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Sem - IV (H)
Paper - C10 T

Topic - Transistor

1. What is "early effect"?

Early effect:- If the reverse bias voltage $|V_{CB}|$ of the collector junction is increased the width of the depletion region of the collector base junction increases. This reduces the effective width by collector voltage is known as "early effect". It is also called base width modulation.

2. What do you mean by "Punch through"?

Punch through := When the reverse bias of the collector junction is increased, the effective base width decreases due to early effect. At a certain reverse bias of the collector junction the deplection region covers the base i.e effective base width becomes zero. Then the potential barrier at the emitter junction is lowered. As a result, an excessively large emitter current flows. This phenomena is called punch through.

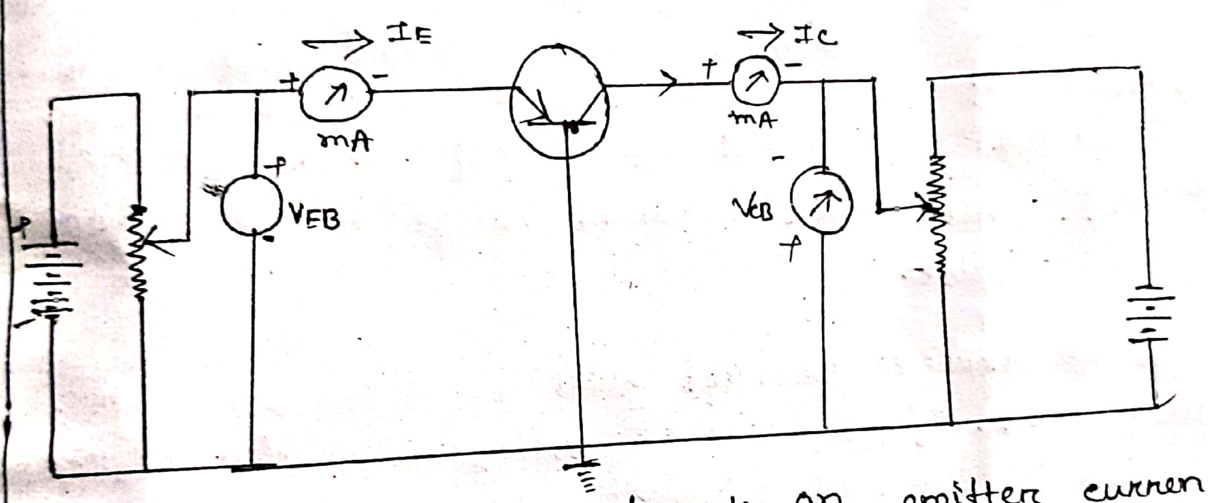
3. Why is biasing of transistor is necessary?

Ans:= Biasing of a transistor means d.c sources are are connected to the emitter - base junction such that the junction is forward biased and d.c sources are connected to the collector - base junction such that the junction is reverse biased. Also the establishment of the d.c operating pt. at suitable location on the active region of the characteristics must necessary for stability of biasing.

Thus d.c sources are necessary to make the transistor able to amplify signals. So to analyse the performance of a transistor amplifier it becomes important.

Common- Base characteristics

Circuit diagram :-



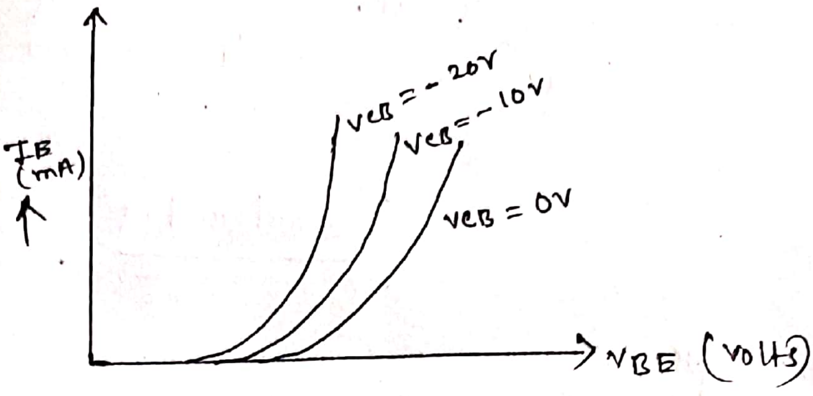
The collector current depends on emitter current and collector to base ~~current~~ voltage i.e $I_c = f(I_E, V_{CB})$

The emitter-base voltage depends on emitter current and collector to base voltage i.e $V_{EB} = f(I_E, V_{CB})$.

Here, the input current is the emitter current (I_E)
the input voltage is the emitter base voltage (VEB
the output current is the collector current (I_c)
the output voltage is the collector-base voltage (vc

Input characteristics :-

The plot of I_E against V_{EB} with V_{CB} as a Parameter is called input characteristics for the CB mode.



In the normal operating region of a transistor the emitter-base junction is forward biased and the input characteristics are similar to that of a forward biased p-n junction. I_E increases exponentially with the increase of $|V_{EB}|$. There exists a cut-in voltage V_γ below which I_E is negligible.

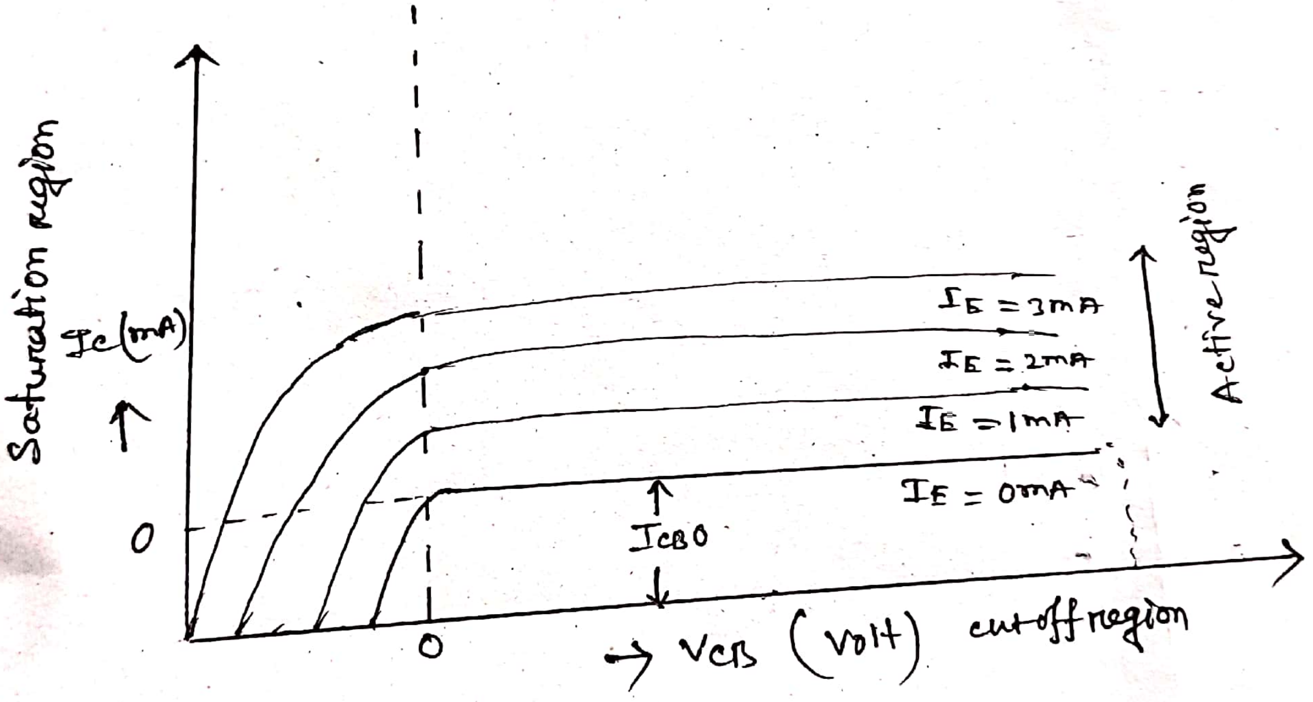
An increase in $|V_{CB}|$ causes I_E to increase with a given V_{EB}. If the reverse voltage $|V_{CB}|$ of the collector junction is increased the width of the depletion region of the collector-base junction increases. This reduces the effective width of the base region, which is called early effect.

Due to early effect, the gradient of minority carriers in the base region increases. The injected carrier travel through the base by diffusion, hence I_E increases with $|V_{CB}|$.

output characteristics :-

In CB mode the variation of the output collector current (I_C) with output collector base voltage (V_{CB}) taking input emitter current (I_E) as parameter, gives the static output characteristics.

output characteristics have there distinct regions -



a) **Active region :**

In this region emitter junction is forward biased and the collector junction is reverse biased. Above to the ordinate $I_E = 0$ and right to the ordinate $V_{CB} = 0$ is active region.

At the lower end of the active region ($I_E = 0$), the collector current is simply the reverse saturation current I_{CBO}. Now as I_E increases above zero, the collector current $I_C = \alpha I_E + I_{CBO} \approx \alpha I_E$

Since α is close to unity, I_C is slightly smaller than I_E. In this region collector current is almost independent of V_{CB}. Increase in V_{CB}, effective base width decreases. It reduces the probability of recombination of carriers, while diffusing through the base. Thus I_C is increased very slightly.

b) **Saturation region :**

In this region, both the emitter and collector junctions are forward biased. Left to the ordinate $V_{CB} = 0$ and above to the ordinate $I_E = 0$ is the saturation region.

It is seen that I_C is not zero even when $V_{CB} = 0$. To reduce I_C to zero it is necessary to apply a small forward bias to the collector. In an n-p-n transistor under forward biased condition electrons flow from n collector to p base. For a forward bias, I_C increases exponentially with voltage according to diode relationship.

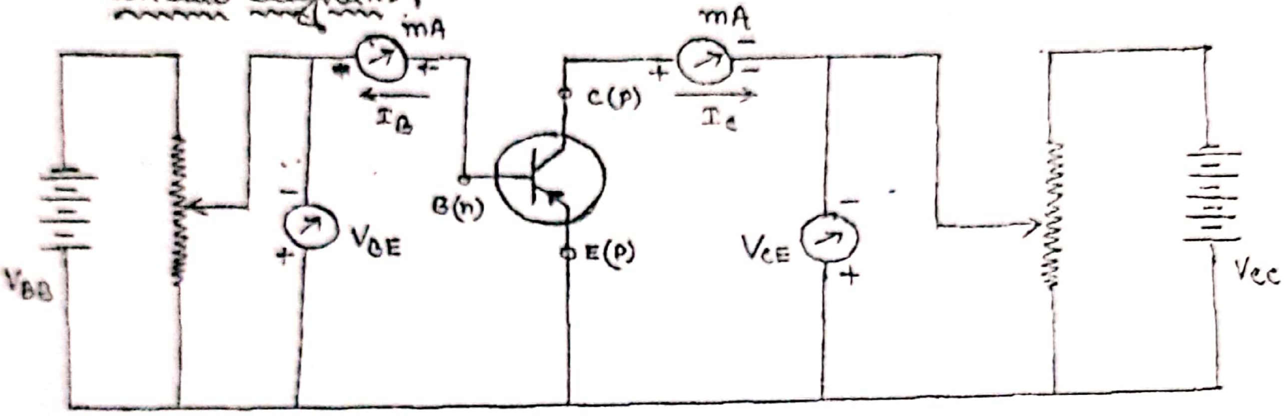
c) **Cut-off region :**

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

Common - Emitter Characteristics :-

Question : Draw the circuit diagram of a p-n-p transistor in common-emitter (CE) mode and discuss the input and output characteristics. V.U - 2006, 2007

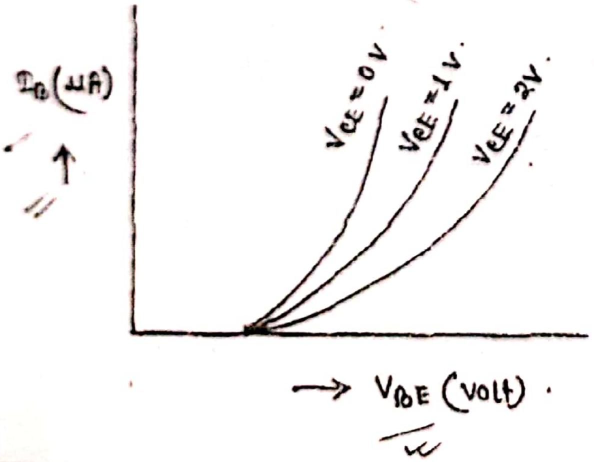
Circuit diagram :



Here, the input current is the base current (I_B)
the input voltage is the base-emitter voltage (V_{BE}).
the output current is the collector current (I_c)
the output voltage is the collector-emitter voltage (V_{CE}).

Input characteristics :

The plot of I_B against V_{BE} with V_{CE} as a parameter is the input characteristics for the CE mode.

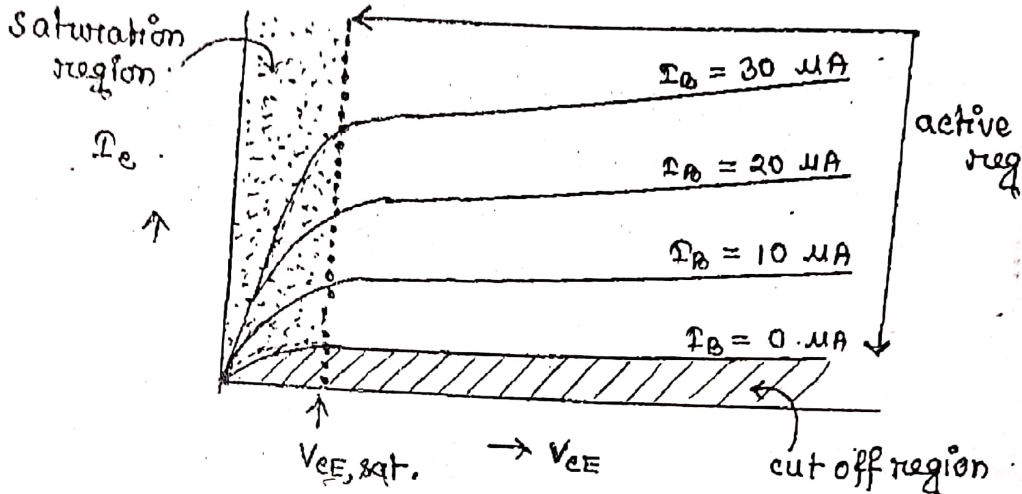


The characteristic curves are similar to that of a forward biased p-n junction. For a constant V_{BE}, I_B decreases with increase in V_{CE}. Increase in V_{CE}, effective base width decreases, as a result the recombination base current decreases.

Output characteristics :

The plot of I_C against V_{CE} with I_B as a parameter is kn as output characteristics in CE mode.

The output characteristics consist of three distinct regi



a) Active region :

In this region, the collector junction is reverse biased and the emitter junction is reverse biased. The active region is located right to the ordinate V_{CE} = a few tength of a volt. and above the characteristic $I_B = 0$.

The curves in the active region are not horizontal lines. For a fixed I_B, $|I_C|$ increases due to base width modulation or Early effect.

b) Saturation region :

In this region both the emitter and collector junctions are forward biased.

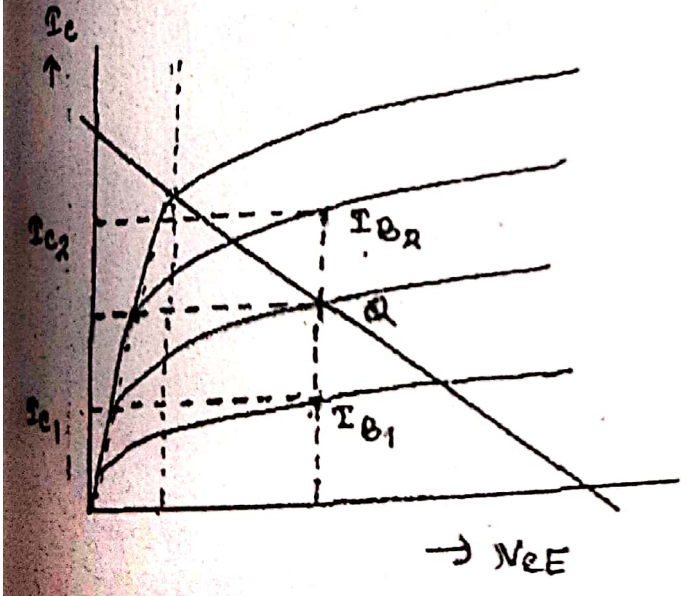
Since the forward biasing voltage V_{EB} and V_{CB} are only a few tenths of a volt, $V_{CE.sat.} = V_{CB} - V_{EB}$ is also a few tenths of a volt. In this region collector current becomes almost independent of base current.

c) Cut off region :

With $I_B = 0$, $I_C = -(\beta+1) I_{CBO} = I_{CEO}$ is the collector to emitter current with the base is open. Since $\beta >> 1$, I_{CEO} has significant value and hence it is not enough to make $I_B = 0$ to cut off the transistor. The cut off condition occours when $I_E = 0$, $I_B = -I_{CBO}$ and $I_C = I_{CBO}$. This occours only when emitter junction is reverse biased.

Hence in cut off region both the emitter and collector junctions are reverse biased..

Explain how the two constants of a transistor can be obtained from output characteristics in CE mode. (V.U-2006).



Two constants are β_{dc} and β_{ac}

Where $\beta_{dc} = \frac{I_C}{I_B}$.

and $\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\Big|_{V_{CE} = constant.}$

From the o/p characteristics. choosing Q point, we can calculat

$$\beta_{dc} = \frac{I_{C2}}{I_{B2}} \text{ or } \frac{I_{C1}}{I_{B1}}.$$

We cal calculate $\beta_{ac} = \frac{I_{C2} - I_{C1}}{I_{B2} - I_{B1}}$. from the figure.

Problem ① In a transistor connected in CE mode if the base current is changed from 20 μA to the collector current changes at a fixed $V_{CE} = 7.5$ Volt, the collector current changes 2.2 mA to 3.2 mA. Find $\beta_{a.c}$ and $\beta_{d.c}$ at the mea operating point.

Solution :

$$\beta_{a.c} = \frac{\Delta I_C}{\Delta I_B}\Big|_{V_{CE} = \text{constant}}$$

$$= \frac{(3.2 - 2.2)\ mA}{(30 - 20)\ \mu A} = \frac{1\ mA}{10\ \mu A} = 100.$$

$$\beta_{d.c} = \frac{I_C}{I_B} = \frac{(3.2 + 2.2)/2\ \ mA}{(30 + 20)/2\ \ \mu A}$$

$$= \frac{2.7\ mA}{25\ \mu A} = 108.$$

Problem ② An n-p-n transistor with $\alpha = 0.98$ is opera in the CB configuration. If the emitter cu is 3 mA and the reverse saturation curre is $I_{CO} = 10\ \mu A$, What are the base current and the collector current?

V.U-2002

Solution :

$$\alpha = 0.98$$

$$I_E = 3\ mA.$$

$$I_{CO} = 10\ \mu A = 10^{-2}\ mA.$$

$$\therefore I_C = \alpha I_E + I_{CO}.$$

$$= 0.98 \times 3\ mA + 0.01\ mA.$$

$$= \underline{2.95\ mA}.$$

Again $I_E = I_B + I_C$.

$$\Rightarrow I_B = I_E - I_C = 3\ mA - 2.95\ mA$$

$$= \underline{\underline{0.05\ mA}}.$$

Problem ③ : A transistor operating in CE mode draws a constant base current I_B of 30 μA. The collector current I_c is found to change from 3·5 mA to 3·7 mA when the collector emitter voltage V_{CE} changes from 7·5 volt to 12·5 volt. Calculate the output resistance and β at $V_{CE} = 12{\cdot}5$ volt. What is the value of α ?

V.U- 2003
C.U - 2002

Solution : Output resistance $R_0 = \dfrac{\Delta V_{CE}}{\Delta I_C}$

$$\cancel{= (3\cdot7 - 3\cdot5)\,mA}$$

$$= \frac{(12\cdot5 - 7\cdot5)\ \text{Volt}}{(3\cdot7 - 3\cdot5)\ mA}$$

$$= \frac{5\ \text{Volt}}{0\cdot2\ mA} = \underline{25\ K\Omega}$$

$$\beta = \left.\frac{I_C}{I_B}\right|_{V_{CE} = 12\cdot5V} = \frac{3\cdot7\ mA}{30\ \mu A} = \underline{123\cdot3}$$

$$\alpha = \frac{\beta}{\beta+1} = \frac{123\cdot3}{124\cdot3} = \underline{\underline{0\cdot992}}$$

Problem ④ : A transistor has α = 0·99 . If it is connected in CE mode what would be the change in collector current for a change of 10 μA in base current ?

Solution :

$\alpha = 0\cdot99$

$\Delta I_c = 10\ \mu A$

$$\therefore\ \beta = \frac{\alpha}{1-\alpha} = \frac{0\cdot99}{1-0\cdot99} = 99$$

$$\text{Again}\ \ \beta = \frac{\Delta I_c}{\Delta I_B}$$

$$\therefore\ \Delta I_B = \beta \cdot \Delta I_c = 99 \times 10\ \mu A = \underline{0\cdot99\ mA}$$

Problem ⑤ : A transistor in CE mode is connected with a resistance 5 KΩ and a power supply of 5 volt in the collector circuit. If $\alpha = 0.998$ and the voltage drop across the 5Ω resistor is 5 V, find the base current.

C.U - 2000

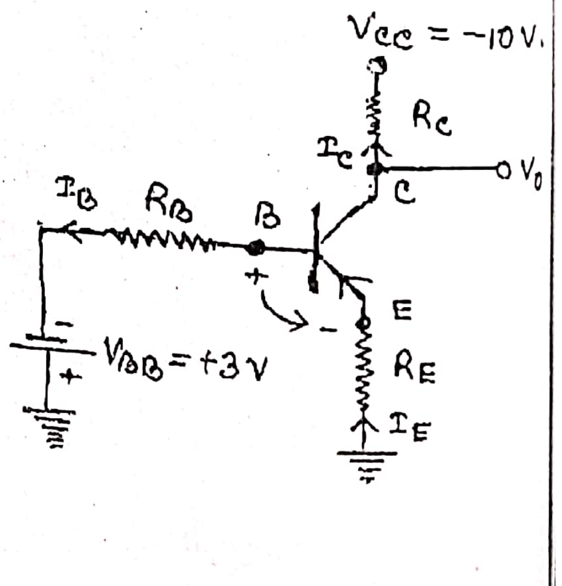
Solution :
$$I_C = \frac{V_{CC}}{R_C} = \frac{5\,V}{5\,K\Omega} = 1\,mA.$$

$$\text{and } \beta = \frac{\alpha}{1-\alpha} = \frac{0.998}{1-0.998} = 499.$$

Again
$$\beta = \frac{I_C}{I_B}$$
$$\therefore I_B = \frac{I_C}{\beta} = \frac{1\,mA}{499} \approx 2\,\mu A$$

Problem ⑥ : Suppose the transistor of the following circuit has $\beta = h_{fe} = 100$. Find whether the transistor is operating in the active, saturation or cut-off region (ii) the value of output voltage V_0. Assume $|V_{BE}| = 0.$ and $V_{CE \cdot sat} = 0.2\,V$.

C.U - 1998



Solution :

$R_B = 100\,K\Omega$

$R_C = 2\,K\Omega$

$R_E = 500\,\Omega$

We know $I_C = \beta I_B$.

and $I_E = I_B + I_C = (1+\beta) I_B$.

Apply KVL to the input circuit,
$$I_E R_E - V_{BE} + I_B R_B - V_{BB} = 0.$$
$$\Rightarrow \cancel{I_B} = \cancel{\frac{V_{BB} + V_{BE}}{R_B +}}$$
$$\Rightarrow (1+\beta) I_B R_E + I_B R_B = V_{BB} + V_{BE}$$
$$\Rightarrow I_B = \frac{V_{BB} + V_{BE}}{R_B + (\beta+1) R_E}$$

$$\therefore I_B = \frac{(3-0.7)\text{ Volt}}{100+(100+1)\times 0.5\text{ K}\Omega} = 0.0153\text{ mA}.$$

$$\therefore I_C = \beta I_B = 100\times 0.0153\text{ mA} = 1.53\text{ mA}.$$

Apply KVL to the output circuit,

$$I_C R_C - V_{CC} - V_{CE} + I_E R_E = 0.$$

$$\Rightarrow V_{CE} = -V_{CC} + I_C(R_E + R_C) \quad \because I_E \approx I_C.$$

$$= -10\text{ V} + 1.53\text{ mA}\,(2+0.5)\text{ K}\Omega.$$

$$= -10 + 3.225\text{ Volt}$$

$$= \underline{-6.175\text{ volt}}.$$

Since $\underline{|V_{CE}| > V_{CE \cdot sat}}$ thus the transistor is operating in the active region.

ii). To find output, we apply KVL

$$V_o + V_{CC} - I_C R_C = 0.$$

$$\Rightarrow V_o = I_C R_C - V_{CC}.$$

$$= 1.53\text{ mA}\times 2\text{ K}\Omega - 10\text{ V}.$$

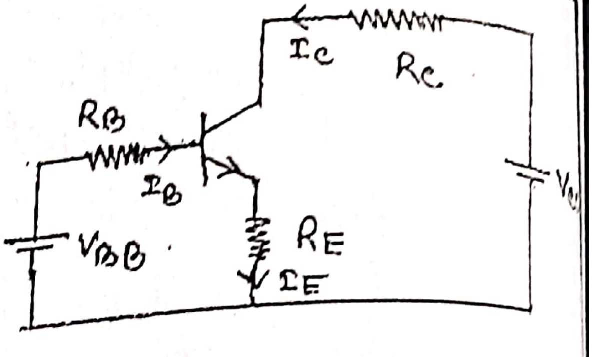
$$= \underline{-6.94\text{ volt}}$$

Problem ⑦

C.U - 1997

V.U - 2001

The transistor in the following figure has $\beta = 100$ an $I_{CBO} = 20$ nA. Calculate I_B, I_C and V_{CE} and hen decide in which region the transistor operates. Given: $V_{BE.active} = 0.7$ volt, $V_{BE.sat} = 0.8$ volt, $V_{CE.sat}$



Solution : $V_{BB} = 5$ volt

$V_{CC} = 10$ volt.

$R_C = 3\ K\Omega$

$R_B = 50\ K\Omega$.

$R_E = 2\ K\Omega$.

$$I_E = I_B + I_C = I_B + \beta I_B = (\beta+1)\, I_B .$$

Applying KVL to the base circuit, we get -

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E$$

$$\Rightarrow \quad I_B = \frac{V_{BB} - V_{BE}}{R_B + (\beta+1) R_E}$$

$$= \frac{(5 - 0.7)\text{ volt}}{50 + (100+1)\times 2\ K\Omega}$$

$$= 17.06 \times 10^{-3}\ \text{mA}$$

$$= 17.06\ \text{nA}.$$

$$\therefore\ I_C = \beta I_B + (\beta+1) I_{CBO}$$

$$= 100 \times 17.06\ \text{nA} + (100+1)\times 20\ \text{nA}.$$

$$= 1.708 \times 10^{+3}\ \text{nA}$$

$$= 1.708\ \text{mA}.$$

Applying KVL to the collector circuit, we get -

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

$$\Rightarrow\ V_{CE} = V_{CC} - I_C (R_C + R_E) \quad \text{as } I_E \approx I_C$$

$$= 10\text{ volt} - 1.708\text{ mA } (3+2)\ K\Omega$$

$$= 1.46\text{ volt}.$$

Since $V_{CE} > V_{CE.sat}$, hence the transistor is operating in the active region.

Problem ⑧ V.U-2005 : A silicon n-p-n transistor having $\beta = 100$ and $I_{co} = 22\ nA$ operated in CE configuration as in figure. Assuming $V_{BE} = 0.7$ volt, determine the transistor currents and the region of operation of the transistor.

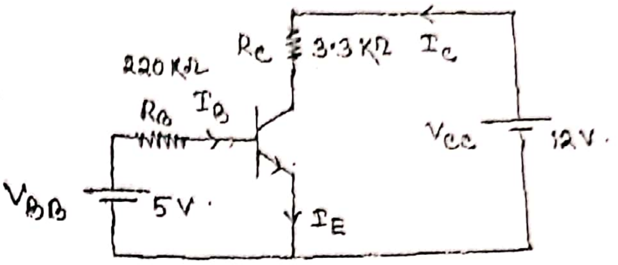
$V_{CE \cdot sat} = 0.2$ Volt

Solution :

$I_C = \beta I_B + (\beta+1) I_{CO}$ ✓

$I_E = I_B + I_C$

$\approx (1+\beta) I_B$.



Apply KVL to the base circuit, we get –

$V_{BB} = I_B R_B + V_{BE}$

$\Rightarrow I_B = \dfrac{V_{BB} - V_{BE}}{R_B} = \dfrac{(5-0.7)\ \text{Volt}}{220\ K\Omega} = \dfrac{4.3}{220}\ mA$

$= 0.01955\ mA$

$= 19.55\ \mu A$

$\therefore I_C = \beta I_B + (\beta+1) I_{CO}$

$= 100 \times 19.55\ \mu A + (100+1) \times 22 \times 10^{-3}\ A$

$= 1955 + 2.222\ \mu A$

= ~~1956.222 μA~~

$= 1957.222\ \mu A$

$= 1.957\ mA$.

$\therefore I_E = I_B + I_C = (0.01955 + 1.957)\ mA = 1.95895\ mA$

Apply KVL to the collector circuit,

$V_{CC} = I_C R_C + V_{CE}$

$\Rightarrow V_{CE} = V_{CC} - I_C R_C = 12\ \text{Volt} - 1.957\ mA \times 3.3\ K\Omega$.

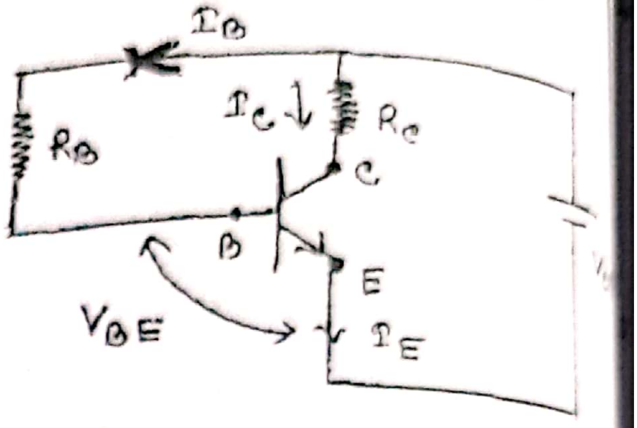
$= (12 - 6.46)$ Volt .

$= 3.54$ Volt

Since $V_{CE} > V_{CE \cdot sat}$, hence the transistor is operating in active region. ✓

Problem ⑨ : Find the transistor currents and collector emitter voltage in the adjacent circuit fo silicon transistor with $\beta = 100$ and havin negligible I_{CO} . Assume $V_{BE} = 0{\cdot}7$ volt

V.U. 2007



Solution: $R_B = 250\ K\Omega$

$R_C = 2\ K\Omega$

$V_{CC} = 10$ volt.

$\beta = 100$

$V_{BE} = 0{\cdot}7$ volt.

Applying KVL to the whole loop,

$$V_{CC} = I_B R_B + V_{BE}$$

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{(10 - 0{\cdot}7)\ \text{Volt}}{250\ \ K\Omega} = \frac{4{\cdot}3}{250}$$

$$= 17{\cdot}2$$

$$\therefore I_C = \beta I_B = 100 \times 17{\cdot}2\ \mu A = \underline{1{\cdot}72\ mA}.$$

$$\therefore I_E = I_B + I_C = 0{\cdot}0172\ mA + 1{\cdot}72\ mA = \underline{1{\cdot}7372}$$

Applying KVL to the output circuit,

$$V_{CC} = I_C R_C + V_{CE}$$

$$\Rightarrow V_{CE} = V_{CC} - I_C R_C$$

$$= 10\ \text{Volt} - 1{\cdot}72\ mA \times 2\ K\Omega$$

$$= (10 - 3{\cdot}44)\ \text{Volt}$$

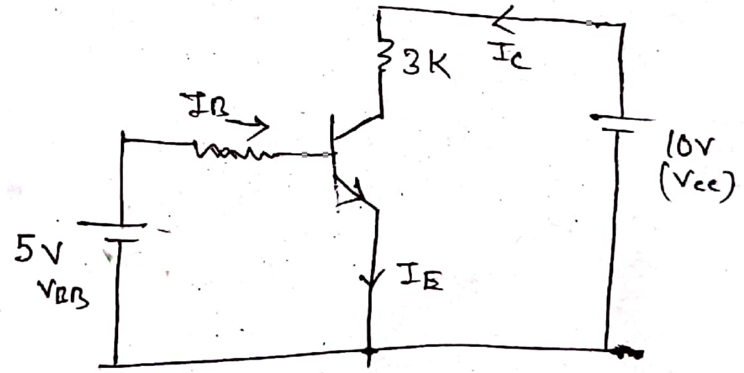
$$= \underline{6{\cdot}56\ \text{Volt}}$$

Problem base questions :=

1. The voltage drop across 5.6 kΩ resistance which is connected in the collector circuit is 5.6 volts. Find the base current. The current gain $\alpha = 0.998$. The transistor is connected in CE mode configuration.

2. Find the transistor currents I_c, I_B, I_E in the following circuit. Given the transistor is Silicon transistor.

$\beta = 100$, $I_{co} = 20nA$



3. For npn transistor in the CE mode with negligible Ico. Given $\beta = 50$, $V_{BB} = 4Volt$, $R_B = 100k\Omega$, $R_c = 4k\Omega$ and $V_{cc} = 10$ vol

Draw the circuit diagram. calculate the currents I_B and I_c assuming $V_{BE} = 0.7$ volt in the active region.