BIPOLAR JUNCTION TRANSISTOR (BJT)

Bipolar junction transistor:

→ It is a three terminal device whose terminals represented as emitter, base, collector.

→ The transistor is called BJT because both holes and electrons take part in current conduction process.

→ It is an active device

→ The main function of a transistor is amplification (active mode of operation)

→ It is also used in switching ckt (saturation and cutoff mode of operation)

→ According to structure, transistors are divided into two types

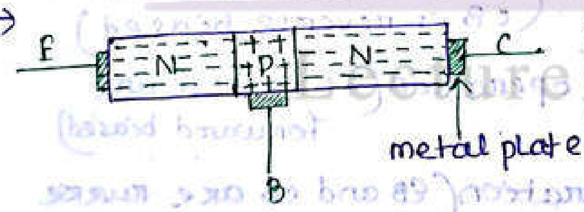
↳ i) NPN transistor

↳ ii) PNP transistor

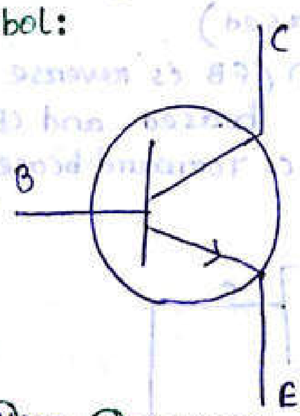
NPN

→ when p-type semiconductor is sandwiched between two N-type semiconductor, it is called NPN transistor

→



symbol:

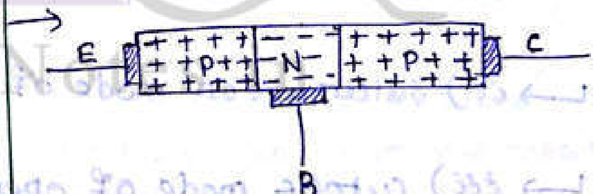


NOT Pointing iN.

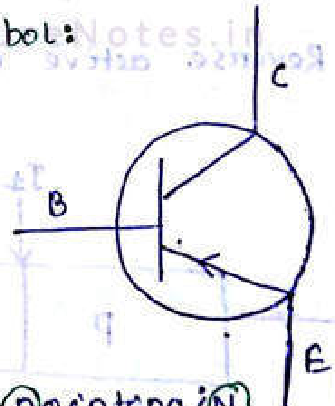
PNP

→ when N-type semiconductor is sandwiched between two P-type semiconductor, it is called PNP transistor.

→



symbol:



Pointing iN

Terminals BJT :

- i) Emitter
- ii) Base
- iii) collector

i) **Emitter** : It is heavily doped region as it emits charge carriers.

ii) **Base** : The width of the base is very less than emitter and collector. Base is lightly doped. It controls the flow of electricity from emitter to collector.

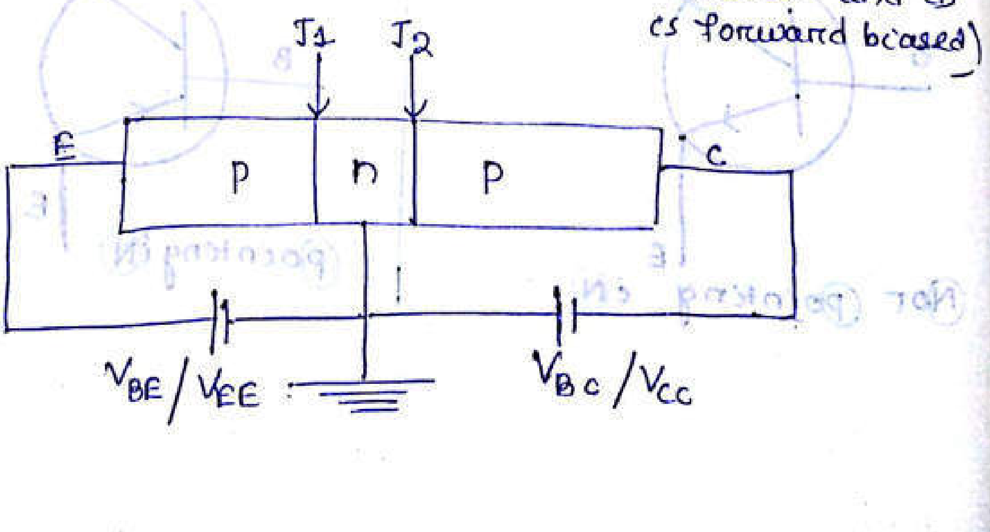
iii) **collector** : The name collector suggests that it collects the charge carriers and it is moderately doped. The width of the collector region is larger that emitter and base.

Q. Why NPN transistor is mostly used in amplification and switching?

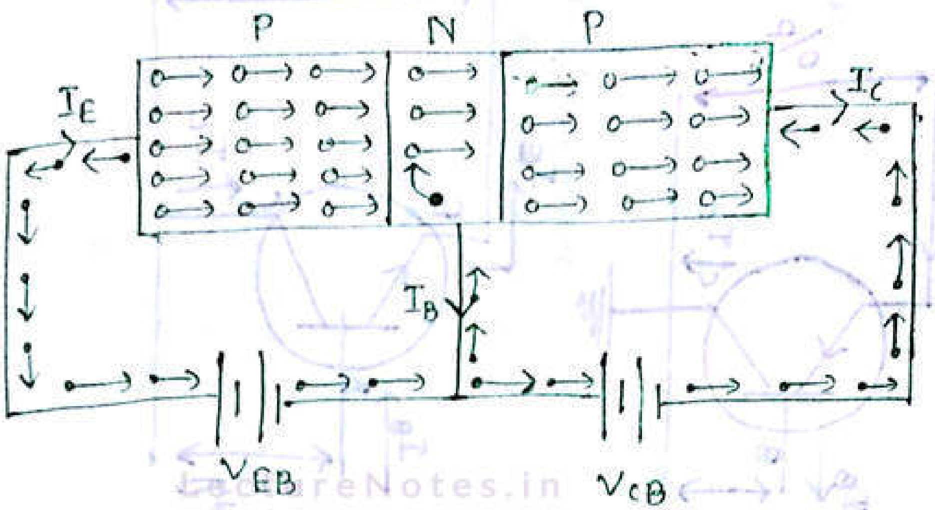
→ In NPN transistor the majority charge carriers are e^-s whereas in PNP holes are the majority charge carriers. The mobility of e^- is much higher than holes. Due to high mobility, the operation becomes faster.

Modes of operation :

- i) Active mode of operation (BE is forward biased, CB is reverse biased)
- ii) saturation mode of operation (EB and CB are forward biased)
- iii) cutoff mode of operation (EB and CB are reverse biased)
- iv) Reverse active mode of operation (EB is reverse biased and CB is forward biased)



OPERATION OF PNP TRANSISTOR :



→ According to the figure i/p voltage is applied between emitter and base while o/p voltage is in between collector and base.

→ The i/p section is forward biased i.e emitter is connected +ve w.r.t to base.

→ The o/p is reverse biased i.e collector is connected -ve w.r.t base

→ The forward bias causes the holes in the p-type emitter to flow toward the base. Hence emitter current results.

→ when these holes flow through the N-type base, they tend to combine with e^-s. As the base is lightly doped and very thin, only a few holes (less than 5%) combines with e^-s. Hense base current (I_B) results.

→ The reminder (more than 95%) cross over into the collector region resulting collector current.

→ In this way almost the entire emitter current flows in the collector circuit. Therefore, the emitter current is the sum of collector and base currents i.e

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

Q. what are the 3 configurations of BJT to work as an amplifier.

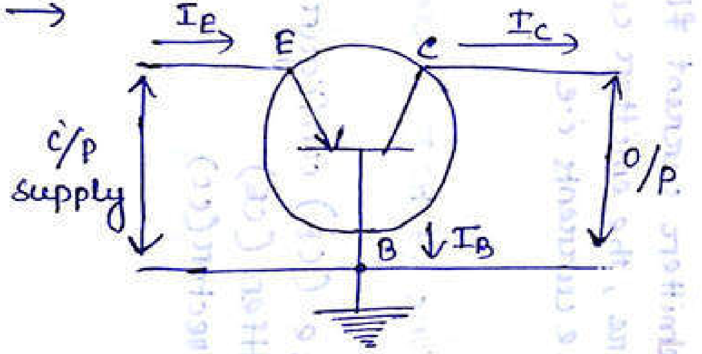
→

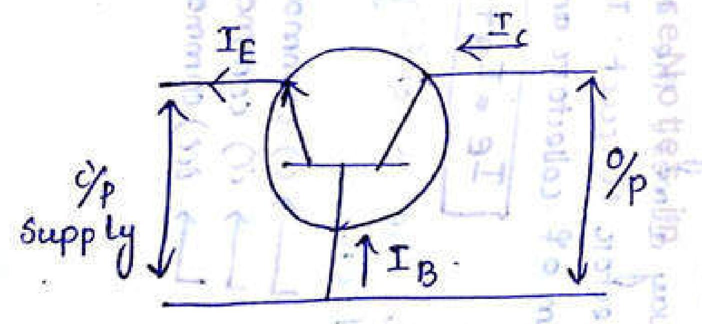
- i) common base (CB)
- ii) common emitter (CE)
- iii) common collector (CC)

Common Base (CB)

→ Base terminal is common to both i/p and o/p

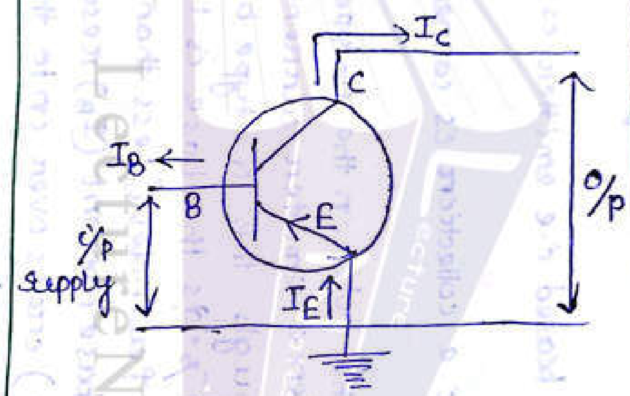
→

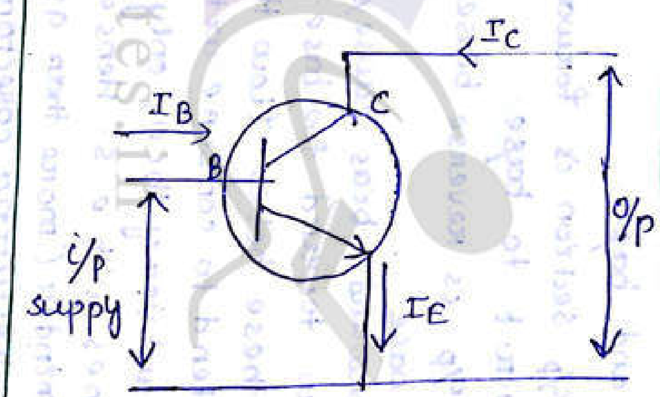




Common Emitter

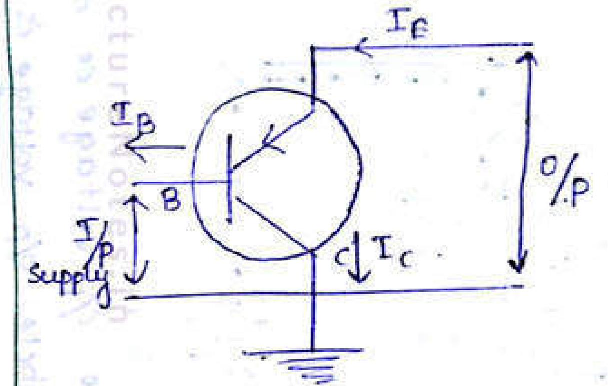
→ Emitter terminal is common to both i/p and o/p

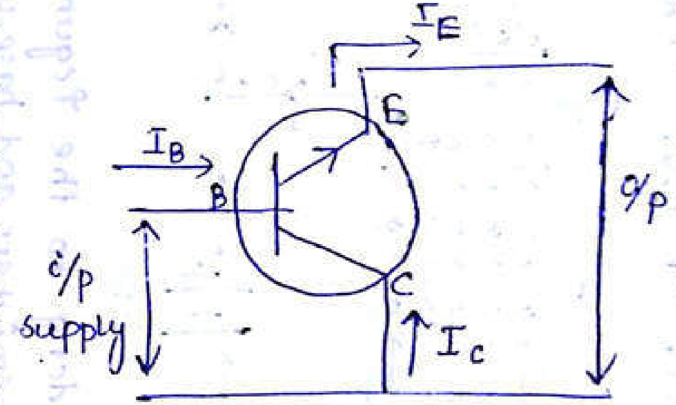




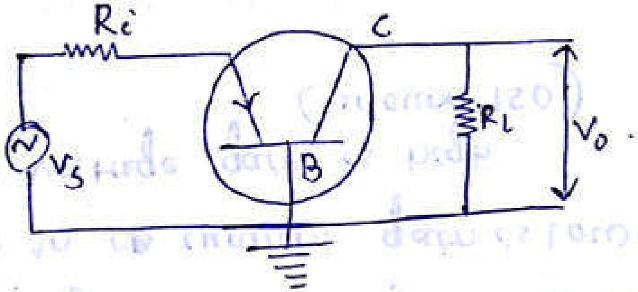
Common Collector

→ collector terminal is common to both i/p and o/p





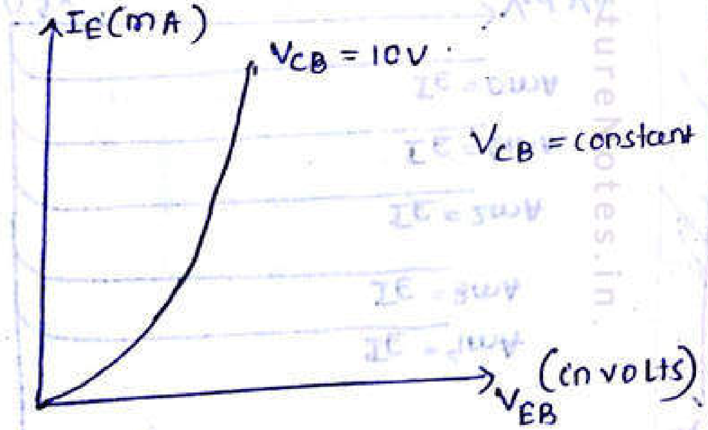
→ Amplifier connection:



characteristics:

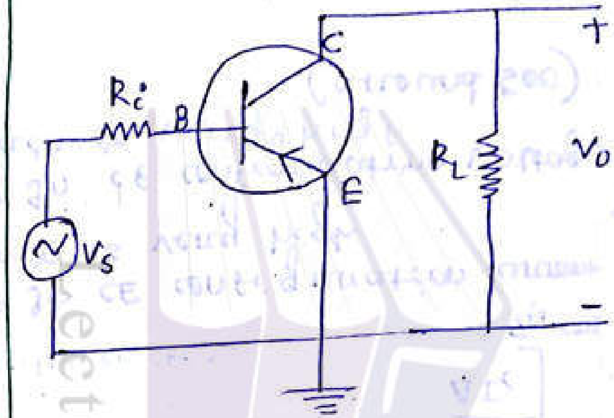
↳ i/p characteristics
↳ o/p characteristics

i/p characteristics –



i/p resistance (r_i) = $\left.\dfrac{\Delta V_{BE}}{\Delta I_E}\right]_{V_{CB}=const}$

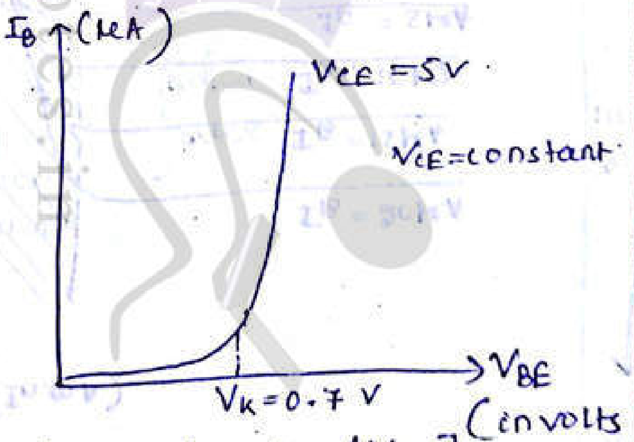
→ Amplifier connection:



characteristics:

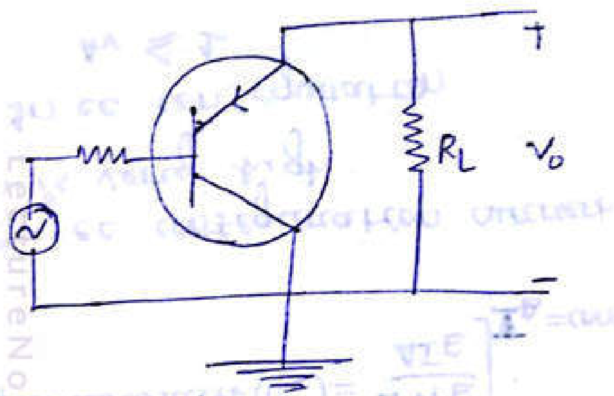
↳ i/p characteristics
↳ o/p characteristics

i/p characteristics –



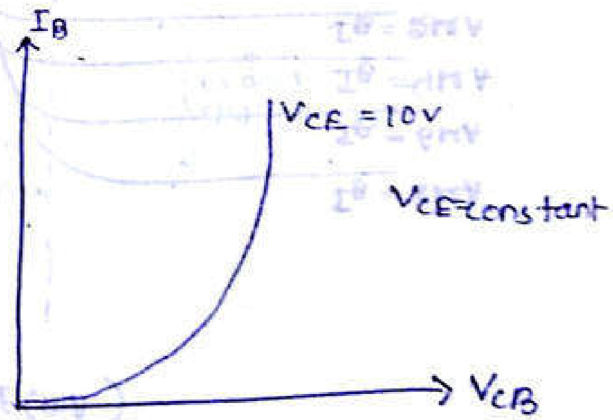
i/p resistance (r_i) = $\left.\dfrac{\Delta V_{BE}}{\Delta I_B}\right]_{V_{CE}=const}$

Amplifier connection:



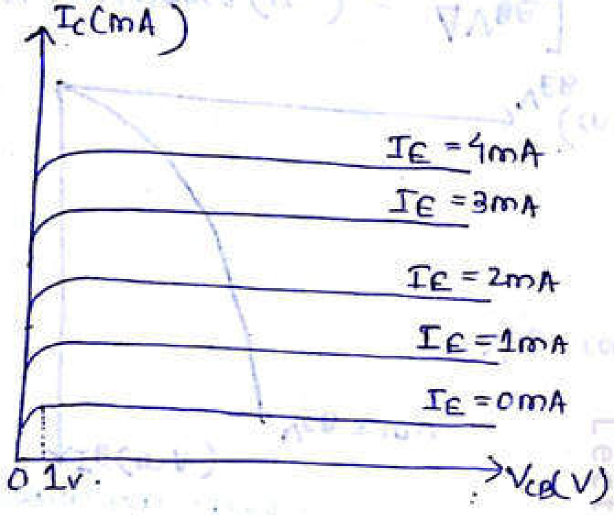
characteristics:

↳ i/p characteristics
↳ o/p characteristics



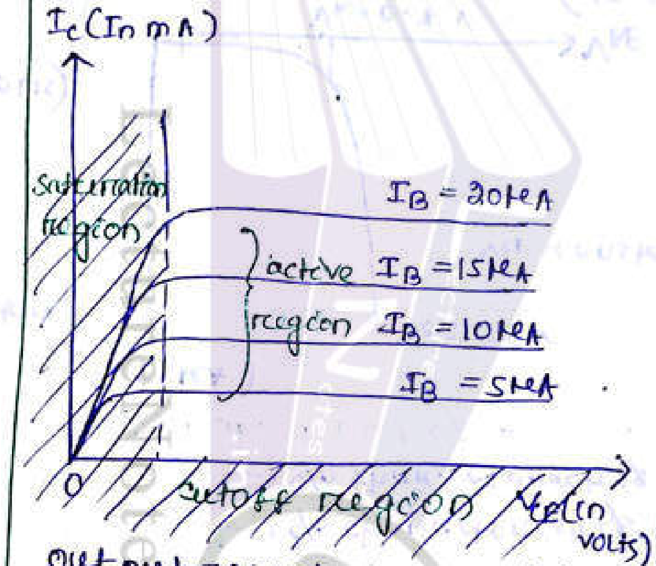
i/p resistance (r_i) = $\left.\dfrac{\Delta V_{CB}}{\Delta I_B}\right]_{V_{CE}=const}$

O/p characteristics-



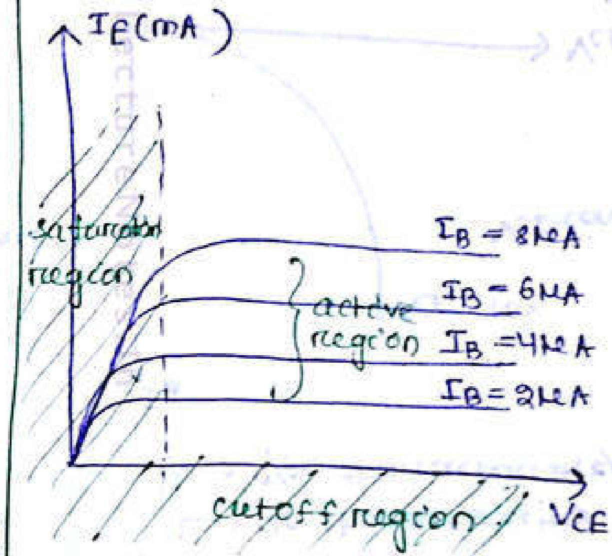
output resistance(r_0) = $\left.\frac{\Delta V_{CB}}{\Delta I_C}\right]_{I_E=const}$

O/p characteristics :



output resistance r_0 = $\left.\frac{\Delta V_{CE}}{\Delta I_C}\right]_{I_B=const}$

O/p characteristics:



outputresistance(r_0) = $\left.\frac{\Delta V_{CE}}{\Delta I_E}\right]_{I_B=const}$

Why CE is mostly used as an amplifier ckt :-

→ In CB current gain is Low
→ voltage gain is high (around 150)

→ In CE configuration current gain is very high.
→ In CE configuration voltage gain is very high. (around 500)

→ In CC configuration current gain is very high.
→ In CC configuration $A_V \leq 1$

→ In CB configuration i/p impedance is low (nearly 100Ω)	→ I/p impedance is high (around 750Ω)	→ I/p impedance is very high (around 750kΩ)
→ o/p impedance is very high (nearly 450kΩ)	→ o/p impedance is high (Around 45kΩ)	→ o/p impedance is low (Around 50Ω)
→ power gain is low	→ power gain is high	→ power gain is medium.

Current amplification factor :

It is the ratio between change in o/p current and change in i/p current.

CB current amplification factor : (α)

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

CE current amplification factor : (β)

$$\boxed{\beta = \frac{\Delta I_C}{\Delta I_B}}$$

CC current amplification factor : (γ)

$$\boxed{\gamma = \frac{\Delta I_E}{\Delta I_B}}$$

Relation between α & β :

We know

$$I_E = I_C + I_B.$$

$$\Delta I_E = \Delta I_C + \Delta I_B$$

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

$$= \frac{\Delta I_C}{\Delta I_C + \Delta I_B} = \frac{\beta \Delta I_B}{\beta \Delta I_B + \Delta I_B} \left(\because \beta = \frac{\Delta I_C}{\Delta I_B}\right)$$

$$= \frac{\beta \cancel{\Delta I_B}}{(\beta + 1)\cancel{\Delta I_B}} = \frac{\beta}{\beta + 1}.$$

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

$$\beta = \frac{\Delta I_C}{\Delta I_B}.$$

$$= \frac{\alpha \Delta I_E}{\Delta I_E - \alpha \Delta I_E} \left(\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right)$$

$$= \frac{\cancel{\Delta I_E}\, \alpha}{\cancel{\Delta I_E}(1 - \alpha)} = \frac{\alpha}{1 - \alpha}$$

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

Relation between β & γ:

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

$$\beta = \frac{\Delta I_E - \Delta I_B}{\Delta I_B}$$

$$= \frac{\gamma \Delta I_B - \Delta I_B}{\Delta I_B} \quad \left(\because \gamma = \frac{\Delta I_E}{\Delta I_B}\right)$$

$$= \frac{\cancel{\Delta I_B}(\gamma - 1)}{\cancel{\Delta I_B}}$$

$$\Rightarrow \boxed{\beta = \gamma - 1}$$

$$\Rightarrow \boxed{\gamma = \beta + 1}$$

Transistor Leakage Current:

CB:

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

$$\Rightarrow I_C = \alpha I_E + \underbrace{I_{CBO}}_{\text{Leakage current}}$$

CE:

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

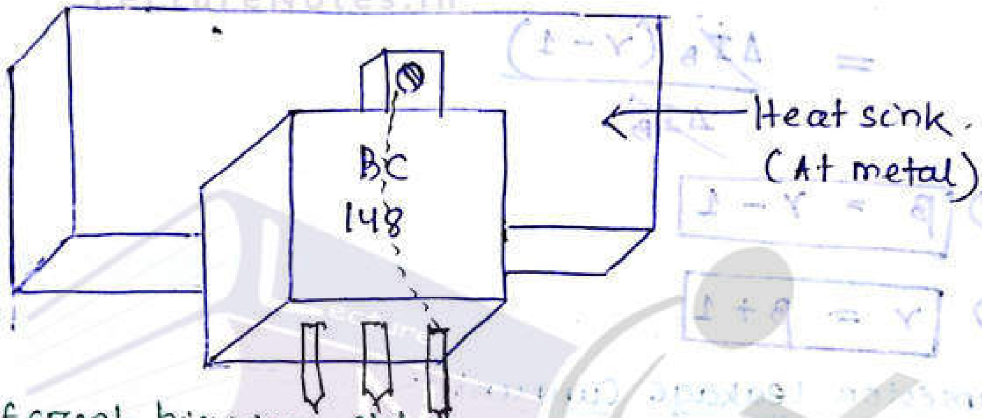
$$\Rightarrow I_C = \beta I_B + \underbrace{I_{CEO}}_{\text{Leakage current}}$$

Thermal run away:

The self destruction of unstabilized transistor with excessive generation of heat at collector (due to collision of charge carriers) is called thermal run away.

Q. How thermal runaway can be avoided?

→ By connecting a heat sink made up of aluminium metal at the collector terminal, we can be ensure that, the maximum amount of heat gets absorbed by the metal plate which ultimately save BJT



Different biasing ckt:

↳ fixed bias

↳ Emitter bias / Emitter stabilized bias

↳ voltage divider bias

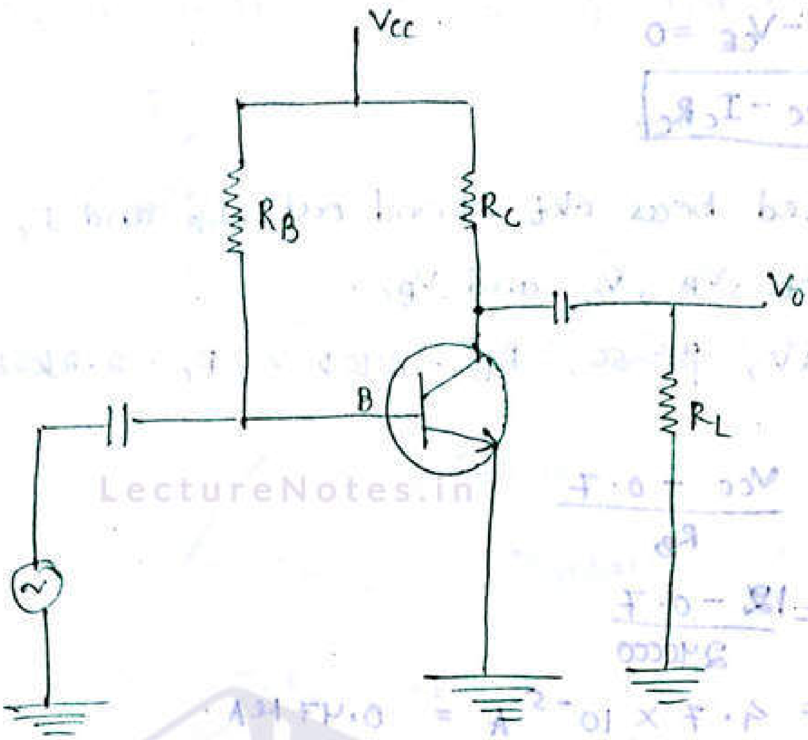
↳ Dc bias with voltage feed back / Dc bias with collector bias.

Biasing ckt:

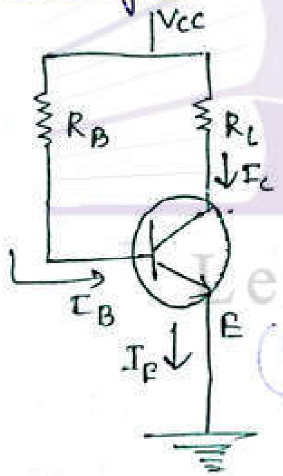
It is a ckt arrangement around the BJT which helps in amplifying the i/p signal in such a way that maximum and faithful o/p with stability can be obtained.

Dc analysis	AC analysis
→ In dc signals analysis all ac signals are removed along with capacitor.	→ All dc sources reduce to zero.
→ Objective is to find – i) Q point (operating point) ii) Dc load line	→ Objective to find – i) voltage gain ii) Current gain iii) i/p impedence iv) o/p impedence.

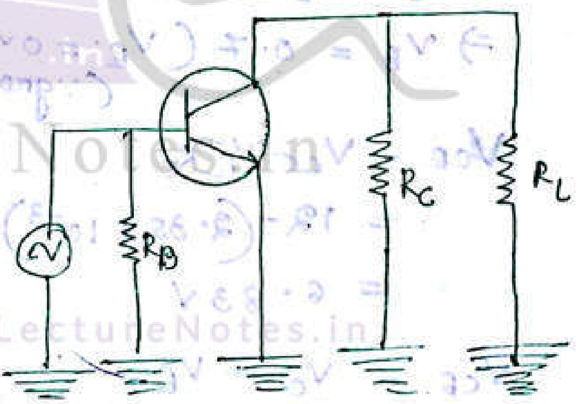
Fixed bias ckt :



dc analysis



Ac analysis



From i/p

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$\Rightarrow I_B = \frac{V_{CC} - 0.7}{R_B} \text{ (for si)}$$

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

$$\Rightarrow \boxed{I_C = \beta I_B}$$

From o/p :

$V_{CC} - I_C R_C - V_{CE} = 0$

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

Q. For fixed bias ckt find out I_B and I_C. Find V_{CE}, V_B, V_C and V_{BC}.

$V_{CC} = 12V$, $\beta = 50$, $R_B = 240k\Omega$, $R_C = 2.2k\Omega$.

→

$$I_B = \frac{V_{CC} - 0.7}{R_B}$$

$$= \frac{12 - 0.7}{240000}$$

$$= 4.7 \times 10^{-5} A = 0.47 \mu A.$$

$$I_C = \beta I_B = 4.7 \times 10^{-5} \times 50 = 2.35 \times 10^{-3} A.$$

$$V_{BE} = 0.7V$$

$$\Rightarrow V_B - V_E = 0.7$$

$$\Rightarrow V_B = 0.7 \left(V_E = 0V\right) \text{(}\because\text{ grounded)}$$

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

$$= 12 - (2.35 \times 10^{-3})(2.2 \times 10^3)$$

$$= 6.83V$$

$$V_{CE} = V_C - V_E.$$

$$\Rightarrow V_{CE} = V_C - 0 \Rightarrow V_{CE} = V_C$$

$$\Rightarrow V_C = 6.83V$$

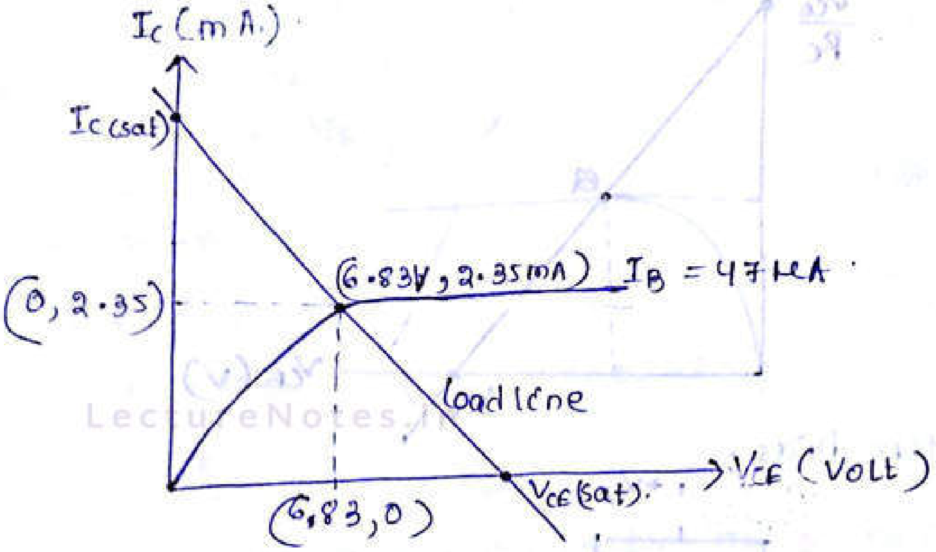
$$V_{BC} = V_B - V_C$$

$$= 0.7 - 6.83 = -6.13V$$

Load line:

It is a straight line joining saturated value of o/p current and saturated value of o/p voltage.

operating point : It is an intersection point of I_B & loadline in CE o/p characteristics .



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

$$\Rightarrow V_{CE(sat)}\Big|_{I_C=0} = V_{CC}$$

$$\Rightarrow I_{C\,sat}\Big|_{V_{CE}=0} = \frac{V_{CC}}{R_C}$$

Q. why it is called fixed ckt ?

→ $$I_B = \frac{V_{CC} - 0.7V}{R_B}$$

∴ V_{CC} , 0.7 and R_B are constant value .

⇒ I_B is also constant .

∴ All the values are constant .

So it is called fixed bias ckt .

*
$$I_B = \frac{V_{CC} - 0.7}{R_B}$$

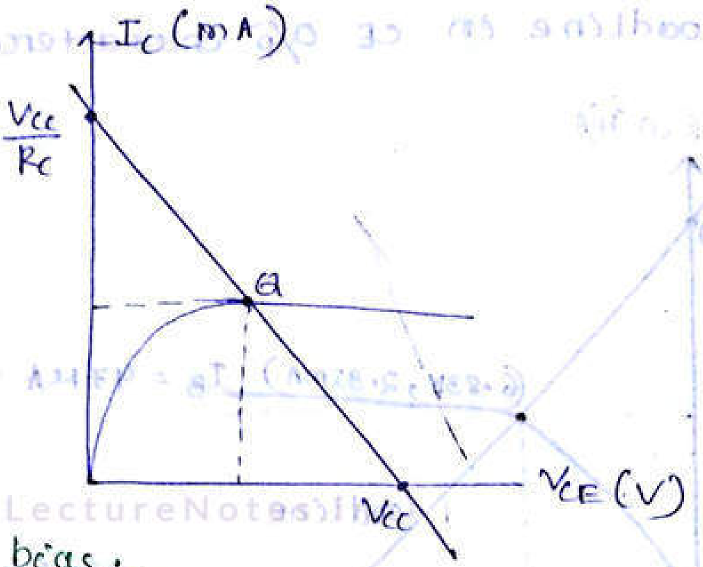
$$I_C = \beta I_B$$

$$V_{CC} - I_C R_C - V_{CE} = 0$$

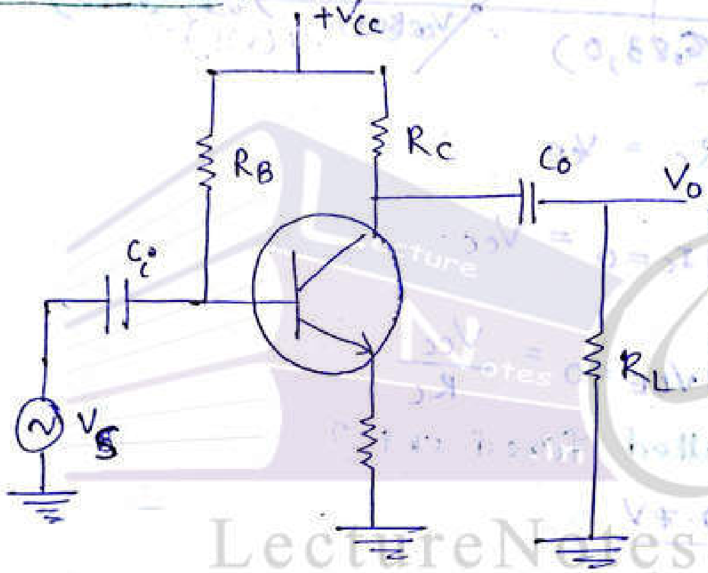
$$\Rightarrow V_{CE} = V_{CC} - I_C R_C$$

$$\Rightarrow V_{CE}(sat) = +V_{CC} \quad (\because I_C = 0)$$

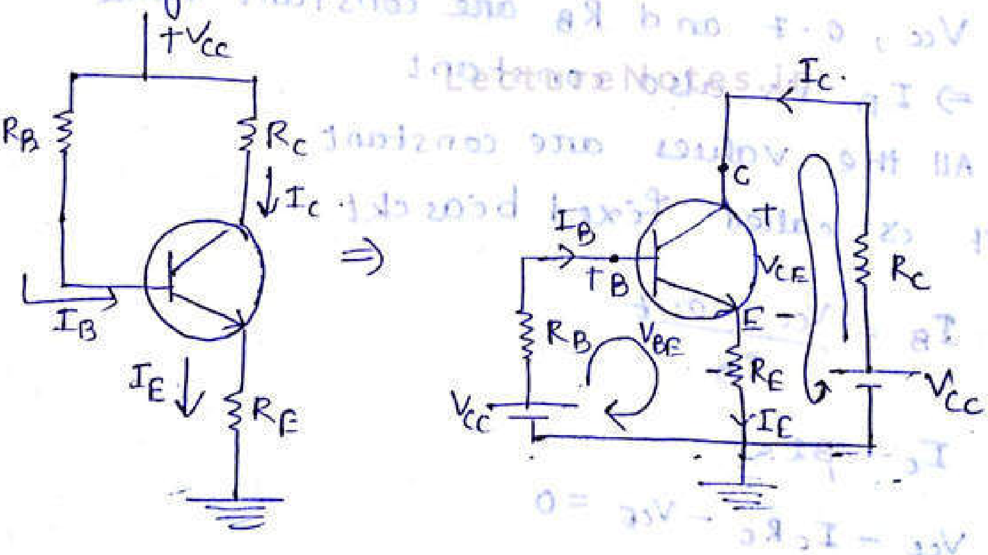
$$\Rightarrow I_C(sat) = V_{CC}/R_C \quad (\because V_{CE} = 0)$$



Emitter bias:



dc biasing ckt:



Apply KVL at i/p loop.

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0 \quad (\because I_E = (\beta+1) I_B).$$

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

Apply KVL at O/p loop

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

$$\Rightarrow V_{CC} - I_C R_C - V_{CE} - I_C R_E = 0 \quad (\because I_C = I_E)$$

$$\Rightarrow \boxed{V_{CC} - I_C (R_C + R_E) = V_{CE}}$$

* A good biasing ckt must be independent of 'β' because 'β' is strongly depends on temperature.
* If temp ↑, β ↑. Ultimately I_C ↑
* I_C should be independent of β.

$$\frac{I_E}{\beta+1} = \frac{V_{CC} - 0.7}{R_B + (\beta+1) R_E}$$

$$\Rightarrow I_E = \frac{(V_{CC} - 0.7)(\beta+1)}{R_B + (\beta+1) R_E}$$

$$\Rightarrow I_E = \frac{V_{CC} - 0.7V}{\frac{R_B}{\beta+1} + R_E}$$

If $\frac{R_B}{\beta+1} << R_E$

$\frac{R_B}{\beta+1}$ can be neglected

$$\Rightarrow \boxed{I_E = \frac{V_{CC} - 0.7V}{R_E}}$$

We know, $\frac{I_C}{I_E} = \alpha$.

The maximum value of $\alpha = 1$

So $I_C \cong I_E$. Hence, $\boxed{I_C = \frac{V_{CC} - 0.7V}{R_E}}$

→ The I_c current eq^n is independent of β because even if temperature increases or leakage current increases, the I_c current almost remains fixed.

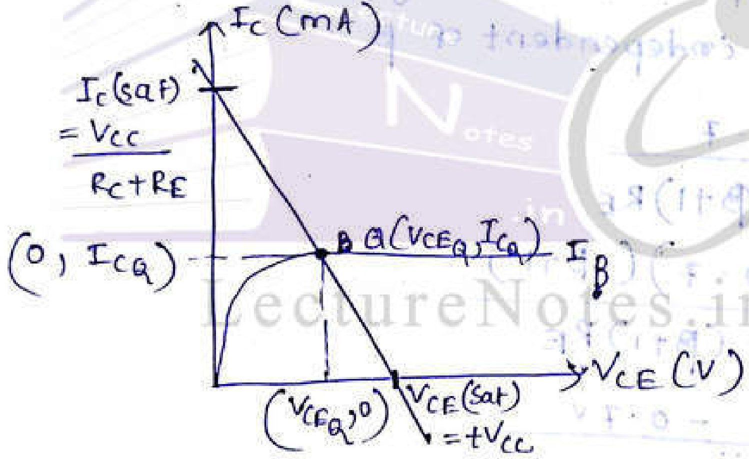
→ The R_E resistor provide a -ve feedback to the ckt which helps in maintaining the operating point and also stability of the ckt.

→ If a ckt is independent of β, that ckt is known as self biased.

→ we know $V_{CE} = V_{CC} - I_C(R_C + R_E)$

$$V_{CE}(sat)\Big|_{I_C=0} = +V_{CC}$$

$$I_C(sat)\Big|_{V_{CE}=0} = \frac{V_{CC}}{R_C + R_E}$$



V_{CE} → collector voltage w.r.t emitter.

V_C → collector voltage w.r.t ground.

$V_{CC} - I_C R_C - V_C = 0$.

$\Rightarrow \boxed{V_C = V_{CC} - I_C R_C}$

V_B → Base voltage w.r.t ground.

$V_B - V_{BE} - I_E R_E = 0$

$\Rightarrow \boxed{V_B = V_{BE} + I_E R_E}$

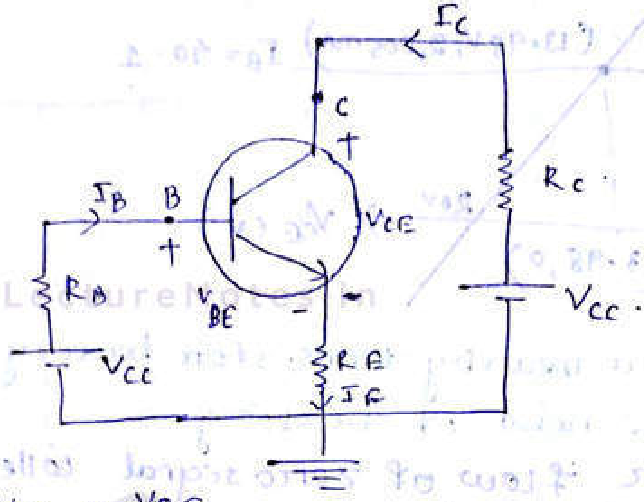
or

$V_{BE} = V_B - V_E$

$\Rightarrow V_{BE} = V_B - I_E R_E \Rightarrow \boxed{V_B = V_{BE} + I_E R_E}$

Q. For emitter bias ckt $R_B = 430K\Omega$, $R_C = 2K\Omega$, $R_E = 1K\Omega$, $V_{CC} = 20V$, $\beta = 50$. The I/p, o/p and bypass capacitors $10\mu F$ each. Find I_B, I_C, I_E, V_{CE}, V_C, V_E, V_B, V_{BC}.

→



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

$$= \frac{20 - 0.7}{430000 + (51 \times 1000)}$$

$$= 4.01 \times 10^{-5} A$$

$$I_C = \beta I_B = 50 \times 4.01 \times 10^{-5} = 2.005 \times 10^{-3} A$$

$$V_C = V_{CC} - I_C R_C$$

$$= 20 - [(2.005 \times 10^{-3}) \times 2000]$$

$$= 15.99 V$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$= 20 - (2.005 \times 10^{-3}) \times (2000 + 1000)$$

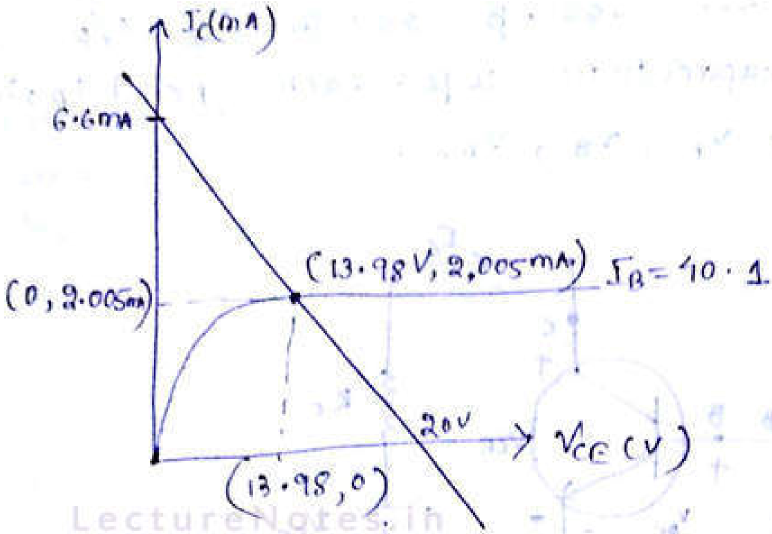
$$= 13.985 V$$

$$V_E = I_E R_E \simeq I_C R_E = 2.005 \times 10^{-3} \times 1000$$

$$= 2.005 V$$

$$V_{CE}(sat) = V_{CC} = 20V$$

$$I_C(sat) = \frac{V_{CC}}{R_C + R_E} = \frac{20}{3000\Omega} = 6.6 \times 10^{-3} A = 6.6 mA$$



Q. what do you mean by transistor biasing? what is the need of biasing.?

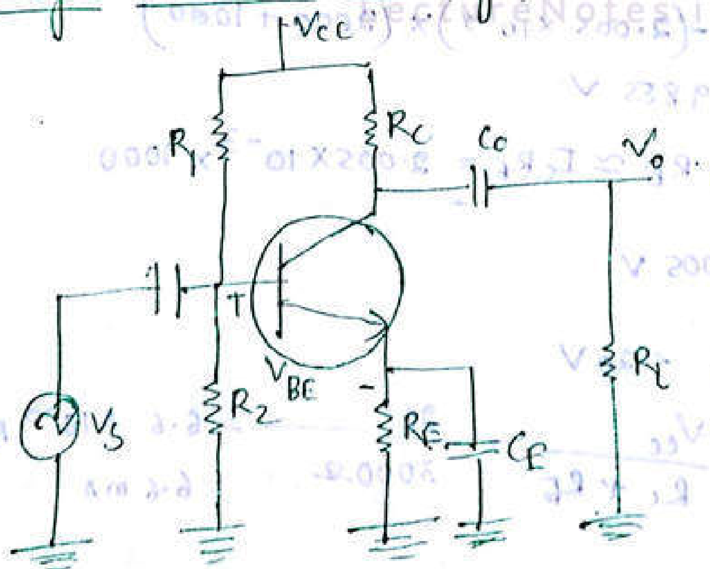
→ The proper flow of zero signal collector current (flow of dc current) and the maintainance of operating point during the passage of signal.

→ The operating point is established nearly the middle of the active region.

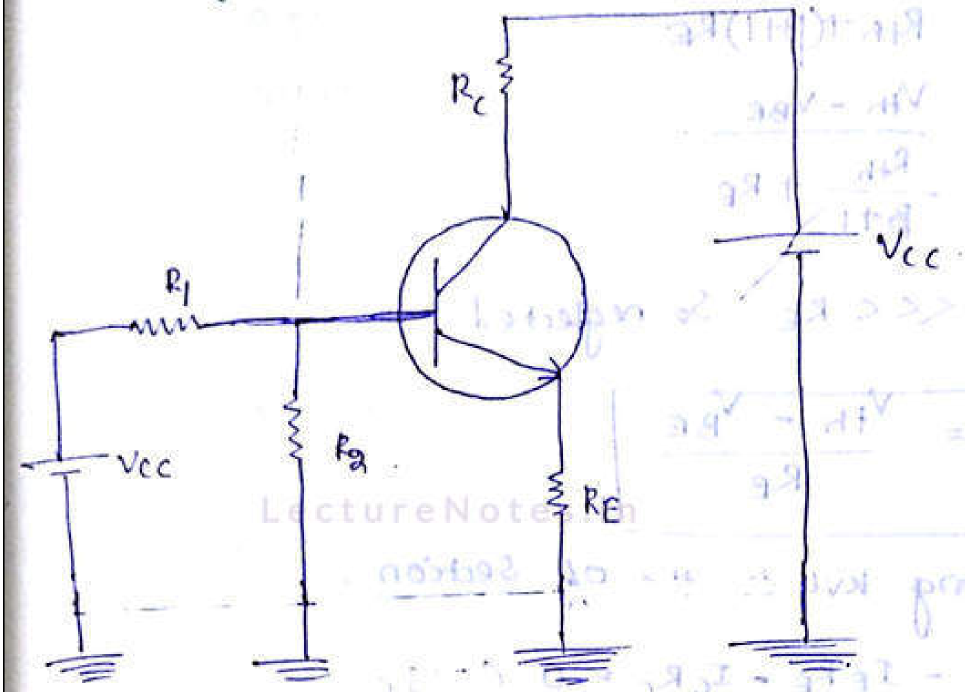
→ The I_C is stablized against temperature variation.

→ The operating point should be independent of 'β'.

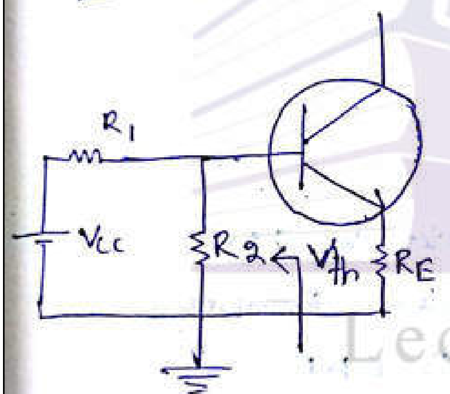
Voltage divider biasing:

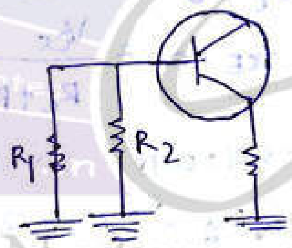


Dc analysis :

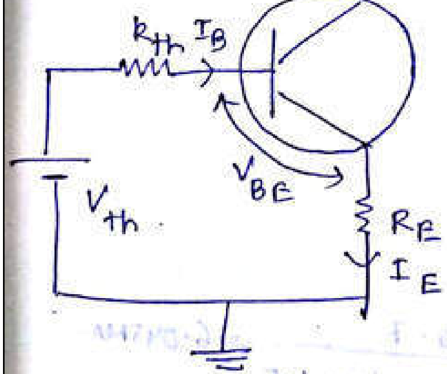


i/p section : Thevnin resistance





$R_{th} = R_1 \| R_2$



By KVL

$$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0 \Rightarrow V_{th} - I_B R_{th} - V_{BE} - (\beta+1) I_B R_E = 0$$

$$\Rightarrow \boxed{I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta+1) R_E}}$$

$$\frac{I_E}{\beta+1} = \frac{V_{th} - V_{BE}}{R_{th} + (\beta+1)R_E}$$

$$I_E = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta+1} + R_E}$$

$\frac{R_{th}}{\beta+1} <<< R_E$. So neglected

$$\boxed{I_C \simeq I_E = \frac{V_{th} - V_{BE}}{R_E}}$$

By applying KVL in the o/p section.

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

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

$$V_{CE}(sat)\Big|_{I_C=0} = +V_{CC}$$

$$I_C(sat)\Big|_{V_{CE}=0} = \frac{V_{CC}}{R_C + R_E}$$

2. For a voltage divider bias ckt $V_{CC} = 22V$, $R_1 = 39k\Omega$, $R_2 = 3.9k\Omega$, $R_C = 10k\Omega$, $R_E = 1.5k\Omega$, $\beta = 140$. Coupling capacitors is $10\mu F$. Bypass capacitor $50\mu F$. Find I_C, I_B, I_E, V_{CE}, V_C, V_B, V_E, V_{BC}, $I_C(sat)$, $V_{CE}(sat)$.

$\rightarrow$

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = 3.54k\Omega$$

$$V_{th} = \left(\frac{V_{CC}}{R_1 + R_2}\right) R_2 = 2V.$$

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta+1)R_E} = \frac{2 - 0.7}{3.55 + 141 \times 1.5} = 6.045\mu A.$$

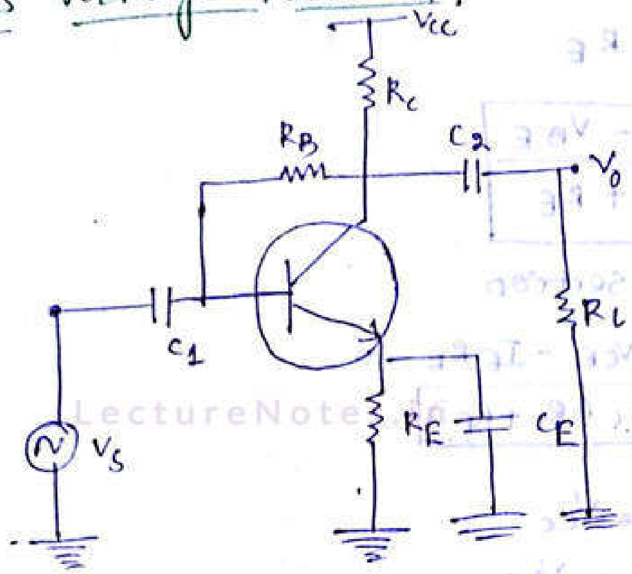
$$I_C = \frac{V_{th} - V_{BE}}{R_E} = \frac{2 - 0.7}{1.5}$$

$$= 0.86.$$

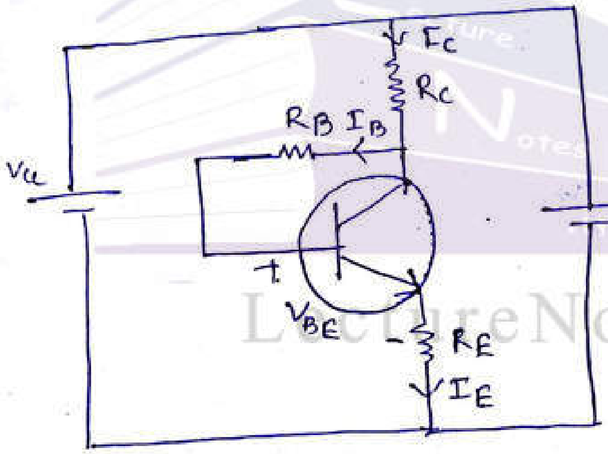
$V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 12.11V$

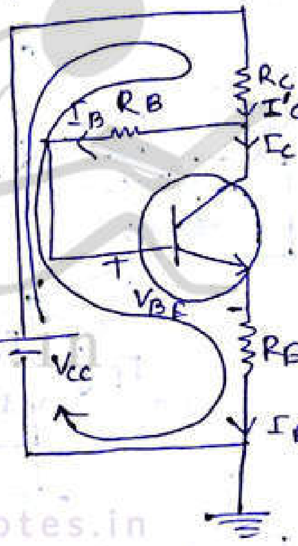
DC bias voltage feedback :



DC analysis :



i/p section:



By apply KVL in the i/p section.

$$V_{CC} - I'_C R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} - I_C R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad (\because I'_C \simeq I_C \simeq I_E)$$

$$\Rightarrow V_{CC} - I_E R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad (\because I_C \cong I_E)$$

$$\Rightarrow V_{CC} - I_E(R_C + R_E) - I_B R_B - V_{BE} = 0$$

$$\Rightarrow V_{CC} - V_{BE} = I_E(R_C + R_E) + I_B R_B$$

$$= (\beta+1) I_B (R_C + R_E) + I_B R_B \quad (\because I_E = (\beta+1) I_B)$$

$$\Rightarrow \boxed{I_B = \frac{V_{CC} - V_{BE}}{(\beta+1)(R_C + R_E) + R_B}}$$

$$I_E = \frac{V_{CC} - V_{BE}}{(R_C + R_E) + \frac{R_B}{\beta + 1}}$$

$$\frac{R_B}{\beta + 1} << R_C + R_E$$

$$\boxed{I_C \cong I_E = \frac{V_{CC} - V_{BE}}{R_C + R_E}}$$

Apply KVL at the o/p section

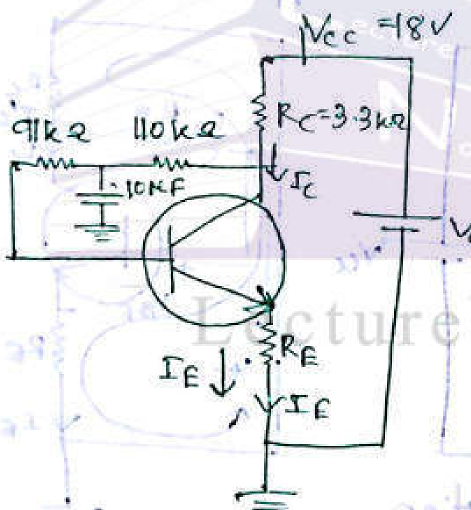
$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\Rightarrow \boxed{V_{CE} = V_{CC} - I_C (R_C + R_E)}$$

$$V_{CE}(sat)\Big|_{I_C = 0} = V_{CC}$$

$$I_C(sat)\Big|_{V_{CE} = 0} = \frac{V_{CC}}{R_C + R_E}$$

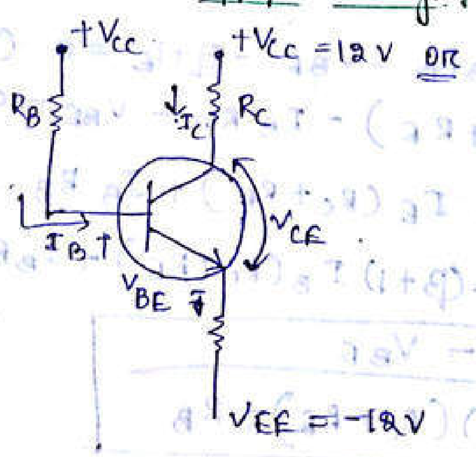
Q.



$I_C, I_B, I_E = ?$

$V_{CE} = ?$

Biasing with two supply voltage:



OR