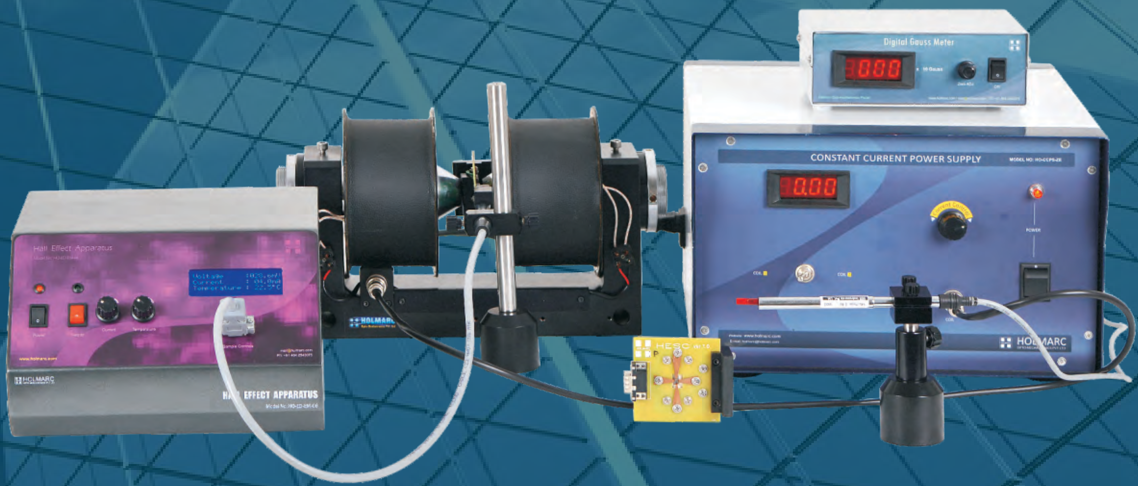
HOLMARC
OPTO-MECHATRONICS LTD

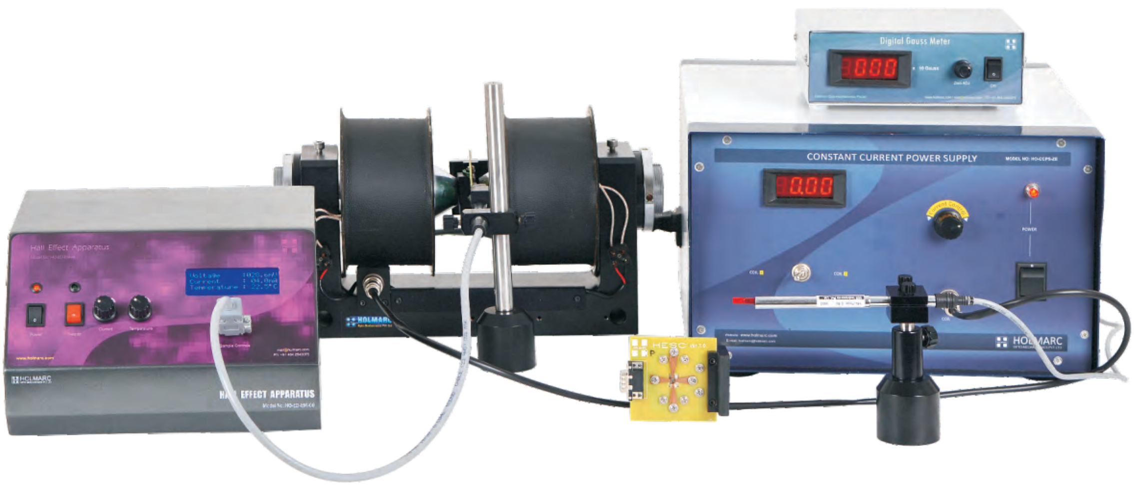
Hall Effect Apparatus

Model: HO-ED-EM-06



INSTRUCTION MANUAL

Instruction Manual



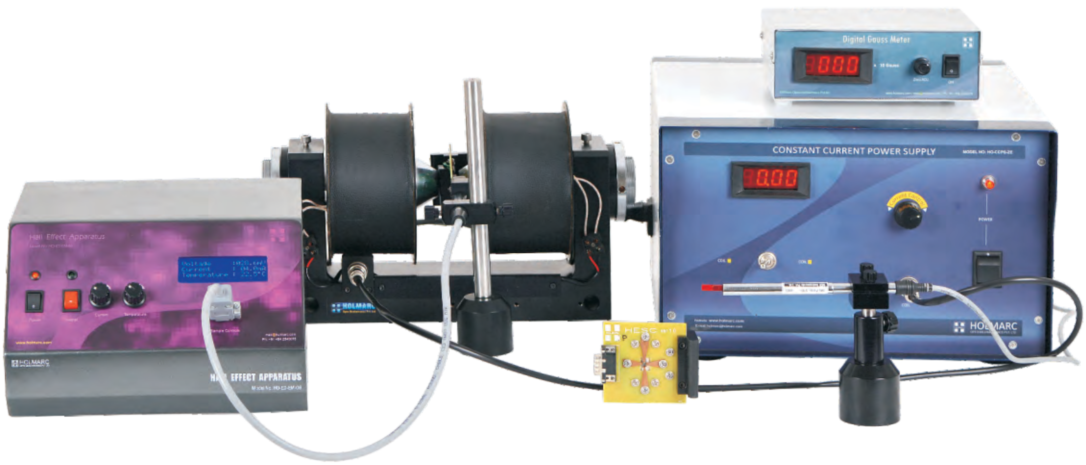
Hall Effect Apparatus

Model: HO-ED-EM-06

CONTENT Page

Product Features

Holmarc's Hall Effect Apparatus, Model No: **HO-ED-EM-06** can be used for the determination of Hall coefficient, concentration of charge carriers, mobility of charge carriers, field dependence and to find the type of a semiconducting material. This highly modern and easy-to-use equipment system for determining the conducting mechanisms in semiconductors guarantees a simple and clear experiment set-up, a minimum preparation time and safe execution of the experiments.



The system consists of two cartridges, each of which is equipped with a 'p' and 'n' doped germanium crystal .The cartridges can be plugged easily and safely into the D connector system. The Hall Effect set up provides all operating parameters for the samples and displays the Hall voltage, sample current as well as the sample temperature. The doped Germanium samples are used to measure the Hall-voltage as a function of the sample current and the sample temperature.

The Experiments Possible using our setup are :

- Measurement of Hall voltage as a function of
    - a) Magnetic flux density B
    - b) Sample temperature T
    - c) Sample current I

    for n and p-doped germanium crystal.
- The density and mobility of charge carriers.
- Hall coefficient of a semi conductor crystal.

Getting Started

a. Safety instructions

- Read the complete operating instruction before starting the experiment, it avoids unnecessary damage to the instrument.
- Try to operate the instrument in a moisture free atmosphere to avoid the risk of explosion.

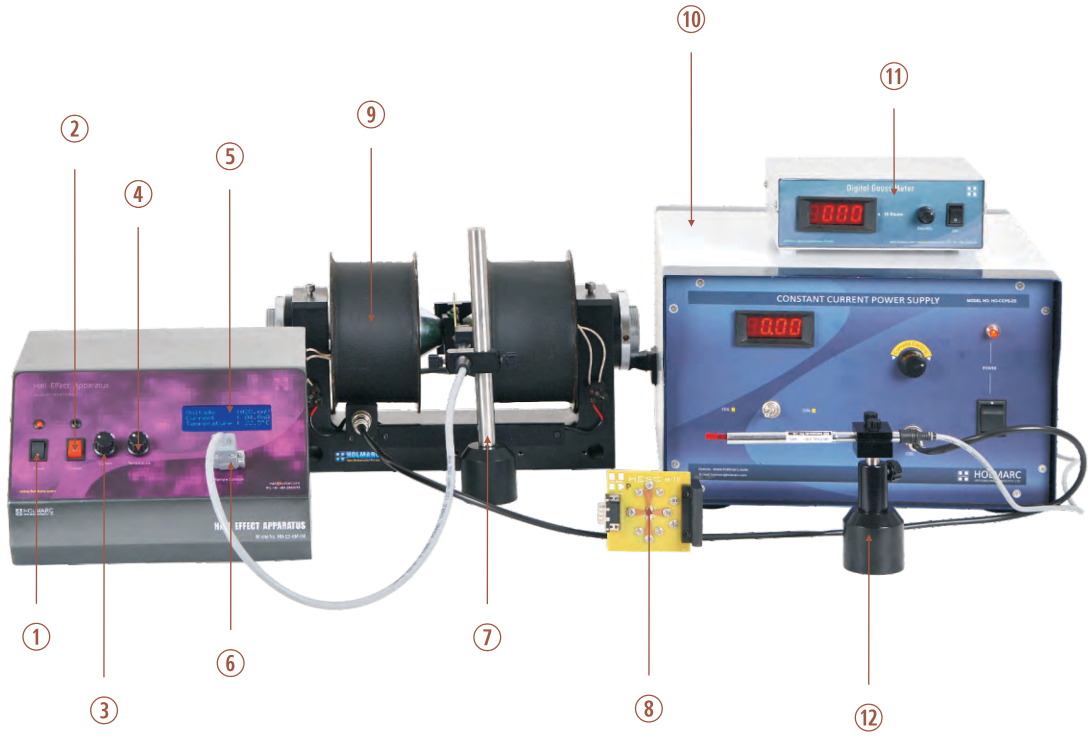
Caution ! : Be careful while handling the Hall Effect cartridge it may heat up during the operation and can cause burns on your hands. Do not increase the temperature across cartridge above 60°C.

- Do not try to switch on the instrument if you find any signs of damage to both instrument and power code.
- Only use the instrument for the purpose for which it is designed.
- The gauss meter probe is highly fragile so please be careful with it.
- Handle the n type and p type germanium crystal cartridges carefully to avoid breakage.
- Switch OFF the Hall Effect set up after every set of measurements Otherwise, errors may arise.

Before doing this experiment please go through the whole theory behind this, remember these key words...

- *semiconductors*
- *extrinsic semiconductors*
- *lorentz force*

b. Parts Listing



1. Power switch of Hall effect Control unit
2. Heater On / Off Switch
3. Sample Current Controller
4. Sample Temperature Controller
5. Digital display for Voltage, Current and Temperature
6. Sample Control Probe
7. Sample Holder with rigid base
8. Hall Effect cartridge
9. Electromagnet
10. Electromagnet Power supply
11. Digital Gauss Meter
12. Gauss Probe Mount

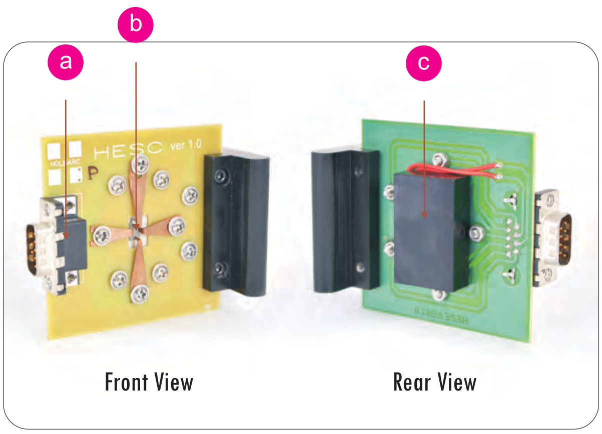
c. Quick Start

1. Hall Effect Control Unit

Current	:	0 - 10 mA
Voltage	:	0 - 200.0 mV
Temperature	:	Ambient - 100°C
Display	:	3½ digits, 7 segment LCD DPM
Input voltage	:	230 V / 50 Hz

2. Sample Holder with Rigid base

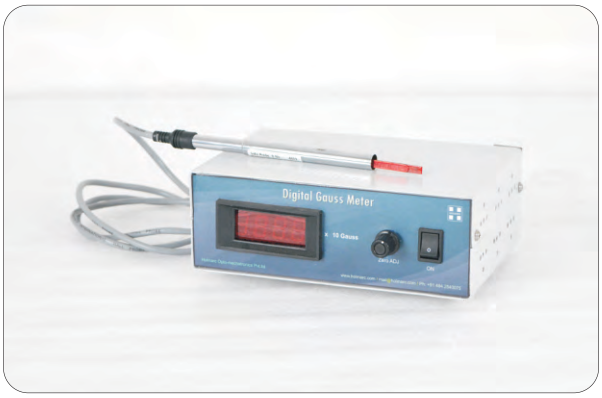
6. Hall Effect Cartridge



Crystal : n-type and p-type lightly doped Germanium (Ge)

a. D connector socket
b. Ge Crystal
c. Heating Unit with Temperature Sensor

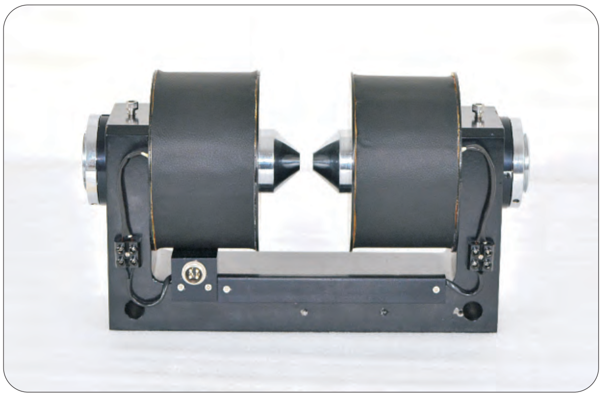
4. Digital Gauss Meter



Range	:	0 - 20 kG
Accuracy	:	± 0.5%
Display	:	31/2 digit, 7 segment LED
Power	:	220V +/- 10%, 50Hz
Transducer	:	Indium Arsenide (InAs)

5. Gauss Probe Mount

6. Electromagnet



Field Density	:	0 - 5,000 ±5% gauss in an air - gap of 20 mm.
Yoke material	:	Mild Steel

7. Electromagnet Power supply

Power input	:	230 V - 50 Hz
Current	:	0 - 3.5 A variable

8. Electromagnet Connecting Cable

8. AC Power code

:: Fundamentals

Aim :

- To measure the Hall voltage as a function of
  - a) Sample current I_H
  - b) Sample temperature T_H,

  for n and p-doped germanium crystal
- To determine the hall coefficient of the doped germanium semiconductor crystal.
- To determine mobility and density of charge carriers of the same semiconductor crystal.

Theory :

Usually materials with a lower carrier density will exhibit the Hall Effect more strongly for a given current. Semiconductor materials such as silicon, germanium, gallium-arsenide etc... provides the low carrier densities needed to realize them as practical transducer elements. Semiconductor materials have carrier concentrations that are orders of magnitude lower than those found in metals. This is because in metals most atoms contribute a conduction electron, whereas the conduction electrons in semiconductors are more tightly held. Electrons in a semiconductor only become available for conduction only when they acquire enough thermal energy to reach a conduction state; this shows that the carrier concentration depends highly on temperature.

As we know doped semiconductors known as extrinsic semiconductors are widely used in applications due to its higher conductivity. As we add impurities to a pure semiconductor the number of charge carriers, either electrons (n - type) or holes (p - type), which take part in conduction becomes higher and its conductivity increases. Usually to measure the Hall Effect properties we make use of doped semiconductors. Measurements of Hall effects are effective to know the electronic properties of solids or liquids.

When a semiconductor sample is subjected to mutually perpendicular electric and magnetic field, a voltage develops in a direction that is perpendicular to both the electric and magnetic fields, this is known as Hall Effect.

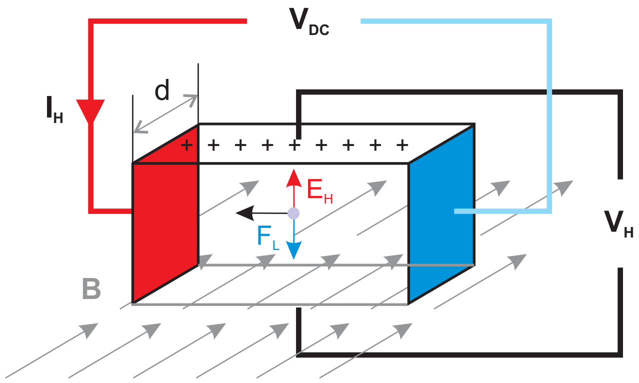


Fig. : Hall Effect schematically: Inside a charge carrying conductor which is located in the magnetic field B the Lorentz force F_L is causing an electrical field E_H resulting in a Hall voltage V_H (I_H denotes the transverse current).

Consider a current-carrying rectangular slab of a semiconductor placed in a magnetic field 'B' perpendicular to the direction of the current 'I_H' and a transverse electric field 'E_H'. Since the charge carriers experience a force due to the external magnetic field, known as the Lorentz force and they will be accelerated towards one side of the current carrying conductor(can be predicted by right hand rule), but will be trapped inside the conductor. And this produces a potential difference 'V_H', known as Hall Voltage in a direction perpendicular to both the applied electric and magnetic fields.

And it can be expressed using the equation,

$$V_H = \frac{1}{ne} \frac{BI_H}{d} \quad \text{.........................} \quad (1)$$

where,

d is the thickness of the semiconductor sample

n is the concentration of charge carriers

and e is the charge of an electron = 1.6 X 10^{-19} C

The factor 1/ne is called the Hall coefficient, R_H,

$$R_H = \frac{1}{ne} \quad \text{.........................} \quad (2)$$

Therefore, once the Hall Coefficient is known, the concentration of charge carriers 'n' can be found. The sign of the Hall coefficient is determined by the polarity of the charge carriers: a negative sign implies carriers with a negative charge ("normal Hall effect"), and a positive sign, carriers with a positive charge ("anomalous Hall effect"),which is the main application of Hall Effect experiment, it reveals the type of charge carrier in a semiconducting material. The Hall coefficient always depends on the material and also on the temperature of the material. For metals R_H is very small, however, for semiconductors R_H become significantly large. The polarity of the charge carriers can be determined from the direction of the Hall voltage.

Combining Equations (1) and (2) R_H becomes,

$$R_H = \frac{V_H}{I_H} \frac{d}{B} \quad \text{......................... } (3)$$

The Hall Coefficient can also be used to find the mobility of the charge carriers 'μ',

$$\mu = R_H . \sigma \quad \text{....................... } (4)$$

where, $\sigma = ne\mu$ is the conductivity of the material

By plotting a graph between I_H and V_H at a particular magnetic field and by finding its slope one can measure the hall coefficient of a semiconducting material,thus the carrier concentration and its mobility.

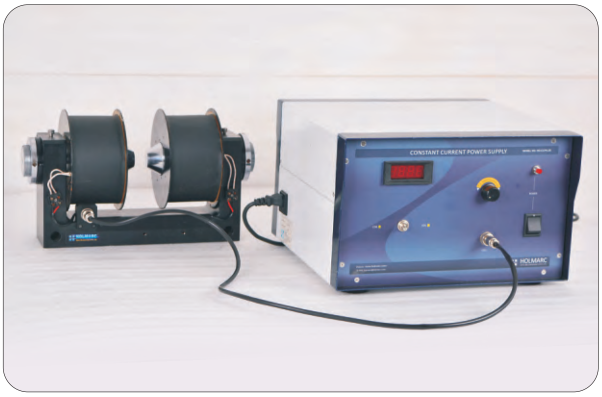
Experimental Set-up & Procedure

A. Calibration of Magnetic flux density :

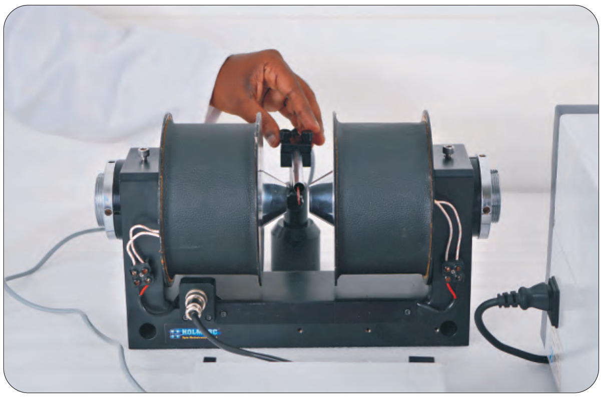
1. Connect the power code of Digital Gauss meter to the socket.

2. Mount the Hall probe of the Digital Gauss meter in the probe holder. Pull back the cover on the probe to expose the sensor tip.

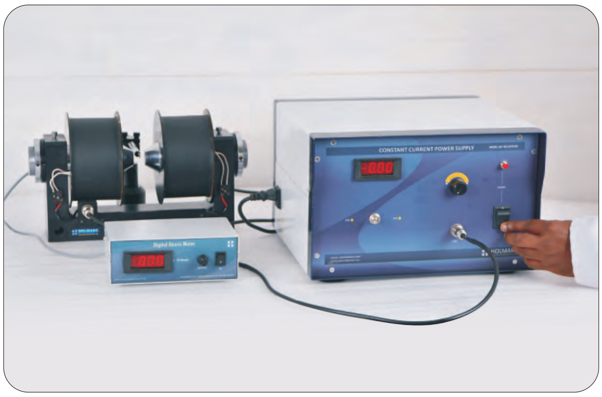
3. Connect the Constant Current Power Supply to Electromagnet using the provided cable.

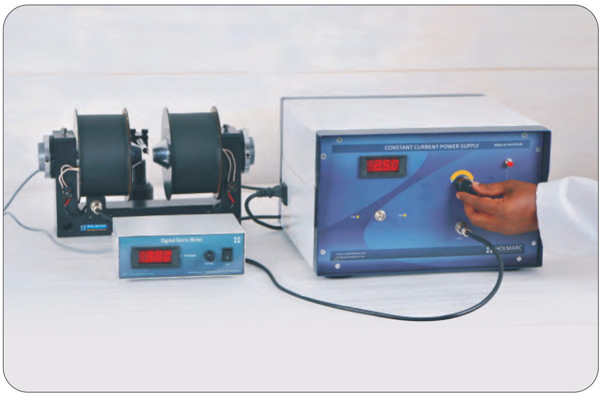


4. Introduce the gauss meter probe at the centre of the air gap between the pole pieces of the electromagnet such that the surface of the probe is parallel to the pole pieces. The transducer (Indium Arsenide) is at the tip of the probe, therefore the tip of the probe should be at the centre of the air gap (before introducing it into the air gap switch on the gauss meter using the zero correction knob on it make the magnetic field shown on it to zero).



5. Switch on the Digital Gauss meter and the electromagnet power supply, (Before switching it on make sure that the position of the current changing knob is at minimum). Then slowly increase the current through the electromagnet from zero to its maximum value in regular intervals and note the corresponding magnetic field reading from the digital gauss meter.





6. Plot the graph between the current (I, on x-axis) and the magnetic flux density (B, on y-axis).

B. Hall voltage as a function of sample current, I_H

1. Connect the Power cable to Hall Effect Control Unit. Insert the Hall Effect Cartridge into multi pin socket of the sample holder. Make sure that the cartridge perfectly fit into the socket and the circuit board is correctly aligned.

2. Connect the sample control probe to Hall Effect Control unit through D connector and turn on the Hall Effect set up.

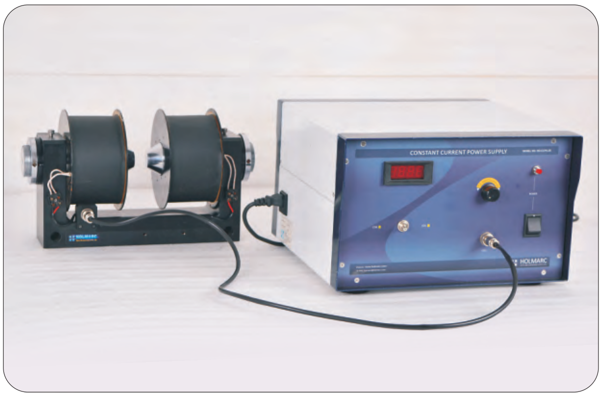
3. Now the display of the hall effect control unit shows 'HOLMARC HALL EFFECT APPARATUS' and after a moment it automatically shows the present value of current, 'I_H', Hall voltage 'V_H', and the temperature 'T_H' of the sample. Reduce the current to minimum by adjusting the current control knob.

4. To observe the hall voltage as a function of sample current vary the sample current from zero to a maximum value and record the corresponding

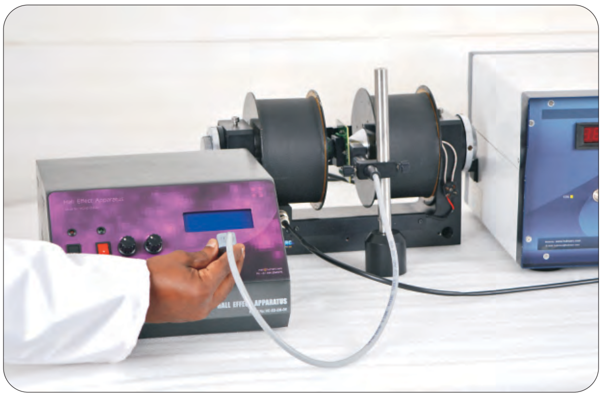
Plot a graph with sample current IH on x-axis and the corresponding Hall voltage VH on y-axis.

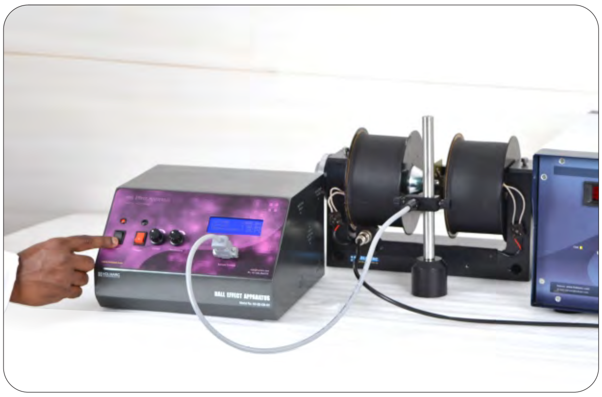
C. Variation of Hall voltage with current at a particular magnetic field

1. Variation of Hall voltage with current at a particular magnetic field



2. Introduce the Hall Cartridge at the centre of the air gap between the pole pieces of the electromagnet such that the surface of the Cartridge is perpendicular to the pole pieces. The crystal in the probe should be at the centre of the air gap without touching poles pieces. Connect the probe to the control unit using the D-connector. Then turn on the Hall Effect control unit.





3. Now set the sample current to zero by turning the current control knob in front of the Hall Effect control unit. Then switch on the constant current power supply and set the current 'I' to a particular value say 0.6A, and note the corresponding magnetic field (we have already calibrated the electromagnet before so note the value of magnetic field that we have obtained for the selected

4. Then start increasing the sample current in equal steps and note the corresponding hall voltage from the control unit.

Now find difference between the hall voltage obtained when there weren't any magnetic field (as in section B) and hall voltage obtained when magnetic field is applied for each value of current applied. (ie; at B = 0 Gauss, I_H= 1 mA, Hall voltage V_H= 10.5 mV and at B = 1G, I_H = 1 mA itself V_H = 16.8 mA then Hall voltage at sample current I_H= 1 mA, V_H= 16.8 - 10.5 = 6.3 mV do the same to obtain hall voltage corresponding to any particular sample current).

Plot a graph between the sample current and the corresponding hall voltage, obtain a straight line and find the slope of the line at a particular point (obtain V_H / I_H). Find the hall coefficient using the equation and there by mobility and density of the charge carriers in the sample.

Repeat the experiment at a different magnetic field.

(You can also do the same experiment by fixing the sample current at any particular value and changing magnetic flux at regular intervals thus obtaining a relation between hall voltage, V_H and changing magnetic flux and, B).

Hall voltage as a function of temperature T

1. Carefully insert the Hall Cartridge into the attachment on the console. Connect the sample and Hall Effect control unit using the D connector. Turn on the control unit and set the sample current at a particular value, say 0.4mA.

2. Turn on the heater increase the temperature gradually and note corresponding hall voltage. Tabulate the hall voltage as a function of temperature and plot a graph with temperature on x-axis and the corresponding hall voltage at y - axis.

Observations and Calculations

Table 1: Calibration of Magnetic Field :

Sl No:	Current (A)	Magnetic Flux Density X 10 Gauss
1.		
2.		
3.		
4.		
5.		
6.		

Plot a graph with current on x - axis and magnetic flux density on y - axis

Table 2: Voltage as a function of sample current (without any magnetic field)

Sl No:	Current I (mA)	Voltage V(mV)
1.		
2.		
3.		
4.		
5.		
6.		

Plot graph with sample current on x - axis and sample voltage on y - axis.

Table 3 : Hall voltage as a function of sample current at a particular magnetic flux density

Applied magnetic flux = ... Gauss

Sl No:	Current I (mA)	Hall voltage(mV)
1.		
2.		
3.		
4.		
5.		
6.		

Sample details :

Sample : Germanium p - type or n - type

Thickness of the sample, d = 0.5 mm

Resistivity of the sample, ρ = 10 Ωcm

Conductivity of the sample, σ = 1 / ρ = ... $\Omega^{-1}cm^{-1}$

Magnetic flux selected for the experiment, B = ...Gauss

Slope of the graph between hall current and hall voltage at magnetic flux, B

$$\frac{V_H}{I_H} = \text{................} \; mV/mA$$

We have following equations to find the Hall coefficient, carrier

$$V_H = \frac{1}{ne} \frac{BI_H}{d}$$ and

The hall coefficient, $$R_H = \frac{1}{ne}$$

Consider e as charge of an electron, e = 1.6 x 10^{-19}

Comparing the two equations above, we have,

$$R_H = \frac{V_H}{I_H} \frac{d}{B} \text{ x } 10^8 \ cm^3 / Coulomb$$

(This 10^8 is multiplied to satisfy power variation occurs due to unit conversion).

Carrier Density

We get Carrier Density from the equation,

$$n = \frac{1}{R_H e} \ / cm^3$$

Carrier Mobility

We get Carrier Mobility can be obtained from the equation,

$$\mu = R_H . \sigma \quad cm^2 \ Volt^{-1} \ sec^{-1}$$

Table 4: Hall voltage VH as a function of Temperature, at I_H = 4mA

Trial no:	Temperature (T) °C	Hall Voltage(V_H) mV
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

Result :

Hall coefficient of the given sample, R_H = ... cm^3 $Coulomb^{-1}$

Carrier density of majority charge carriers, n = ... cm^3

Carrier Mobility μ = ... cm^2 $Volt^{-1}$ sec^{-1}

Experimental Example

Table 1: Calibration of magnetic field

Sl No:	Current (A)	Magnetic Flux Density X 10 Gauss
1	0.1	30
2	0.2	43
3	0.3	57
4	0.4	71
5	0.5	85
6	0.6	100
7	0.7	116
8	0.8	131
9	0.9	148
10	1.0	162
11	1.1	179
12	1.2	194
13	1.3	209
14	1.4	224
15	1.5	239
16	1.6	253
17	1.7	267
18	1.8	281
19	1.9	294
20	2	309
21	2.1	322
22	2.2	335
23	2.3	349
24	2.4	363
25	2.5	375
26	2.6	388
27	2.7	401
28	2.8	413
29	2.9	425
30	3	437
30.	3.1	449
1	3.2	461
0.2	3.3	473
0.3	3.4	485
0.4	3.5	498

Table 2: Voltage as a function of sample current (without magnetic field)

Sl No:	Current I (mA)	Voltage V(mV)
1	0.5	1.7
2	1	2.2
3	1.5	2.9
4	2	4.1
5	2.5	5.3
6	3	6.1
7	3.5	6.7
8	4	7.3
9	4.5	8
10	5	8.7
11	5.5	9.6
12	6	10.5
13	6.5	11.5
14	7	12.6
15	7.5	12.7
16	8	12.7
17	8.5	12.6
18	9	12.5
19	9.5	12.4

Table 3 : Hall voltage as a function of sample current (with applied magnetic field)

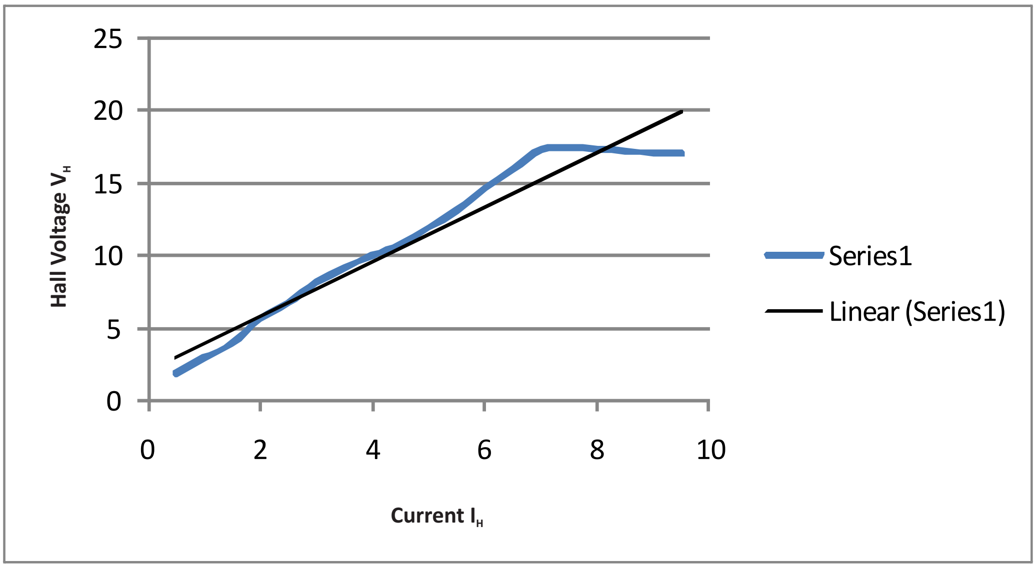
Applied magnetic flux, B = 1160 Gauss

Sl No:	Current I (mA)	Hall voltage(mV)
1	0.5	3.5
2	1	5.1
3	1.5	6.8
4	2	9.7
5	2.5	12
6	3	14.2
7	3.5	15.8
8	4	17.3
9	4.5	18.7
10	5	20.6
11	5.5	22.7
12	6	25.1
13	6.5	27.4
14	7	29.9
15	7.5	30.1
16	8	30
17	8.5	29.8
18	9	29.5
19	9.5	29.4

Subtracting hall voltage in table 2 from table 3, Hall voltage as a function of current

Sl No:	Current I (mA)	Hall voltage(mV)
1	0.5	1.8
2	1	2.9
3	1.5	3.9
4	2	5.6
5	2.5	6.7
6	3	8.1
7	3.5	9.1
8	4	10
9	4.5	10.7
10	5	11.9
11	5.5	13.1
12	6	14.6
13	6.5	15.9
14	7	17.3
15	7.5	17.4
16	8	17.3
17	8.5	17.2
18	9	17
19	9.5	17

Plotting graph between current (I_H) and Hall voltage(V_H)



Sample : Germanium p-type or n-type

Thickness of the sample, d = 0.5 mm

Resistivity of the sample, ρ = 10 Ωcm

Conductivity of the sample, σ = $1 / \rho = 1 / 10 = 0.1\ \Omega^{-1}\text{cm}^{-1}$

Applied magnetic flux, B = 1160 Gauss

Slope of the graph between hall current and hall voltage at magnetic flux, B

V_H / I_H = 1.877895 mV / mA

Hall coefficient R_H = $(V_H / I_H)\ (d / B) \times 10^8\ \text{cm}^3 / \text{Coulomb}$

R_H = $1.877895 \times (0.5 \times 10^{-1} / 1160)$

= $8.09437 \times 10^{-5}\ \text{VcmA}^{-1}\text{Gauss}^{-1}$

= $8.09437 \times 10^{-5} \times 10^{8}\ \text{cm}^3 / \text{Coulomb}$

= $8.09437 \times 10^{3}\ \text{cm}^3 / \text{Coulomb}$

We get Carrier Density from the equation,

n = $1 / (R_H\ e)\ \ / \text{cm}^3$

= $1 / (8.09437 \times 10^3 \times 1.6 \times 10^{-19})$

= 7.72 x1014 / cm^3

Carrier mobility can be obtained from the equation,

μ = $R_H.\sigma\ \ \text{cm}^2\,\text{Volt}^{-1}\ \text{sec}^{-1}$

μ = $8.09437 \times 10^3 \times 0.1$

= $809.437\ \text{cm}^2\,\text{Volt}^{-1}\,\text{sec}^{-1}$

Best of luck for your experiment...

Technical Support

Before you call the HOLMARC Technical Support staff, kindly gather the following information:

- If your problem is computer / software related, Please note:
  - Type of computer (make, model, speed)
  - What kind of problem you are facing (Technical details)

- If your problem is with the HOLMARC apparatus, Please note:
  - Title and model number (usually listed on the label)
  - Approximate age of apparatus
  - A detailed description of the problem / sequence of events
  - Have the manual in hand to discuss your queries

Feedback

If you have any comments regarding our product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, kindly inform us. HOLMARC appreciates any customer feedback. Your inputs help us evaluate and improve our product.

For technical support, contact us at
Ph: 91-484-254-0075
Fax: 91-484-254-3755
E-mail: mail@holmarc.com
Web: www.holmarc.com

Holmarc Limited Warranty

Every Holmarc Instruments and its accessories are warranted by HOLMARC OPTO-MECHATRONICS P LTD for a period of ONE YEAR from the date of original purchase.

Holmarc will repair or replace a product, or part thereof, found by Holmarc to be defective, provided the defective part is returned to Holmarc, with proof of purchase.

This warranty applies to the original purchaser and our distributors and is non-transferable.

Each returned part or product must include a written statement detailing the nature of the claimed defect, as well as the end user's name, address, and phone number.

This warranty is not valid in cases where the product has been abused or mishandled, where unauthorized repairs have been attempted or performed, or where depreciation of the product is due to normal wear-and-tear.

Holmarc specifically disclaims special, indirect, or consequential damages or lost profit which may result from a breach of this warranty. Any implied warranties which cannot be disclaimed are hereby limited to a term of one year from the date of original retail purchase.

Holmarc reserves the right to change product specifications or to discontinue products without notice.

Please refer our commercial invoice for warranty claim.

(Authorized Signatory)

HOLMARC
OPTO-MECHATRONICS PVT. LTD

Holmarc Opto-Mechatronics P Ltd has been organized as a provide of engineering tools for scientific research. Our company is equipped to meet most challenging and demanding requirements of scientific community with our manufacturing and development capabilities in optics, mechanics, electronics & software. At Holmarc, experienced engineers, designers & technicians work hand in hand to deliver state of the art engineering solutions to our clients.

All of us at Holmarc stay tuned to absorb changes in technology as fast as possible. We deliberately keep our technical skills as well as manufacturing infrastructure flexible and maintain a dynamic work culture throughout our operations.

We have distributors and collaborators in all parts of the world and are well equipped to serve world scientific community. We welcome queries irrespective of geographical and political boundaries.

HOLMARC

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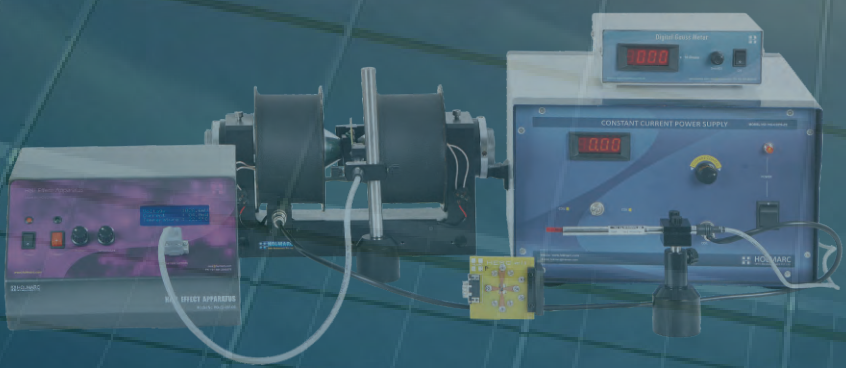

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