JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

- Year & Sem – Ist Year , Ist Sem
- Subject – Engineering Physics
- Chapter –Material Science and Semiconductor Physics (Part-B)
- Department- Applied Science (Physics)

VISION

To become a renowned institute of outcome based learning and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

MISSION

- Focus on valuation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- Identify based on informed perception of Indian, regional and global needs, the areas of focus and provide platform to gain knowledge and solutions.
- Offer opportunities for interaction between academia and industry.
- Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

Syllabus & Course Outcomes

- **Syllabus :- Material Science & Semiconductor Physics:** Bonding in solids: covalent and metallic bonding, Energy bands in solids: Classification of solids as Insulators, Semiconductors and Conductors, Intrinsic and extrinsic semiconductors, Fermi dirac distribution function and Fermi energy, Conductivity in semiconductors, Hall Effect: Theory, Hall Coefficient and applications.
- **Course Outcomes:** Students will be able to describe key concepts, fundamental laws of Hall effect, electrical conductivity to understand the Physics of semiconductors and materials.

CONTENTS

- Semiconductors and its types
- Conductivity in Semiconductors
- Hall Effect and its applications
- Problems
- Lecture contents with a blend of NPTEL contents and other platforms
- References/ Bibliography

Lecture Plan

S. No	Topics	Lectures required	Lect. No.
1	Semiconductors: intrinsic and extrinsic semiconductors	1	1
2	Conductivity in Semiconductors.	1	2
3	Hall Effect: Theory & Hall coefficient	1	3
4	Applications of Hall effect and Problems	1	4

Semiconductors

- Semiconductors are those substances whose conductivity or resistivity lies in between conductors and insulators.
- At absolute zero semiconductors behave as perfect insulators.
- The interesting feature of semiconductors is that they are bipolar and current is transported by two charge carriers (electrons and holes) of opposite sign.

Types of Semiconductors

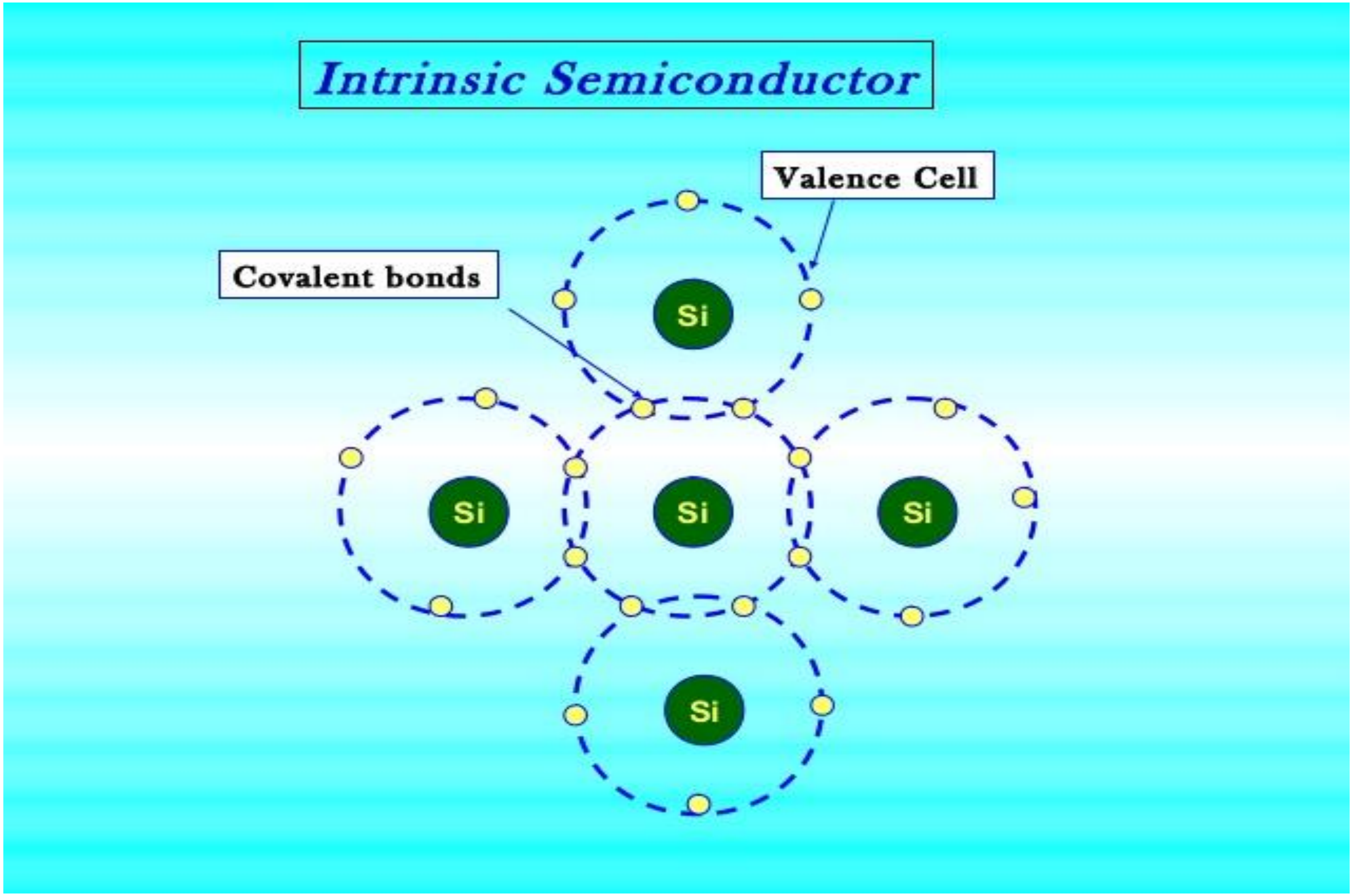
Semiconductors are mainly of two types-

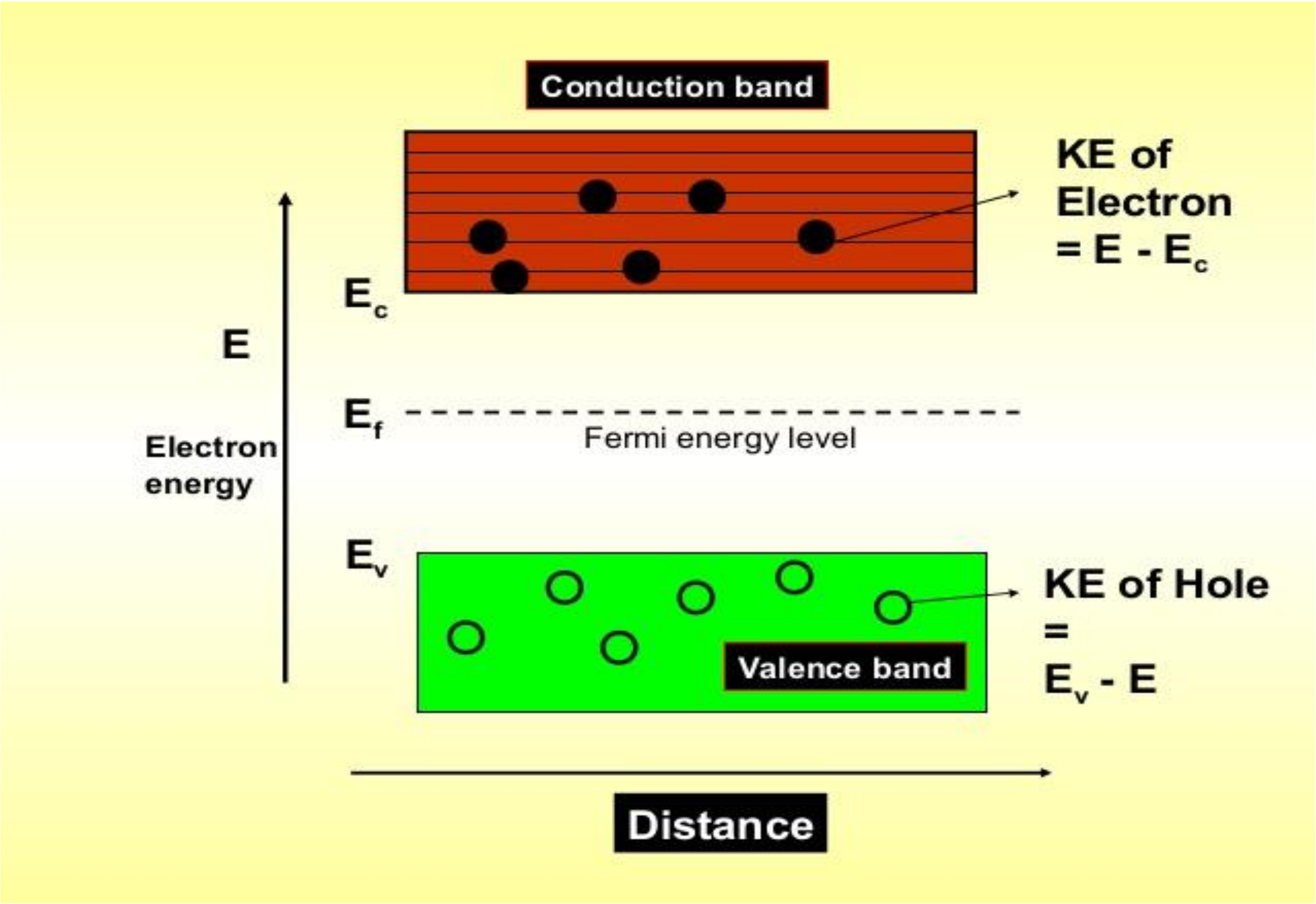
(a) Intrinsic semiconductors

(b) Extrinsic semiconductors

Intrinsic Semiconductors

- Pure semiconductors are called intrinsic semiconductors.
- At absolute zero they behave as perfect insulators and conductors at higher temperatures.
- Silicon and Germanium are best examples and they possess diamond cubic crystalline structures .
- Since the electrons and holes are generated in pairs, concentration of electrons is equal to the concentration of holes. Hence Fermi level lies in between valence band and conduction band.


Intrinsic Semiconductor
Valence Cell
Covalent bonds
Si
Si
Si
Si
Si


Conduction band
KE of Electron = E - E$_c$
E$_c$
E
Electron energy
E$_f$
Fermi energy level
E$_v$
KE of Hole = E$_v$ - E
Valence band
Distance

Extrinsic semiconductors

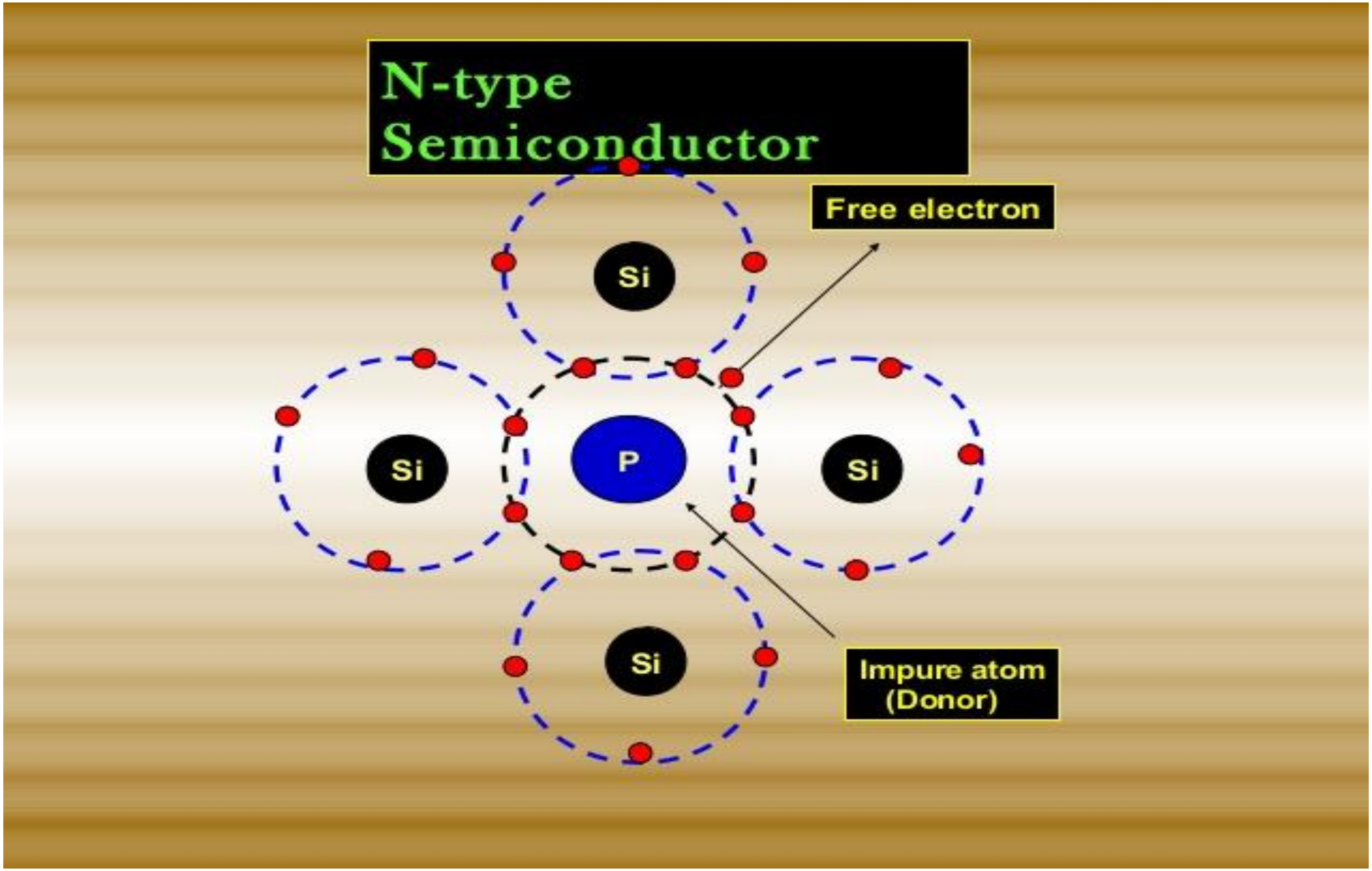
- Extrinsic semiconductors are those in which impurities of large quantity are present. Usually the impurities can be either 3rd group or 5th group elements.
- Based on the impurities present, extrinsic semiconductors are classified in two categories-

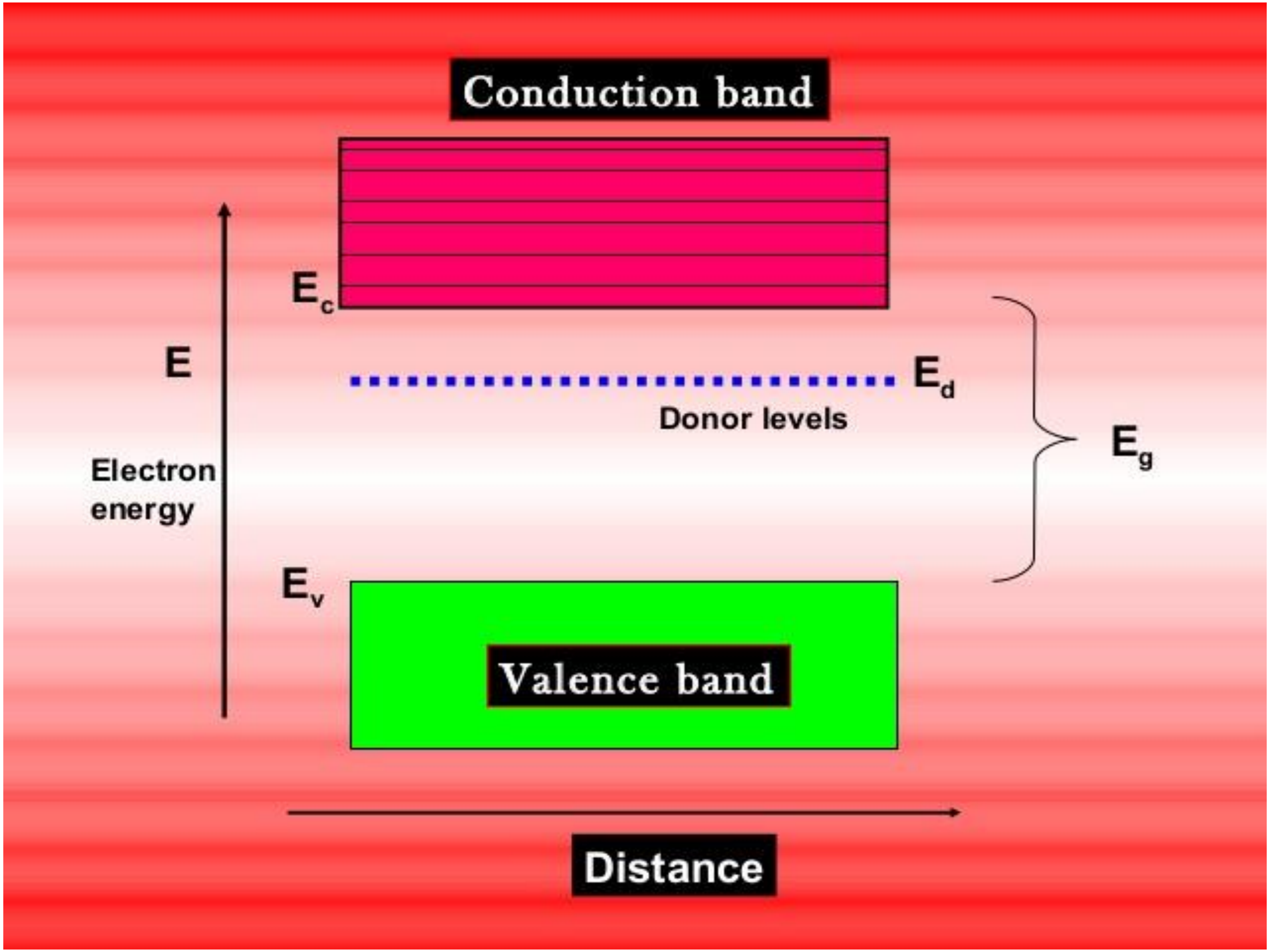
  (a) N- type semiconductors

  (b) P- type semiconductors

N- type semiconductors

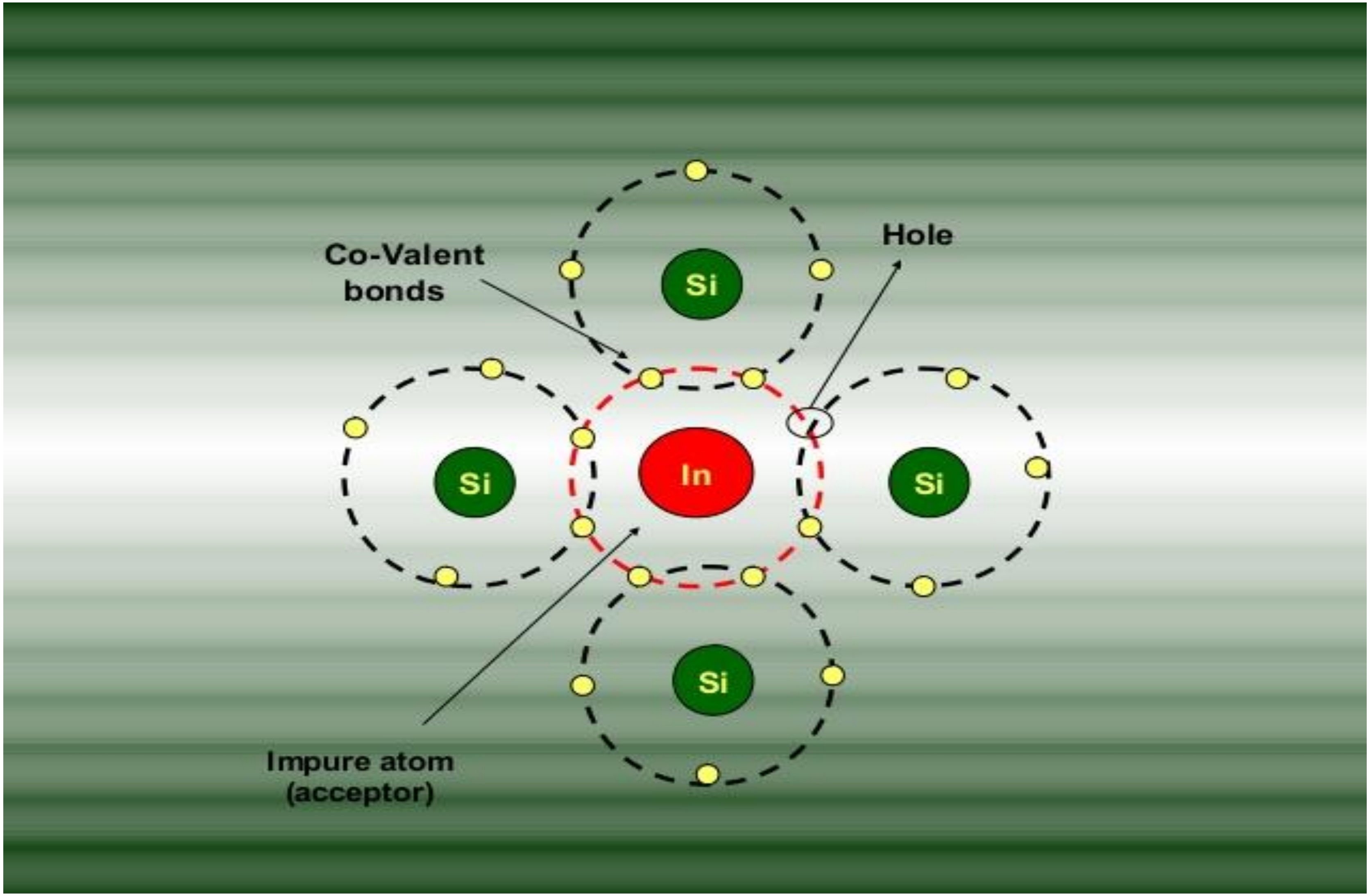
- If a 5th group impurity element is added to a pure semiconductor , N - type semiconductor is formed. eg. P, As,
- Electrons are the majority charge carriers and holes are minority charge carriers.
- When any pentavalent element such as phosphorous is added to pure semiconductors four electrons are involved in covalent bonding with four neighboring pure semiconductor atoms.
- The fifth electron is free and weekly bound to the parent atom. These are also called donors since each impurity element provides one free electron to the crystal.
- The donor level lies very close to the conduction band since there is an increase in the concentration of electrons in the conduction band.

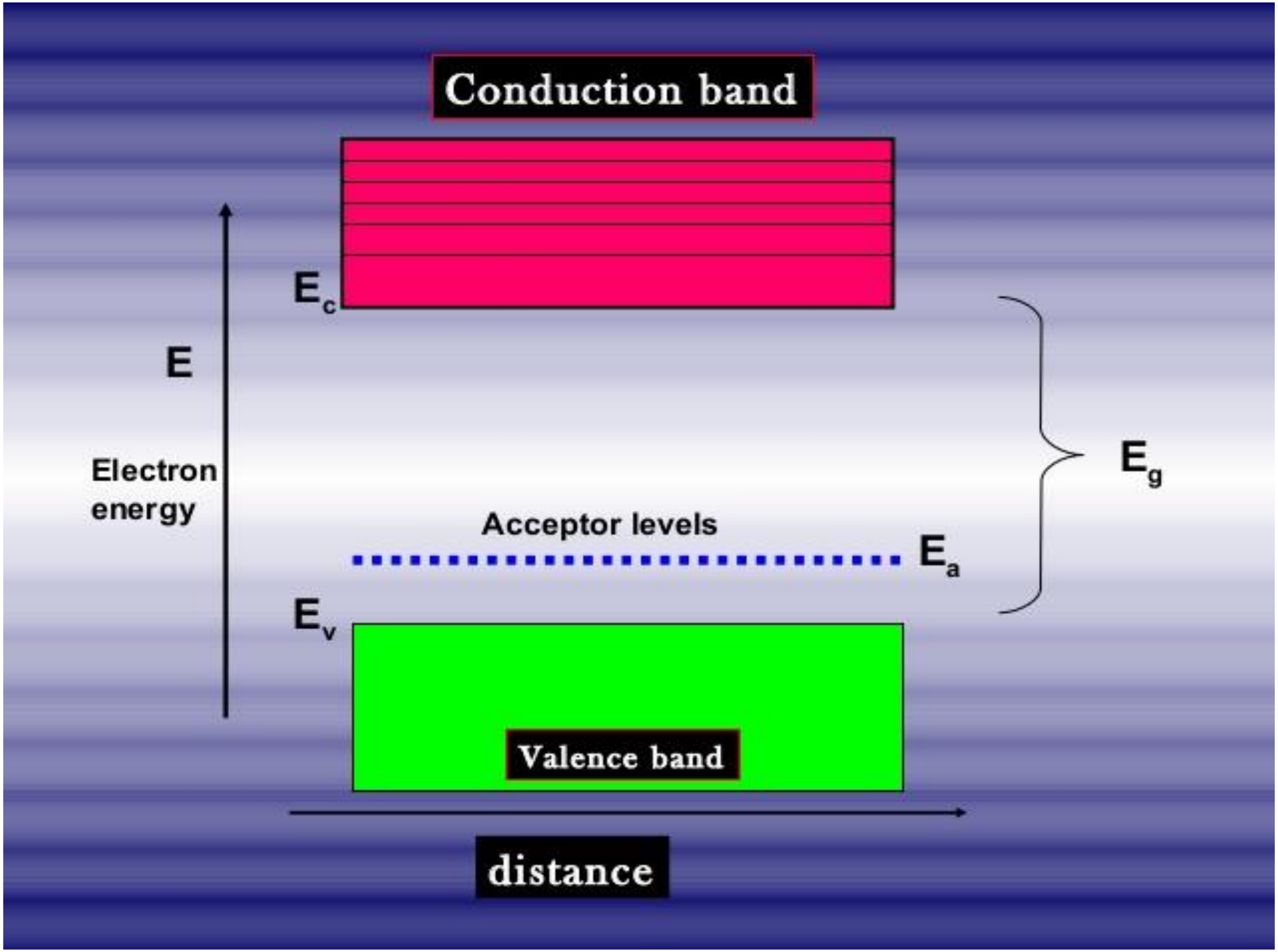

N-type
Semiconductor
Free electron
Si
Si
P
Si
Si
Impure atom
(Donor)


Conduction band
E
Electron
energy
E_c
E_d
Donor levels
E_g
E_v
Valence band
Distance

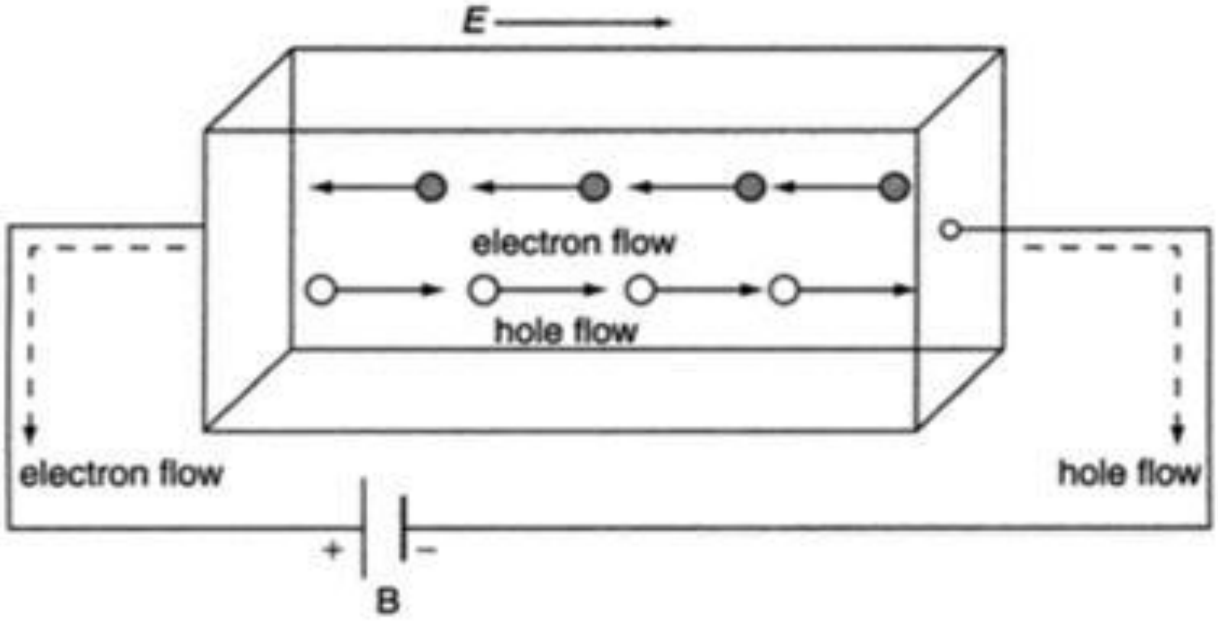
P- type semiconductors

- If a 3rd group impurity element is added to a pure semiconductor , P- type semiconductor is formed. Eg. Al, B, In
- Holes are the majority charge carriers and electrons are minority charge carriers.
- When any trivalent impurity element such as In is added to intrinsic semiconductor all the three electrons are involved in covalent bonding with three neighboring Si atoms.
- These compounds accepts one extra electron from the neighboring atoms to complete the fourth covalent bond. So these are also called acceptors.
- The donor level lies very close to the valence band since there is an decrease in the concentration of electrons in the valence band.


Co-Valent
bonds
Hole
Si
Si
In
Si
Si
Impure atom
(acceptor)


Conduction band
E_c
E
Electron energy
Acceptor levels
E_a
E_g
E_v
Valence band
distance

Conductivity in Semiconductors



Conductivity in Semiconductors

- The electric field 'E' exist along X-direction. The field accelerate electrons along –ve X direction and holes along +ve X direction.
- The current density due to the movement of electrons is given by

  $J_n = qnv_d = qn\mu_n E$ ………….. (1) (where $v_d = \mu E$)
- The current density due to the movement of holes is given by

  $J_p = qpv_d = qp\mu_P E$ ……………. (2)

(Where v_d = Drift velocity of charge carriers, n = concentration of electrons, p= concentration of holes , μ = mobility of charge carriers ,E= electric field)

Adding eqs (1) and (2)

$$J = J_n + J_p$$

$$J = qn\mu_n E + qp\mu_P E$$

$$J = q(n\mu_n + p\mu_P)E \quad ….. \quad (3)$$

Since $J = \sigma E$ ………………… (4)

Conductivity in Semiconductors

Comparing 3rd and 4th

$$\sigma = q(n\mu_n + p\mu_P) \ldots\ldots\ldots\ldots\ldots(5)$$

σ = conductivity of semiconductors

In intrinsic semiconductors :

since $n= p= n_i$, (where n_i = intrinsic concentration)

$$\sigma_i = q\, n_i(\mu_n + \mu_P)$$

In Extrinsic semiconductors :

(a) N- type semiconductors

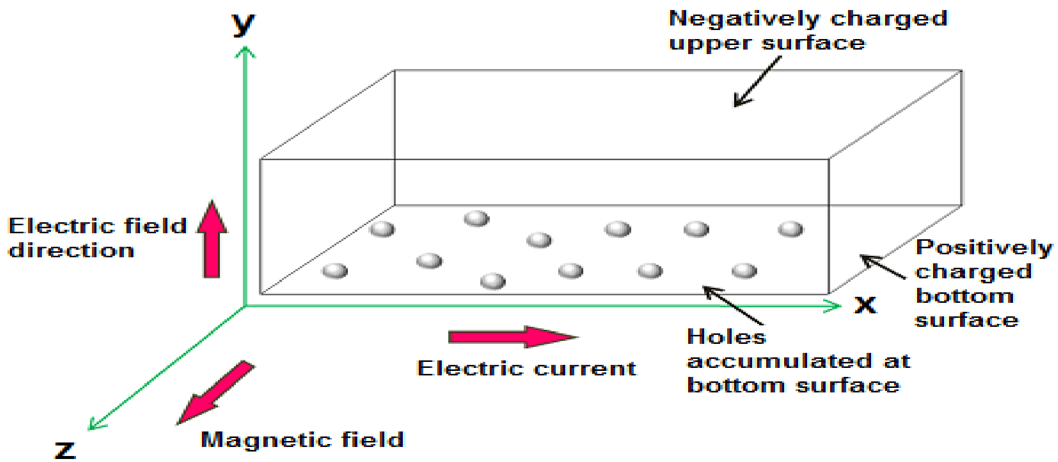
$\sigma_n = qn\mu_n$ (since n>> p)

(b) P- type semiconductors

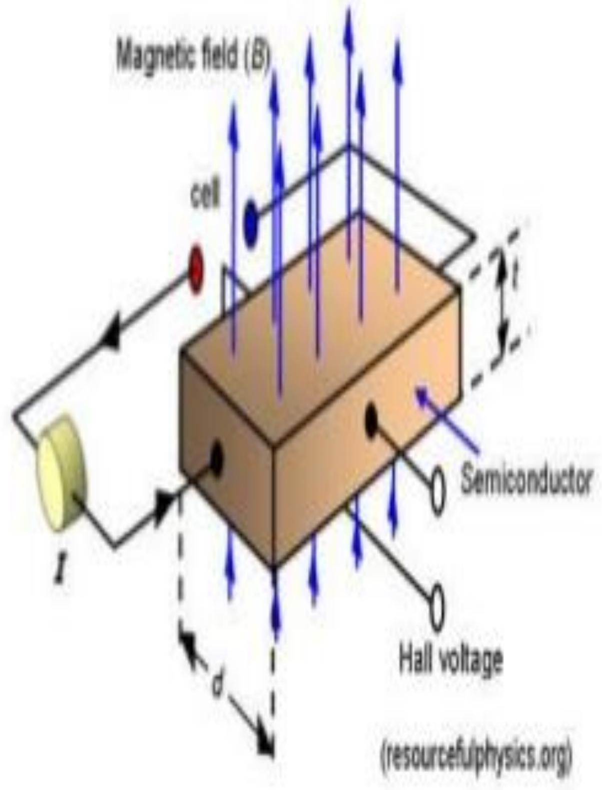
$\sigma_p = qp\mu_P$ (since p>> n)

Hall Effect

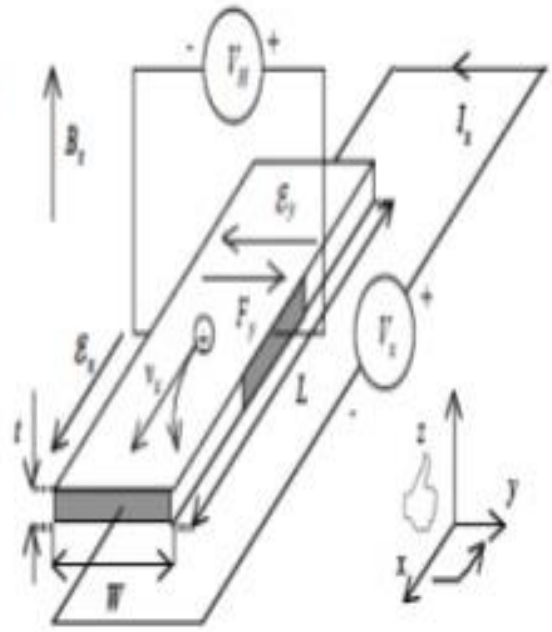
If a specimen (metal or a semiconductor) carrying a current (I) is placed perpendicular to a magnetic field (B) than an electric field is developed perpendicular to both I and B. This developed electric field is called Hall electric field (E_H).



The Hall effect describes the behavior of the free carriers in a semiconductor when applying an electric as well as a magnetic field. The experimental setup shown in Figure, depicts a semiconductor bar with a rectangular cross section and length *L*. A voltage *Vx* is applied between the two contacts, resulting in a field along the *x*-direction. The magnetic field is applied in the *z*-direction.



the holes move in the positive *x*-direction. The magnetic field causes a force to act on the mobile particles in a direction dictated by the right hand rule. As a result there is a force, F_Y along the positive *y*-direction, which moves the holes to the right. In steady state this force is balanced by an electric field, E_Y, so that there is no net force on the holes. As a result there is a voltage across the sample, which can be measured with a high impedance voltmeter. This voltage, V_H, is called the Hall voltage. Given the sign convention as shown in Figure , the hall voltage is positive for holes.



Hall effect experiment

Consider a current-carrying conductor in the form of a rectangular strip is placed in a magnetic field with the lines of force at right angles to the current, a transverse e.m.f. – the so called Hall voltage – is set up across the strip. This phenomenon is due to the Lorentz force: the charge carriers which give rise to the current flow through the specimen are deflected in the magnetic field B as a function of their sign and of their velocity v:

$$F_B = qBV_d \qquad \ldots(1)$$

Where (V_d)is Drift velocity which is the average velocity in the direction of an applied electric field of the all conducting charge carriers in the sample

As more and more carriers are deflected, the accumulation of charge produces a "Hall field" EH that exerts a force opposite to the Lorentz force.

So the electric force:

$$F_E = qE \quad \text{...(2)}$$

Equilibrium is reached when these two opposing forces are equal in magnitude, which allows us to determine the drift speed (v)

$$qBV_d = qE$$

$$\therefore V_d = \frac{E}{B} = \frac{V_H}{Bd}$$

but the current in the conductor is given by...

$$I = n e V_d A$$

so $$V_d = \frac{I}{Ane} \quad \text{...(2)}$$

From equation (1) & (2) we get that...

$$\frac{BI}{Ane} = \frac{V_H}{d} \quad \text{...(3)}$$

And it is customary to define the "Hall coefficient" (R_H) in terms of the measured quantities: $R_H = \frac{1}{ne}$

From equation (3) we get that...

$$\frac{V_H}{I} = \frac{Bd}{Ane} = R$$

As R is the resistance of the rectangular strip

But $R = \rho \frac{d}{A}$ $\quad \therefore \rho = \frac{B}{ne}$ Where ρ is the resistivity

And $\sigma = \frac{ne}{B}$ Where σ is the conductivity

And from this equation we can Determine the mobility of the charge carriers which given by

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

Applications of Hall effect

(1) Determination of N-type of semiconductor

For a N-type semiconductor, the Hall coefficient is negative whereas for a P-type semiconductor, it is positive. Thus from the direction of the Hall voltage developed, one can find out the type of semiconductor.

(2) Calculation of carrier concentration

Once Hall coefficient R_H is measured, the carrier concentration can be obtained,

$$n = \frac{1}{eR_H} \quad (or) \quad p = \frac{1}{eR_H}$$

(3) Determination of mobility

We know that, conductivity, $\sigma = e\mu q$ (or) $\mu_n = \frac{\sigma_p}{pe} = \sigma_p . R_H$

Thus by measuring `σ' and RH, μ' can be calculated.

(4) Measurement of magnetic flux density.

Using a semiconductor sample of known `RH', the magnetic flux density can be deduced from,

$$B = \frac{V_H t}{R_H I}$$

Problems

- A n-type semiconductor sample has a hall coefficient $0.0125 m^3 c^{-1}$ and the mobility of majority charge carriers is $0.36\ m^2 v^{-1} s^{-1}$ and a 100 v/m electric field apply on the sample of n-type semiconductor. Find the current density in the sample.
- The Hall coefficient of a specimen of a doped silicon is found to be $3.66 \times 10^{-4}\ m^3 c^{-1}$. The resistivity of the specimen is 8.93×10^{-3} ohm meter. Find the mobility and density of charge carriers.
- In a semiconductor there are 5×10^{19}electrons and 8×10^{20} holes per cube meter. If the mobilities of electrons and holes respectively 0.09 and 0.05 $m^2 v^{-1} s^{-1}$ the determine the

  hall coefficient of semiconductor.

LECTURE CONTENTS WITH A BLEND OF NPTEL CONTENTS AND OTHER PLATFORMS

- https://youtu.be/03j4ZvQCKWY

  (Video lecture by Dr. Amitava Dasgupta)
- https://youtu.be/rwCsBE_06FU

  (Video lecture by Prof. V.K. Tripathi)
- https://nptel.ac.in/courses/108/108/108108122/

  (Video lecture by Prof. Digbijoy N.Nath)
- http://www.digimat.in/nptel/courses/video/115103102/L23.html (Video lecture by Prof. Saurabh Basu)

REFERENCES/BIBLOGRAPHY

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- Handbook of Electronics by G.K. Mithal
- Integrated electronics by Jacob Millman and Hailkias ,Mc Graw Hill Ltd
- Engineering Physics by Dr. Y.C.Bhatt , Ashirwad Publications
- Engineering Electronics by John D Ryder, MC Graw Hill , New Delhi
- Solid State Physics by S. O. Pillai, New Age International Publisher

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THANK YOU !