OPERATING INSTRUCTIONS

FOR

HALL EFFECT EXPERIMENTAL SET-UP

OMEGA TYPE ES-248

Manufacturer & Exporters

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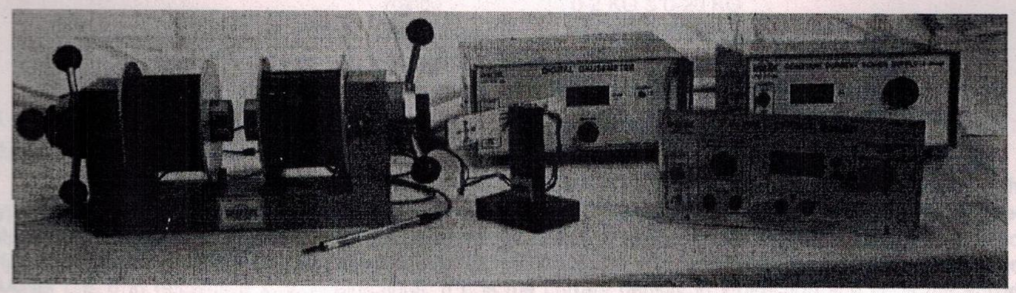
OMEGA TYPE ES-248 Experimental Set Up has been designed specifically for the study of Hall Effect in semiconductor and determination of allied parameters. The set-up consists of Hall Effect Board, Hall Probe, Electromagnet, Constant Current Power supply (0-4A), Digital Gauss Meter with Hall Probe.

The set up is complete in all respect and requires no other apparatus. Practical experience on this set up carries great educative value for Science and Engineering Students.



OBJECT

- Study of Hall Effect in semiconductor and determination of allied parameters.

FEATURES

- The complete Experimental Set-up consists of the following :

1. **HALL EFFECT BOARD (DIGITAL) :** **OMEGA TYPE HEB-248**

   It consists of a digital meter to read Hall voltage (0-200mV) and probe current (0-20mA) selectable by a switch .It also provides constant current power supply. Variation in current is achieved by a potentiometer provided.

SPECIFICATIONS:		*AMMETER*	*VOLTMETER*
Range	:	0-20 mA	0-200mV
Resolution	:	10 uA	0.1mV

2. **HALL PROBE :**

   Germanium Single Crystal N or P -type with four spring type pressure contact is mounted on a sunmica bakelite strip.

   TECHNICAL DETAILS

Material	:	Ge single crystal n or p-type as desired.
Resistivity	:	8-10 ohm.cm.
Contacts	:	Spring type (solid silver)
Zero-field potential	:	<1mV (adjustable)
Hall Voltage	:	25-35mV/10 mA/KG

   The exact values of the Hall Probe supplied into the set-up are pasted inside the box of the probe.

3. **ELECTROMAGNET :**

   The electromagnet have the most widely used 'U' shaped soft iron yoke. The soft iron is of a special quality, structurally uniform, well machined and finished to meet the rigid standards.

   SPECIFICATIONS

Field intensity	: 7.5 KG at 10mm air-gap which flat pole pieces.
Pole pieces	: 50mm diameter.
Energising coils	: Two, each a resistance of about 3.0 ohm.
Power requirement	: 0-30V DC, 4A, its coils are connected in series.

4. **CONSTANT CURRENT POWER SUPPLY OMEGA TYPE CCP-30/4 :**

Current range	:	0 - 4 Amp.
Load regulation (No Load to Full Load)	:	Better than 0.5% of the highest specified output current.
Line regulation (For ±10% Mains Variation)	:	Better than ± 2% of the specified output current.
Metering	:	3 ½ digit 7 segment LED DPM.

5. **DIGITAL GAUSS METER WITH HALL PROBE OMEGA TYPE DGM - 020** : Operates on the principle of Hall Effect in semiconductor. The small Hall Voltage is amplified through a high stability amplifier so that a millivoltmeter connected at the output of the amplifier can be calibrated directly in magnetic field unit (gauss).

SPECIFICATIONS

Range	: 0-2 KG & 0-20 KG.
Resolution	: 1G at 0-2 KG range
Accuracy	: ± 0.5%.
Special Feature	: Indicate the direction of the magnetic field.

6. **HALL PORBE STAND** : Wooden

BASIC PRINCIPAL AND THEORY

The variation of electrical conductivity with temperature does not provide adequate information regarding the type of carriers and their concentration. However the required additional information is provided by Hall effect studies of the specimen. Hall effect is a magneto-electric effect. A specimen rectangular slab of solid in which Hall effect is to be studied is shown as ABCD A' B' C' D' in Fig. (1) with length AB, breadth BC and thickness AA' as l, b, d in respective x, y, z, directions. If I_x is the current density in x-direction and H_z is the applied magnetic field in z-direction, then Hall field E_H developed in y-direction is proportional to I_x and H_z and given by :

$$E_H = R_H I_x H_z \qquad \text{.......... (1)}$$

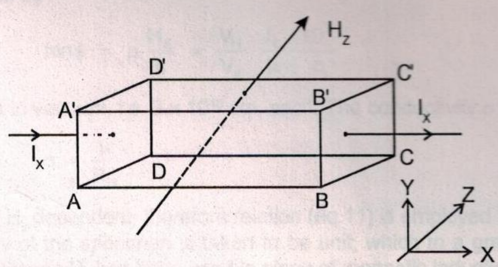


FIG. 1 SAMPLE FOR STUDYING HALL EFFECT

where R_H is known as Hall coefficient and defined by putting I_x, H_z each equal to unity, i.e., Hall coefficient is numerically equal to Hall field for unit current density and unit applied magnetic field. If d be the thickness of crystal along Hall field and V_H be the Hall voltage, then

$$E_H = \frac{V_H}{d} \qquad \text{.......... (2)}$$

If V_x be the drift velocity of electron e in x-direction, then Lorentz force on it is given by

$$F_y = -e[E_y - v_x H_z] \qquad \text{.......... (3)}$$

In equilibrium since $F_y = 0$, therefore (eq. 3) gives

$$E_y = \frac{V_H}{d} = v_x H_z \qquad \text{.......... (4)}$$

Current density is given by

$$I_x = -nev_x \qquad \text{.......... (5)}$$

where n is the number of electrons per unit volume. Since the area of cross-section of the specimen is bd, therefore current density I_x and current i_x are related to each other by

$$i_x = I_x bd \qquad \text{.......... (6)}$$

Substitution of v_x from (eq. 5) and I_x from (eq. 6) in (eq. 1) gives

Hall Coefficient $$R_H = -\frac{1}{ne} = \frac{V_H}{i_x} \cdot \frac{b}{H_z}$$

With V_H in volts, e in coulomb, i_x in ampere and H_z in gauss, it gives :

$$R_H = -\frac{1}{ne} = \frac{V_H}{i_x} \cdot \frac{b}{H_z} \cdot 10^7 \qquad ....(7)$$

Knowing R_H the number of charge carriers per unit volume n is calculated by relation

$$n = \frac{1}{R_H e} \qquad ....(8)$$

where e is the electronic charge in coulomb, i.e., 1.6×10^{-19} coulomb. This gives n per milliliter. Secondly the mobility μ of charge carriers is given by :

$$\mu = R_H \left[\frac{l_x}{bd}\right] \cdot \frac{i_x}{V_x} \qquad ....(9)$$

where l_x is the length of the crystal along the flow of current i_x and V_x is the voltage drop along l_x, d is the thickness of the crystal in z direction. With l_x, b, d in cm, i_x in ampere and V_x in volts, μ is per gauss. However this is drift velocity per unit field and therefore also expressed as cm. sec^{-1} per unit field. Knowing μ the value of Hall angle ϕ in radians is given by :

$$\tan\phi = \mu\frac{H_z}{c} = \frac{V_H}{V_x} \cdot \frac{l_x}{b} \cdot \frac{10^7}{c} \qquad ....(10)$$

where c is the velocity of light in vacuum, i.e. 3×10^{10} cm. sec^{-1}. The conductivity σ in mho. cm^{-1} is given by

$$\sigma = \frac{\mu}{R_H} \qquad ....(11)$$

Since both μ and R_H are field H_z dependent, therefore relation (eq.11) is employed to study the variation of σ with H_z. However the permeability of the specimen is taken to be unit, which to a greater extent is true in case of dielectric media. It is for this reason H_z has been used in place of magnetic induction B_z.

EXPERIMENTAL SET UP

On the basis of above concepts and the relations developed therein, the experimental set up is described as below. The selection of components depends upon the intrinsic nature and physical dimensions of the specimen. A schematic diagram of the experimental set up has been shown in Fig. 2. The rectangular slab of the specimen has been shown as ABCDD'C'B'A'. NS is an electromagnet capable of producing field H_z of the order of 10^3 - 10^4 gauss. A constant current source used in series with the specimen to set current i_x in x-direction. However the voltage drop V_x along the crystal length is measured by a voltmeter. The selection of voltmeter depends upon the resistance of the specimen. The current passing through specimen must never exceed beyond a safe limit otherwise the heating of the crystal takes place and inconsistent erratic results occur.

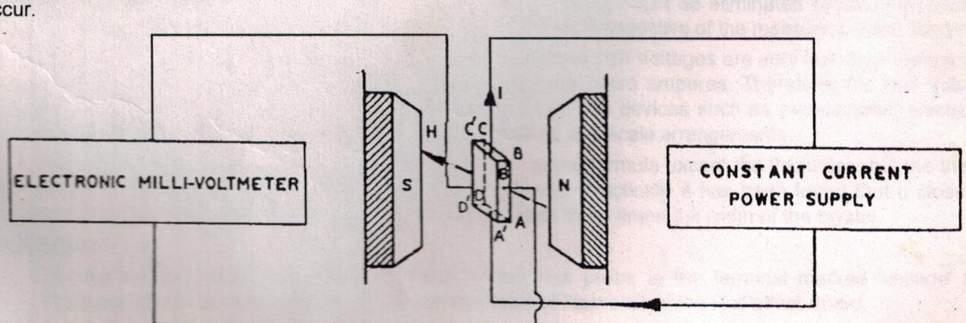


FIG. 2

EXPERIMENTAL CONSIDERATION RELEVANT TO ALL MEASUREMENTS ON SEMICONDUCTORS

1. In single crystal material the resistivity may vary smoothly form point to point. In fact this is generally the case. The question is the amount of this variation rather than its presence. Often however, it is conventionally stated that it is constant within some percentage and when the variation does in fact fall within this tolerance, it is ignored.
2. High resistance or rectification action appears fairly often in electrical contacts to semiconductors and in fact is one of the major problems.
3. Soldered probe contacts, though very much desirable may disturb the current flow (shorting out part of the sample). Soldering directly to the body of the sample can affect the sample properties due to heat and by contamination unless care is taken. These problems can be avoided by using pressure contacts as in the present set-up. The principle draw back of this type of contacts is that they may be noisy. This problem can, however, be managed by keeping the contacts clean and firm.
4. The current through the sample should not be large enough to cause heating. A further precaution is necessary to prevent 'injecting effect' from affecting the measurement. Even good contacts to germanium for example, may have this effect. This can be minimized by keeping the voltage drop at the contacts low. If the surface near the contacts is rough and the electric flow in the crystal is low, these injected carriers will recombine before reaching the measuring probes. Since Hall coefficient is independent of current, it is possible to determine whether or not any of these effects are interfering by measuring the Hall coefficient at different values of current.

EXPERIMENTAL CONSIDERATION WITH THE MEASUREMENTS OF HALL COEFFICIENT

1. The voltage appearing between the Hall probes is not generally, the Hall voltage alone. There are other galvanomagnetic and thermomagnetic effects (Nernst effect, Rhighleduc effect and Ettingshausen effect) which can produce voltages between the Hall Probes. In addition, IR drop due to probe misalignment (zero magnetic field potential) and thermoelectric voltage due to transverse thermal gradient may be present. All these except, the Ettingshausen effect are eliminated by the method of averaging four readings.

   The Ettingshausen effect is negligible in materials in which a high thermal conductivity is primarily due to lattice conductivity or in which the thermoelectric power is small.

   When the voltage between the Hall probes is measured for both directions of current, only the Hall voltage and IR drop reverse. Therefore, the average of these readings eliminates the influence of the other effects. Further, when Hall voltage is measured for both the directions of the magnetic field, the IR drop does not reverse and may therefore be eliminated.
2. The Hall Probe must be adjusted in the field until the position of maximum voltage is reached. This is the position when direction of current in the probe and magnetic field would be perpendicular to each other.
3. The resistance of the sample changes when the magnetic field is turned on. This phenomena called magneto-resistance is due to the fact that the drift velocity of all carriers is not the same, with magnetic field on, the Hall voltage compensates exactly the Lorentz force for carriers with average velocity. Slower carriers will be over compensated and faster ones under compensated, resulting in trajectories that are not along the applied external field. This results in effective decrease of the mean free path and hence an increase in resistivity.

   Therefore, while taking readings with a varying magnetic field at a particular current value, it is necessary that current value should be adjusted, every time. The problem can be eliminated by using a constant current power supply, which would keep the current constant irrespective of the resistance of the sample.
4. In general, the resistance of the sample is very high and the Hall Voltages are very low. This means that practically there is hardly any current - not more than few micro amperes. Therefore, the Hall Voltage should only be measured with a high input impedance ($\cong$ 1M) devices such as electrometer, electronic millivoltmeters or good potentiometers preferably with lamp and scale arrangements.
5. Although the dimensions of the crystal do not appear in the formula except the thickness, but the theory assumes that all the carriers are moving only lengthwise. Practically it has been found that a closer to ideal situation may be obtained if the length may be taken three times the width of the crystal.

PROCEDURE

1. Connect the widthwise (red colour) contacts of the Hall probe to the terminal marked 'voltage' and lengthwise (green colour) contacts to the terminal marked "current" of the Hall effect Board.
2. Put the switch marked ON/OFF of Hall effect Board to ON position.

3. Put the meter selector switch towards 20mA and adjust current (not exceeding 8 mA) by current adjust pot.
4. Put the meter selector switch toward 200mV. There may be some voltage reading even outside the magnetic field. This is due to imperfect alignment of the four contacts of the Hall probe and is generally known as 'Zero field potential'. In case its value is comparable to the Hall voltage, it should be adjusted to a minimum possible {for Hall probe (Ge) only}. In all cases, this error should be subtracted from the Hall voltage reading.
5. Now place the probe in the magnetic field as shown in Fig. 2 (The gap between the poles N and S should be fixed say 10mm)
6. Connect the constant current power supply with electromagnet. Switch on the supply and adjust the current to any desired value. Rotate the Hall probe till it become perpendicular to magnetic field. Hall voltage will be maximum in this adjustment.
7. Measure Hall voltage for both the direction of the current by interchanging the current leads and magnetic field by changing power supply leads (as such you will get four observations for a particular value of current and magnetic field)
8. Measure the Hall voltage as a function of current keeping the magnetic field constant. Plot a graph and determine V_H / I_x from its slop.
9. Now change the magnetic field by varying the current to electromagnet and repeat the step 8.
10. Calculate value of R_H for each H_z and Plot the variations of R_H versus H_z.

MEASUREMENT OF MAGNETIC FIELD

1. Use Digital Gauss Meter Omega Type DGM-020 for measurement of the magnetic field.
2. Connect the two pin mains lead of Gauss Meter to AC mains having 230V± 10% at 50Hz.
3. Put ON/OFF switch to ON position and adjust the reading of the meter to zero by 'zero adj. pot'.
4. Put the Hall probe between poles of the electromagnet, now connect the constant current power supply to electromagnet.
5. Switch on the power supply and vary the current.
6. Note down the readings of magnetic field by Gauss meter at corresponding current values in table1

OBSERVATIONS

Physical dimensions of the demand

l_x = ____cm., b = ________cm., d = ______cm.

TABLE 1

MEASUREMENT OF MAGNETIC FIELD

Sr. No.	Current (A)	Magnetic field (Gauss) H_z
1		
2		
3		
4		
5		
6		

TABLE 2

Zero field potential .....mV.

Sr. No.	Magnetic field	Constant Current (mA) I_x	Hall voltage (volt) V_H	V_H/Ix form graph	Hall coefficient R_H cm^3 $coulomb^{-1}$
1					
2					
3					
4					

TABLE 3

Sr. No.	Hall coefficient R_H cm^3 $coulomb^{-1}$	No. of charge carriers per unit volume (n) cm^{-3}	Mobility of charge carriers (μ) cm^2 $volt^{-1}sec^{-1}$	Hall angle		Conductivity σ
				tan ϕ	ϕ	

REFERENCES

(i) Advance practical physics (part - 1) : by S.P. Singh

(ii) Experiments in Modern Physics : by A.C. Melissions

(iii) Hall effect related phenomena : by E.H. Putley Butherworth.

***ACCESSORIES :* ELECTROMAGNET, TYPE EMU-10**

These electromagnets have the most widely used 'U' shaped soft iron yoke. The soft iron is of a special quality structurally uniform, well machined and finished to meet the rigid standard.

The pole pieces are made from dead annealed soft iron blocks of the best quality available. They are well shaped, machined and finished normally flat pole pieces are supplied with these magnets.

The coils are wound on non-magnetic formers with uniform layers of enamelled copper wire. The new and modern design of the coils provides good thermal conductivity characteristics and eliminates troublesome hot spots even at high magnetic fields.

SPECIFICATIONS :

Field Intensity	:	7.5 K Gauss at 10 mm. The air – gap is continuously variable with two way knobbed wheel screw adjusting system.
Pole Pieces	:	50 mm diameter normally flat faced pole pieces are supplied with the magnet.
Yoke Material	:	'U' shaped soft iron.
Power Requirement	:	0-4, Amp., if coils are connected in series.

UNPACKING :

01. Keep the case in upright position and remove all the nails from the top lid.
02. Remove the side panels also and unscrew the clamp holding the base of the magnet with the bottom of packing case.
03. Put the magnet on a table. The magnet is in a assembled state, including the coils connections. Fix the handles provided in a small box with the magnet.

OPERATION INSTRUCTIONS :

01. Connect the two coils in series properly i.e. the current in both coils should be in the same direction. Opposite direction would result in little or no magnetic field between the pole pieces.
02. Adjust air – gap to desired width.
03. Do not place a sample yet.
04. Ensure that the power supply is 'OFF'.
05. Ensure that the current control of the power supply is in the minimum position.
06. Connect the magnet leads to the power supply.
07. Switch on the power supply and slowly increase the current. A slight pull of the pole pieces will be observed in the initial setting of the air-gap.
08. Reduce the current to minimum and re-adjust the air - gap if required.
09. Place the sample to be exposed to magnetic field in the air – gap
10. Avoid personal exposure to the magnetic field.
11. Increase the current to a desired level. Measure the field with Gauss Meter or any other device available.
12. Extreme care should be taken in handling the magnet as well as the power supply.
13. To switch off, reduce the current to minimum, and then put the switch to OFF.
14. Connect the leads to the power supply and switch on the power supply. The Electromagnet is now ready touse.

PRECAUTIONS :

01. Power Supply should be connected to a 3, pin mains socket having good earth connection.
02. Always increase or decrease the current gradually, switch 'ON' or 'OFF' the power supply at the zero current position.
03. The magnet is calibrated at a air-gap of 10 mm, for other air - gap position the magnetic filed may be measured by Gauss Meter.
04. While making connections, make sure that the power supply is off.
05. Do not suddenly switch 'ON' or 'OFF' the Power Supply when current is flowing through the coils.
06. Always increase or decrease current gradually.
07. The magnet may be kept covered when not in use to avoid collection of dust.
08. Keep the pole pieces and all plated parts covered with grease to avoid rusting.

ENCLOSURES : Nil

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