Module - 1

Semiconductor Diodes

Diodes
+
Rectifiers.

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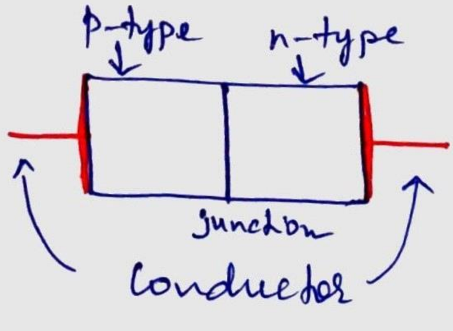
Semiconductor Diodes

* The term diode refers to a two-electrode or two-terminal semiconductor device.
* It is a pn-junction with a connecting lead on each side.
* A diode is a one-way device: offers low resistance to current flow when forward-biased and offers high resistance and acts as open switch when reverse-biased.
* A constant voltage drop occurs across a forward biased diode.

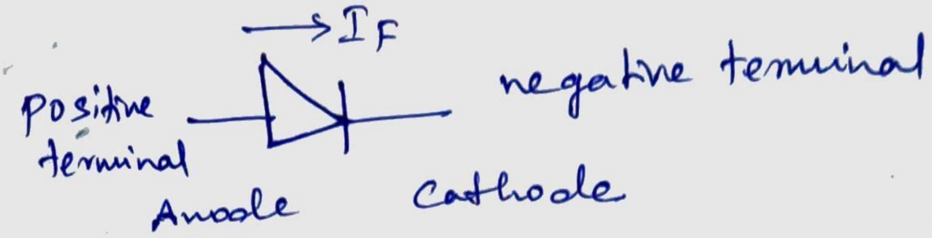
P-n junction Diode



A pn junction permits substantial current flow when forward-biased and blocks current when reverse-biased. Thus, it can be used as a switch: Its ON when forward biased and OFF when reverse biased.

A pn junction provided with copper wire connecting leads becomes an electronic device known as diode.

The circuit symbol for a diode is as shown below.



The arrow head indicates the conventional direction of current flow. when diode is forward biased.

The p-side is always the positive terminal and is termed as Anode.

The n-side is always the negative terminal and is termed as cathode

A pn junction diode can be destroyed

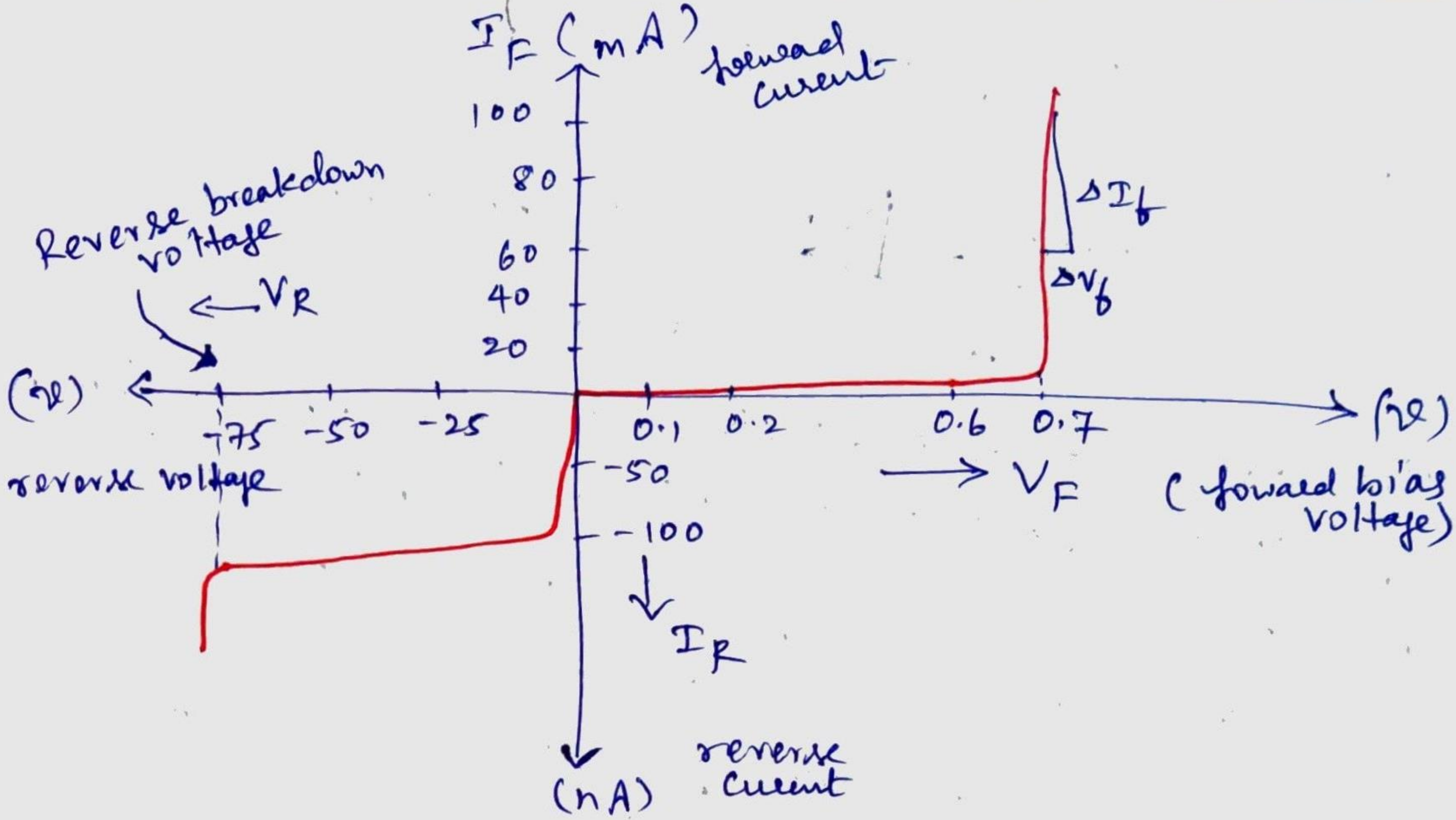
- when a high magnitude of forward current overheats the device
- or a large reverse voltage causes the junction to breakdown.

For this reason, the maximum forward current & maximum reverse voltage for diodes are specified on the manufacture's data sheet.

Characteristics and Parameters of a Diode

There are two characteristics for a diode namely:

1. Forward characteristics
2. Reverse characteristics.



Typical forward & Reverse characteristics of a silicon diode.

From the above diagram, which depicts the forward characteristics (1st quadrant) and reverse characteristics (3rd quadrant) for a a silicon diode, it is clear that

* the forward current (I_F) remains very low until the diode forward bias voltage (V_F) exceeds approximately 0.7 V.
  After V_F becomes greater than 0.7V, I_F increases linearly.

* The reverse current (I_R) is very much smaller than its forward current. (Therefore, the scale of reverse characteristics is in nA)
  the I_R is normally less than 100 nA. and is almost completely independent of

of reverse - bias voltage. ~~The reverse~~

* The reverse curent is usually less than $\frac{1}{10,000}$ of the lowest normal forward current.

Therefore the reverse-biased diode may be treated almost as an open switch.

* when diode reverse voltage (V_R) is sufficiently increased, the device goes into reverse breakdown. For Silicon, this occurs at $V = -75V$.

Diode Parameters :

The important diode parameters are :

(i) Forward Voltage drop (V_F)
(ii) Reverse saturation current (I_R)
(iii) Reverse breakdown voltage (V_{BR})
(iv) Dynamic resistance (r_d)
(v) Maximum forward current $I_{F(max)}$

Normally these parameters are listed on the diode data sheet. provided by the device manufacturer.

Forward Voltage drop V_F for Silicon is approximately $V_F \simeq 0.7V$.
It is the voltage across the diode when it is conducting (ON)
Reverse saturation current (I_R) is the leakage current when diode is not conducting (OFF) for Silicon it is $I_R \simeq 100nA$.

Reverse breakdown voltage: It is the reverse voltage value at which the pn junction breaks down and reverse current increases drastically, and damages the diode.

for Silicon $V_{BR} = 75V$.

The **dynamic resistance** of the diode is the resistance offered to changing levels of forward voltage. It is given by the formula

$$r_d = \frac{\Delta V_F}{\Delta I_F}$$

(This can be calculated from the slope of the forward characteristics)

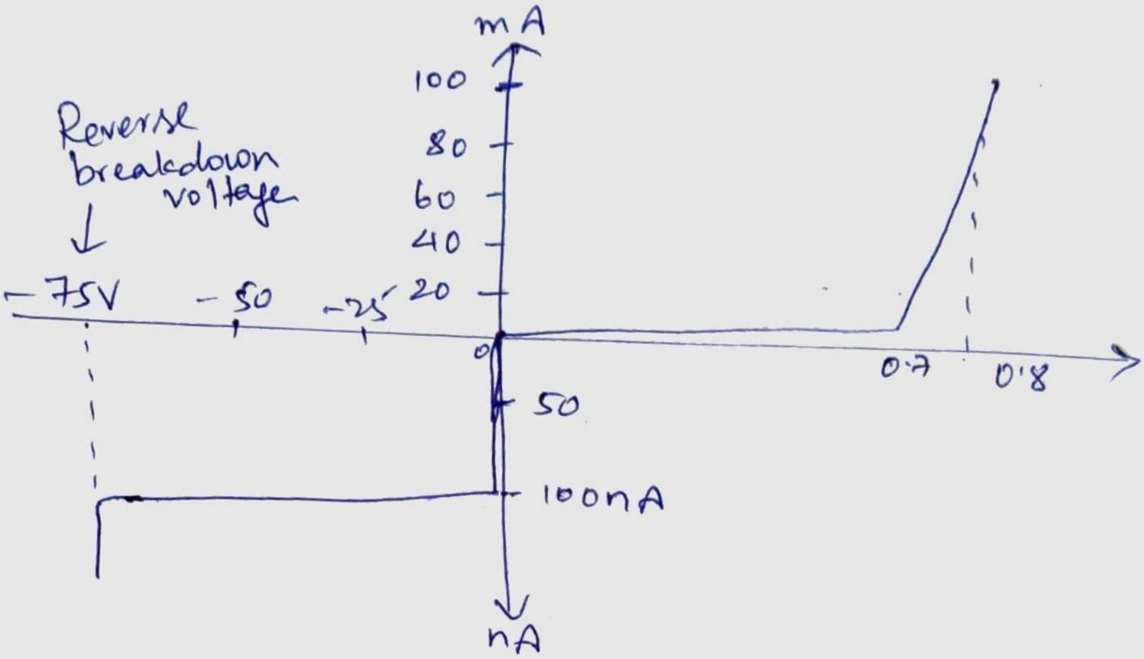
It is also calculated by the rule-of-thumb equation

$$r_d' = \frac{26mV}{I_F}$$

Thus for example, ~~if~~ for a diode passing a 1mA forward current,

$$r_d' = \frac{26mA}{1mA} = \underline{\underline{26\Omega}}.$$

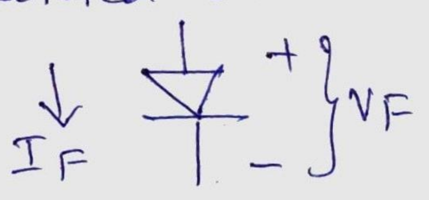
1) Calculate the forward and reverse resistance offered by a silicon diode with the characteristics as in the below figure. at $I_F = 100mA$ and at $V_R = 50V$.



From the characteristics,

At $I_F = 100mA$, $V_F = 0.75V$.

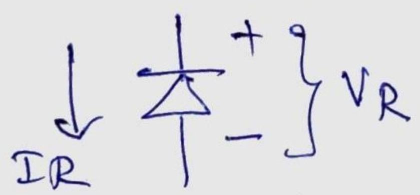
The Forward resistance (R_F) of a diode is represented as



$$R_F = \frac{V_F}{I_F}$$

$$\therefore R_F = \frac{V_F}{I_F} = \frac{0.75}{100 \times 10^{-3}} = 7.5\Omega$$

The reverse resistance (R_R) of a diode is represented as



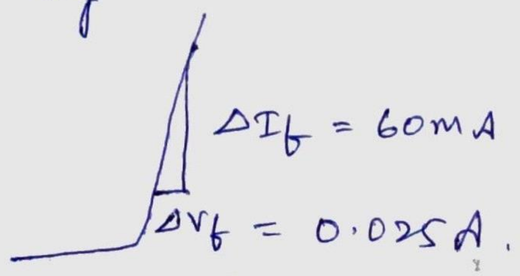
$$R_R = \frac{V_R}{I_R}$$

From the characteristics, $V_R = 50V$, $I_R = 100nA$

$$\therefore R_R = \frac{V_R}{I_R} = \frac{50}{100 \times 10^{-9}} = 500M\Omega$$

2) Determine the dynamic resistance at a forward current of 70 mA for the diode characteristic given

The dynamic resistance (r_d) of a diode is given by



$$r_d = \frac{\Delta V_F}{\Delta I_f}.$$

From characteristics, at $I_F = 70\,mA$,

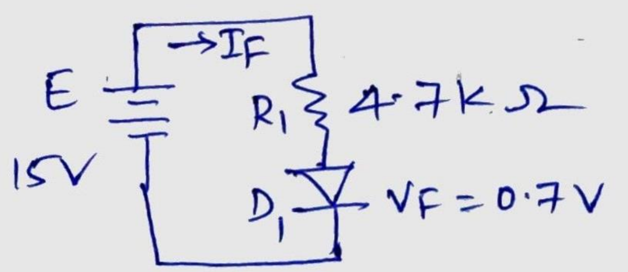
$\Delta I_f = 60\,mA$

$\Delta V_f = 0.025\,V.$

$$r_d = \frac{\Delta V_F}{\Delta I_F} = \frac{0.025}{60m}$$

$$= 0.42\,\Omega$$

(3) A silicon diode is used in the ckt shown. Calculate diode current.



Soln: The circuit forms a closed loop with a series current I_F in the loop.

Apply KVL to the loop:

$$E = I_F R_1 + V_F$$

For a forward biased diode $V_F = 0.7\,V$.

$$\therefore \quad I_F R_1 = E - V_F$$

$$I_F = \frac{E - V_F}{R_1}$$

$$= \frac{15 - 0.7}{4.7 \times 10^3}$$

$$I_F = \underline{\underline{3.04\,mA}}$$

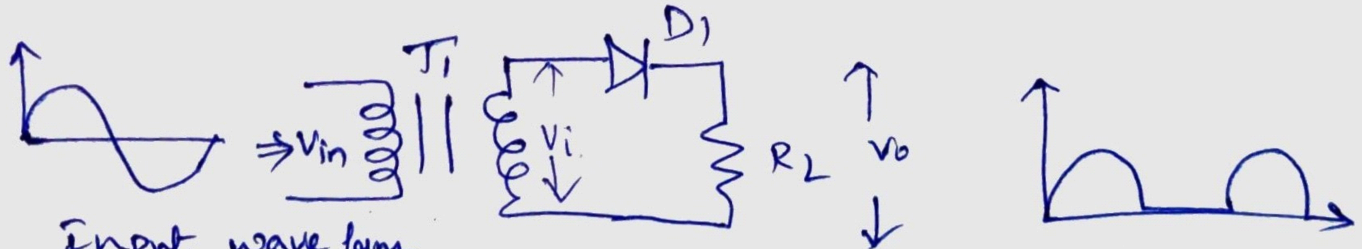
Diode Applications

One of the most important applications of diodes is rectification; which is conversion of a sinusoidal ac waveform into single-polarity half cycles.

Rectification may be performed by half-wave or full-wave rectifier circuits.

(a) Half-Wave Rectification

A diode half wave rectification circuit is shown in the figure below:



Input wave form

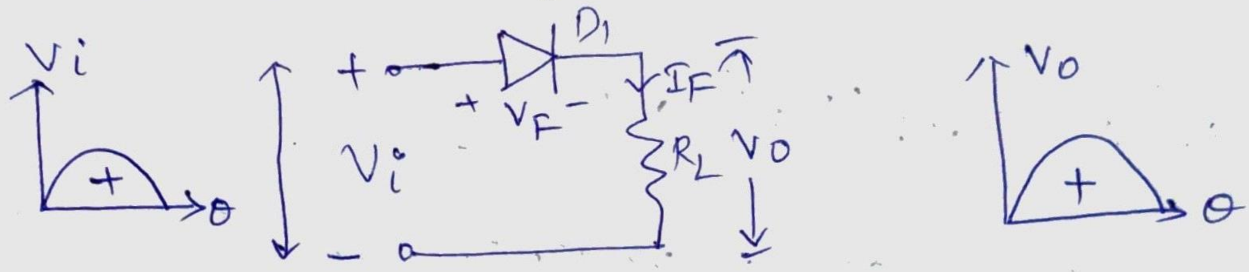
output waveform

T = transformer

D_1 = Diode & R_L = output/load resistance

An alternating input voltage is applied via transformer (T_1) to a single diode (D_1) connected in series with a load resistor R_L. The transformer steps down the higher input voltage to a lower magnitude as well as it isolates the dc-side of the rectifier from the ac-supply.

During the <u>positive half cycle</u>, the diode is forward biased, as shown below.



The voltage drop across the diode during positive half cycle is V_F. The output voltage across R_L which is V_O is $V_i - V_F$.

Therefore the peak output voltage is given by

$$\boxed{V_{po} = V_{pi} - V_F}$$

where V_{pi} = peak input voltage $= \sqrt{2}\, V(RMS)_i$

The diode peak forward current is given by

$$\boxed{I_p = \frac{V_{po}}{R_L}}$$

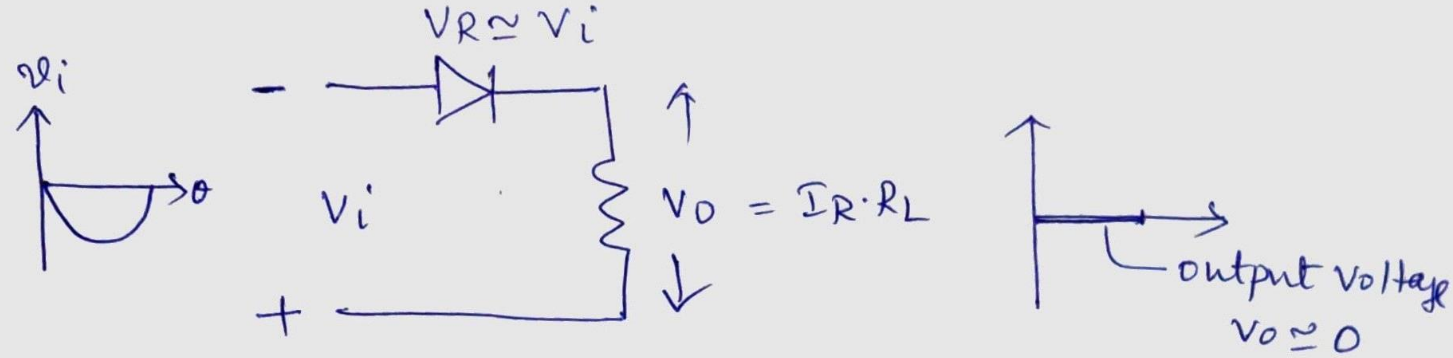
During the <u>negative half cycle</u>, the diode is reverse biased and offers very high resistance to current. Therefore, there is only a very small reverse current flowing.

The output voltage

$$-V_O = -I_R R_L$$

Since the current I_R is very small, practically V_O is zero.

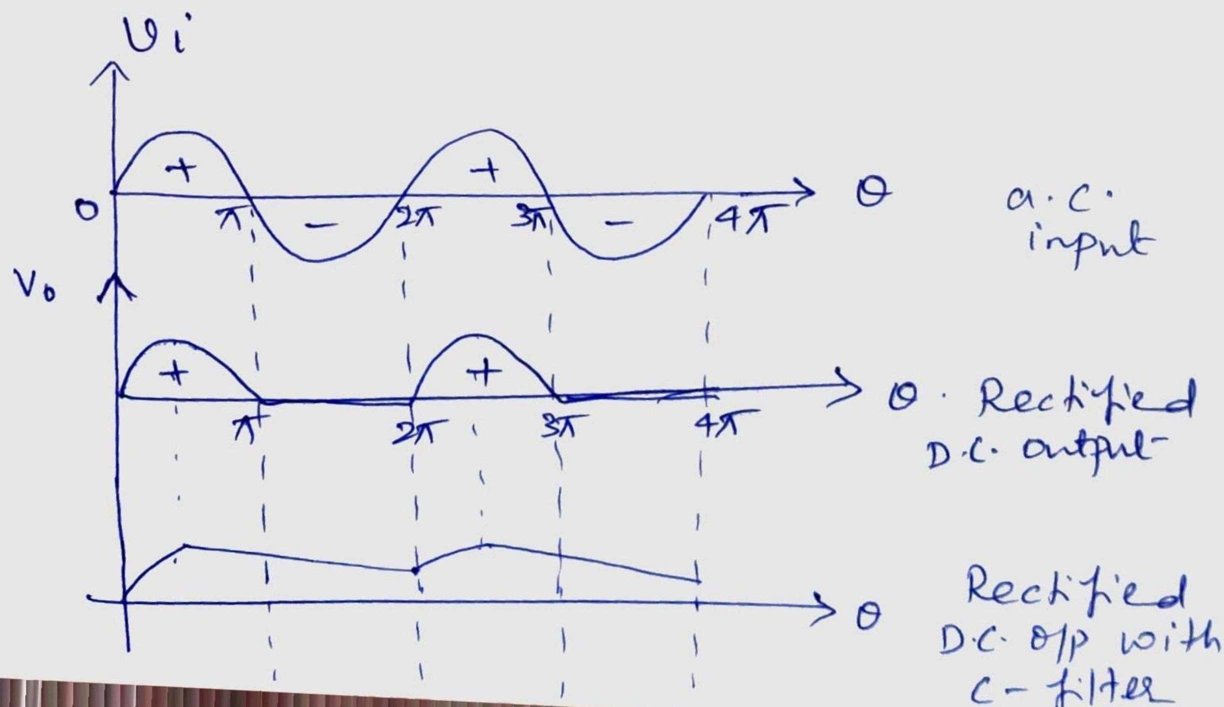
Hence ~~at the~~ during reverse bias, the peak voltage of negative half cycle of the input appears fully across the diode.



The peak reverse voltage or peak-inverse voltage (PIV) is given by

$$\boxed{V_R = PIV = V_{pi}}$$

Thus for one full cycle of input a.c. voltage the output voltage is represented as



The average and RMS value of rectified D.C. output voltage is given by the formula : The pulsating DC o/p has both a.c. + d.c. component.

D.C. component $\boxed{V_{o(avg)} = \frac{V_{po}}{\pi} = 0.318\, V_{po}}$

a.c. component $\boxed{V_{o(RMS)} = \frac{V_{po}}{2} = 0.5\, V_{po}}$

1) A diode with $V_F = 0.7\,V$ is connected as a half-wave. The load resistance is $500\,\Omega$. The rms input a.c. is 22 V. Determine the peak output voltage, peak load current and diode peak reverse voltage.

Soln: The peak input voltage

$$V_{pi} = \sqrt{2}\, V_i = 1.414 \times 22$$
$$= \underline{\underline{31.1\,V}}$$

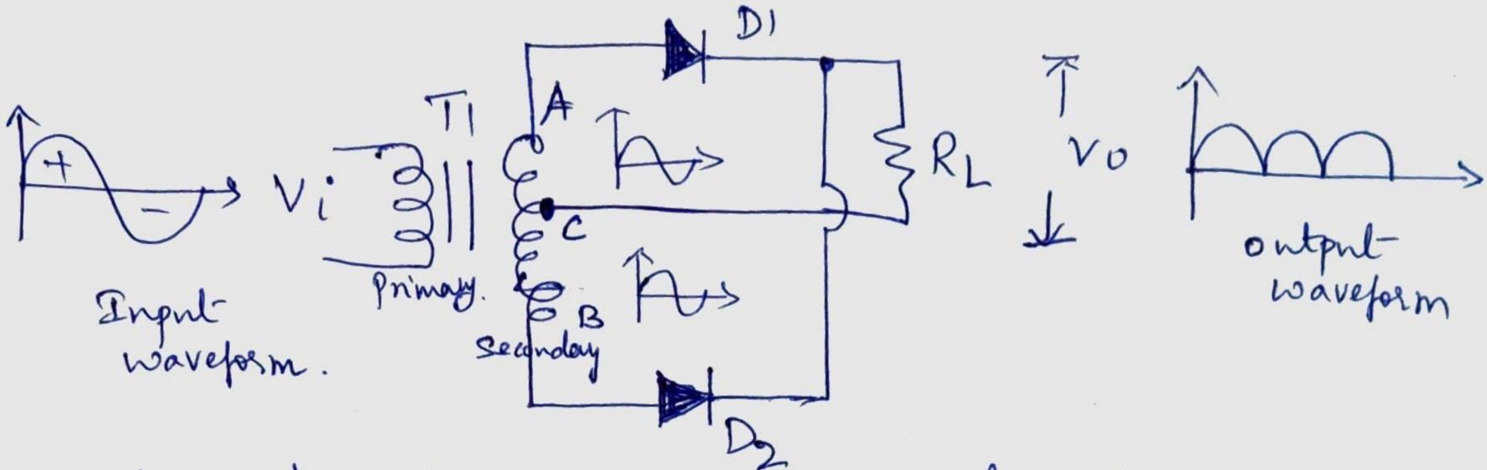
$$V_{po} = V_{pi} - V_F$$
$$= 31.1 - 0.7$$
$$= \underline{\underline{30.4\,V}}$$

$$I_p = \frac{V_{po}}{R_L} = \frac{30.4}{500} = \underline{\underline{60.8\,mA}}$$

$$PIV = V_{pi} = \underline{\underline{31.1\,V}}.$$

(b) Full-wave Rectification :

The full-wave rectifier uses two diodes and input is supplied from a transformer (T1). The Circuit is essentially a combination of two half wave rectifier circuits, each supplied from one half of the transformer Secondary.



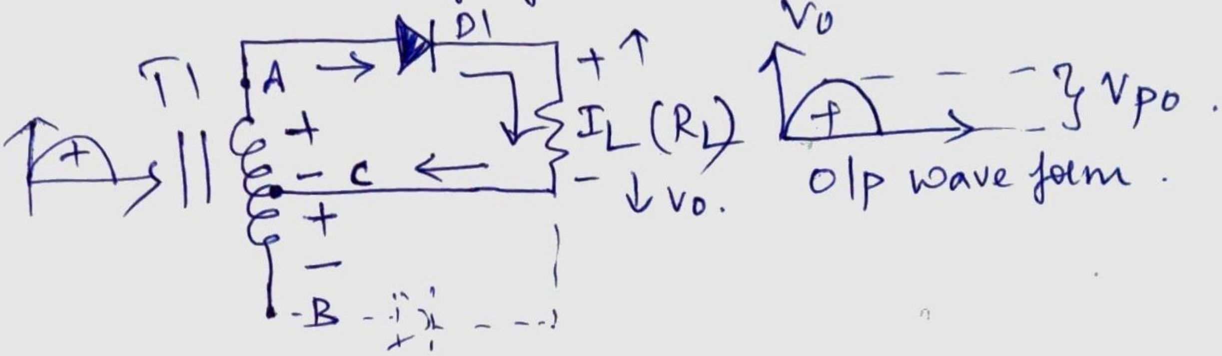
On the transformer secondary side, there are 3 ends : top end - A
bottom end - B
Centre tap - C.

When top end A is positive, during positive half cycle of input, D1 is forward biased. The current flows from D1 via RL back to Centre tap point C. of the transformer. During this positive half cycle, the bottom end point is negative and D2 is reverse biased.

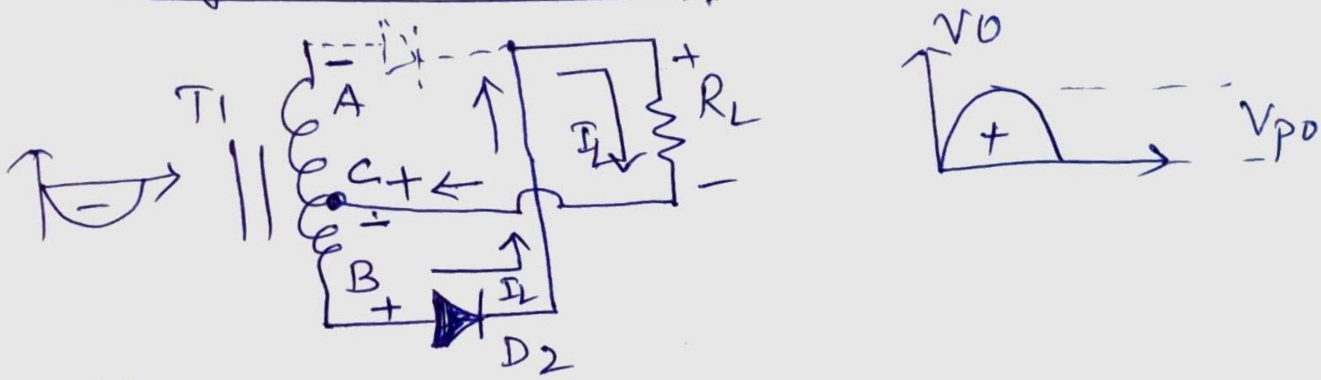
When bottom end B is positive, during negative half cycle of the input, D2 is forward biased and curent flows from bottom terminal of transformer Seconday (B) through (via) D2 and RL from top of the secondary & back to transfomer Centre-tap.

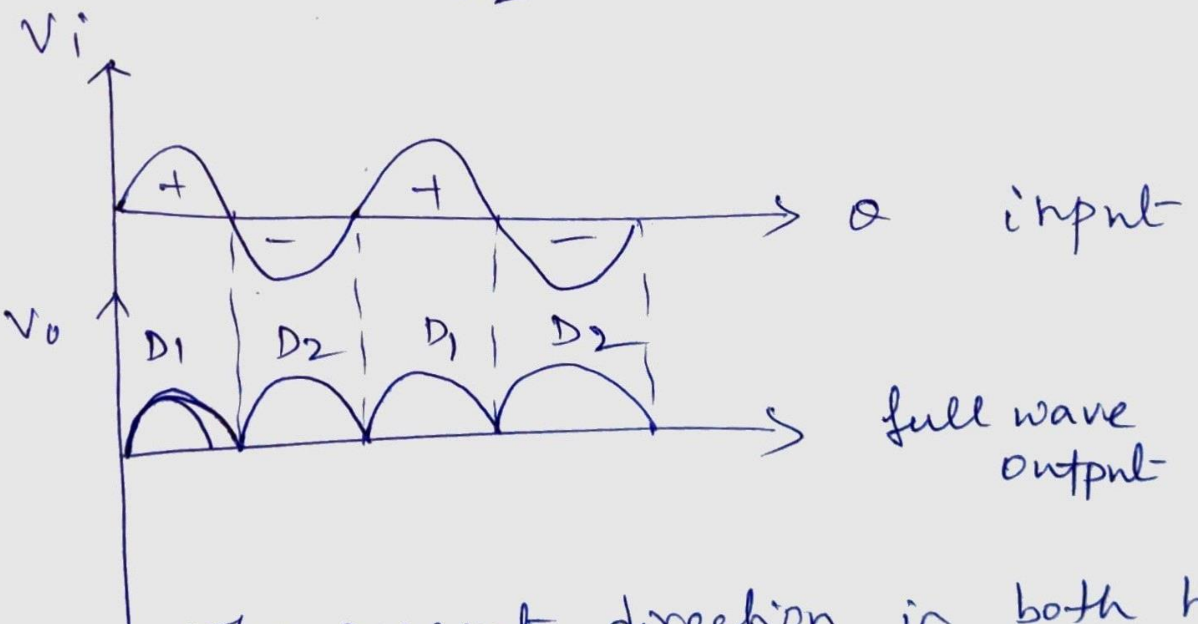
The output waveform is the combination of two half-cycles making a continuous series of positive half cycles. of sinusoidal waveforms. leading to full-wave rectification.

Positive half cycle



Negative half cycle.





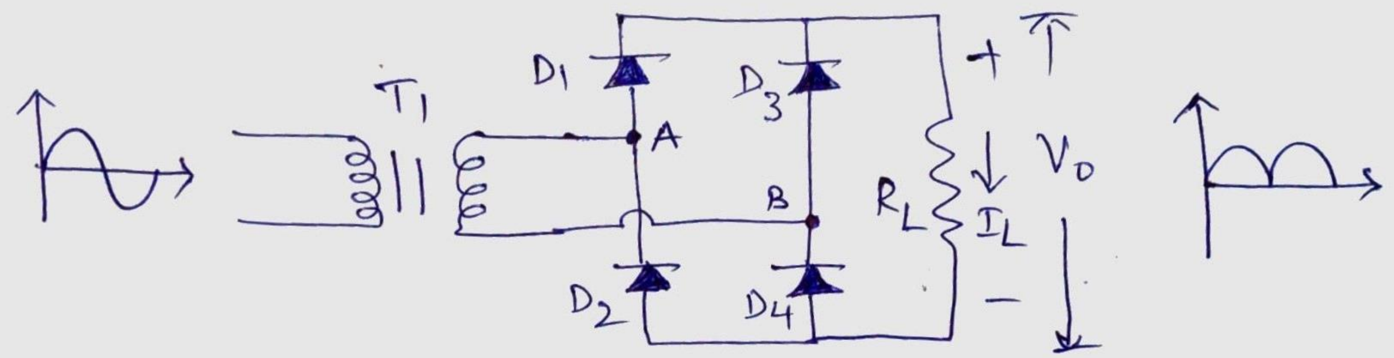
The current direction in both half cycles is same in R_L.

Bridge Rectifier

The centre-tapped transformer used in the fullwave rectifier is usually more expensive and requires more space than additional diodes.

Therefore a bridge rectifier with 4 diodes known as bridge rectifier / full wave rectifier is most frequently used for rectification.

The bridge rectifier consists of four diodes connected as shown below:

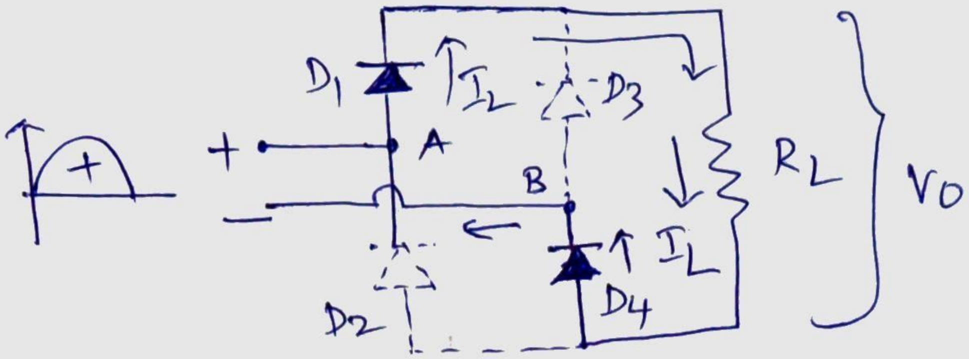


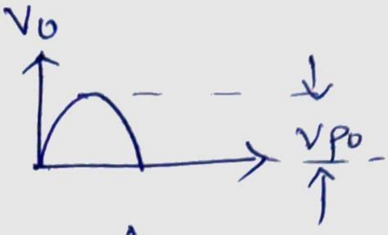
During the positive half cycle of input voltage, diodes D_1 and D_4 will conduct with terminal A being +ve and B being −ve. Load current (I_L) flows +ve terminal A through D1 to RL and then from RL through D4 back to negative terminal B.

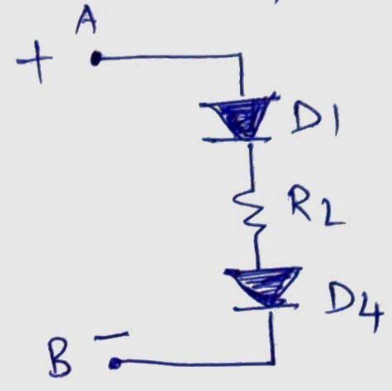
During the negative half cycle, A is −ve and terminal B is +ve therefore D_2 and D_3 are forward biased. The current flows from terminal B through D_3 to R_3 & then from R_L to negative terminal A via D2.

Direction of current in R_L remains unchanged.

+ve half cycle :

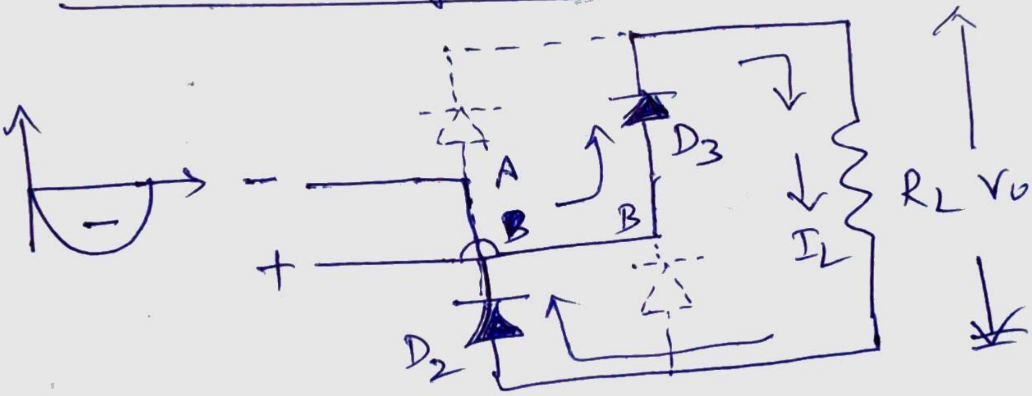


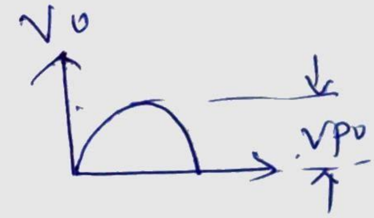


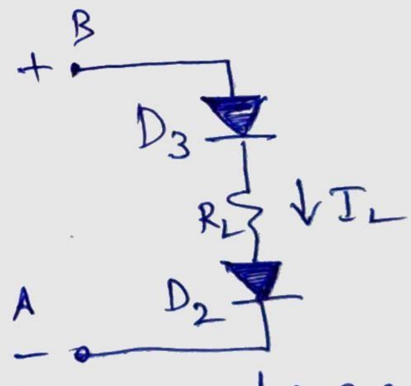


D_1 & D_4 Forward biased.

-ve half cycle :







D_3 & D_2 forward biased.

The bridge rectifier has two diodes in series with the supply voltage and load. Each diode has a positive / forward voltage drop of V_F.

$\therefore$ The peak output voltage is

$$\boxed{V_{po} = V_{pi} - 2V_F}$$

The output voltage will have both D.C. and a.c. component in the form of + half cycles.

The average value of full-wave rectified waveform

$$\boxed{V_{o(avg)} = 0.637\,V_{po}}$$ D.C. component

The RMS value of the full-wave rectified waveform

$$\boxed{V_{o(RMS)} = 0.707\,V_{po}}$$ A.C. component

Ex: Determine the peak output voltage and current for the bridge rectifier when $V_i = 30V$, $R_L = 300\Omega$ and diodes have $V_F = 0.7V$.

Soln: the diodes input RMS $V = 30V$

$\therefore$ Peak input voltage

$$V_{pi} = \sqrt{2}\,V_{i(RMS)}$$
$$= 1.414 \times 30$$
$$= 42.42V$$

wkt

$$V_{po} = V_{pi} - 2V_F \quad \text{(2 diodes)}$$
$$= 42.42 - (2 \times 0.7)$$
$$= \underline{41V}$$

$$I_p = \frac{V_{po}}{R_L} = \frac{41}{300} = \underline{137\,mA}$$