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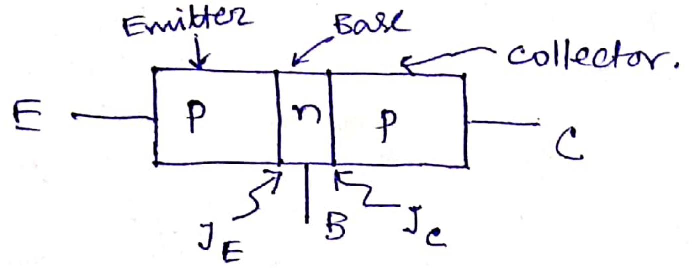
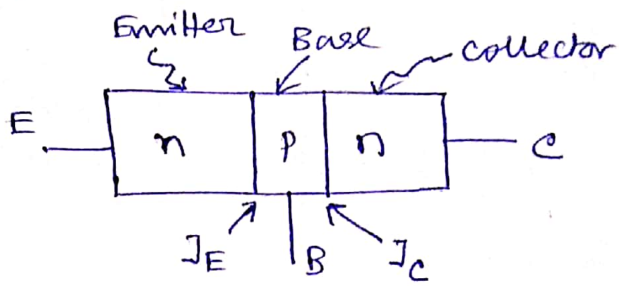
BIPOLAR JUNCTION TRANSISTOR

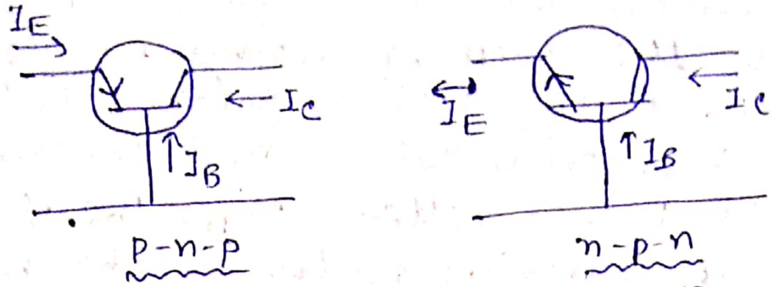
A BJT is a three layer, two junction semiconductor device. It is formed by sandwitching a p-type or an n-type material between two opposite types of material forming either an n-p-n and p-n-p transistor. The three regions of a transistor are called emitter, base and collector. p-n-p and n-p-n transistors are schematically shown in fig. The middle portion of the transistor is called the base, and the two end portions are known as emitter and





the collector. The emitter-base junction is usually reffer to as the emitter junction (J_E) and the collector base junction is reffer to as collector junction (J_c). Since both the majority and minority carriers are involved in a junction transistor, this device is termed the bipolar junction transistor (BJT).

In the normal transistor operation, emitter base junction is forward biased and the collector base junction is reverse biased. The circuit symbols for the p-n-p and n-p-n transistor is shown in fig. The arrow on the emitter specifies the direction of the current when emitter base junction is forward biased.

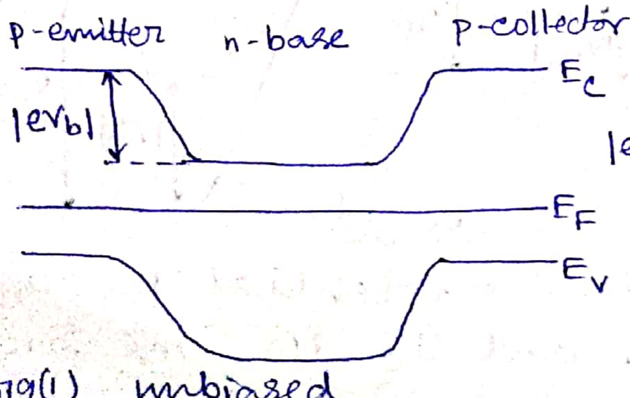


Therefore, the current enters the transistor through the emitter terminal for a p-n-p transistor and leaves the transistor through the emitter terminal for an n-p-n transistor.

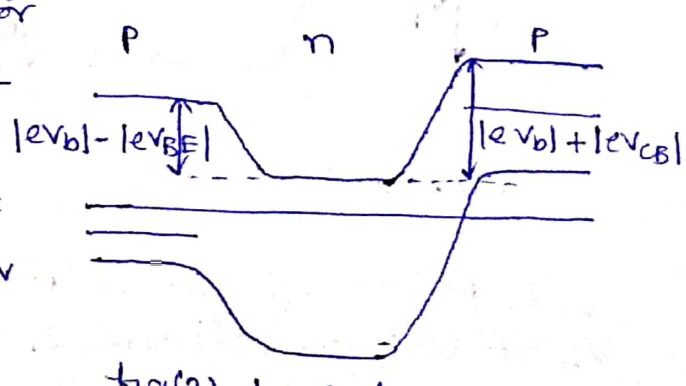
In transistor the emitter layer is heavily doped and the collector only lightly doped. The doping of base layer is also made considerably lower than that of the outer layers. For normal operation emitter base junction is forward biased and collector base junction is reverse biased. The emitter (in p-n-p transistor) injects holes into base and these holes are finally collected by the collector. Since the EB junction is forward biased its dynamic resistance is small and since the C-B junction is reverse biased its dynamic resistance is large. Due to transistor action it is found that an almost same current passes from a low resistor input circuit to a high resistor output circuit. The term transistor has been derived from the words 'transfer resistor'.

Energy band diagram of a Transistor :-

In fig (1) shows the energy band diagram of an unbiased transistor with completely symmetric p-n junctions, where V_b is the



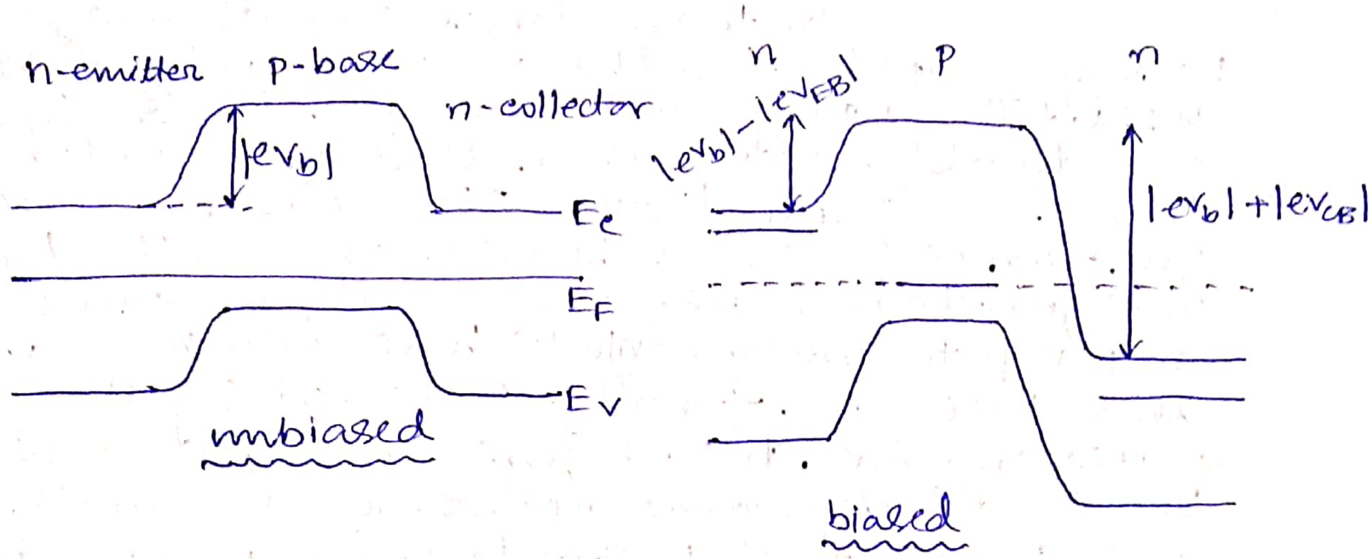
fig(1) unbiased



fig(2) biased

(3)

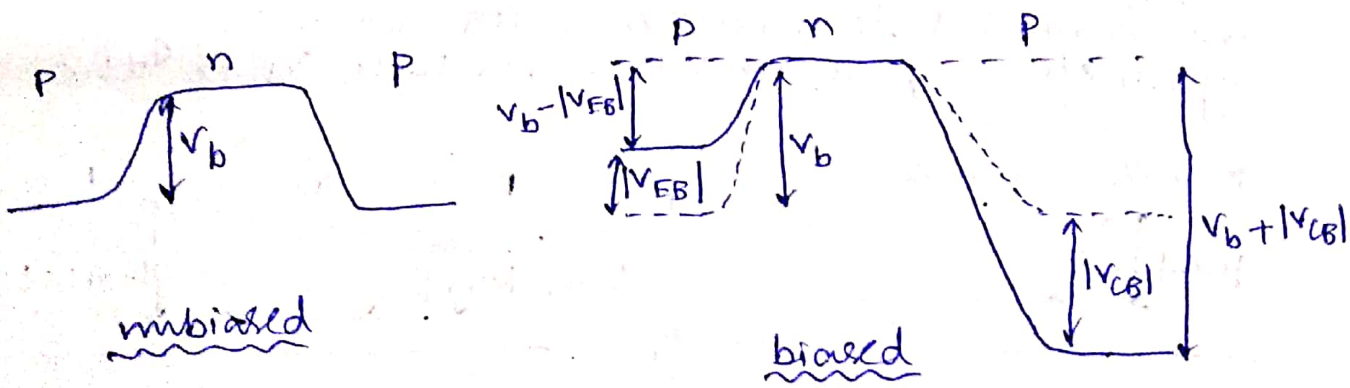
intrinsic potential barrier at the two junctions. In fig (2) shows the corresponding energy band diagram with E-B junction forward biased by a voltage V_{EB} and collector base junction reverse biased by a voltage V_{CB}. The forward biasing of E-B junction reduces the intrinsic energy barrier $|eV_b|$ to the $|eV_b| - |eV_{EB}|$ and the reverse biasing of CB junction increases the energy barrier to $|eV_b| + |eV_{CB}|$. Similar diagram for n-p-n transistor.



Transistor operation and current component :-

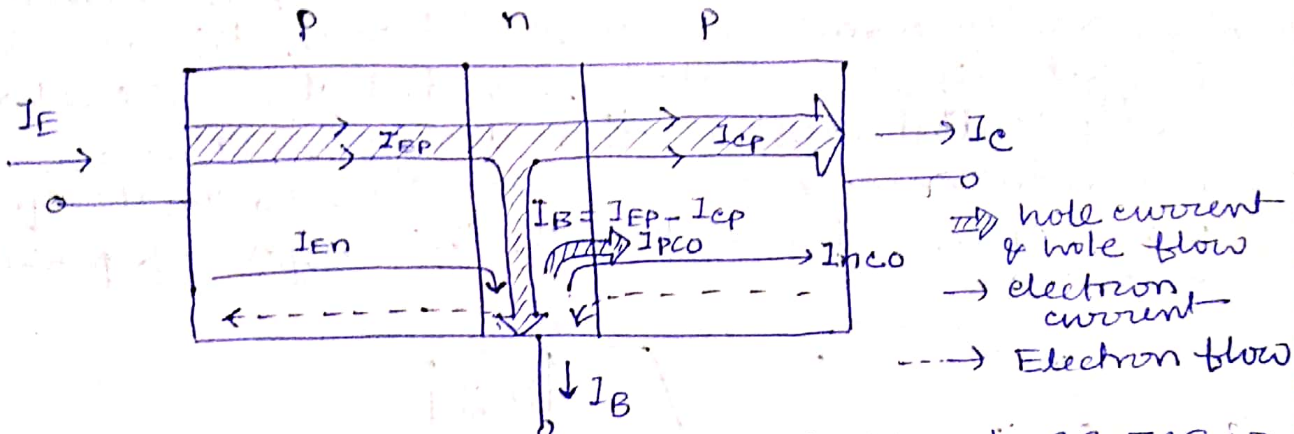
for p-n-p transistor :-

We consider a p-n-p transistor with its E-B junction forward biased and C-B junction reverse biased. In the absence of any external bias all the currents through the transistor must be zero. In fig shows the potential distribution in an unbiased p-n-p transistor.



and there is an intrinsic potential barrier V_b at the junctions J_E and J_C. Now the forward biasing voltage V_{EB} reduces the emitter base potential barrier to $V_b - |V_{EB}|$ whereas the reverse biasing voltage V_{CB} increases the potential barrier across collector to $V_b + |V_{CB}|$

The lowering of emitter junction barrier permits injection of holes from emitter to base and injection of electrons from base to emitter. This two flows constitute the emitter current as $I_E = I_{PE} + I_{nE}$ where I_{PE} is due to holes moving from emitter to base and I_{nE} is due to electrons going from base to emitter. As doping of emitter region is much higher than that of the base. So $I_{PE} \gg I_{nE}$



The injected holes diffuse through the base region towards the collector junction, while diffusing through the base a few of the injected holes (typically 1-3%) are lost due to recombination with majority electrons in the base. The hole reaching the collector junction fall down the potential barrier and are immediately collected by the collector. This gives rise to the component I_{PC} of the collector current. I_{PC} is slightly smaller than I_{PE} and the difference $(I_{PE} - I_{PC})$ constitutes a part of the base current. Since the collector junction is reverse biased there is a small collector current even with emitter open. This ~~coo~~ current consists of two components: I_{nco} due to minority electrons flowing from p-side to n-side across ~~car~~ collector junction J_c and I_{PCO} due to minority

(5) holes moving from n-side to p-side across J_C. The resultant $I_{nco} + I_{pco} = I_{co}$ = reverse saturation current.

We can now express the terminal currents in term of the various current component describe above :-

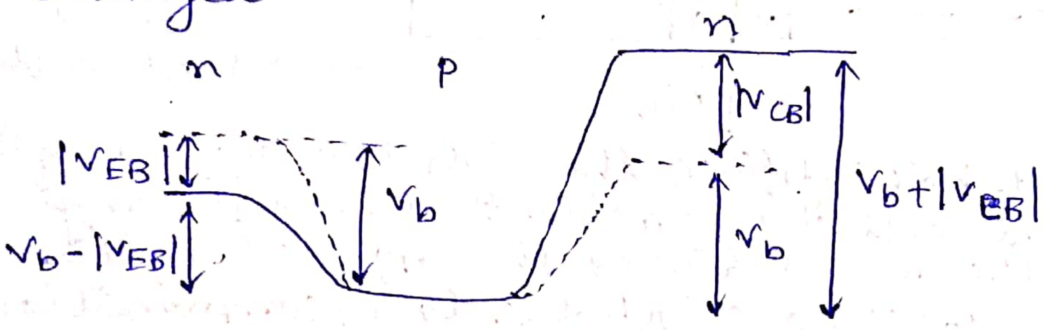
$$I_E = I_{EP} + I_{En}$$
$$I_C = I_{pC} + I_{nC}$$

$$I_B = I_E - I_C$$
$$= (I_{EP} + I_{En}) - (I_{pC} + I_{nC})$$

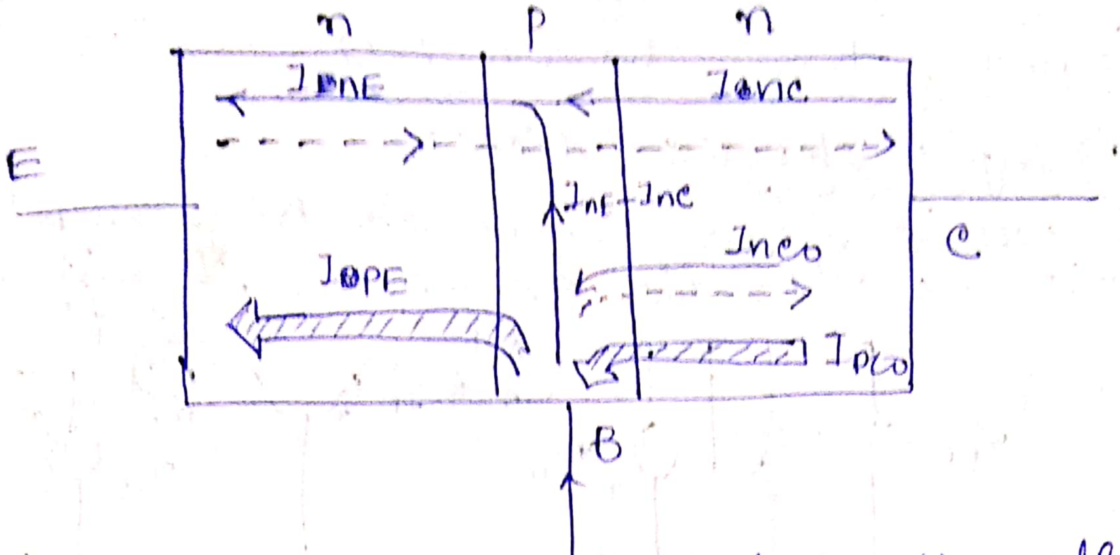
$$I_E = I_B + I_C$$

for n-p-n transistor :-

The operation of an n-p-n transistor is exactly same as above but with the roles played by the electrons and holes interchange. The potential distribution diagram for an n-p-n transistor will be similar to that of a p-n-p transistor but with the sign of potential changed.



Here the majority electrons from emitter are injected into the base and majority holes from base are injected into emitter region. The two constitutes the emitter current as $I_E = I_{nE} + I_{pE}$. Since the doping of emitter region is much higher than that of the base, $I_{nE} \gg I_{pE}$ and we have $I_E \approx I_{nE}$. The injected electrons diffuse through base towards the collector junction. A few of injected electrons are lost due to recombination with majority holes in the base. The electrons reaching the



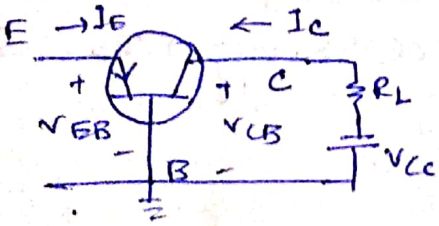
collector junction are collected by the collector and give rise to the current component I_{nC}. The difference $I_{nE} - I_{nC}$ constitutes a part of base current. Since the collector junction is reverse biased there is also reverse saturation current through the junction. This component is denoted by I_{CO}. It consist of two part: I_{nCO}, due to movement of minority electrons from base to collector. and I_{pCO}, due to movement of minority holes from collector to base.

So, $I_{CO} = I_{pCO} + I_{nCO}$. So total collector current is $I_C = I_{nC} + I_{CO}$.

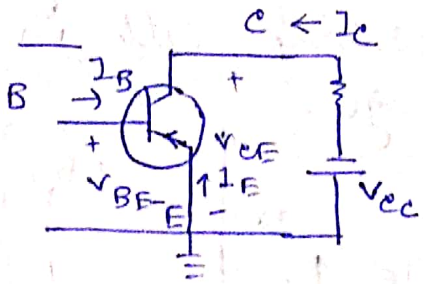
and $I_E = I_B + I_C$.

Mode of transistor operation :-

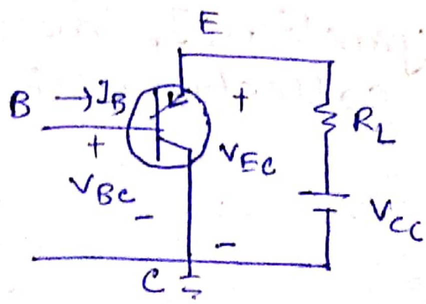
A transistor can be operated in any of the following three modes depending on the common terminal between the i/p and o/p terminal.



CB config



CE config



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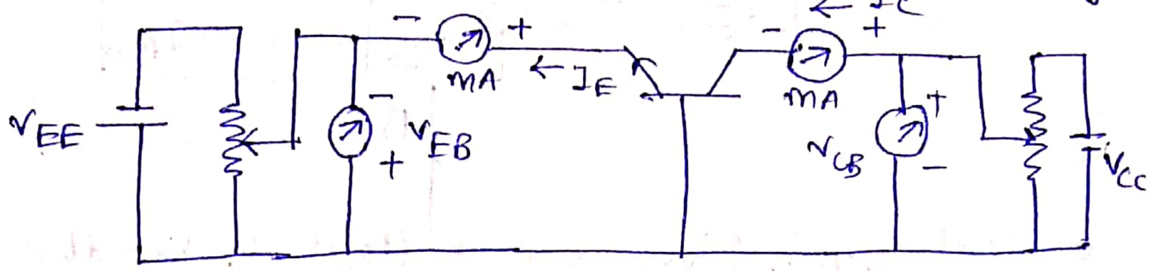
Characteristic curves of a transistor :-

Common Base Characteristics :-

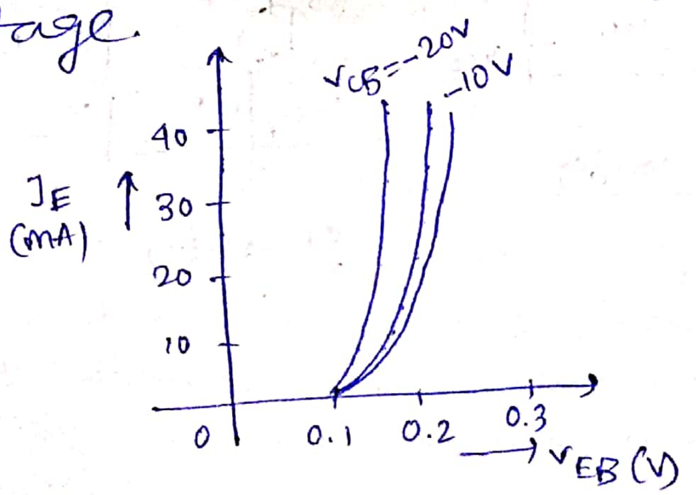
a) Input characteristics :-

The circuit arrangement for drawing the CB static characteristic curves as shown in fig



a) Input characteristics :-

For normal operation, the emitter base junction is biased in forward direction. Therefore, the variation of I_E with V_{EB} with fixed V_{CB} is similar to the forward characteristic of a p-n diode. However with an increase of $|V_{CB}|$ I_E increases for a fixed V_{EB}. When $|V_{CB}|$ increases, the width of the deplation region at the collector base junction increases, thereby reducing the effective base width. The change of effective base width by the collector voltage is termed by the Early effect. The decrease of the effective base width enhance the concentration gradient of holes in the base region. Since the hole current injected across the emitter junction is proportional to the hole concentration gradient at that junction, I_E increases with increasing reverse collector voltage.

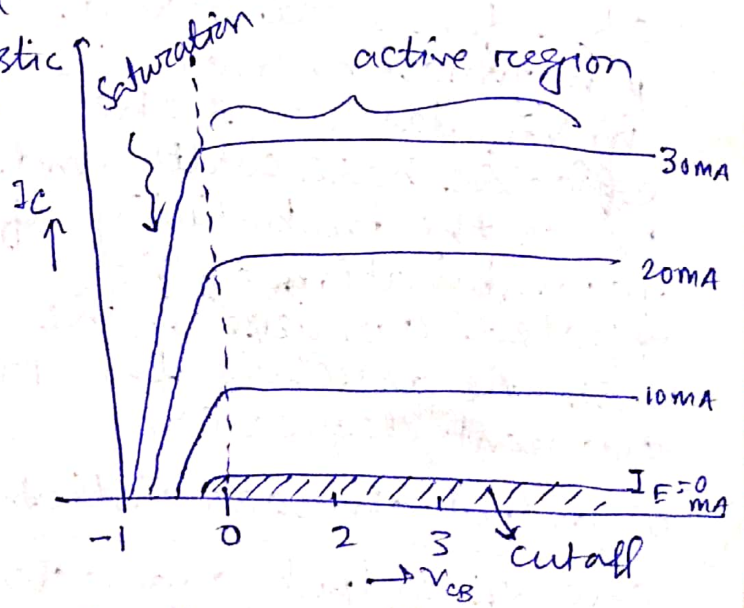


b) output characteristics :-

for the CB mode, the collector current I_C is the o/p current, the collector-base voltage V_{CB} is the o/p voltage and emitter current I_E is the i/p current. So, the plot of I_C vs V_{CB} with I_E as a parameter is the CB o/p characteristic. The o/p characteristics can be divided into three distinct regions, namely, the active region, the saturation region and the cut off region.

In active region transistor used as an amplifier. In this region, the emitter junction is forward biased and collector junction is reverse biased. When the emitter junction is forward biased, an emitter current I_E flows. Since the recombination in the base region is small, most of the current will reach the collector. However $|I_C|$ rises slightly with an increase of $|V_{CB}|$. and o/p characteristics are nearly parallel lines.

In saturation region, both emitter & collector junctions are forward biased. In fig it represents the region to the left of the ordinate $V_{CB}=0$ and above the characteristic for $I_E=0$. It is seen that I_C is not zero even when $V_{CB}=0$. This happens so because the injected carriers still find a potential down at the collector junction due to contact potential difference.



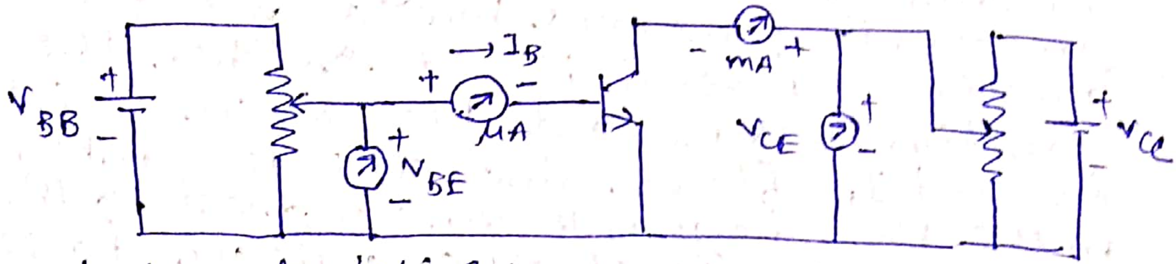
To reduce I_C to zero it is necessary to apply a small forward bias to the collector. and this causes the collector current exponentialy with collector base forward

(9) voltage as in a p-n diode. The large change in the collector current for a small change in V_{CB} in the saturation region is thus accounted for.

In cut off region both the emitter and collector junctions are reverse biased. In fig this region is located to the right of the ordinate $V_{CB} = 0$ and below the characteristic for $I_E = 0$

Common Emitter characteristics :-

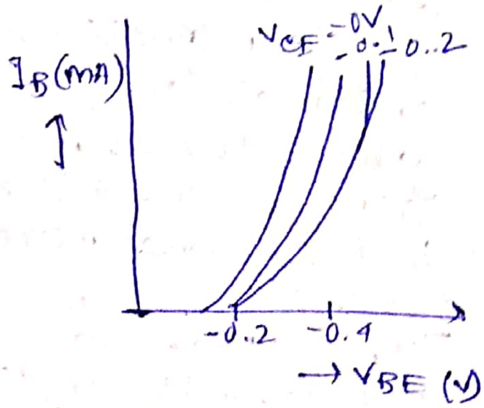
The circuit arrangement for drawing the CE characteristics of the most prevalent n-p-n transistor is shown in fig. below -



a) Input characteristics ;-

The variation of the i/p base current (I_B) with i/p base emitter voltage V_{BE} taking the o/p collector emitter voltage V_{CE} as parameter, gives the CE input characteristics as shown in fig

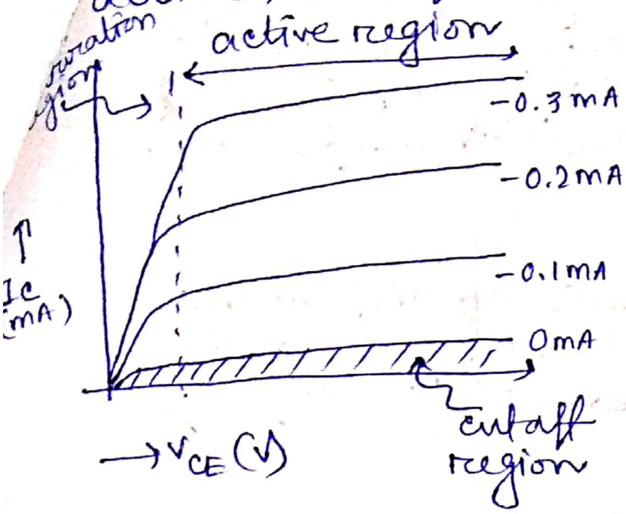
The characteristics are similar to that of a forward biased p-n junction. Increase in V_{CE} decreases the effective base width and hence the probability of recombination of the injected carriers in the base. As a result the recombination base current decreases.



b) output characteristics ;-

The CE output characteristics are obtained by plotting output current I_C as a function of the o/p voltage V_{CE} taking i/p base current I_B as parameter as shown in fig. Here the curve may be divided into three regions -

active, cut off and saturation regions.



In this region, the collector junction is reverse biased and the emitter junction is forward biased. The active region is located to the right of the ordinate V_{CE} = a few tenths of a volt and above the characteristics for $I_B = 0$. If a transistor is to be used as an amplifier with out much distortion, it has to be operated in the active region. The curves in the active region are not horizontal lines.

In CE configuration, the collector current is not cut off when $I_B = 0$, To cut off the transistor, in addition to reducing I_B to zero, the emitter junction has to be reverse biased slightly.

In this region, both the collector and emitter junctions are forward biased by at least the cutin voltage. Since the voltage $|V_{EB}|$ or $|V_{CB}|$ for a forward biased junction is only a few tenths of a volt and $V_{CE} = V_{CB} - V_{EB}$, we find that V_{CE} is also a few tenths of a volt at saturation. So, the saturation region lies very close to the zero voltage axis, when all the curves coincide and fall quickly towards the origin.

What is α and β of a transistor :-

The quantity α represents the friction of the emitter current contributed by the carriers injected into the base and reaching the collector. α is called the dc current gain of the common base transistor.

$$\alpha = \frac{I_C}{I_E}$$

α lies between 0.95 and 0.995. α is not a constant for a given transistor but varies with the emitter current I_E, collector voltage V_{CB} and the temparature.

The maximum current gain of a transistor operated in the common-emitter mode is denoted by β. It is also denoted by ~~hfe~~ h_{FE}. It is also called forward current transfer ratio.

$$\beta(h_{FE}) = \frac{I_c}{I_B}$$

commercial transistor have value of h_{FE} in the region from 20 to 200. The value of β is not same for any two transistor even belonging to the same type.

Relation between α and β :-

we know that, $I_E = I_c + I_B$

$$\Rightarrow \frac{I_E}{I_c} = 1 + \frac{I_B}{I_c}$$

$$\Rightarrow \frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\Rightarrow \frac{1}{\beta} = \frac{1}{\alpha} - 1$$

$$= \frac{1-\alpha}{\alpha}$$

$$\Rightarrow \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

Establish the relation $I_c = \beta I_B + (1+\beta) I_{co}$:-

we know that, $I_c = \alpha I_E + I_{co}$

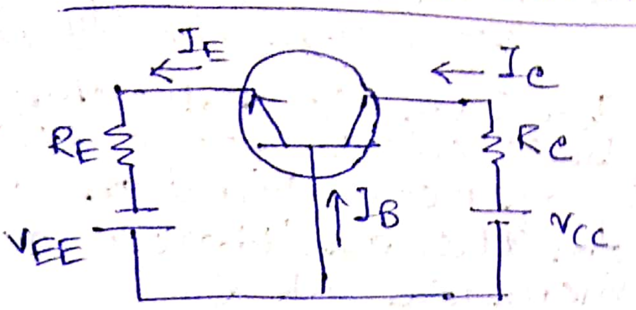
$$= \alpha(I_B + I_c) + I_{co}$$

$$\Rightarrow I_c(1-\alpha) = \alpha I_B + I_{co}$$

$$\Rightarrow I_c = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{co}$$

$$= \beta I_B + (1+\beta) I_{co}$$

Transistor as an amplifier :-



Total power across the i/p

$$P_E = I_E^2 R_E$$

Total power across the o/p

$$P_C = I_C^2 R_C$$

power gain, $A_p = \left| \frac{\text{o/p power}}{\text{i/p power}} \right| = \left| \frac{P_C}{P_E} \right|$

$$= \frac{I_C^2 R_C}{I_E^2 R_E}$$

$$= \frac{I_C^2 R_C}{(I_B + I_C)^2 R_E}$$

$$= \frac{I_C^2 R_C}{I_C^2 R_E} \quad [\because I_B << I_C]$$

$$= \frac{R_C}{R_E}$$

As, $R_C >> R_E$, $\therefore A_p > 1$

Thus a weak signal applied in the i/p circuit appears in the amplified form in the collector circuit. Thus transistor act as an amplifier.

What is punch through?

As the reverse bias of the collector junction is increased, the effective base width decreases (Early effect). At a certain reverse bias of the collector junction, the depletion region covers the base, reducing the effective base width to zero. As the collector voltage penetrates the base, the potential barrier at the emitter junction is lowered. As a result an excessively large emitter current flow. This phenomenon is called punch-through.