

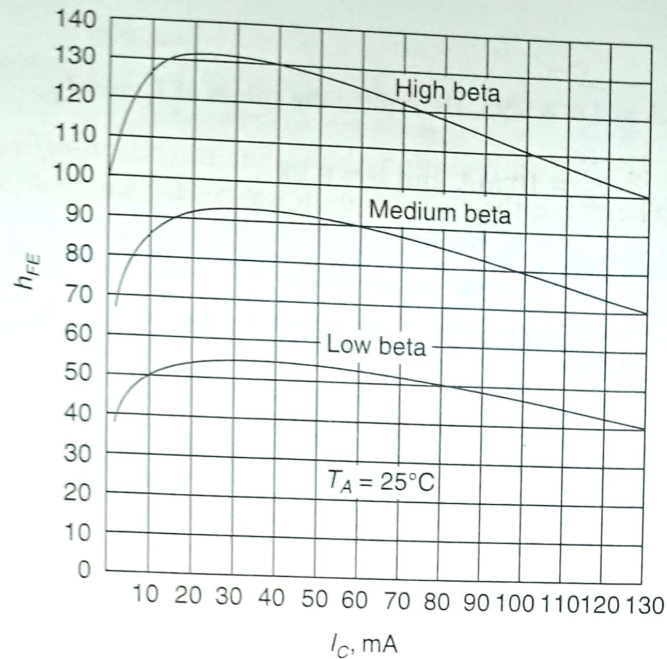


Fig. 6.17 Characteristic curves of d.c. current gain h_{FE} (at $V_{CE} = -0.25$ V) versus collector current for low, medium and high beta values

EXAMPLE 6.2

In a common-base connection, the emitter current I_E is 6.28 mA and the collector current I_C is 6.20 mA. Determine the common-base d.c. current gain.

Solution Given $I_E = 6.28$ mA and $I_C = 6.20$ mA

We know that common-base d.c. current gain,

$$\alpha = \frac{I_C}{I_E} = \frac{6.20 \times 10^{-3}}{6.28 \times 10^{-3}} = 0.987$$

EXAMPLE 6.3

The common-base d.c. current gain of a transistor is 0.967. If the emitter current is 10 mA, what is the value of base current?

Solution Given $\alpha = 0.967$ and $I_E = 10$ mA

The common-base d.c. current gain (α) is

$$\alpha = 0.967 = \frac{I_C}{I_E} = \frac{I_C}{10}$$

Therefore,

$$I_C = 0.967 \times 10 = 9.67 \text{ mA}$$

The emitter current

$$I_E = I_B + I_C$$

i.e.

$$10 = I_B + 9.67$$

Therefore,

$$I_B = 0.33 \text{ mA}$$

EXAMPLE 6.4

The transistor has $I_E = 10 \text{ mA}$ and $\alpha = 0.98$. Determine the values of I_C and I_B .

Solution Given $I_E = 10 \text{ mA}$ and $\alpha = 0.98$

The common-base d.c. current gain, $\alpha = \frac{I_C}{I_E}$

i.e. $0.98 = \frac{I_C}{10}$

Therefore $I_C = 0.98 \times 10 = 9.8 \text{ mA}$

The emitter current $I_E = I_B + I_C$

i.e. $10 = I_B + 9.8$

Therefore, $I_B = 0.2 \text{ mA}$

EXAMPLE 6.5

If a transistor has a α of 0.97, find the value of β . If $\beta = 200$, find the value of α .

Solution If $\alpha = 0.97$, $\beta = \frac{\alpha}{1 - \alpha} = \frac{0.97}{1 - 0.97} = 32.33$

If $\beta = 200$, $\alpha = \frac{\beta}{\beta + 1} = \frac{200}{200 + 1} = 0.995$

EXAMPLE 6.6

A transistor has $\beta = 100$. If the collector current is 40 mA, find the value of emitter current.

Solution Given $\beta = 100$ and $I_C = 40 \text{ mA}$

$$\beta = 100 = \frac{I_C}{I_B} = \frac{40}{I_B}$$

Therefore, $I_B = 40/100 = 0.4 \text{ mA}$ and

$$I_E = I_B + I_C = (0.4 + 40) \times 10^{-3} = 40.4 \text{ mA}$$

EXAMPLE 6.7

A transistor has $\beta = 150$. Find the collector and base currents, if $I_E = 10 \text{ mA}$.

Solution Given $\beta = 150$ and $I_E = 10 \text{ mA}$

The common-base current gain, $\alpha = \frac{\beta}{\beta + 1} = \frac{150}{150 + 1} = 0.993$

Also,

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

i.e.

$$0.993 = \frac{I_C}{10}$$

Therefore,

$$I_C = 0.993 \times 10 = 9.93 \text{ mA}$$

The emitter current

$$I_E = I_B + I_C$$

i.e.

$$10 \times 10^{-3} = I_B + 9.93 \times 10^{-3}$$

Therefore,

$$I_B = (10 - 9.93) \times 10^{-3} = 0.07 \text{ mA}$$

EXAMPLE 6.8

Determine the values of I_B and I_E for the transistor circuit if $I_C = 80 \text{ mA}$ and $\beta = 170$.

Solution Given

$$\beta = 170 \text{ and } I_C = 80 \text{ mA}$$

We know that (β),

$$\beta = 170 = \frac{I_C}{I_B} = \frac{80 \times 10^{-3}}{I_B}$$

Therefore,

$$I_B = \frac{80 \times 10^{-3}}{170} = 0.47 \text{ mA}$$

and

$$I_E = I_B + I_C = (0.47 + 80) \text{ mA} = 80.47 \text{ mA}$$

EXAMPLE 6.9

Determine the values of I_C and I_E for the transistor circuit of $\beta = 200$ and $I_B = 0.125 \text{ mA}$.

Solution Given

$$I_B = 0.125 \text{ mA and } \beta = 200$$

Therefore,

$$\beta = 200 = \frac{I_C}{I_B} = \frac{I_C}{0.125 \times 10^{-3}}$$

Therefore,

$$I_C = 200 \times 0.125 \times 10^{-3} = 25 \text{ mA}$$

and

$$I_E = I_B + I_C = (0.125 + 25) \times 10^{-3} = 25.125 \text{ mA}$$

EXAMPLE 6.10

Determine the values of I_C and I_B for the transistor circuit of $I_E = 12 \text{ mA}$ and $\beta = 100$.

Solution Given

$$I_E = 12 \text{ mA and } \beta = 100$$

We know that base current,

$$I_B = \frac{I_E}{1 + \beta} = \frac{12 \times 10^{-3}}{1 + 100} = 0.1188 \text{ mA}$$

and collector current,

$$I_C = I_E - I_B = (12 - 0.1188) \times 10^{-3} = 11.8812 \text{ mA}$$

EXAMPLE 6.11

A transistor has $I_B = 100 \mu\text{A}$ and $I_C = 2 \mu\text{A}$. Find (a) β of the transistor, (b) α of the transistor, (c) emitter current I_E , (d) if I_B changes by $+25 \mu\text{A}$ and I_C changes by $+0.6 \text{ mA}$, find the new value of β .

Solution Given

$$I_B = 100 \mu\text{A} = 100 \times 10^{-6} \text{ A and } I_C = 2 \text{ mA} = 2 \times 10^{-3} \text{ A.}$$

(a) To find β of the transistor

$$\beta = \frac{I_C}{I_B} = \frac{2 \times 10^{-3}}{100 \times 10^{-6}} = 20$$

(b) To find α of the transistor

$$\alpha = \frac{\beta}{\beta + 1} = \frac{20}{1 + 20} = 0.952$$

(c) To find emitter current, I_E

$$\begin{aligned} I_E &= I_B + I_C = 100 \times 10^{-6} + 2 \times 10^{-3} \text{ A} \\ &= (0.01 + 2) \times 10^{-3} = 2.01 \times 10^{-3} \text{ A} = 2.01 \text{ mA} \end{aligned}$$

(d) To find the new value of β when $\Delta I_B = 25 \mu\text{A}$ and $\Delta I_C = 0.6 \text{ mA}$

Therefore,

$$I_B = (100 + 25) \mu\text{A} = 125 \mu\text{A}$$

$$I_C = (2 + 0.6) \text{ mA} = 2.6 \text{ mA}$$

New value of β of the transistor,

$$\beta = \frac{I_C}{I_B} = \frac{2.6 \times 10^{-3}}{125 \times 10^{-6}} = 20.8$$

EXAMPLE 6.12

For a transistor circuit having $\alpha = 0.98$, $I_{CBO} = I_{CO} = 5 \mu\text{A}$ and $I_B = 100 \mu\text{A}$, find I_C and I_E .

Solution Given

The collector current is

$$\alpha = 0.98, I_{CBO} = I_{CO} = 5 \mu\text{A and } I_B = 100 \mu\text{A}$$

The emitter current is

$$I_C = \frac{\alpha \cdot I_B}{1 - \alpha} + \frac{I_{CO}}{1 - \alpha} = \frac{0.98 \times 100 \times 10^{-6}}{1 - 0.98} + \frac{5 \times 10^{-6}}{1 - 0.98} = 5.15 \text{ mA}$$

$$I_E = I_B + I_C = 100 \times 10^{-6} + 5.15 \times 10^{-3} = 5.25 \text{ mA}$$

EXAMPLE 6.13

A germanium transistor used in a complementary symmetry amplifier has $I_{CBO} = 10 \mu\text{A}$ at 27°C and $h_{FE} = 50$. (a) Find I_C when $I_B = 0.25 \mu\text{A}$ and (b) assuming h_{FE} does not increase with temperature, find the value of new collector current, if the transistor's temperature rises to 50°C .

Solution Given

(a) To find the value of collector current when $I_B = 0.25 \text{ mA}$

$$I_{CBO} = 10 \mu\text{A and } h_{FE} (= \beta) = 50$$

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

$$= 50 \times (0.25 \times 10^{-3}) + (1 + 50) \times (10 \times 10^{-6}) \text{ A} = 13.01 \text{ mA}$$

(b) To find the value of new collector current if temperature rises to 50°C

We know that I_{CBO} doubles for every 10°C rise in temperature. Therefore,

$$I'_{CBO} (\beta = 50) = I_{CBO} \times 2^{(T_2 - T_1)/10} = 10 \times 2^{(50 - 27)/10} \mu A \\ = 10 \times 2^{2.3} \mu A = 49.2 \mu A$$

Therefore, the collector current at 50°C is

$$I_C = \beta \cdot I_B + (1 + \beta) I'_{CBO} \\ = 50 \times (0.25 \times 10^{-3}) + (1 + 50) \times 49.2 \times 10^{-6} A = 15.01 \text{ mA}$$

EXAMPLE 6.14

When the emitter current of a transistor is changed by 1 mA, there is a change in collector current by 0.99 mA. Find the current gain of the transistor.

Solution The current gain of the transistor is $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{0.99 \times 10^{-3}}{1 \times 10^{-3}} = 0.99$

EXAMPLE 6.15

The d.c. current gain of a transistor in CE mode is 100. Determine its d.c. current gain in CB mode.

Solution The d.c. current gain of the transistor in CB mode is $\alpha_{d.c.} = \frac{\beta_{d.c.}}{1 + \beta_{d.c.}}$

$$= \frac{100}{1 + 100} = 0.99$$

EXAMPLE 6.16

When I_E of a transistor is changed by 1 mA, its I_C changes by 0.995 mA. Find its common base current gain α , and common-emitter current gain β .

Solution Common-base current gain is $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{0.995 \times 10^{-3}}{1 \times 10^{-3}} = 0.995$

Common-emitter current gain is $\beta = \frac{\alpha}{1 - \alpha} = \frac{0.995}{1 - 0.995} = 199$

EXAMPLE 6.17

The current gain of a transistor in CE mode is 49. Calculate its common-base current gain. Find the base current when the emitter current is 3 mA.

Solution Given

$$\beta = 49$$

We know that

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

Therefore, the common-base current gain is $\alpha = \frac{49}{1 + 49} = 0.98$

We also know that

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

Therefore,

$$I_C = \alpha I_E = 0.98 \times 3 \times 10^{-3} = 2.94 \text{ mA}$$

EXAMPLE 6.18

Determine I_C , I_E and α for a transistor circuit having $I_B = 15 \mu\text{A}$ and $\beta = 150$.

Solution The collector current, $I_C = \beta I_B = 150 \times 15 \times 10^{-6} = 2.25 \text{ mA}$

The emitter current, $I_E = I_C + I_B = 2.25 \times 10^{-3} + 15 \times 10^{-6} = 2.265 \text{ mA}$

Common-base current gain, $\alpha = \frac{\beta}{1 + \beta} = \frac{150}{151} = 0.9934$

EXAMPLE 6.19

Determine the base, collector and emitter currents and V_{CE} for a CE circuit shown in Fig. 6.18. For $V_{CC} = 10 \text{ V}$, $V_{BB} = 4 \text{ V}$, $R_B = 200 \text{ k}\Omega$, $R_C = 2 \text{ k}\Omega$, $V_{BE}(\text{on}) = 0.7 \text{ V}$, $\beta = 200$.

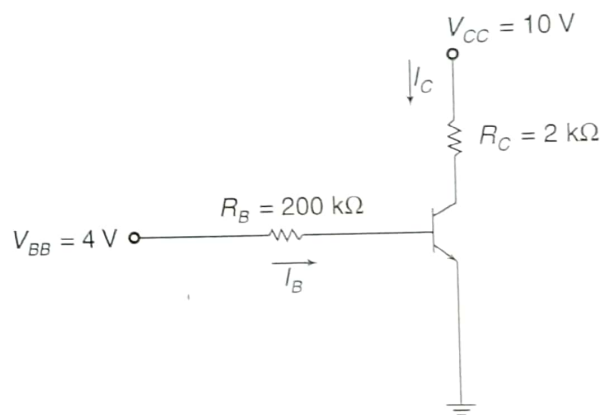


Fig. 6.18

Solution Referring to Fig. 6.18, the base current is

$$I_B = \frac{V_{BB} - V_{BE}(\text{on})}{R_B} = \frac{4 - 0.7}{200 \times 10^3} = 16.5 \mu\text{A}$$

The collector current is

$$I_C = \beta I_B = 200 \times 16.5 \times 10^{-6} = 3.3 \text{ mA}$$

The emitter current is

$$I_E = I_C + I_B = 3.3 \times 10^{-3} + 16.5 \times 10^{-6} = 3.3165 \text{ mA}$$

Therefore,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 3.3 \times 10^{-3} \times 2 \times 10^3 = 3.4 \text{ V}$$

EXAMPLE 6.20

Calculate the values of I_C and I_E for a transistor with $\alpha_{\text{d.c.}} = 0.99$ and $I_{CBO} = 5 \mu\text{A}$. I_B is measured $20 \mu\text{A}$.

Solution Given $\alpha_{d.c.} = 0.99$, $I_{CBO} = 5 \mu A$ and $I_B = 20 \mu A$

$$I_C = \frac{\alpha_{d.c.} I_B}{1 - \alpha_{d.c.}} + \frac{I_{CBO}}{1 - \alpha_{d.c.}} = \frac{0.99 \times 20 \times 10^{-6}}{1 - 0.99} + \frac{5 \times 10^{-6}}{1 - 0.99} = 2.48 \text{ mA}$$

Therefore,

$$I_E = I_B + I_C = 20 \times 10^{-6} + 2.48 \times 10^{-3} = 2.5 \text{ mA}$$

EXAMPLE 6.21

The reverse leakage current of the transistor when connected in CB configuration is $0.2 \mu A$ and it is $18 \mu A$ when the same transistor is connected in CE configuration. Calculate $\alpha_{d.c.}$ and $\beta_{d.c.}$ of the transistor.

Solution The leakage current $I_{CBO} = 0.2 \mu A$

$$I_{CEO} = 18 \mu A$$

Assume that

$$I_B = 30 \text{ mA}$$

$$I_E = I_B + I_C$$

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

We know that

$$I_{CEO} = \frac{I_{CBO}}{1 - \alpha} = (1 + \beta) I_{CBO}$$

$$\beta = \frac{I_{CEO}}{I_{CBO}} - 1 = \frac{18}{0.2} - 1 = 89$$

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

$$= 89 (30 \times 10^{-3}) + (1 + 89) (0.2 \times 10^{-6})$$

$$= 2.67 \text{ A}$$

$$\alpha_{d.c.} = 1 - \frac{I_{CBO}}{I_{CEO}} = 1 - \frac{0.2 \times 10^{-6}}{18 \times 10^{-6}} = 0.988$$

$$\beta_{d.c.} = \frac{I_C - I_{CBO}}{I_B - I_{CEO}}$$

$$= \frac{2.67 - 0.2 \times 10^{-6}}{30 \times 10^{-3} - 18 \times 10^{-6}} = 89$$

EXAMPLE 6.22

If $\alpha_{d.c.} = 0.99$ and $I_{CBO} = 50 \mu A$, find emitter current.

Solution Given

$$\alpha_{d.c.} = 0.99 \text{ and } I_{CBO} = 50 \mu A,$$

$$I_B = 1 \text{ mA}$$

$$I_C = \frac{\alpha_{d.c.} I_B}{1 - \alpha_{d.c.}} + \frac{I_{CBO}}{1 - \alpha_{d.c.}} = \frac{0.99 (1 \times 10^{-3})}{1 - 0.99} + \frac{50 \times 10^{-6}}{1 - 0.99}$$

$$= \frac{0.99 \times 10^{-3}}{0.01} + \frac{50 \times 10^{-6}}{0.01} = 99 \text{ mA} + 5 \text{ mA} = 104 \text{ mA}$$

$$I_E = I_C + I_B = 104 \text{ mA} + 1 \text{ mA} = 105 \text{ mA}$$

EXAMPLE 6.23

For the CE amplifier circuit shown in Fig. 6.19, find the percentage change in collector current if the transistor with $h_{fc} = 50$ is replaced by another transistor with $h_{fc} = 150$. Assume $V_{BE} = 0.6$.

Solution $V_B = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{5 \times 10^3}{5 \times 10^3 + 25 \times 10^3} \times 12 = 2 \text{ V}$

$$V_E = V_B - V_{BE} = 2 - 0.6 = 1.4 \text{ V}$$

Here, $I_E = \frac{V_E}{R_E} = \frac{1.4}{100} = 14 \text{ mA}$

For $\beta = 50$, $I_B = \frac{I_E}{1 + \beta} = \frac{14 \times 10^{-3}}{51} = 274.5 \mu\text{A}$

Therefore, $I_{C1} = \beta I_B = 50 \times 274.5 \times 10^{-6} = 13.725 \text{ mA}$

For $\beta = 150$, $I_B = \frac{I_E}{1 + \beta} = \frac{14 \times 10^{-3}}{151} = 92.715 \mu\text{A}$

Therefore, $I_{C2} = \beta I_B = 150 \times 92.715 \times 10^{-6} = 13.907 \text{ mA}$

Hence, the percentage change in collector current is calculated as

$$\frac{I_{C2} - I_{C1}}{I_{C1}} \times 100 = \frac{13.907 \times 10^{-3} - 13.725 \times 10^{-3}}{13.725 \times 10^{-3}} \times 100 = 1.326\%$$

EXAMPLE 6.24

Given an NPN transistor for which $\alpha = 0.98$, $I_{CO} = 2 \mu\text{A}$ and $I_{CEO} = 16 \mu\text{A}$. A common emitter connection is used as shown in Fig. 6.20 with $V_{CC} = 12 \text{ V}$ and $R_C = 4 \text{ k}\Omega$. What is the minimum base current required in order that transistor enter into saturation region.

Solution Given $\alpha = 0.98$, $I_{CO} = 2 \mu\text{A}$, $I_{CEO} = 1.6 \mu\text{A}$, $V_{CC} = 12 \text{ V}$ and $R_C = 4 \text{ k}\Omega$

$$I_{C(\text{sat})} = \frac{V_{CC}}{R_C} = \frac{12}{4 \times 10^3} = 3 \text{ mA}$$

$$\beta = \frac{\alpha}{1 - \alpha} = \frac{0.98}{1 - 0.98} = 49$$

$$I_{B(\text{min})}$$

$$= \frac{3 \times 10^{-3}}{49} = 61.224 \times 10^{-6} = 61.224 \mu\text{A}$$

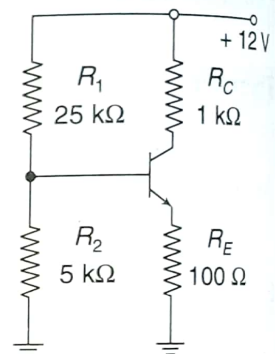


Fig. 6.19

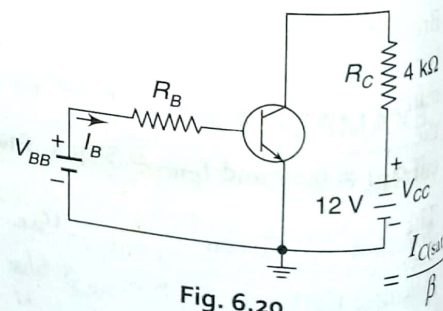


Fig. 6.20

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Solution
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6.9 E

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EXAMPLE 6.25

A transistor operating in *CB* configuration has $I_C = 2.98 \text{ mA}$, $I_E = 3 \text{ mA}$ and $I_{CO} = 0.01 \text{ mA}$. What current will flow in the collector circuit of this transistor when connected in *CE* configuration with a base current of $30 \mu\text{A}$?

Solution

Given

$$I_C = 2.98 \text{ mA}, I_E = 3 \text{ mA}, I_{CO} = 0.01 \text{ mA} \text{ and } I_B = 30 \mu\text{A}.$$

For *CB* configuration,

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

Therefore,

$$\alpha = \frac{I_C - I_{CO}}{I_E} = \frac{(2.98 - 0.01) \times 10^{-3}}{3 \times 10^{-3}} = 0.99$$

$$\beta = \frac{\alpha}{1 - \alpha} = \frac{0.99}{1 - 0.99} = 99$$

For *CE* configuration,

$$\begin{aligned} I_C &= \beta I_B + (1 + \beta) I_{CO} \\ &= 99 \times 30 \times 10^{-6} + (1 + 99) \times 0.01 \times 10^{-3} = 3.97 \text{ mA}. \end{aligned}$$

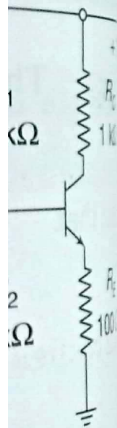


Fig. 6.19

6.9 BREAKDOWN IN TRANSISTORS

There is a possibility of voltage breakdown in the transistor at high voltages even though the rated dissipation of the transistor is not exceeded. Therefore, there is an upper limit to the maximum allowable collector junction voltage. There are two types of breakdown, namely, *Avalanche breakdown* and *reach-through* or *punch-through*.

6.9.1 Avalanche Breakdown and Multiplication

When a diode is reverse biased, there is a limit on the voltage that can be applied. Similarly, in the transistor, the maximum reverse voltage that can be applied is limited.

$$I_{Bmin} = \frac{I_{Csat}}{\beta} = \frac{4.8}{\beta}$$

$$I_B > I_{Bmin}$$

$$0.1 > 4.8/\beta, \quad \beta > 48 \text{ (saturation)}$$

→ In ckt shown silicon transistor has $\beta = 30$ find the region of operation and o/p voltage.

1) i.e. $V_i = 12V$ and $R_1 = 15k\Omega$.

2) i.e. $V_i = 10V$ and $R_1 = 40k$ (active)

3) i.e. $V_i = 1V$ and $R_1 = 15k$

So 1) $V_i = 12V$ & $R_1 = 15k\Omega$

Let Q be in saturation

② $I_C?$ $I_C = \frac{12 - V_{CE}}{2.2k} = \frac{12 - 0.2}{2.2k} = \frac{11.8}{2.2} = 5.36 \text{ mA}$

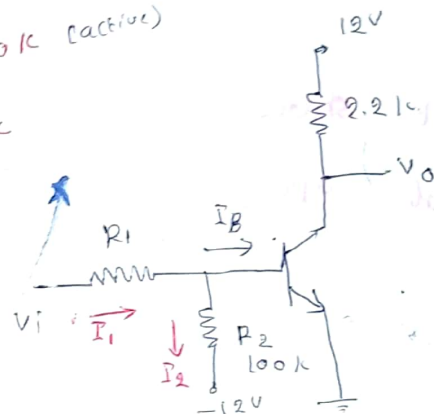
KCL, $I_1 = I_2 + I_B \Rightarrow I_B = I_1 - I_2$

$$I_B = \frac{V_i - V_{BE}}{R_1} - \frac{V_{BE} - (-12)}{R_2} = \frac{11.8}{15} - \frac{12.8}{100} = 0.618 \text{ mA}$$

③ $I_{Bmin} = \frac{I_{Csat}}{\beta} = \frac{5.36}{30} = 0.178 \text{ mA}$

$(I_B > I_{Bmin}) \therefore Q$ is in saturation

$V_o = V_{CE} = 0.2 \text{ volt}$



1) $V_i = 1V$ $R_i = 15k\Omega$

$I_{B \min} = 0.178 mA$

$I_B = \frac{1-0.8}{15} - \frac{12-8}{100} = -0.114 mA$

Q is in cut-off region

When transistor is in cut-off all currents will be

zero $V_o = 12 - 2.2 I_C = 12 - 0 = 12V$

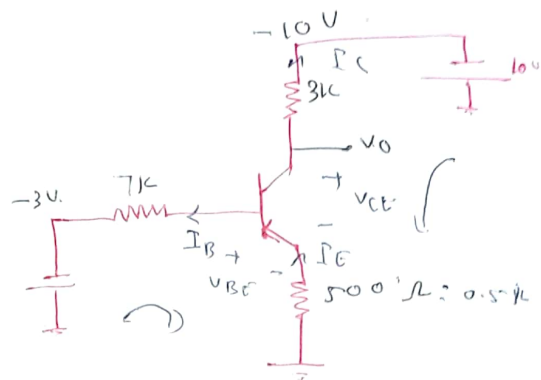
→ In ckt shown silicon transistor has $\beta = 100$, find the region of operation and o/p voltage.

Sol $I_E = I_B + I_C$

① Let Q be in saturation

$V_{BE} = -0.8V$

$V_{CE} = -0.2V$



② $0.5(I_E) - V_{BE} + I_B \cdot 7k + 9 = 0$

$0.5(I_B + I_C) + I_B \cdot 7 = +3 + V_{BE} = +3 - 0.8$

$7.5 I_B + 0.5 I_C = 2.2$ — ①

$0.5(I_B + I_C) - V_{CE} + 3 I_C - 10 = 0$

$0.5 I_B + 3.5 I_C = 10 + V_{CE} = 9.8$ — ②

Solve ① and ②.

$I_B = 0.107 mA$

$I_C = 2.78 mA$

$$I_{B(\min)} = \frac{I_{C(sat)}}{\beta} = \frac{2.78}{100} = 0.0278 \text{ mA}$$

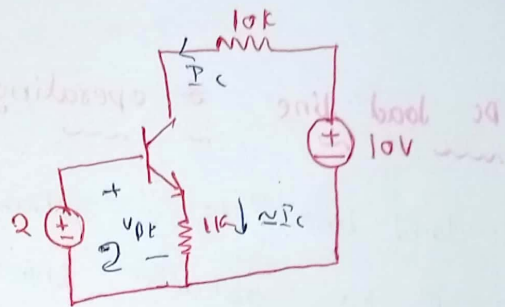
$$I_B > I_{B(\min)}$$

$\therefore Q$ is saturation.

$$V_O = 3I_C - 10 = -1.66 \text{ V} //$$

→ In ckt shown transistor has large β and $V_{BE} = 0.7 \text{ V}$
find the region of operation

① As p-type base is at +2V,
emitter junction must be in
forward bias. hence
transistor is in either active
(or) saturation region.



② To decide the correct region of operation V_{CB} should
be calculated by assuming transistor in active region

③ If $V_{CB} + V_C$ collector junction is in RB $\Rightarrow$ active
region
If $V_{CB} - V_E$ I_C is in F.B $\rightarrow$ saturation

$$\text{KVL} \quad 2 = V_{BE} + I_C \times 10 = 0$$

$$I_C = \frac{2 - V_{BE}}{10} = 1.3 \text{ mA}$$

$$\text{KVL in outer loop} = -10 + 10I_C + V_{CB} + 2 = 0$$

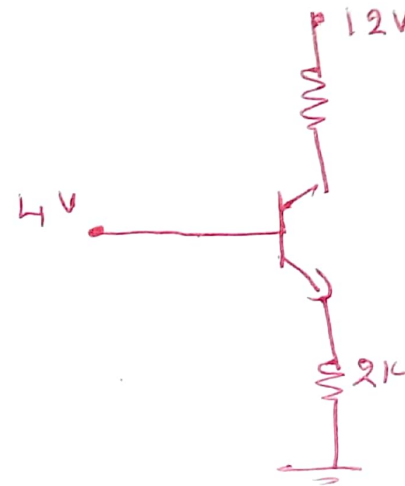
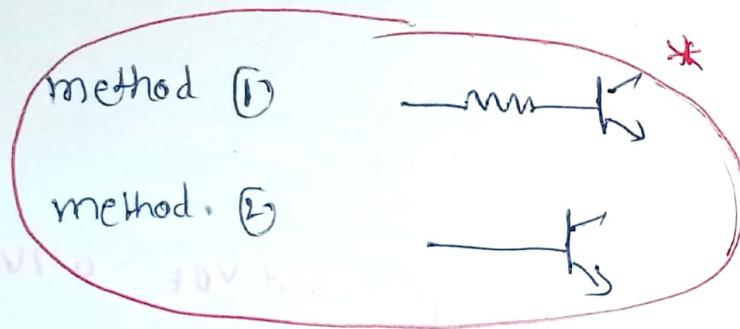
$$V_{CB} = 8 - 10I_C$$

$$= -0.5 \text{ V} //$$

$$= -5 \text{ V}$$

Transistor is in saturation region

→ In ckt shown silicon transistor has $\beta = 100$ find the region of operation



DC load line & operating point:-

DC load line is a straight line plotted on I_C vs V_{CE} graph to obtain the values of V_{CE} & I_C graphically in given circuit.