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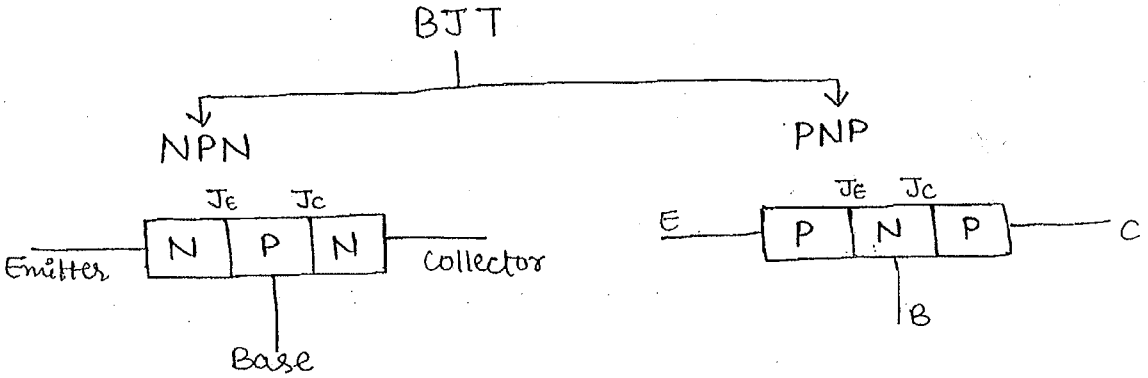
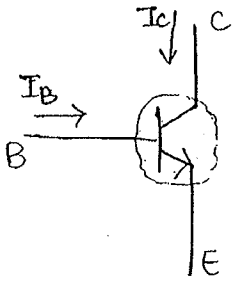
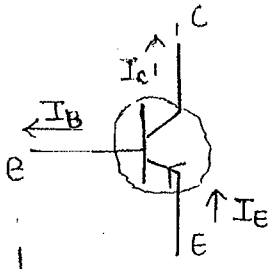
BJT Circuits :







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

	Region of operation	J_E	J_C	Application
①	Cut-off	R.B.	R.B.	OFF Switch
②	Saturation	F.B.	F.B	ON Switch
③	Active or Forward Active	F.B.	R.B.	Amplifier
④	Reverse Active	R.B.	F.B.	Attenuator,

⇒ BJT is not used in Reverse active region because BJT acts as Attenuator in Reverse Active mode. (Gain < 1)

Important Formulae —

① $I_E = I_{ES}\left(e^{V_{BE}/V_T} - 1\right)$ for NPN

$I_E = I_{ES}\left(e^{V_{EB}/V_T} - 1\right)$ for PNP

where, I_{ES} → Reverse saturation current in emitter junction (J_E)

$$I_{ES} \simeq \frac{A q n_i^2 \times D_B}{W_B \times N_B}$$, $I_{ES} \propto$ Area of J_E

$\boxed{I_E \propto \text{Area of } J_E}$

D_B < D_P for PNP, D_N for NPN , W_B → Base width

N_B → Doping conc. of base.

② If BJT is an Active Region

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

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

where,

I_{CO} → Reverse saturation current of J_C. It is also negligible effect.

α → common base current Gain ($\alpha = \beta^* \gamma$)

β → common emitter current Gain

$$\boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{or} \quad \boxed{\alpha = \frac{\beta}{\beta+1}}$$

$\therefore \alpha \simeq 1$

$\therefore \beta$: large number

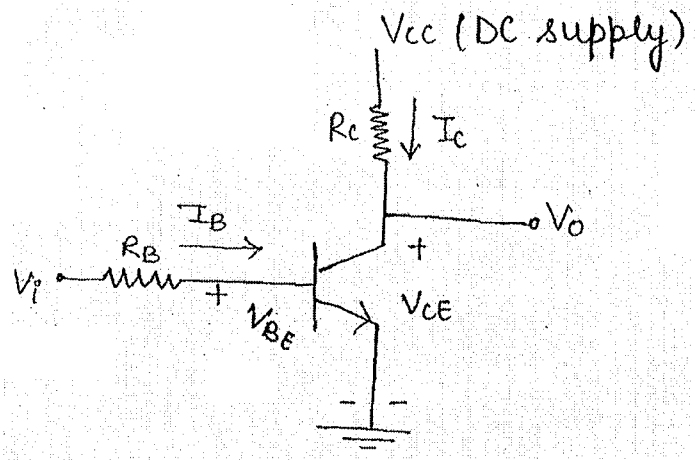
* β is a measure of amplification property of BJT.

* A large β indicates better amplification property.

$\therefore I_C \simeq \alpha I_E$, $I_C = \alpha I_{ES}\left(e^{V_{BE}/V_T} - 1\right)$

$\boxed{I_C = I_S\left(e^{V_{BE}/V_T} - 1\right)}$ $\therefore I_S = \alpha \times I_{ES}$ ↓ Saturation current

BJT behaviour in a circuit :-



Let V_i be varied :-

(I) If $V_i < V_{BE}$ (cut in)

BJT remains OFF.

$I_B = 0$, $I_C = 0$

$\therefore V_o = V_{CE} = V_{cc} - I_C R_C = V_{cc}$

$I_C R_C \downarrow 0$

V_{BE} (cut in) $\begin{cases} 0.6\,V \text{ for Si} \\ 0.1\,V \text{ for Ge} \end{cases}$

(II) If $V_i > V_{BE}$ (cut in)

BJT starts conduction

i.e. I_B & I_C will flow.

$\therefore \boxed{I_B = \dfrac{V_i - V_{BE}}{R_B}}$ $\boxed{I_C = \beta I_B}$

$\therefore \boxed{V_o = V_{CE} = V_{cc} - I_C R_C}$

If $V_i \uparrow \rightarrow I_B \uparrow \rightarrow I_C \uparrow \rightarrow$ Voltage drop in R_C ($I_C R_C$) $\uparrow \rightarrow V_{CE} \downarrow$

* V_{CE} can decrease upto V_{CEsat}
* V_{CEsat} is the minimum possible voltage which can appear b/w collector & Emitter.
* V_{CE} can not become zero due to internal resistance of BJT.

V_{CEsat} $\begin{cases} 0.2\,V \text{ for Si} \\ 0.1\,V \text{ for Ge} \end{cases}$

* If V_{CE} becomes V_{CEsat} then it remains constant at V_{CEsat}. Hence, collector current (I_C) also becomes constant & BJT is said to be in saturation.

If BJT enters in saturation. then,

$$\boxed{V_{CE} = V_{CEsat}}$$

& I_C remains constant at I_{Csat}

$$\boxed{I_{Csat} = \frac{V_{CC} - V_{CEsat}}{R_C}}$$

↳ saturated collector current (I_C)
OR
maximum collector current (I_C)

* Base current (I_B) keeps increasing with V_i. Hence, BJT can not satisfy the relation $\boxed{I_C = \beta I_B}$ in saturation.

* In saturation, $\boxed{\beta I_B > I_C}$ or $\boxed{I_C < \beta I_B}$ or

$$\boxed{I_E > \frac{I_{Csat}}{\beta}}$$

* Emitter current (I_E) also keep increasing. Because

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

* Forced β :- It is the ratio of I_{Csat} & I_B, when BJT is in saturation.

$$\boxed{\beta_{Forced} = \frac{I_{Csat}}{I_B}}$$

If $V_i \uparrow \rightarrow I_B \uparrow \rightarrow \beta_{Forced} \downarrow$

$\therefore$ $\boxed{\beta > \beta_{Forced}}$

✳ Overdrive (Degree of Saturation):

It is the ratio of normal β & Forced β

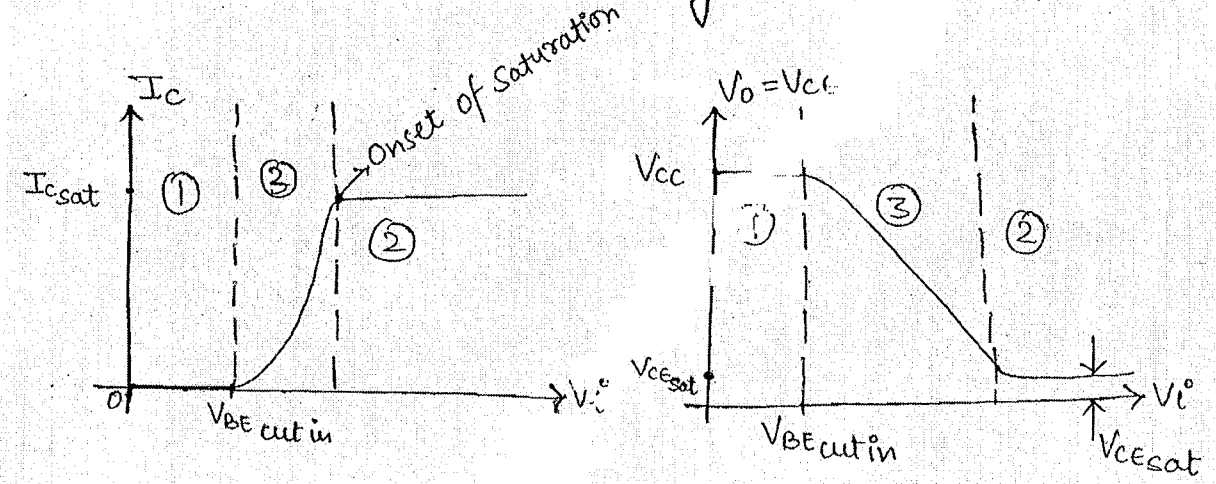
$$\text{Overdrive} = \frac{\beta}{\beta_{Forced}}$$

Overdrive is a measure of level of saturation.

Overdrive = 1 ⇒ onset (begining) of saturation.

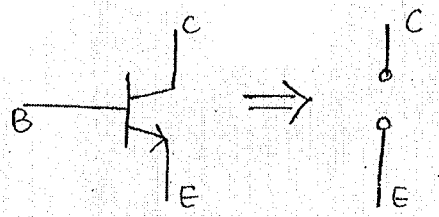
Overdrive > 1 ⇒ weak saturation (or) Soft Saturation

Overdrive >> 1 ⇒ Strong saturation (or) Hard Saturation



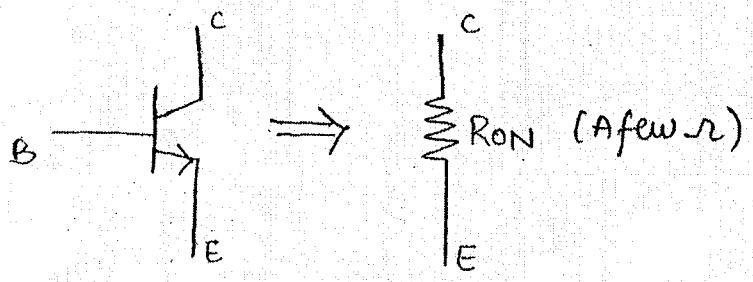
⇒ Region ① is cut-off Region.

$I_C = 0$, $V_{CE} = V_{CC}$ } open circuit OR OFF switch



⇒ Region ② is saturation region, where I_C remains constant w.r.t. V_i

$I_C = I_{Csat}$, $V_{CE} = V_{CEsat}$ } ON switch



R_{ON} ⟹ ON resistance of BJT.

$$R_{ON} = \frac{V_{CE\,sat}}{I_{C\,sat}}$$

⇒ Region (3) is active region, where collector current (I_C) varies with input voltage (V_i)

→ A BJT is said to be active if collector current (I_C) changes acc. to input voltage. (V_i)

→ If BJT is used as small signal amplifier then it is operated in active region, so that small changes in input can create proportionate change in I_C.

Procedure to Check Operating Region of BJT.

Method 1:

① Assume BJT in saturation

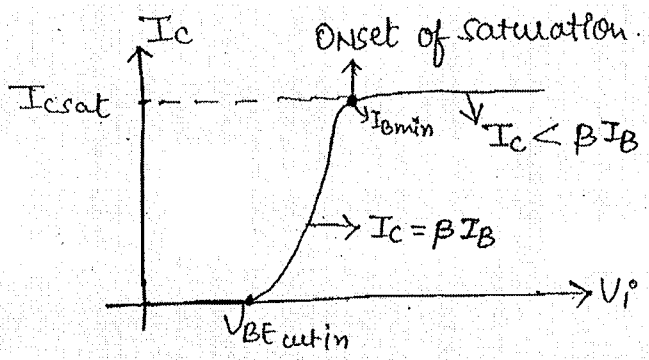
$V_{CE} = V_{CE\,sat}$ < 0.2V for Si, 0.1V for Ge

② Calculate I_B and I_C or $I_{C\,sat}$

③ Calculate minimum base current required to operate in BJT in saturation ($I_{B\,min}$).

$$I_{B\,min} = \frac{I_{C\,sat}}{\beta} \quad *$$

↳ Base current at onset of saturation.



④ Compare I_B and I_{Bmin}.

If $I_B \geq I_{Bmin} \Rightarrow$ BJT is in saturation region.

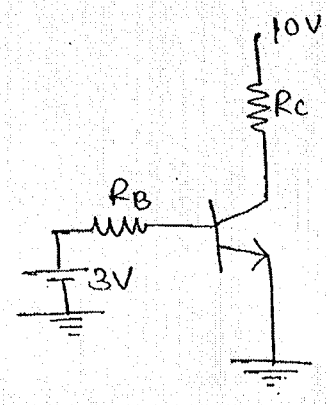
If $I_B < I_{Bmin} \Rightarrow$ BJT is in active region.

Que- In circuit shown BJT has $\beta = 100$, $V_{CEsat} = 0.2V$ and $V_{BEsat} = 0.8V$, find,

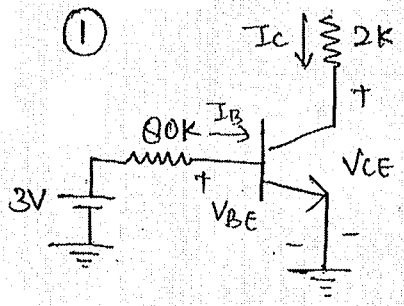
(I) operating region if $R_C = 2K$, $R_B = 80K$

(II) If $R_C = 1K$, then find the value of R_B such that BJT remains in saturation.

Sol:- $\because V_i = 3V$



(I)



let Assume BJT in saturation

$V_{CE} = 0.2V$

$V_{BE} = 0.8V$

$$\therefore I_B = \frac{3 - V_{BE}}{80} = \frac{2.2}{80} = 0.0275\,mA$$

$$I_C = I_{Csat} = \frac{10 - V_{CE}}{2} = \frac{9.8}{2} = 4.9\,mA.$$