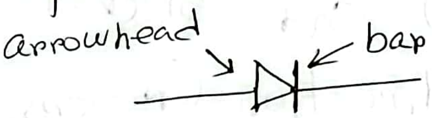
Chapter-6

Semiconductor Diode

□ **Crystal diode:** A pn junction is known as a semiconductor ~~di~~ or crystal diode.

Properties:

1. Allows current in one direction.
2. represented by:



3. If the arrowhead is positive w.r.t. bar of the symbole, the diode is forward biased.
4. If the arrowhead of diode is negative w.r.t. bar of the diode, the diode is reverse biased.
5. Red marks denotes arrow and blue marks indicates bar.
6. Used for converting AC to DC
7. Small and Lightweight.
8. Needs a small voltage to work.

田 What is Rectifier? Explain, how crystal diode can be used as rectifier?

⇒ A rectifier is an electrical circuit that converts AC into DC.

How a crystal diode is used as a Rectifier:

A crystal diode can be used as a rectifier because it allows current to flow in only one direction (forward bias) and blocks current in the opposite direction (reverse bias). This property makes it useful for rectification.

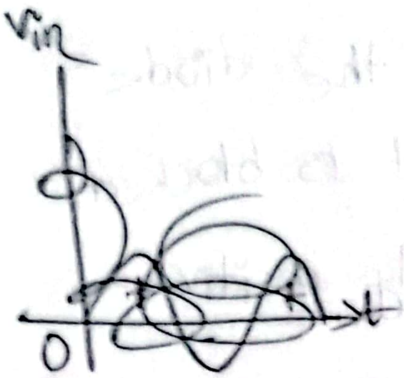
Types of rectifiers using a Crystal Diode:

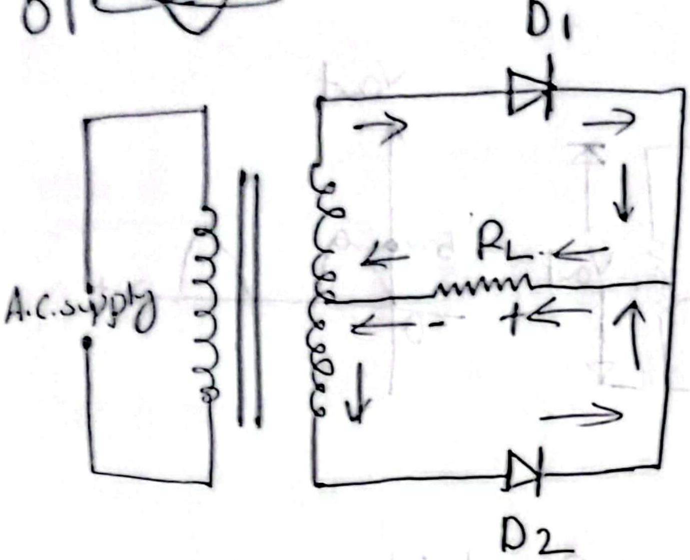
1. Half-wave Rectifier:

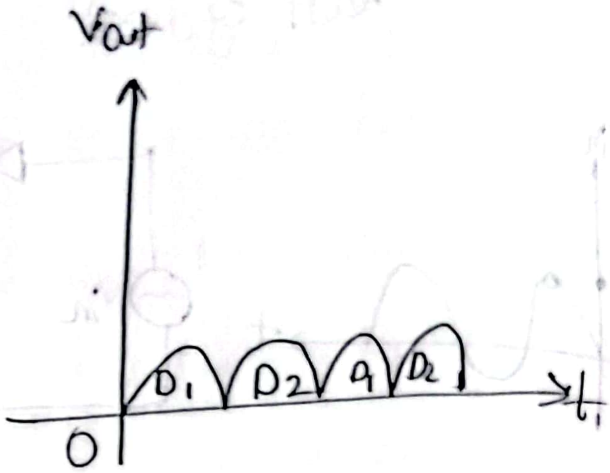
* Circuit: Uses one diode to pass only one half of the AC cycle.

* Working:

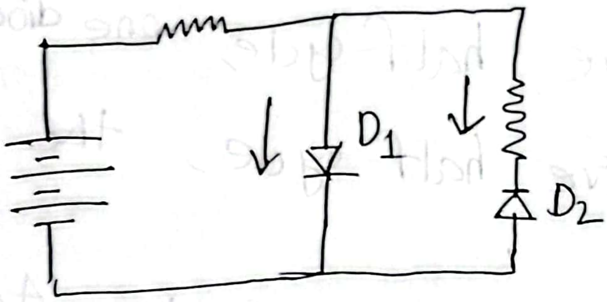
→ During the positive half-cycle, the diode is forward biased and current flows.







Exm: 6.1 → Find whether the diodes are forward or reverse biased.



Soln: → The conventional current coming out of a battery flows in the branch circuits. In diode D_1, the conventional current flows in the direction of arrowhead and this is forward biased. In diode D_2, the conventional current flows ~~thro in the direction~~ opposite to arrowhead and this is reverse biased.

Resistance of crystal diode:

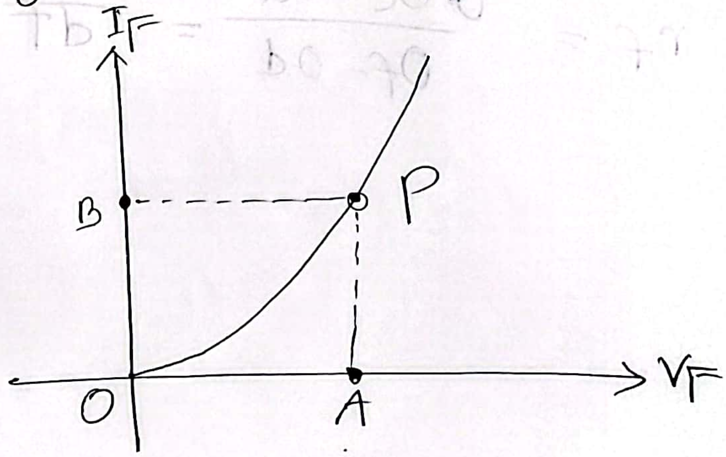
A crystal diode has two types of resistance :

1. Forward resistance.
2. Reverse resistance.

1. Forward resistance: The resistance offered by the diode to the forward bias is known as forward resistance. There are two types, d.c. forward resistance & a.c. forward resistance.

* d.c. or static forward resistance: It is the opposition offered by the diode to the direct current. It is the ratio of d.c. voltage across the diode to the current flowing through it.

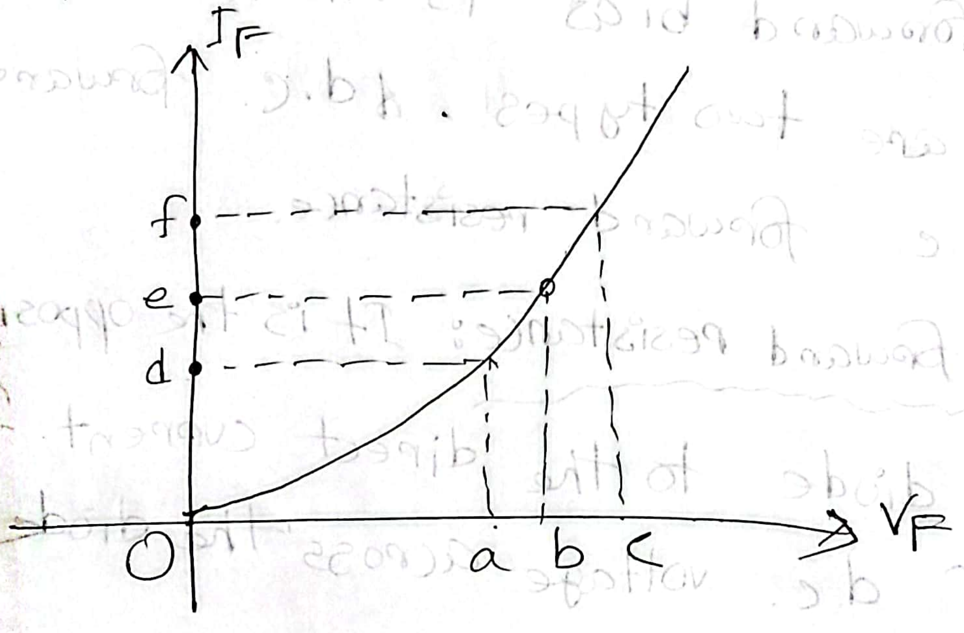
$$R_f = \frac{V}{I}$$



$$R_f = \frac{OA}{OB}$$

* A.C. or dynamic forward resistance: It is the opposition ~~to~~ offered by the diode to the changing forward current. It is measured by the ratio of change in voltage across diode to the resulting change in current through it.

$$r_f = \cancel{\text{change}} \text{ is } \frac{\Delta V}{\Delta I}$$



$$r_f = \frac{Oc - Oa}{Of - Od} = \frac{ac}{df}$$

2. Reverse resistance: The resistance offered by the diode to the reverse bias is known as reverse resistance. It can be d.c. reverse resistance or a.c. reverse resistance depending upon whether the reverse bias is direct or changing voltage. Ideally, the reverse resistance of a diode is infinite. In practice, the reverse resistance is not infinite because a small leakage current exist. The reverse resistance is very large compared to forward resistance. In Ge diodes, the ratio of reverse to forward is 40000:1 while for silicon this ratio is 1000000:1.

Exm: 6.2:

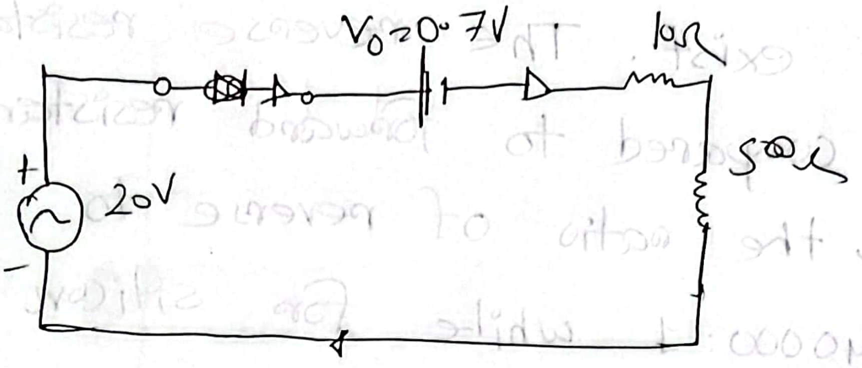
peak input voltage = 20V

Forward resistance, $r_f = 10\Omega$

Load " , $R_L = 500\Omega$

Potential barrier voltage, $V_0 = 0.7V$ (Si)

The diode will conduct during the positive half-cycles of a.c. input voltage only.



i) ~~peak current =~~ when $V_{in} = V_F = 20V$ the input voltage reaches the positive peak: the peak current through the diode will occur.

$$V_F = V_0 + (I_f)_{peak}(r_f + R_L) \quad \text{--- (1)}$$

$$\therefore \Rightarrow (I_f)_{peak} = \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500}$$

$$= \frac{19.3}{510} A$$

$$= 37.8 mA \text{ (Ans)}$$

ii) peak output voltage :- $(I_f)_{peak} \times R_L$

$= 37.8\,mA \times 500\,\Omega = 18.9\,V$ Ans.

Ideal diode, For an ideal diode, put $V_0 = 0$ and $r_f = 0$ in eqn. (1)

Now,

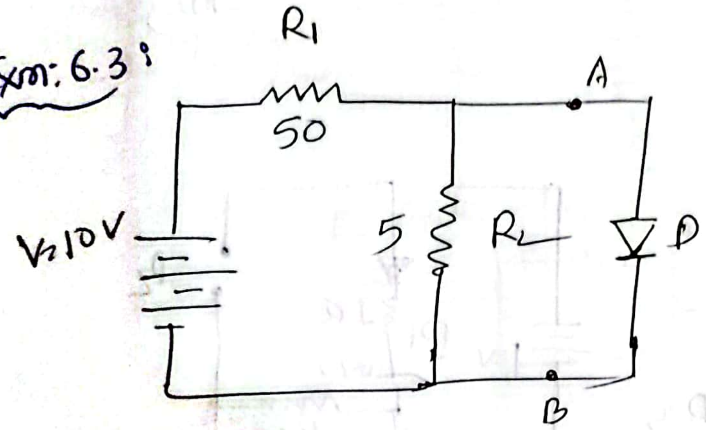
$$V_F = (I_f)_{peak} \times R_L$$

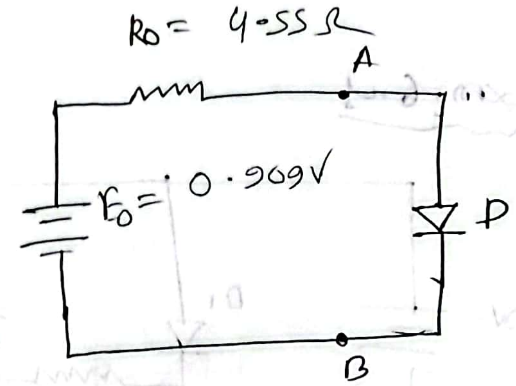
$$= (I_f)_{peak} = \frac{V_F}{R_L} = \frac{20}{500} = 40\,mA$$

Peak output voltage $= (I_f)_{peak} \times R_L$

$= 20\,V$ Ans.

Exm: 6.3 :





We shall use thevenin's theorem to find current.

For thevenin's voltage

= open circuited voltage across AB with diode removed

$$= \frac{R_2}{R_1+R_2} \times V = \frac{5}{55} \times 10 = 0.909\,V$$

R_0 = thevenin's resistance

= resistance at terminals AB with diode removed and battery replaced by a short circuit.

$$= \frac{R_2 \times R_1}{R_1 + R_2} = \frac{50 \times 5}{55} = 4.55\,\Omega$$

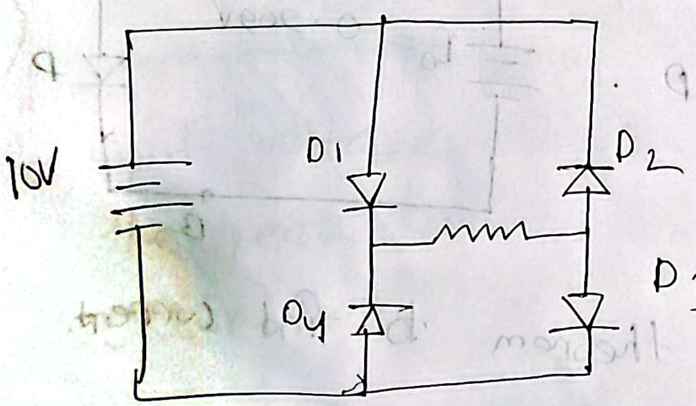
Since the diode is ideal, it has zero resistance.

$$\therefore \text{Current}, I = \frac{E_0}{R_0} = \frac{0.909}{4.55} = 0.2\,A$$

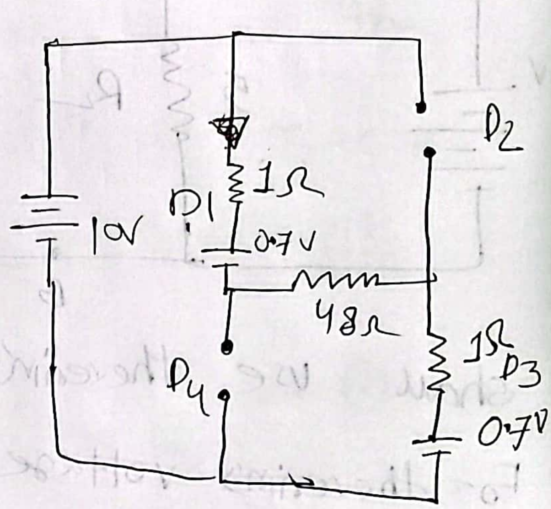
$= 200\,mA$

Ans.)

Exm: 6.4



(ii)



Diodes D_1 and D_3 are forward biased and D_2 and D_4 are reverse biased.

we can consider the branches containing diodes D_2 and D_4 as open.

NOW,

$V_0 = 0.7\ V$

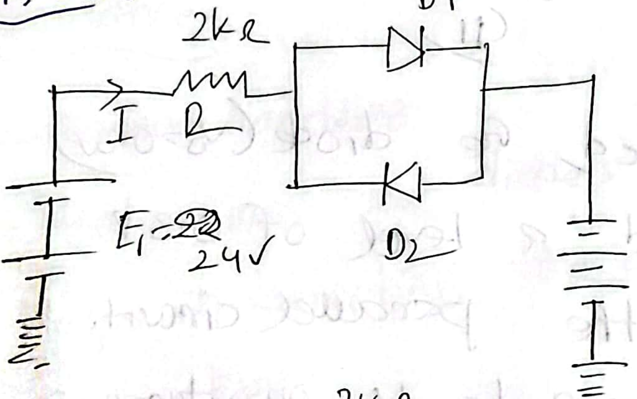
net circuit voltage $= 10 - 0.7 - 0.7 = 8.6V$

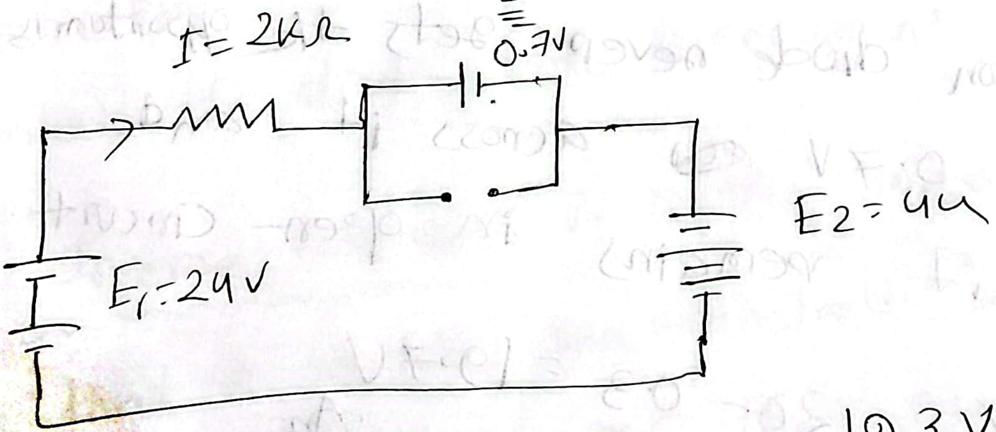
Total resistance $= 1+48+1 = 50\Omega$

circuit current $= 8.6/50 = 0.172A = 172mA$

Ans

Exm. 6.5:



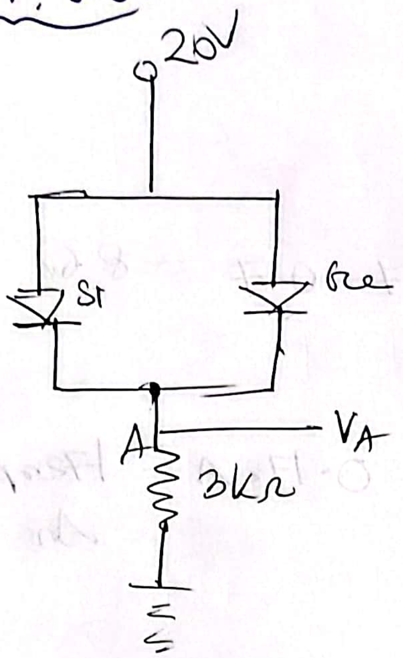


$\therefore I = \dfrac{24 - 0.7 - 4}{2} = \dfrac{19.3V}{2k\Omega}$

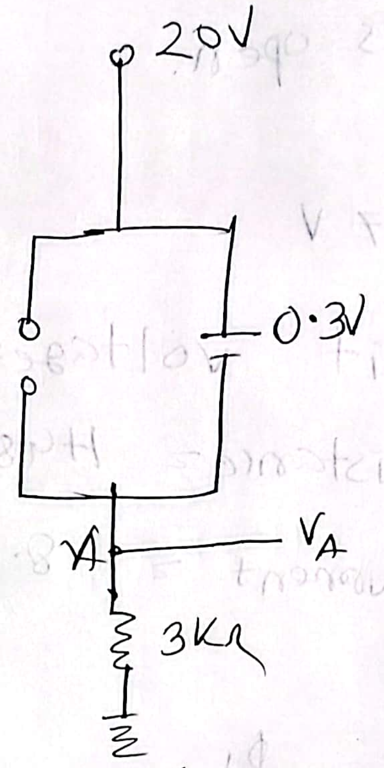
$= 9.65mA$

Ans

Exm. 6.6:



(i)



(ii)

when voltage is applied, Ge diode ($V_0 = 0.3V$) will turn on first and a level of 0.3V is maintained across the parallel circuit. The silicon diode never gets the opportunity to have 0.7V ~~ac~~ across it and therefore it remains in open-circuit.

$$V_A = 20 - 0.3 = 19.7V$$

Ans.

4 Identify Forward current, Peak inverse voltage, reverse current or leakage current and why they are important in diode operation.

⇒ 1. Forward current: It is the maximum forward current that a diode can conduct without damage. If exceeded, the diode will be destroyed due to overheating.

Importance:

~~1. Power handling~~

1. Determines the diode's conduction capability.
2. Helps in selecting the diode for current-handling applications.
3. Protects the diode from overcurrent damage.

2. Peak Inverse voltage: It is the maximum reverse voltage that a diode can withstand without destroying the function. If the reverse voltage across PIV, the diode will be destroyed due to overheating.

Importance:

1. It is very important when diode is used as a rectifier.
2. Ensures that the diode does not fail in rectifier circuits.
3. Protects circuits from high voltage spikes.
4. Helps in selecting a diode with sufficient voltage rating to prevent damage.

3. Leakage Current or reverse currents

A small current flows when the diode is reverse biased. This current is due to the minority carries. It increases with temperature.

Importance:

1. Affects efficiency in rectifier circuits
2. Can lead to power loss if too high.
3. Important in low-power & precision circuits

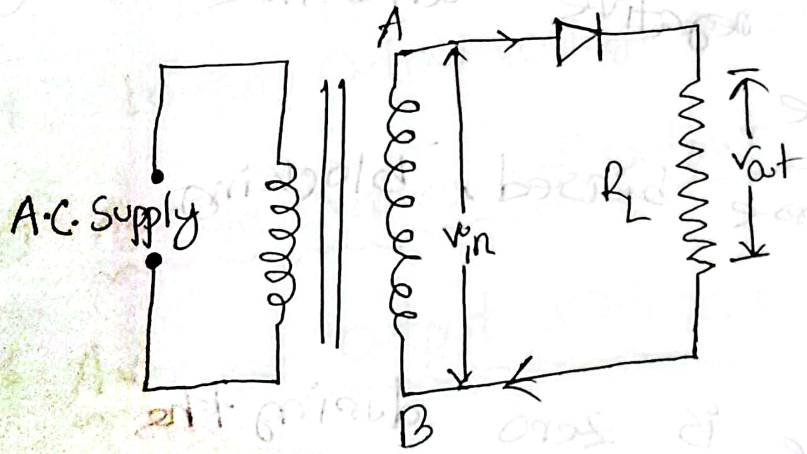
Half-wave rectifier

A half-wave rectifier is a circuit that converts AC into DC by allowing only one half-cycle of the AC signal to pass while blocking the other half.

Circuit Components:

1. AC input source
2. Diode
3. Load resistor

Diagram:



I/O voltage diagram:

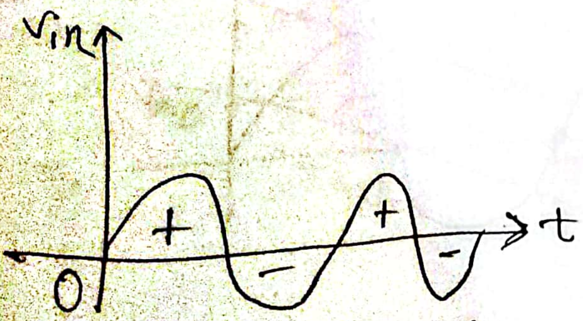


Fig: Input voltage.

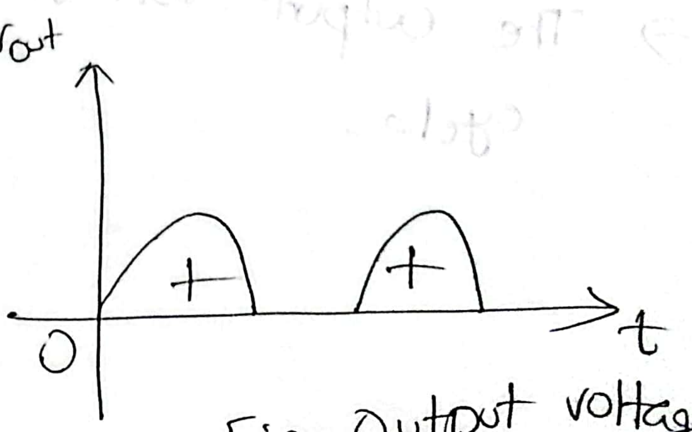


Fig: Output voltage

Working Principle:

During the Positive Half-Cycle:

→ The anode of the diode becomes positive and the cathode is negative.

→ The diode is forward biased and current flows through the load resistor (R_L).

→ The output voltage follows the positive half of the input AC waveform.

During the negative Half Cycle:

→ The anode becomes negative and the cathode is positive.

→ The diode is reverse biased, blocking current flow.

→ The output voltage is zero during the cyclo.

Advantages:

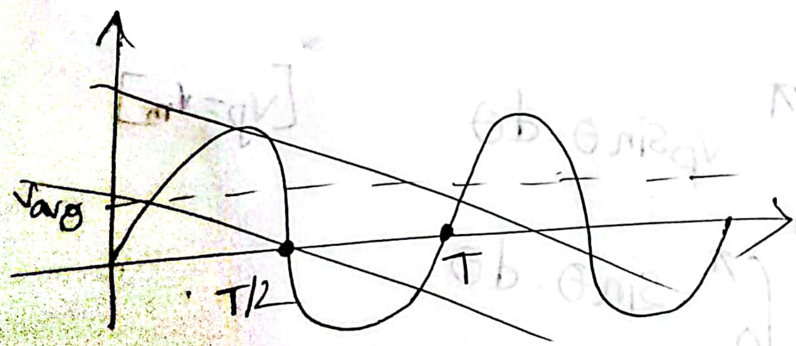
1. Simple circuit design
2. Low cost
3. Smaller size
4. Easy to use

Disadvantages:

1. Low efficiency
2. Pulsating DC output
3. High Ripple Factor
4. Lower Output voltage & current

Average values of Output voltage & Currente

1. Average output voltage:



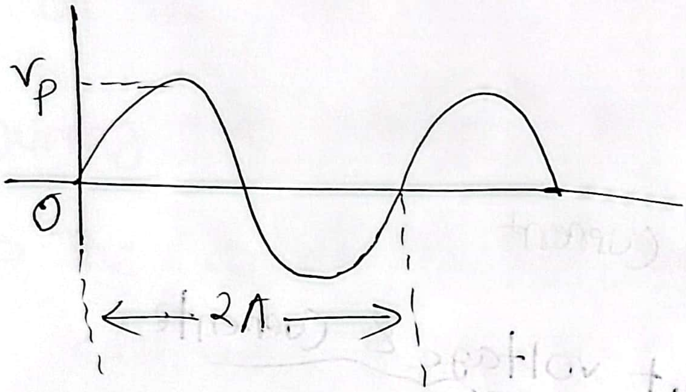
$$V_{dc} = V_{avg} = \frac{1}{T}\int_0^T V(t).dt$$

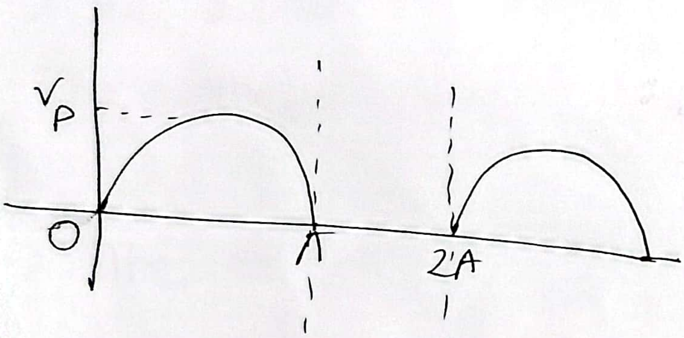
$$= \frac{1}{T}\left[\int_0^{T/2} V_m \sin\omega t \, .dt + 0\right]$$

$$= \frac{1}{T}\int_0^{T/2} V_m \sin\omega t.dt$$

$$= \frac{1}{T} V_m \int_0^{T/2} \sin\omega t \, dt$$

$$= \frac{1}{T}.V_m \left[\frac{-\cos\omega t}{\omega}\right]_0^{T/2}$$





$$V_{dc} = V_{Avg} = \frac{1}{2\pi}\int_0^{\pi} V_p \sin\theta . d\theta \qquad [V_p = V_m]$$

$$= \frac{V_p}{2\pi}\int_0^{\pi} \sin\theta . d\theta$$

$$= \frac{V_p}{2\pi}\left[-\cos\theta\right]_0^\pi$$

$$= \cancel{\frac{V_p}{2\pi}\left[-\cos\pi - (-\cos 0)\right]}$$

$$= \cancel{\frac{V_p}{2\pi}\left[1-1\right]}$$

$$= \cancel{-\frac{V_\pi}{2\pi}}$$

$$= \frac{V_p}{2\pi}\left[-\cos\pi - (-\cos 0)\right]$$

$$= \frac{V_p}{2\pi}\left(-\cos\pi + \cos 0\right)$$

$$= -\frac{V_p}{2\pi}\left(\cos\pi - \cos 0\right)$$

$$= -\frac{V_p}{2\pi}\left[-1-1\right]$$

$$= -\frac{V_p}{2\pi}(-2)$$

$$= \frac{V_p}{\pi} = \frac{V_m}{\pi}$$

$$V_{dc} = 0.318 V_p = 0.318 V_m$$

2. Average current:

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi} \times \frac{1}{R_L}$$

$$= 0.318 \frac{V_m}{R_L}$$

$$= 0.318\, I_m$$

$$= \frac{I_m}{\pi}$$

Or,

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta \cdot d\theta$$

$$= \frac{I_m}{2\pi}\int_0^{\pi} \sin\theta . d\theta$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{2\pi}\left[-\cos\pi + \cos 0\right]$$

$$= -\frac{I_m}{2\pi}\left[\cos\pi - \cos 0\right]$$

$$= -\frac{I_m}{2\pi}\left[-1-1\right]$$

$$= -\frac{I_m}{2\pi}(-2)$$

$$I_{dc} = \frac{I_m}{\pi}$$

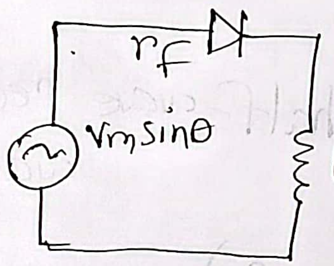
Efficiency of halfwave rectifier:

The ratio of d.c. power output to the applied input a.c. power is known as rectifier efficiency.

$$\eta = \frac{\text{d.c. power output}}{\text{input a.c. power}}$$

Input A.C power, $P_{ac} = I^2_{rms}(r_f + R_L)$

Output D.C power, $P_{dc} = I^2_{dc} \times R_L$



d.c. power: The output current is pulsating direct current. Therefore, in order to find d.c power, average current has to be found out.

$$I_{avg} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i\,d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin\theta}{r_f + R_L}\,d\theta$$

$$= \frac{V_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta\,d\theta$$

$$= \frac{V_m}{2\pi(r_f+R_L)}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{V_m}{2\pi(r_f+R_L)} \times 2 = \frac{V_m}{r_f+R_L} \times \frac{1}{\pi}$$

$$= \frac{I_m}{\pi} \qquad \left[\because I_m = \frac{V_m}{r_f+R_L}\right]$$

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{I_m}{\pi}\right)^2 \times R_L$$

$$P_{ac} = I_{rms}^2 (r_f+R_L)$$

$I_{rms} = I_m/2$ (For a half-wave rectified wave)

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 \times (r_f+R_L)$$

$$\therefore \eta = \frac{(I_m/\pi)^2 \times (R_L)}{(I_m/2)^2 \times (r_f+R_L)}$$

$$= \frac{0.406 R_L}{r_f+R_L} = \frac{0.406}{1+\frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible.

$\therefore$ Max rectifier efficiency $= 40.6\%$

Example: 6.12: The applied input a.c. power to a half wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.

i) what is the rectification efficiency?

ii) what happens to remaining 60 watts?

(i)

$$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. output power}}$$

$$= \frac{40}{100} = 0.4 = 40\%$$

(ii)

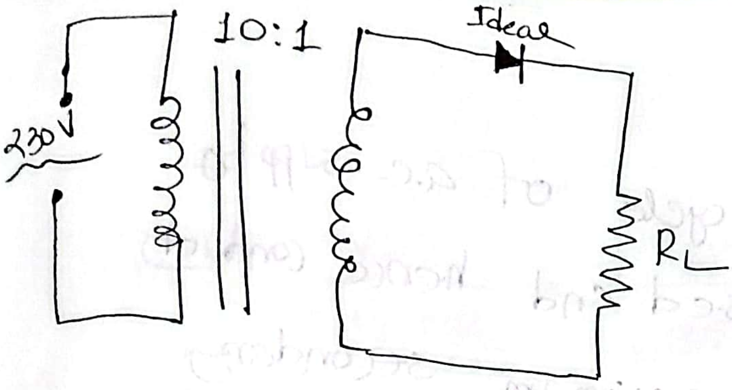
40% of efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance.

The 100W a.c. power is contained as 50W in positive half-cycles and 50 w in negative half-cycles. The 50-w in the negative half-cycles are not supplied at all. Only 50 w in the positive half-cycles are converted into 40 w.

$\therefore$ Power efficiency $= \frac{40}{50} \times 100 = 80\%$

Although 100 w of a.c. power was supplied the half-wave rectifier accepted only 50 w and converted ~~into~~ it into 40 w d.c. power. Therefore, it is appropriate to say that efficiency of rectification is 40% and not 80% which is power efficiency.

Example: 6.13: An a.c. supply of 230V is applied to a half wave rectifier circuit through a transformer of turn ratio 10:1. Find (i) the output d.c. voltage & ii) the peak inverse voltage. Assume the diode to be ideal.



⇒ Primary to secondary turns is :

$$\frac{N_1}{N_2} = \frac{10}{1}$$

R.M.S. primary voltage = 230V.

∴ MAX. primary voltage is

$$V_{pm} = (\sqrt{2}) \times \text{r.m.s. primary voltage}$$
$$= (\sqrt{2}) \times 230 = 325.3 \text{ V}$$

Max. secondary voltage is

$$V_{sm} = V_{pm} \times \frac{N_2}{N} = 325.3 \times \frac{1}{10} = 32.53\text{V}$$

(i)

$$I_{dc} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = 10.36\text{V}$$

Ans

(ii)

During the negative half-cycle of a.c. supply the diode is reverse biased and hence conducts no current. Therefore the maximum secondary voltage appears across the diode.

∴ Peak inverse voltage = 32.53 V (Ans)

Example; 6.14: A crystal diode having internal resistance $r_f = 20\Omega$ is used for half wave rectification. If the applied voltage $v = 50 \sin\omega t$ and load resistance $R_L = 800\Omega$ find:

i) I_m, I_{dc}, I_{rms}

ii) a.c. power input & d.c power output.

iii) d.c. output voltage

iv) efficiency of rectification.

⇒ $v = 50 \sin\omega t$

∴ Maximum voltage = 50V.

$V_m = \uparrow$

(i)

$$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{(800+20)} = 0.061\ A = 61\ mA$$

$$I_{dc} = \cancel{\frac{V_m}{\pi}}\ \frac{I_m}{\pi} = \frac{61}{\pi} = 19.4\ mA$$

$$I_{rms} = \frac{I_m}{2} = \frac{61}{2} = 30.5\ mA$$

(Ans:)

(ii)

$$\text{ac. power input} = (I_{rms})^2 \times (r_f + R_L)$$

$$= \left(\frac{30.5}{1000}\right)^2 \times (\cancel{900})\ (820)$$

$$= 0.763\ W$$

$$\text{dc power input} = (I_{dc})^2 \times R_L$$

$$= \left(\frac{19.4}{1000}\right)^2 \times (800)$$

$$= 0.301\ W$$

(An..)

(iii)

dc output voltage, $V_{dc} = \cancel{\frac{V_m}{\pi}} \; I_{dc} \times R_L$

$= \cancel{\frac{50}{\pi}} \; \frac{19.4 \times 800}{1000}$

$= 15.52\,V$ (Ans.)

(iv)

efficiency $= \frac{0.301}{0.763} \times 100 = 39.5\%$ Ans.

Example: 6.15: A half-wave rectifier is used to supply 50V d.c. ~~v~~ to a resistive load of 800 Ω. The diode has a resistance of 25Ω Calculate a-c voltage.

⇒ d.c. output voltage, $V_{dc} = 50V$

Load, $R_L = 800\Omega$.

Diode, $r_f = 25\Omega$.

$V_{dc} = I_{dc} \times R_L$

$I_{dc} = \cancel{\frac{50}{800}} =$

Let, V_m be the maximum value of ac voltage required.

$$V_{dc} = I_{dc} \times R_L$$

$$\Rightarrow \cancel{I_{dc}} \quad V_{dc} = \frac{I_m}{\pi} \times R_L \qquad \left[I_m = \frac{V_m}{r_f + R_L} \right]$$

$$\Rightarrow V_{dc} = \frac{V_m}{\pi (r_f + R_L)} \times R_L$$

$$\Rightarrow 50 = \frac{V_m}{\pi (25 + 800)} \times 800$$

$$\Rightarrow V_m = \frac{50 \times \pi \times 825}{800}$$

$$= 162 V \quad \text{(An:)}$$