Digital Electronics & Logic Design

(EC 207)

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Course Outline

- **PN DIODE AND TRANSITOR** **(04 Hours)**

  PN Diode Theory, PN Characteristic and Breakdown Region, PN Diode Application as Rectifier, Zener Diode Theory, Zener Voltage Regulator, Diode as Clamper and Clipper, Photodiode Theory, LED Theory, 7 Segment LED Circuit Diagram and Multi Colour LED, LASER Diode Theory and Applications, Bipolar Junction Transistor Theory, Transistor Symbols And Terminals, Common Collector, Emitter and Base Configurations, Different Biasing Techniques, Concept of Transistor Amplifier, Introduction to FET Transistor And Its Feature.

- **WAVESHAPING CIRCUITS AND OPERATIONAL AMPLIFIER** **(06 Hours)**

  Linear Wave Shaping Circuits, RC High Pass and Low Pass Circuits, RC Integrator and Differentiator Circuits, Nonlinear Wave Shaping Circuits, Two Level Diode Clipper Circuits, Clamping Circuits, Operational Amplifier OP-AMP with Block Diagram, Schematic Symbol of OP-AMP, The 741 Package Style and Pinouts, Specifications of Op-Amp, Inverting and Non-Inverting Amplifier, Voltage Follower Circuit, Multistage OP-AMP Circuit, OP-AMP Averaging Amplifier, OP-AMP Subtractor.

- **BOOLEAN ALGEBRA AND SWITCHING FUNCTIONS** **(04 Hours)**

  Basic Logic Operation and Logic Gates, Truth Table, Basic Postulates and Fundamental Theorems of Boolean Algebra, Standard Representations of Logic Functions- SOP and POS Forms, Simplification of Switching Functions-K-Map and Quine-Mccluskey Tabular Methods, Synthesis of Combinational Logic Circuits.

- **COMBINATIONAL LOGIC CIRCUIT USING MSI INTEGRATED CIRCUITS** **(07 Hours)**

Course Outline

Binary Parallel Adder; BCD Adder; Encoder, Priority Encoder, Decoder; Multiplexer and Demultiplexer Circuits; Implementation of Boolean Functions Using Decoder and Multiplexer; Arithmetic and Logic Unit; BCD to 7-Segment Decoder; Common Anode and Common Cathode 7-Segment Displays; Random Access Memory, Read Only Memory And Erasable Programmable ROMS; Programmable Logic Array (PLA) and Programmable Array Logic (PAL).

- **INTRODUCTION TO SEQUENTIAL LOGIC CIRCUITS** **(04 Hours)**

  Basic Concepts of Sequential Circuits; Cross Coupled SR Flip-Flop Using NAND or NOR Gates; JK Flip-Flop Rise Condition; Clocked Flip-Flop; D-Type and Toggle Flip-Flops; Truth Tables and Excitation Tables for Flip-Flops; Master Slave Configuration; Edge Triggered and Level Triggered Flip-Flops; Elimination of Switch Bounce using Flip-Flops; Flip-Flops with Preset and Clear.

- **SEQUENTIAL LOGIC CIRCUIT DESIGN** **(06 Hours)**

  Basic Concepts of Counters and Registers; Binary Counters; BCD Counters; Up Down Counter; Johnson Counter, Module-N Counter; Design of Counter Using State Diagrams and Table; Sequence Generators; Shift Left and Right Register; Registers With Parallel Load; Serial-In-Parallel-Out (SIPO) And Parallel-In-Serial-Out(PISO); Register using Different Type of Flip-Flop.

- **REGISTER TRANSFER LOGIC** **(04 Hours)**

  Arithmetic, Logic and Shift Micro-Operation; Conditional Control Statements; Fixed-Point and Floating-Point Data; Arithmetic Shifts; Instruction Code and Design Of Simple Computer.

- **PROCESSOR LOGIC DESIGN** **(03 Hours)**

  Processor Organization; Design of Arithmetic Logic Unit; Design of Accumulator.

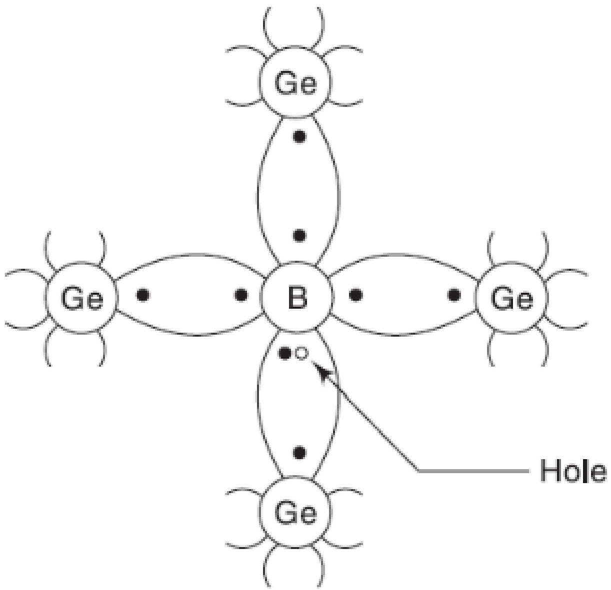
- **CONTROL LOGIC DESIGN** **(04 Hours)**

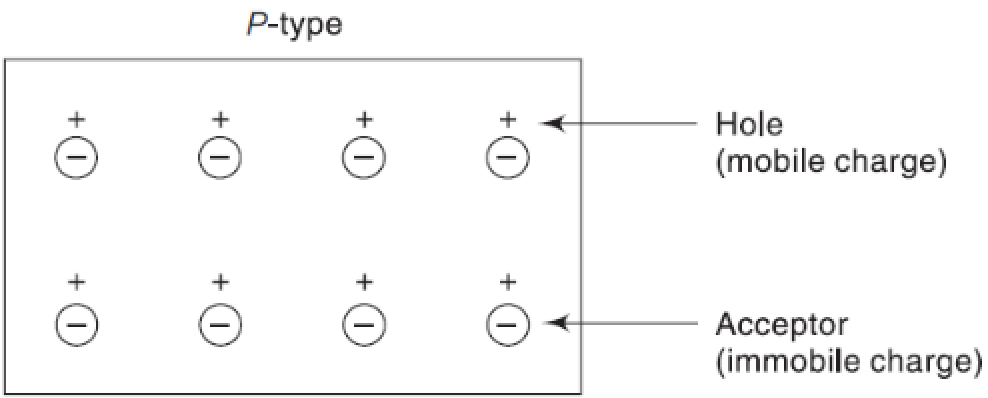
  Control Organization; Hard-Wired Control; Micro Program Control; Control Of Processor Unit; PLA Control.

Course Text and Materials

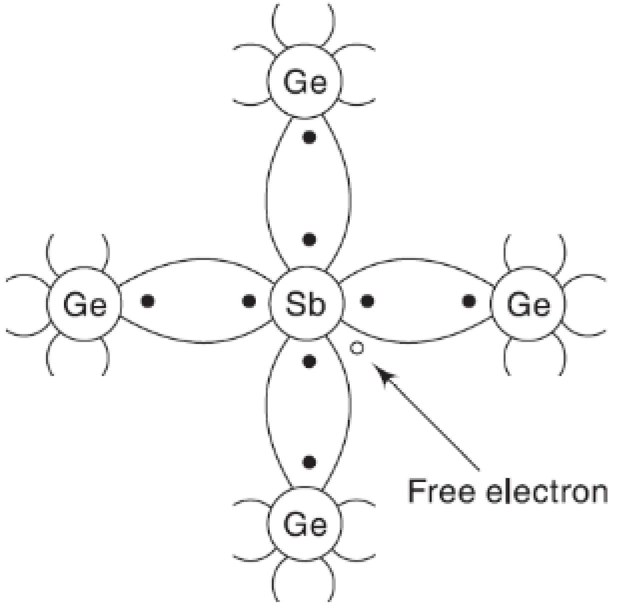
1. Schilling Donald L. and Belove E., "Electronics Circuits- Discrete and Integrated", 3rd Ed., McGraw-Hill, 1989, Reprint 2008.
2. Millman Jacob, Halkias Christos C. and Parikh C., "Integrated Electronics", 2nd Ed., McGraw-Hill, 2009.
3. Taub H. and Mothibi Suryaprakash, Millman J., "Pulse, Digital and Switching Waveforms", 2nd Ed., McGraw-Hill, 2007.
4. Mano Morris, "Digital Logic and Computer Design", 5th Ed., Pearson Education, 2005.
5. Lee Samual, "Digital Circuits and Logic Design", 1st Ed., PHI, 1998.

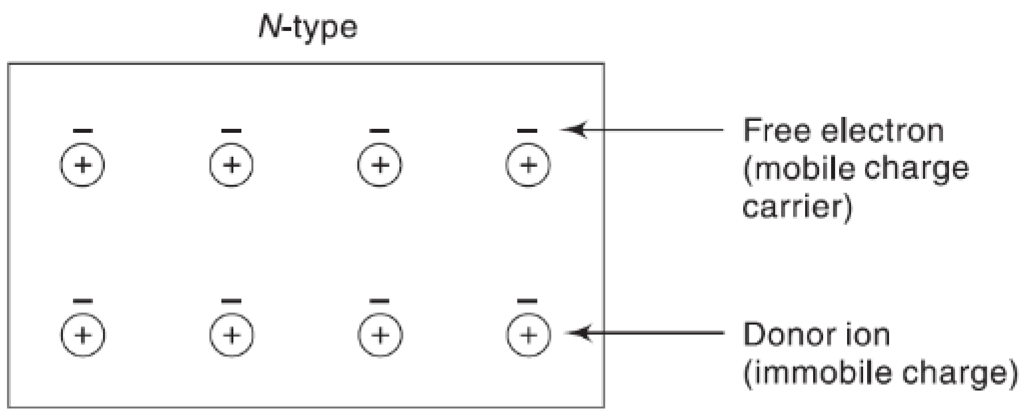
Germanium doped with Boron (Trivalent Impurity)





Germanium doped with Antimony (Pentavalent Impurity)



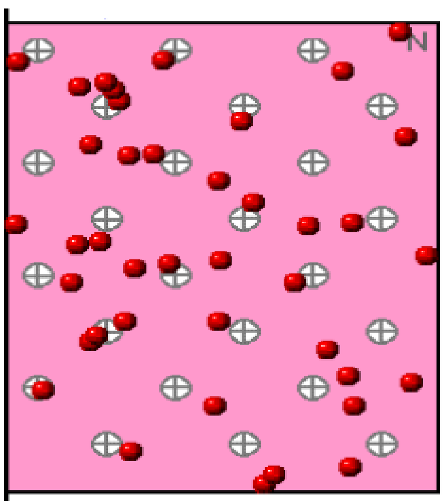


Carrier Transport

Spatially variant fixed charge creates an electric field:

$$\frac{d\xi}{dx} = \frac{\rho}{\varepsilon}$$

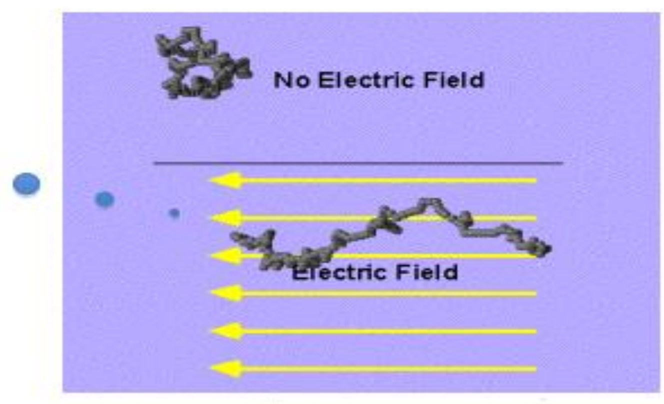
ξ = electric field
ρ = charge density
ε = material permittivity



Drift Current: Net charge moves parallel to electric field

$$J_h = q\mu_h p\xi$$

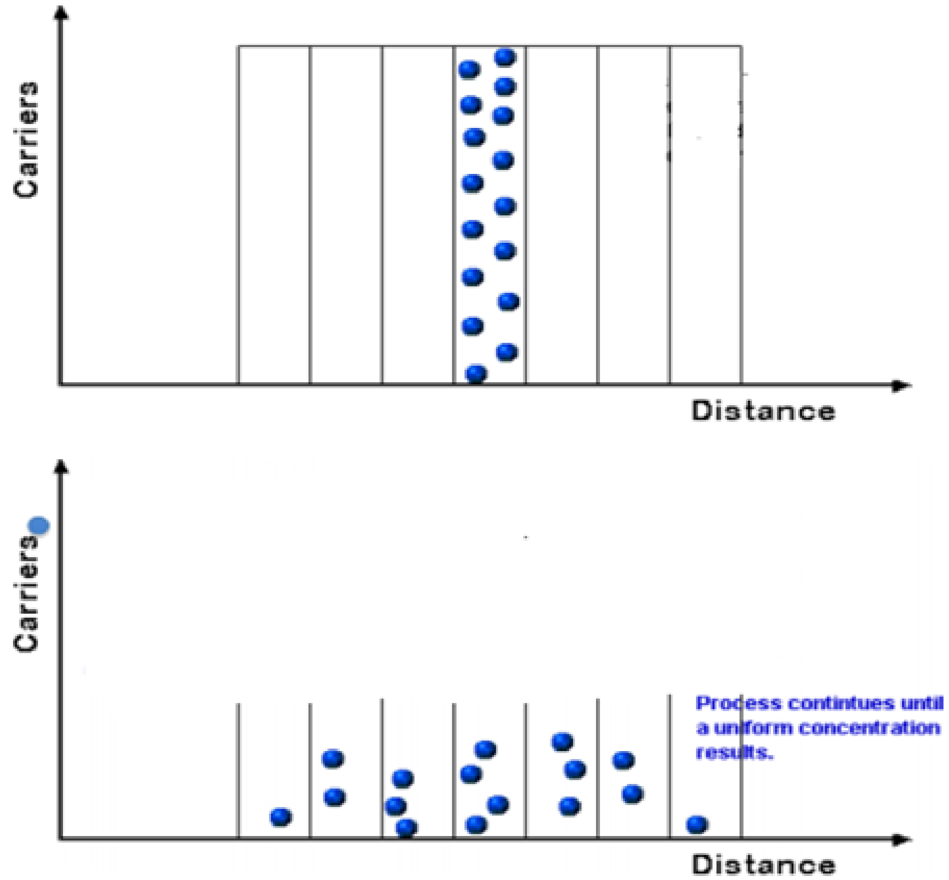
$$J_e = q\mu_e n\xi$$

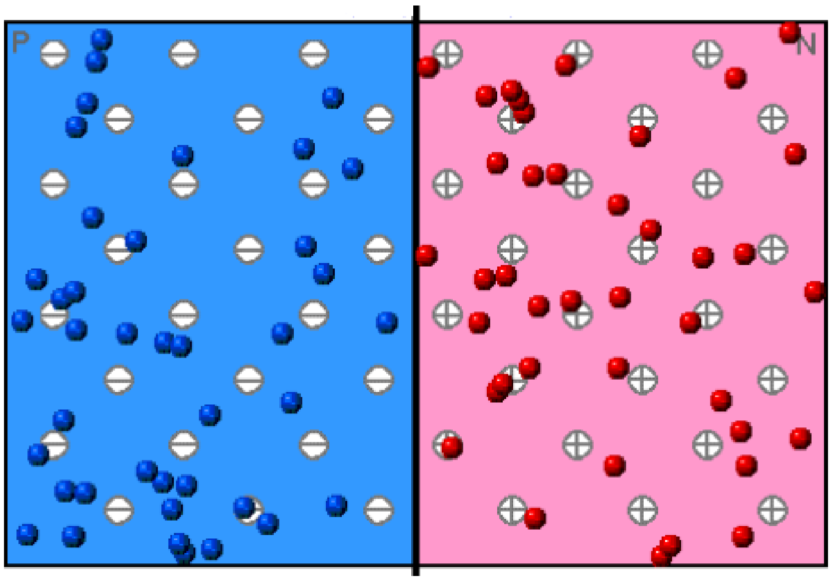


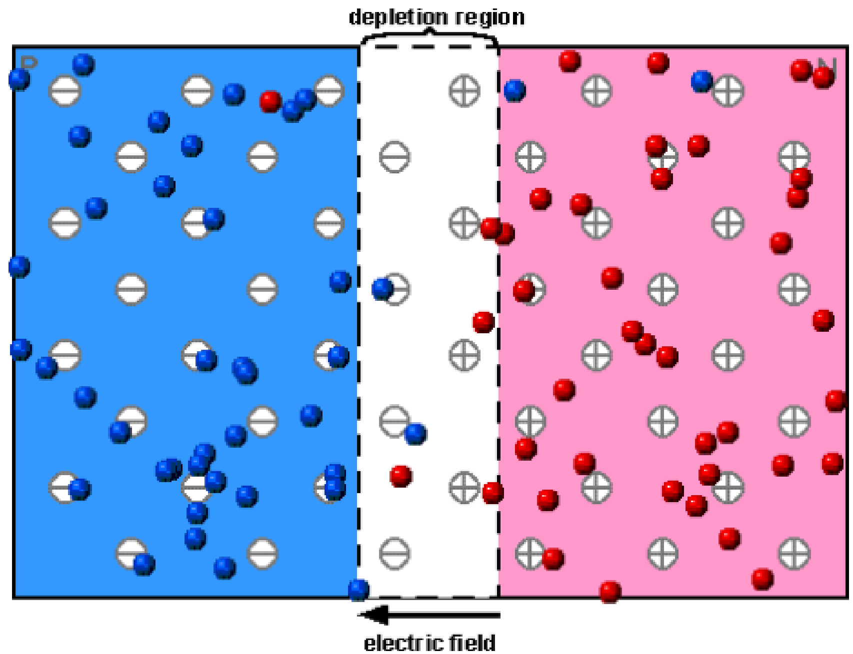
Carrier Transport

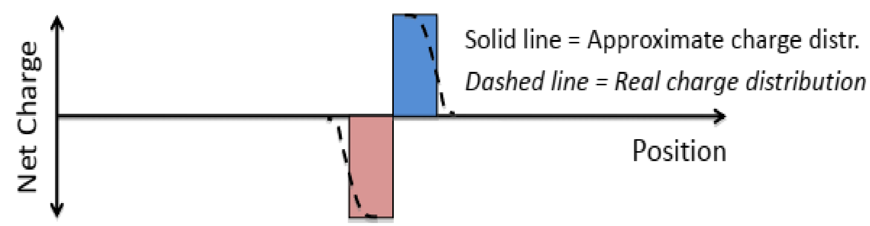
$$J_h = -qD_h \frac{dp}{dx}$$

$$J_e = qD_e \frac{dn}{dx}$$




P
N

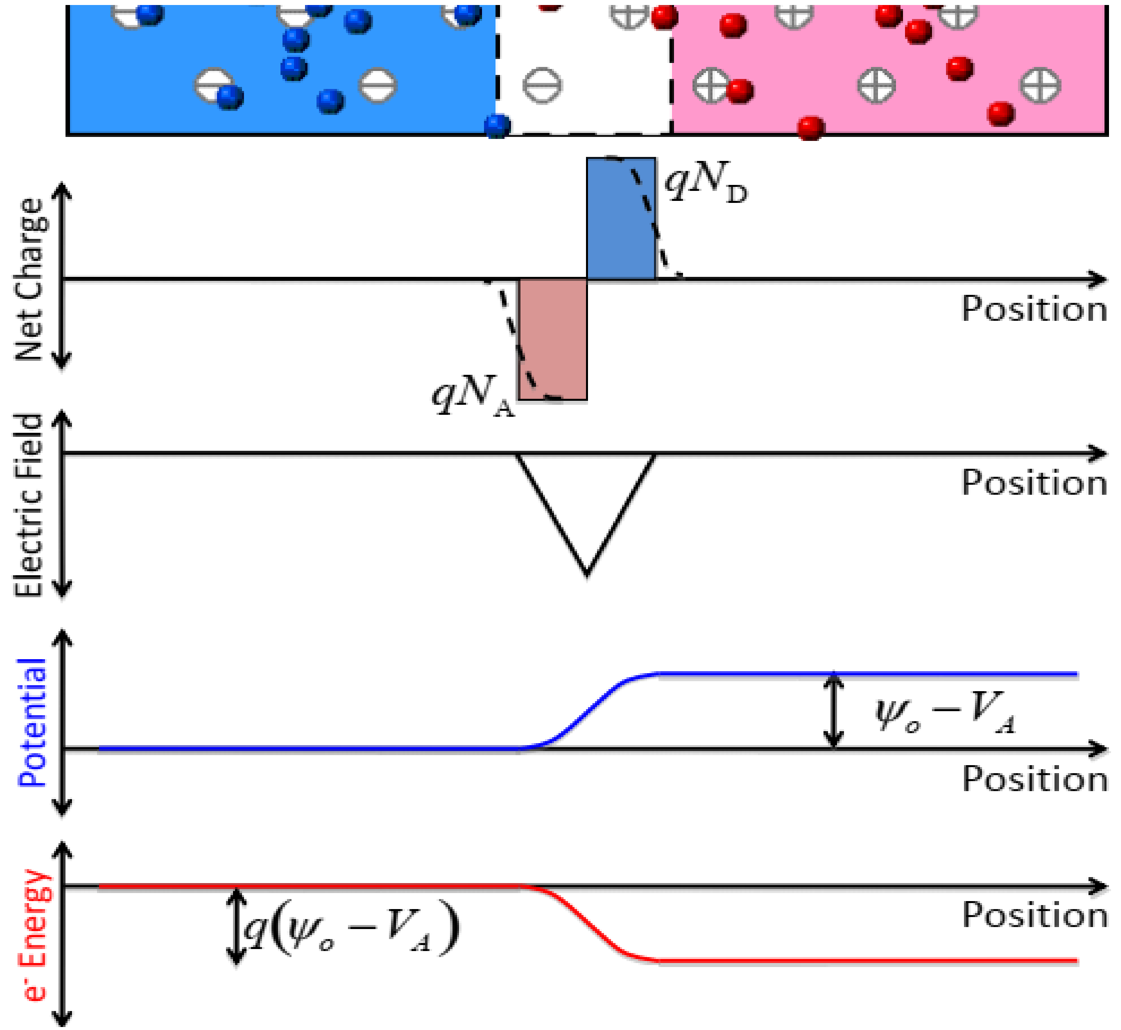

depletion region
P
N
electric field


Net Charge
Position
Solid line = Approximate charge distr.
Dashed line = Real charge distribution

$$\frac{d\xi}{dx} = \frac{\rho}{\varepsilon}$$

$$\frac{d\psi}{dx} = -\xi$$

$$E = q\psi$$



pn-junction, under dark conditions

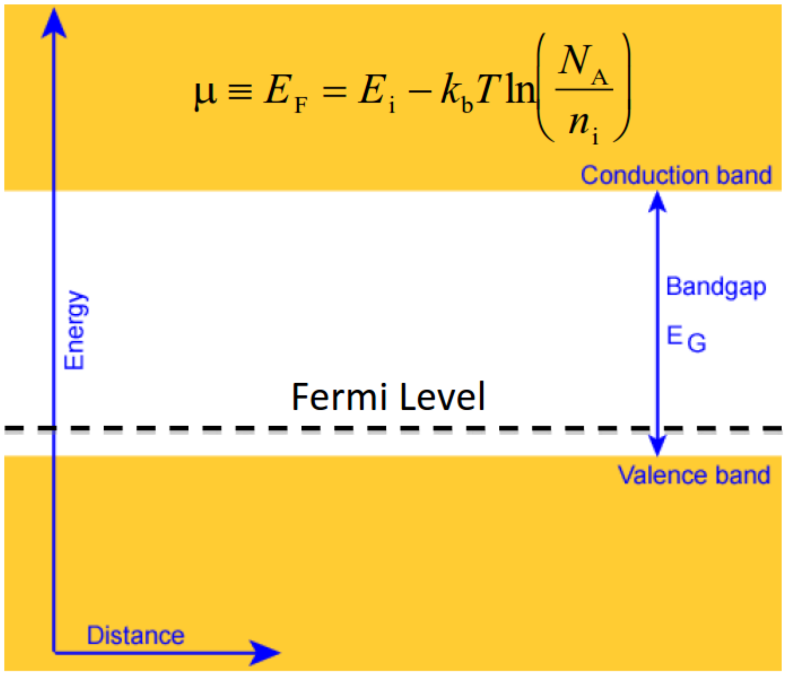
	No Bias	Forward Bias	Reverse Bias
Model Circuit	P - + - + - + N	P N	P N
Band Diagram	E p-type n-type x e^- diffusion: e^- drift:	E p-type n-type x e^- diffusion: e^- drift:	E p-type n-type x e^- diffusion: e^- drift:
I-V Curve	I V	I V	I V

pn-junction, under dark conditions

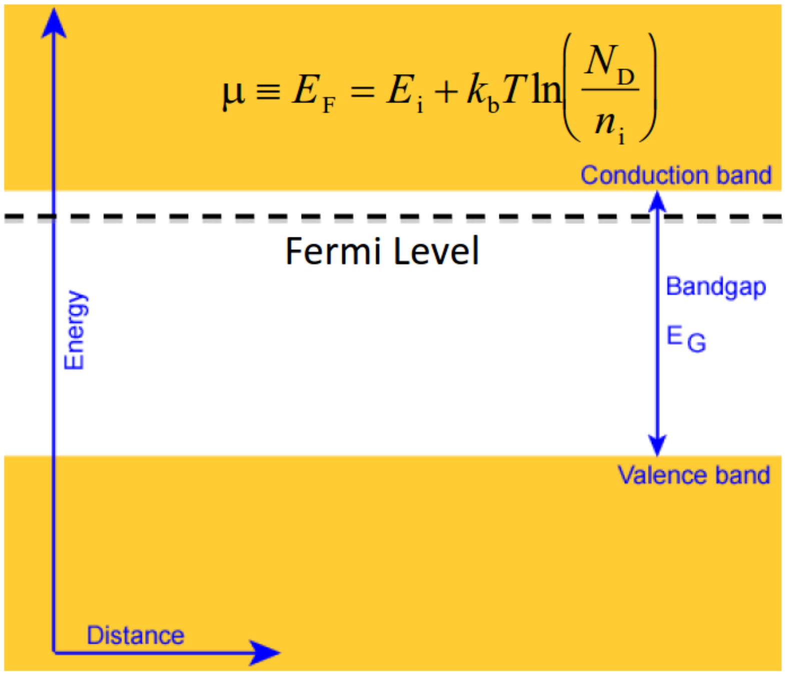
	No Bias	Forward Bias	Reverse Bias
Model Circuit	P - - - + + + N	P N	P N
Band Diagram	E p-type n-type x e^- diffusion: e^- drift:		x
I-V Curve	I V	I V	I V

Tasks:

1. Draw band diagram (electron energy as a function of position).
2. Draw relative magnitudes of electron drift and diffusion currents.

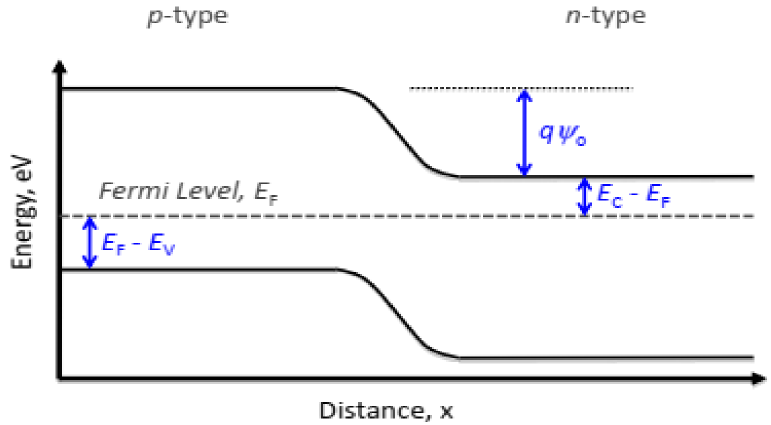


$\mu \equiv E_F = E_i - k_b T \ln\left(\frac{N_A}{n_i}\right)$
Conduction band
Bandgap
E_G
Fermi Level
Valence band
Energy
Distance



$\mu \equiv E_F = E_i + k_b T \ln\left(\frac{N_D}{n_i}\right)$
Conduction band
Fermi Level
Bandgap
E_G
Valence band
Energy
Distance

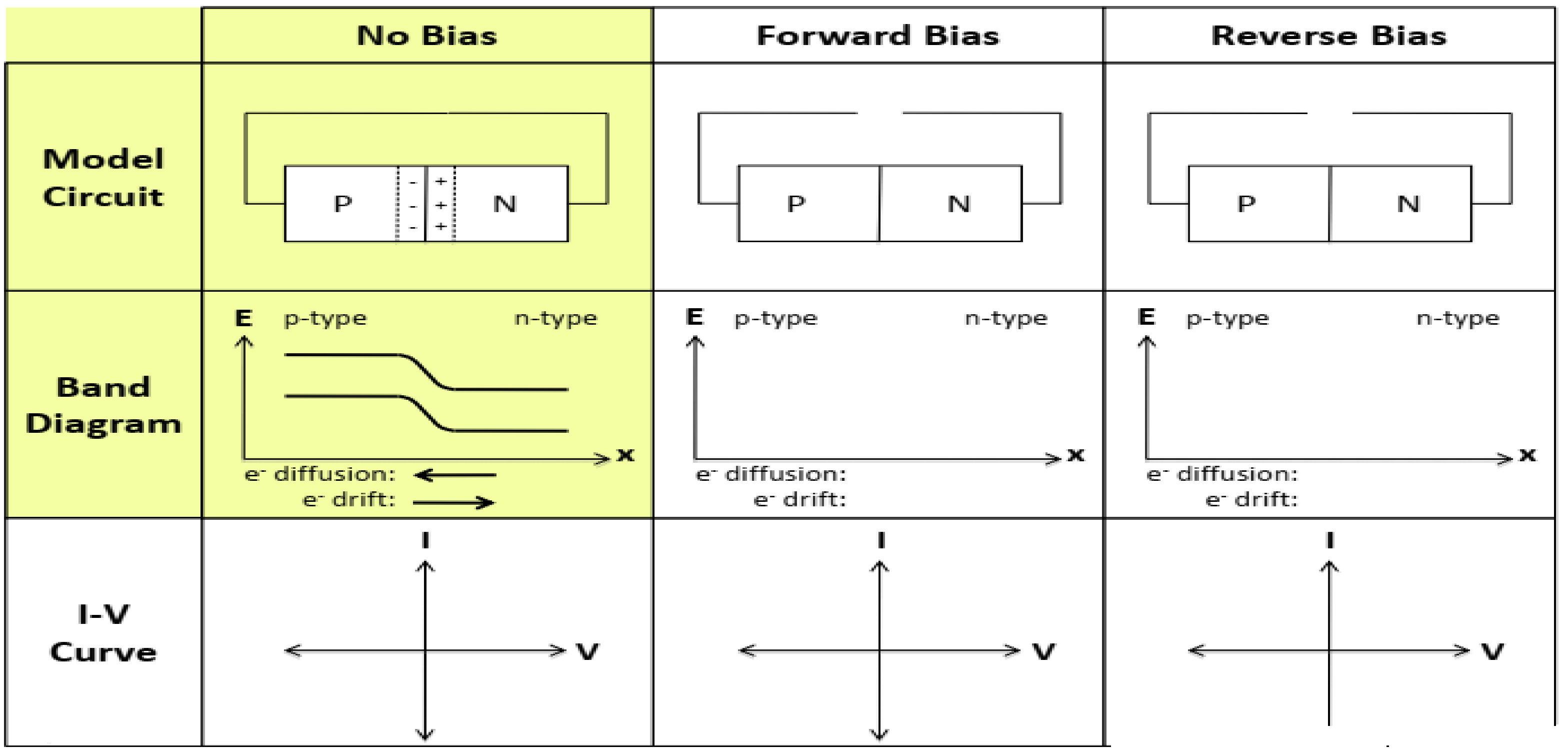
Voltage Across a *pn*-Junction



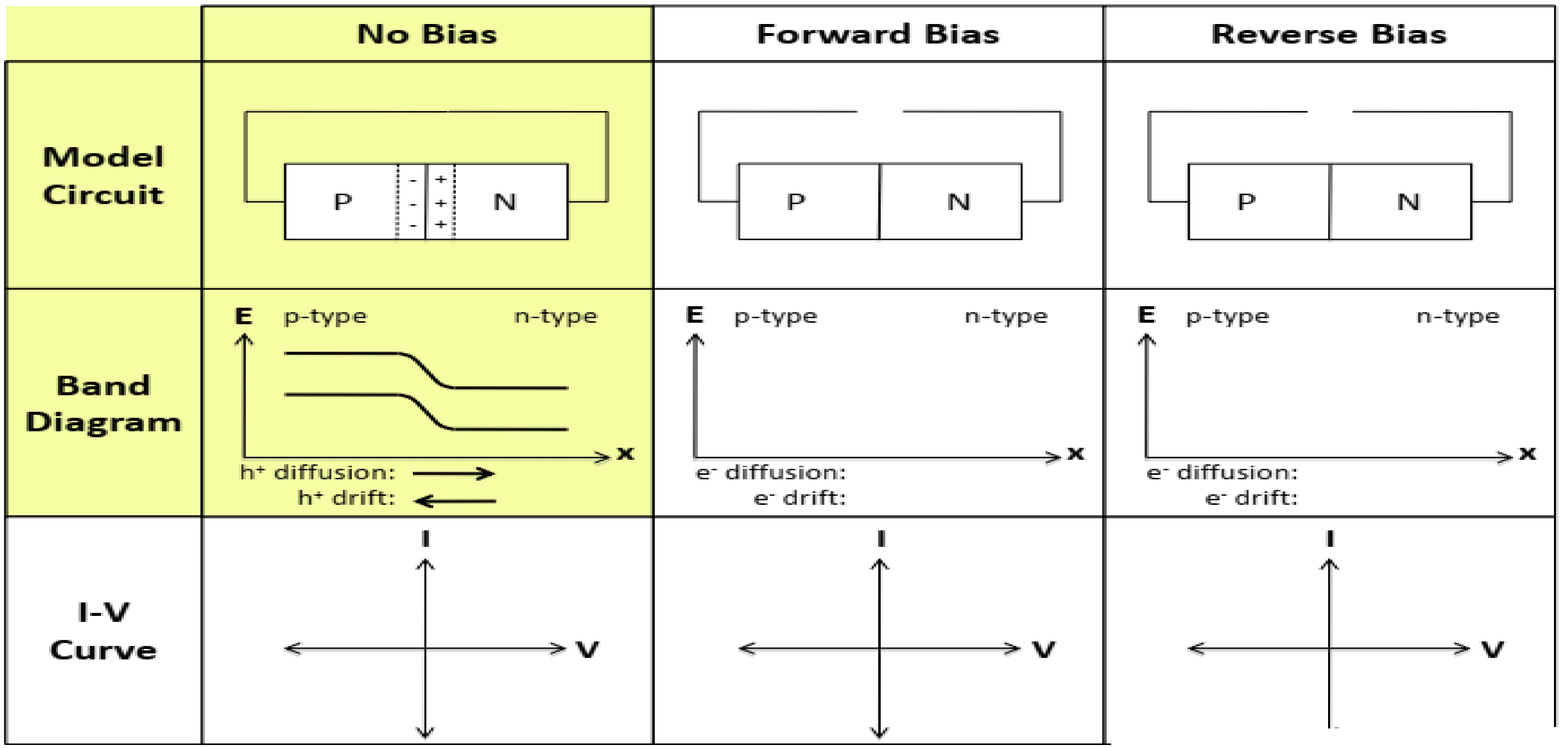
$$q\psi_o = E_g - (E_F - E_V) - (E_C - E_F)$$
$$= \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$$

Built-in pn-junction potential a function of dopant concentrations.

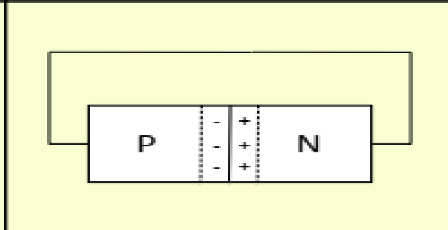
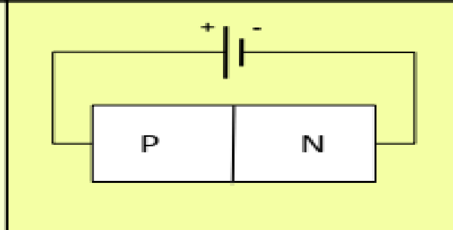
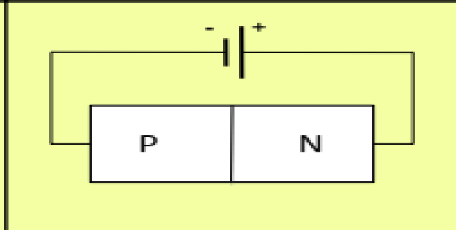
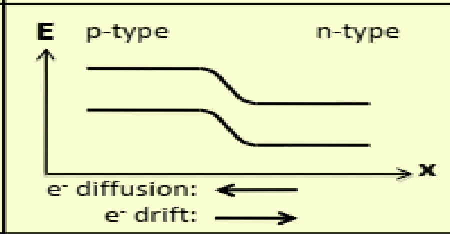
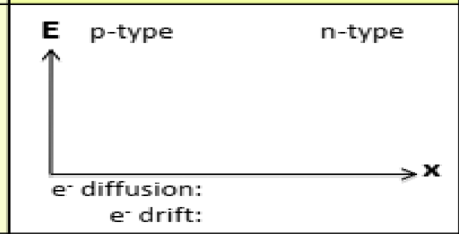
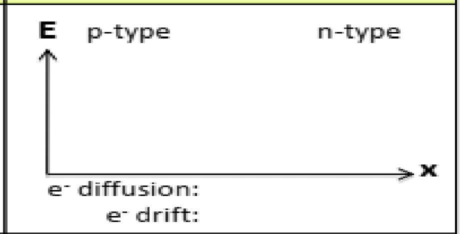
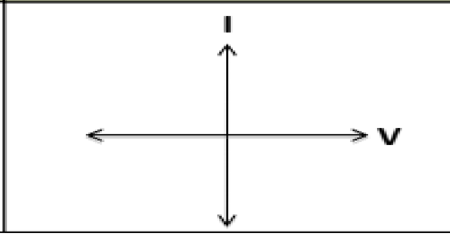
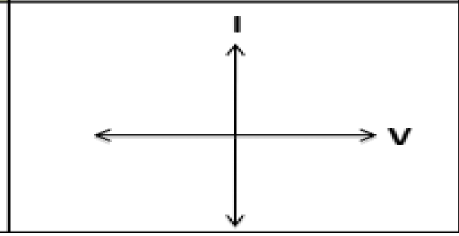
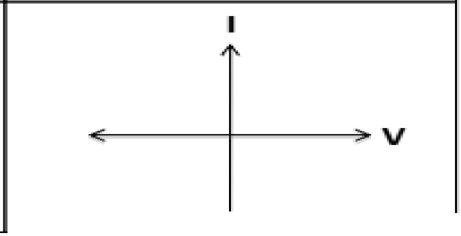
pn-junction, under dark conditions



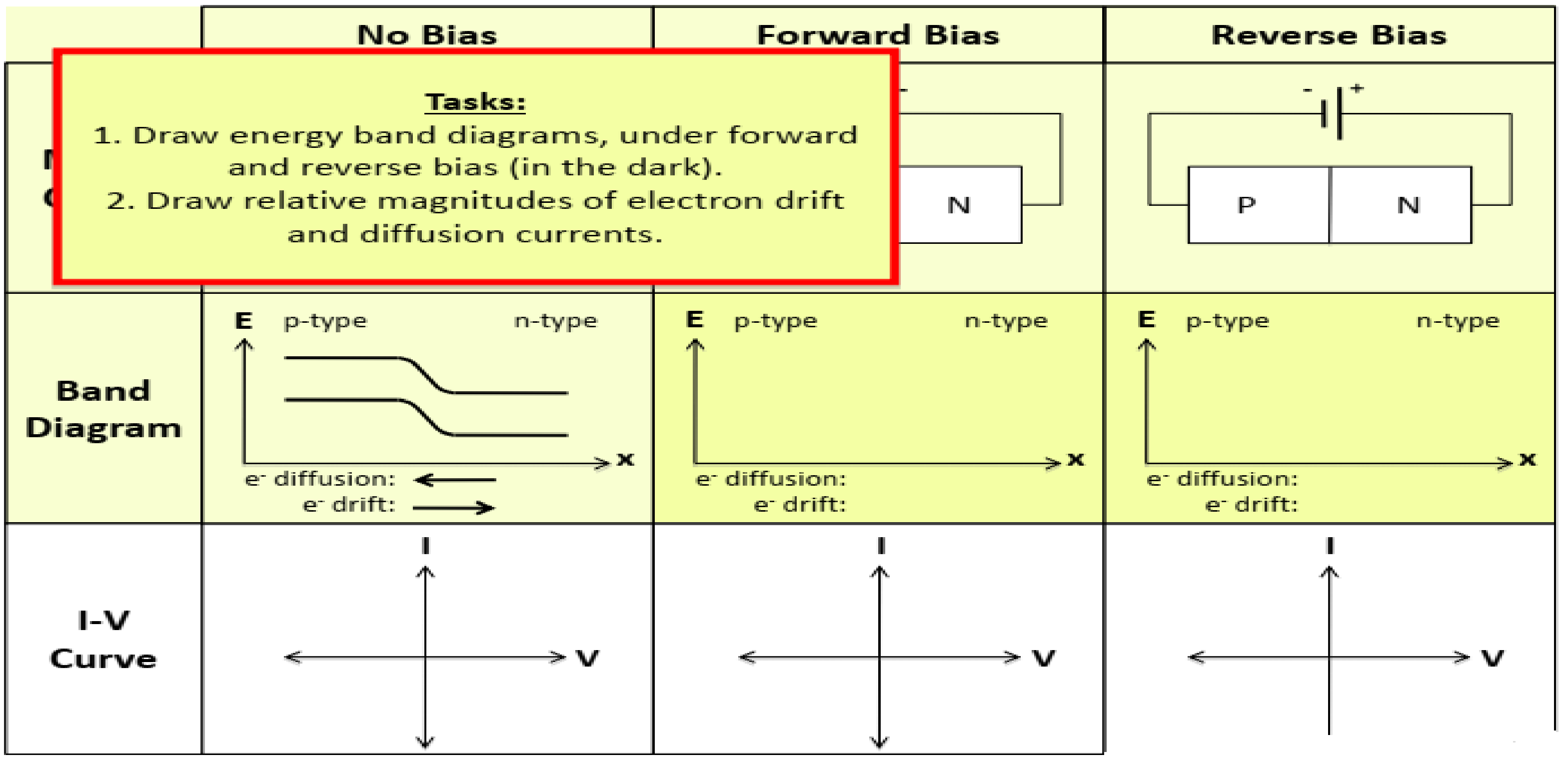
pn-junction, under dark conditions



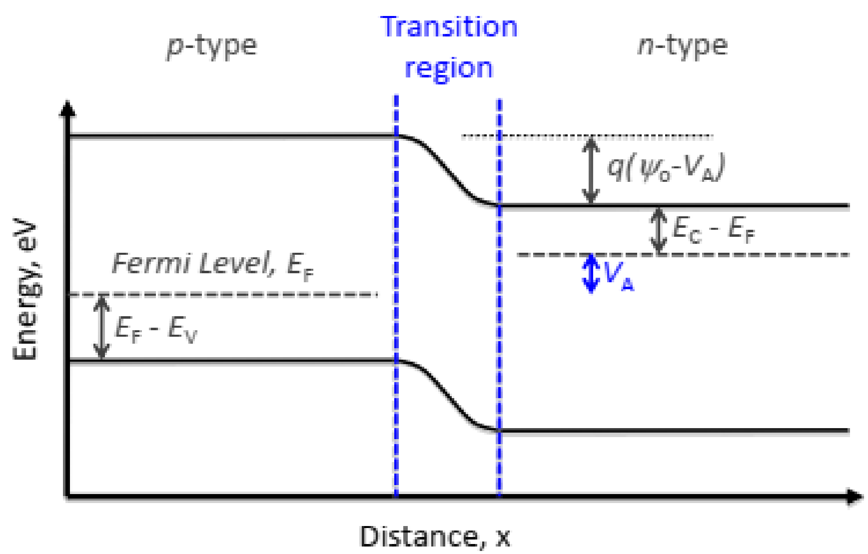
pn-junction, under dark conditions

	No Bias	Forward Bias	Reverse Bias
Model Circuit	 P - - - + + + N	 + - P N	 - + P N
Band Diagram	 E p-type n-type x e⁻ diffusion: e⁻ drift:	 E p-type n-type x e⁻ diffusion: e⁻ drift:	 E p-type n-type x e⁻ diffusion: e⁻ drift:
I-V Curve	 I V	 I V	 I V

pn-junction, under dark conditions

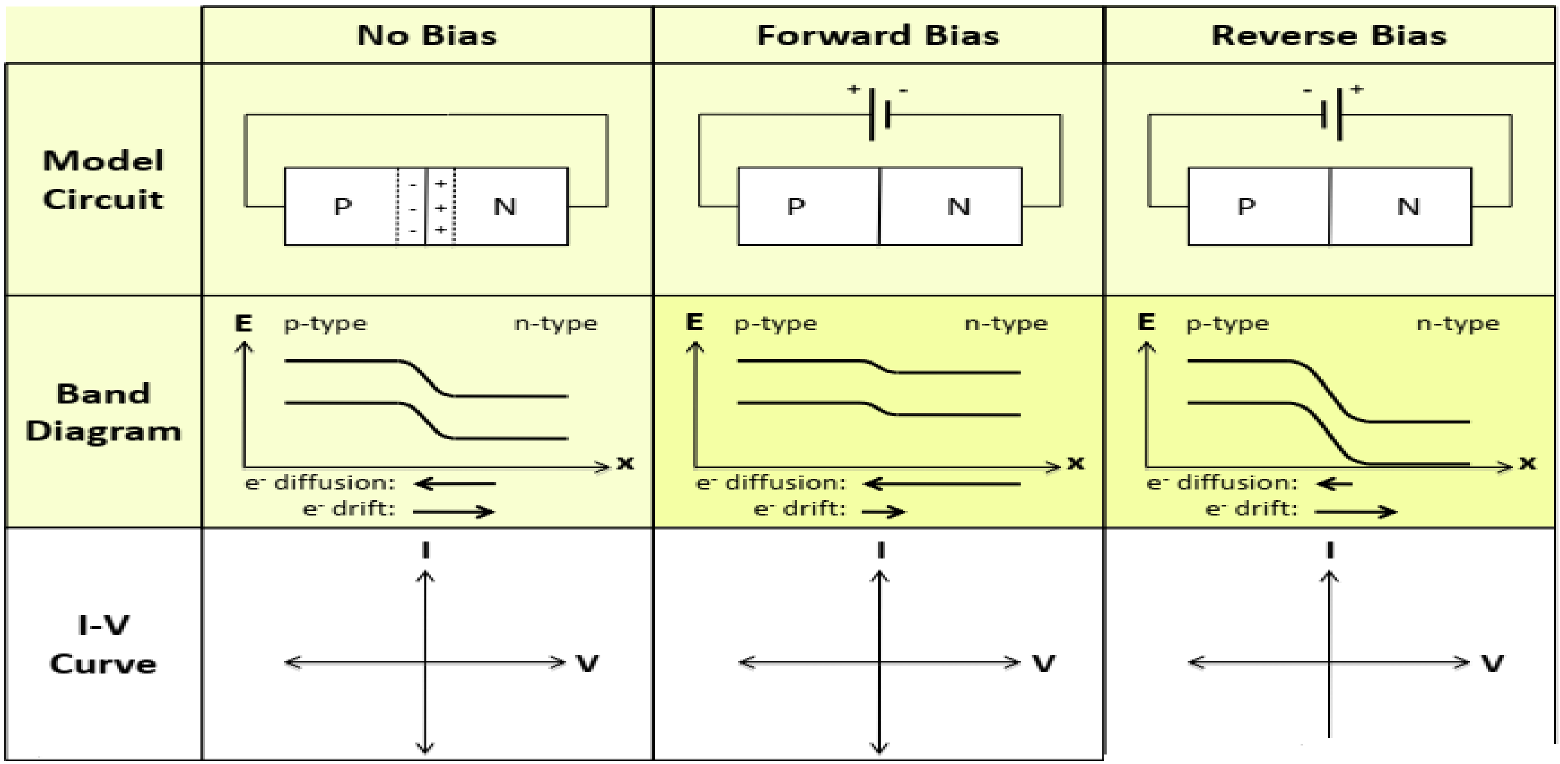


Effect of Bias on Width of Space-Charge Region

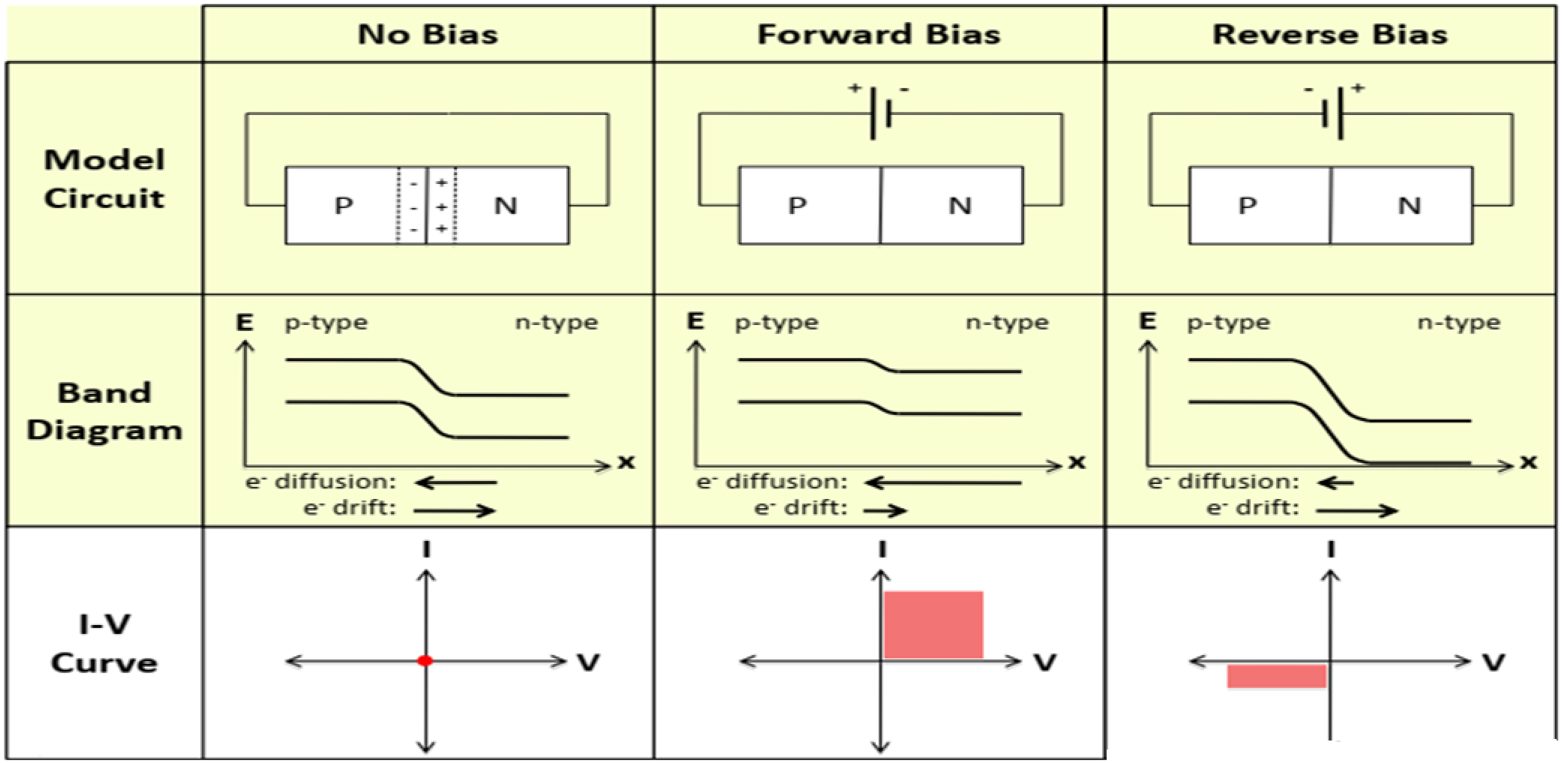


$$q(\psi_o - V_A) = k_b T \ln\left(\frac{N_A N_D}{n_i^2}\right) - V_A$$

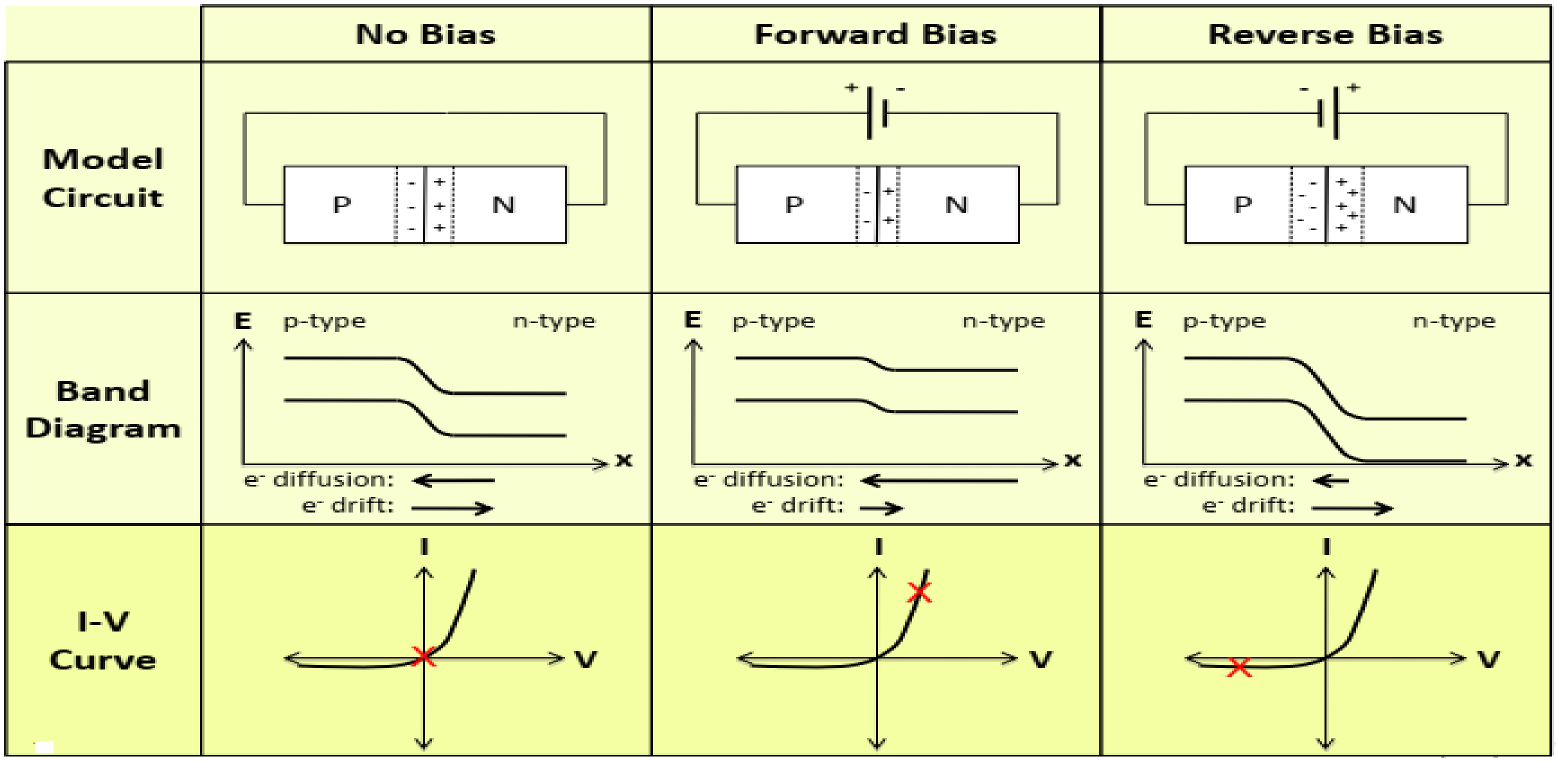
pn-junction, under dark conditions



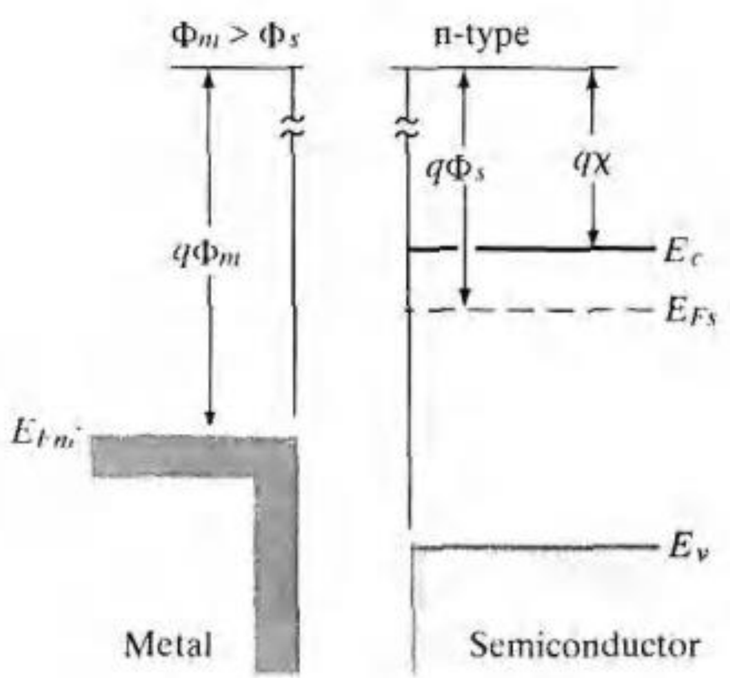
pn-junction, under dark conditions

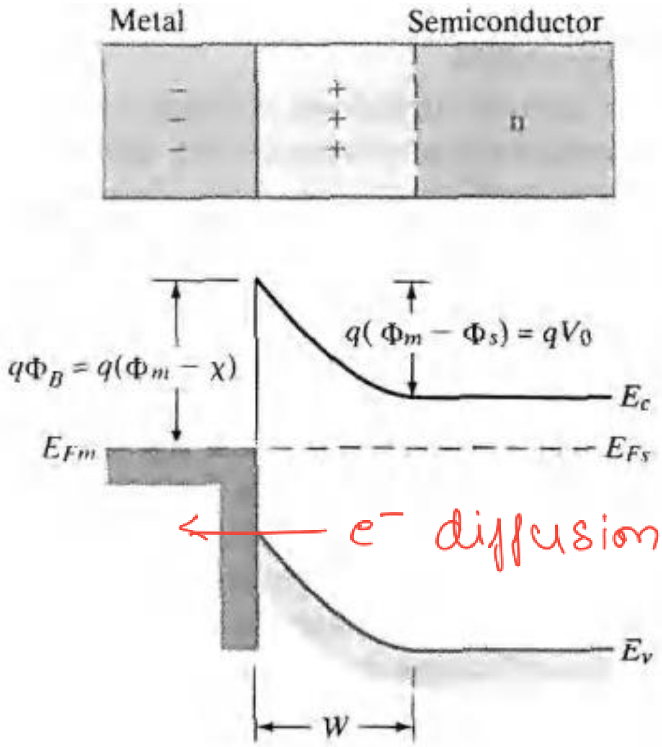


pn-junction, under dark conditions



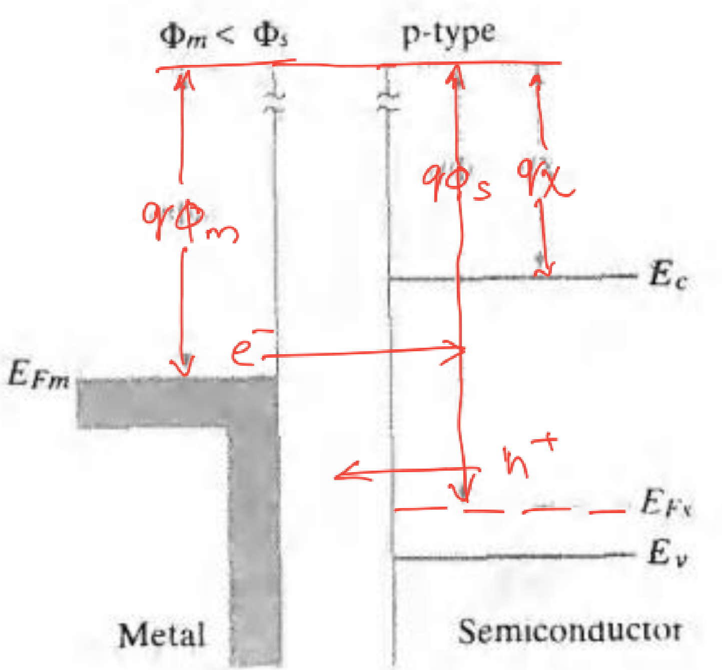
Metal Semiconductor Junction

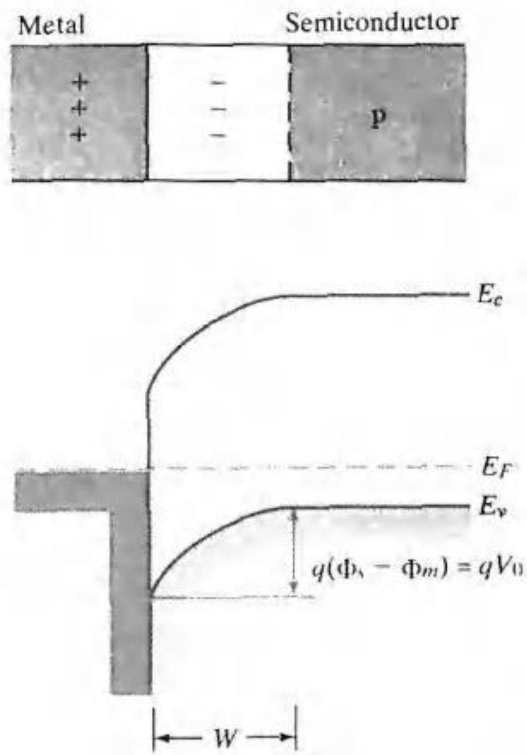




- Majority carrier concentration is decreasing in the semiconductor → **Schottky Junction**
- Upward band bending results in the barrier for electron flow → **Schottky Junction**

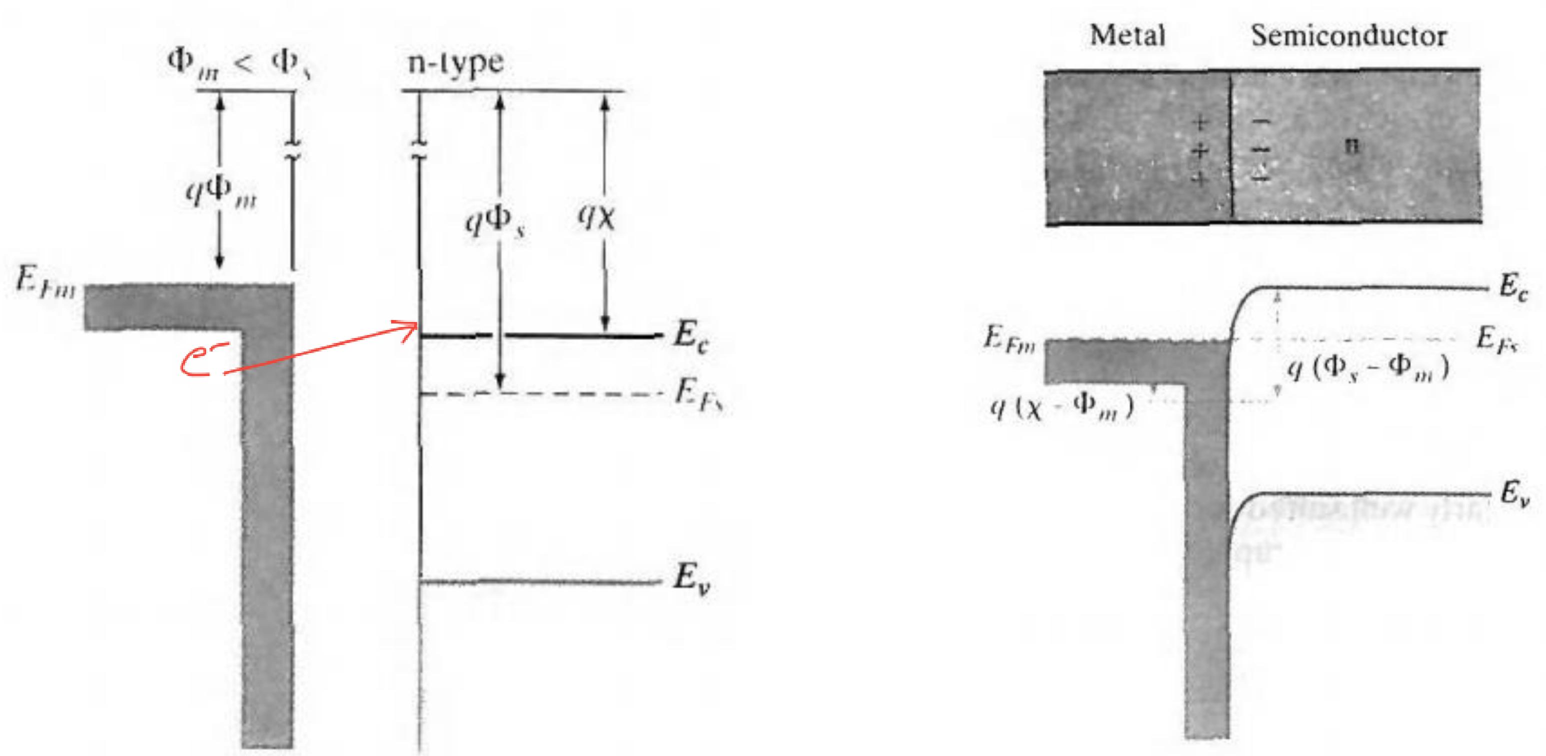
Metal Semiconductor Junction





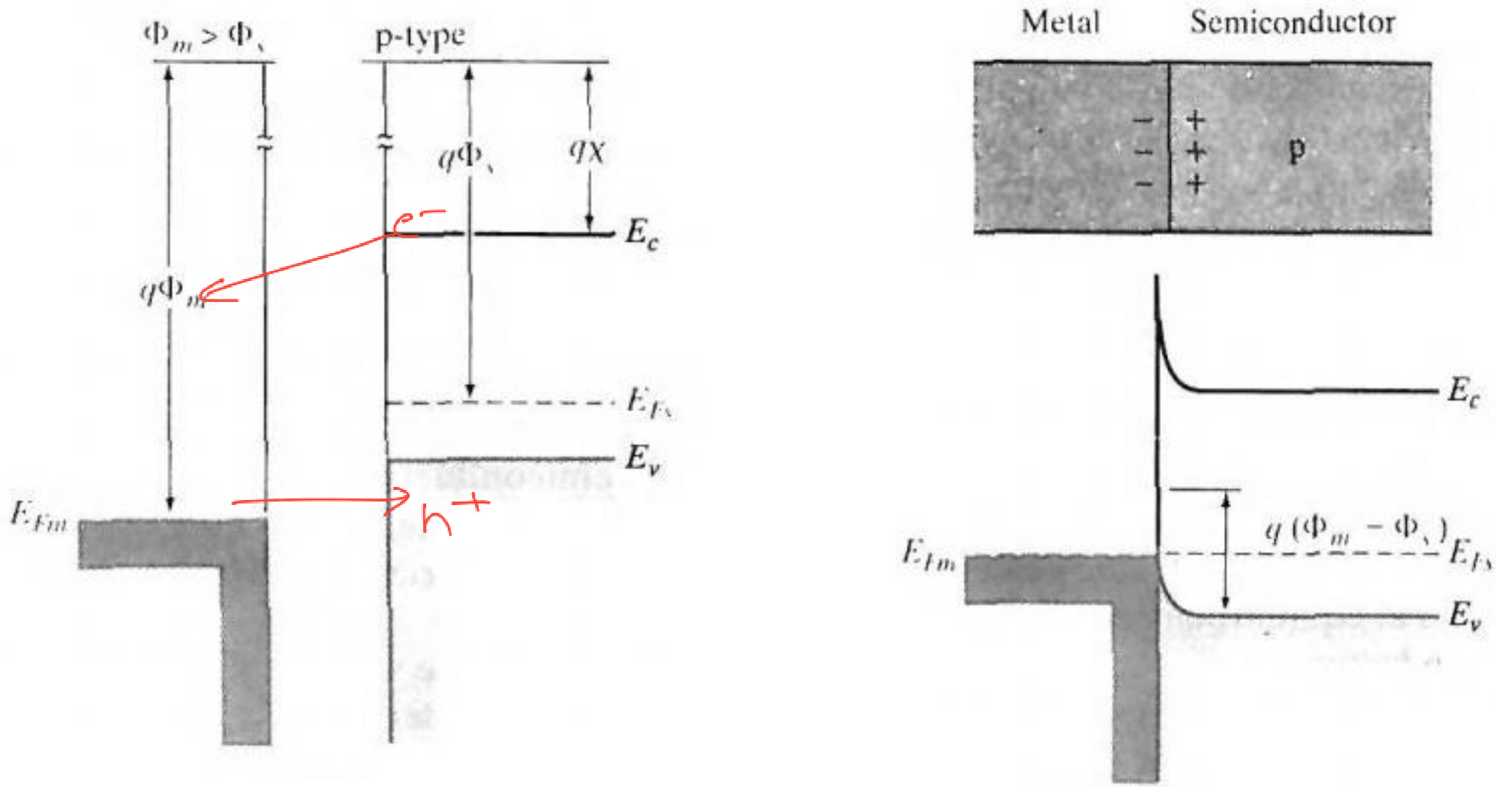
- Majority carrier concentration is decreasing in the semiconductor → **Schottky Junction**
- Downward band bending results in the barrier for the flow of hole (for hole barrier visualization draw inverted band diagram) → **Schottky Junction**

Metal Semiconductor Junction

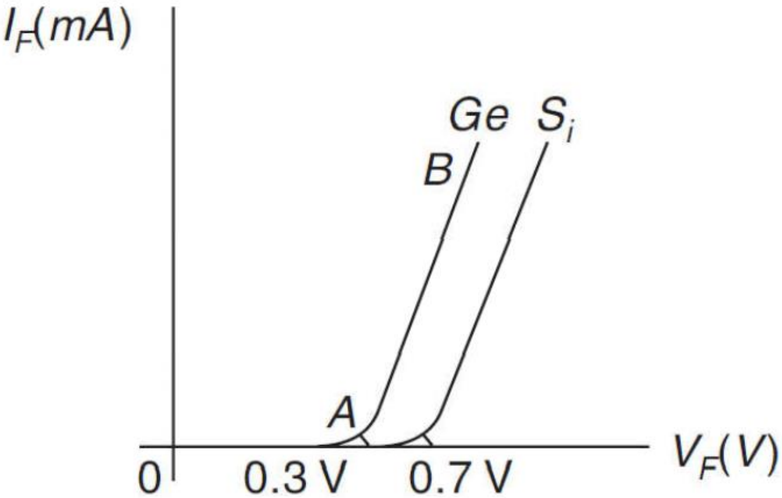


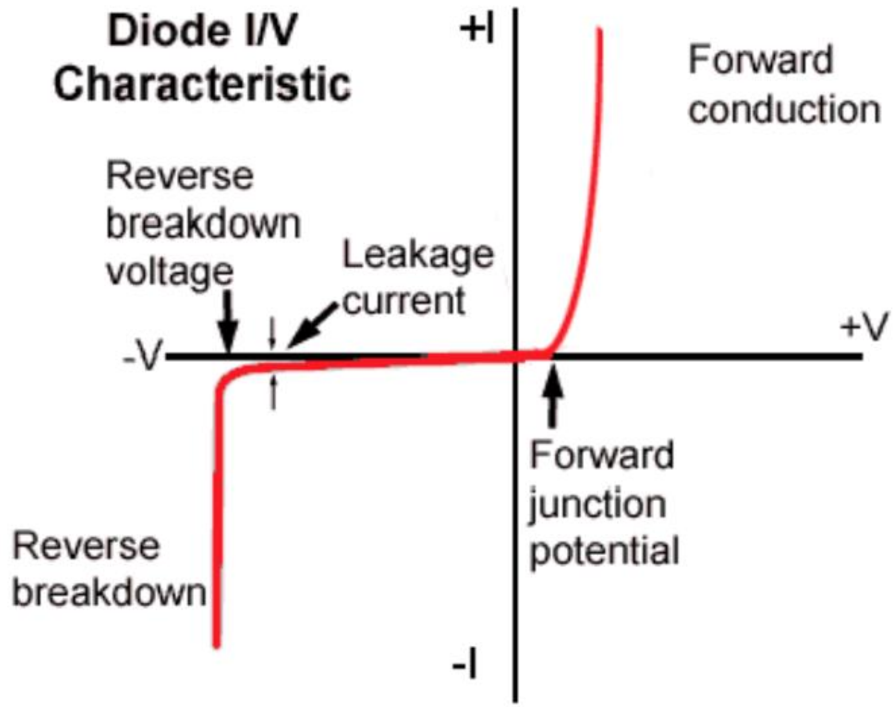
- Majority carrier concentration is increasing in the semiconductor → **Linear Junction**
- Downward band bending results in the no barrier for electron flow → **Linear Junction**

Metal Semiconductor Junction



- Majority carrier concentration is increasing in the semiconductor → **Linear Junction**
- Upward band bending results in the no barrier for hole flow (for hole barrier visualization draw inverted band diagram) → **Linear Junction**

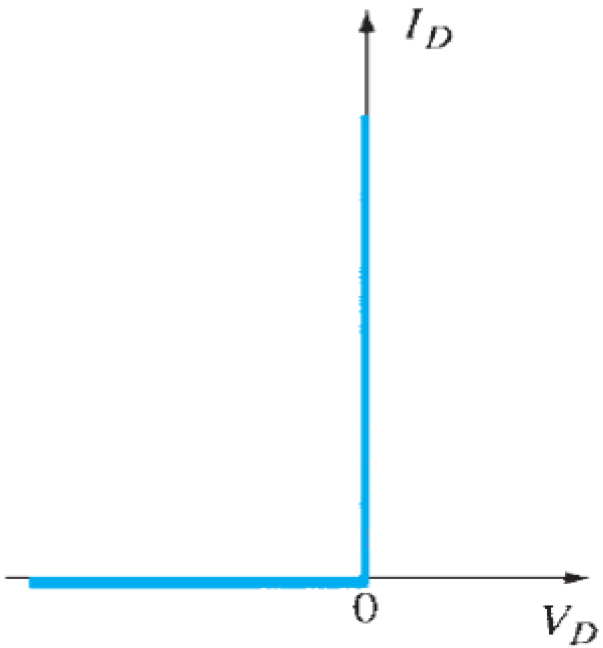


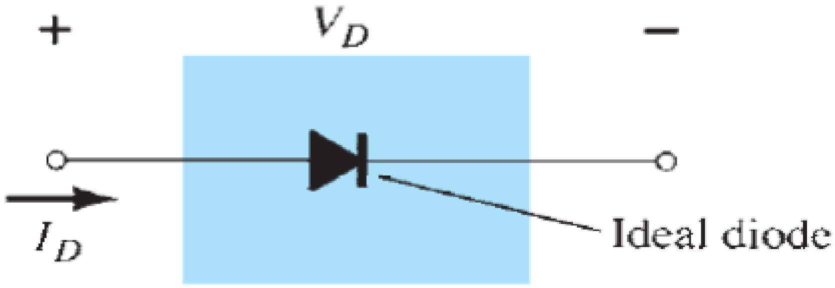


$$I_D = I_s(e^{V_D/nV_T} - 1)$$

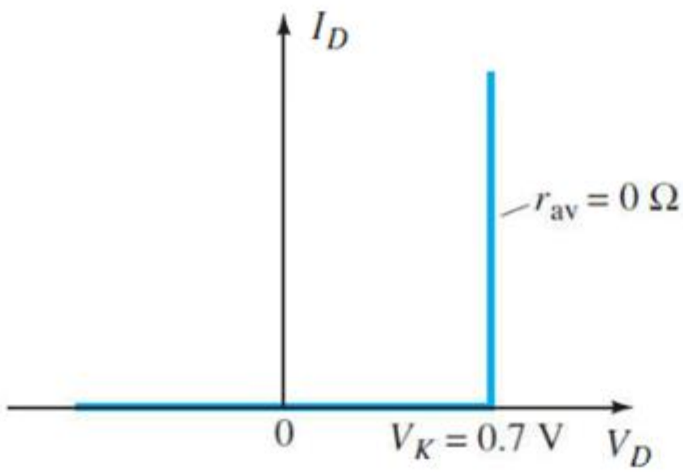
Ideal Diode

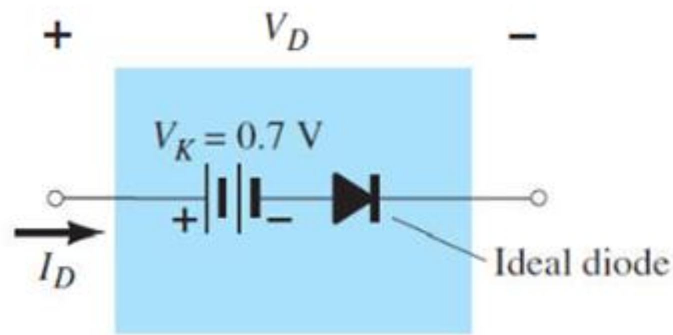
Diode will behave as short circuit as soon as the voltage across it becomes greater than zero

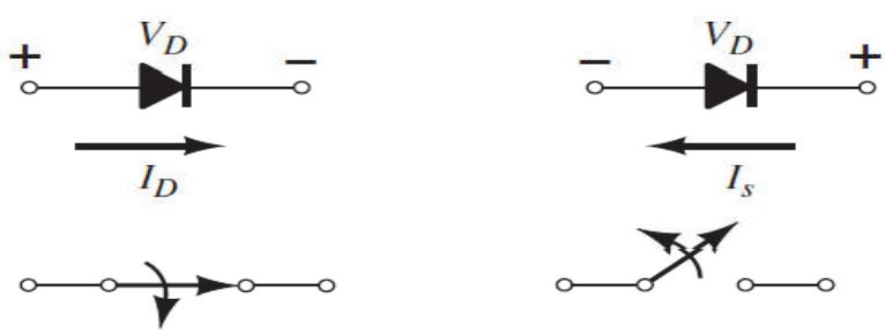


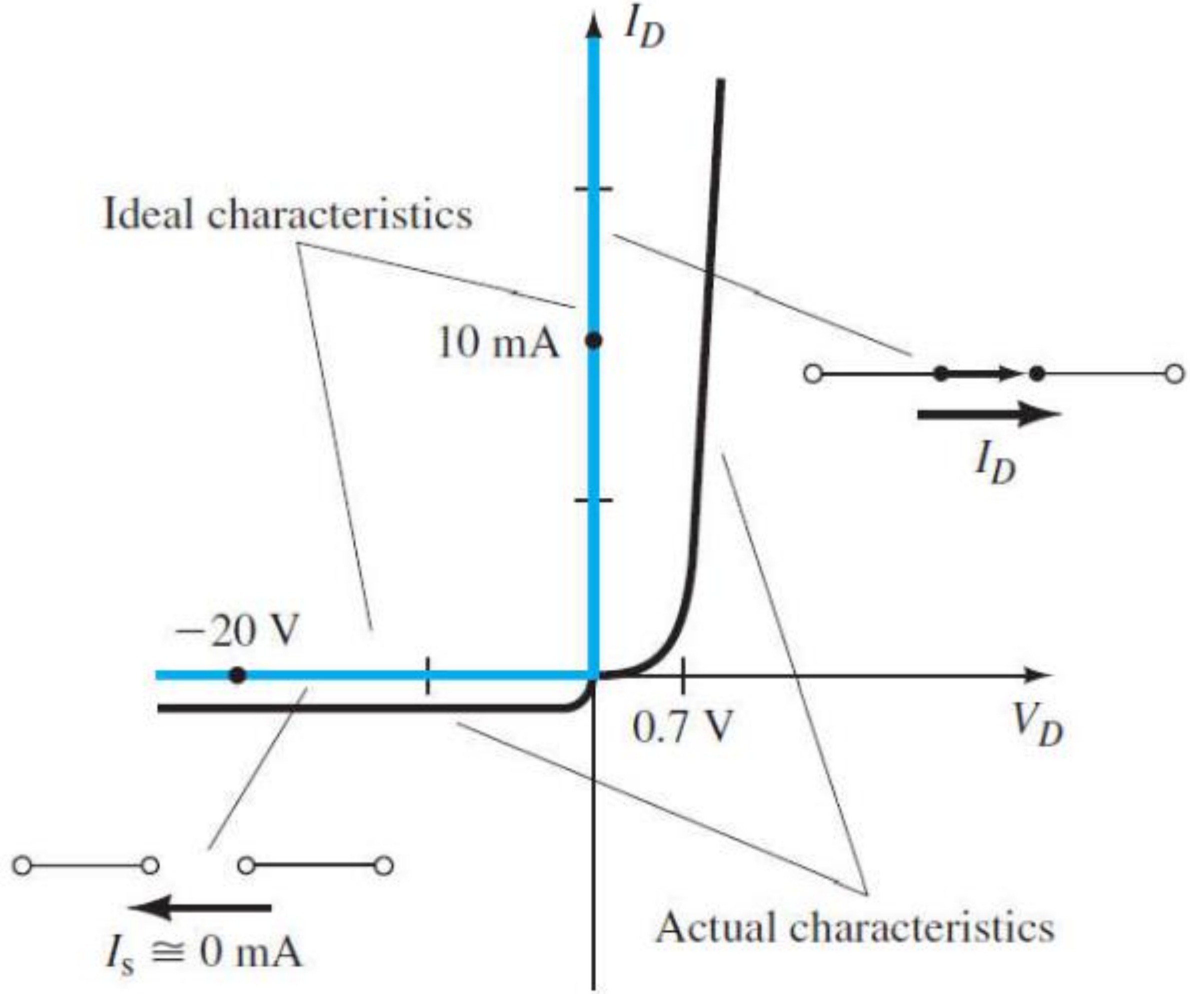


We must overcome the potential barrier of 0.7 volts (silicon) for a diode to make it forward bias



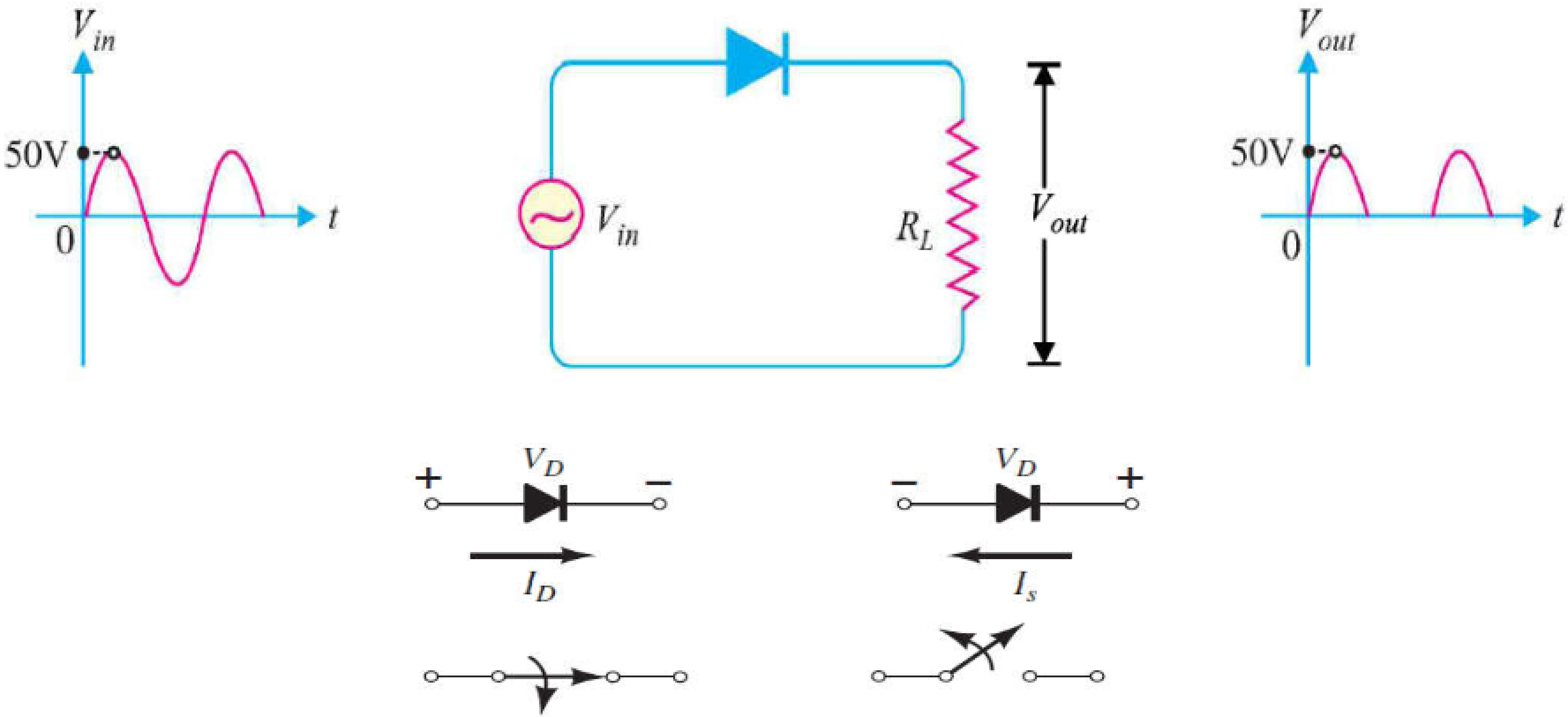




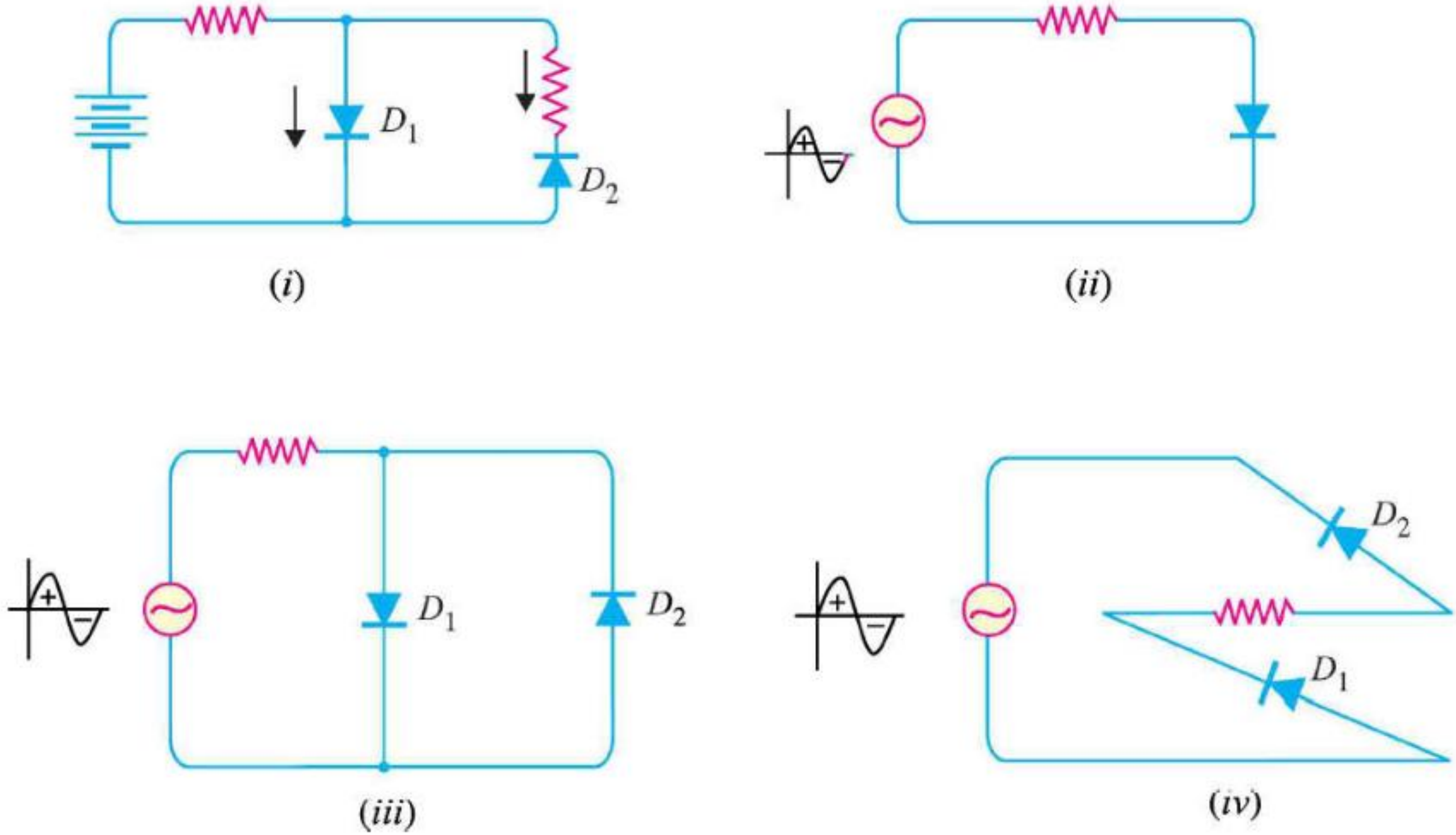

I_D
Ideal characteristics
10 mA
I_D
−20 V
0.7 V
V_D
$I_s \cong 0$ mA
Actual characteristics

Diode as Rectifier

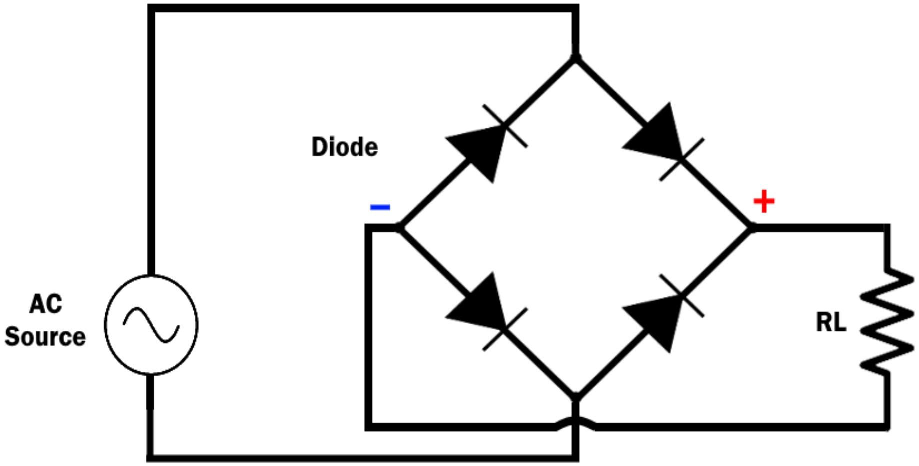
- Diode behaves as a switch
- Forward Biased – Closed Switch, connects AC Supply to load
- Reverse Biased – Open Switch, disconnects AC with load



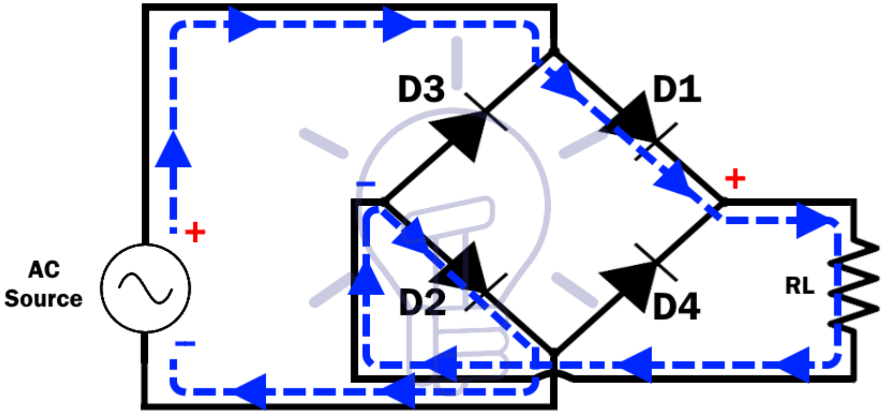
Identify whether the diode/diodes is/are forward or reverse biased?



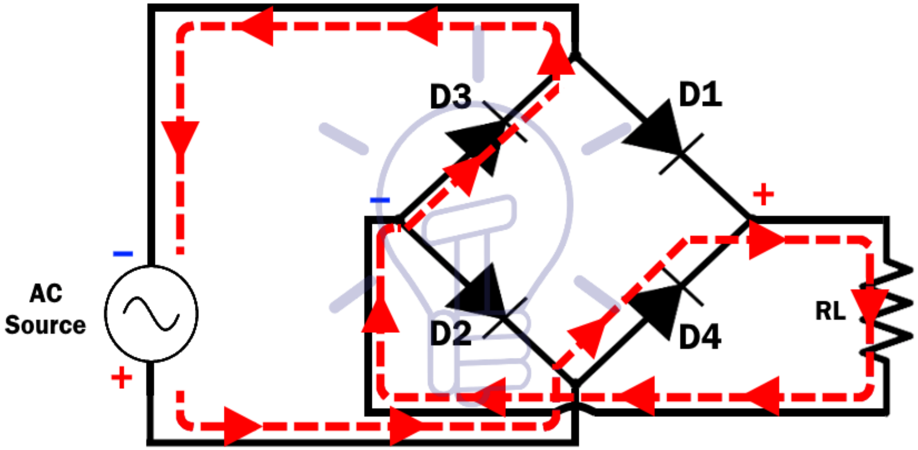
Diode as Rectifier



Bridge Rectifier



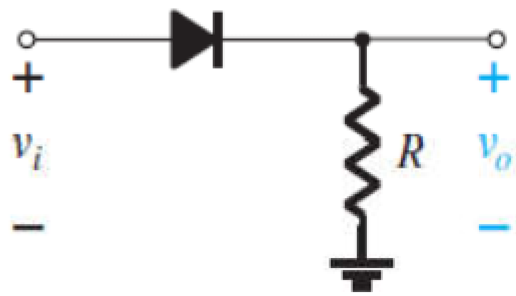
Bridge Rectifier During Positive Cycle

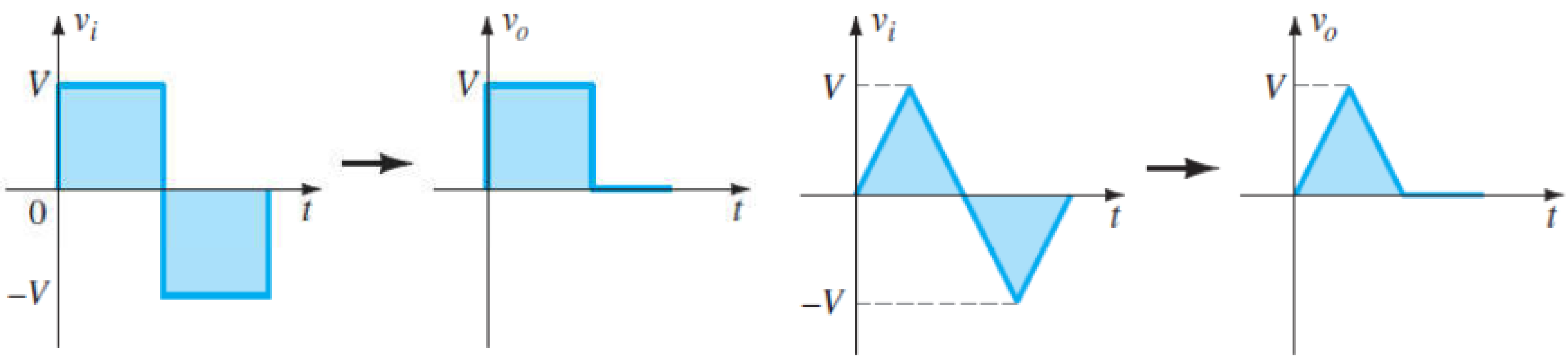


Bridge Rectifier During Negative Cycle

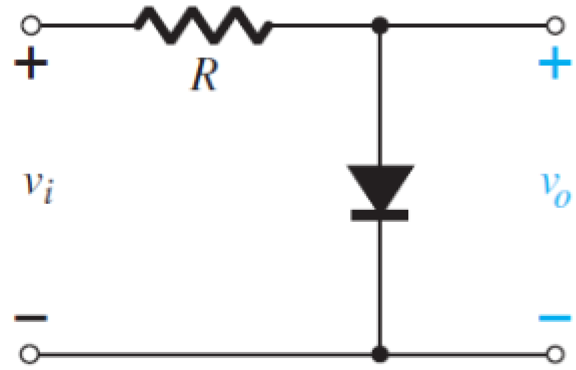
Diode as a Clipper (Series)

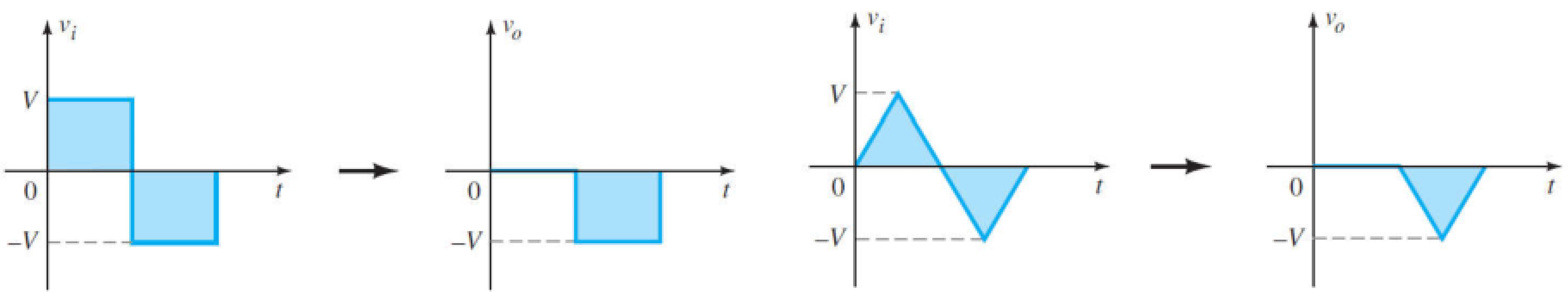
Clipping a portion of an input signal without distorting the remaining part of the waveform



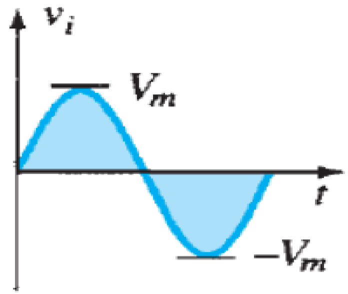


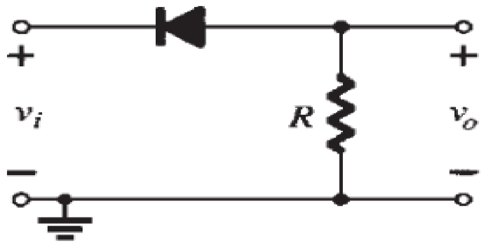
Diode as a Clipper (Shunt)

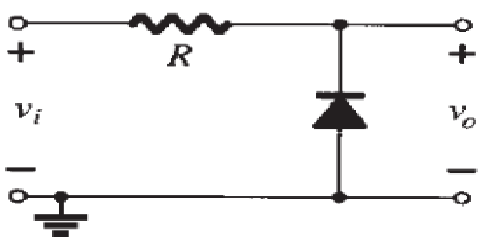


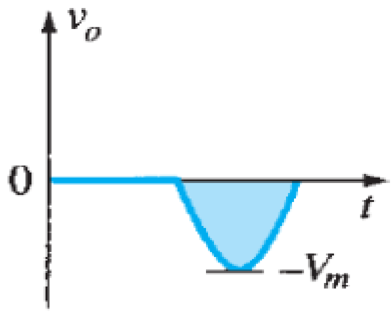


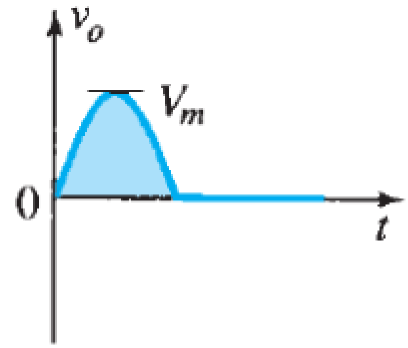
Diode as a Clipper (Task)





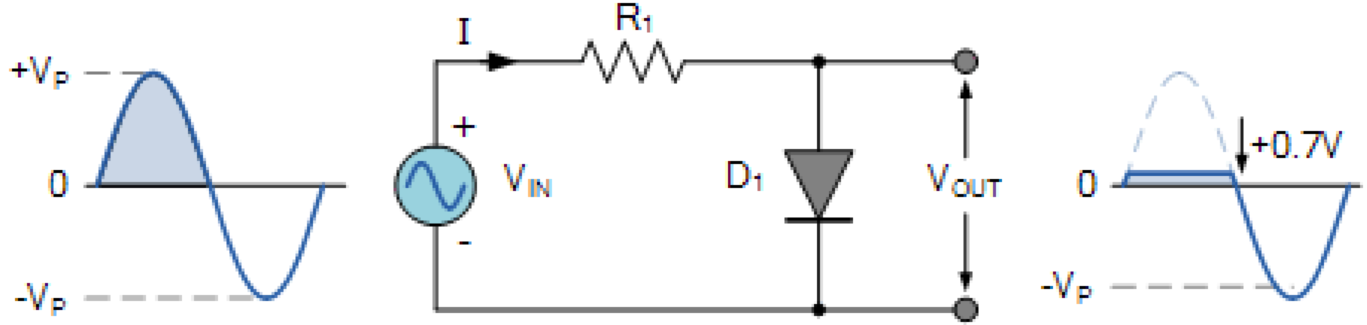




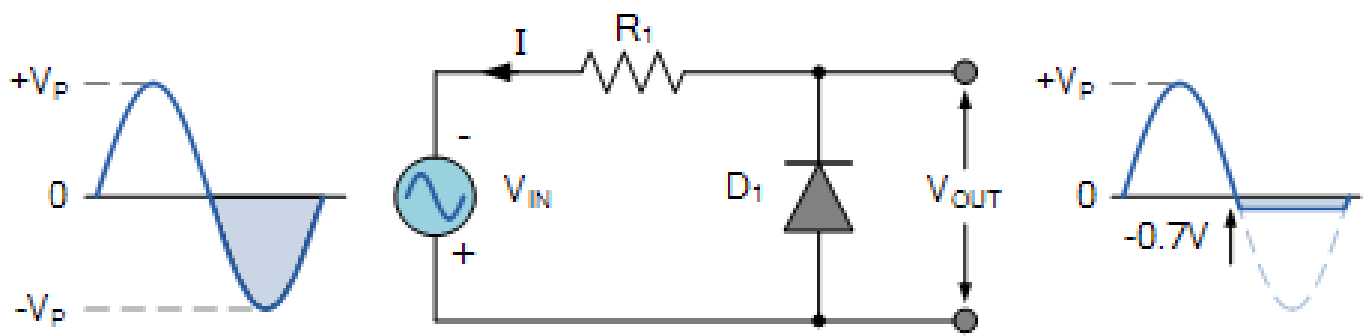


Diode as a Clipper

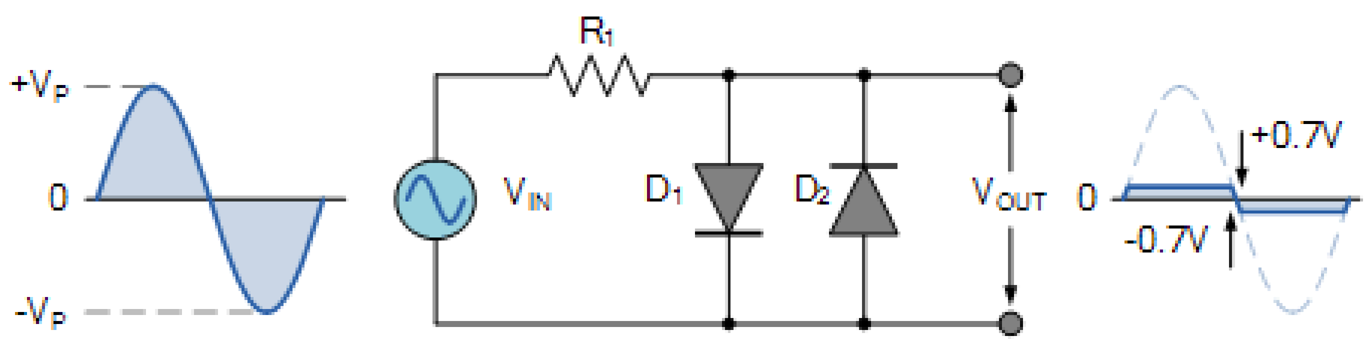
Positive Clipper



Negative Clipper

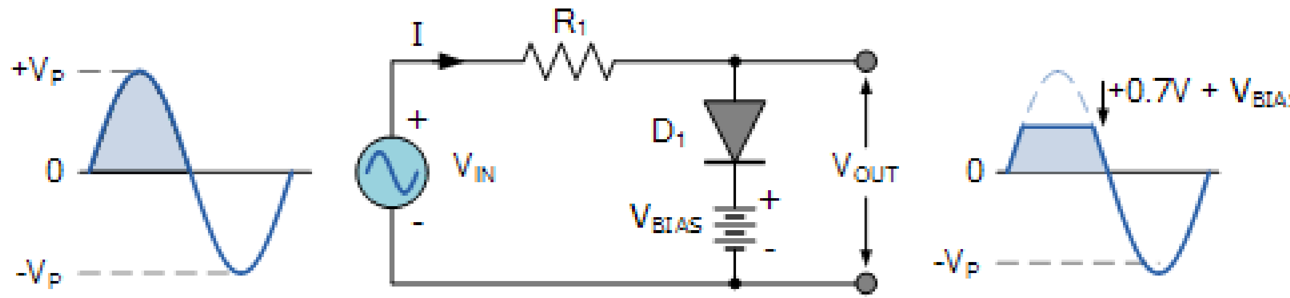


Clipper

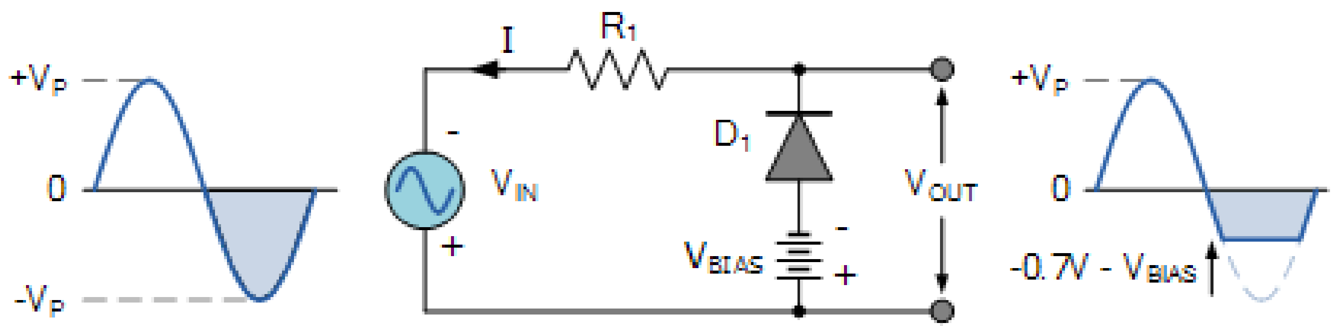


Diode as a Clipper

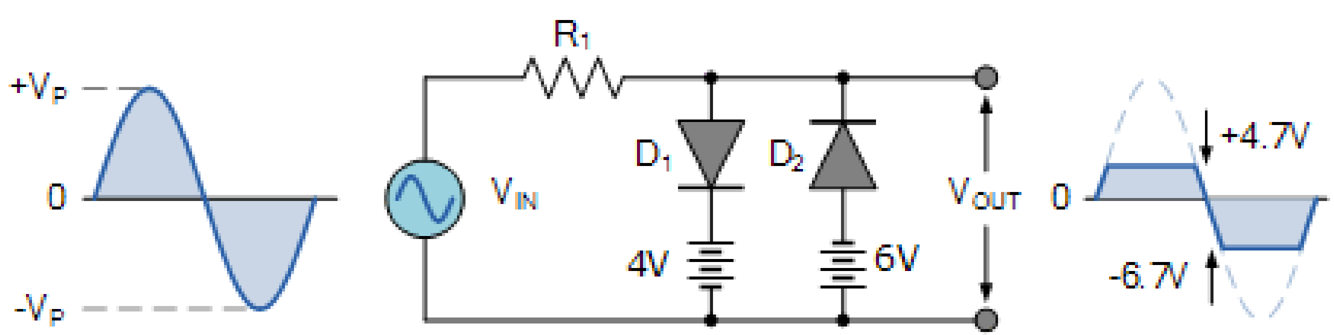
Positive Biased Clipper



Negative Biased Clipper

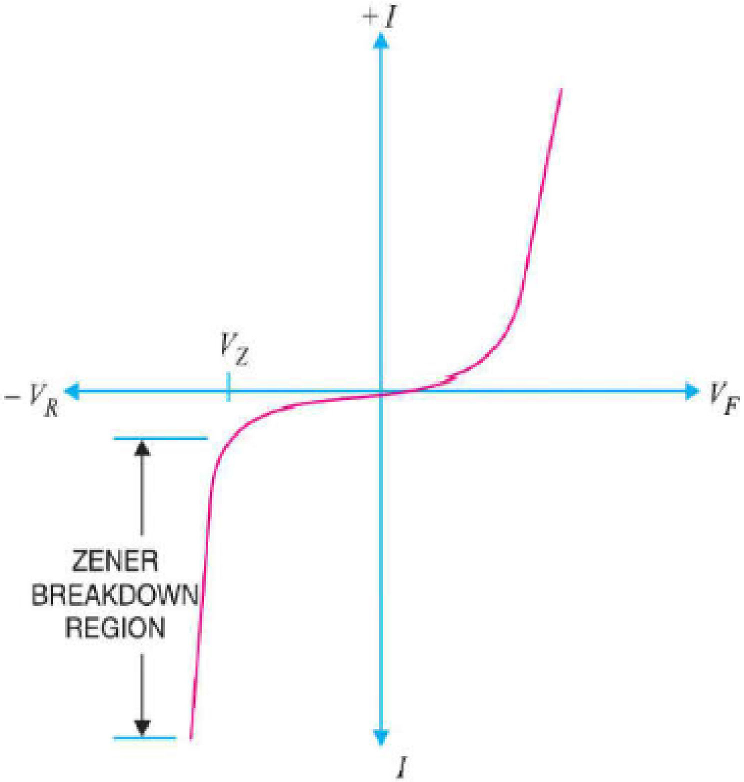


Clipper



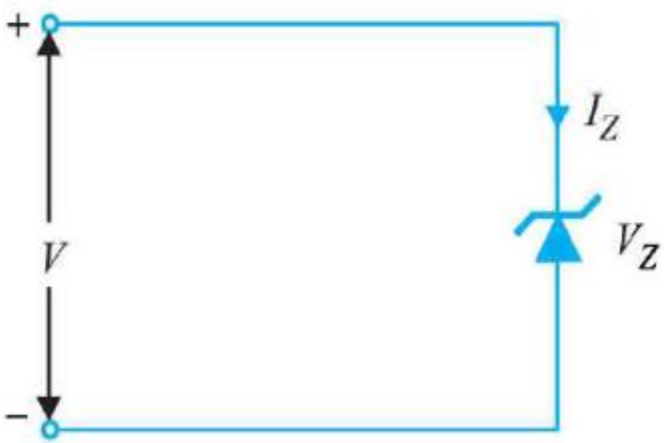
Zener Diode

- A special diode designed to operate in reverse breakdown region
- An ordinary diode will get damaged due to excessive current
- A zener diode is heavily doped to reduce the breakdown voltage as well as depletion layer width
- As a result the diode has a **sharp** reverse breakdown voltage
- Characteristics show two imp points
  - After breakdown, the diode current increases rapidly
  - The reverse voltage across the diode remains constant.
  - This phenomenon of voltage remaining constant helps us to use Zener diode in voltage regulation.



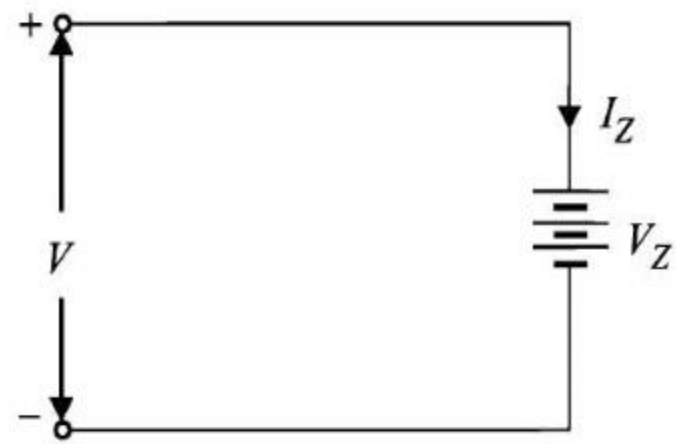
Zener Diode

- Always operated in reverse bias
- When forward biased, will behave as a normal diode
- When the reverse voltage across the diode is greater than or equal to the breakdown voltage, it can be replaced by a battery e qual to the Vz (Zener Voltage or Breakdown Voltage)



(i)

$V \geq V_Z$

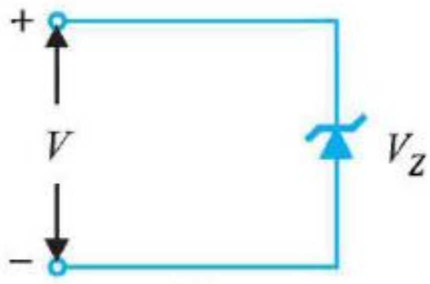


(ii)

Equivalent circuit of zener for ''on'' state

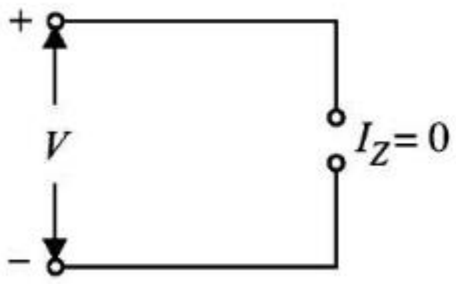
Zener Diode

- However if the reverse voltage is less than the breakdown voltage, it will work as open circuit as shown below.



(i)

$V_Z > V > 0$



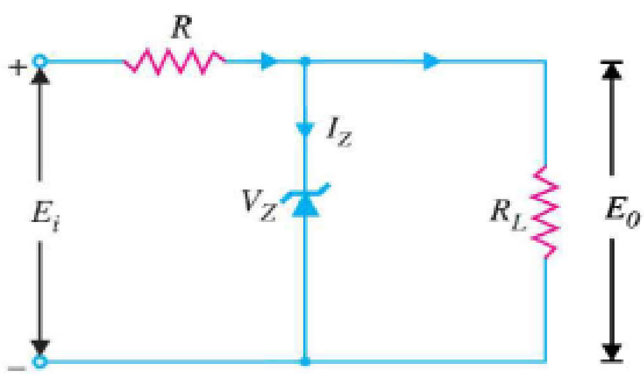
(ii)

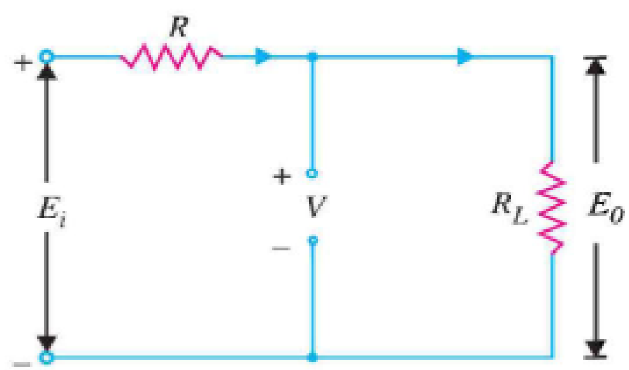
Equivalent circuit of zener for "off" state

Zener Diode as a Regulator

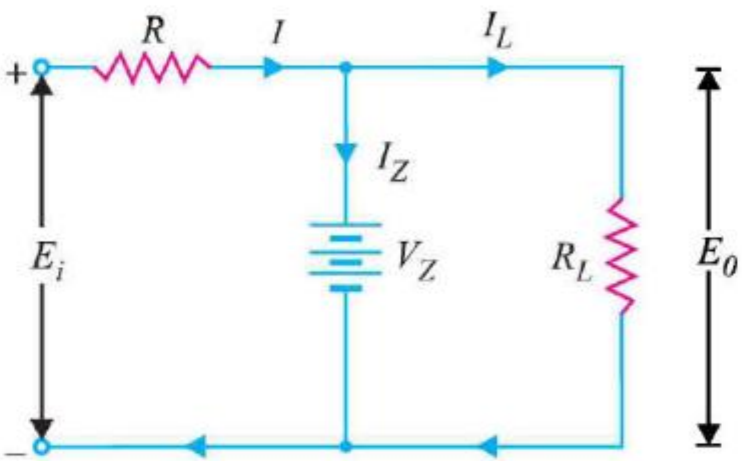
- ❑ Try to find the state of the zener diode (Off, Forward Biased, Reverse Biased, Reverse Biased and in Breakdown)
- ❑ Remove the diode and find the voltage across Load Resistance
- ❑ If above voltage is greater than specified breakdown voltage of zener diode than replace it by a battey of Vz. The voltage now across both diode as well as the Load resistance will remain constant at Vz.
- ❑ If it less, then the replace it by an open circuit. In this case there is no regulation and the voltage across the load fluctuates as per the variations in the input power supply.

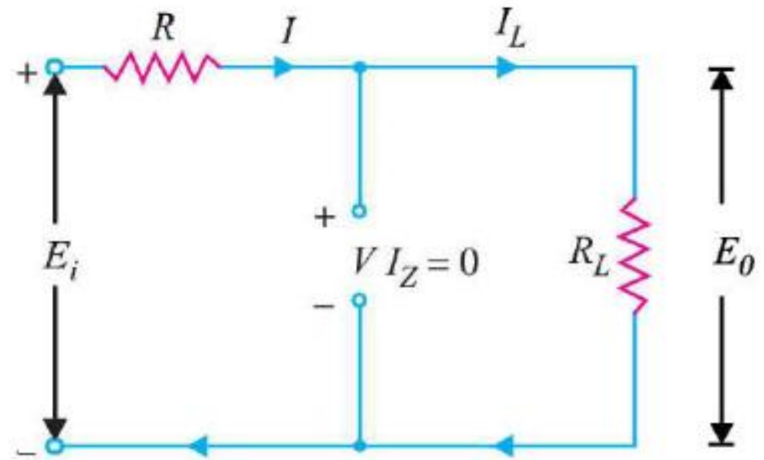
$$V = E_0 = \frac{R_L E_i}{R + R_L}$$





Zener Diode as a regulator

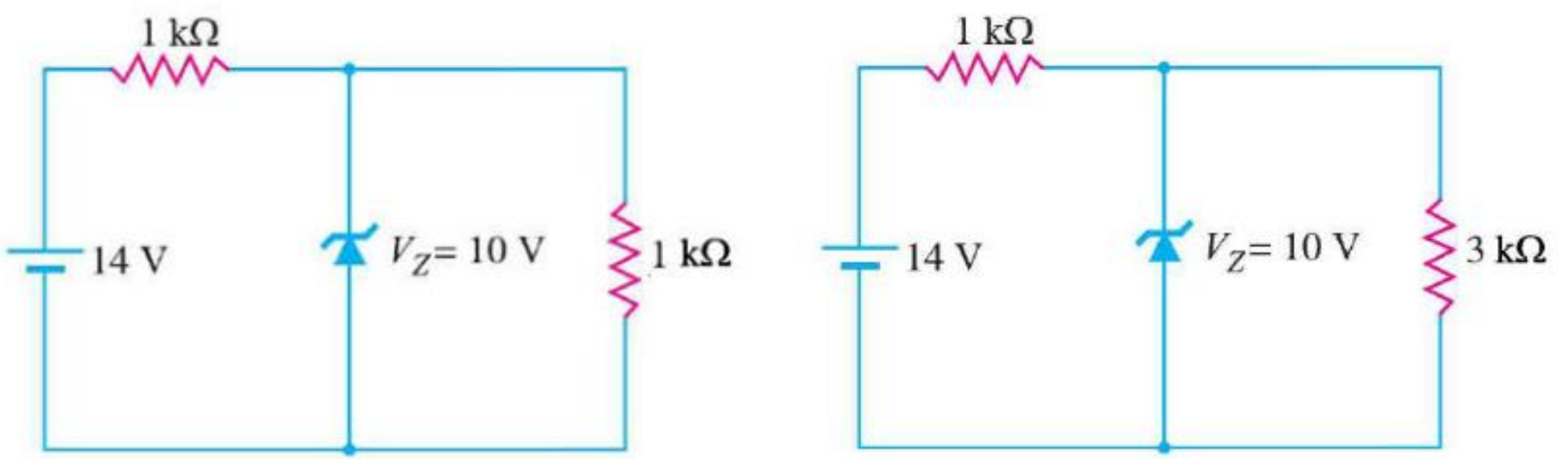




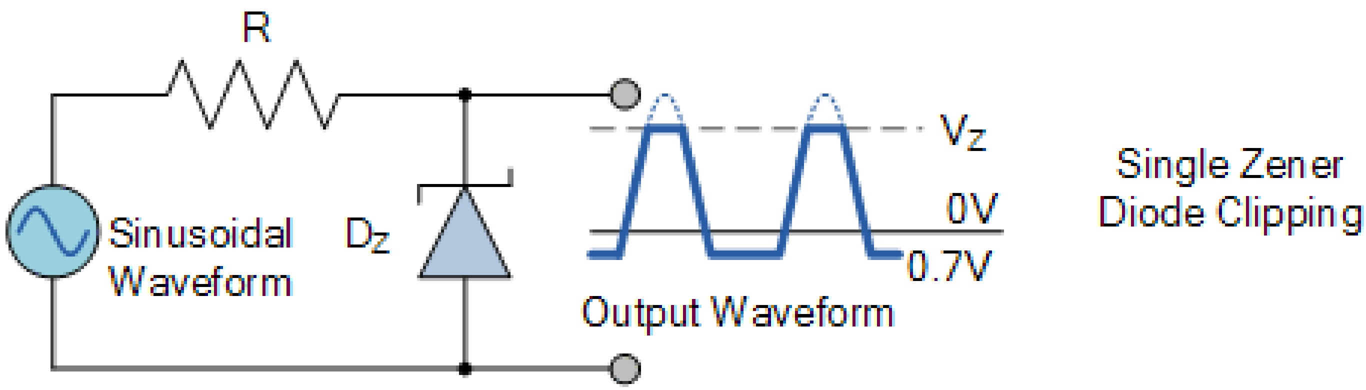
- $V > V_Z$: $E_0 = V_Z$, $I_Z = I - I_L$, $P_Z = V_Z$, $I_L = V_Z/R_L$
- $V < V_Z$: $I = I_L$, $I_Z = 0$, $P_Z = 0$ $(P_Z = V_Z I_Z)$ $I_L = E_i/(R+R_L)$

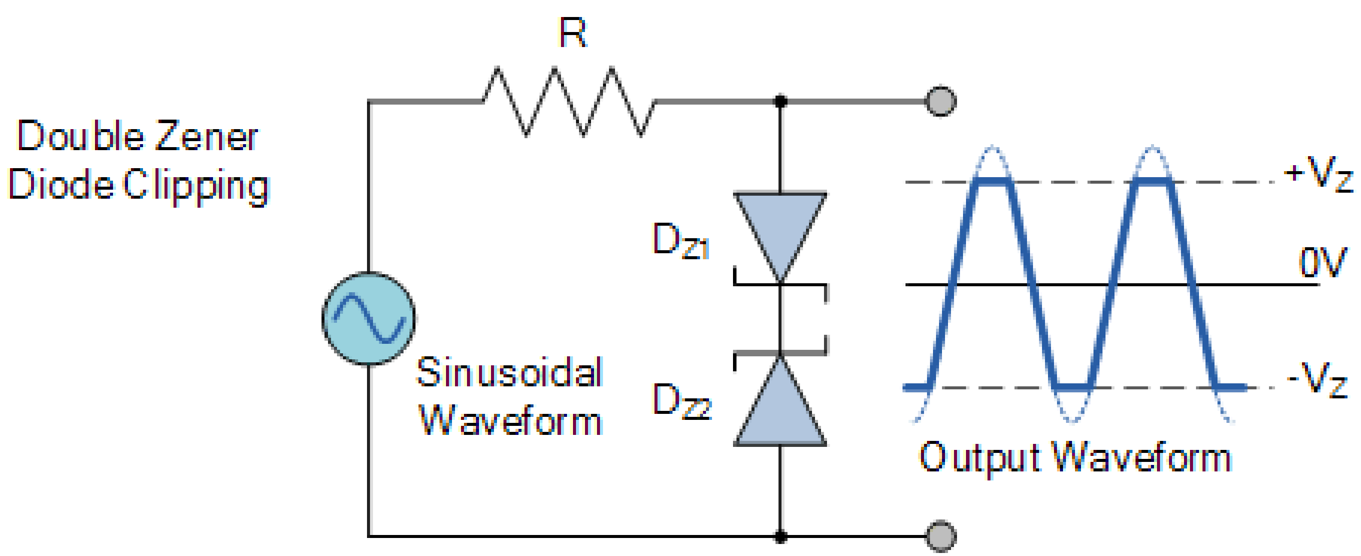
Zener Diode as a Regulator

Determine whether Zener diode is on or off? Accordingly specify the output voltage.



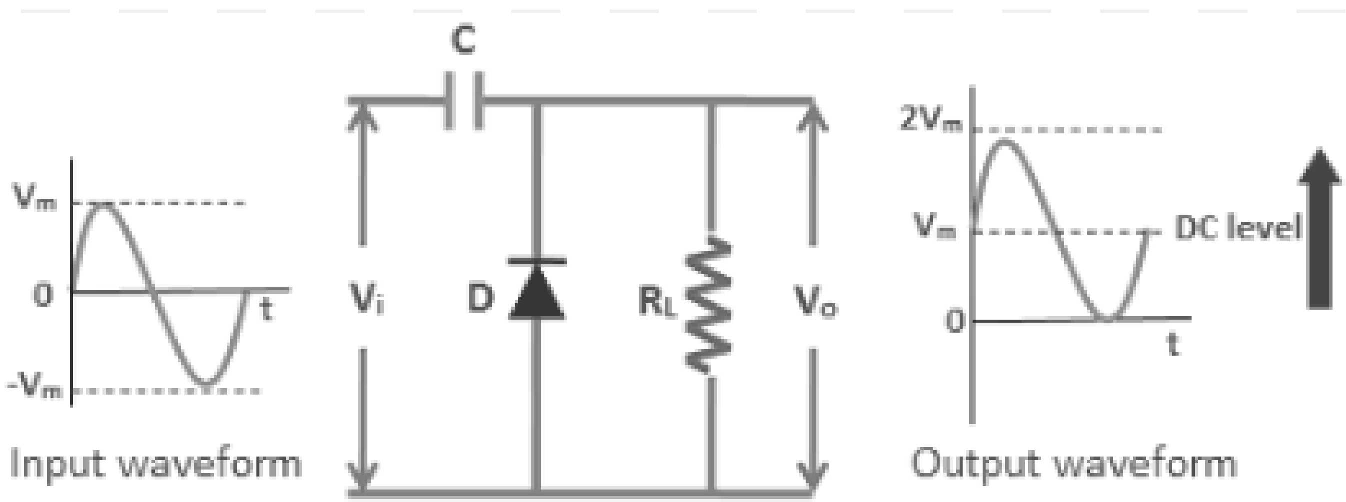
Zener Diode as a Clipper





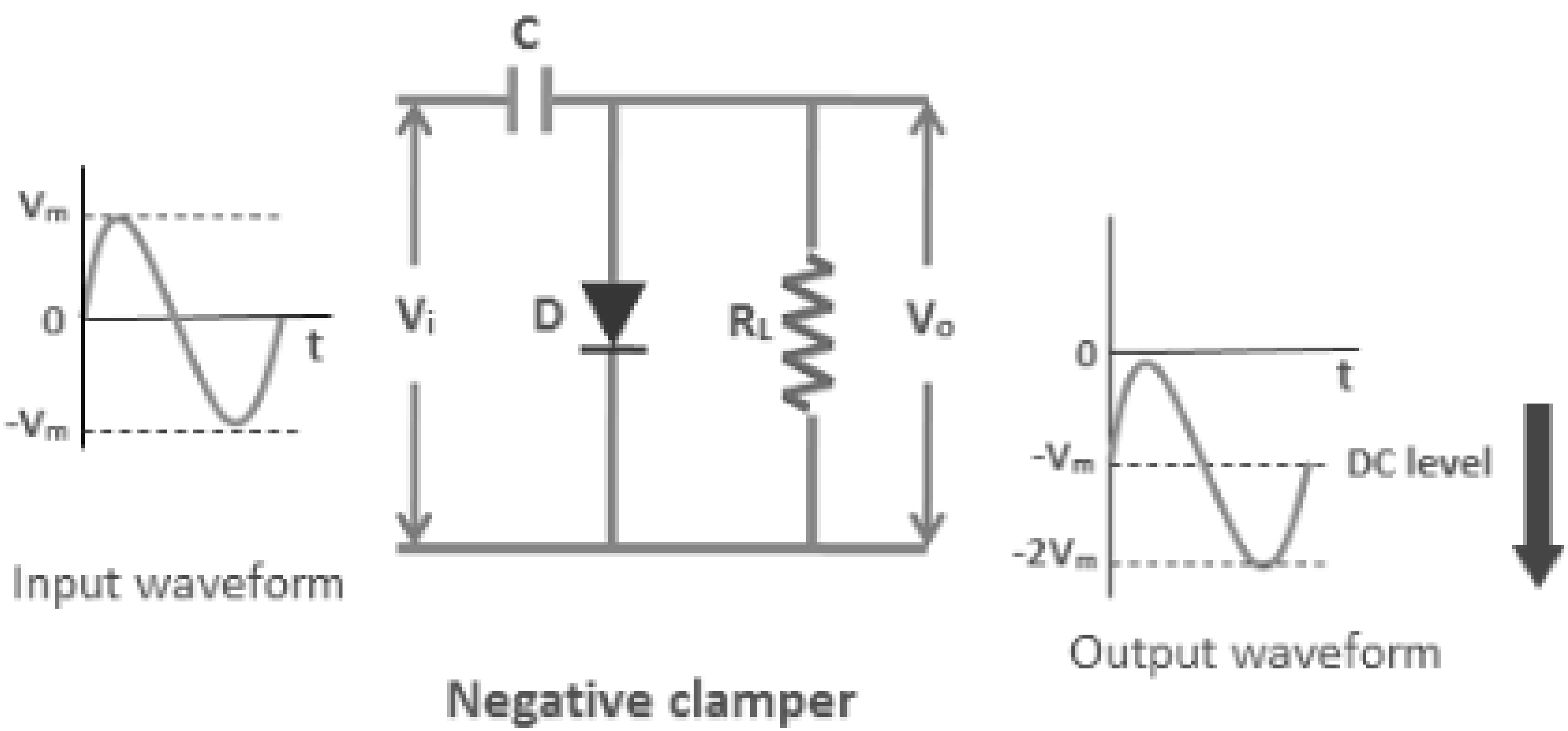
Diode as a Clamper

- **Clamper**: Circuit used to shift the DC level of the signal without changing the shape of the applied signal.
- **Types:** a) Positive b) Negative, c) Biased

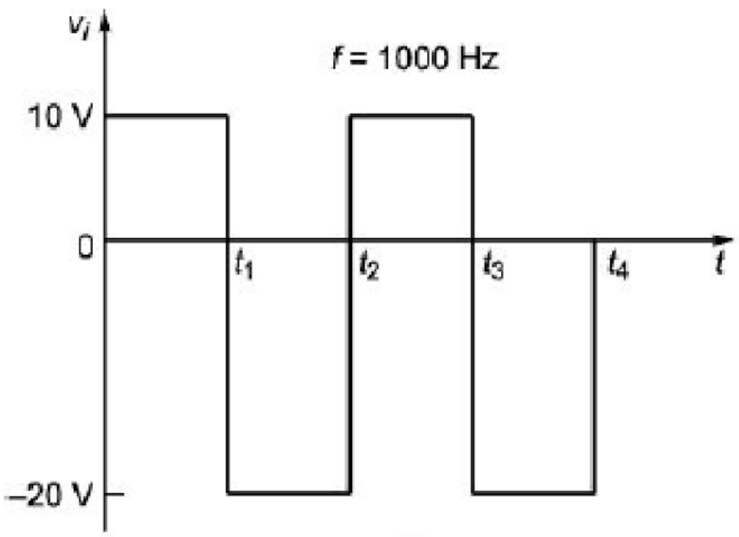


Positive clamper

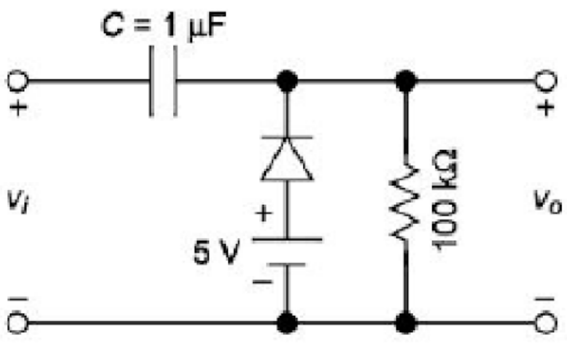
Diode as a Clamper



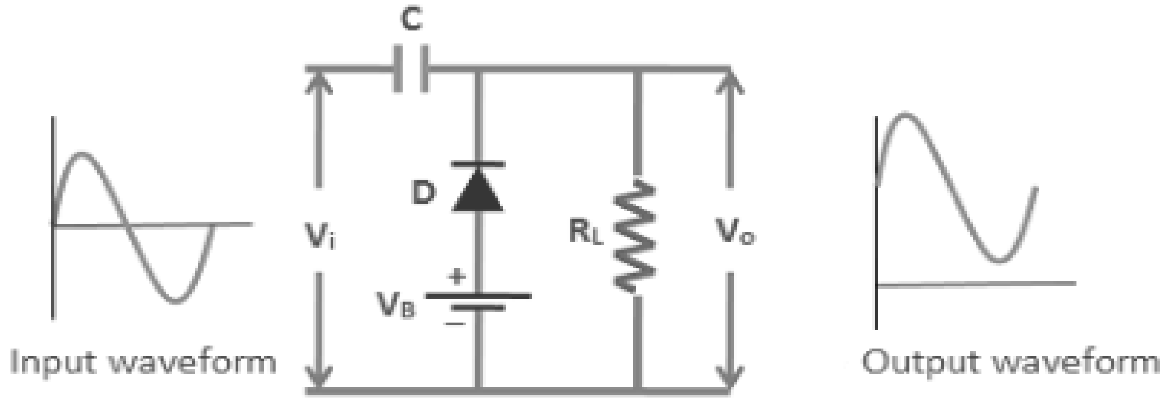
Diode as a Clamper (Practice)



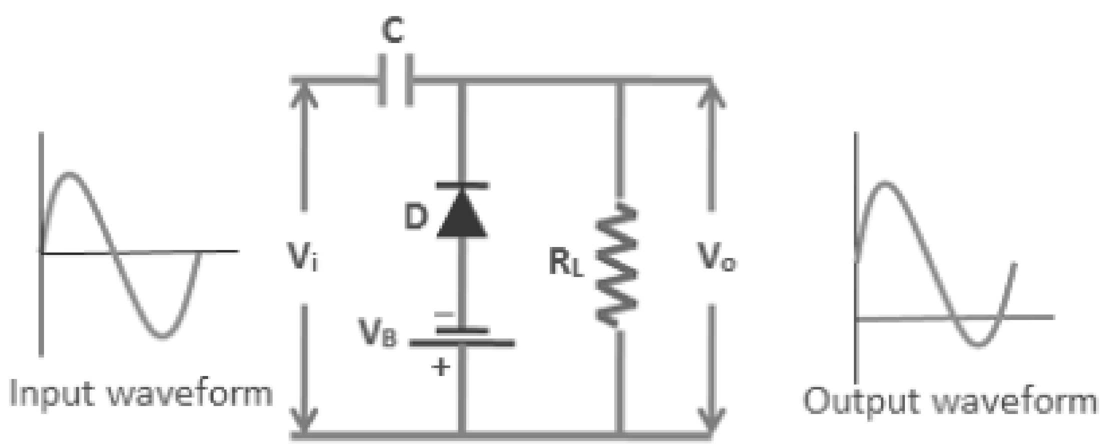
(a)



(b)

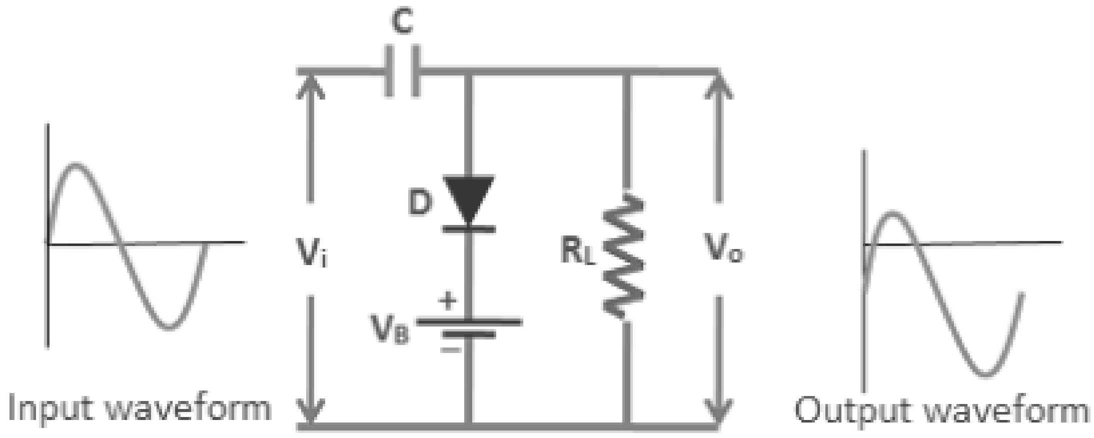


Positive clamper with positive bias

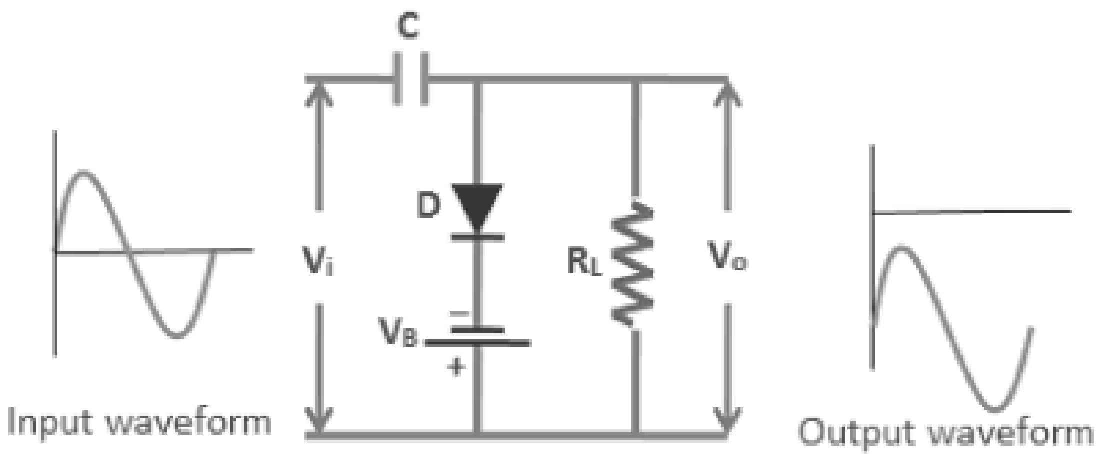


Positive clamper with negative bias

Diode as a Clamper

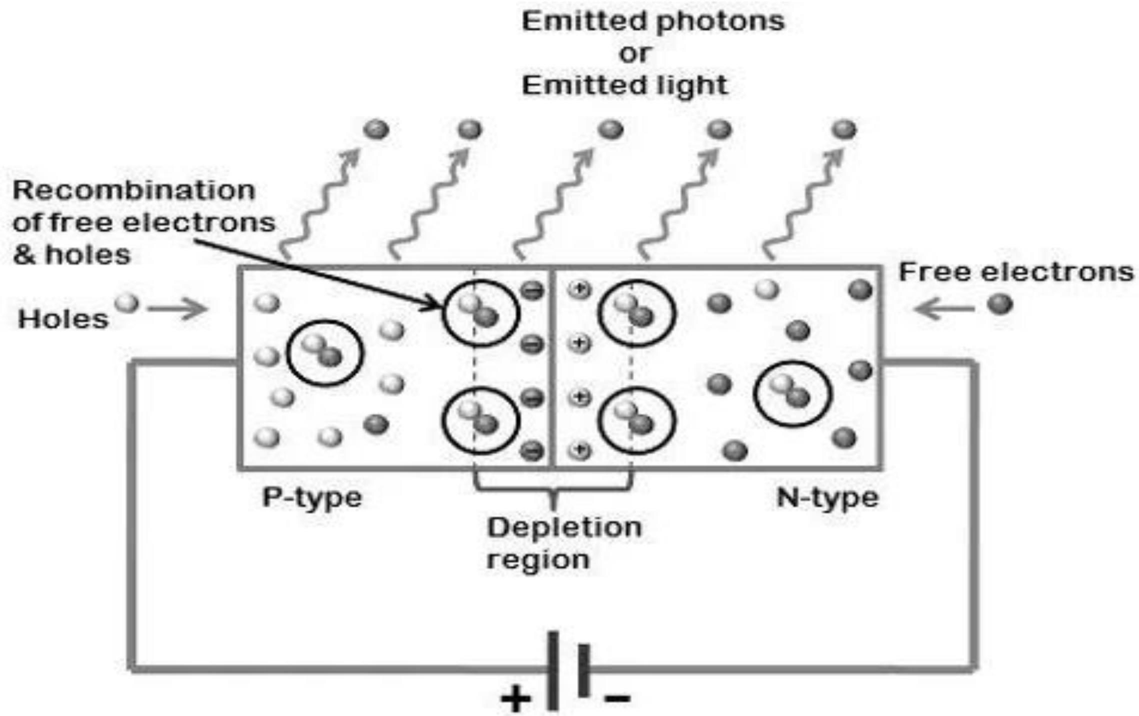


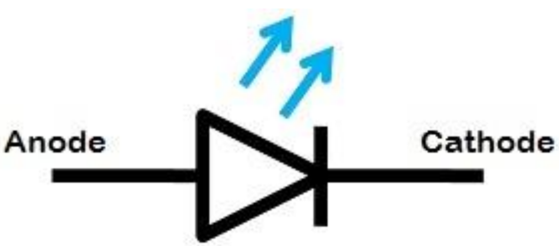
Negative clamper with positive bias

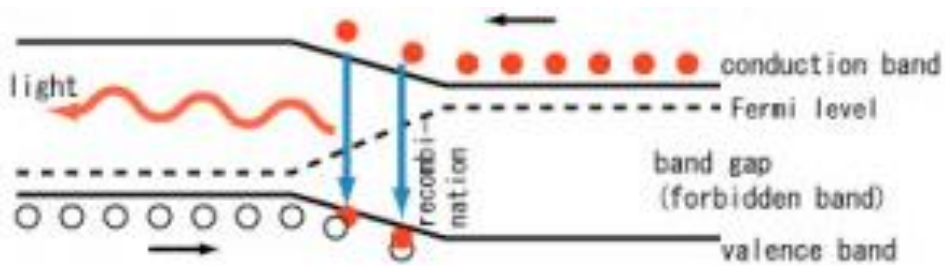


Negative clamper with negative bias

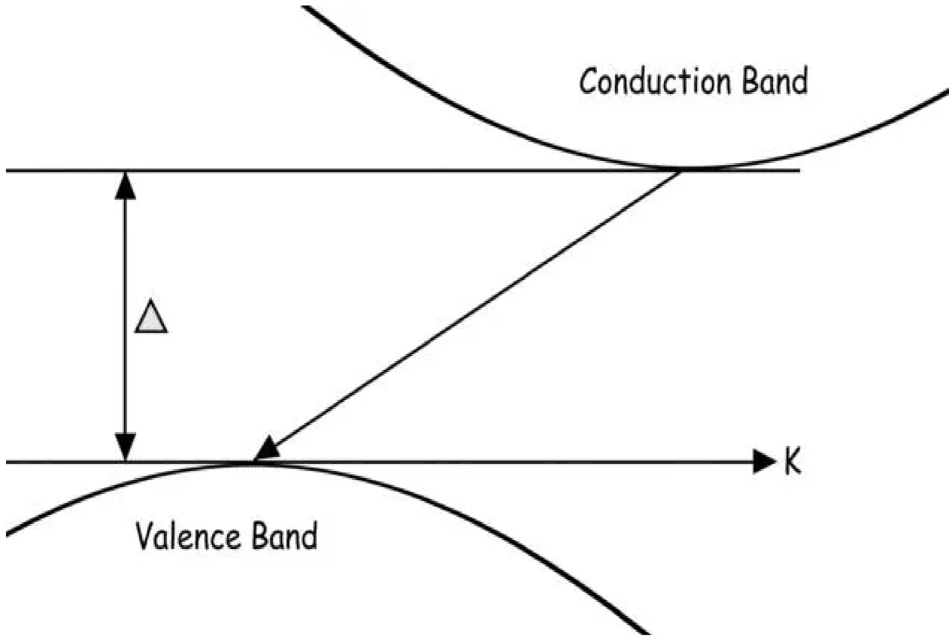
Light Emitting Diodes



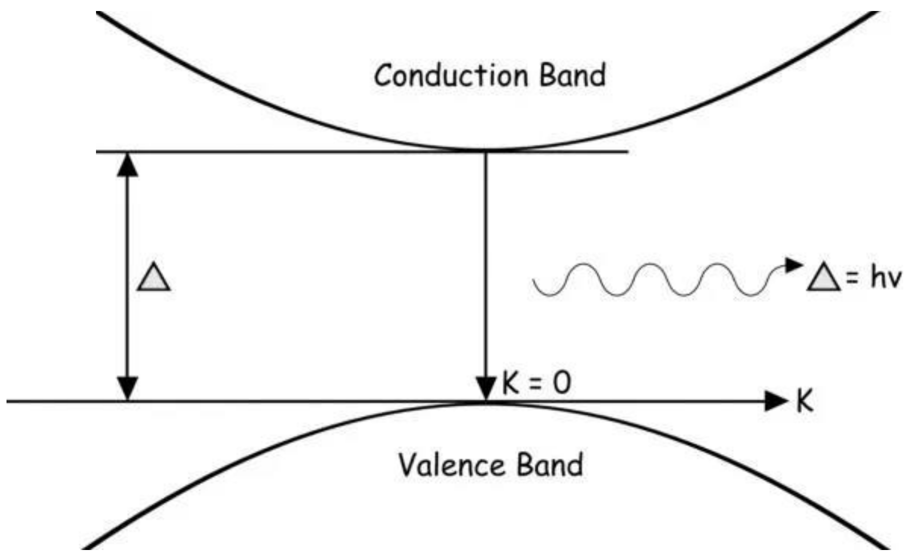




Light Emitting Diodes

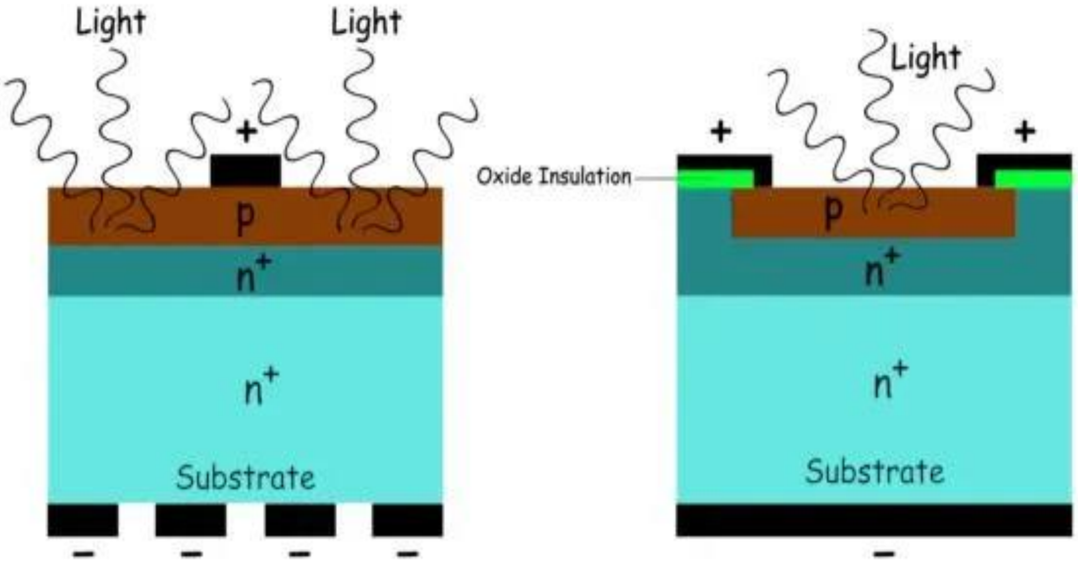


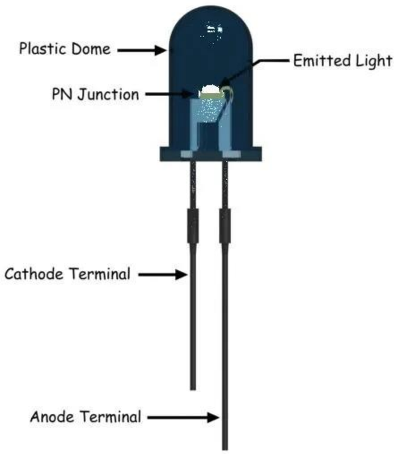
Indirect Band Gap



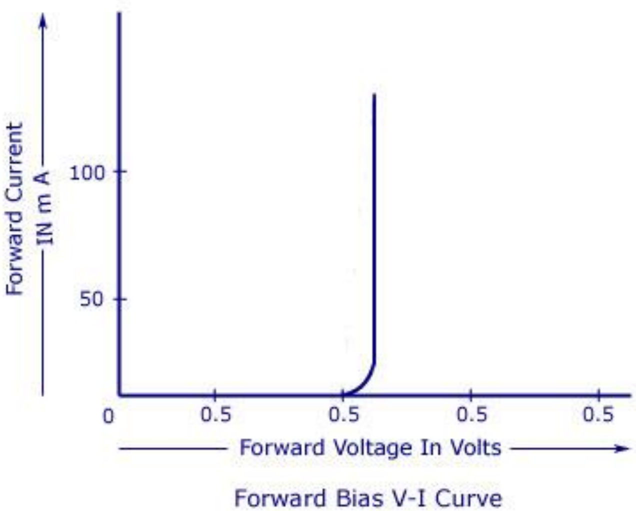
Direct Band Gap

Light Emitting Diodes





LED

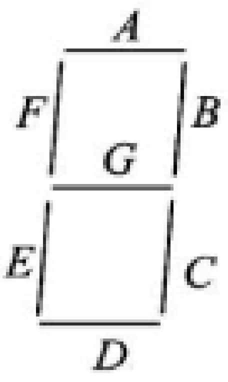


Light Emitting Diodes

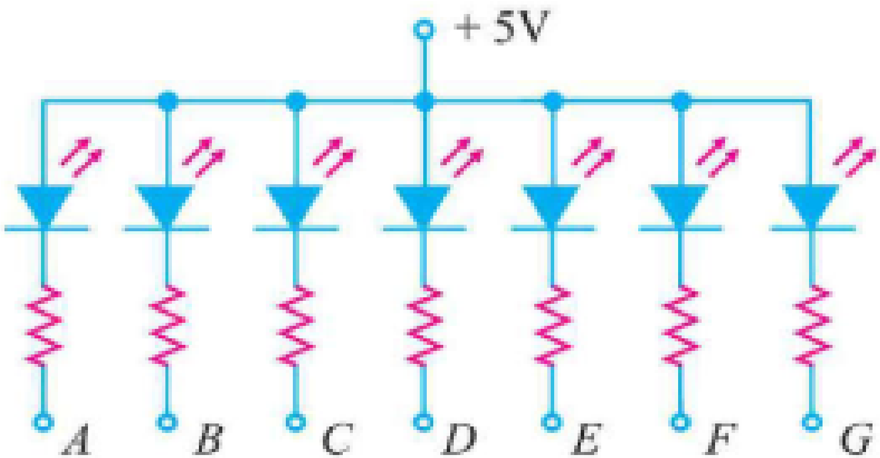
- ❑ It is a diode which emits visible light when forward biased
- ❑ Made from Gallium, Phosphorus or/and Arsenic (GaAs, GaPh, GaInPh). Changing the element and proportion changes the color.
- ❑ Gallium Arsenide – Red Light
- ❑ Gallium Phosphide – Green Light
- ❑ When LED is forward biased, the electrons cross the junction and recombine with holes.
- ❑ These electrons being in conduction band are at higher energy levels.
- ❑ When they recombine, energy is released in the for m of heat and light.
- ❑ For Si and Ge diodes, the entire energy is given in the form of heat and the emitted light is insignificant.
- ❑ For LED, the sufficient energy is emitted as light that too in the visible region.
- ❑ Works as a normal diode when forward biased.

Seven Segment Display

- LEDs are grouped to form a Seven Segment Display
- It contains seven LEDs A, B, C, D, E, F and G in shape of a figure '8'
- If a particular LED is forward biased then that LED will glow, thereby lighting up that segment or bar.
- By forward biasing various combinations of these seven LEDs, it is possible to display any number between 0 – 9.



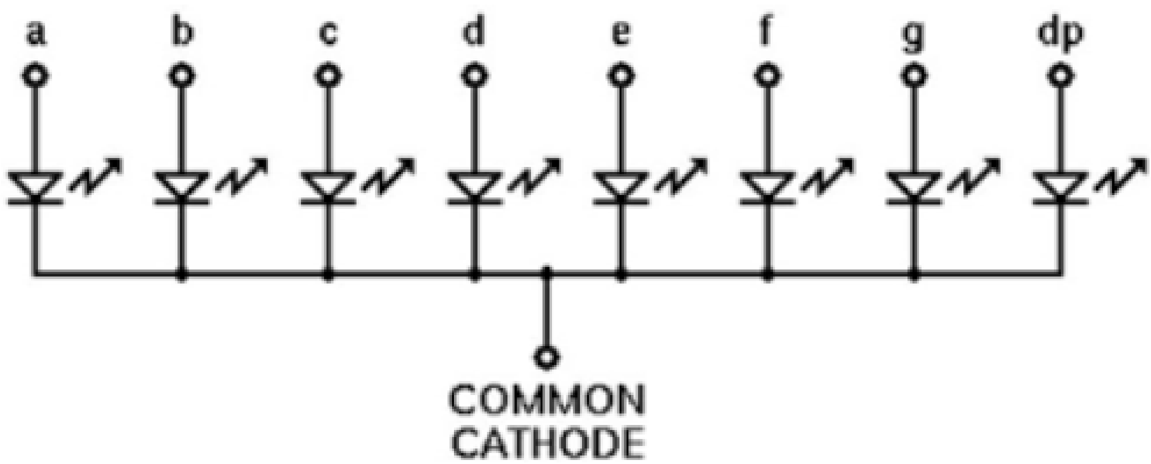
(i)



(ii)

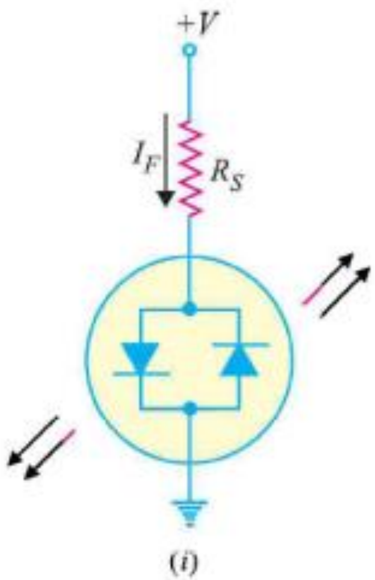
Seven Segment Display

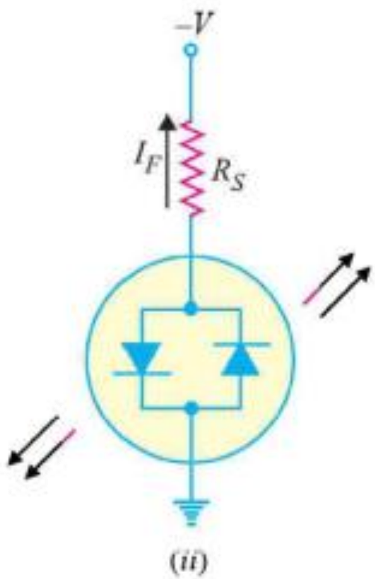
- Eg. When A, B, C and D are lit, (By forward biasing them), the dis play will show number ‘3’
- To get ‘0’ all segments except ‘G’ are lit.
- In figure (ii) external resistors are included to limit current thereby preventing LEDs from damage
- The configuration is referred to as Common Anode type. We also have Common Cathode type SSDs.

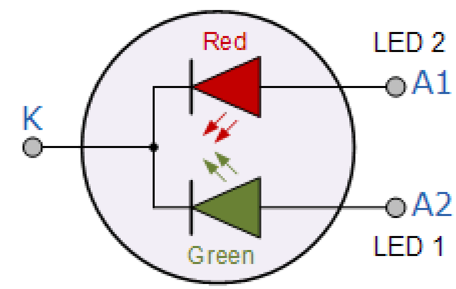


Light Emitting Diodes

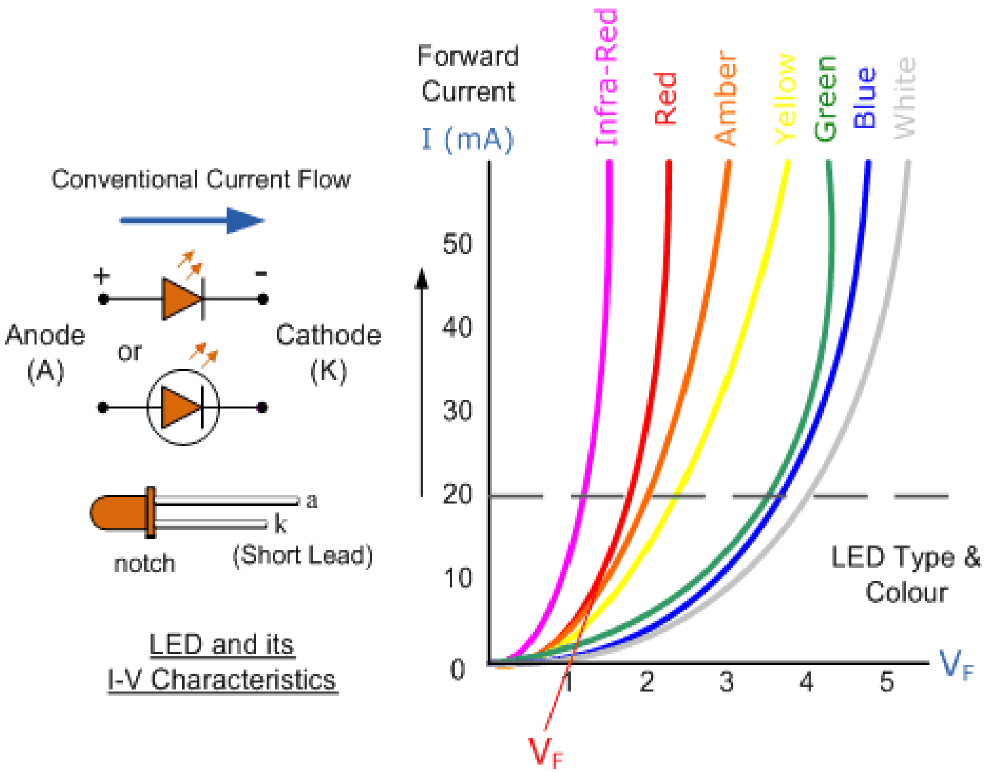
- These LEDs emit one color when forward biased and another when reverse biased
- Comprises of two PN-junctions connected in reverse-parallel mode.
- Usually when forward biased these LEDs emit RED color and when reverse biased they emit GREEN color.
- If these are switched fast between the two polarities then they emit the third color. For example RED and GREEN combination will emit Yellow as third color.







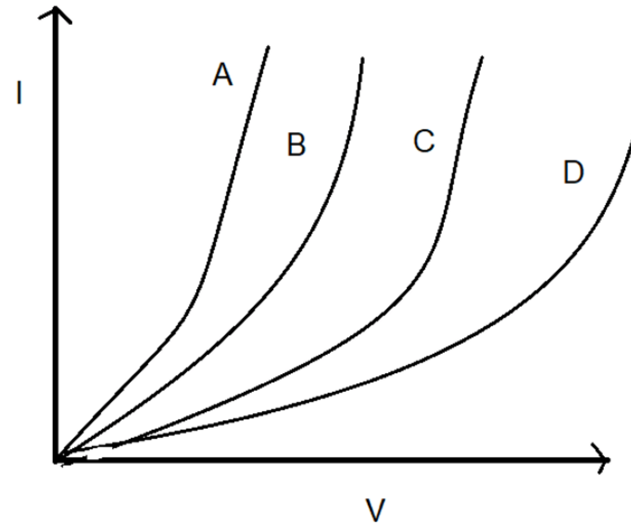
Light Emitting Diodes



Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_F @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
AlGaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

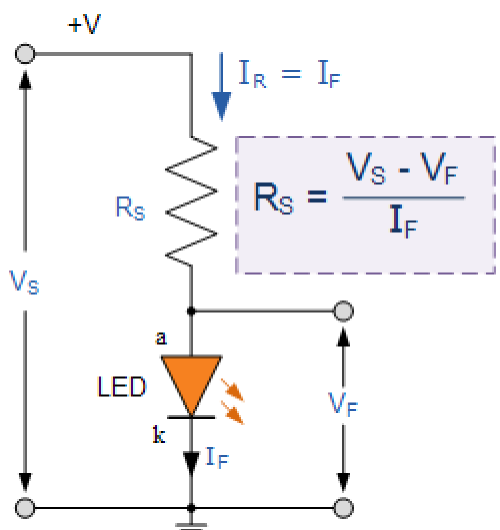
Q1: An LED is fabricated with the material having bandgap of 1.54 eV. Find the Respective Emission wavelength of the LED at the room temperature.

Q2: Which of the following curve would have the highest wavelength?



Q3: Find the current range for which LED will glow.

Q4:



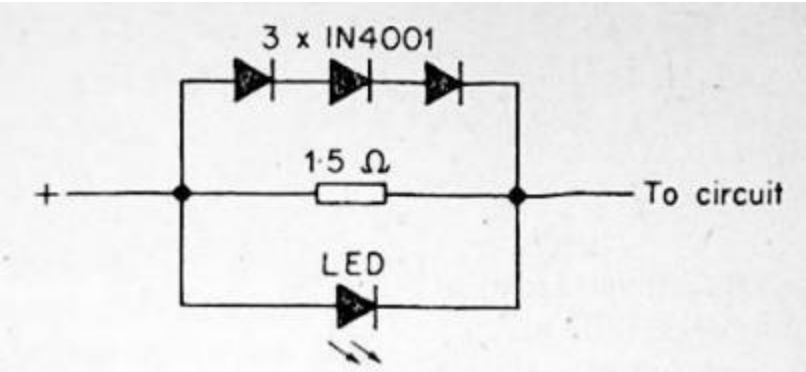
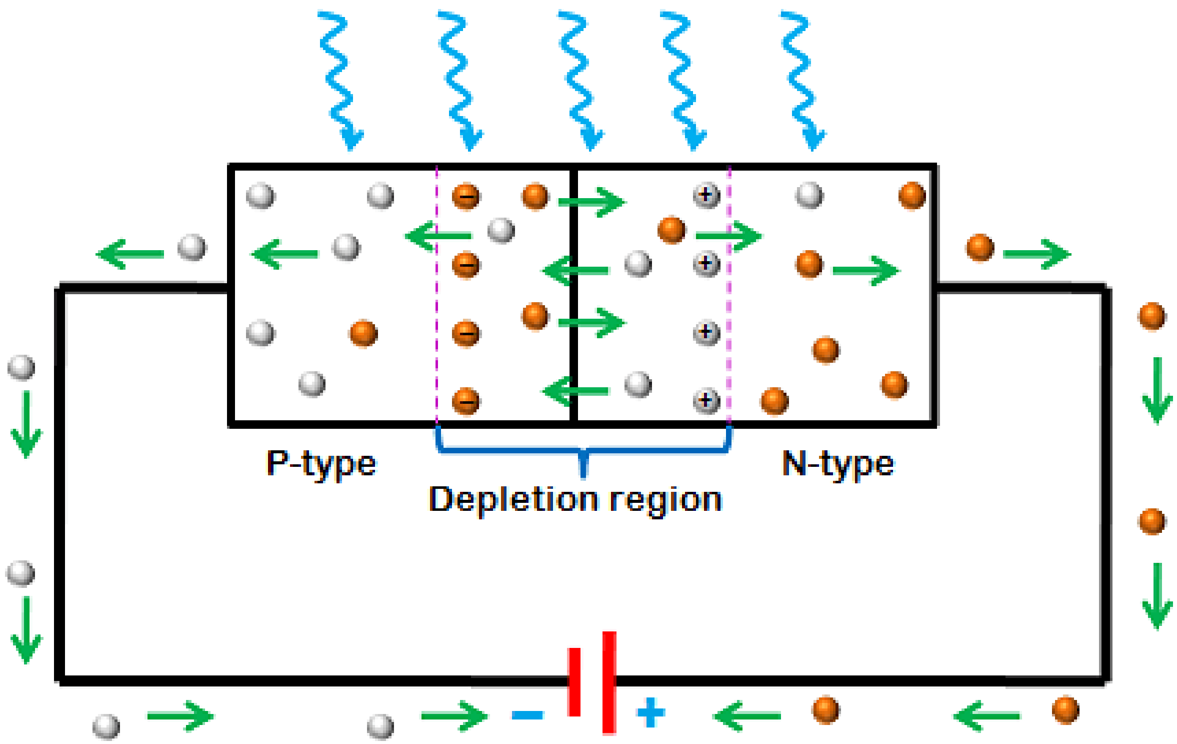
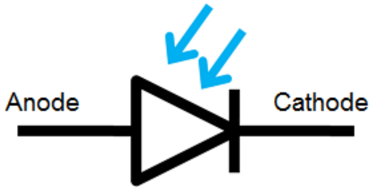


Photo Diodes



PN Junction photodiode



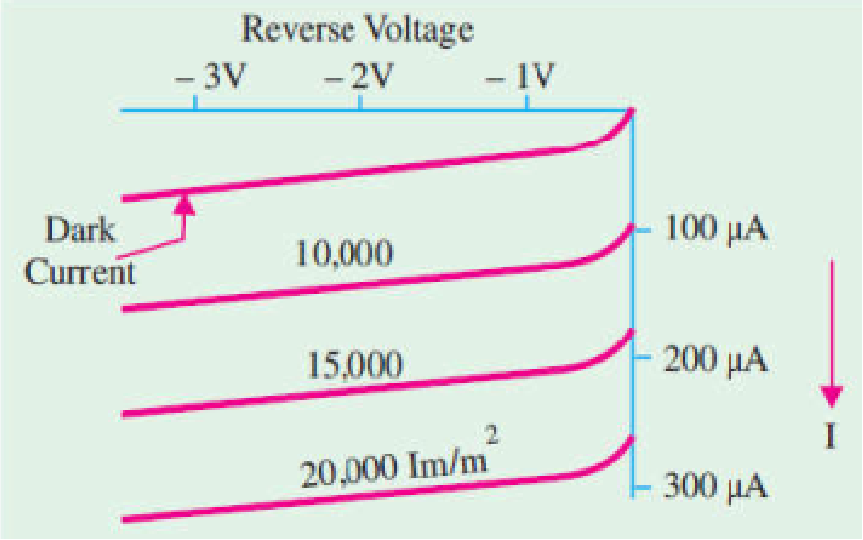
Photodiode symbol

Photo Diodes

❑ The characteristics of a photodiode is shown below. The reverse current increases in direct proportion to the level of illumination.

❑ Even when no light is applied, there is a minimum reverse leakage current called dark current, flowing through the device. Germanium has a higher dark current than silicon

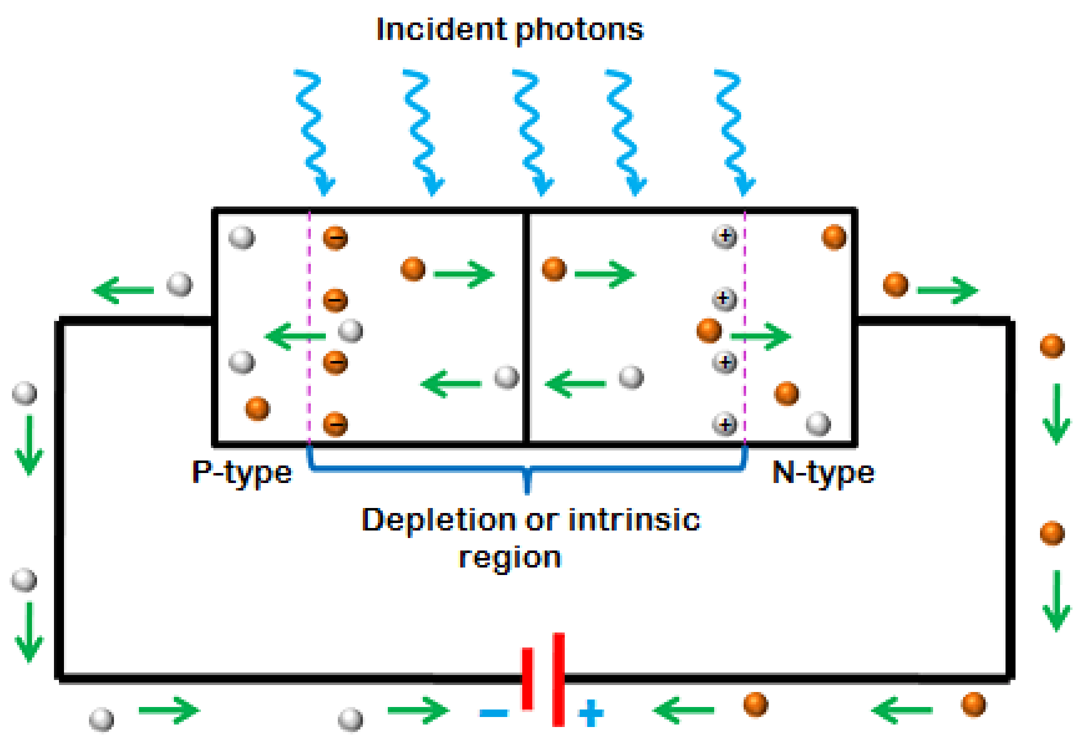
❑ Resistance of Photo-diode when no light falls is called Dark Resistan ce and is given by



$$R_R = \frac{V_R}{\text{Dark current}}$$

$$I_T = I_L + I_0[1 - e^{VB/\eta VT}]$$

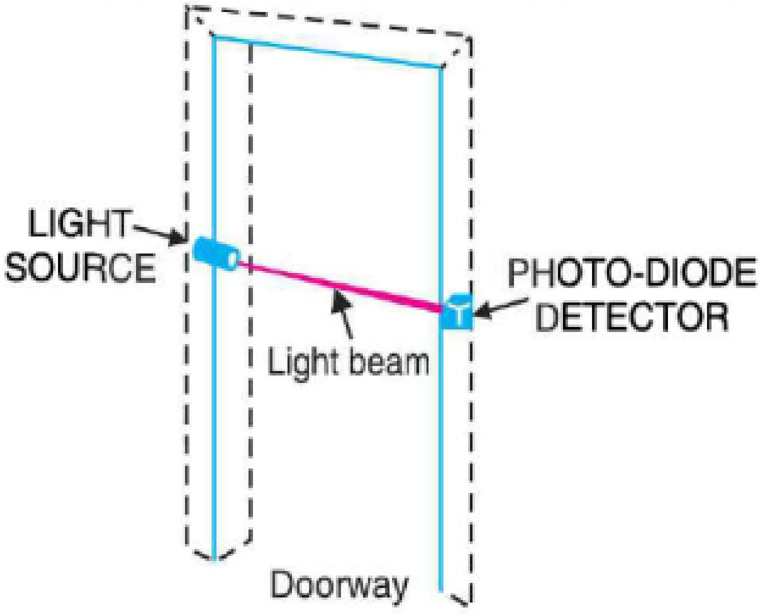
Photo Diodes



PIN photodiode

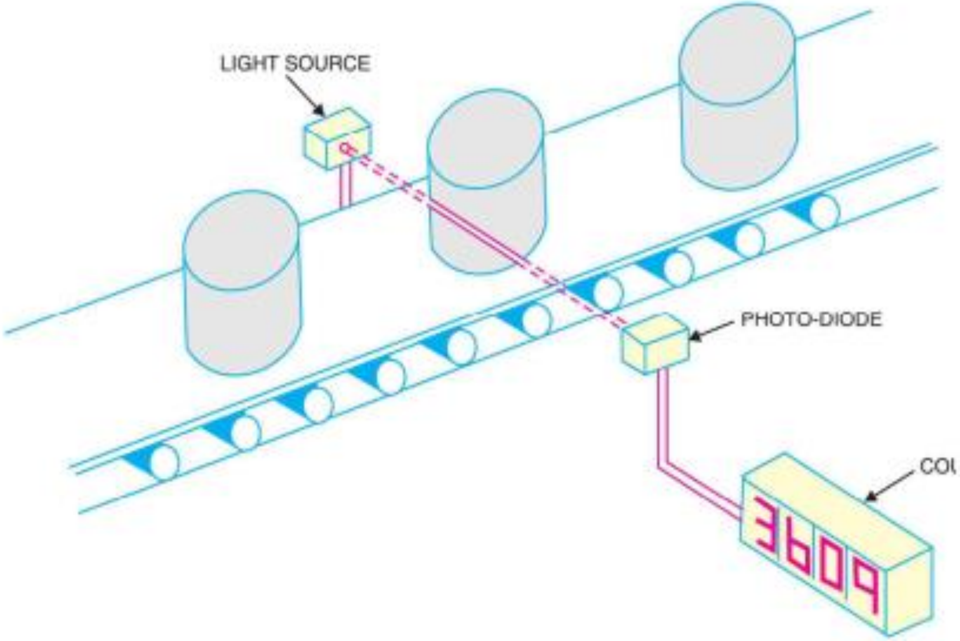
Alarm Circuit

- ❑ Light from a beam is allowed to fall on a photo-diode
- ❑ Reverse current will continue to flow till beam is not broken
- ❑ If a person passes, the beam breaks, the reverse current drops down to the dark current level
- ❑ This can be used to sound an alarm



Counter Circuit

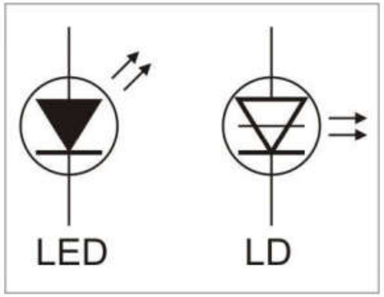
- Source sends a concentrated beam to a photo-diode across a conveyor.
- As the object passes, the beam breaks, the reverse current drops down to the dark current level and the count increases by one.

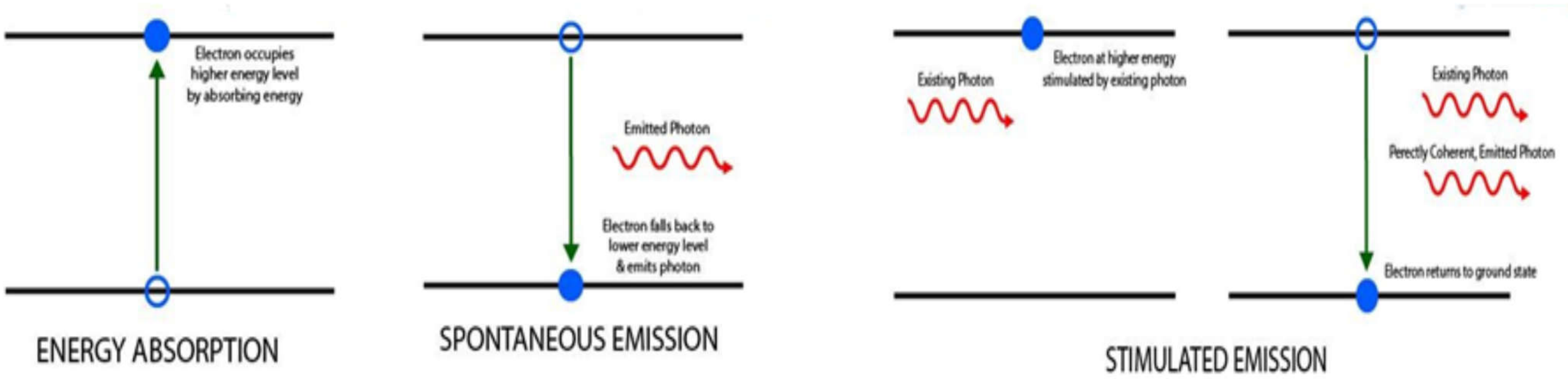


Laser Diodes

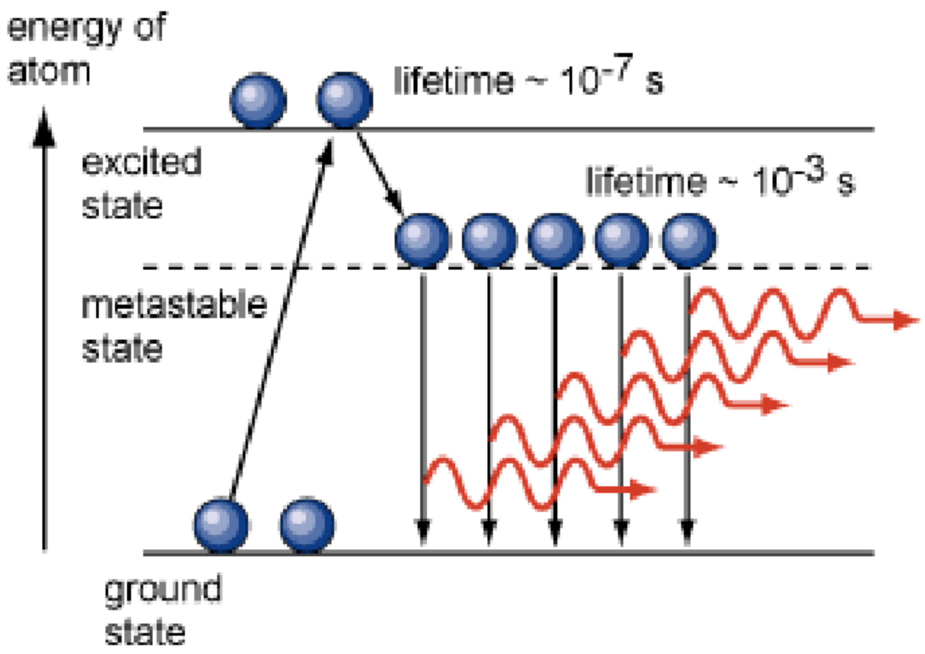
Light Amplification (by) Stimulated Emission (of) Radiation

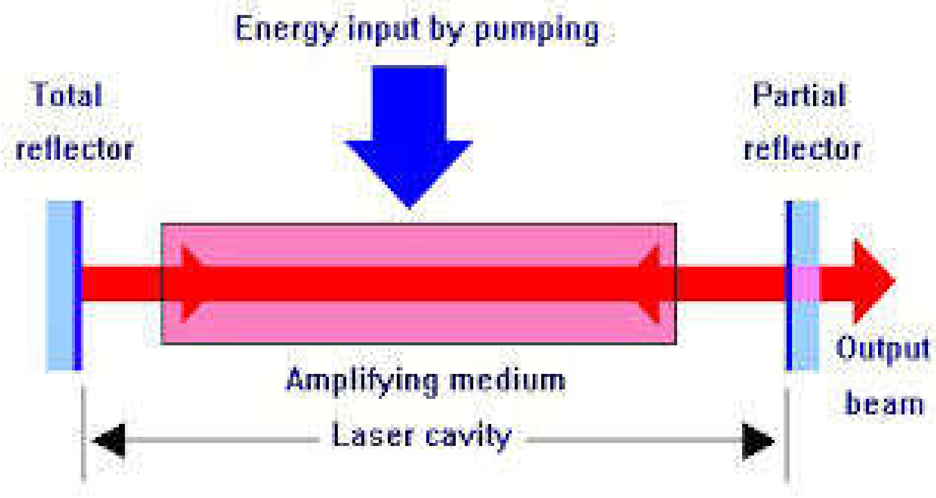
- ❑ Like LEDs, LASER diodes are PN Junction devices used under Forward Bias
- ❑ **Monochromatic :** Emits only one wavelength hence only color.
- ❑ **Collimated :** Emitted light waves travel parallel to each other.
- ❑ **Coherent Radiation :** Transmitted waves are of same frequency and phase in visible or infrared spectrum





Laser Diodes





$$f = n\,(v/2L)$$

Laser Diodes

Laser Diode