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Module - 5

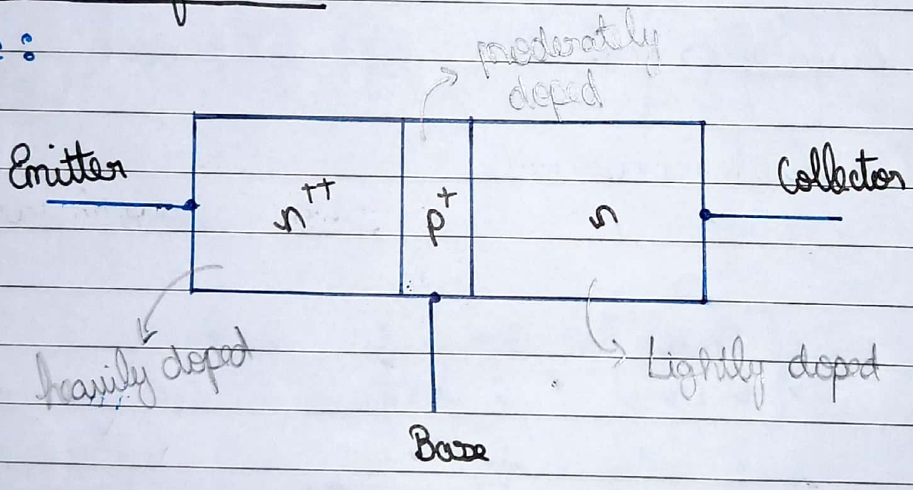
Bipolar Junction Transistor

- Transistor - An active device that transfers charge carriers with with a resistive force. (Transfer resistor)

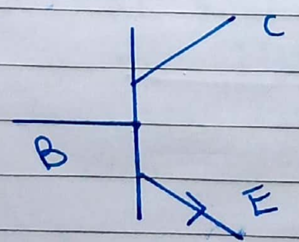
BJT → npn (used to teach), pnp

* Structure of BJT:

- npn :

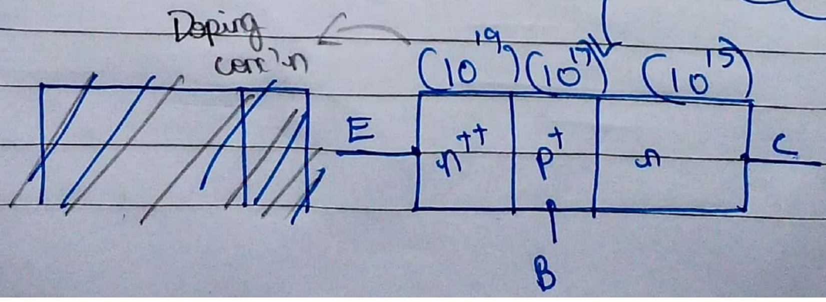


→ Base width is less and the emitter is heavily doped to produce more current.

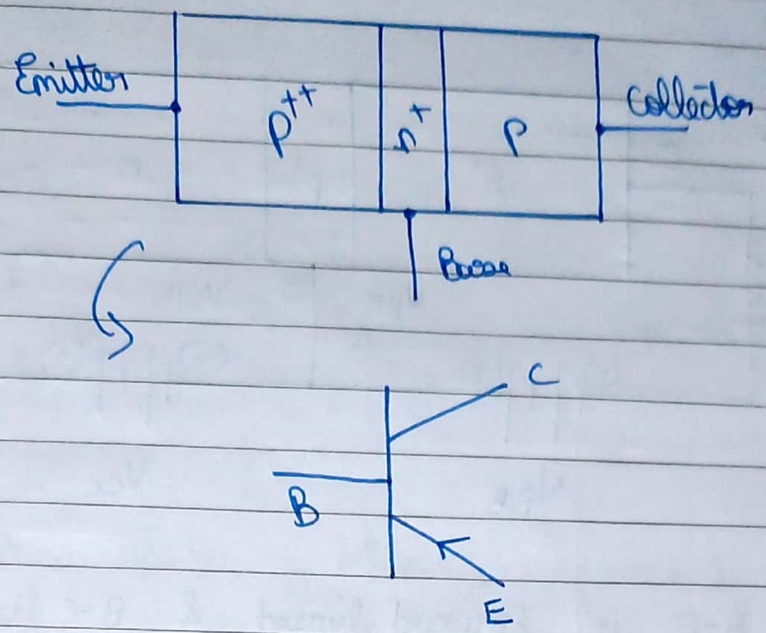


E → heavily doped, less area
B → moderately doped, very less area
C → lightly doped, more area

Ideally :



• pnp :



* Configuration of BJT :

→ Common Base
→ common Emitter (Standard configuration)
→ Common Collector

NOTE :

• Base - input
Emitter - output

• V_{BE} (voltage between base & emitter) controls output current.
• C-E configuration provides voltage & current amplification.

* Operation of BJT :

	Input Junction (V_{BE})	Output Junction (V_{BC})	
1.	Forward	Forward	→ Saturation → on switch
2.	Reverse	Reverse	→ Cut-off → off switch
3.	Forward	Reverse	→ Forward active mode → amplification
4.	Reverse	Forward	→ Reverse operation mode ↳ NOT USED OFTEN

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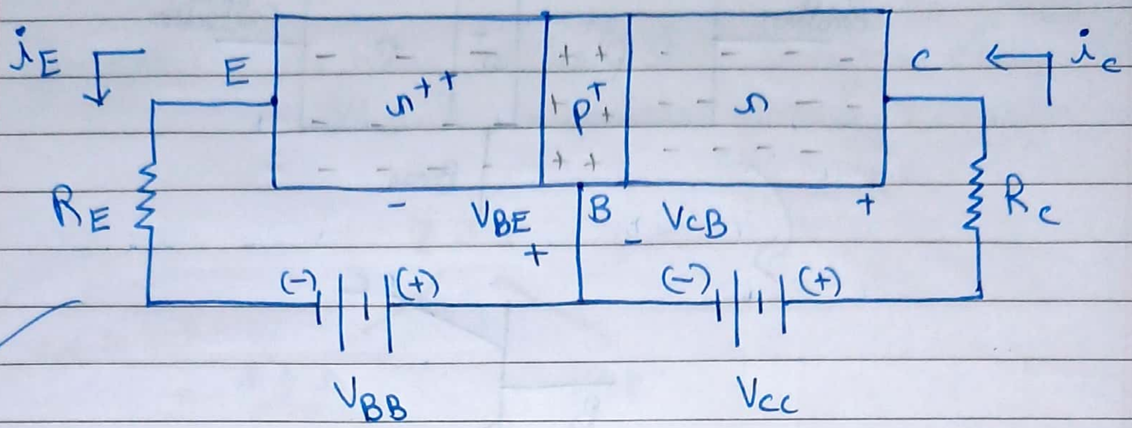
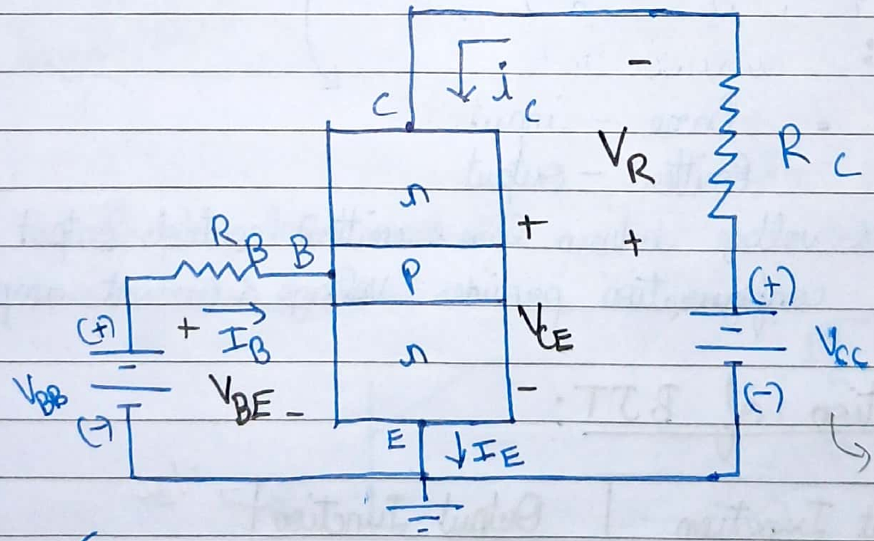
• Structure and working of npn: (common-Emitter config.)



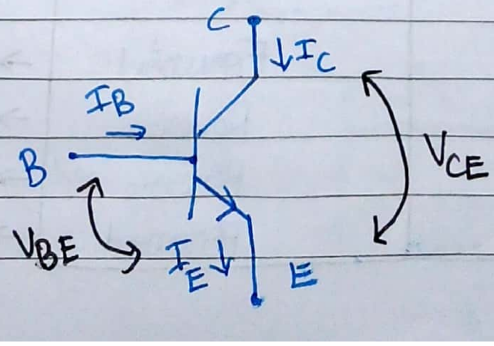
• Here, B-E is forward biased & B-C is reverse biased to operate npn in (amplification) forward active mode.

• R_E / R_C (current limiting resistor) → helps to minimise current flow to protect the transistor.



$V_{CC} = V_R + V_{CE}$

(Transistor can also be rep. as)



- Here, (for CE config.) I_B → input current , I_C → output current
  V_{BE} → input voltage V_{CE} → output voltage

The electrons from the emitter (produced due to Forward bias) is injected into the base, which creates an excess conc'n of minority carriers in the base. (minority since the base is p-type).

↓

The Base-collector junction is reverse biased, hence conc'n of e^- is very less

↓

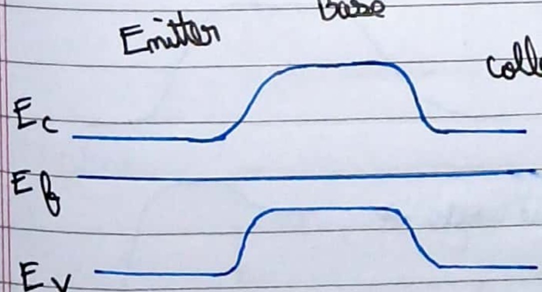
due to the large gradient in e^- conc'n, the electrons from the base will diffuse across to the collector.

↓

→ The width of the base is very small to prevent recombination of e^- & holes (recombination cannot be totally prevented but can be prevented to the maximum level)

Because of this, $I_E \simeq I_C$
since $I_E = I_C + I_B$
and $I_C >> I_B$

- Energy Band diagrams:



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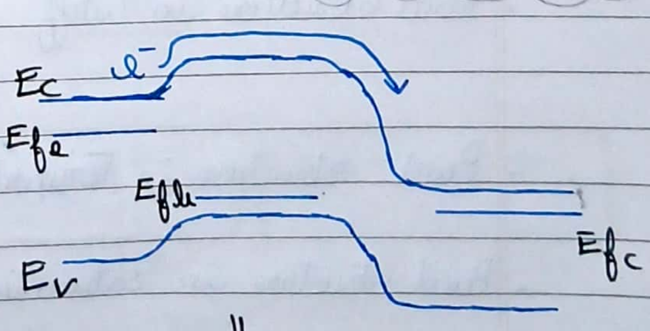
Under Zero-Bias



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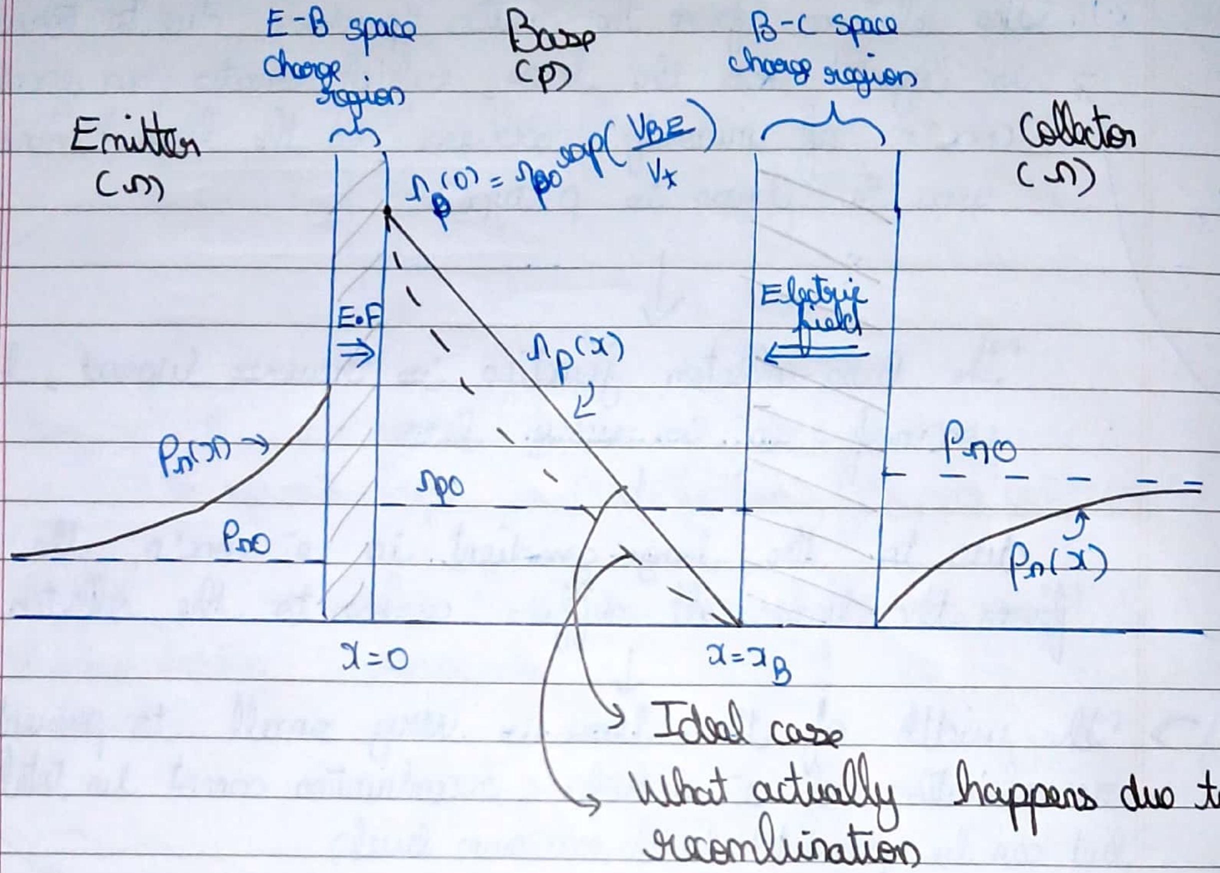
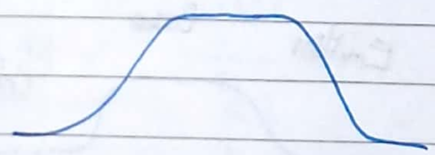
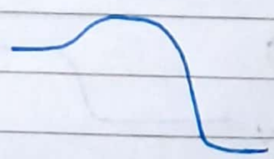
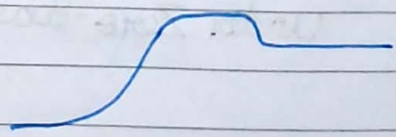
Under Forward bias

Note: From the Energy band diagram, it can be observed that more no. of e^- move from emitter to collector in forward bias due to the shortened height of the potential barrier.



- $x_B \rightarrow$ width of base after depletion region

NOTE:

- Band structure in Cutoff $\rightarrow$ 
- Band structure in Forward active mode $\rightarrow$ 
- Band structure in saturation $\rightarrow$ 
- Band structure in reverse active $\rightarrow$ 

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* Transistor Current Relations:

- **Collector current:**

We know,

$$J_n = \frac{I_n}{A} = q D_n \frac{dn}{dx}$$

$$\Rightarrow I_n = q D_n \times A \frac{dn}{dx}$$

Here, in a npn transistor,

$$I_C = q D_n A_{BE} \times \left[\frac{n_p(x) - 0}{0 - x_B} \right]$$

$$= q D_n A_{BE} \times \left[\frac{n_{po} \exp\left(\frac{V_{BE}}{V_T}\right)}{-x_B} \right]$$

$$I_s \quad = -\left(\frac{q D_n A_{BE} n_{po}}{x_B} \right) \exp\left(\frac{V_{BE}}{V_T} \right)$$

$$\boxed{I_C = I_s \times \exp\left(\frac{V_{BE}}{V_T} \right)}$$

also,

$$\boxed{I_C = \beta I_B + (\beta+1) I_{CBO}} \quad \boxed{I_C = \alpha I_E + I_{CBO}}$$

where, $\beta = \frac{I_C}{I_B}$, $\alpha = \frac{I_C}{I_E}$

$I_{CBO} \rightarrow$ reverse saturation current

- **Base Current :**

$$\boxed{I_B = (1-\alpha) I_E - I_{CBO}}$$

- **Emitter current :**

$$\boxed{I_E = I_C + I_B}$$

$$\boxed{I_C = \alpha I_E + I_{CBO}}$$

- **Output Voltage** → $\boxed{V_{CC} = (I_C R_C) + (V_{CB} + V_{BE})}$

(or)

$\boxed{V_{CC} = V_R + V_{CE}}$ → Refer circuit of npn transistor

Note :

- $\alpha \simeq \frac{I_C}{I_E}$
  ↓
  Common Base Current Gain

- $\beta \simeq \frac{I_C}{I_B}$
  ↓
  Common Collector Current Gain

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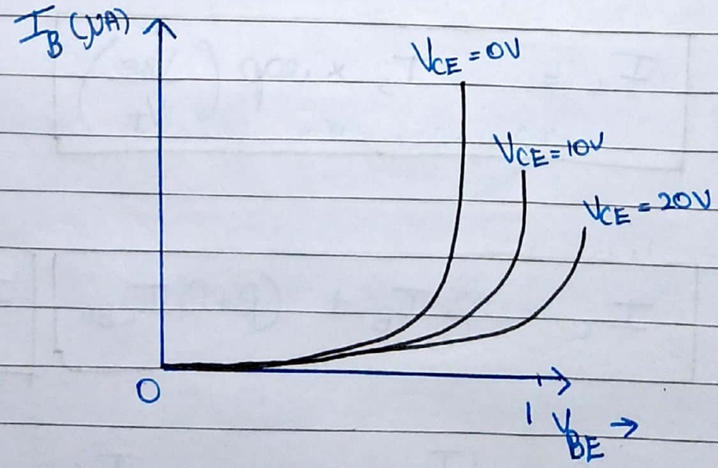
* Transistor Characteristics :

- **Input characteristic :**



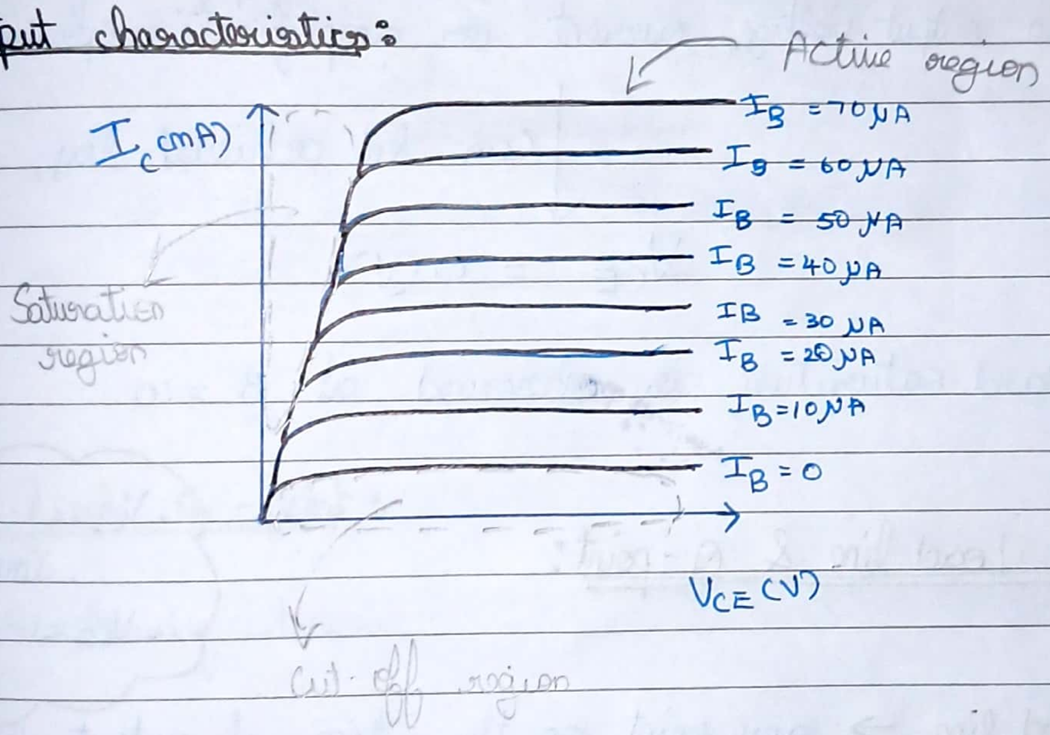
→ The Input voltage (V_{BE}) Vs Input current (I_B) with output voltage (V_{CE}) as constant.

Note:

- The constant V_{CE} supply makes sure the base region is present to maintain neutrality by providing extra charge carriers to the base.

↳ This is the reason for shifting in i/p characteristics for different V_{CE} values.

- Output characteristics:



→ Output voltage (V_{CE}) Vs Output current (I_C) with input current (I_B) as constant.

* Non-Ideal Effects :-

- Base - Width Modulation:

↳ aka Early effect.

↳ refers to the change in width of the base region (x_B) as V_{CB} varies.

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- Reduction in x_B increases diffusion current

↳ reduction in x_B (base width) will occur when V_{CB} increases, which increases the Base-collector space charge region.

- **Hard Saturation:**

↳ a state of transistor which cannot provide further increase in output voltage, current or amplification. (provides max current)

can be achieved by,

$$V_{CE} = 0 \, (V)$$

- Hard saturation is observed at $\beta = 10$.

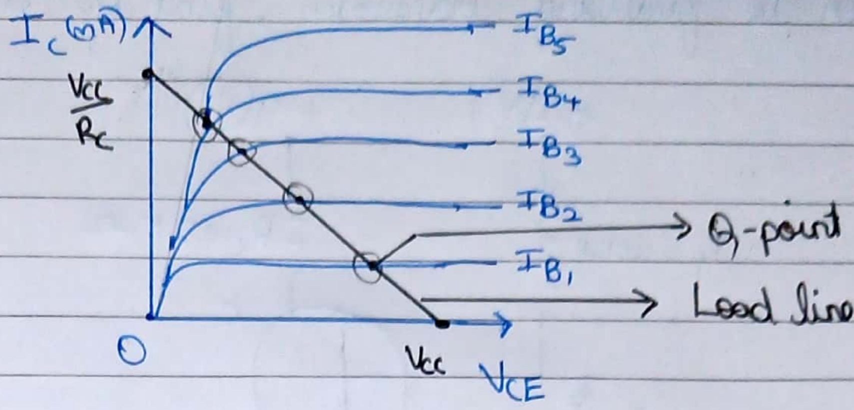
* DC Load line & Q-point:

- $V_{CE} = 1$ for amplification
- $V_{CE} < 1$ for saturation

- **Load line** → any point on the line of output characteristic where a circuit acts as an amplifier, present in the active region.

- **Q-point** → point on the loadline where faithful amplification is achieved by the transistor.

- Faithful amplification → perfect amplification of the input signal



Here, at $I_C = 0$, we get the cut-off region.

$$\Rightarrow \boxed{V_{CE} = V_{CC}} \qquad \{\because V_{CC} = V_{CE} + I_C R_C\}$$

at $V_{CE} = 0$, we get the saturation point (Max. current)

$$\Rightarrow \boxed{I_C = \frac{V_{CC}}{R_C}}$$

- To find Q-point:

We already know,

$$I_C = \beta I_B$$

$$\Rightarrow \boxed{I_{CQ} = \beta I_B}$$

and, $\boxed{V_{CEQ} = V_{CC} - I_{CQ} R_C}$

To find I_B,

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

and finally,

$\boxed{(V_{CEQ}, I_{CQ})}$ gives the Q-point //

Assume $V_{BE} = 0.65V$ if not given in Q

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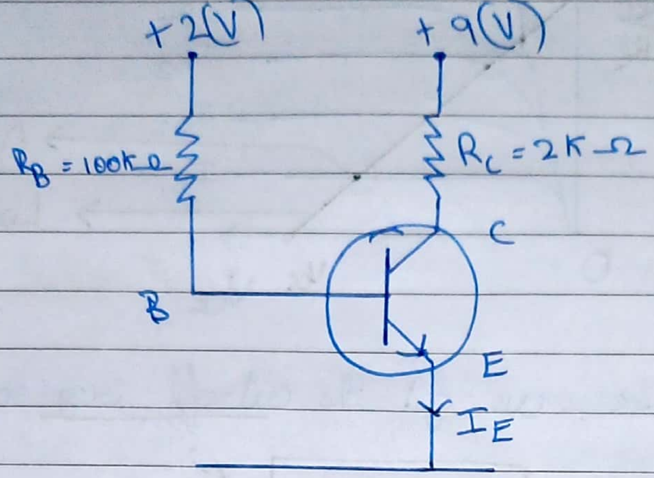
Eg: ① For the following transistor, find the Q-point given $\beta = 50$.



Ans: Given,

$$V_{CC} = 9V$$
$$V_{BB} = 2V$$
$$\beta = 50$$

Now, $I_C = \frac{V_{CC}}{R_C} = \frac{9}{2000} = 4.5 mA$

also, $I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{2 - 0.65}{100 \times 10^3} = 13.5 \mu A$

To find the Q-point,

$$I_{CQ} = \beta \times I_B = (50)(13.5 \times 10^{-6})$$
$$= 0.675 mA$$

and $V_{CEQ} = V_{CC} - I_{CQ} R_C = 9 - (0.675 \times 10^{-3})(2000)$
$$= 7.65 V$$

∴ Required Q-point is (7.65 V, 0.675 mA)//