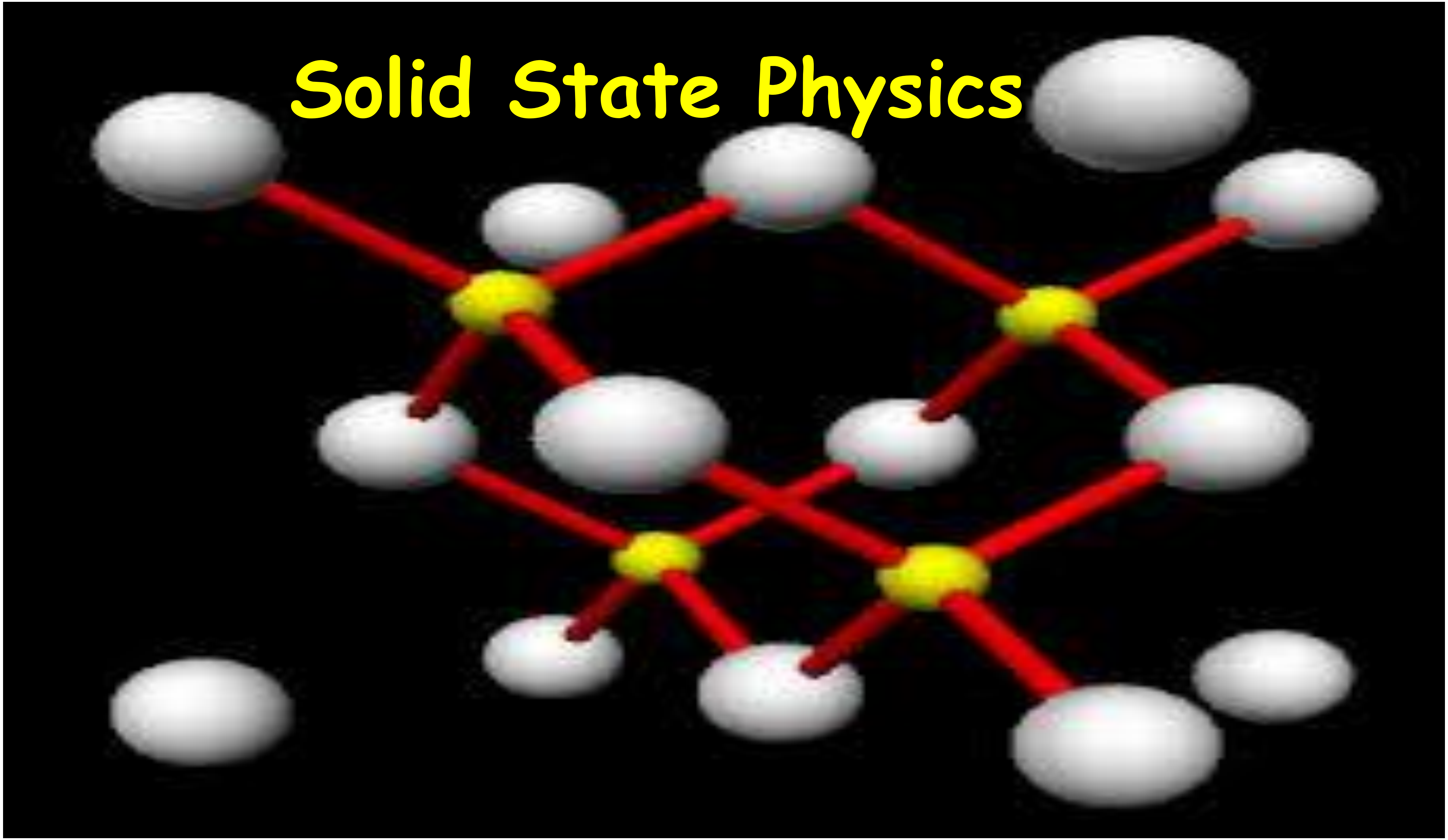
Solid State Physics



Solid

(State of Matter or densely packed collection of atoms)

Insulators: Resistivity $\approx$ 10^{10} to 10^{22} ohm-cm

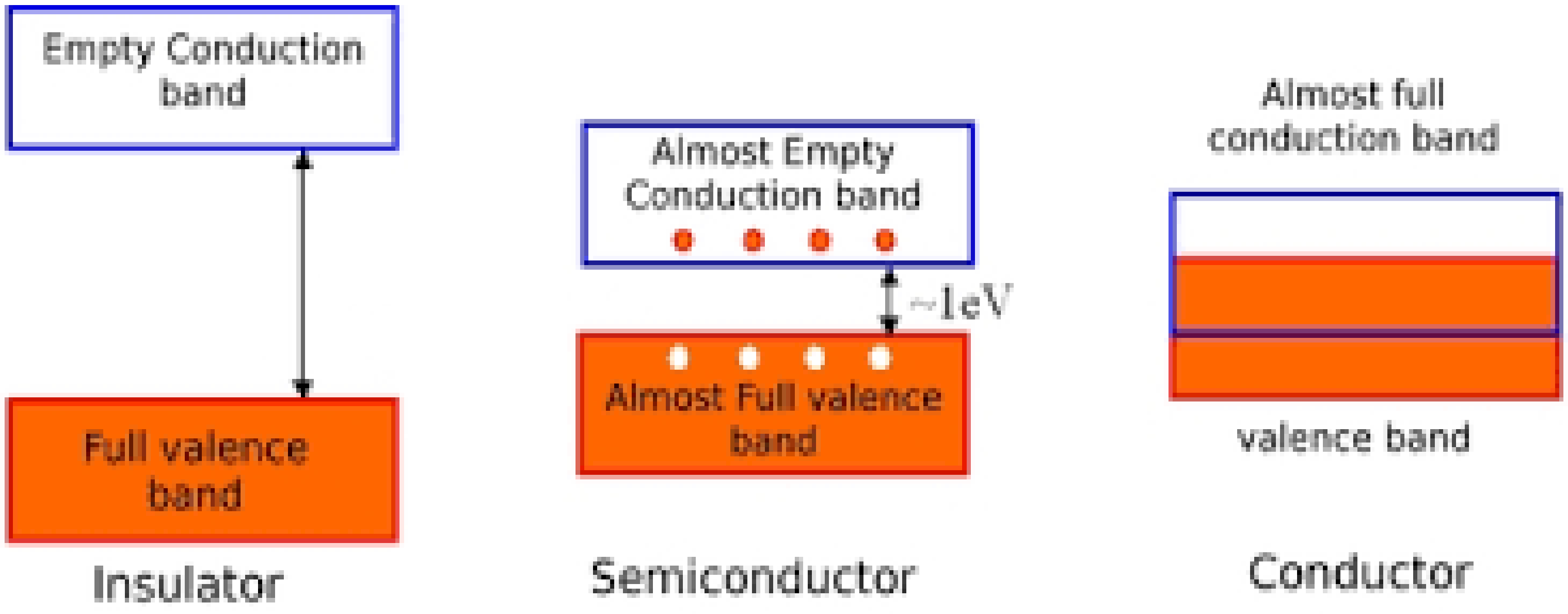
Conductors: Resistivity $\approx$ 10^{-4} to 10^{-6} ohm-cm

Semiconductors: Resistivity $\approx$ 10^{6} ohm-cm

Properties of Solid:

Electrical, Optical, Magnetic and Dielectric

Classification of solids on the basis of energy band gap

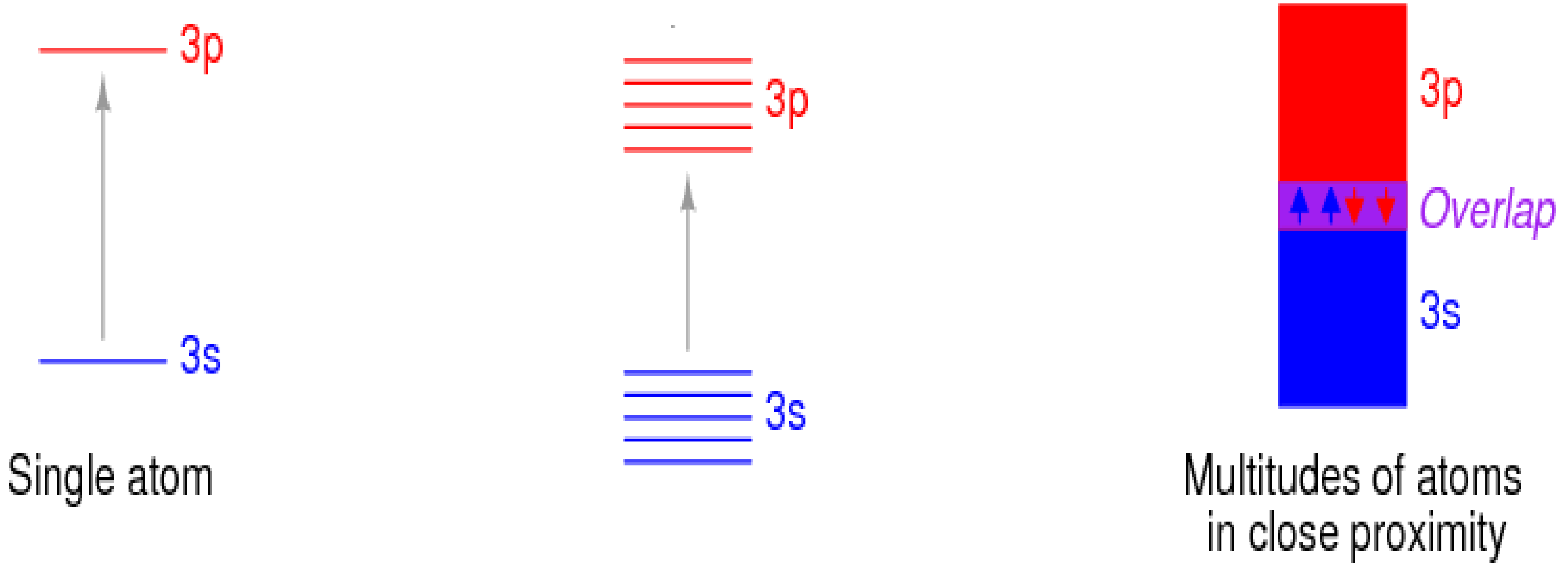


Eg > 5 eV **Eg < 2 eV** **Eg = 0 eV**

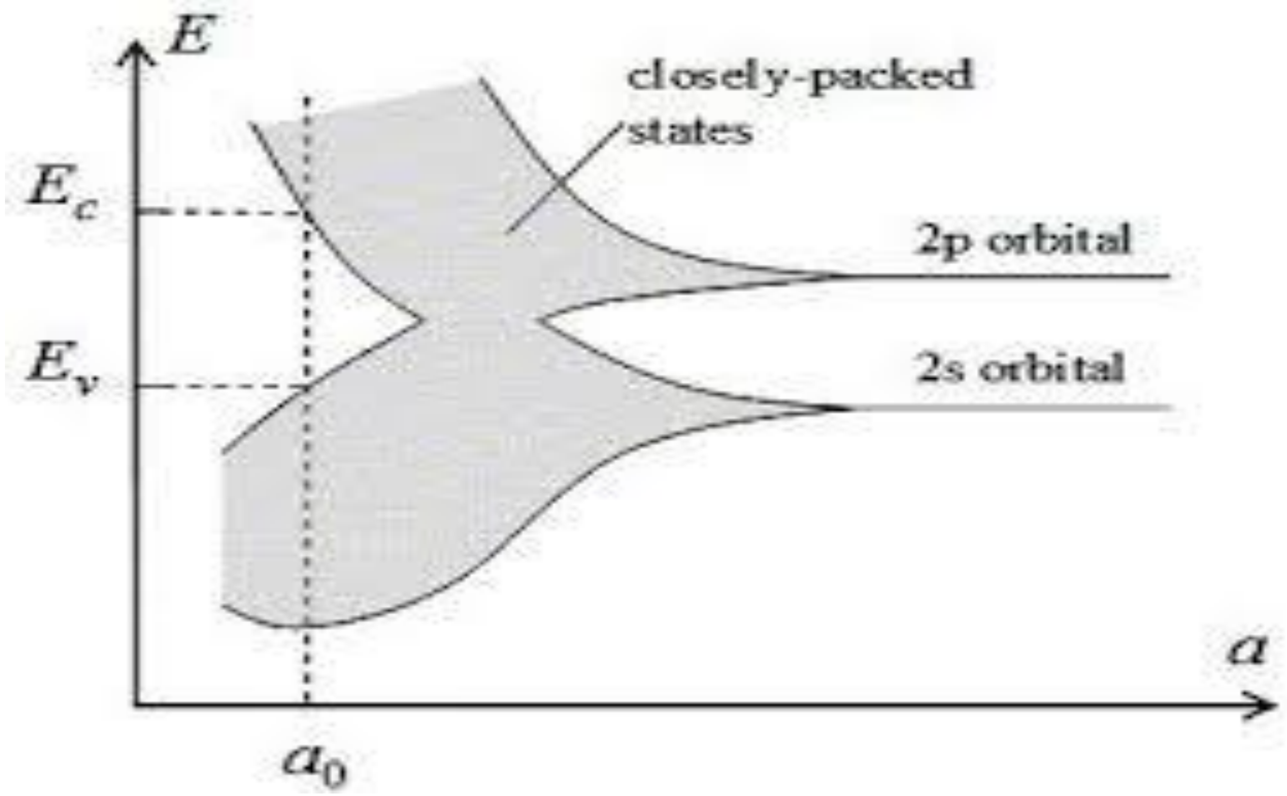
Formation of energy bands in solids

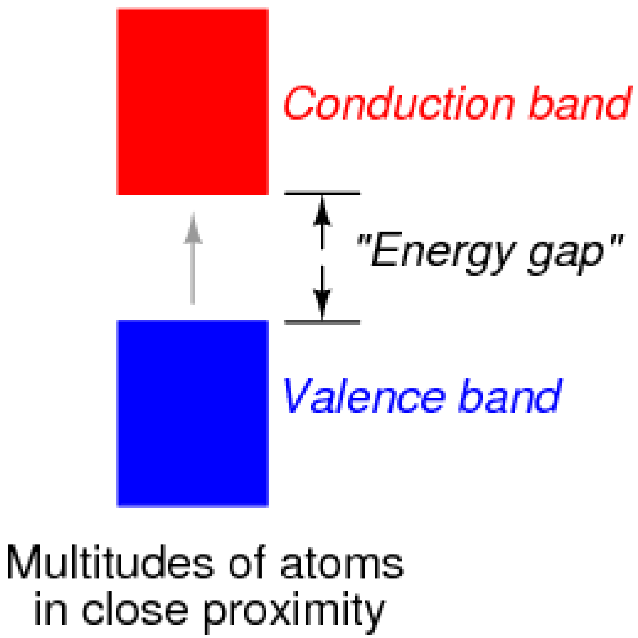
Isolated atom: Energy levels are discrete and sharp

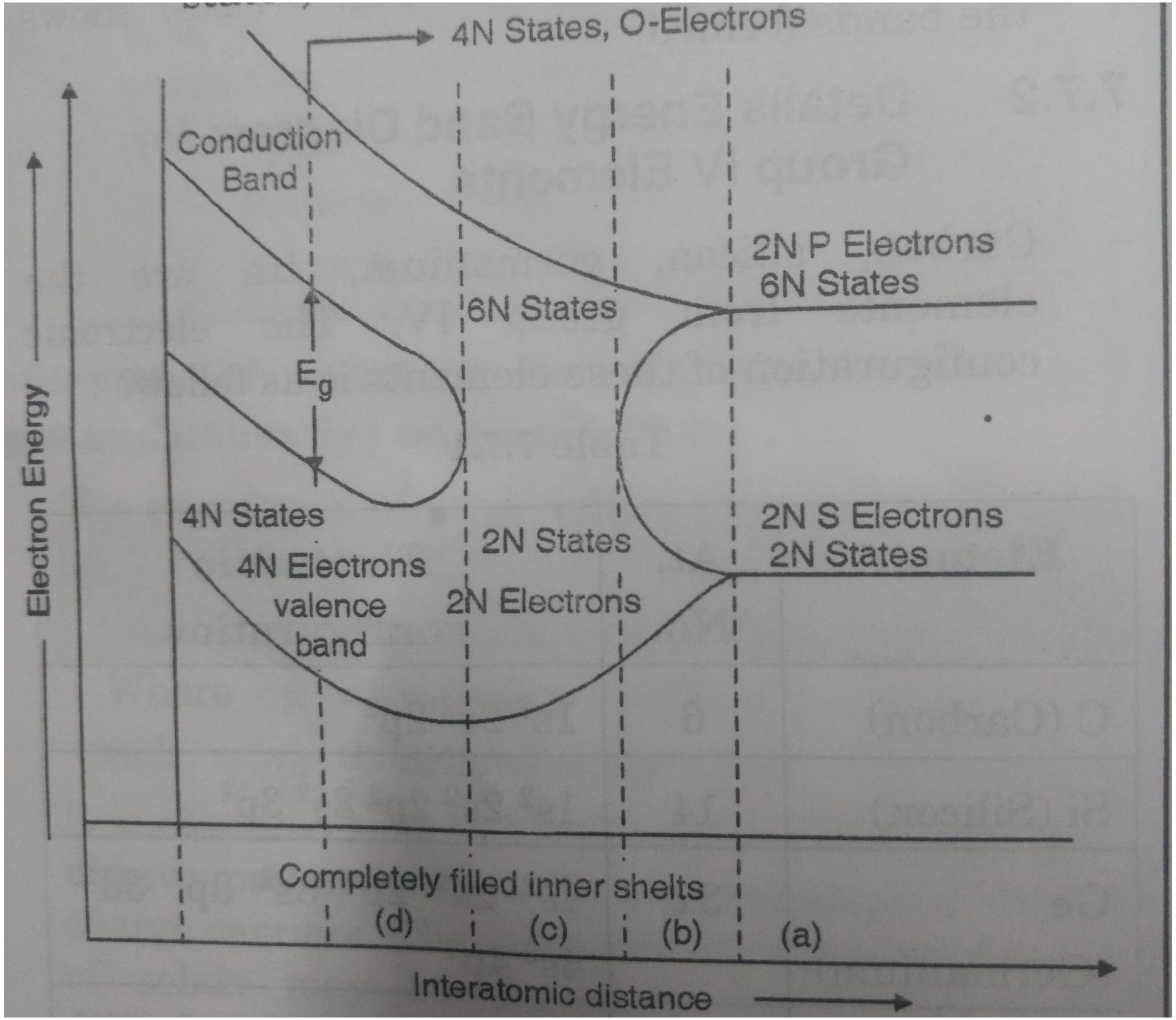
Atoms in solid: Energy splits into number of energy levels according Pauli's exclusion principle



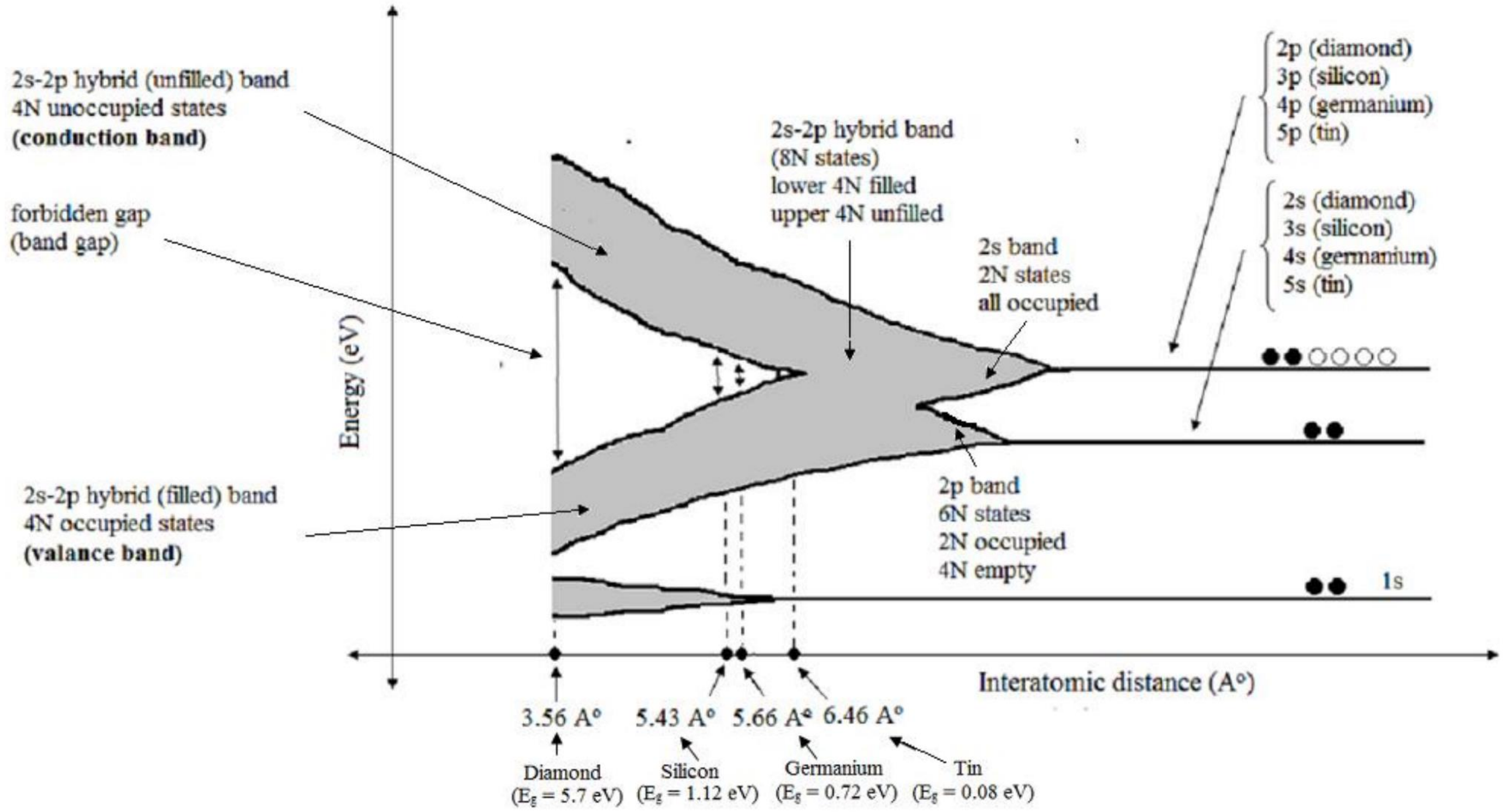
Band Theory of Solids







4N States, O-Electrons
Conduction
Band
E_g
6N States
2N P Electrons
6N States
4N States
4N Electrons
valence
band
2N States
2N Electrons
2N S Electrons
2N States
Electron Energy
Completely filled inner shelts
(d)
(c)
(b)
(a)
Interatomic distance


2s-2p hybrid (unfilled) band
4N unoccupied states
(conduction band)
forbidden gap
(band gap)
2s-2p hybrid (filled) band
4N occupied states
(valance band)
Energy (eV)
2s-2p hybrid band
(8N states)
lower 4N filled
upper 4N unfilled
2s band
2N states
all occupied
2p band
6N states
2N occupied
4N empty
2p (diamond)
3p (silicon)
4p (germanium)
5p (tin)
2s (diamond)
3s (silicon)
4s (germanium)
5s (tin)
1s
Interatomic distance (A°)
3.56 A°
5.43 A°
5.66 A°
6.46 A°
Diamond
(E_g = 5.7 eV)
Silicon
(E_g = 1.12 eV)
Germanium
(E_g = 0.72 eV)
Tin
(E_g = 0.08 eV)

Conduction Band:
The energy band hosting the free electrons capable for electrical conduction is called conduction band.

Valence Band:
The energy band occupied by valence electrons that can be incorporated into conduction band is called valence band

Forbidden Gap:
The energy interval between the top edge of valence band and the bottom edge of the conduction band is called forbidden or energy gap

The minimum energy required to transfer the electron from VB to CB.

Classical Free Electron Theory of Metals

- Classical electron theory: Drude and Lorentz
- Behaviour of valence electrons in metallic solid: **conduction electrons are completely free**
- Free electrons: electron gas; move inside the metal without collision
- Electron velocity in metal: Maxwell-Boltzman distribution (velocity like gas molecules)
- Kinetic energy of electron: 3 kT/2 at temperature T (same as gas molecules)
- Motion of electrons: Random in absence of electric field (like gas molecules)
- In presence of electric field: Electron will move opposite to the direction of electric field with drift velocity with velocity of random motion
- Electrostatic force of attraction between free electron and ion cores: negligible
- Mean free path: Average distance between two successive collisions
- Temperature increases – collision increases- resistivity increases

Failure of Classical Free Electron Theory

1. It predicts, resistivity is directly proportional to square root of absolute temperature, **Experimentally, directly proportional to the absolute temperature**

2. It shows larger conductivity for divalent and trivalent atoms (Zn and Al) compared to monovalent atoms (Cu and Ag)
   Experimentally, Cu and Ag are good conductors

Quantum mechanical free electron theory

- Proposed by Sommerfeld
- Distribution of electrons: Fermi-Dirac distribution (Pauli's exclusion principle)
- P.E. of electron at rest inside metal is lower than that of electron outside the metal at RT (Potential inside conductor is zero)
- Classification of solid on band theory: metal, semiconductor, insulator

1. According to quantum free electron theory the electrons follow ……… distribution of energy.

a) binomial
b) Maxwell-Boltzmann
c) Fermi-Dirac
d) Bose-Einstein

2. According to classical free electron theory the electrons follow ……… distribution of energy.

a) Binomial
b) Maxwell-Boltzmann
c) Fermi-Dirac
d) Bose-Einstein

3. According to classical free electron theory the electrons …………… in absence of external electric field.

a) remain at rest
b) move randomly
c) have drift velocity
d) none of the above

4. The classical free electron theory of metals was initiated by …………………

a) Pauli b) Summerfield c) Lorentz and Drude d) Fermi-Dirac

Electrical Conductivity

Conductivity: number of charge carriers present in material

Conductivity of Metals/Conductors

According to Free Electron theory : Electrons move freely

Conductor in absence of electric field: random motion of electrons

Presence of electric field: electron motion in one direction (current will flow)

Drift velocity : $V_d = \mu_e E$,

Consider, n = number of free electrons per unit volume

V = applied voltage

l = length of conductor

E = electric field

The total charge present in solid : nAv_de (rate of flow of charge)

$R = \rho l/A$

$\rho = 1/ n \mu_e e$

$\sigma = n \mu_e e$

Conductivity of Semiconductors (intrinsic and extrinsic)

Total current flow : electrons and holes

Consider, n_e = number of electrons in CB

n_h = number of holes in VB

μ_e = electron mobility

μ_h = hole mobility

v_e = drift velocity of electrons

v_h = drift velocity of holes

V = applied voltage

l = length of conductor

E = electric field

A = cross section area

$$\boxed{\begin{aligned} &\mathbf{R = l/Ae\,(\mu_e n_e + \mu_h n_h)} \\ &\boldsymbol{\rho = 1/\,e\,(\mu_e n_e + \mu_h n_h)} \\ &\boldsymbol{\sigma = e\,(\mu_e n_e + \mu_h n_h)} \end{aligned}}$$

Effect of external factors on conductivity

- Why external factors affect the conductivity?

  Conductivity is directly proportional to charge concentration in solid

1. **Temperature**
2. **Light**
3. **Impurity**

Resistivity	**Temperature**	**Light**	**Impurity**
Metal	Increases	Constant	Increases
Semiconductor	Decreases	Decreases	Decreases

1. Calculate the conductivity of pure silicon at RT when the concentration of carriers is 1.6 x 10^{10} /cm^3

Given: ni = 1.6 x 10^{10} /cm^3

μ_e = 1500 cm^2/volt-sec

μ_h = 500 cm^2/volt-sec

Formula: $\boldsymbol{\sigma = e\,(\mu_e n_e + \mu_h n_h)}$

$\boldsymbol{\sigma_i = e\, n_i\,(\mu_e + \mu_h)}$

Ans: $\boldsymbol{\sigma = 5.12 \times 10^{-6}}$ **mho/cm**

2. Calculate the current produced in a small Germanium plate of area 1 cm^2 and thickness 0.3 mm when P.D. of 2 V is applied across the faces

Given:

$n_i = 2 \times 10^{19} /m^3$

$\mu_e = 0.36\ m^2/\text{volt-sec}$

$\mu_h = 0.17\ m^2/\text{volt-sec}$

$e = 1.6 \times 10^{-19}\ C$

$A = 1 \times 10^{-4}\ m^2$

$L = 0.3 \times 10^{-3}\ m$

Formula:

$I = n_i e E A (\boldsymbol{\mu_e} + \boldsymbol{\mu_h})$

$I = e A n_i(\boldsymbol{\mu_e} + \boldsymbol{\mu_h}) V/L$

Ans: **I = 1.13 A**

3. The resistivity of an n-type semiconductor is 10^{-6} ohm-cm. Calculate the number of donors atom which must be added to obtain the resistivity

Given: μ_e = 1000 cm^2/volt-sec

$\boldsymbol{\rho}$ = 10^{-6} ohm-cm

Formula: $\boldsymbol{\rho = 1/\, e\,(\mu_e n_e + \mu_h n_h)}$

For n-type (when concentration of donor atom is more), $\boldsymbol{n_e = n_d}$

$\boldsymbol{\rho = 1/\, e\mu_e n_d}$

Ans: $\boldsymbol{n_d = 6.25 \times 10^{21}}$ **atoms**

4. Calculate the number of acceptors to be added to a Ge sample to obtain the resistivity of 20 ohm-cm.

Given : $\mu = 1700\ cm^2\ /V.\ sec$

$$\rho = 1/\ n_a e\ \mu$$

$$n_a = 1.83\ X\ 10^{14}\ /cm^3$$

Calculate the free electron density in copper, if each copper atom donates one electron to the conduction band. (Properties of copper: Density = 8.96 gm/cc, atomic weight 63.5 and Avogadro's number = 6.02×10^{23} atoms/mole).

63.5 gm of copper contains 6.023×10^{23} atoms

1gm of copper $= 6.023 \times 10^{23}/63.5 =$ Z atoms/gm

8.96 gm/cc of copper $= 8.96$ (gm/cc) x Z (atoms/gm)

$n_e = 8.5 \times 10^{22}$ electron /cc

Calculate the conductivity of copper, for which **μe = 34.8 cm2/V-s and** Density = 8.96 gm/cc. Assume that there is one free electron per atom. Atomic weight = 63.5. If an electric field of 10 V/cm is applied, find the average velocity of free electrons.

n_e = 8.5×10^{22} electron /cc ……………………from last question

$\sigma = e\,\mu_e n_e = 47.3 \times 10^4$ mho/cm

$v_d = \mu_e E = 348$ cm/s

Calculate the conductivity of a Ge sample if donor impurity added to the extent of one part in 10^7 Ge atoms at RT.

Given:

$N_a = 6.02 \text{ X } 10^{23}$ atoms /gm-mole
Atomic weight of Ge = 72.6
density = 5.32 gm/cc
mobility μ_e = 3800cm^2/V-sec

Formula: $\boldsymbol{\sigma = e n_d \mu_e}$

Concentration of Ge atoms = (Avogadros no. X density) /Atomic weight = 4.41×10^{22} atoms/cm^3

Since there is one donor atom per 10^7 Ge atoms (10^7 : 1)

n_d= Concentration of atoms/ (10^7) = 4.41×10^{15} /cc

Ans: $\boldsymbol{\sigma = 2.68}$ **mho/cm**

Intrinsic Si is doped with phosphorus with atomic ratio of 10^8 (Si): 1(P). Calculate the conductivity of N type Si thus formed.

Given: $\mu_e = 1400\ cm^2V/s$
Atomic weight of Si = 28.085
A. No. = 6.022×10^{23} atoms/mole
density of Si = 2.3 gm/cm^3

Formula: $\boldsymbol{\sigma = e n_d \mu_e}$

Concentration of Si atoms = (Avogadros no. X density) /Atomic weight

Since there is one donor atom per 10^8 Si atoms then

n_d = Concentration of atoms/10^8

Ans: **σ = 0.112 mho/cm**

Find the drift velocity for the electron in silver wire of radius 1.00 mm and carrying a current of 2A. Density of silver is 10.5 g/cm^3

Given: $r = 1$ mm
$I = 2A$
density = $10.5 g/cm^3$
A.W of Ag = 108

Formula: $I = neAv_d$
$v_d = I/neA$

$A = \pi r^2$ (area of wire)

What is n?
Concentration of Ag atoms = (Avogadros no. X density) /Atomic weight

$v = 7 \times 10^{-4}$ m/s

Density of States (DOS)

Total number of available states per unit energy and per unit volume within particular band

The states available for electrons to occupy

Conduction band: how many states for electrons
Valence band: how many states for holes

$$g(E)\,dE = \frac{4\pi}{h^3}\, 2m^{3/2}\, E^{1/2}\, dE$$

g (E) dE = no. of states per unit volume in energy interval E and E + dE

The density of states increases with increasing energy from bottom of band

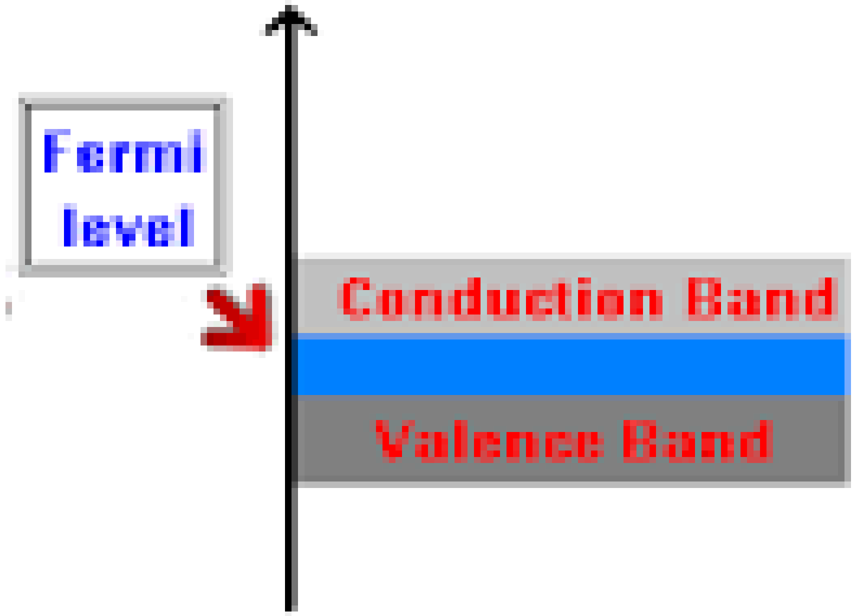
Fermi Energy or Fermi Level

The highest occupied energy level of electrons at absolute zero temperature is called Fermi level (E_F)

Fermi level in metals

At 0 K,

All levels full upto E_F and empty above E_F



At high temperature,

Electrons are present in higher energy state

Fermi level in Semiconductors

Fermi-Dirac Probability Distribution Function

Maxwell-Boltzman distribution: non-interacting particles, distinguished (gas molecules)

Electrons are interacting particles: can not distinguished (fermions), Pauli's exclusion principle

Fermi-Dirac distribution

$$F(E) \text{ or } P(E) = \frac{1}{1 + e^{(E-EF)/kT}}$$

What is the probability of occupancy of electron in given energy state as function of temperature

$$F(E) = \frac{1}{1+ e^{(E-EF)/kT}}$$

1. **At T = 0 K, and E < E_F**

   F(E) = 1

All the energy states below Fermi level are full and therefore occupation probability of electrons is 1 or 100%

2. **At T = 0 K, and E > E_F**

   F(E) = 0

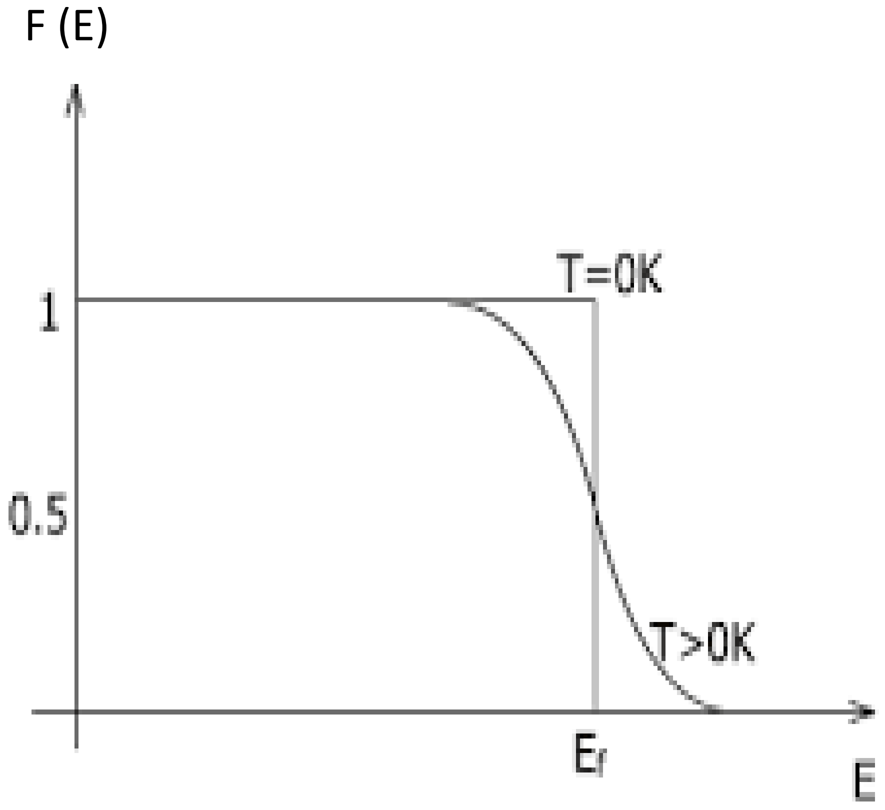
All the energy states above Fermi level are unoccupied and occupation probability is 0

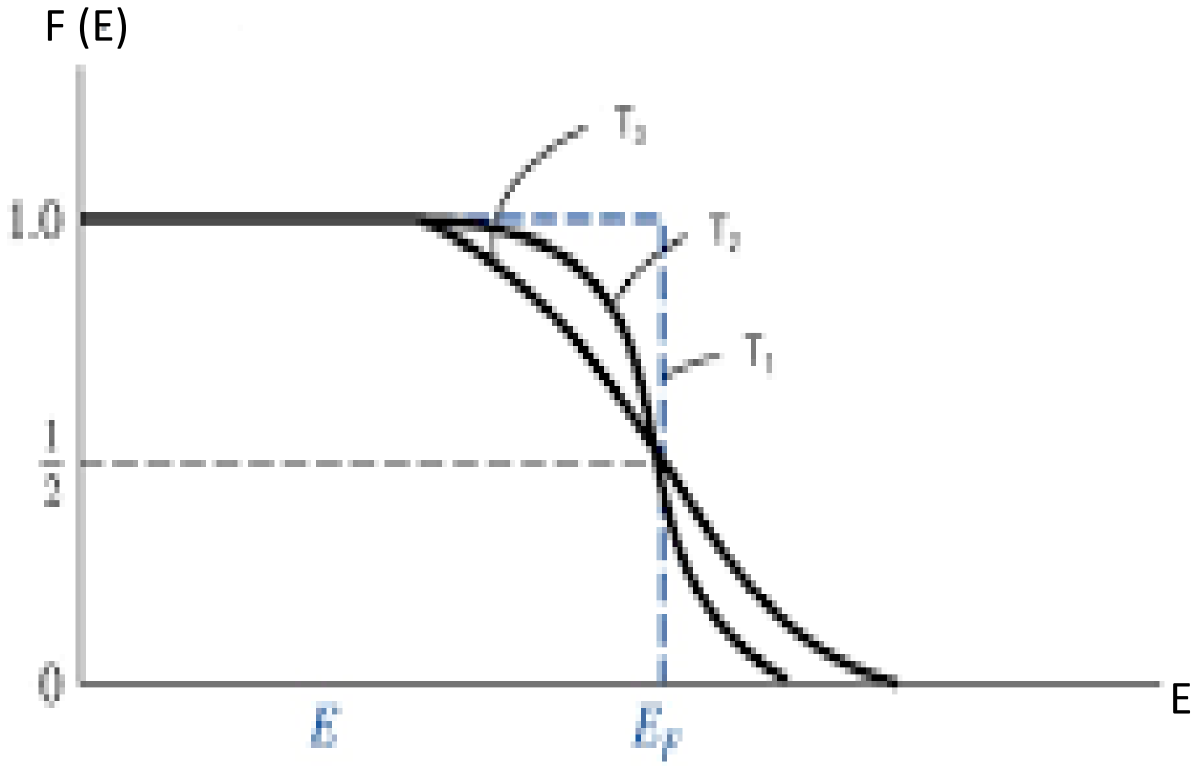
3. **At any temperature (T > 0 K) , and E = E_F**

   F(E) = 1/2

The energy state with 50% probability

Probability of occupation





Fermi level in Intrinsic Semiconductors

$$F(E) = \frac{1}{1+e^{(E-EF)/kT}}$$

- At 0 K, valence band is completely filled and conduction band is empty
- C.B. energy = E_C and V. B. = E_V
- At T > 0K, n_c = number of electrons in CB

  n_v = number of electrons in VB

  $N = n_c + n_v$, total number of electrons

According probability function, $P(E_c) = n_c / N$

$n_c = N\,P(E_c)$

$$P(E_c) = \frac{1}{1+e^{(Ec-EF)/kT}}$$

$$\mathrm{n_c} = \frac{N}{1+ e^{(Ec-EF)/kT}}$$

$$\mathrm{n_v} = \frac{N}{1+ e^{(Ev-EF)/kT}}$$

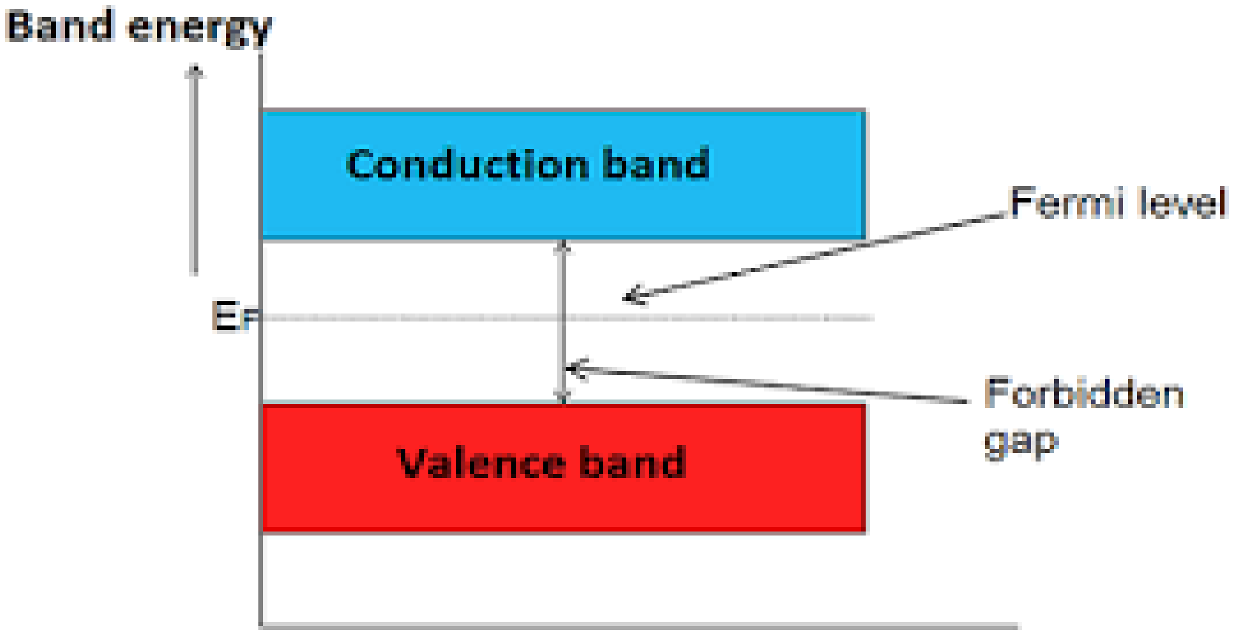
$$\mathrm{N} = \frac{N}{1+ e^{(Ec-EF)/kT}} + \frac{N}{1+ e^{(Ev-EF)/kT}}$$

$$e^{\frac{E_c+Ev-2EF}{kT}} = 1$$

$$\frac{E_c + Ev - 2EF}{kT} = 0$$

$$\boxed{\boldsymbol{E_F = \frac{E_c + Ev}{2}}}$$

Fermi level in Intrinsic Semiconductors

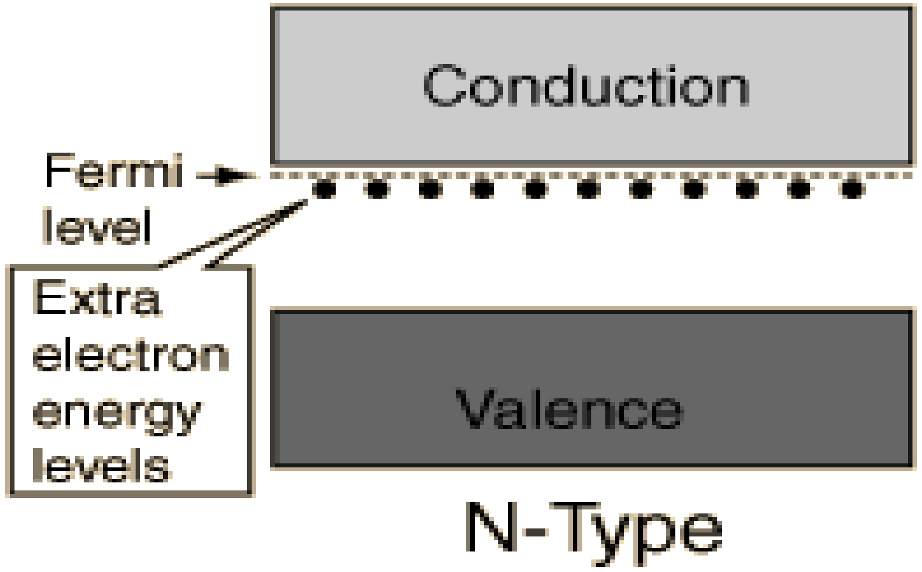


Fermi level in Extrinsic Semiconductors

a) Position of Fermi level in n-type semiconductor

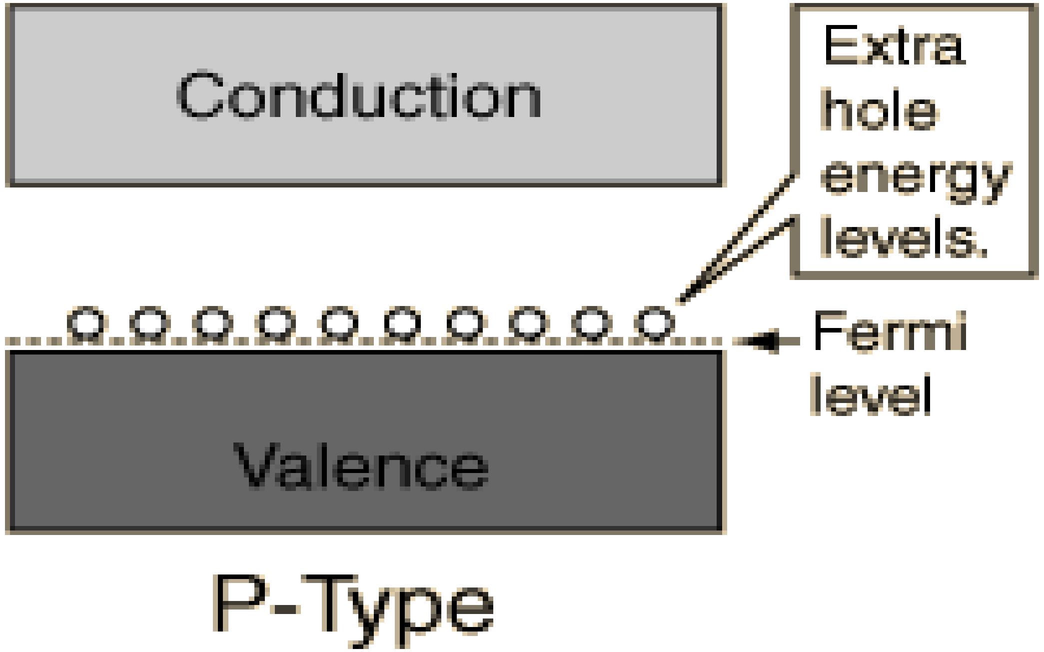
- Pentavalent impurity (donors): more number of electrons than holes
- Fermi level will shift upward
- Donor energy level near to bottom of CB

- At 0K, donor levels are occupied and no electrons in CB
- P (E) = 1 up to donor level and P(E) = 0 at CB
- Fermi level, $E_d < E_F < E_C$



b) Position of Fermi level in p-type semiconductor

- Acceptors impurity: more number of holes than electrons
- Fermi level will shift downward
- Acceptor energy level near to top of VB



- At 0 K, Fermi level, $E_V < E_F < E_a$

Effect of Temperature and Doping Concentration on Fermi Level

1. Effect of temperature on n-type semiconductor

At low temperature:

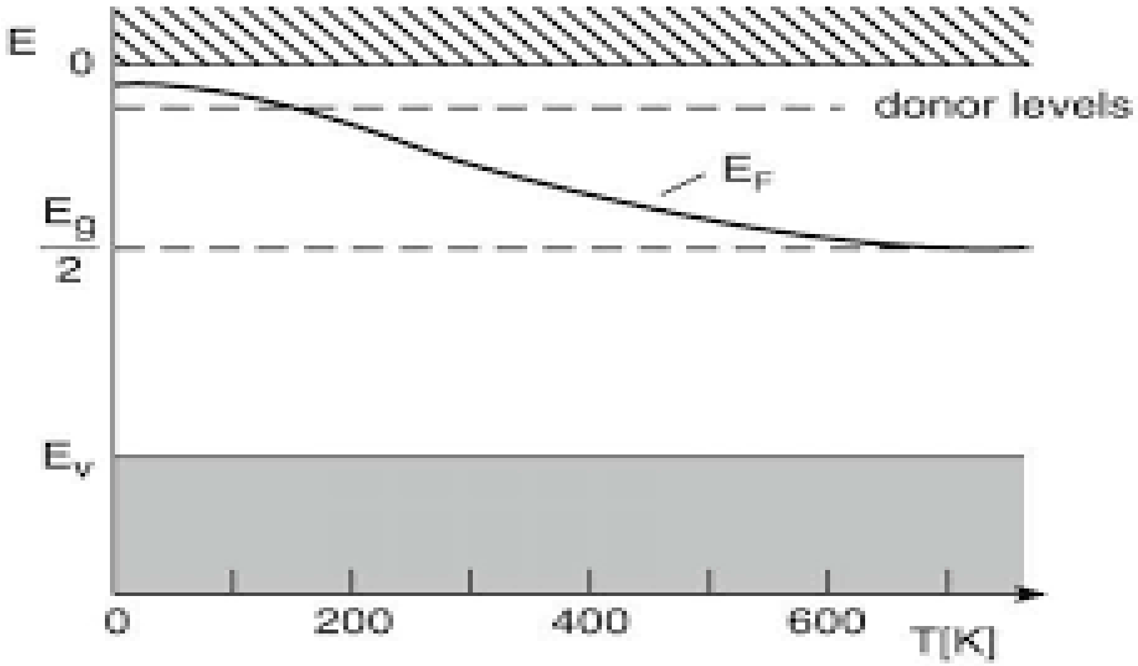
- Fermi level lies between E_C and E_d

With increase in temperature:

- Electron transfer from donor atom to CB
- Density of electron in CB will increase
- Donor level and Fermi level will decrease

At high temperature:

- Electron-hole pair generation
- Number of electron and holes will be same
- Extrinsic transforms to intrinsic



2. Effect of temperature on p-type semiconductor

At low temperature:

- Fermi level lies between E_v and E_a

With increase in temperature:

- Electron transfer from VB atom to acceptor level: hole created
- Density of electron in acceptor atom will increase
- Fermi level will start to increase and will shift upward

At high temperature:

- Electron-hole pair generation
- Number of electron and holes will be same
- Extrinsic transforms to intrinsic

1. Effect of doping concentration on n-type semiconductor

- Donor atom : discrete energy levels due to low concentration below the CB
- High concentration: interaction between atom increases
- Energy level of donor atoms splits: band
- At very high concentration: band become broaden and overlap with CB
- Fermi level: shifts upward near to CB
- Fermi level moves into CB: with further increasing doping concentration

2. Effect of doping concentration on p-type semiconductor

- Acceptor atom : discrete energy levels due to low concentration above the VB
- High concentration: interaction between atom increases
- Energy level of acceptor atoms splits: band formed
- At very high concentration: band become broaden and overlap with VB
- Fermi level: shifts downward near to VB
- Fermi level moves into VB: with further increasing doping concentration

Drift Current and Diffusion Current

Drift Current:
Current flowing through material in presence of electric field

Diffusion Current:

- Carrier concentration gradient: number of charge carriers (electrons or holes) are uneven
- Transfer of charge carrier from concentration of high to low region
- Directional movement of charge carriers : current (diffusion)
- After even distribution: electric field required for diffusion current

P-N Junction Diode

Diode:
Two terminal device with cathode and anode

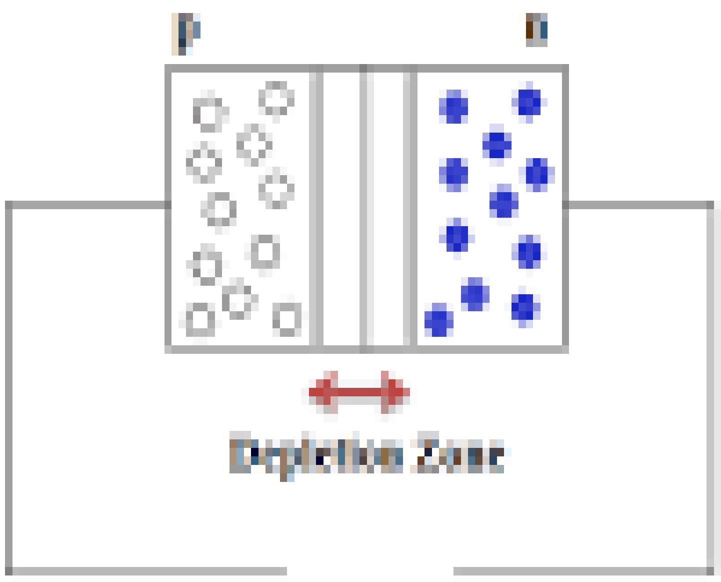
P-N junction diode: P type and N-type semiconductor together and forms a junction

- Diffusion
- Depletion layer or space charge region
- Potential barrier or barrier height (V_0)

Energy Band Diagram of P-N Junction Diode with and without Potential

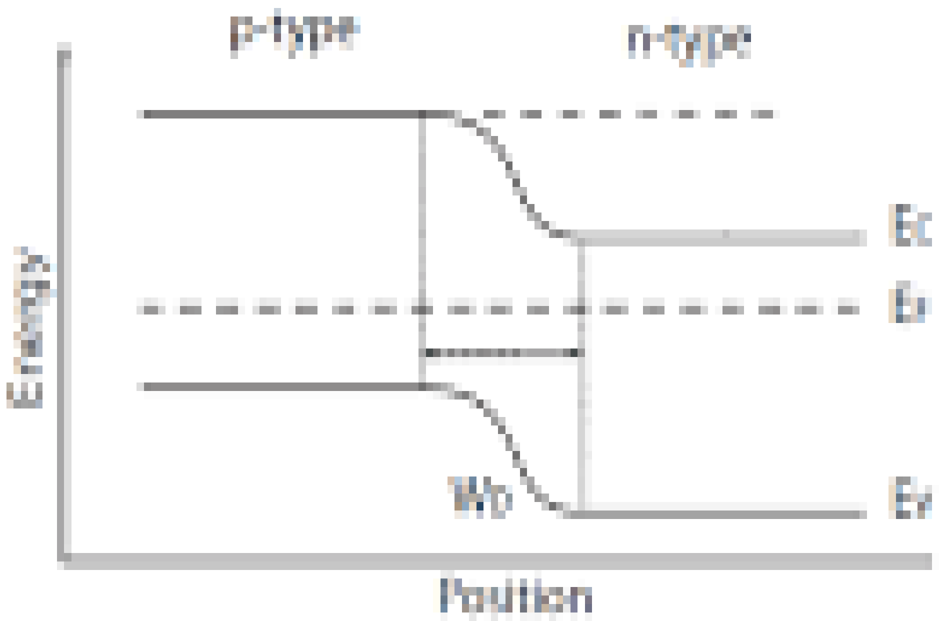
a) Zero bias : No potential

- CB and VB of P-type semiconductor: shift upward
- CB shift: potential difference of eV_B over CB of N-type
- Fermi level: equilibrium



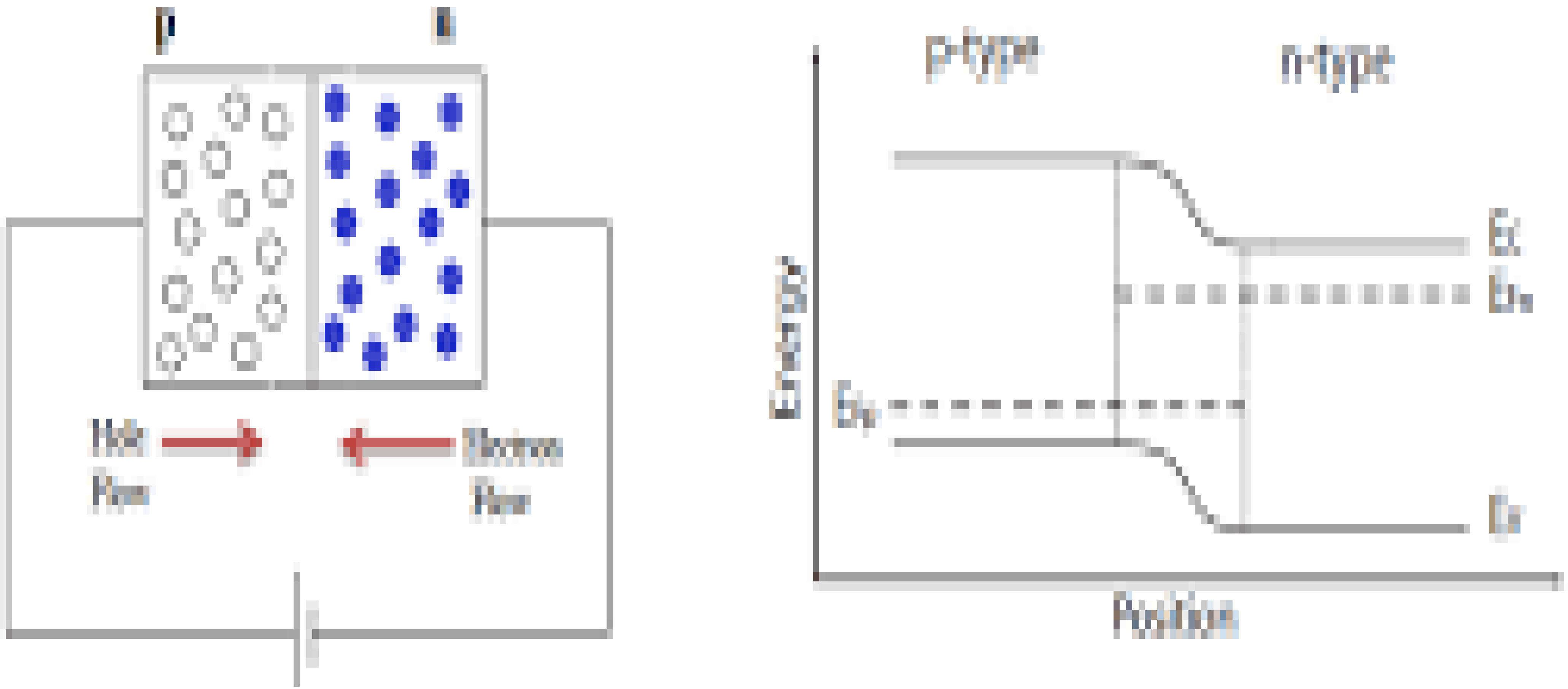
without bias voltage

a



b) Forward bias

- P-type : positive and N-type: negative
- Energy of electrons in N-side: increases by eV, V-applied voltage
- Reduction of potential barrier by e $(V_B - V)$
- Electrons can easily cross the junction
- External potential > Barrier potential : current flow


p
n
Hole Flow
Electron Flow
p-type
n-type
Energy
E_c
E_{Fn}
E_{Fp}
E_V
Position

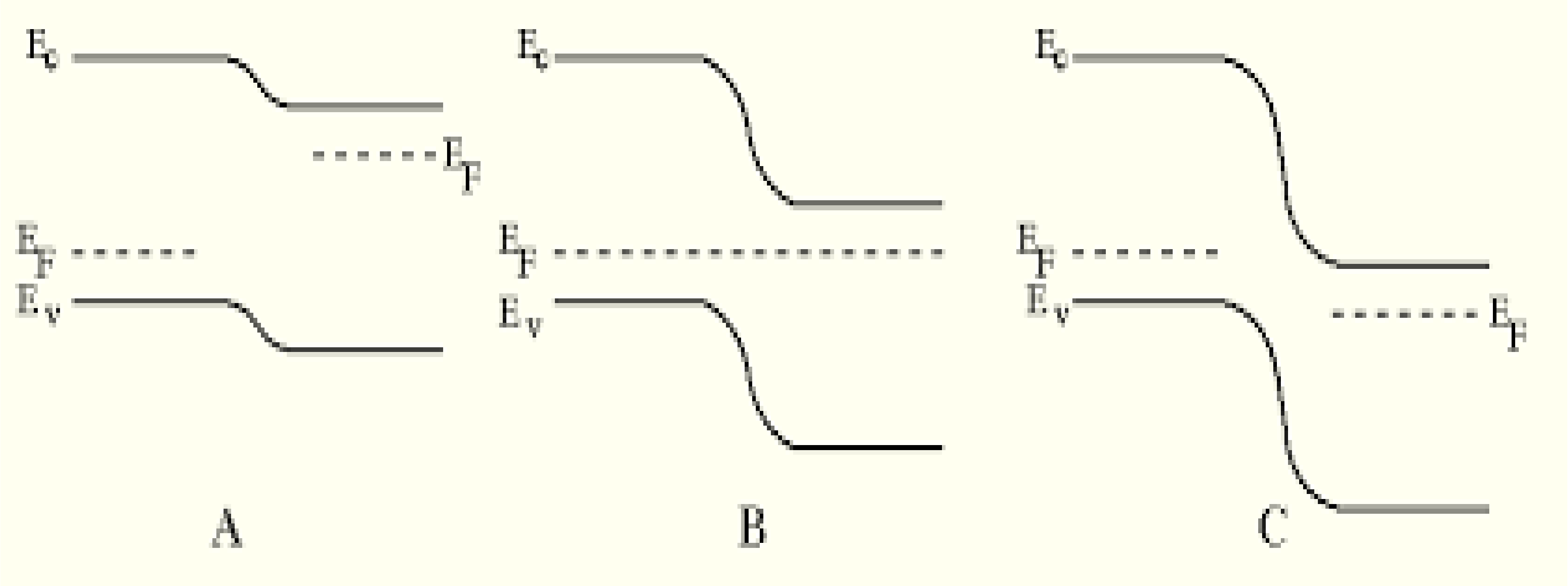
c) Reverse bias

- P-type : negative and N-type: positive
- Electrons energy will decrease by eV
- Potential barrier will increase by e (V_B+V): width of depletion layer increase
- Majority charge carriers (electrons and hole) can not cross the junction
- External potential > Barrier potential : current flow due to minority charge carriers

Forward biased

Zero biased (equilibrium)

Reversed biased



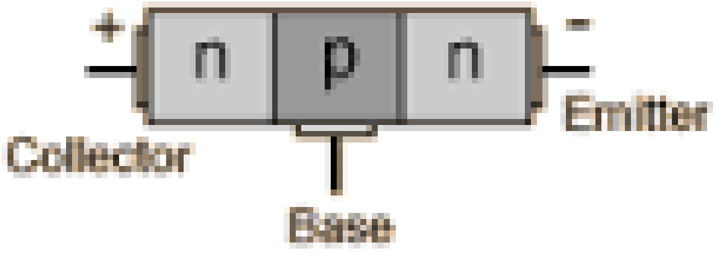
Transistor

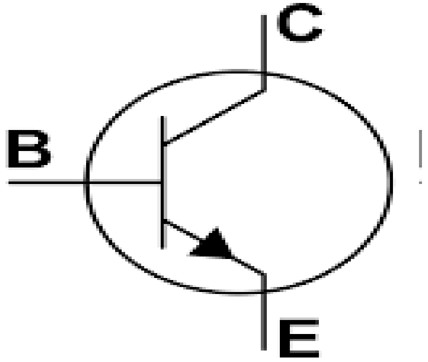
- Transistor : transfer of resistor or voltage and current
- Construction: **two p-n junction diode** with three layers
- Three layers: **Emitter, Base, and Collector**
- Bipolar transistor: current flow due to electrons and holes
- Impurity doping and concentration is different for three layers
- Applications: switch or amplifier
- Two types: **N-P-N transistor and P-N-P transistor**

Emitter	**Base**	**Collector**
N or P type	Depending on emitter	Same as emitter
Size: large	thin	Very large
Heavily doped	Lightly doped	Lightly doped
Supply majority charge carriers to base	Control current flow	Collect majority charge carriers emitted by emitter
Always in forward bias	-	Always in reverse bias

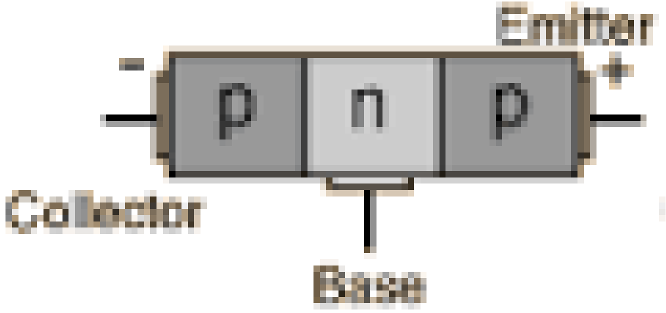
Construction of transistor

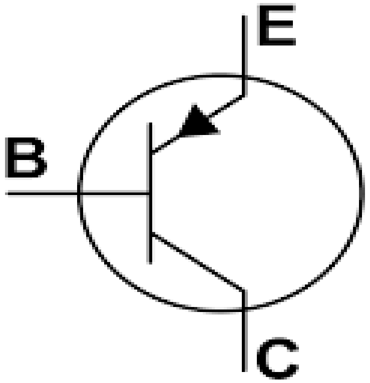
1. N-P-N Transistor





2. P-N-P Transistor

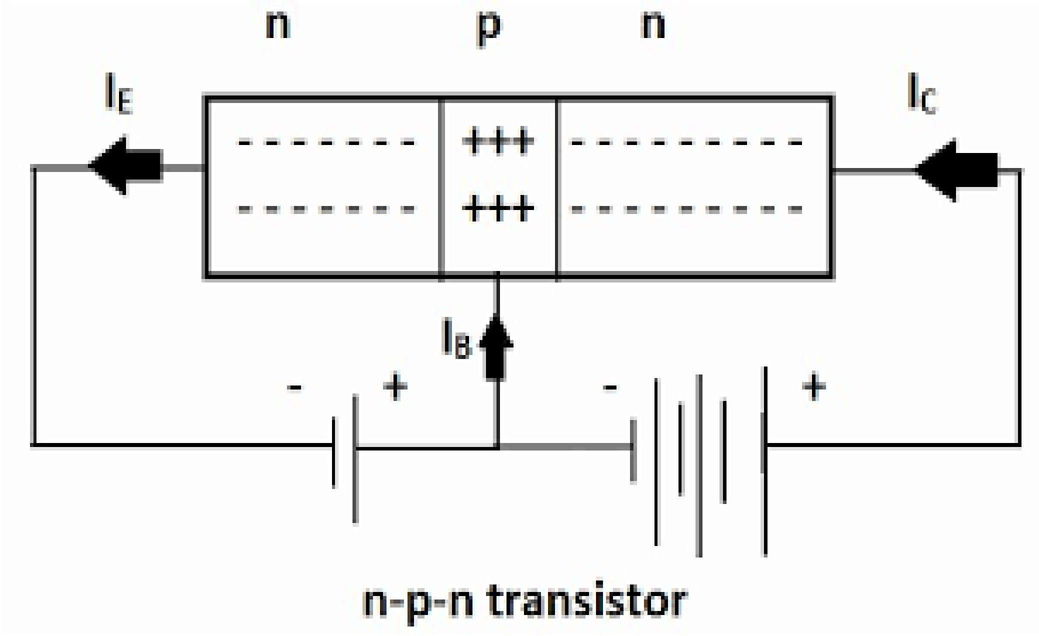




Working of Transistor

1. N-P-N Transistor

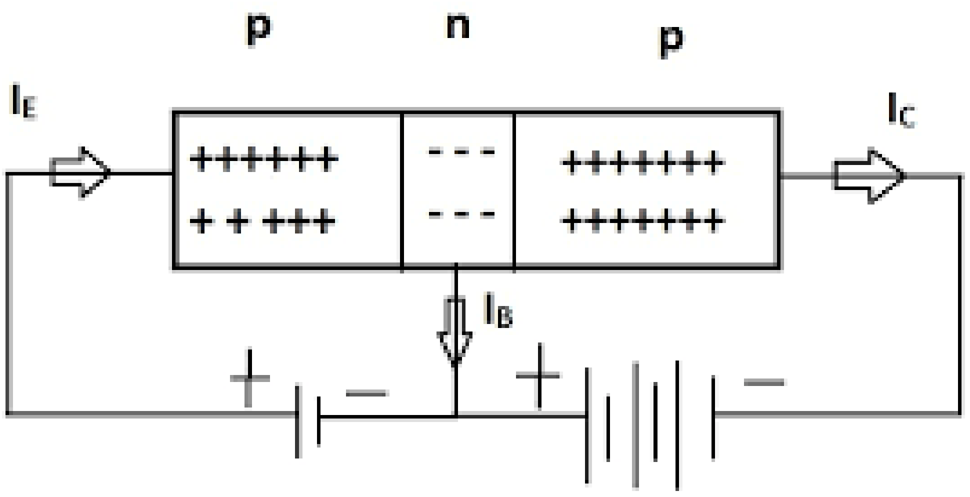
- Emitter-base junction: forward bias (V_{BE})
- **Emitter current (I_E)**: increases due to reduction in potential barrier
- Electrons flow from emitter to base
- **Base current (I_B):** Recombination of electrons (emitter) and holes (base)
- Electrons will pass through base to collector: base is thin and low doping
- **Collector current (I_C):** Transmitted electrons will attracted by V_{BC} (reverse bias)



Current flow due to electrons (majority charge carriers)

2. P-N-P Transistor

- Emitter-base junction: forward bias (V_{BE})
- **Emitter current (I_E)**: increases due to reduction in potential barrier
- Holes flow from emitter to base
- **Base current (I_B):** Recombination of electrons (emitter) and holes (base)
- Holes will pass through base to collector: base is thin and low doping
- **Collector current (I_C):** Transmitted holes will attracted by V_{BC} (reverse bias)

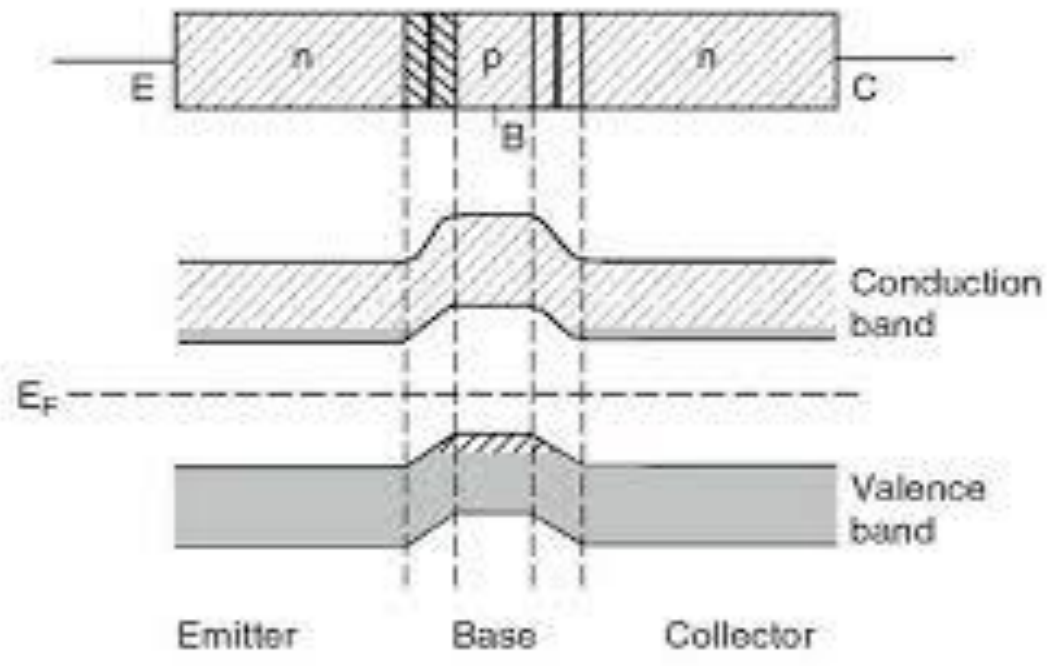


p-n-p transistor

Current flow due to holes (majority charge carriers)

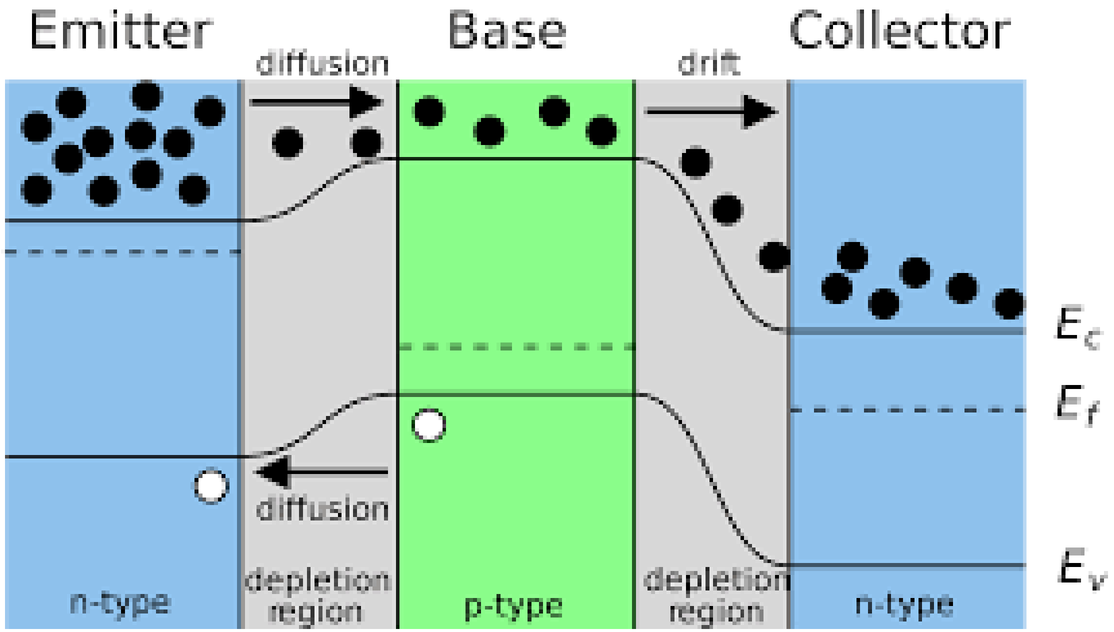
Energy Band Diagram of N-P-N Transistor

No Bias N-P-N Transistor



Fermi level equilibrium condition

Biased N-P-N Transistor



- **Emitter-base: Forward bias**
- Electron energy will increase by eV_{BE}
- Potential barrier will decrease by $e(V_B\text{-}V_{BE})$
- Fermi level: shift upward
- **Base-collector: Reverse bias**
- Electron energy will decrease by eV_{BC}
- Potential Barrier increase by $e(V_B+ V_{BC})$
- Fermi level: shift downward

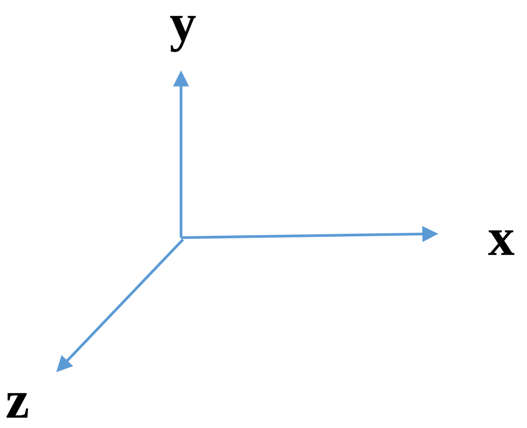
Hall Effect

Edwin Hall : 1879

1. To determine type of semiconductor
2. Charge carrier concentration (density)
3. Mobility and sign of electrons or holes

When current carrying conductor is placed in transverse magnetic field (B), an electric field E is induced in the direction perpendicular to both current (I) and magnetic filed (B)

- length: L
- thickness: t
- width: w
- magnetic field: B (z-direction)
- current: I (x-direction)
- electron: flowing –x direction
- charge: e with velocity v_{-x}



The force acting on charge particle

Lorentz force, $F_y = (\vec{e})\ (\vec{v}_{-x}\ X\ B_z)$

$F = -y$ direction

The force due to built up electric field (E_H)

$F_y = (-e)\ E_{-y}$

$F = y$ direction

Lorentz force = F due to E

(steady state position or no accumulation of charges)

N-type semiconductor

i. $R_H = 1/en = V_H\, w/IB$

ii. $V_H = BI/new$

iii. $n = BI/ewV_H$

iv. $\mu_n = \sigma R_H$

P-type semiconductor

i. $R_H = 1/ep = V_H\, w/IB$

ii. $p = BI/ewV_H$

iii. $\mu_p = \sigma R_H$

Applications

1. Measuring carrier concentration
2. Measuring mobility
3. R_H = + ve : P-type and R_H = -ve: N-type

Solar Cell/Photovoltaic Cell

It is P-N junction which converts light energy into electrical energy.

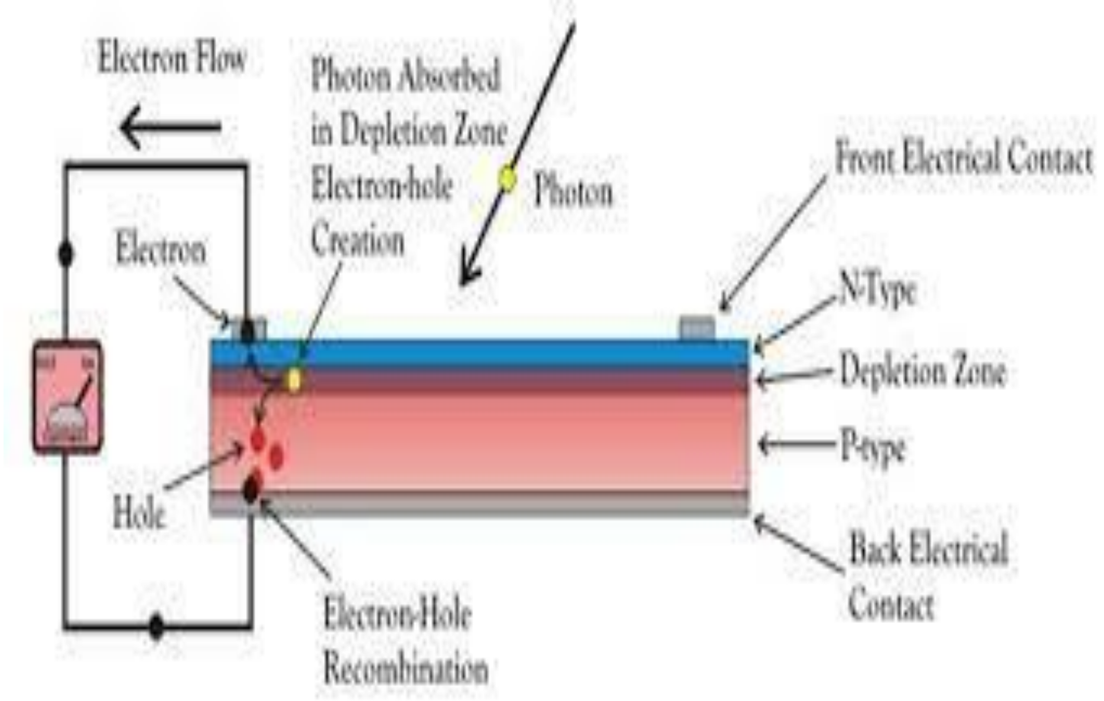
Operation of solar cell

1. Absorption of light to generate electron-hole pairs
2. Separation of charge carriers
3. Extraction of these carriers to external circuit

Construction and Working

- P-N junction diode in glass material
- Thickness of P and N is very small to avoid recombination
- Doping is heavy to get large photo-voltage
- Metal contacts on both sides

- P-N junction
- Solar light incident: P-N junction
- Energy $h\nu > E_g$; absorption takes place
- Electron-hole pairs generated in both P and N type
- These charge carriers reach to depletion layer by diffusion
- Separated by external field



V_{OC} **: Open circuit voltage :** accumulation of electrons and holes on two sides gives maximum voltage

I_{SC}**: Short circuit current :** maximum current flow

Parameters affect the solar cell efficiency

- **Intensity of light affects the current**
- **Surface area of cell**

Efficiency (η) = Output/Input

$$\eta = \frac{\textbf{Power output}}{\textbf{incident solar light power}}$$

Power output or maximum power output ?

$$\boxed{\text{Fill Factor} = \frac{\text{usable power}}{\text{Ideal power}}}$$

Ideal Power : maximum current X maximum voltage

At, V_{OC}: max; I_{SC}: zero
I_{SC}: max; V_{OC}: zero

Ideal power will be zero: It will not give maximum power from solar cell

I-V Characteristics of Solar Cell

- Variation of load resistance (R_L) : voltage and current measurement
- R_L maximum: high voltage and less current
- R_L minimum: less voltage and high current

$$\text{Fill Factor} = \frac{V_m \text{ X Im}}{V_{oc}\ X\ Isc}$$

V_m : maximum voltage
I_m: maximum current

Calculate the energy gap of Si, given that it is transparent to radiation of wavelength greater than 11000 A^0

Given: $\lambda = 11000\ \mathbf{A^0}$

Formula: $E_g = h\nu = hc/\lambda$

Ans: 1.13 eV

Calculate the mobility of charge carriers in a doped Si whose conductivity is 100 per ohm-m and Hall coefficient is 3.6 X 10^{-4} m^3/Coulomb

Given: σ = 100 per ohm-m

R_H = 3.6 X 10_{-4} m^3/Coulomb

Formula: $\mu = \sigma R_H$

Ans: 0.036 m^2/V-sec

A slab of Si 2 cm in length 1.5 cm wide and 2mm thick is applied with magnetic field of 0.4T along its thickness. When a current of 75A flows along the length, the voltage measured across the width is 0.81 mV. Calculate the concentration of mobile electrons in Si.

Given:

$l = 2cm$

$w = 1.5$ cm

$t = 2mm$

$B = 0.4T$

$I = 75A$

$V_H = 0.81$ mV

Formula:

$V_H = IBt/enA$

$n = IBt/eAV_H$

Ans: **1.54×10^{25} /m³**

The Hall coefficient of specimen of a Si is found to be 3.66 X 10^4 m^3/C. The resistivity of specimen is 8.93 X 10^{-3} ohm-m. Determine the mobility of the charge carriers.

Given: $\rho = 8.93 \times 10^{-3}$

$R_H = 3.66 \times 10^4\ m^3/C$

Formula: $R_H = 1/qn$ and $\sigma = qn\mu$

$\rho = 1/qn\mu = R_H / \mu$

$\boldsymbol{\mu = R_H / \rho}$

Ans: $\mathbf{4.098 \times 10^{-2}\ m^2/V\text{-}sec}$

Calculate the number of acceptors to be added to a Ge sample to obtain resistivity of 10 ohm-cm

Given: $\mu = 1700\ cm^2/volt\text{-}sec$

$\rho = 10$ ohm-cm

Formula: $\boldsymbol{\rho = 1/ (\mu n_a e)}$

$\boldsymbol{n_a = 1/(\rho\mu e)}$

Ans: $\boldsymbol{3.6 \times 10^{14}\ /cm^3}$

At absolute zero temperature, Si acts as?

a) non-metal

b) metal

c) insulator

d) none of these

Ans : c

Elements in crystalline solid give rise to ……… spectrum.

a) band
b) line
c) continuous
d) all the above

Ans : a

In solids there is significant interaction between ………. electrons of different atoms.

a) innermost
b) free
c) outermost
d) all the above

Ans : c

Which is the correct ordering of the band gaps within the group 14 elements?

a) Diamond > silicon < germanium
b) Diamond > silicon > germanium
c) Diamond < silicon > germanium
d) Diamond < silicon < germanium

Ans : b

If N atoms are brought close together to form a solid, the s energy band can accommodate ………… electrons.

a) N *b)* $2\,N$ *c)* $6\,N$ *d)* $8\,N$

Ans : b

If N atoms are brought close together to form a solid, the p energy band can accommodate ………… electrons.

a) N *b)* $2\,N$ *c)* $6\,N$ *d)* $8\,N$

Ans : c

What is the origin of energy bands in solids?

a) Atomic mass

b) Temperature

c) Closely packed periodic structure of solid

d) Atomic number of atoms in solid

Ans : c

An energy band is ………….

a) a set of continuous energies
b) a set of closely spaced allowed energy levels
c) a set of widely spaced allowed energy levels
d) none of the above

Ans : b

Valence band of a semiconductor at temperatures above 0 K will be ………

a) completely filled
b) partially filled
c) completely empty
d) either completely filled or completely empty

Ans : b

The donor impurity levels lie ……….

a) just above the valence band
b) just below the conduction band
c) at the centre of forbidden band
d) just above the conduction band

Ans : b

Conduction band of a semiconductor at 0 K will be ………………..

a) completely filled
b) partially filled
c) completely empty
d) either completely filled or completely empty

Ans : c

According to classical free electron theory the electrons …………… in absence of external electric field.

a) remain at rest
b) move randomly
c) have drift velocity
d) none of the above

Ans : b

According to quantum free electron theory the electrons follow ……… distribution of energy.

a) binomial
b) Maxwell-Boltzmann
c) Fermi-Dirac
d) Bose-Einstein

Ans : c

When N-type semiconductor is heated,

a) number of free electrons increases while that of holes decreases

b) number of holes increases while that of electrons decreases

c) number of electrons and holes remain same

d) number of electron and holes increases equally

Ans : d

A piece of copper and other of germanium are cooled from the room temperature to 80K, then

a) resistance of each will increase

b) resistance of copper will decrease

c) the resistance of copper will increase while that of germanium will decrease

d) the resistance of copper will decrease while that of germanium will increase

Ans : d

If the drift velocity of holes under a field gradient of 100 V/m is 5m/s, the mobility (in the same SI units)is ………

a) 0.05
b) 0.55
c) 500
d) None of the above

Ans : a

Mobility of holes is ____________ mobility of electrons in intrinsic semiconductors.

a) Equal to b) Greater than c) Less than d) Can not define

Ans : c

Which of the following have a positive temperature coefficient of resistance?

a) Good conductor
b) Semiconductor
c) Insulators
d) Both semiconductors and insulators

Ans : a

If a free electron moves towards right and combines with a hole, the hole ………

a) moves towards right
b) moves towards left
c) remains at the same place
d) is neutralized

Ans : d

The value of Fermi Function at 0K for $E < E_F$ is …………

a) 0 b) 1 c) 0.5 d) 0.75

Ans : b

The value of Fermi Function at $T > 0K$ for $E = E_F$ is ....

a) 0 b) 1 c) 0.5 d) 0.75

Ans : c

Fermi level for extrinsic semiconductor depends on

a) Donor element b) Impurity concentration c) Temperature d) All

Ans : d

When we increase the temperature of extrinsic semiconductor, after a certain temperature it behaves like ……

a) an insulator

b) an intrinsic semiconductor

c) a conductor

d) a superconductor

Ans : b

The Fermi level shifts ………… in n-type semiconductor with increase in impurity concentration.

a) upwards
b) downwards
c) neither upward nor downward
d) none of the above

Ans : a

In a p-type semiconductor, the Fermi level at T > 0K is ……………

a) between valence band and acceptor levels
b) between acceptor levels and intrinsic Fermi level
c) between intrinsic Fermi level and donor level
d) between donor level and conduction band

Ans : b

In forward bias, the width of potential barrier in a p-n junction diode?

a) increases

b) decreases

c) remains constant

d) first increases then decreases

Ans : b

In a biased n-p-n transistor, the Fermi level of collector ……….with respect to that in base.

a) remains at the same level
b) shifts upwards
c) shifts downwards
d) first shifts up and then down

Ans : c

When the load resistance connected across the solar cell is infinite, we get ……………

a) open circuit current
b) open circuit voltage
c) short circuit current
d) short circuit voltage

Ans : b

A semiconductor is doped with donor impurity is

a) p type

b) n type

c)npn type

d)pnp type

Ans : b

In a p type semiconductor, the acceptor valence band is

a) above the conduction band of the host crystal

b) below the conduction band of the crystal

c) above the valence band of the crystal

d) below the conduction band of the crystal

Ans : c

A long specimen of *p*-type semiconductor material:

a) Is positively charged
b) Is electrically neutral
c) Has an electric field directed along its length
d) None of the above

Ans : b

The intrinsic semiconductor becomes an insulator at

a) 0°C   b) 0K   c) 300K   d) —100°C

Ans : b

Difference in the variation of resistance with temperature in a metal arises essentially due to the difference in

a) type of bonding
b) crystal structure
c) scattering mechanism with temperature
d) number of charge carriers with temperature

Ans : c

The difference in the variation of resistance with temperature in semiconductor arises essentially due to the difference in

a) type of bonding

b) crystal structure

c) scattering mechanism with temperature

d) number of charge carriers with temperature

Ans : d

The temperature coefficient of the resistance of semiconductors is always

a) positive b) negative

c) zero d) infinite

Ans : b

Electrical conductivity of insulators is of the order of _____________.

a) $10^{-10}(\Omega\text{-mm})^{-1}$
b) $10^{-10}(\Omega\text{-cm})^{-1}$
c) $10^{-10}(\Omega\text{-m})^{-1}$
d) $10^{-8}(\Omega\text{-m})^{-1}$

Ans : a

Unit for electric field strength is

a) A/cm^2 b) mho/meter

c) $cm^2/V.s$ d) V/cm

Ans : d

If the temperature of an extrinsic semiconductor is increased so that the intrinsic carrier concentration is doubled, then:

a) The minority carrier density doubles
b) The majority carrier density doubles
c) Both majority and minority carrier densities double
d) None of the above

Ans : a

The conductivity of an intrinsic semiconductor is given by (symbols have the usual meanings):

a) $\sigma_i = en_i^2 (\mu_n - \mu_p)$
b) $\sigma_i = en_i (\mu_n - \mu_p)$
c) $\sigma_i = en_i (\mu_n + \mu_p)$
d) None of the above

Ans : c

In a p-type semiconductor, the conductivity due to holes (σ_p) is equal to (e is the charge of hole, μ_p is the hole mobility, p_0 is the hole concentration):

a) $p_0.e/\mu_p$
b) $\mu_p/p_0.e$
c) $p_0.e.\mu_p$
d) None of the above

Ans : c

If a bound electron moves towards right and combines with a hole, the hole ………

a) moves towards right
b) moves towards left
c) remains at the same place
d) is neutralized

Ans : b

In an electric field, an electron initially at rest will move ………

a) in the direction of electric field
b) opposite to the direction of electric field
c) perpendicular to the direction of electric field
d) none of the above

Ans : b

The amount of charge flowing through unit cross section area per unit time is known as ....

a) current
b) current density
c) conductance
d) resistance

Ans : b

What is the conductivity of semiconductor if free electron density = $5 x 10^{12}/cm^3$ and hole density = $8 x 10^{13}/cm^3$? [$\mu_e = 2.3$ and $\mu_h = 0.01$ in SI units]

a) 5.634

b) 1.968

c) 3.421

d) 8.964

Ans : b