00907 ± 0.00015

$t = 0.5$ mm

$I_x = 3.63$ mA

$$R_H = \frac{(\text{slope}) \times t}{I_x}$$

$$= \frac{0.00907 \times 0.5 \times 10}{3.63} = +0.0124 \ \frac{m^3}{C}.$$

Error Analysis :-

① Least square fitting error :-

The linear least squares fitting fits the data points into an equation of the form $y = ax + b$.

The loss function which is minimized is

$$\mathcal{L}(a, b) = \sum_{i=1}^{N} (\hat{y}_i - (ax_i + b))^2$$

$\hat{y}_i$ = true value.

a, b = parameters.

Choosing optimal parameters a & b to minimize the loss function

$$\frac{\partial \mathcal{L}}{\partial a} = -2\sum_{i=1}^{N} x_i\left(y_i - (ax_i + b)\right)^2 = 0$$

$$\frac{\partial \mathcal{L}}{\partial b} = -2\sum_{i=1}^{N}\left(y_i - (ax_i + b)\right)^2 = 0$$

N = no. of observations $\{x_i, y_i\}_{i=1}^{N}$ = Data points

$$\Rightarrow \left\{\begin{aligned} a\sum_{i=1}^{N} x_i^2 + b\sum_{i=1}^{N} x_i &= \sum_{i=1}^{N} x_i y_i \\ a\sum_{i=1}^{N} x_i + bN &= \sum_{i=1}^{N} y_i \end{aligned}\right\}$$

Solving the linear system with two equations & two unknowns, gives a & b.

Error in y, $\sigma_y = \sqrt{\frac{1}{(N-2)}\sum_{i=1}^{N}\left(y_i - (ax_i + b)\right)^2}$

Error in slope (a), $\sigma_a = \sigma_y\sqrt{\frac{N}{\Delta}}$

where $\Delta = N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2$

Error in intercept (b), $\sigma_b = \sigma_y\sqrt{\frac{\sum_{i=1}^{N} x_i^2}{\Delta}}$

(II) Error propagation :-

i) n-type Si sample :-

We perform the calculation for slope of corrected Hall voltage v/s Magnetic field (Gauss), it gives, (mV)

slope = a_1 = -0.00365

$\Delta a_1 = \sigma_y\sqrt{\frac{N}{\Delta}} = 0.00007$

t = thickness of sample ($\because$ Assuming $\Delta t = 0$).

$\Delta I_x = 0.01$ mA (least count) $\qquad I_x = 1.69$ mA

$$R_{H_1} = \left(\frac{V_y}{H}\right)\frac{t}{I_x} = \frac{\text{slope} \times t}{I_x} = \frac{a_1 t}{I_x}.$$

$$\Delta R_{H_1} = \sqrt{\left(\frac{\partial R_{H_1}}{\partial a_1}\cdot \Delta a_1\right)^2 + \left(\frac{\partial R_{H_1}}{\partial I_x}\cdot \Delta I_x\right)^2}$$

$$= \sqrt{\left(\frac{t}{I_x}\cdot \Delta a_1\right)^2 + \left(\frac{-a_1 t}{I_x^2}\Delta I_x\right)^2} = \sqrt{\left(\frac{a_1 t}{I_x}\cdot\frac{\Delta a_1}{a_1}\right)^2 + \left(\frac{-a_1 t}{I_x}\cdot\frac{\Delta I_x}{I_x}\right)^2}$$

$$= |R_{H_1}| \sqrt{\left(\frac{\Delta a_1}{a_1}\right)^2 + \left(\frac{\Delta I_x}{I_x}\right)^2} = 0.0108\sqrt{\left(\frac{0.00007}{0.00365}\right)^2 + \left(\frac{0.01}{1.69}\right)^2}$$

$$\Delta R_{H_1} = 0.0002 \ \frac{m^3}{C}.$$

ii) n-type Ge sample :-

Calculating the error in slope for corrected Hall voltage (mV) v/s Magnetic field (Gauss) plot, we obtain,

$$\text{slope} = a_2 = -0.00661$$

$$\Delta a_2 = \sigma_y \sqrt{\frac{N}{\Delta}} = 0.00003$$

Assuming $\Delta t = 0$ (since t was given)

$\Delta I_x = 0.01$ mA (least count)

$$R_{H_2} = \frac{V_y t}{I_x H} = \frac{a_2 t}{I_x}$$

Similarly, $$\Delta R_{H_2} = |R_{H_2}| \sqrt{\left(\frac{\Delta a_2}{a_2}\right)^2 + \left(\frac{\Delta I_x}{I_x}\right)^2}$$

$$\Delta R_{H_2} = \cancel{0.00661}\ 0.0102 \sqrt{\left(\frac{0.00003}{0.00661}\right)^2 + \left(\frac{0.01}{3.24}\right)^2}$$

$$\Delta R_{H_2} = 0.0001 \ \frac{m^3}{C}$$

iii) p-Type Ge sample:-

Calculating the error in ~~slope~~ Hall coefficient for p-type Ge sample

Slope $= a_3 = 0.00907$

$\Delta t = 0$ (assuming)

$\Delta I_x = 0.01$ mA (least)

$I_x = 3.63$ mA

$$\Delta a_3 = \sigma_y \sqrt{\frac{N}{\Delta}} = 0.00015$$

$$R_{H_3} = \frac{V_y t}{I_x H} = \frac{a_3 t}{I_x}$$

Similarly,

$$\Delta R_{H_3} = R_{H_3} \sqrt{\left(\frac{\Delta a_3}{a_3}\right)^2 + \left(\frac{\Delta I_x}{I_x}\right)^2}$$

$$\Delta R_{H_3} = 0.0124 \sqrt{\left(\frac{0.00015}{0.00907}\right)^2 + \left(\frac{0.01}{3.63}\right)^2}$$

$$\Delta R_{H_3} = 0.0002 \ \frac{m^3}{C}.$$

Results & Conclusion :-

The Hall coefficients for 3 samples were calculated at room temperature. They are as follows:-

i) n-type Si sample $R_{H_1} = (-0.0108 \ \frac{m^3}{C} \pm 0.0002) \ \frac{m^3}{C}$

ii) n-type Ge sample $R_{H_2} = (-0.0102 \pm 0.0001) \ \frac{m^3}{C}$

iii) p-type Ge sample $R_{H_3} = (+0.0124 \pm 0.0002) \ \frac{m^3}{C}$

The negative Hall coefficient symbolises negative charge carriers (n-type doping), while positive sign denotes p-type doping. Therefore, majority charge carriers are identifi~~cationed~~ed from the sign of Hall coefficient.

Also, this experiment verifies the linear relation b/w Hall voltage & applied magnetic field $V_H \propto H$, for a fixed probe current.

For the p-type Ge sample, the Hall coefficient decreased with increase in temperature & eventually changed sign verifying the Hall inversion in p-type semiconductors ~~wit~~ due to temperature variation.

Minor deviations can be attributed to the sources of error discussed, ~~below~~. Overall, the results are consistent with the theory of Hall effect in semiconductors.

Sources of Error :-

i) Misalignment of the sample with respect to magnetic field (must be perpendicular)

ii) Inaccuracy in temperature measurements due to thermal gradients b/w the sample & thermocouple.

iii) Electronic noise due to impedence of measuring instruments.

* Result (continued ...)

Also, the carrier density was calculated for given samples

i) for n-type Si sample, $n_1 = (5.78 \pm 0.11) \times 10^{20}\ m^{-3}$

ii) for n-type Ge sample, $n_2 = (6.11 \pm 0.06) \times 10^{20}\ m^{-3}$

iii) for p-type Ge sample, $n_3 = (5.03 \pm 0.08) \times 10^{20}\ m^{-3}$

These values were calculated for samples at room temperature.