Electrical Circuit and Electronics

Semiconductor Diodes

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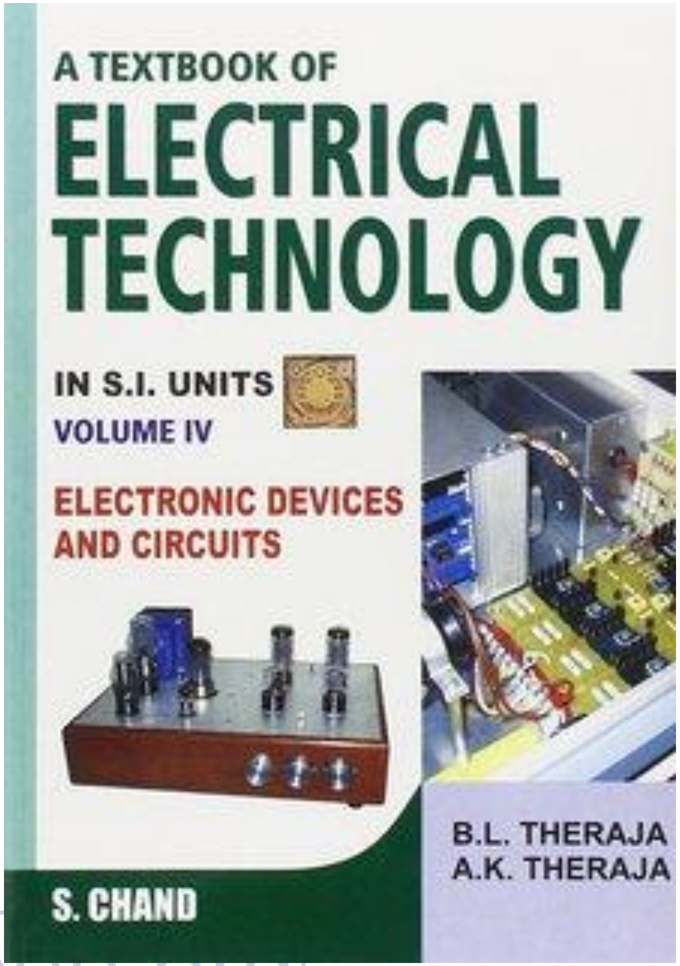
Reference Books Recommended

- **A Textbook of Electrical Technology**

VOLUME: IV

(Electronic Devices and Circuits)

- B. L. Theraja

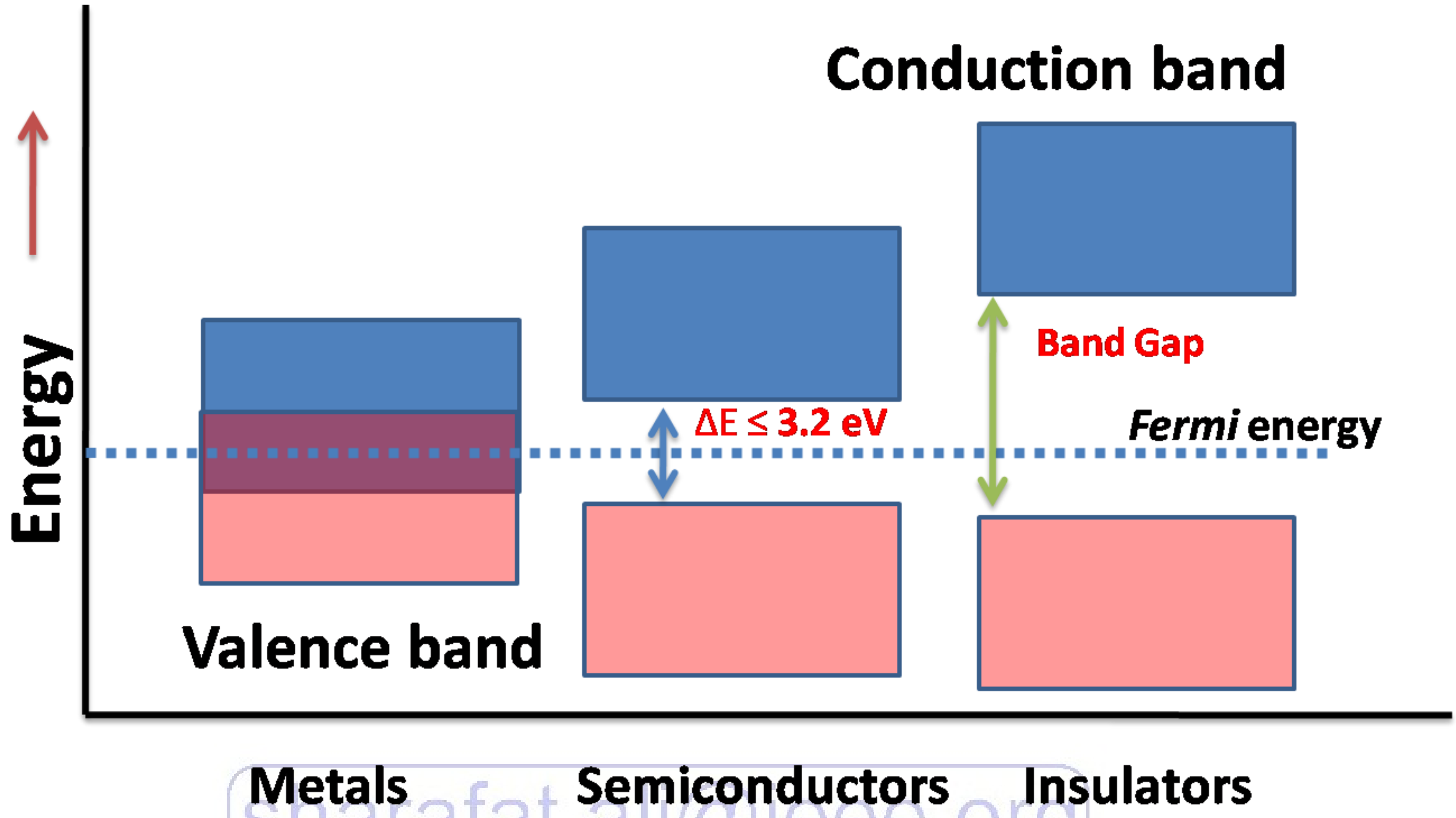


Modern Electronics

Semiconductors

It is a solid substance that has a conductivity between that of an insulator and that of most metals. Such as: Silicon (Si)

Semiconductors

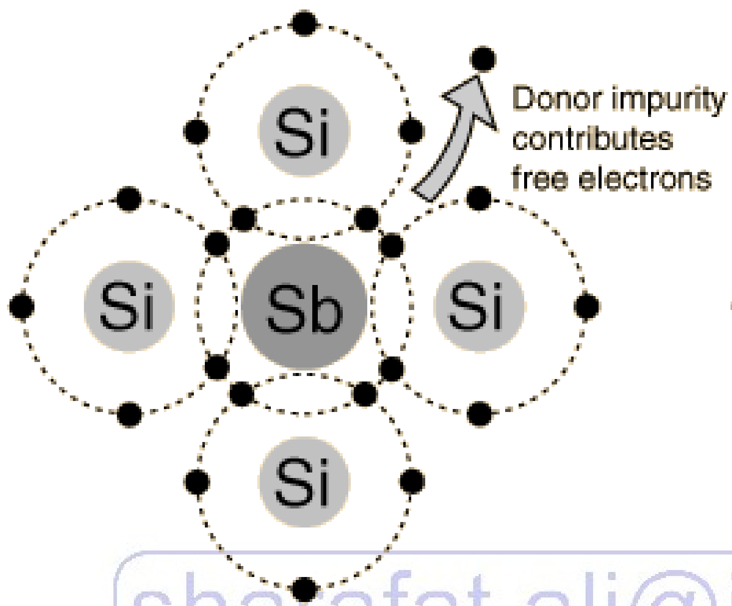


Semiconductors

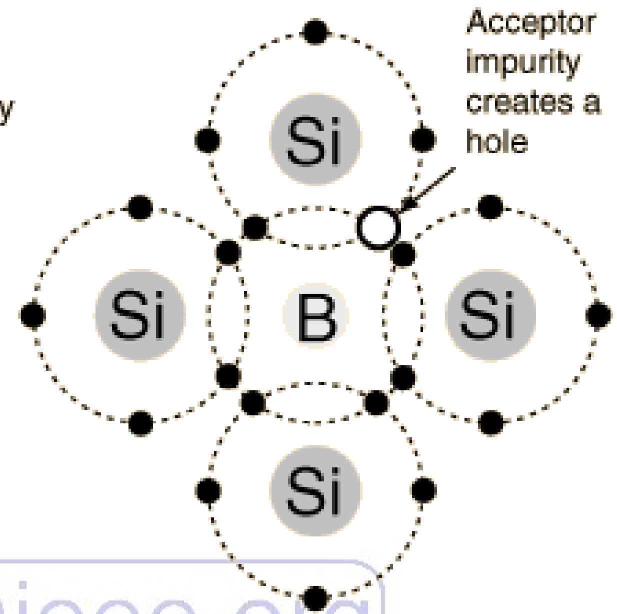
Intrinsic Semiconductors	Extrinsic Semiconductors
Pure materials	Have impurities
Low conductivity	High Conductivity
Number of electrons = Number of holes	Number of electrons ≠ Number of holes
Not used practically usually	Used practically
Fermi energy level lies in the middle of valance band & conduction band	Fermi energy level shifts towards the valance band or conduction band

Extrinsic Semiconductors

- **N type**

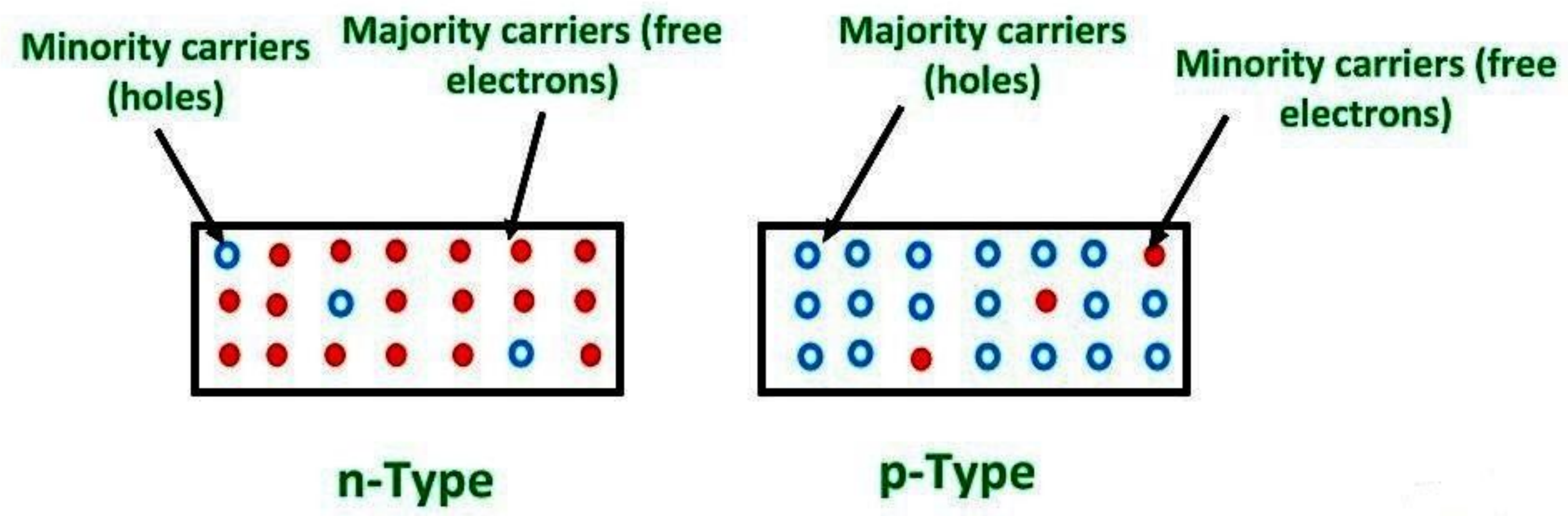


- **P type**



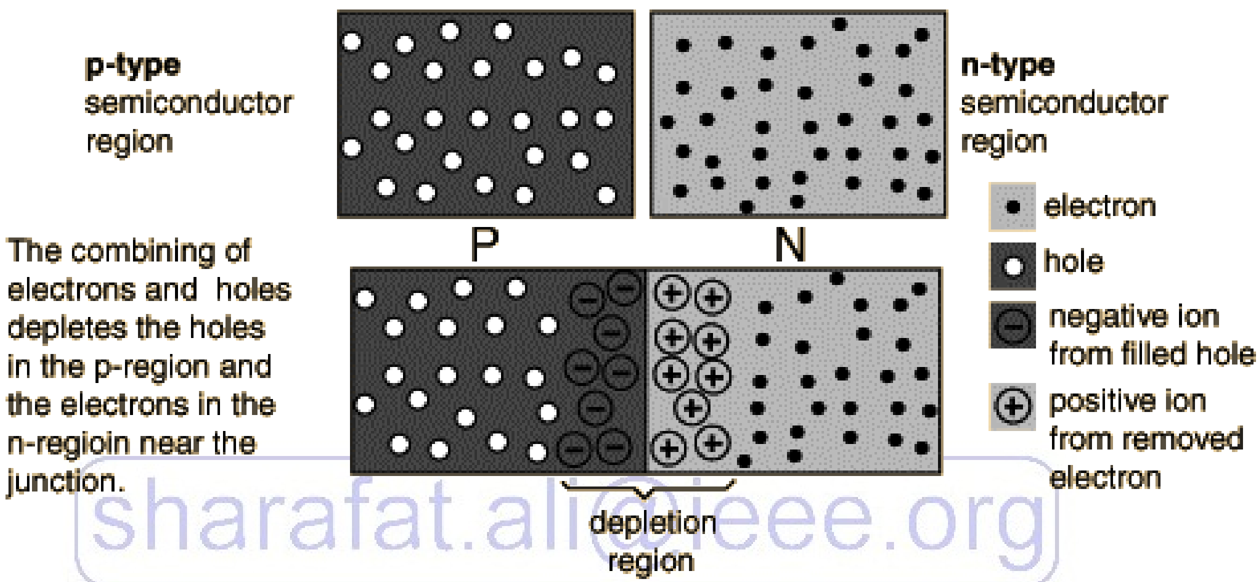
Ref: Theraja: Article 51.23

Majority & Minority Carriers

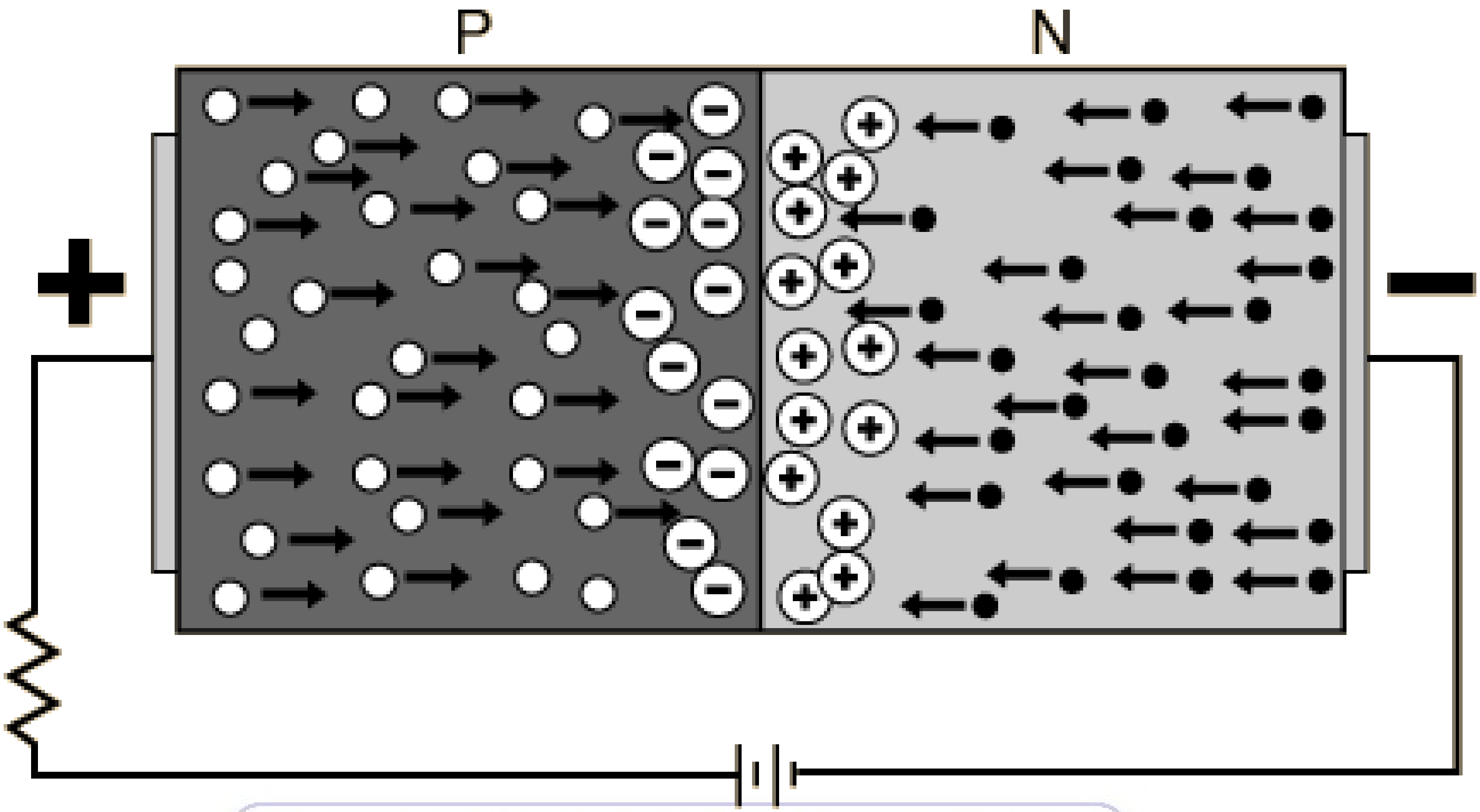


P-N Junction

When one side of an intrinsic semiconductor is doped with acceptor i.e, one side is made p-type by doping with n-type material, a *P-N junction* diode is formed. This is a two terminal device. The *P-N junctions* are formed by joining n-type and p-type semiconductor materials.

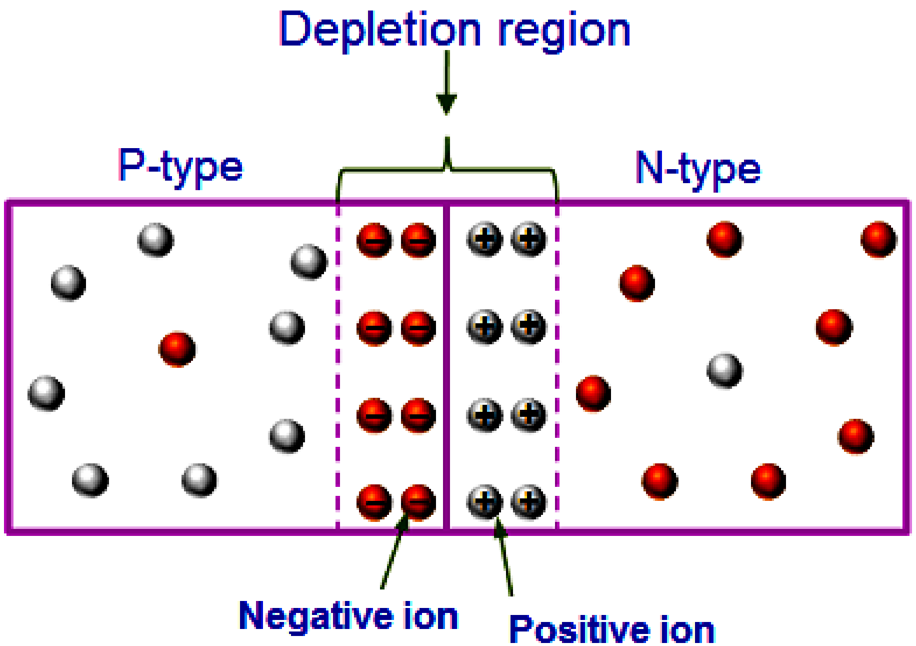


P-N Junction



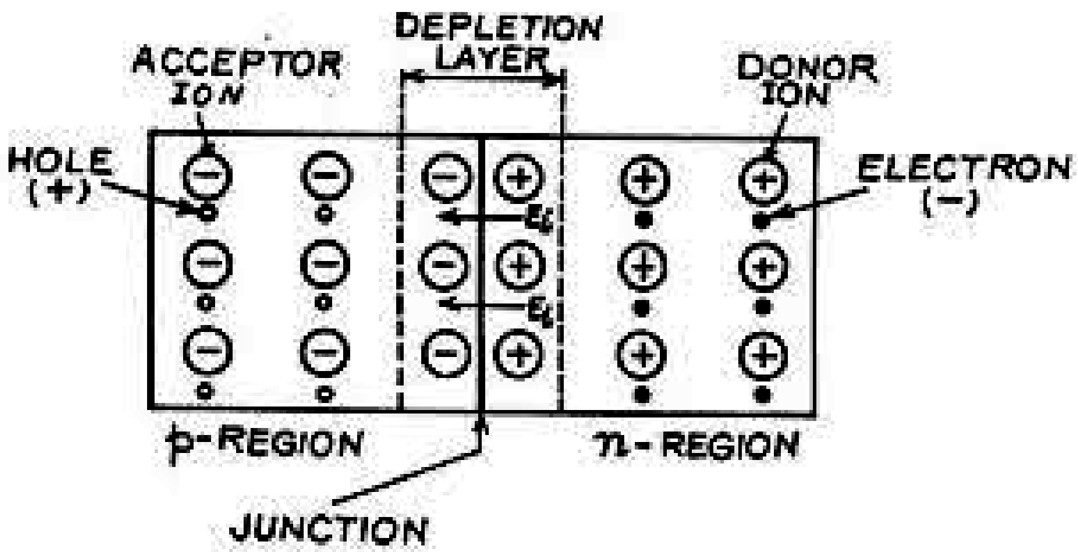
Depletion Region

Depletion region or depletion layer is a region in a P-N junction diode where no mobile charge carriers are present. Depletion layer acts like a barrier that opposes the flow of electrons from n-side and holes from p-side.



Depletion Region

The depletion region is also called as depletion zone, depletion layer, space charge region, or space charge layer. The depletion region acts like a wall between p-type and n-type semiconductor and prevents further flow of free electrons and holes.



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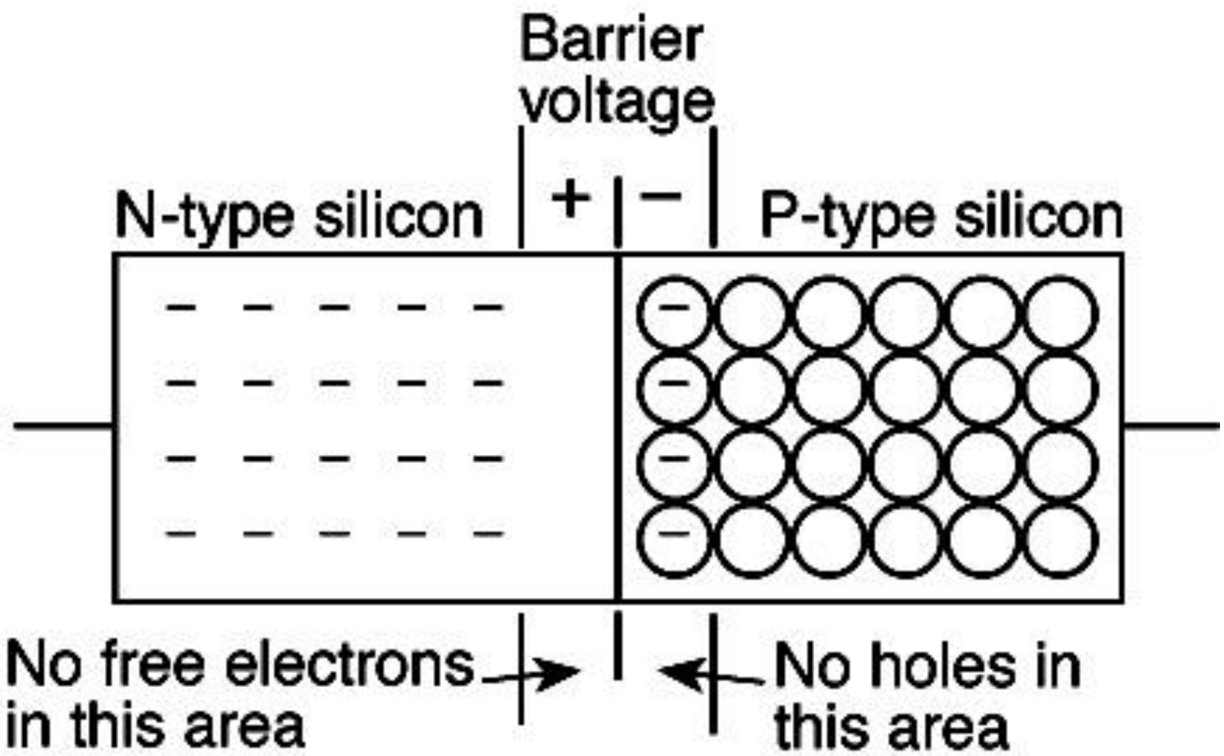
Junction / Barrier Voltage (V_B)

The barrier voltage is the amount of electromotive force required to start current through the P-N junction.



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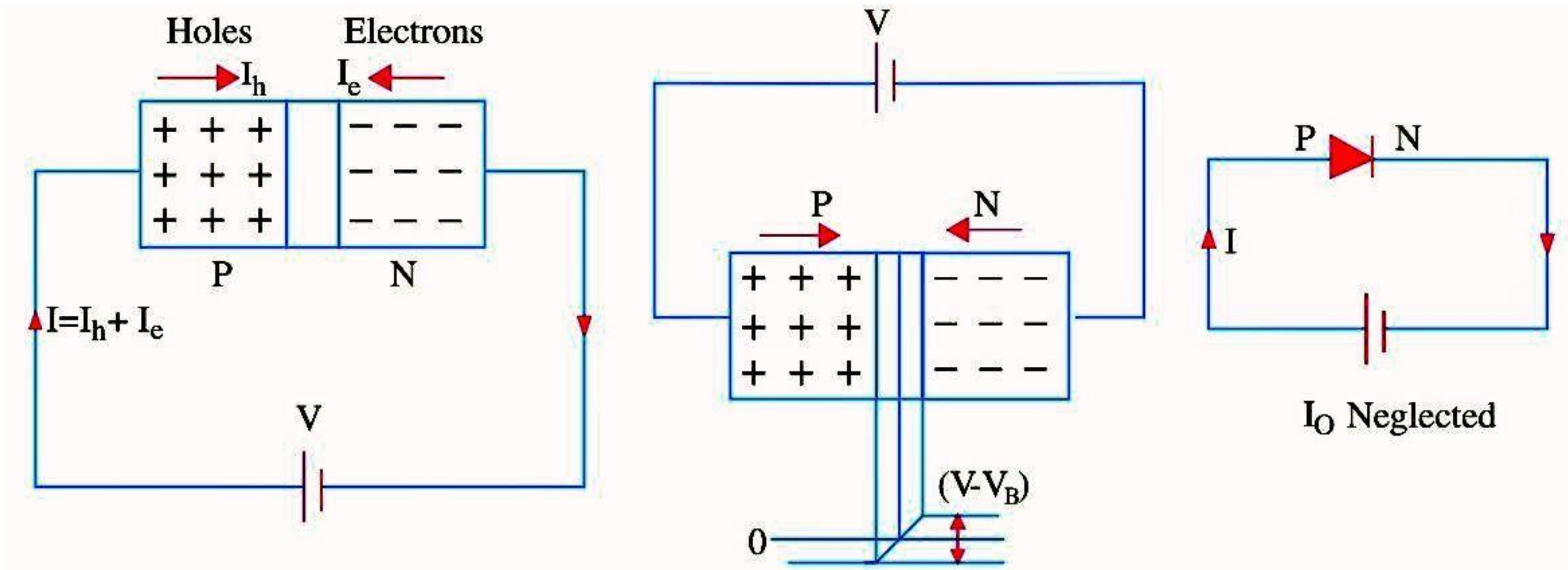
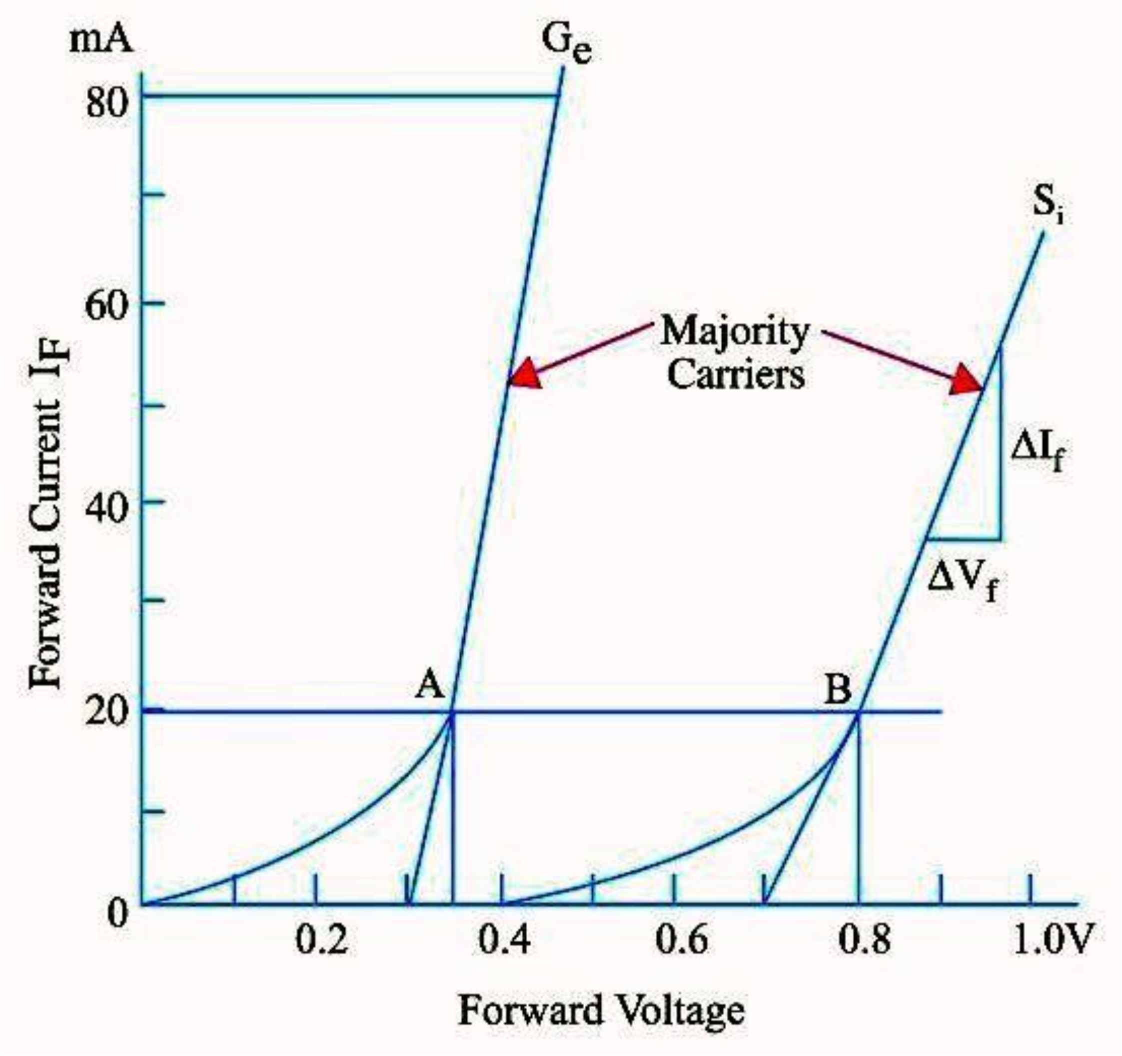
Forward Bias in P-N Junction



Forward V/I Characteristics



Ref: Theraja: Article 51.43: page 2052

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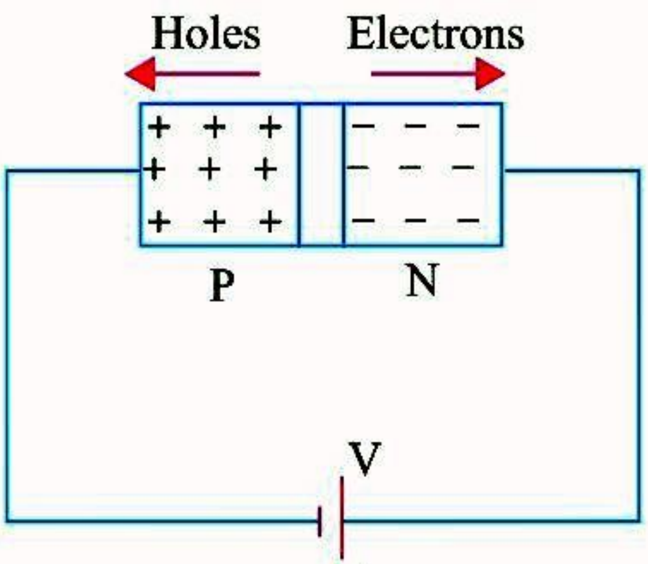
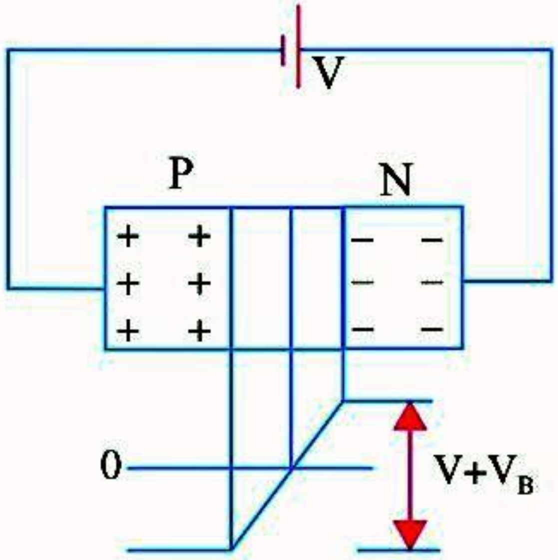
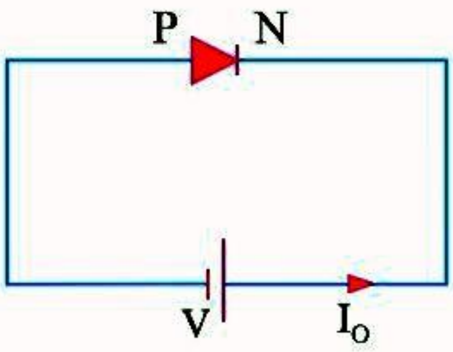
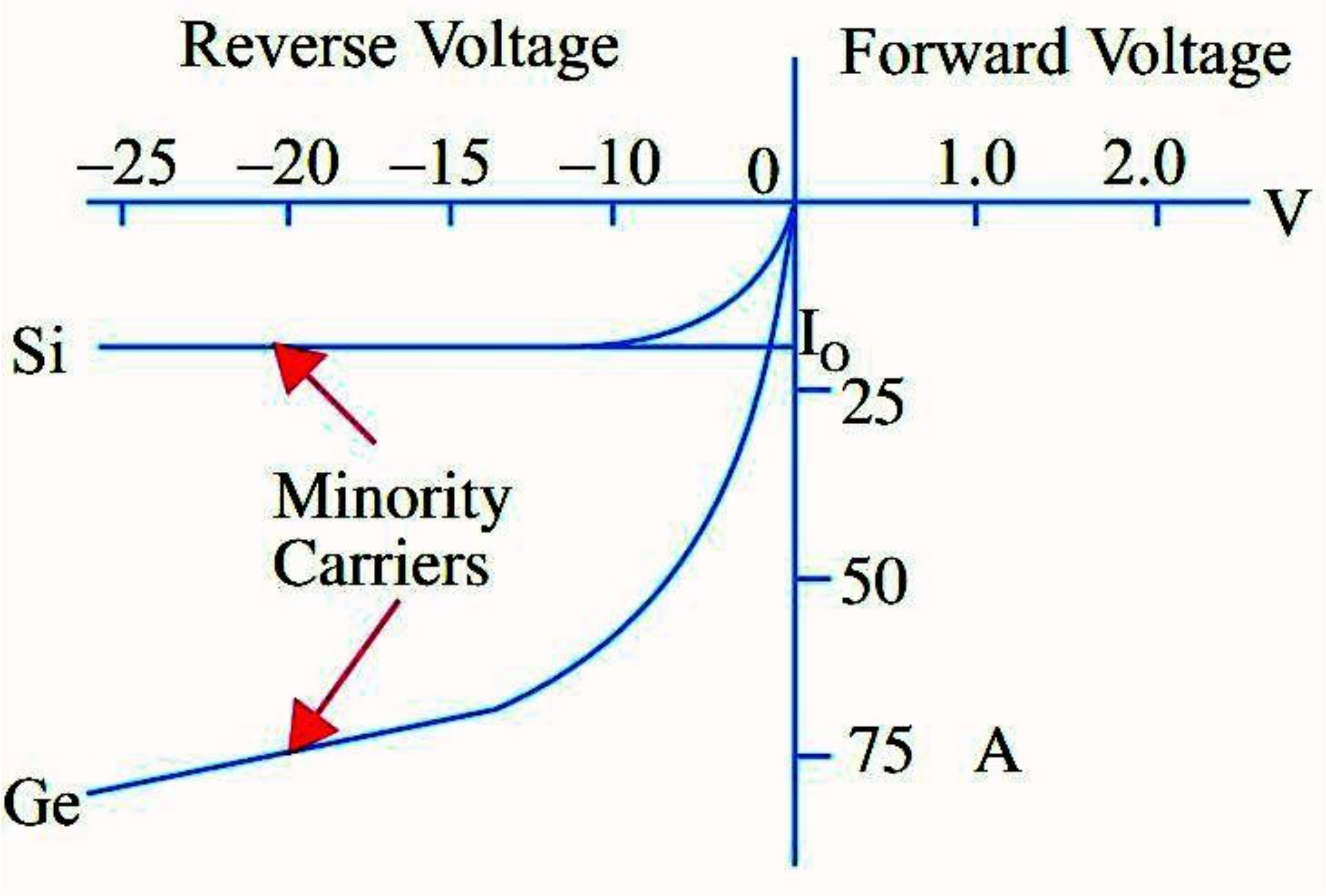
Reverse Bias in P-N Junction







Reverse V/I Characteristics



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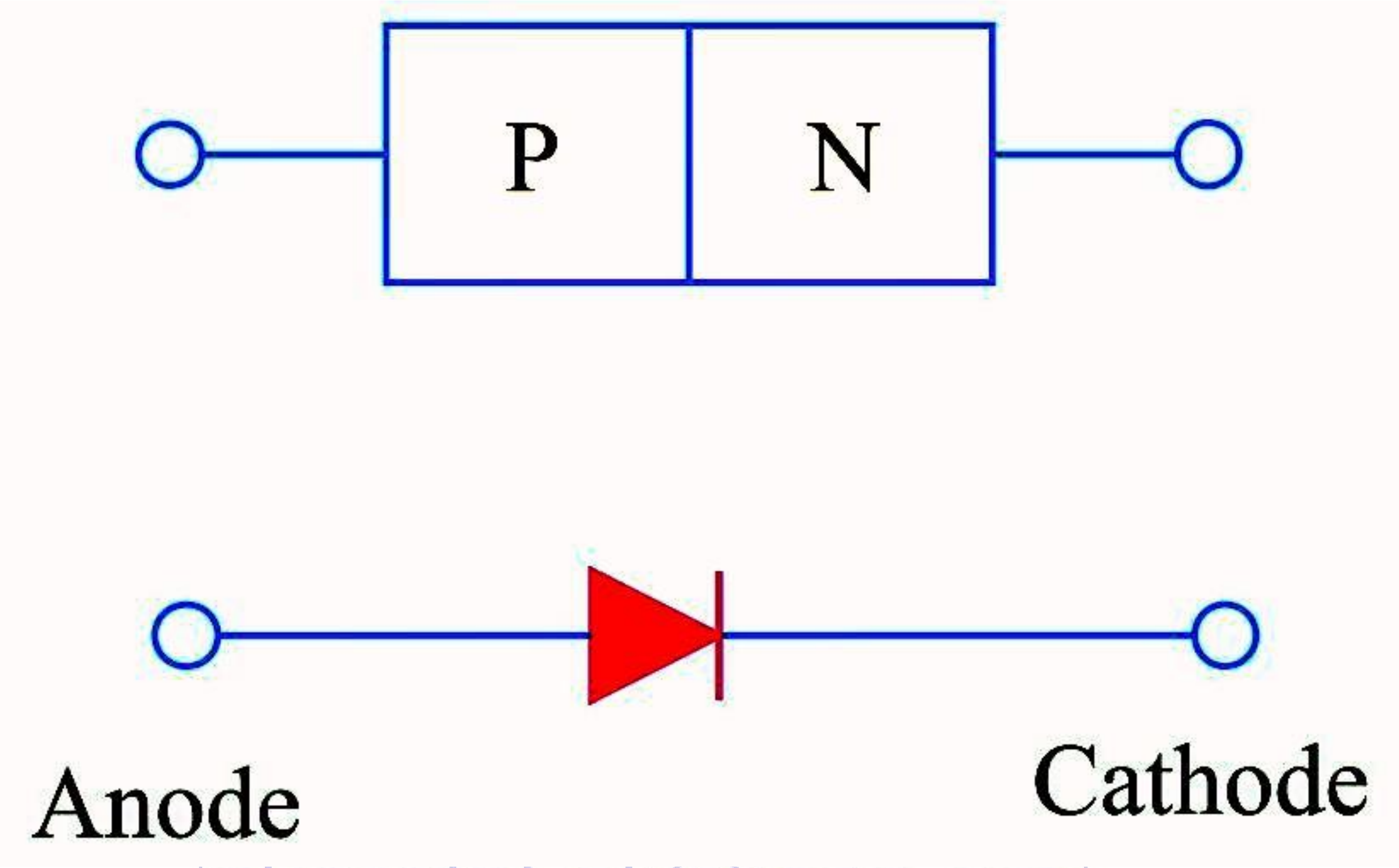
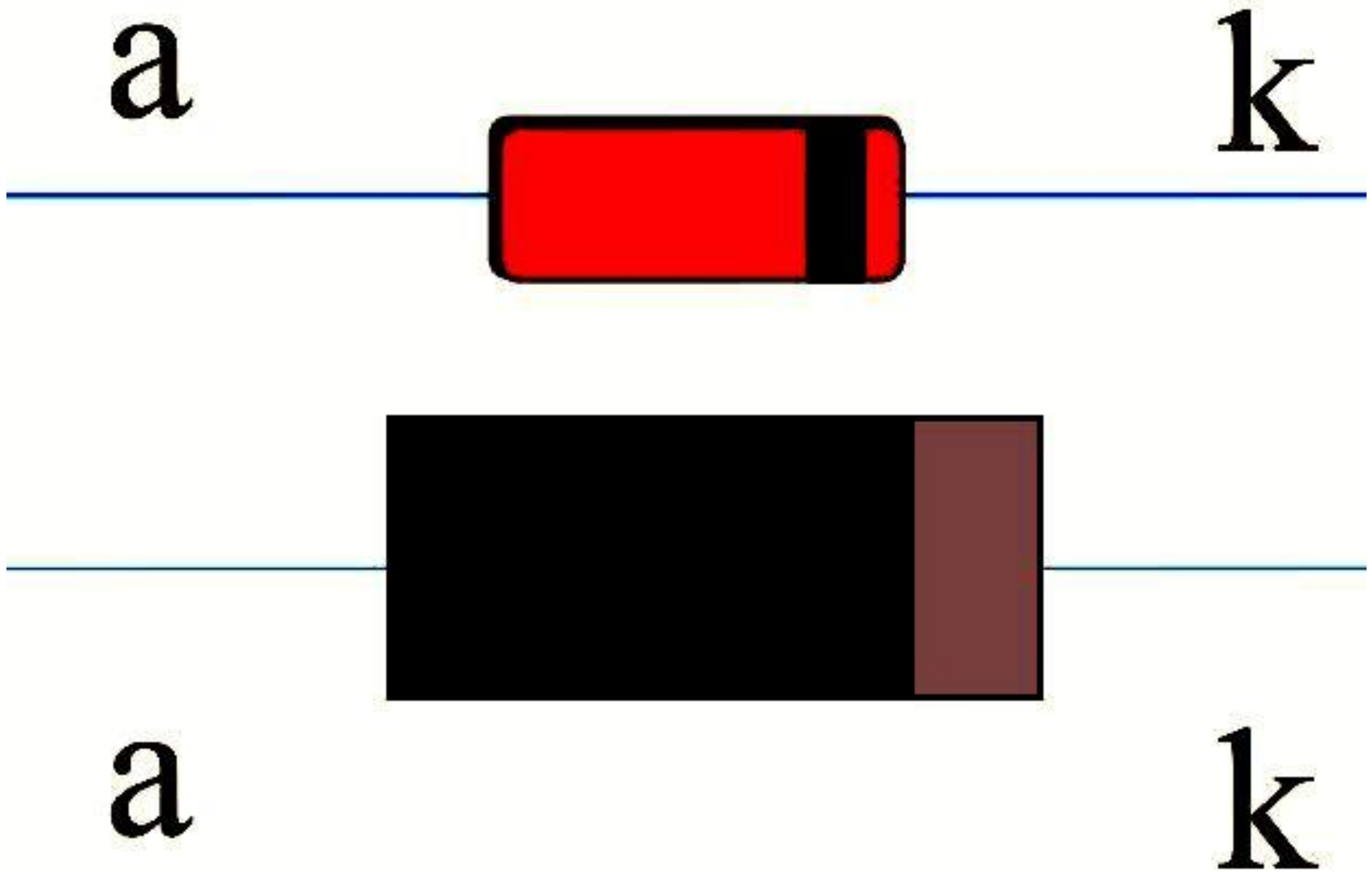
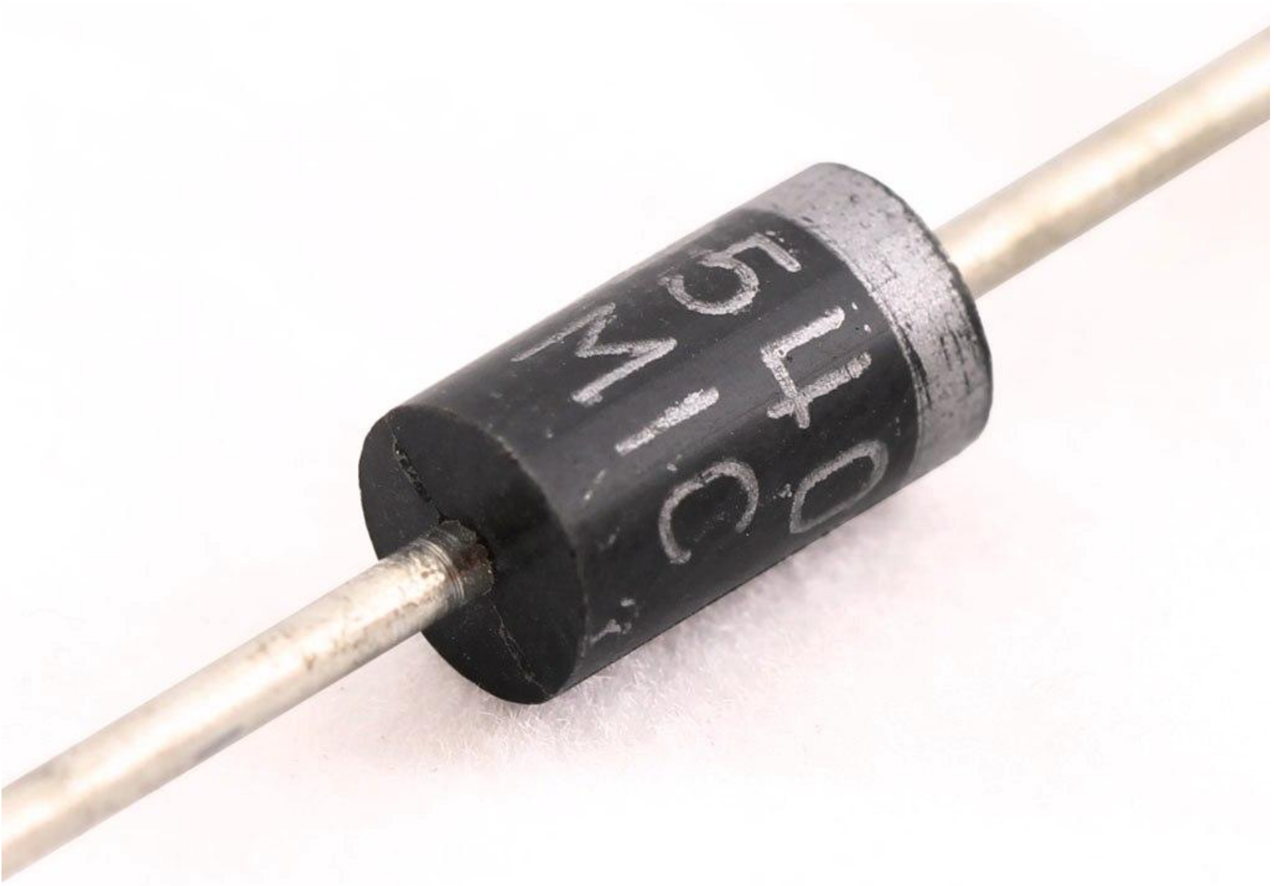
P-N Junction Diode



P-N Junction Diode



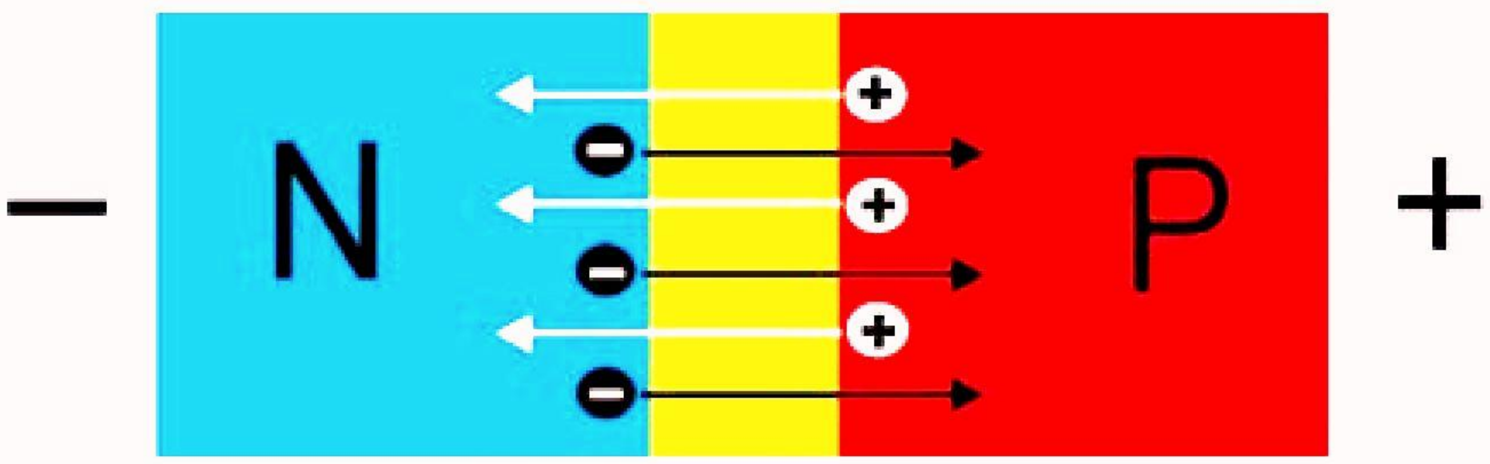
P-N Junction Diode



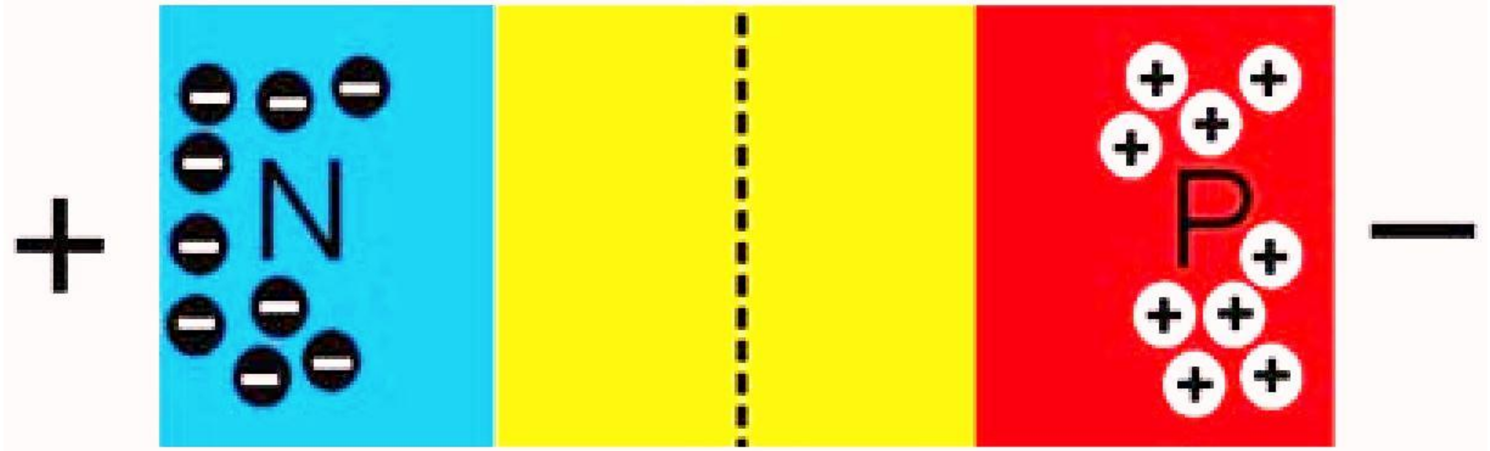
Applications of P-N Junction Diode:

- As power or rectifier diodes. They convert ac current into dc current for dc power supplies of electronic circuits.
- As signal diodes in communication circuits for modulation and demodulation of small signals.
- As Zener diodes in voltage stabilizing circuits.
- As Varactor diodes–for use in voltage-controlled tuning circuits as may be found in radio and TV receivers.
- In logic circuits used in computers.

Forward & Reverse Biased Diode

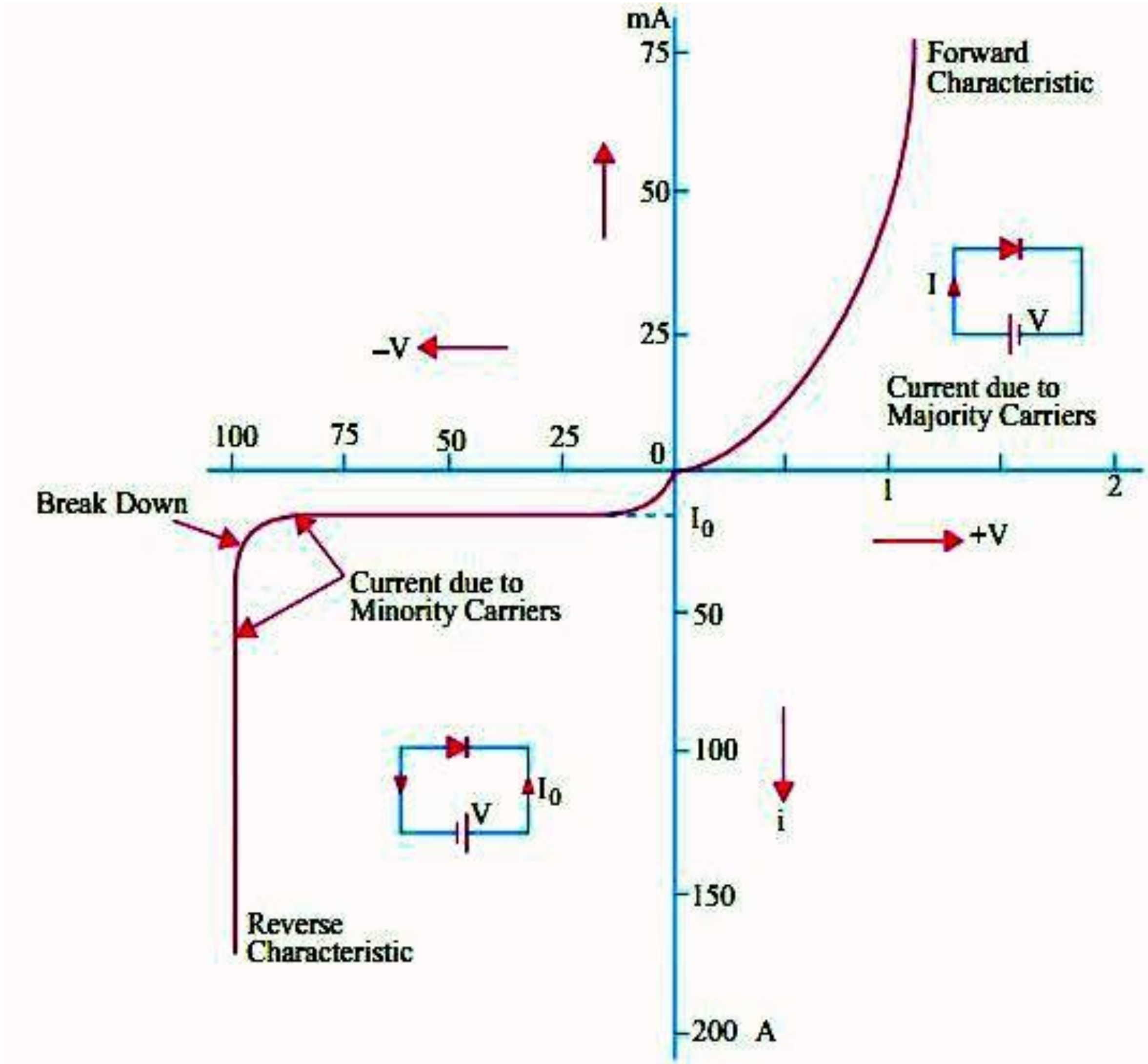


Forward biased diode.



Reverse biased diode.

V/I Characteristic or Static Characteristic



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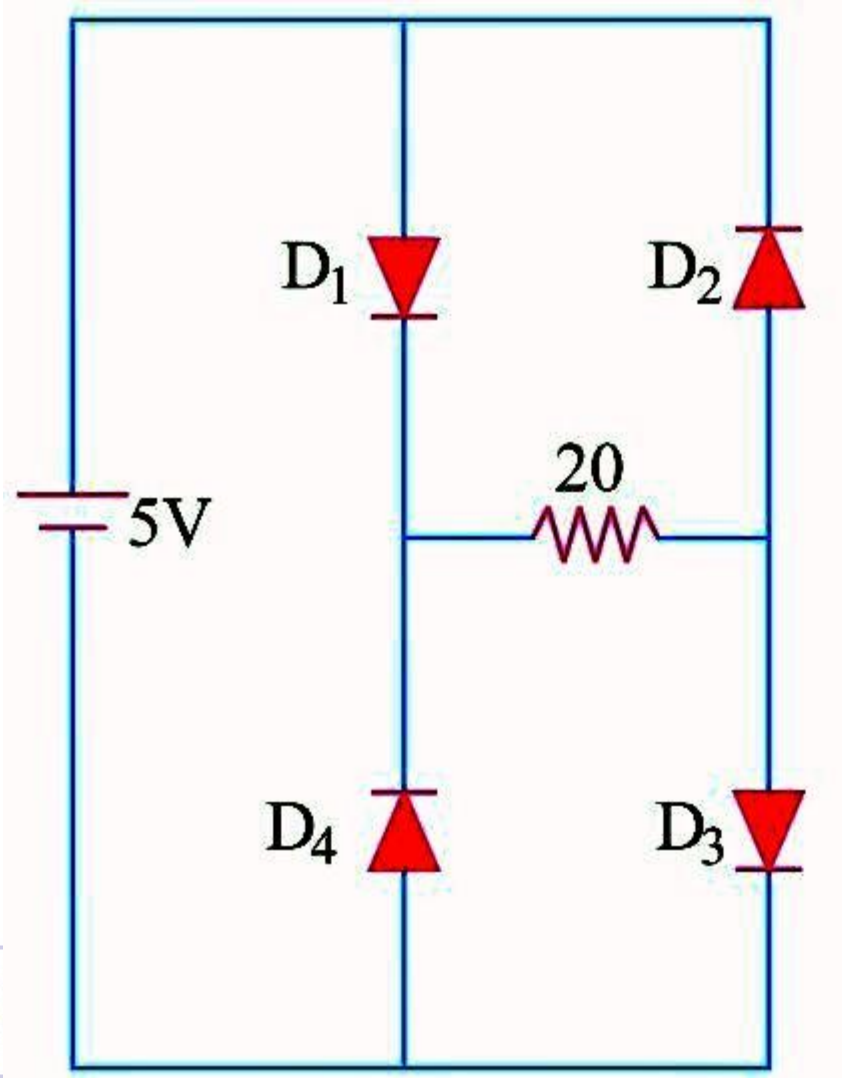
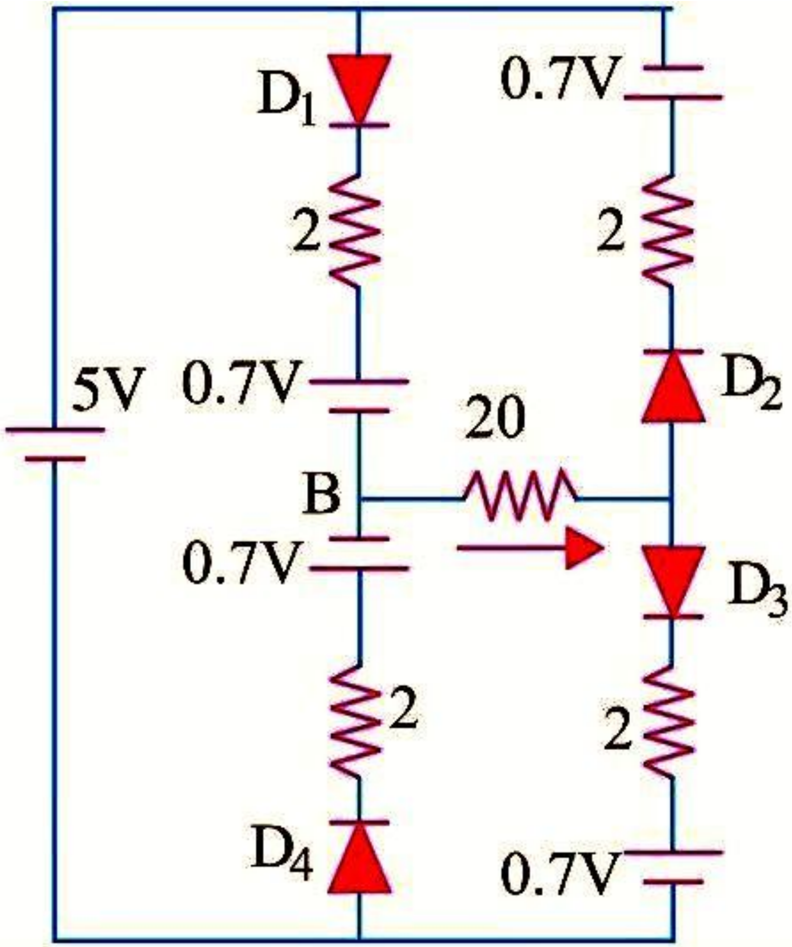
Practice Math Problem

Find the current through the 20 Ω resistor shown in Fig. 52.6 (a). Each silicon diode has a barrier potential of 0.7 V and a dynamic resistance of 2 Ω. Use the diode equivalent circuit technique.



Practice Math Problem

D_1 and D_3 are forward-biased by 5 V battery whereas D_2 and D_4 are reverse-biased



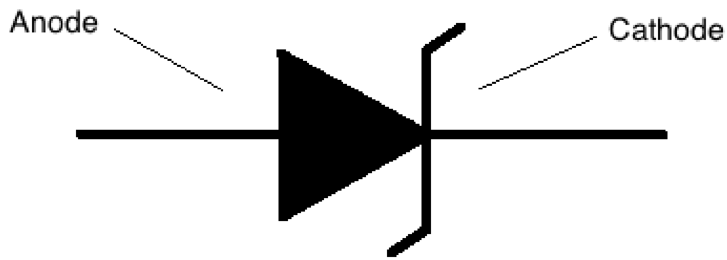
$V_{net} = 5 - 0.7 - 0.7 = 3.6$ V

$R_T = 2 + 20 + 2 = 24\ \Omega$

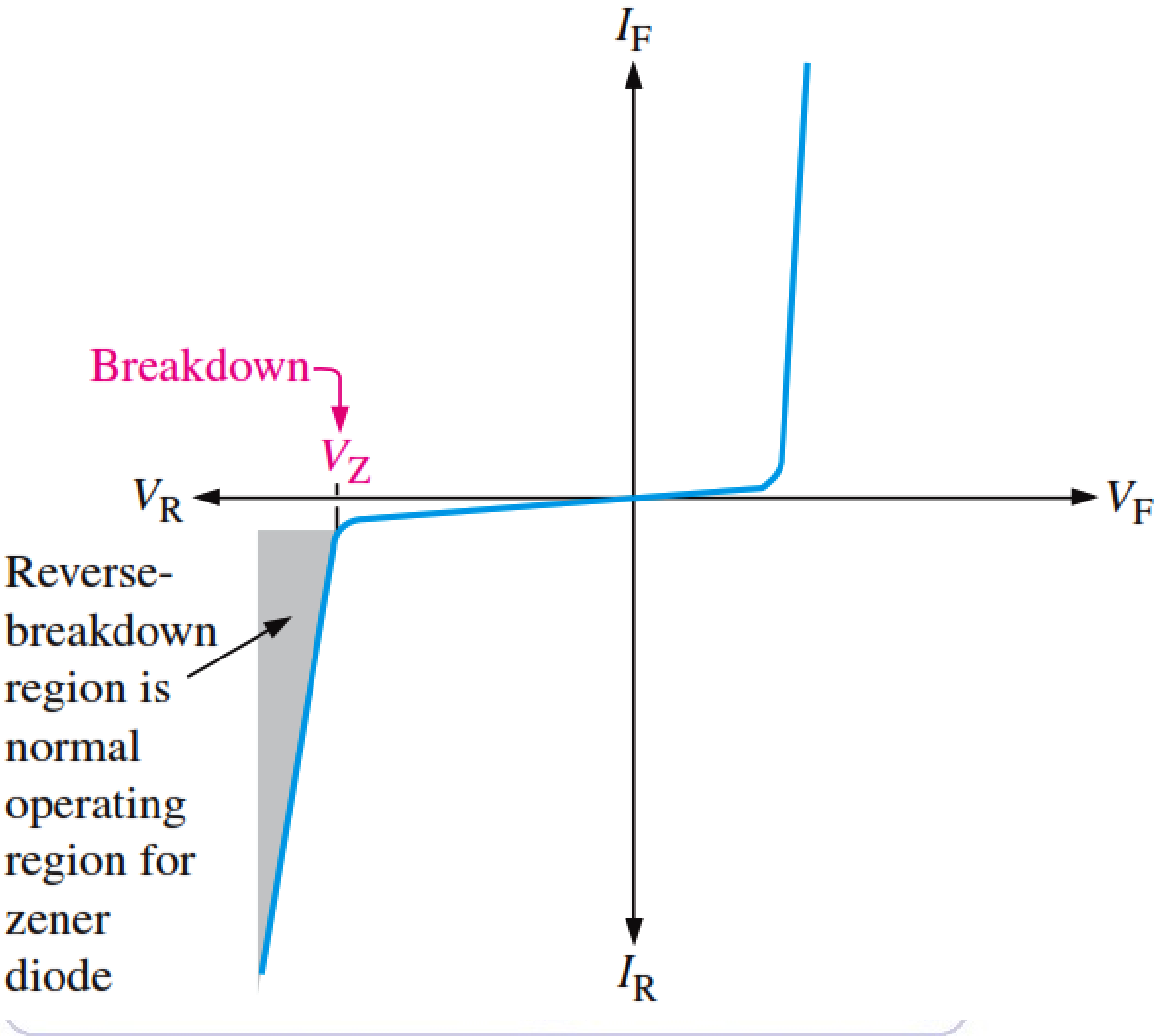
$I = V_{net}/R_T = 3.6/24 = 0.15$ A

Zener Diode

A semiconductor diode in which at a critical reverse voltage a large reverse current can flow.

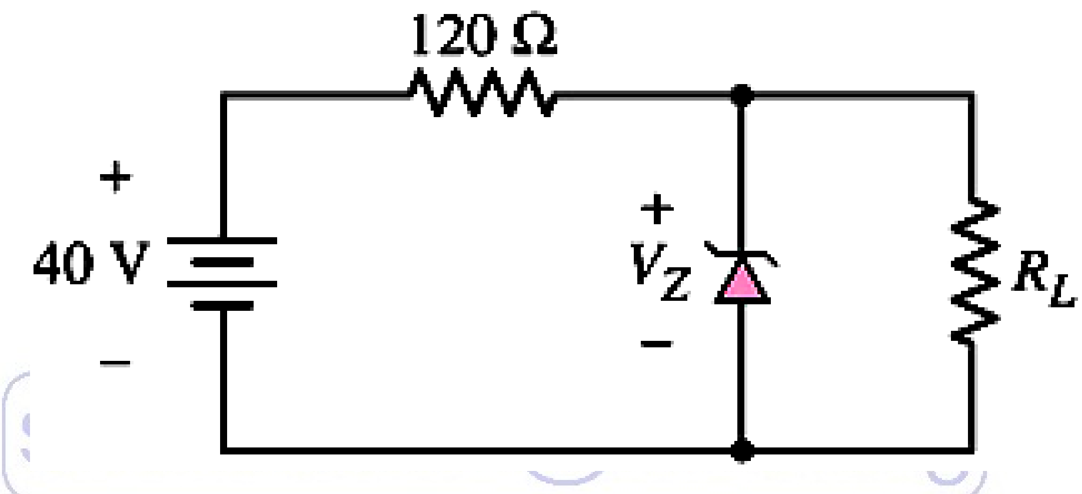


V/I Characteristic of Zener Diode

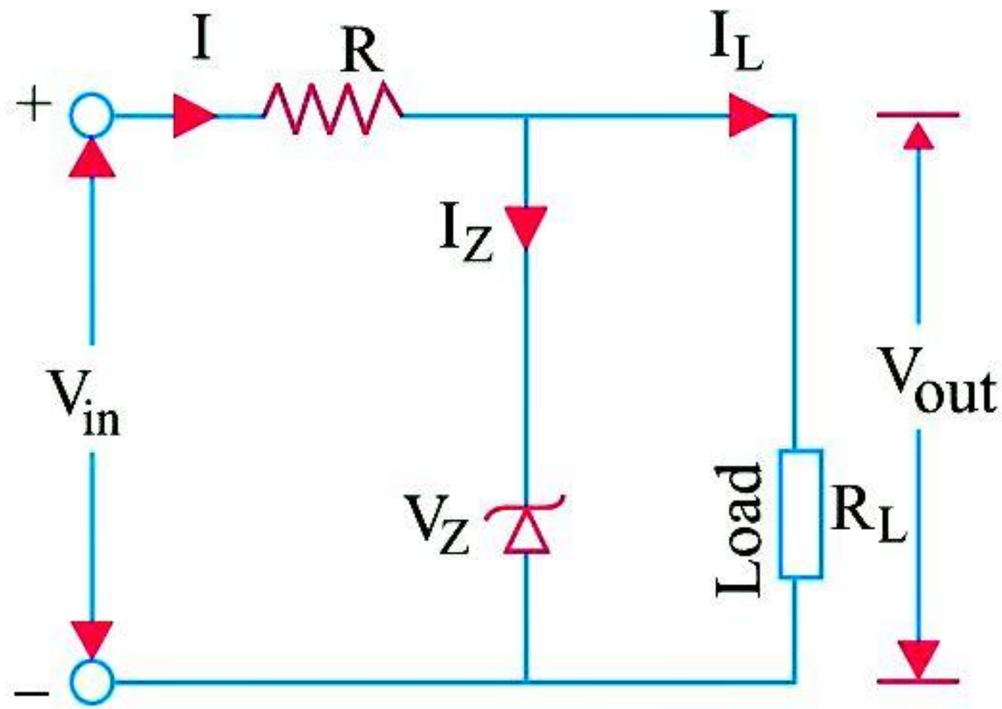


Peak Inverse Voltage (PIV) / Peak Reverse Voltage (PRV):

The maximum reverse biased potential that can be applied before entering the Zener region is called Peak Inverse Voltage (PIV) / Peak Reverse Voltage (PRV).

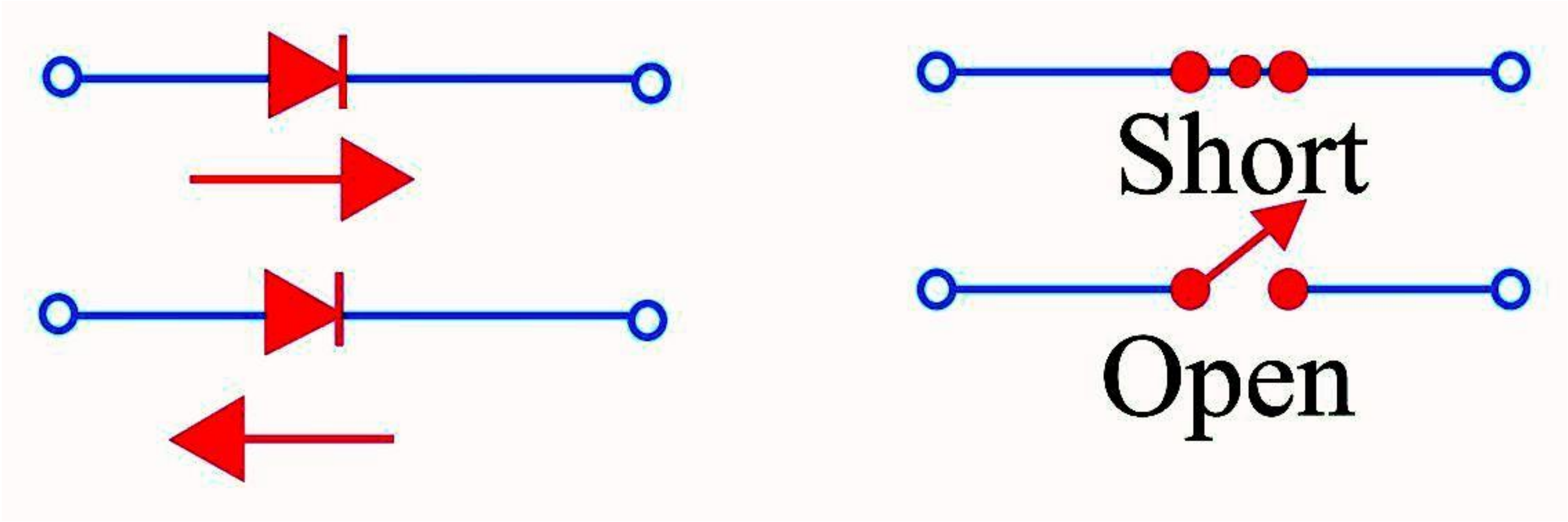


Voltage Regulation using Zener Diode



$$R = \frac{V_{in} - V_{out}}{I_{Zmax}}$$

Ideal Diode



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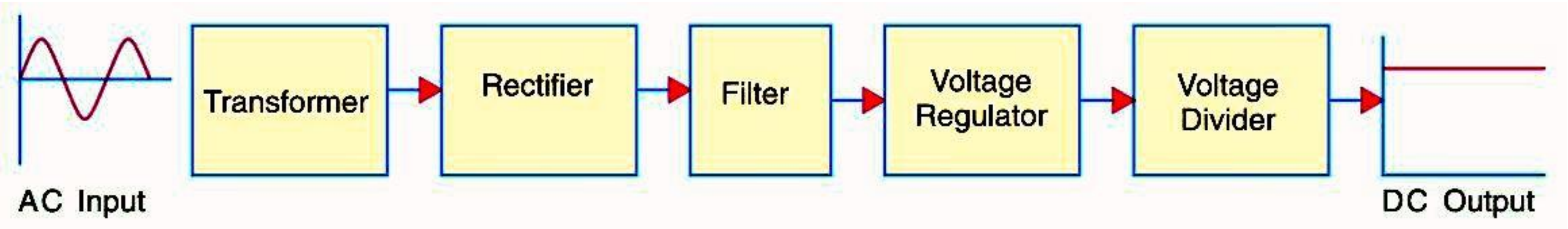
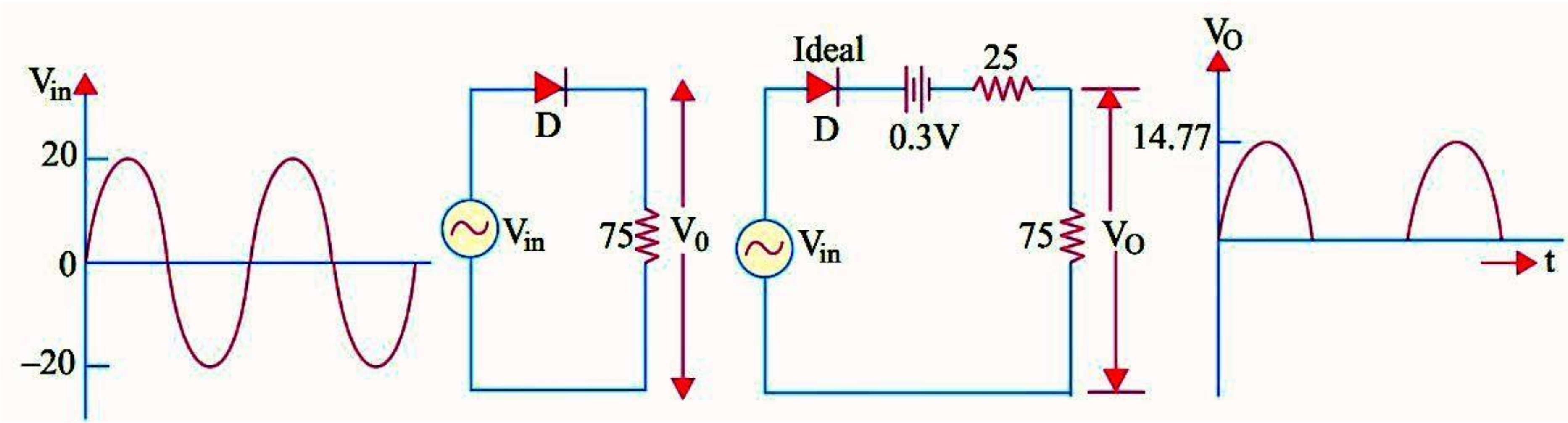
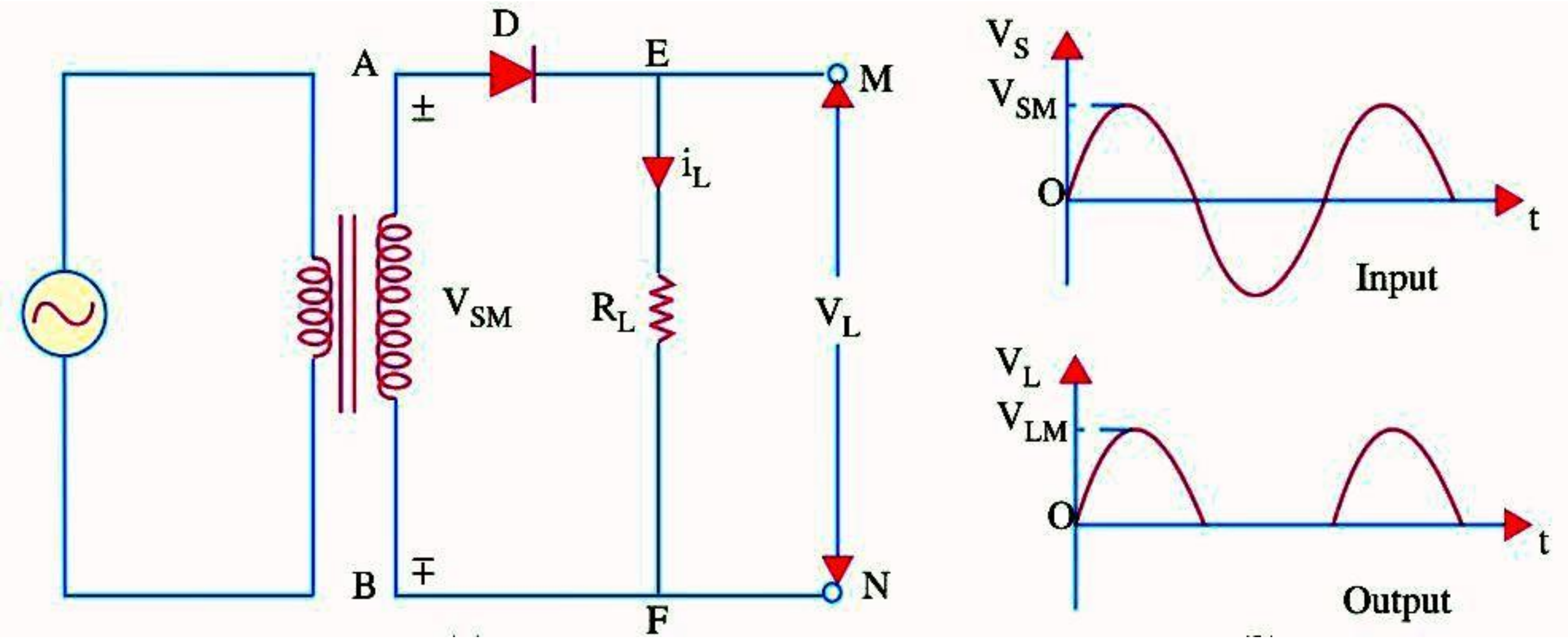
Rectifier


AC Input
Transformer
Rectifier
Filter
Voltage Regulator
Voltage Divider
DC Output

Real Diode



Single Phase Half Wave Rectifier



Single Phase Half Wave Rectifier

- **Average and RMS Values**

V_{sm} = maximum value of transformer secondary voltage
V_s= rms value of secondary voltage
V_{LM} = maximum value of load voltage
= V_{sm} - diode drop - secondary resistance drop
V_L= rms value of load voltage
I_L= rms value of load current
$V_{L(dc)}$ = average value of load voltage
$I_{L(dc)}$ = average value of load current
I_{LM} = maximum value of load current
R_L= load resistance
R_S = transformer secondary resistance
r_d= diode forward resistance
$R_0 = R_S + r_d$

Single Phase Half Wave Rectifier

- **Average and RMS Values**

$I_{LM} = V_{sm} - V_B /(R_S + r_d) + R_L = (V_{sm} - V_B) / (R_0 + R_L)$

$V_{LM} = I_{LM} \,.\, R_L$

$V_{L(dc)} = V_{LM}/\pi = 0.318V_{LM}$

$I_{L(dc)} = I_{LM}/\pi = 0.318I_{LM}$

$I_L = 0.5I_{LM} = 0.5V_{LM}/R_L$

Single Phase Half Wave Rectifier

- **Efficiency**

$\eta = P_{dc}/P_{in}$ = power in the load/input power

$P_{dc} = I_{L(dc)}^{2}R_L = (I_{LM}/\pi)^2.R_L = I_{LM}^{2}.R_L/\pi^2$

$P_{in} = I_L^2 (R_L + R_0) = (I_{LM}/2)^2 (R_L + R_0) = I_{LM}^2 (R_L + R_0)/4$

$\eta = P_{dc}/P_{in} = (4/\pi^2)R_L/(R_L + R_0) = 0.406/(1+ R_0/R_L)$

(I_L = rms value of load current)

If R_0 is neglected h = 40.6%. Obviously, it is the maximum possible efficiency of a half-wave rectifier.

Single Phase Half Wave Rectifier

- **Frequency Components of H.W. Rectified Voltage and Current**

The rms (or effective) value of the total load current is given by:

$I_L = \sqrt{I_{L(dc)}^2 + I_{L(ac)}^2} = \sqrt{I_{L(dc)}^2 + (I_{L1}^2 + I_{L2}^2 + I_{L3}^2 + \ldots\ldots..)}$

The rms (or effective) value of entire load voltage is given by:

$V = \sqrt{V_{L(dc)}^2 + V_{L(ac)}^2} = \sqrt{V_{L(dc)} + V_{L1}^2 + V_{L2}^2 + V_{L3}^2 + \ldots\ldots}$

Single Phase Half Wave Rectifier

- **Ripple Factor**

γ = rms value of ac component/dc value of load voltage = $V_{L(ac)}/V_{L(dc)} = V_{r(rms)}/V_{L(dc)}$

γ = rms value of ac component/dc value of load current

$= I_{L(ac)}/I_{L(dc)}$

We know, $I_{L(ac)} = \sqrt{I_L^2 - I_{L(dc)}^2}$

$\gamma = I_{L(ac)}/I_{L(dc)} = \sqrt{I_L^2 - I_{L(dc)}^2}/I_{L(dc)} = \sqrt{(I_L/I_{L(dc)})^2 - 1}$

Again, $I_L/I_{L(dc)}$ = form factor K_f

Thus, $\gamma = \sqrt{K_f^2 - 1}$ (In this case of Half-Wave rectifies with resistive load but no filter $K_f = \pi/2 = 1.57$)

$\gamma = \sqrt{1.57^2 - 1} = 1.21$

Ref: Theraja: Example 55.5: page 2132

Single Phase Half Wave Rectifier

- **Peak Inverse Voltage (PIV)**

It is the maximum voltage that occurs across the rectifying diode *in the reverse direction*.

$$PIV = V_{SM}$$

- **Transformer Utilization Factor (TUF)**

TUF = dc power delivered to the load /ac rating of transformer secondary

$= P_{dc}/P_{ac.rated}$

$= P_{dc}/P_{in.rated}$

Single Phase Half Wave Rectifier

- **Transformer Utilization Factor (TUF)**

Now, $P_{dc} = V_{L(dc)} . I_{L(dc)}$

$= V_{LM}/\pi \cdot VLM/R_L$

$= V_{LM}^2 / \pi R_L$

$= V_{sm}^2 / \pi R_L$; if drop over R_0 is neglected

Again, $P_{ac.rated} = V_{sm}/\sqrt{2} . I_{LM}/2$

$= V_{sm}/\sqrt{2} \cdot V_{LM}/2R_L$

$= V_{sm}/2\sqrt{2}R_L$

Thus, TUF $= (V_{sm}^2/\pi R_L)/(V_{sm}^2/2\sqrt{2}R_L) = 2\sqrt{2}/\pi = 0.287$

Practice Problem for HW Rectifier

A half-wave rectifier using silicon diode has a secondary emf of 14.14 V (rms) with a resistance of 0.2 Ω. The diode has a forward resistance of 0.05 Ω and a threshold voltage of 0.7 V. If load resistance is 10 Ω, determine:

(i) dc load current

(ii) dc load voltage

(iii) voltage regulation

(iv) efficiency

Ref: Theraja: Example 55.2: page 2135

Practice Problem for HW Rectifier

Solution. $V_{sm} = \sqrt{2} \times 14.14 = 20 \text{ V}, R_0 = 0.2 + 0.05 = 0.25\ \Omega$

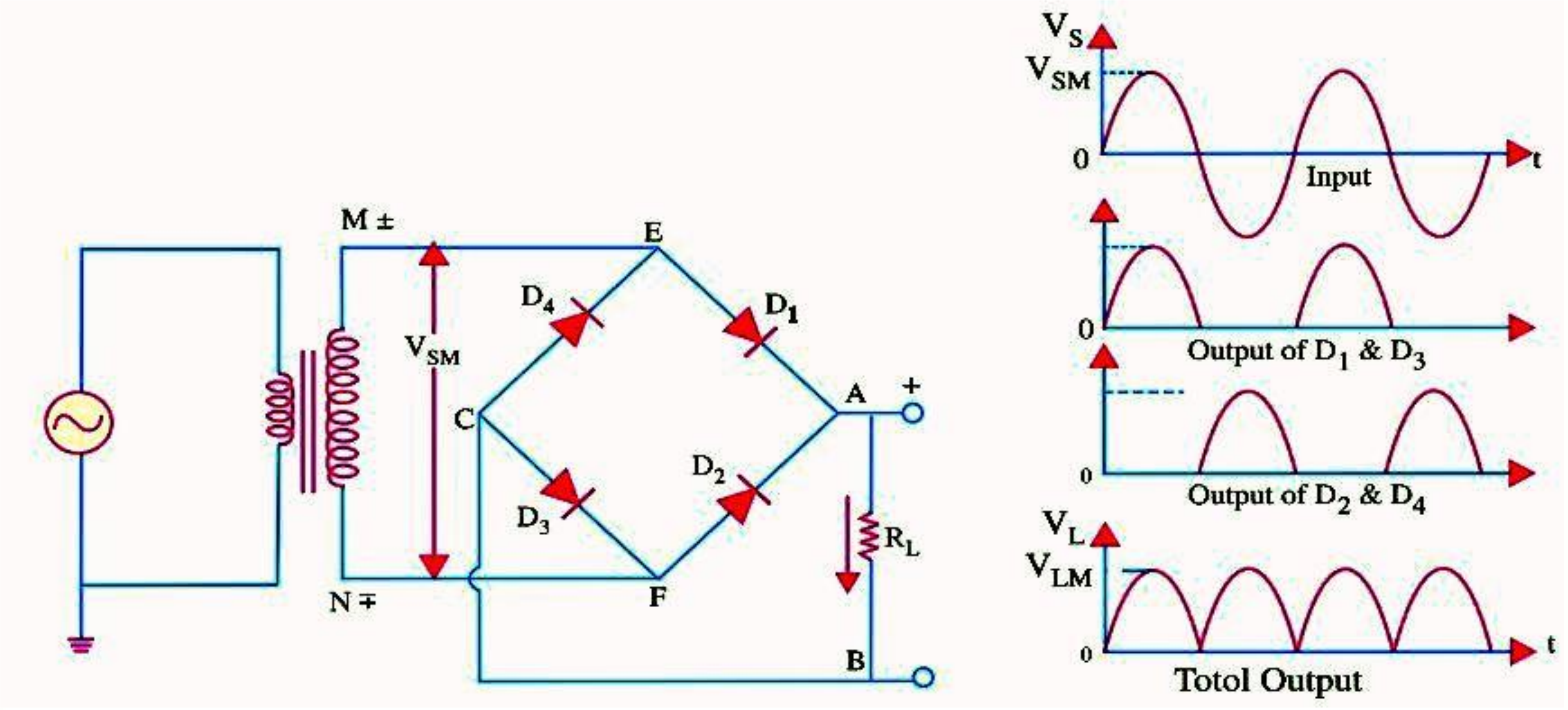
(i) $I_{LM} = \dfrac{V_{sm} - V_B}{R_0 + R_L} = \dfrac{20 - 0.7}{10.25} = 1.88 \text{ A}\ ;\ I_{L(dc)} = \dfrac{I_{LM}}{\pi} = \dfrac{1.88}{\pi} = \mathbf{0.6\ A}$

(ii) $V_{L(dc)} = I_{L(dc)} \,.\, R_L = 0.6 \times 10 = \mathbf{6\ V}$

(iii) $V_R = R_0/R_L = 0.25/10 = 0.025$ or **2.5%**

(iv) $\eta = \dfrac{40.6}{1 + 0.25/10} = \mathbf{39.6\%}$

Single Phase Full Wave Rectifier



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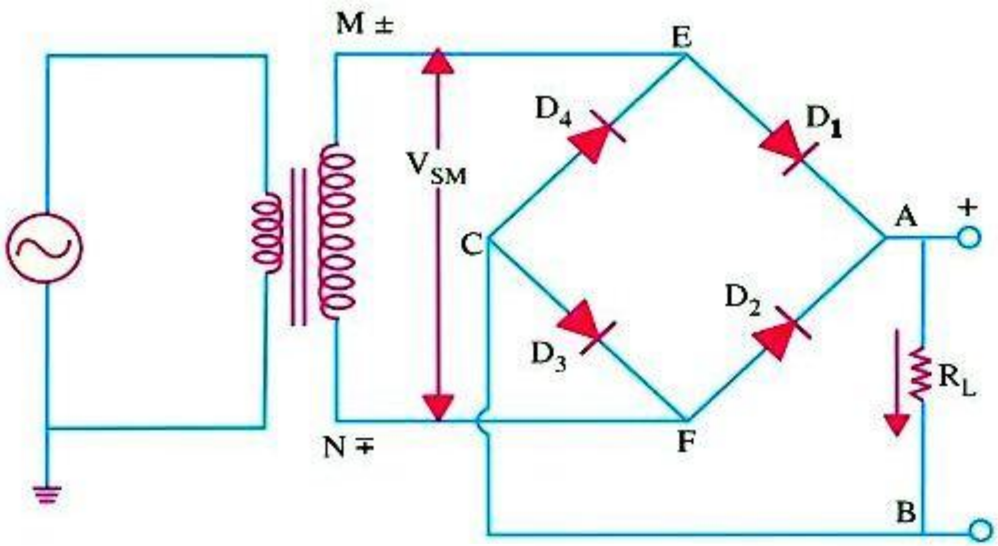
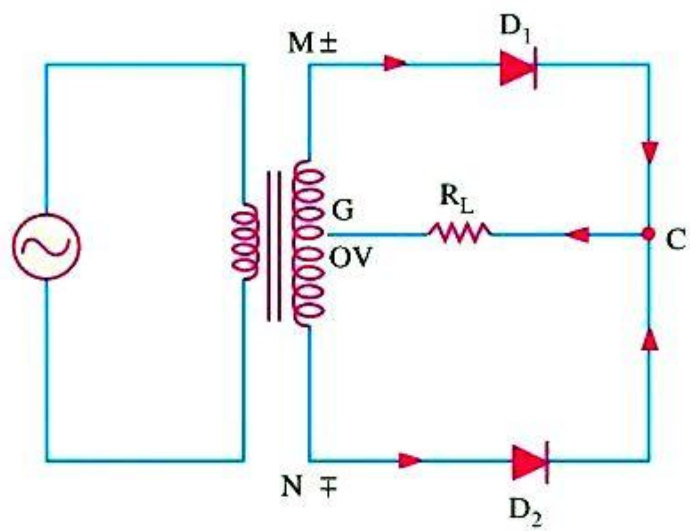
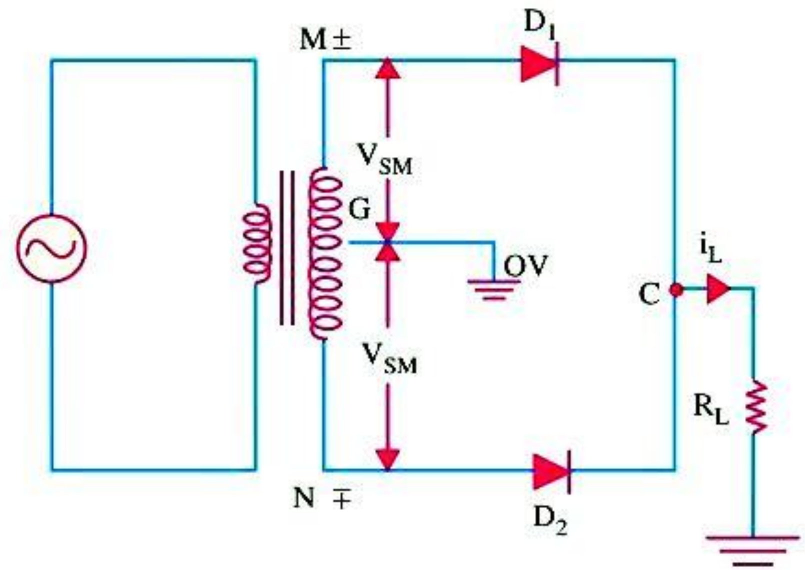
Single Phase Full Wave Rectifier







Centre-tapped Full-wave Rectifier

Single Phase Full Wave Rectifier

- **Average and RMS Values**

$$V_L = V_{LM}/\sqrt{2} = 0.707\, V_{LM}\,;\; V_{L(dc)} = 2\, V_{LM}/\pi = 0.636\, \text{V}$$

$V_{L(ac)}$ = rms value of ac components in the output voltage

$$= \sqrt{V_L^2 - V_{L(dc)}^2}$$

$$I_{LM} = \frac{V_{LM}}{R_L}\;;\quad I_L = \frac{I_{LM}}{\sqrt{2}} = 0.707\, I_{LM}$$

$$I_{L(dc)} = \frac{2\, I_{LM}}{\pi} = 0.636\, I_{LM}\,;\; I_{L(ac)} = \sqrt{I_L^2 - I_{L(dc)}^2}$$

Single Phase Full Wave Rectifier

- **Efficiency**

$$P_{in} = I_L^2 (R_0 + R_L) = \left(\frac{I_{LM}}{\sqrt{2}} \right)^2 (R_0 + R_L) = \frac{1}{2} I_{LM}^2 (R_0 + R_L)$$

$$P_{dc} = I_{L(dc)}^2 (R_0 + R_L) = \left(\frac{2\, I_{LM}}{\pi} \right)^2 (R_0 + R_L) = \frac{4\, I_{LM}^2}{\pi^2} (R_0 + R_L)$$

$$\eta = \frac{P_{dc}}{P_{in}} = \left(\frac{8}{\pi^2} \right) \left(\frac{R_L}{R_0 + R_L} \right) = \frac{0.812}{(1 + R_0 / R_L)} = \frac{81.2\%}{(1 + R_0 / R_L)}$$

Single Phase Full Wave Rectifier

- **Frequency Components**

$$V_L = V_{LM}\left(\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t - \frac{4}{35}\cos 6\omega t - \ldots\right)$$

$$V_{L(\mathrm{dc})} = \frac{2V_{LM}}{\pi}\;;\; V_{L1} = \frac{4V_{LM}}{\sqrt{2}\,3\pi},\; V_{L2} = \frac{4V_{LM}}{\sqrt{2}.15\pi}\text{ etc.}$$

$$V_{L(\mathrm{ac})} = \sqrt{V_{L1^2} + V_{L2^2}} = \sqrt{\left(\frac{4V_{LM}}{\sqrt{2}\,.\,3\pi}\right)^2 + \left(\frac{4V_{IM}}{\sqrt{2}\,.\,15\pi}\right)^2} = 0.305\,V_{LM}$$

$$I_{L(ac)} = I_{r(rms)} = \sqrt{I_{L1}^2 + I_{L2}^2} = 0.305\,I_{LM}$$

Single Phase Full Wave Rectifier

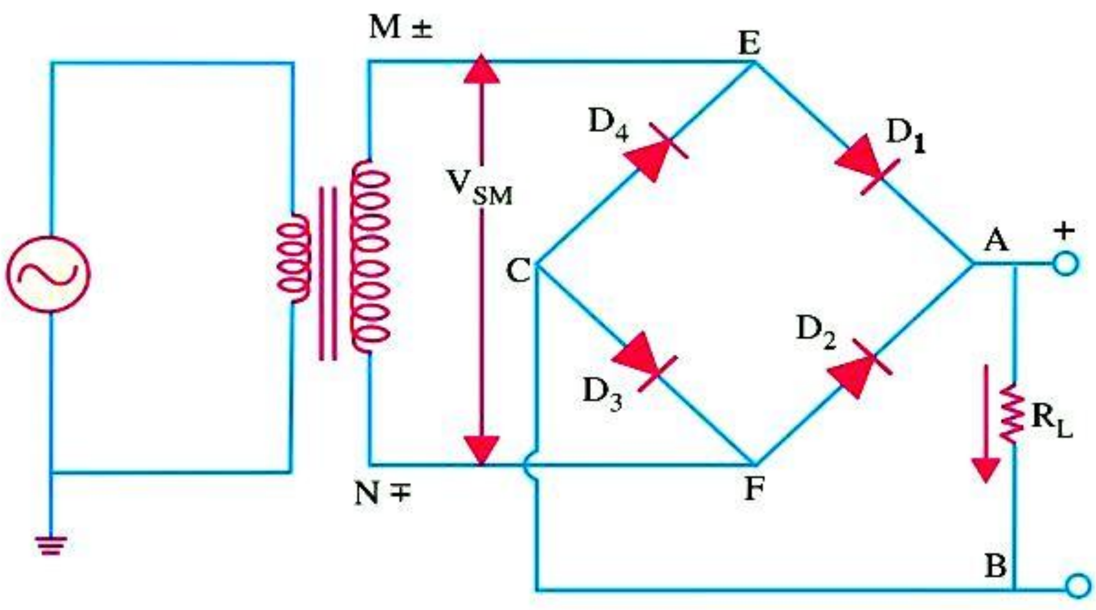
- **Ripple Factor**

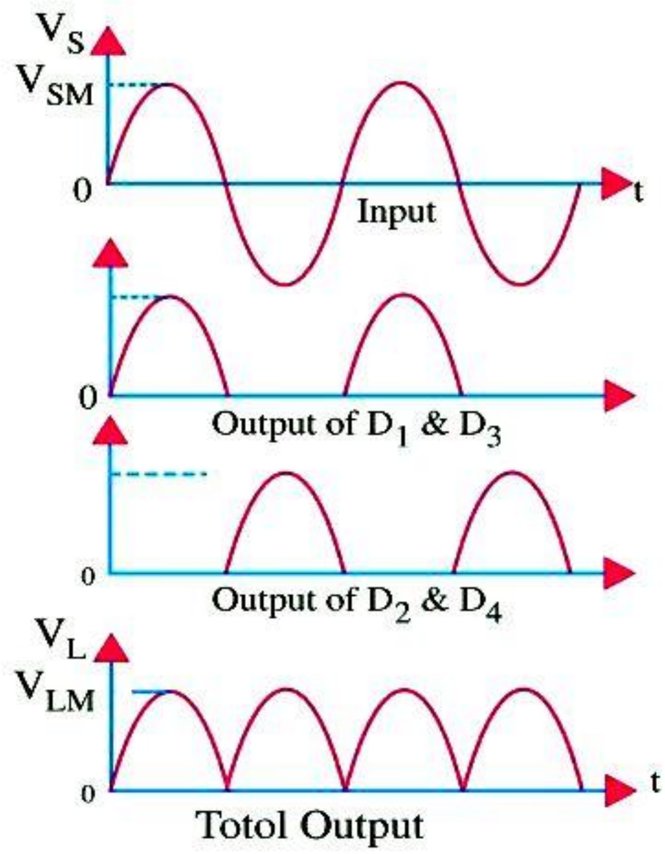
$$\gamma = \frac{V_{L(ac)}}{V_{L(dc)}} = \frac{V_{r(rms)}}{V_{L(rms)}} = \frac{0.305\, V_{LM}}{0.636\, V_{LM}} = 0.482$$

- **PIV**

PIV = 2 V_{sm}

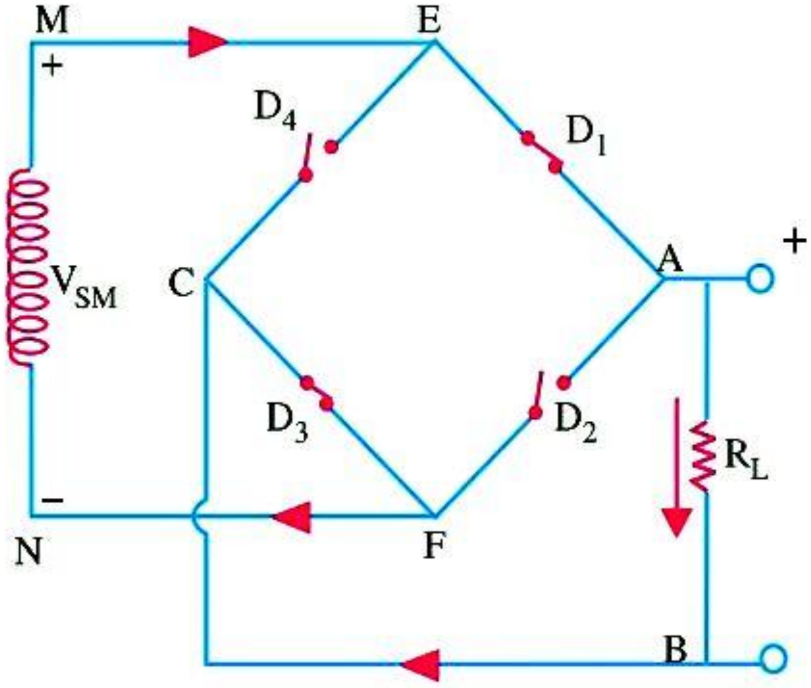
Full Wave Bridge Rectifier

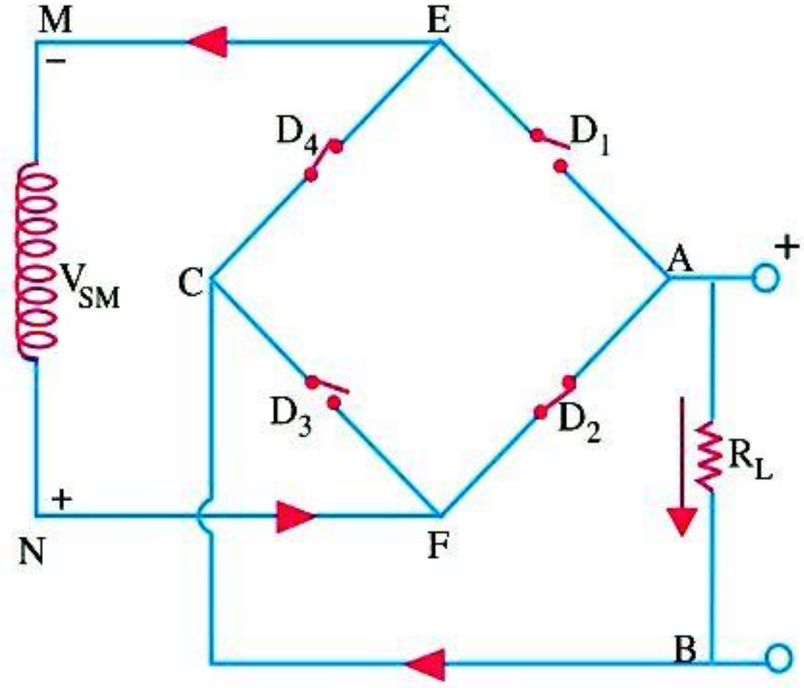




Full Wave Bridge Rectifier Four Discrete Diodes

Full Wave Bridge Rectifier





Full Wave Bridge Rectifier

Advantages of Full Wave Bridge Rectifier Four Discrete Diodes:

- no centre-tap is required on the transformer
- much smaller transformers are required
- it is suitable for high-voltage applications
- it has less *PIV* rating per diode