OSAW

User's Manual

Of

MAGNETO RESISTANCE SET UP

THE ORIENTAL SCIENCE APPARATUS WORKSHOPS
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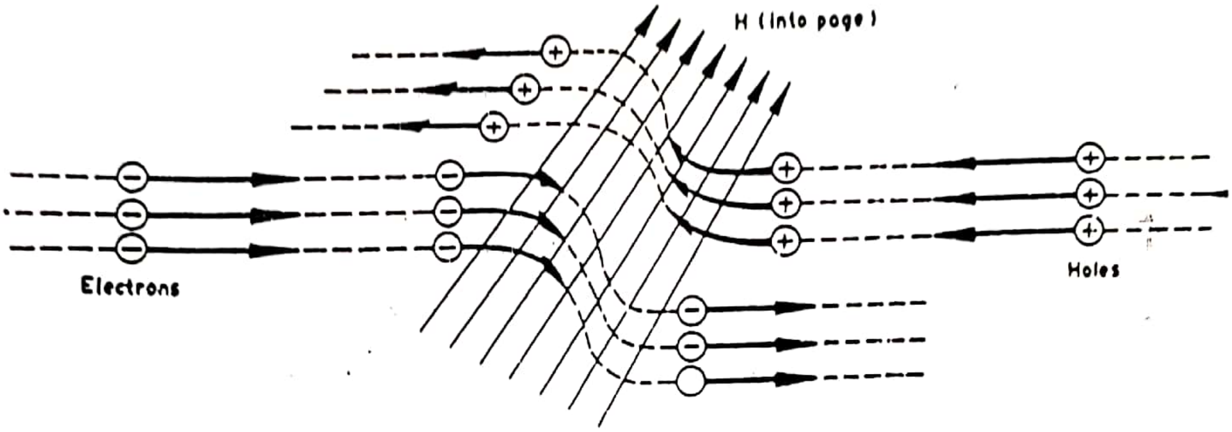

FIG. 1 CARRIER SEPARATION DUE TO A MAGNETIC FIELD

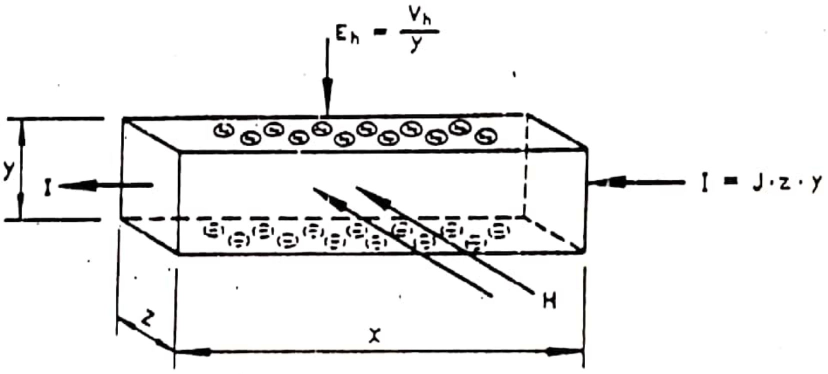

FIG. 2 SAMPLE FOR STUDYING HALL EFFECT

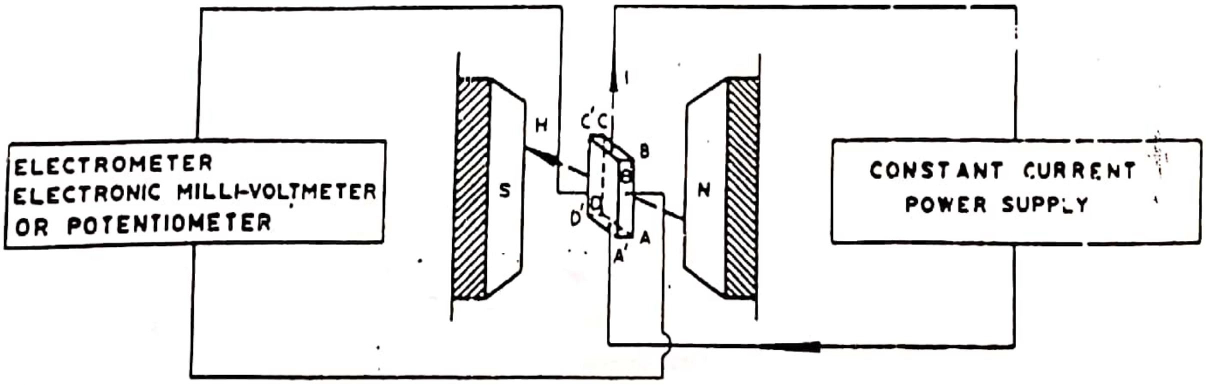

FIG. 3

INTRODUCTION

The conductivity measurements cannot reveal whether one or types of carriers are present; nor distinguish between them. However, this information can be obtained from Hall Effect measurements, which are basic tools for the determination of mobilities. The effect was discovered by E.H. Hall in 1879.

THEORY

As you are undoubtedly aware, a static magnetic field has no effect on charges unless they are in motion. When the charges flow, a magnetic field directed perpendicular to the direction of flow produces a mutually perpendicular force on the charges. When this happens, electrons and holes will be separated by opposite forces. They will in turn produce an electric field ($\bar{E}_h$) which depends on the cross product of the magnetic intensity, $\bar{H}$, and the current density, $\bar{J}$. The situation is demonstrated in Fig. 1.

$$\bar{E}_h = R\,\bar{J} \times \bar{H} \qquad (1)$$

Where R is called the Hall coefficient.

Now, let us consider a bar of semiconductor, having dimension, x, y and z. Let $\bar{J}$ is directed along X and $\bar{H}$ along Z then $\bar{E}_h$ will be along Y, as in Fig. 2.

Then we could write

$$R = \frac{V_h / y}{J H} = \frac{V_h . z}{I H} \qquad (2)$$

Where V_h is the Hall voltage appearing between the two surfaces perpendicular to y and $I = \bar{J} yz$

In general, the Hall voltage is not a linear function of magnetic field applied, i.e. the Hall coefficient is not generally a constant, but a function of the applied magnetic field. Consequently, interpretation of the Hall Voltage is not usually a simple matter. However, it is easy to calculate this (Hall) voltage if it is assumed that all carriers have the same drift velocity. We will do this in two steps (a) by assuming that carriers of only one type are present, and (b) by assuming that carriers of both types are present.

(a) One type of Carrier

Metals and degenerate (doped) semiconductors are the examples of this type where one carrier dominates.

The magnetic force on the carriers is $\bar{E}_m = e(\bar{v} \times \bar{H})$ and is compensated by the Hall field $\bar{F}_h = e\,\bar{E}_h$, where v is the drift velocity of the carriers. Assuming the direction of various vectors as before

$$\bar{v} \times \bar{H} = \bar{E}_h$$

From simple reasoning, the current density $\bar{J}$ is the charge q multiplied by the number of carriers traversing unit area in unit time, which is equivalent to the carrier density multiplied by the drift velocity i.e. $\bar{J} = q\,n\,\bar{v}$

By putting these values in equation (2)

$$R = \frac{E_h}{J\,H} = \frac{v.H}{q\,n\,v\,H} = \frac{1}{n\,q} \qquad (3)$$

From this equation, it is clear that the sign of Hall coefficient depend upon the sign of the q. This means, in a p-type specimen the R would be positive, while in n-type it would be negative. Also for a fixed magnetic field and input current, the Hall voltage is proportional to 1/n or its resistivity. When one carrier dominates, the conductivity of the material is $\sigma = nq\mu$.

where μ is the mobility of the charge carriers.

Thus $\quad \mu = R\sigma \qquad (4)$

Equation (4) provides an experimental measurement of mobility: R is expressed in cm^3 $coulomb^{-1}$ thus μ is expressed in units, of cm^2. $volt^{-1}$ sec^{-1}.

(b) Two type of Carriers

Intrinsic and lightly doped semiconductors are the examples of this type. In such cases, the quantitative interpretation of Hall coefficient is more difficult since both type of carriers contribute to the Hall field. It is also clear that for the same electric field, the Hall voltage of p-carriers will be opposite sign from the n-carriers. As a result, both mobilities enter into any calculation of Hall coefficient and a weighted average is the result* i.e.

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* From Experiments in Modern Physics by Adrian C. Melissions (Academic Press) p. 86.

$$R = \frac{\mu_h^2 p - \mu_e^2 n}{2(\mu_h p + \mu_e n)^2} \qquad (5)$$

Where μ_h and μ_n are the mobilities of holes and electrons; p and n are the carri densities of holes and electrons. Eq. (5) correctly reduces to equation (3) when only one type c carrier is present**.

Since the mobilities μ_h and μ_n are not constants but function of temperature (T) the Hal coefficient given by Eq. (5), is also a function of T and it may become zero, even change sign In general $\mu_n > \mu_h$ so that inversion may happen only if $p > n$; thus 'Hall coefficient inversion' is characteristic only of p-type semiconductors.

At the point of zero Hall coefficient, it is possible to determine the ratio of mobilities and their relative concentration.

Thus we see that the Hall coefficient, in conjunction with resistivity measurements, can provide information on carrier densities, mobilities, impurity concentration and other values. It must be noted, however, that mobilities obtained from Hall Effect measurements $\mu = R\sigma$ do not always agree with directly measured values. The reason being that carriers are distributed in energy, and those with higher velocities will be deviated to a greater extent for a given field. As μ we know varies with carrier velocity.

EXPERIMENTAL TECHNIQUE

(a) Experimental Consideration Relevant to all measurements on Semiconductors

1. In single crystal material the resistivity may vary smoothly from 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's conventionally stated that it is a 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 problem.
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

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** Both Eq. (3) and Eq. (5) have been derived on the assumption that all carriers have same velocity; this is not true, but the exact calculation modifies the results obtained here by a factor of only $3\pi/8$.

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 minimised 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.

(b) 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 rotated 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 (≅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.

BRIEF DESCRIPTION OF THE APPARATUS

1. **Hall probe (Ge crystal)**
2. **Magneto resistance set up**
3. **Electromagnet**
4. **Constant current power supply**
5. **Digital Gauss meter**

1. *Hall Probe (Ge Crystal)*

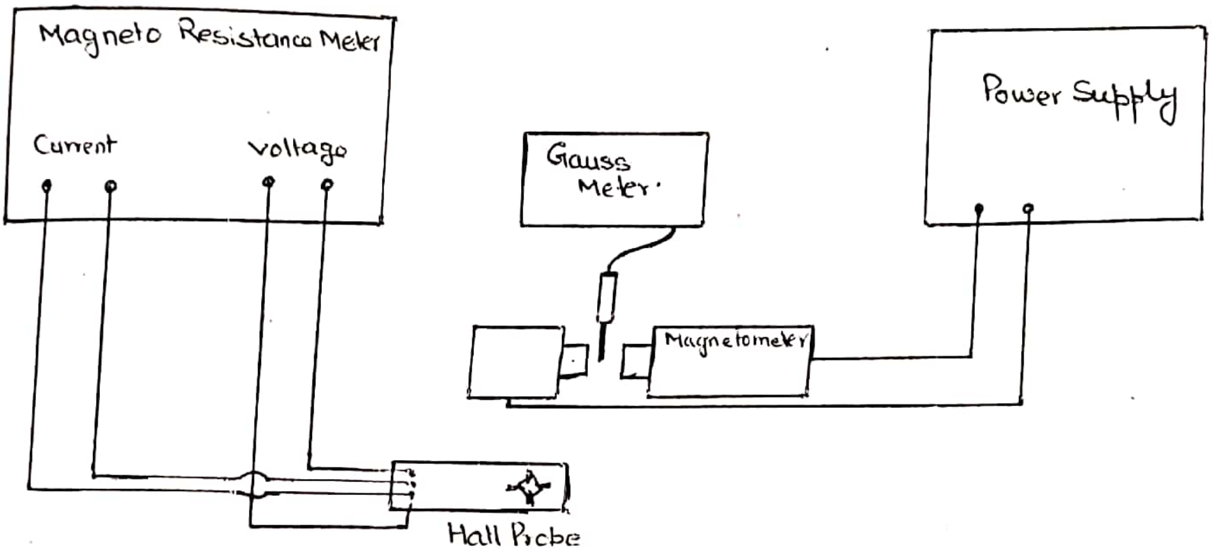
Ge single crystal with four spring type pressure contacts is mounted on a sunmica decorated bakelite strip Four leads are provided for connections with measuring devices.

.Contacts : Spring type (Solid Silver)
Hall Voltage : 0.1 - 1 Volt/100 mA/KG
Thickness of Ge Crystal : 0.4 - 0.5 m.m.
Resistivity : ≥ 10 Ω cm.

The exact value of thickness and resistivity is provided in the test report of the Hall **Probe (Ge) supplied** with the set-up. The student after calculating the Hall Coefficient from this experiment and using the given value of resistivity can also get valuable information about **carrier density and carrier mobilities**. A typical example is provided in the appendix. A further advantage of this type of probe is that the sample can be changed A minor draw back of this arrangement is that the it may require zero adjustment from time to time. This type of probes are specially designed and recommended for Hall Effect experiment.

2. Magneto resistance set up

It is a high performance instrument of outstanding flexibility. The set-up cxonsists of an electronic digital milli voltmeter and a constant current power supply. The Hall voltage and current can be read on the same digital panel meter.


Magneto Resistance Meter
Current
Voltage
Gauss Meter.
Power Supply
Magnetometer
Hall Probe

Measurement of Magneto Resistance of semiconductors

The resistance of the semiconductor changes when the magnetic field is turned on. The phenomenon is called magneto resistance on increasing the magnetic field, the Hall voltage V_H increases, As more carriers move in a direction perpendicular to the direction of applied voltage potential V, less number of carriers move in the direction of V and less current flows for a given V hence the resistance of semiconductor sample increases.

Procedure :-

1. Make the connections as shown in fig. Connect the input current leads (Red) of Hall probe (N type) with current terminals and output voltage leads (Green) with voltmeter terminals of magneto resistance set-up.
2. Switch on the magneto resistance set up. and adjust the current say at 8mA and see the voltage in voltmeter of magneto resistance set up. 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.
3. This voltage should be deducted from the value measured in magnetic field.
4. Now place the Hall probe in magnetic field and adjust the current in power supply to achieve the I K Gauss magnetic field. Measure the Hall voltage at I K Gauss field and calculate the resistance of Hall probe at I K Gauss and 8 mA current flow through it using ohms law

$$R = V/I$$

Suppose the voltage at I K Gauss is 30 mV

Then Resistance is = **30 mV/8mA = 3.75 Ohms**

4. Now take the reading of Hall voltage with different value of magnetic field say at 2 K, 3 K and 5 K Gauss and calculate the value of magneto resistance by using above formula. You will found that on increasing the magnetic field, the Hall voltage will increase and so resistance will increase.

(a) Digital Millivoltmeter

Intersil 3½ digit single chip A/D Converter ICL 7107 have been used. It has high accuracy like, auto zero to less than 10 µV, zero drift less than 1 µV/°C, input bias current of 10 pA and roll over error of less than one count. Since the use of internal reference causes the degradation in performance due to internal heating, an external reference has been used. This voltmeter is much more convenient to use in Hall experiment, because the input of either polarity can be measured.

Specifications

Range	:	0 - 200.0 mV
Resolution	:	100 µV
Accuracy	:	±0.1% of reading ±1 digit
Impedance	:	1 Mohm
Special Features	:	Auto Zero & polarity indicator
Overload Indicator	:	Sign of 1 on the left & blanking of other digits.

(b) Constant Current Power Supply

This power supply specially designed for Hall Probe provides 100 percent protection against crystal burn-out due to excessive current. The basic scheme is to use the feed - back principle to limit the load current of the supply to a pre - set maximum value. Variations in the current are achieved by a potentiometer. The supply is a highly regulated and practically ripple free d.c. source. The current is measured by the digital panel meter.

Specifications

Current range	:	(0 - 20 mA) or as required for the particular Hall Probe
Resolution	:	10 µA
Accuracy	:	±0.2% of the reading ±1 digit
Load regulation	:	0.03% for 0 to full load
Line regulation	:	0.05% for 10% changes.

3. Electromagnet

Field Intensity	:	5K 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.
Energising Coils	:	Two, each coil is wound on non magnetic formers and has a resistance of about 3.0 ohm.
Yoke Material	:	'U' shaped soft iron
Power Requirement	:	0-16V@5 A if coils are connected in series.

5. Digital Gaussmeter

The Gaussmeter operates on the principle of Hall Effect in semiconductors. A semiconductor material carrying current develops an electromotive force, when placed in a magnetic field, in a direction perpendicular to the direction of both electric current and magnetic field. The magnitude of this e.m.f. is proportional to the field intensity if the current is kept constant, this e.m.f. is called the Hall Voltage. This 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 K gauss & 0 - 20 K gauss
Resolution	:	1 gauss at 0 - 2 K gauss range
Accuracy	:	± 0.5%
Display	:	3½ digit, 7 segment LED DPM
Detector	:	Hall probe with an Imported Hall Element
Power	:	220 V, 50 Hz
Special	:	Indicates the direction of the magnetic field.