Engineering Physics (2025)
Course code 25PY101
Unit 1: Metals and Semiconductors

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Unit 1 Plan

1. Condensed matter
2. Metals
3. Classical free electron theory
4. Expression of electrical conductivity
5. Introduction to Semiconductors
6. Electrical conductivity of semiconductors
7. Hall effect
8. Concept of Panchabhuta

Unit 1 Plan

Hall effect

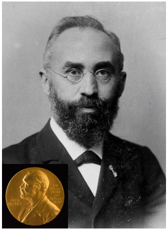
- In the presence of magnetic field acting perpendicular to the flow of electrons, the electrons experience a Lorentz force that deviates their path in the transverse direction. Accumulation of electrons along the edges leads to generation of voltage. This is called **Hall effect**.
- Hall effect is prominent in two dimensional geometry and can be considered the advent of research on thin films.
- It was discovered before the discovery of electron!
- In the context of semiconductors, Hall effect has contribution from holes, in addition to electrons. It also helps determine
    - the type of semiconductor (n or p),
    - the majority carrier concentration, and
    - the majority carrier mobility.

E. Hall

Hall effect: Lorentz force

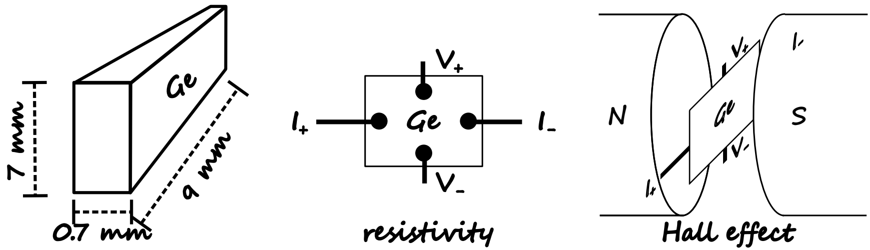
- In the presence of electric field **E** and magnetic field **B**, the electron experiences a force given by

$$\begin{aligned} \mathbf{F}_{\mathrm{Lorentz}} &= \mathbf{F}_{\mathrm{elec}} + \mathbf{F}_{\mathrm{mag}} \\ &= -e\mathbf{E} - e\mathbf{v} \times \mathbf{B} \end{aligned}$$



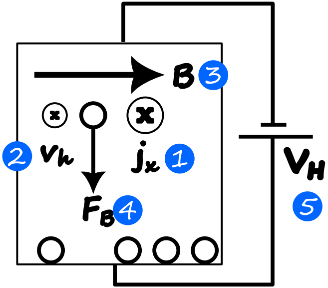
H. Lorentz

Hall effect: experiment



- The aim is to find the charge carrier type of Germanium crystal of dimensions 9 mm x 7 mm x 0.7 mm.
- The resistivity is measured in the **four-probe geometry**.
- Current is applied along x direction.
- Magnetic field of 0.1 T is applied along z direction. [$1\,\mathrm{T}=10^4\,\mathrm{G}$]
- The Hall voltage is measured along y direction.

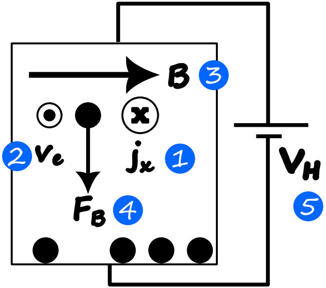
Hall effect in p-type semiconductor



Hall effect for holes

1. Current along x.
2. Electron drift along x.
3. Magnetic field along z.
4. Magnetic force along $-y$.
5. The buildup of holes **induces** an electric field in the $+y$ direction.
6. The corresponding voltage across the width is positive.

Hall effect in n-type semiconductor



Hall effect for electrons

1. Current along x.
2. Electron drift along $-x$.
3. Magnetic field along z.
4. Magnetic force along $-y$.
5. The buildup of electrons **induces** an electric field in the $-y$ direction.
6. The corresponding voltage across the width is negative.

Hall field and Hall voltage

- In the steady state, the magnetic field force is balanced by the induced electric field

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = q(E_y - v_x B_z) = 0$$

- The induced electric field, called the **Hall field** is given by

$$\boxed{E_y = v_x B_z.}$$

- The Hall field produces a voltage across the semiconductor, which is called the **Hall voltage** given by

$$V_H = E_H w$$

  where w is the width of the semiconductor.

- The Hall voltage is positive for p-type and negative for n-type semiconductor.

Hall coefficient

Definition

Hall coefficient R_H is defined as the Hall field per unit current density per unit magnetic field.

- R_H is given by

$$R_H := \frac{E_H}{j_x B_z} = \frac{v}{j_x}$$

- E_H is positive for holes and negative for electrons.
- However, the current density j is related to the drift velocity v by

$$j = nev \qquad [j = pev \quad \text{for holes}]$$

- Therefore,

$$\boxed{R_H(\text{electron}) = -\frac{1}{ne}, \qquad R_H(\text{hole}) = +\frac{1}{pe}}$$

Charge carrier properties

- Semiconductor type: The sign of Hall voltage determines the type of majority carrier in a semiconductor
- Majority carrier density: The Hall coefficient gives the majority carrier density as

$$\boxed{n = \frac{1}{R_H e}}$$

- Majority carrier mobility: If the conductivity of the semiconductor σ is measured in the absence of magnetic field, then the mobility of majority carriers is given by

$$\boxed{\mu = \frac{\sigma}{ne}}$$

Test your Understanding

Problem

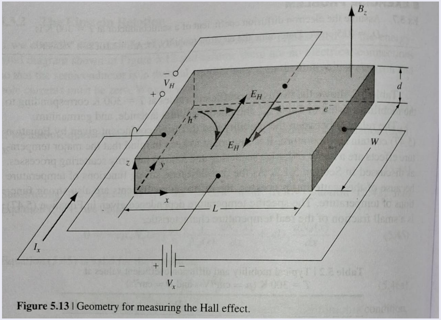
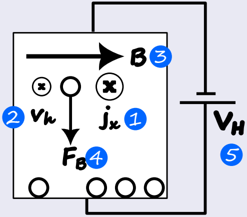


Figure 5.13 | Geometry for measuring the Hall effect.



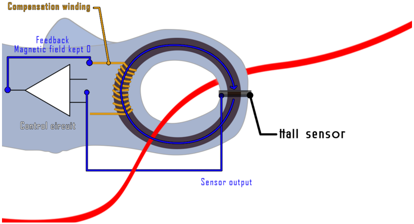
Hall effect for holes

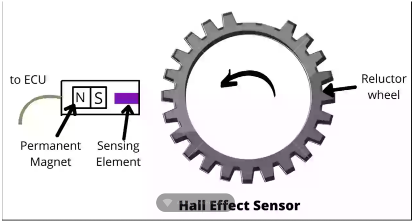
Taken from Neamen. Section 5.4.

Determine the majority carrier type, concentration and mobility.
$L = 10^{-1}\,\text{cm},\; W = 10^{-2}\,\text{cm},\; d = 10^{-3}\,\text{cm}.\; I_x = 1\,\text{mA},\; V_x = 12.5\,\text{V},$
$B = 500\,\text{G},\; V_H = -6.25\,\text{mV}.$

Applications of Hall effect

- Magnetic sensor: Hall voltage is directly proportional to Magnetic field
    - Gaussmeter
    - Compass sensor in smartphones
    - Current measurement without direct contact



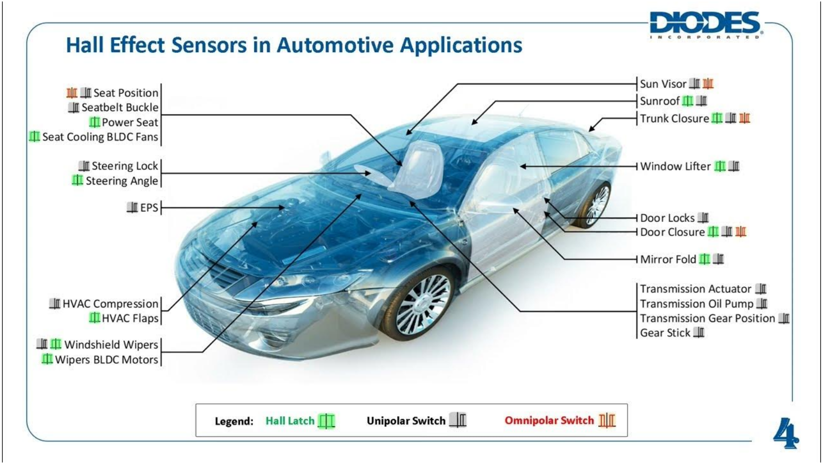


(a) Non contact Ammeter, (b) Rotation sensor

Applications of Hall effect

- Magnetic latch (💋)
- Magnetic switch (👋)

Proximity sensor
Rotation sensor



Reference: Youtube link

Summary of Hall effect

- The Hall effect is a consequence of charged carrier moving in the presence of **perpendicular** electric and magnetic fields.
- The charged carrier is deflected, **inducing** a Hall voltage.
- The polarity of the Hall voltage depends on type of the semiconductor.
- The majority carrier concentration and mobility can be determined from the Hall voltage.