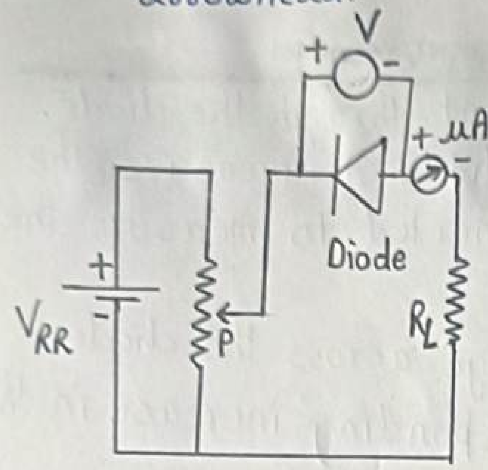
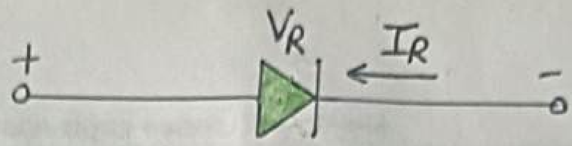
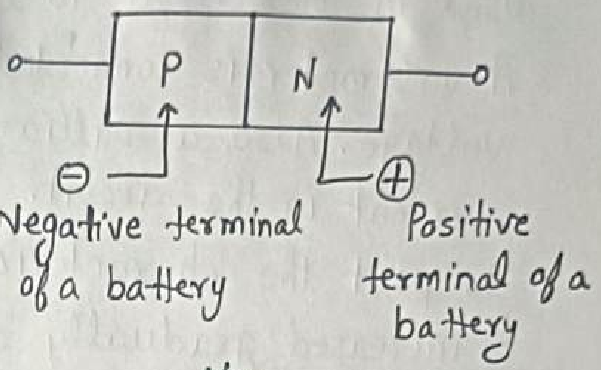
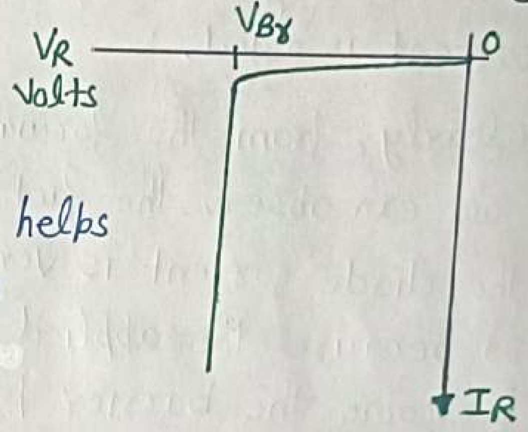
arrowhead.









In the circuit, battery V_{RR} is connected to the diode through potentiometer P. The potentiometer helps in varying the voltage across the diode. A voltmeter is connected across the diode to measure the voltage. A microammeter is also connected to measure the current in the circuit.

From the reverse characteristics, it is clear that below the breakdown voltage (V_{Br}), the diode current is very small and almost remains constant. This current is also known as reverse saturation current I_o. It is in the order of µA for Ge Diode and nanoampere for Si Diode. This current is due to the movement of minority carriers which are thermally produced. It means that reverse bias current is temperature dependent and does not depend upon the applied reverse bias voltage.

But, if a large reverse bias voltage is applied, a process known as junction breakdown occurs. Due to this, the diode reverse current increases rapidly. The applied reverse bias voltage at which this occurs is called as breakdown voltage (V_{Br}) of a diode.

Diode Current Equation

Diode current equation is given as

$$I = I_0 \left[e^{V_F/nV_T} - 1 \right] \quad \text{— (I)}$$

where, I = diode current

I_0 = diode reverse saturation current at room temperature

V_F = forward voltage applied across the diode

n = a constant < 1 for Ge Diode, 2 for Si Diode

V_T = voltage equivalent of temperature

$$= \frac{KT}{q} = \frac{T}{11,600} V.$$

K = Botzmann's constant = 1.38×10^{-23} J/K

q = electric charge = 1.6×10^{-19} C

T = Diode junction temperature (in K)

At room temperature ($T=300K$), $V_T = 26mV$.

Putting V_T in equation (I), we get

$$I = I_0 [e^{40V_F/n} - 1]$$

For Ge Diode $n=1 \Rightarrow I = I_0 [e^{40V_F} - 1]$

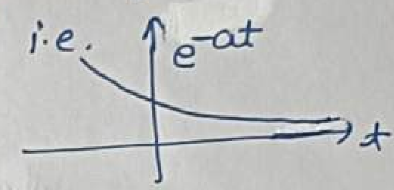
For Si Diode $n=2 \Rightarrow I = I_0 [e^{20V_F} - 1]$

If applied voltage is greater than unity, then

$$I = I_0 e^{V_F/nV_T} - I_0$$

$$I \approx I_0 e^{V_F/nV_T}$$

If the diode is reverse biased, the current equation will be obtained by putting $V = -V$ i.e.



$$\boxed{I = I_0 \left[e^{-V_R/nV_T} - 1 \right]}$$

or, $I = I_0 e^{-V_R/nV_T} - I_0$

if $V_R >> V_T$, then $e^{-V_R/nV_T} << 1$.

Therefore, $\boxed{I \approx -I_0}$

Note:- This above equation is valid as long as $V < V_{Br}$. i.e. reverse applied voltage is less than reverse breakdown voltage.

Q:- The reverse saturation current at room temperature is 0.3 uA when a reverse bias is applied to a germanium diode. Find the value of current flowing in the diode when 0.15V forward bias is applied at room temperature.

Sol:- Given, $I_0 = 0.3\,\mu A = 0.3 \times 10^{-6} A$

Now, Diode current, $I_F = I_0 \left[e^{V_F/nV_T} - 1 \right]$

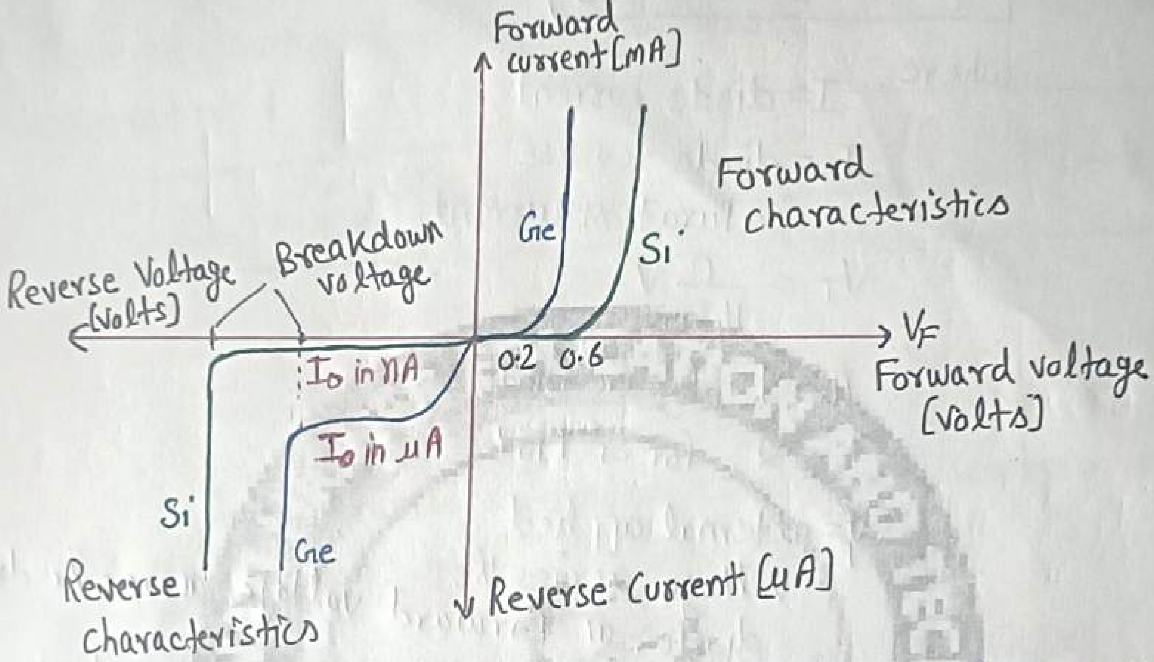
$$= 0.3 \times 10^{-6} \left[e^{0.15/1 \times 26 \times 10^{-3}} - 1 \right]$$

$$= 0.3 \times 10^{-6} \left[e^{5.769} - 1 \right]$$

$$= 0.3 \times 10^{-6} \times \left[320.217 - 1 \right]$$

$$I_F = 95.76\,\mu A$$

Complete V-I characteristics of Si and Ge Diode



(i) Cut-in voltage or knee voltage for Silicon and Germanium diodes are 0.6V and 0.2V respectively.

(ii) Breakdown voltage V_{BR} of Silicon diode is higher than that of the Germanium diode.

(iii) The reverse saturation current I_0 for a Ge Diode is in few μA whereas that for a silicon diode, it is in nA.

S.No.	Parameter of Comparison	Silicon Diode	Germanium Diode
1	Material used	Silicon	Germanium
2	Cut-in voltage	0.6V	0.2V
3	Reverse saturation Current	nano ampere	micro ampere
4	Effect of temperature	Less	More
5	Breakdown voltage	Higher	Lower
6	Applications	Rectifiers, clippers, clampers etc	Low voltage Low temperature applications

Effect of temperature on the V-I characteristics

As we know, diode current is given as

$$I_F = I_0 \left[e^{V_F/nV_T} - 1 \right]$$

where, I = diode current

I_0 = diode reverse saturation current.

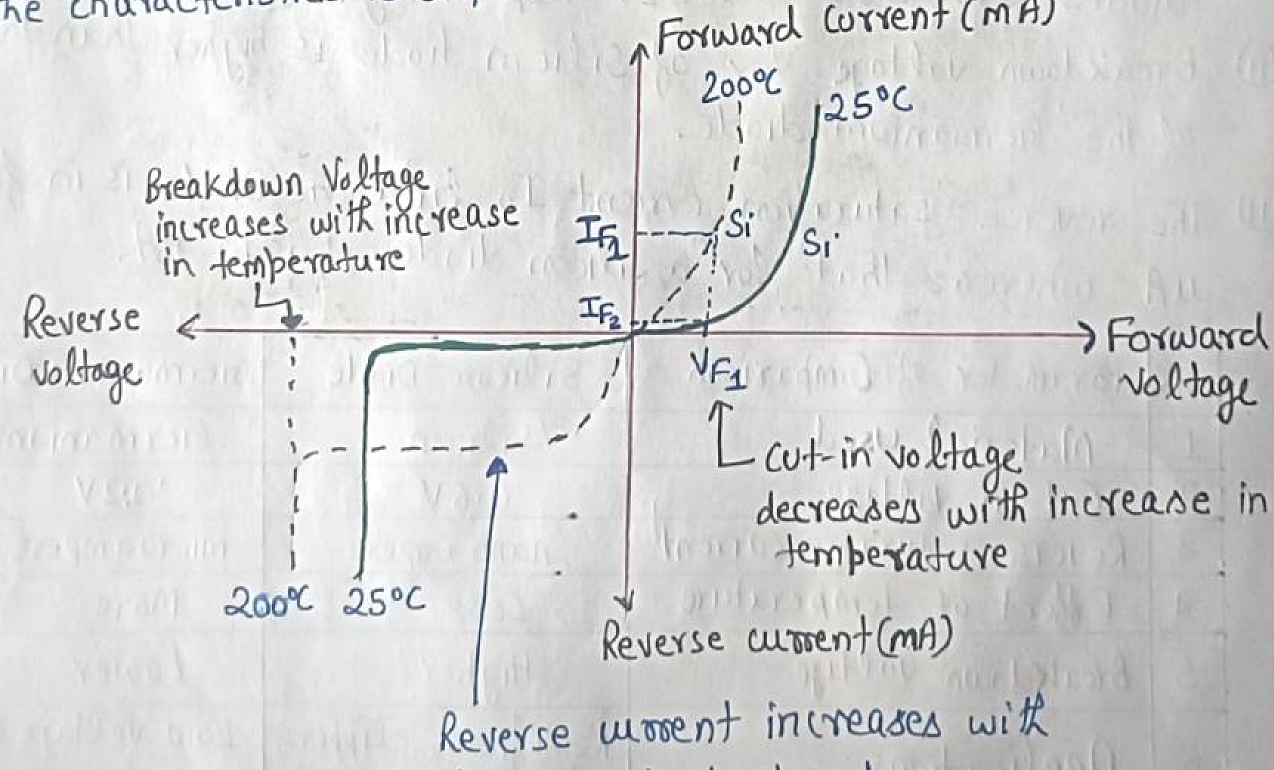
$V_T = \frac{T}{11,600}$ V

$\eta = 1$ for Ge Diode

2 for Si Diode

V_F = external applied voltage across the diode. or Forward voltage across the diode

Two parameters I_0 and V_T are temperature dependent. Hence, the characteristics is dependent on the temperature.



Conclusions

① Reduction in cut-in voltage takes place with increase in temperature.

(ii) The breakdown voltage increases with increase in temperature.

(iii) Reverse saturation current increases with increase in temperature.

Note:- $I_{o2} = [2^{\Delta T/10}] I_{o1}$ or, $I_{o2} = (2^{(T_2 - T_1)/10}] I_{o1}$

where,

I_{o1} = Reverse saturation current at T_1 temperature

I_{o2} = Reverse saturation current at temperature T_2.

and $\Delta T = |T_2 - T_1|$

(a) The reverse saturation current increases at a rate of 7% for every 1°C rise in temperature. Also, I_o doubles its value for every 10°C rise in temperature.

(b) I_o for Si Diode is lower than that of Ge Diode.

Q A Si Diode has a saturation current of 7nA at 25°C. Determine the saturation current at 100°C.

Sol:- Given, Reverse saturation current at 25°C = 7nA

i.e. $I_{o1} = 7nA$

$T_1 = 25°C$ and $T_2 = 100°C$

$\Delta T = T_2 - T_1 = 100 - 25 = 75°$

∴ Reverse saturation current, $I_{o2} = I_{o1}[2^{\Delta T/10}]$

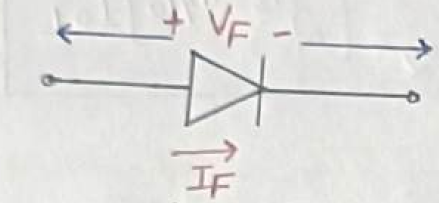
$= 7nA[2^{75/10}]$

$= 7nA \times 2^{7.5} = 1.267 \mu A$

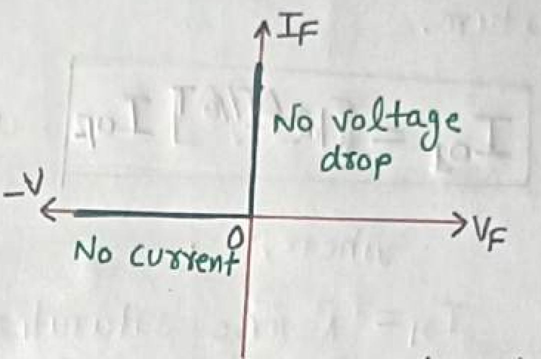
Ideal and Practical Diodes :- Diode Equivalent circuits

(I) An Ideal Diode :- First Approximation

Since the barrier potential V_T is very small, it can be neglected. In this case, the equivalent circuit is called ideal equivalent circuit.



Ideal diode
[when V_T is neglected]



Characteristic for ideal diode

From the characteristics of ideal diode, it can be observed that in forward bias there is zero voltage drop across the diode and the current flowing through the diode is maximum.
It means that in forward bias, diode is working as a perfect conductor.
In reverse bias, there is no current through the diode and it works as perfect insulator.

Forward bias

closed switch
[Diode ON]

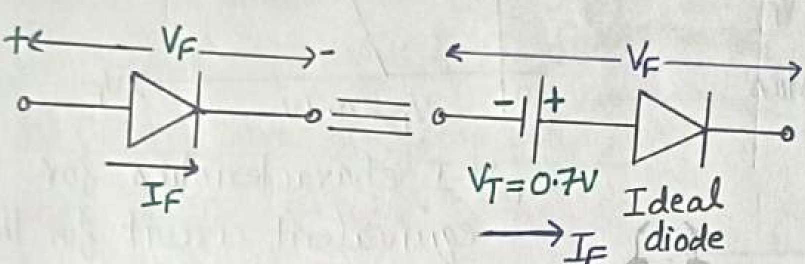
Reverse bias

Open switch
[Diode OFF]

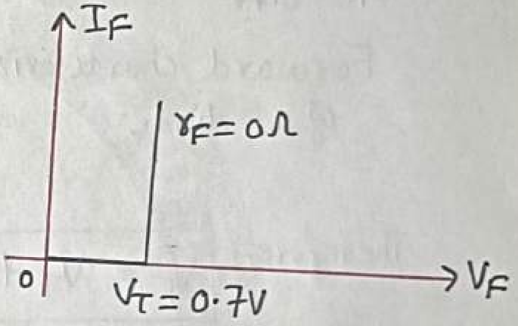
Ideal diode can also be used as a perfect switch. The switch is closed if the diode is forward bias and is open if the diode is reverse bias.

Clearly, it can be observed that an ideal diode offers zero resistance in forward bias because there is zero voltage drop [R= V/I] and infinite resistance in reverse bias because there is zero current [R= V/I]

(II) Simplified Equivalent Circuit: Second Approximation



Equivalent circuit for second approximation of a diode



V-I characteristics of a Silicon diode for second approximation.

For most of the applications of diode, the forward resistance r_F is very small. If it is neglected then not much error is introduced. Applying this concept, we get another equivalent circuit known as simplified equivalent circuit or the equivalent circuit for the second approximation of a diode.

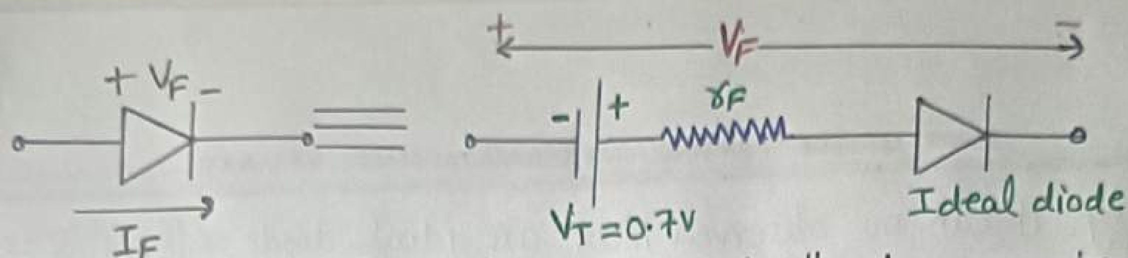
It can be noted from the V-I characteristics that if forward resistance r_F is zero, then at V_T (i.e. knee voltage] the current becomes a vertical straight line.

(III) Piecewise Linear Equivalent Circuit:- Third Approximation

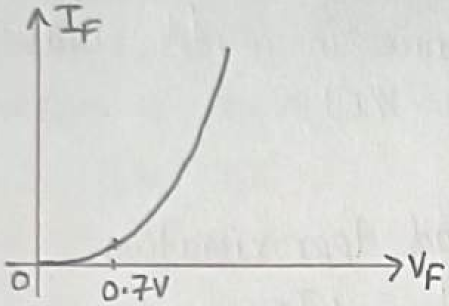
In this approximation, the forward voltage drop V_F has to overcome two voltage drops i.e.

(a) Potential barrier V_T [0.7V for Si and 0.3 V for Ge]

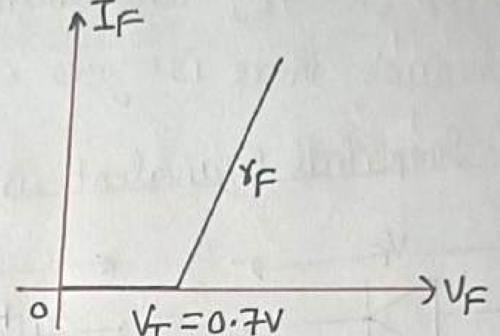
(b) forward resistance drop or internal drop $I_F \cdot r_F$.



Equivalent circuit to third approximation



Forward characteristics of a diode



V-I characteristics for equivalent circuit for third approximation

Therefore, $V_F = V_T + I_F r_F$

where, r_F = forward resistance which is varying because the V-I characteristics curve is non-linear.

Now, if the V-I characteristic is assumed as linear then forward resistance r_F is constant. Hence, due to this concept, we can replace the non-linear curve by straight-line segments. This type of equivalent circuit is known as third approximation of a diode.

Comparison of Ideal Diode and Practical Diode

S.No:-	Parameter of Comparison	Ideal Diode	Practical Diode
1:-	Forward Resistance	0 [zero]	Few Ohm [10-100 Ω]
2:-	Reverse Resistance	∞ [Infinite]	Few hundred KΩ [10-100KΩ]
3:-	Cut-in voltage	0 [Zero]	Si Diode → 0.6V Ge Diode → 0.2V
4:-	Reverse saturation current	0 [Zero]	Si Diode → nA Ge Diode → μA
5:-	Equivalent circuit in the Forward biased state	Closed switch	A — r_F — V_T — D — K
6:-	Equivalent circuit in the Reverse biased state	Open switch	A — High resis R_R — K

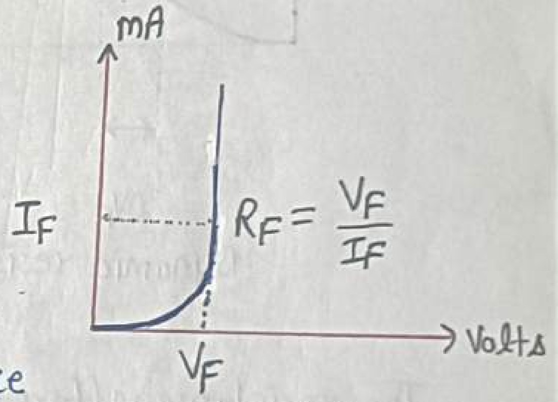
Diode Resistance

For practical diode, resistance is non-zero and finite. The resistance of a diode will change depending on the region of characteristics it is operating in. It can be classified as:-

ⓐ DC or Static Resistance [R_F]

ⓑ AC or Dynamic Resistance (r_F)

ⓐ DC or Static Resistance [R_F]



DC or Static Resistance.

When a DC voltage is applied to a diode, a DC current will flow through it and the operating point on the characteristic curve of the diode will not change its position with time. The resistance of a diode can be obtained by the ratio of V_F and I_F. This resistance is called as DC or Static resistance and it is denoted by R_F.

$$\text{Static Resistance, } R_F = \frac{V_F}{I_F}$$

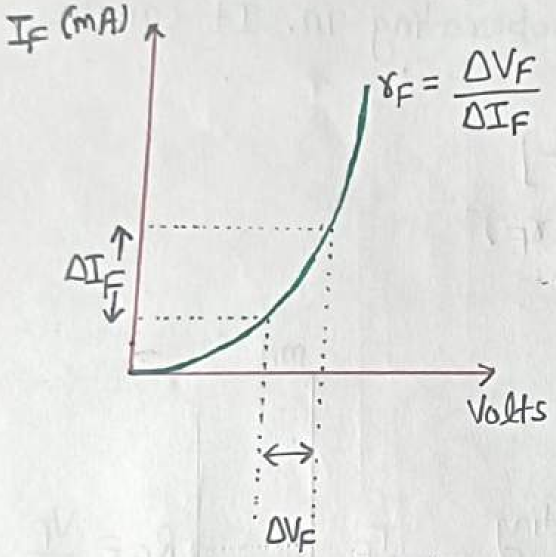
Similarly, we can define the static resistance of a diode in the reverse biased condition as R_r. It is the ratio of reverse voltage to reverse current at a particular operating point.

Range:- $R_F \Rightarrow 10\Omega$ to 50Ω

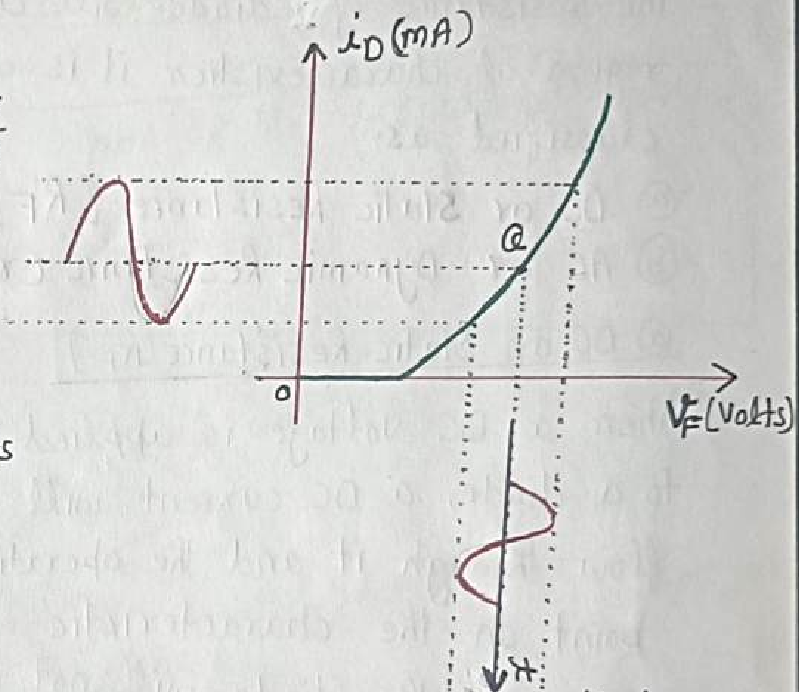
$R_r \Rightarrow$ few hundred $K\Omega$ [$10 - 100K\Omega$]

(b) AC or Dynamic Resistance (r_F)

When an AC voltage is applied, the operating point of the diode does not remain fixed. Its position will keep changing continuously, due to change in the input voltage.



Dynamic resistance



Variation in diode current due to ac voltage

The resistance offered by a diode to the AC operating conditions is known as the Dynamic Resistance or Incremental Resistance or AC Resistance. It is denoted by r_F and is given as

$$\text{Dynamic Resistance, } r_F = \frac{\Delta V_F}{\Delta I_F}$$

Also; $$\text{Dynamic Resistance, } r_F = \frac{1}{\text{slope of the characteristics}}$$

A reverse dynamic resistance can also be defined as the reciprocal of slope of the reverse characteristics. The reverse dynamic resistance is very large.