# Module 3 : Bipolar Junction Transistors.

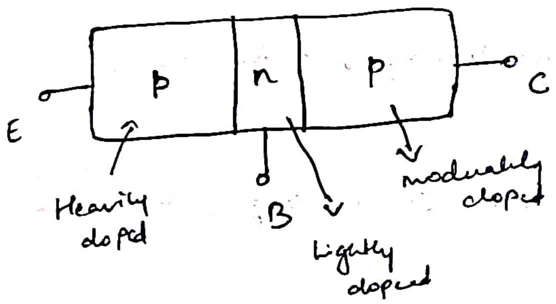
Diode is a two-layer, one-junction semiconductor device which conducts current in a particular ~~operation~~ direction and whose magnitude is controlled by external circuit supply.

A transistor is a combination of two back to back diodes. It is 3 layer 2-junction device which has npn and pnp form and is called a transistor, with a terminal connected to each layer, it acts as a two port device wherein one of the terminals is common between the two ports. Such a transistor is known as Bipolar Junction Transistor (BJT) which acts as a current-controlled device with the output current being controlled by the input current.

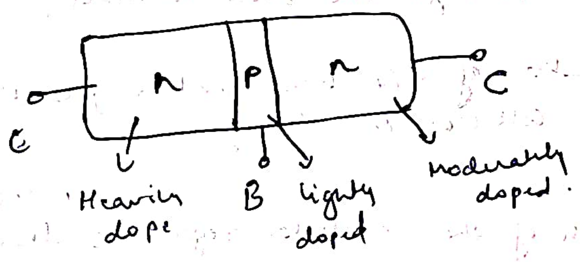
A BJT can be used as an amplifier or a switch.

## BJT construction and operation.

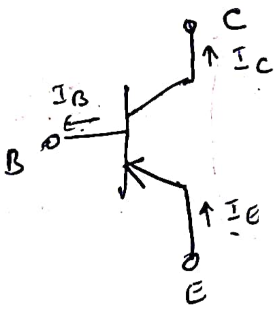
E - Emitter
B - Base
C - collector.



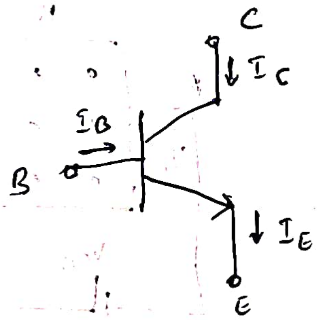

pnp transistor.




npn transistor.




pnp transistor symbol.

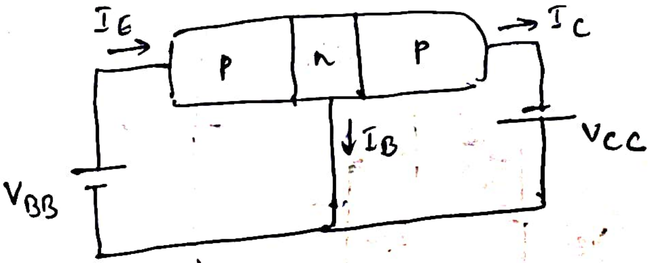



npn transistor symbol.

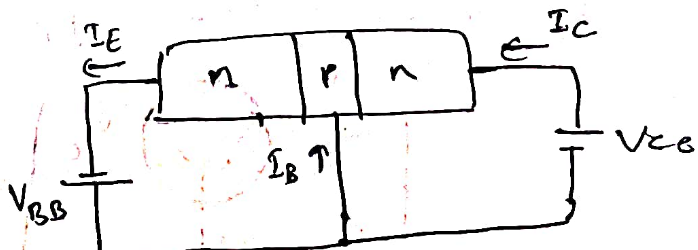
There are 2 junction: EB junction and CB junction. A transistor is like 2 diodes.

EB Junction : Forward Biased diode

CB Junction : Reverse Biased diode.

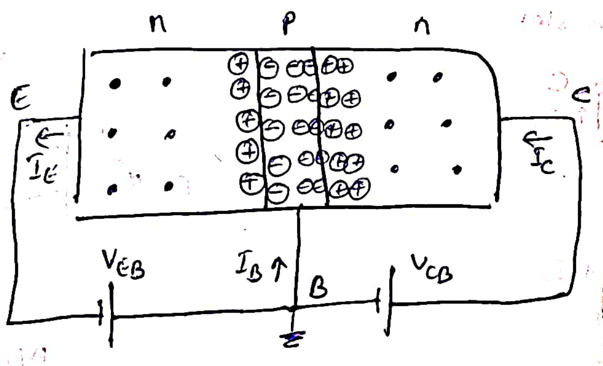



pnp biasing.




npn biasing

* Two pn junctions are formed with depletion regions and barrier voltage at each junction.
* The barrier voltages are negative on the p-side and positive on the n-side.
* EB is forward biased, so that the charge carriers are emitted into the base.
* CB is reverse biased and its depletion region penetrates deep into base.
* Base section is made as narrow as possible so that charge carriers move easily from emitter to collector.
* Base is lightly doped, so that few charge carriers are available to recombine with the majority charge carriers from the emitter.
* Most charge carriers from the emitter flow to the collector, a few flow out through the base terminal.
* Variation of the base emitter junction bias voltages alters the base, emitter and collector currents.
* width of the collector region is ~~less~~ more than the emitter region ~~but more~~ and more than the base region.

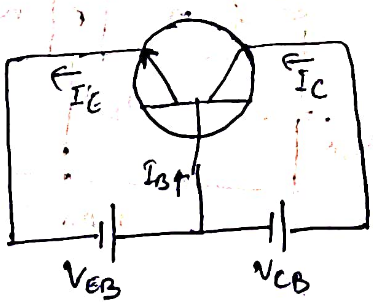



Factor affecting width of the depletion region
→ Reverse bias (inversely propotional)
→ Dopant Concentration
→ Forward bias.

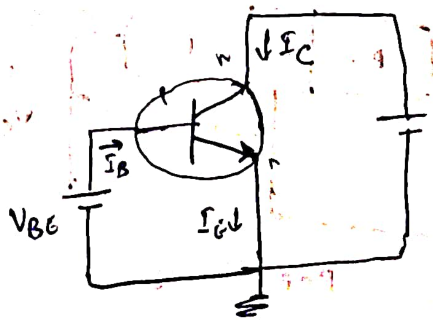
BJT Configurations.

1. Common Base Configuration
2. Common Emitter configuration
3. Common collector configuration.

$V_{CE} - V_{BE} \neq V_{BB}$




CB configuration




CE configuration.

## BJT current components.

Emitter current relation with collector and base currents is given by

$$I_E = I_C + I_B$$

when emitter circuit is open, there is no supply of free electrons from emitter to collector. Even then, there is a small amount of collector current called reverse saturation current $I_{CBO}$ (due to thermally generated electron-hole pairs).

Total collector current is

$$I_C = \alpha_{dc} I_E + I_{CBO}$$

Where $\alpha_{dc}$ is fraction of emitter current that flows to the collector

common base dc current gain. $\alpha_{dc} = \dfrac{I_C - I_{CBO}}{I_E}$

Since $I_{CBO}$ is very small,

$$\alpha_{dc} = \frac{I_C}{I_E}$$

Also

common emitter dc current gain $\beta_{dc} = \dfrac{I_C}{I_B}$, another symbol $h_{FE}$

Relation b/w current gains $\alpha_{dc}$ and $\beta_{dc}$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}$$

when $I_B = 0$, $I_C = I_{CEO}$ (collector cut off current).

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha_{dc}}.$$

## Terminal Voltages.

For npn, Base bias voltage $V_B$ connected via Resistor $R_B$ and collector supply $V_{CC}$ is connected via $R_C$.

$$V_{CC} >> V_B$$

Typical base emitter voltages - 0.7V for Si, 0.3V for Ge transistor.
Typical collector voltages - 3V to 20V for most transistors.

Q. Calculate $I_C$ and $I_E$ for a transistor that has $\alpha_{dc} = 0.98$ and $I_B = 100\,\mu A$. Determine the value of $\beta_{dc}$ (or $h_{FE}$) for the transistor.

$$\alpha_{dc} = 0.98$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{0.98}{1-0.98}$$

$$= 49$$

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

$$I_C = \beta_{dc} \cdot I_B$$

$$= 49 \times 100 \times 10^{-6}$$

$$= 4.9 mA.$$

$$I_E = \frac{I_C}{\alpha_{dc}} = \frac{4.9 \times 10^{-3}}{0.98}$$

$$= 5 mA.$$

Q. Calculate $\alpha_{dc}$ and $\beta_{dc}$ for the transistor ($Q_1$) if $I_C$ is measured as 1mA and $I_B$ is 25 $\mu A$. Determine the new base current to give $I_C = 5mA$.

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

$$= \frac{1 \times 10^{-3}}{25 \times 10^{-6}} = 40$$

$$I_E = I_C + I_B = 1.025 mA$$

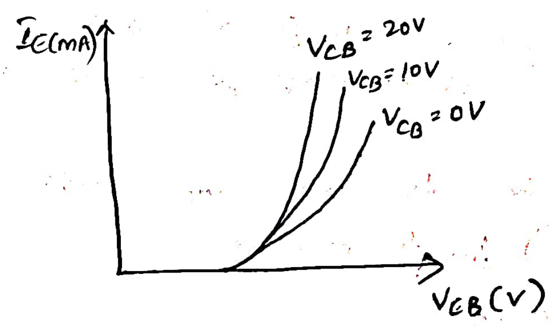
$$\alpha_{dc} = \frac{I_C}{I_E} = \frac{10^{-3}}{1.025 \times 10^{-3}}$$

$$= 0.976$$

New base current $I_B = \frac{I_C}{\beta_{dc}}$

$$= \frac{5mA}{40} = 125 \mu A.$$

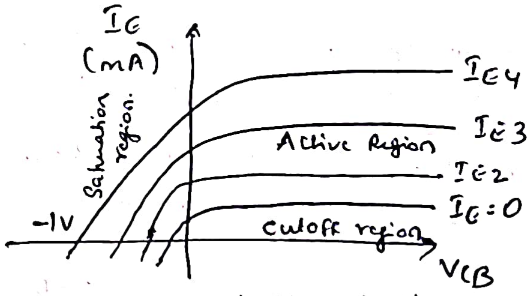
BJT Charachristics : CB Charachistics.




Input charachistics
(plot of input current versus i/p voltage for const value of output voltage $V_{CB}$.

As $V_{EB}$ is increased, $I_E$ increases. The charachistics curve is similiar to diode charachistics.

If $V_{CB}$ is increased, then $I_E$ shoots up early. This is due to the increase electric field aiding the flow of electrons from emitter



output characteristics.

Output characteristics is a plot of $I_C$ versus output voltage $V_{CB}$ for various const values of input current $I_E$. Characteristics is divided into 3 regions namely Active, Saturation and cut off region.

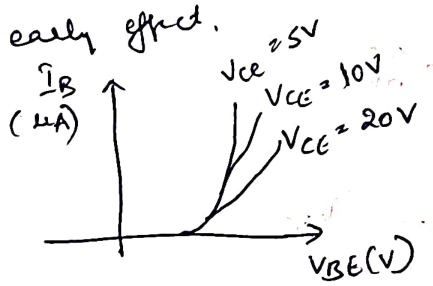
a) Active Region — Region to the right of y-axis above $I_E = 0$ curve. Where the curves are linear.
$I_E$ is positive non zero (i.e E-B diode is forward biased) and
$V_{CB}$ is positive (C-B diode is reverse biased).
When $V_{CB}$ is increased $I_C$ increases slightly. This is because, when $V_{CB}$ is increased, depletion region width at C-B junction increases, effectively base width decreases and hence $I_B$ decreases. Due to this collector current $I_C$ increases. This effect is known as Early effect (base width modulation)
If $I_E$ is increased to higher const value, $I_C$ also increases.
When $I_E = 0$, $I_C = I_{CBO}$. $I_{CBO}$ doubles for every ten degree rise in temperature.

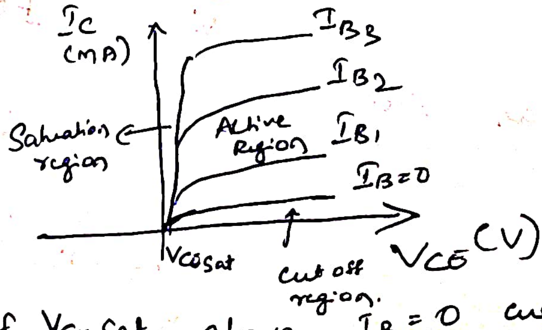
b) Saturation Region. This is the region to the left of y-axis above $I_E = 0$ curve. In this $I_E$ is positive nonzero (E-B diode forward biased) and $V_{CB}$ is negative (C-B diode is forward biased). $I_C$ decreases exponentially in this region.

c) cut off region: This is the region below $I_E = 0$ curve. In this emitter current $I_E$ is less than zero (E-B diode is reverse biased) and collector to base voltage $V_{CB}$ is positive (C-B diode is reverse biased). Transistor is said to be in off state since $I_C = 0$.

Common Emitter Input and output Characteristics -

Input characteristics of CE is a plot of input current $I_B$ versus input voltage $V_{BE}$ for various values of output voltage $V_{CE}$. As $V_{BE}$ is increased, $I_B$ increases. The characteristic curve is similar to diode characteristics. If $V_{CE}$ is increased to higher const value, then $I_B$ decreases slightly. This is due to early effect.



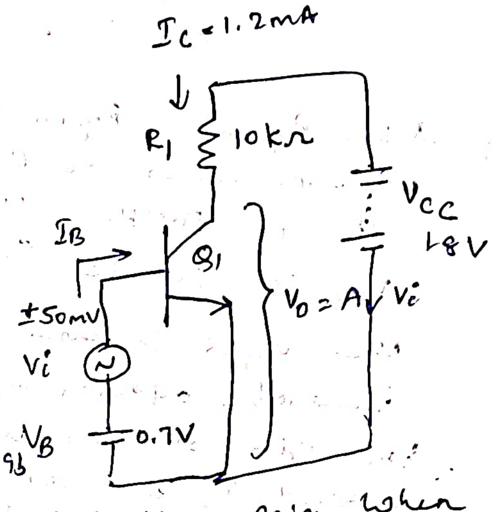




Active Region. Region to the right of $V_{CE\,sat}$ above $I_B = 0$ curve
$V_{CE} = V_{CB} + V_{BE}$. If $V_{CE} > V_{CEsat}$, then $V_{CB}$ becomes positive (CB diode is reverse biased). If ~~$V_{BE}$~~ $I_B > 0$, EB is forward biased.

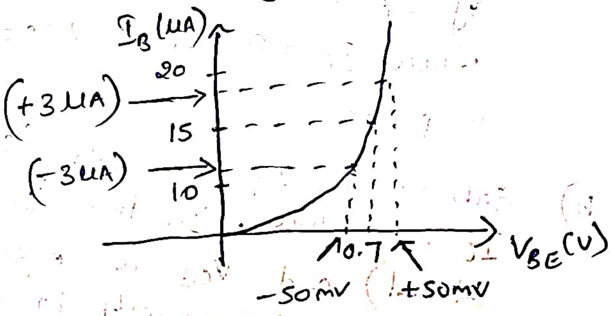
Saturation region - Region to the left of $V_{CEsat}$ and right of y-axis. Region E-B diode and C-B diode are both forward biased.

Cut off region - Region below $I_B = 0$ curve. In this E-B diode and C-B diode are both reverse biased, Transistor is said to be in OFF state since $I_C$ is almost zero.

## BJT as an amplifier.




Determine the dc collector voltage for the circuit in Fig. 4-19a if the transistor has $I_B / V_{BE}$ characteristics shown in fig. 4-19b and $\beta_{dc} = \beta_{ac} = 80$. Calculate the circuit voltage gain when $V_i = \pm 50mV$.




$I_B = 15\,\mu A$, $V_B = 0.7V$.

$I_C = \beta_{dc} I_B = 80 \times 15\,\mu A$

$= 1.2mA$.

$V_C = V_{CC} - (I_C R_1)$

$= 18 - (1.2mA \times 10k\Omega)$

$= 6V$.

$I_B = \pm 3\,\mu A$ for $V_i = \pm 50mV$.

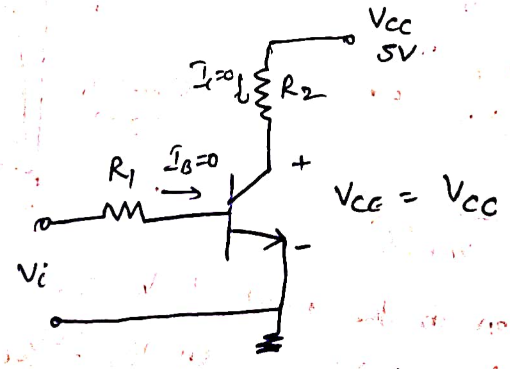
$I_C = \beta_{ac} I_B = 80 \times \pm 3\,\mu A$

$= \pm 240\,\mu A$.

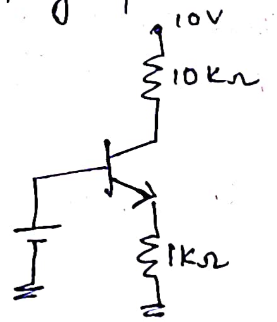
$I_C \cdot R_1 = \pm 240\,\mu A \times 10k\Omega = \pm 2.4V$

$$A_V = \frac{V_o}{V_i} = \frac{\pm 2.4V}{\pm 50mV} = 48.$$

## BJT as switch.



Q. Find the region of operation. If $B$ is very large & $V_{BE} = 0.7V$




$B >>$ large, $I_B$ very small.
$\Rightarrow I_E \approx I_C$.

B.E junction is forward biased since p – +ve terminal, n to –ve terminal.

$10 = 10\times10^3 \times I_C + V_{CB} + 2$

$8 = 10\times10^3 \times I_C + V_{CB}$.

$2 = V_{BE} + I_E \times 10^3$

$= V_{BE} + (I_C + I_B)10^3$

$1.3 = \cancel{(B+1)\frac{I}{B}10^3}\ I_C \times 10^3$

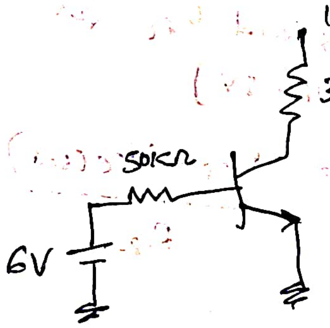
$\underline{I_C = 1.3mA}$.

$8 = 10\times10^3 \times 1.3\times10^{-3} + V_{CB}$

$\underline{V_{CB} = -5V}$, $V_{CB} \rightarrow -ve \Rightarrow$ C-B ~~$V_{CB}$~~ $\rightarrow$ forward biased.

~~$V_C - V_B$~~ $= -5$ Transistor is in saturation region.

Q. Find the region of operation if $B = 100$, $V_{CEsat} = 0.2V$, $V_{BEsat} = 0.8V$




$5 = 50\times10^3 I_B + 0.8$

$I_B = \frac{4.2}{50\times10^3}$

$\underline{= 0.084\ mA}$.

$10 = 3\times10^3 I_C + V_{CE(sat)}$.

$9.8 = 3\times10^3 I_C$

$I_C = \frac{9.8}{3\times10^3} = \underline{3.267\ mA} = I_{C(sat)}$.

$I_{Bmin} = \frac{I_{Csat}}{B} = \frac{3.267\times10^{-3}}{100} = 0.0327\ mA$.

Since $I_B > I_{Bmin}$, transistor is in saturation region.

$10 = 3\times I_C + V_{CB} + 50\times I_B + 6$

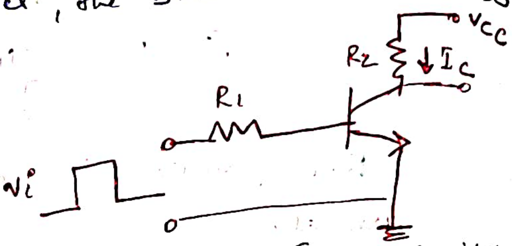
$4 = 9.801 + V_{CB} + 4.2$

$\underline{V_{CB} = -10V}$.

BJT as a switch.

The switching circuit is similar to an amplifier circuit except that a pulse waveform input, instead of a bias voltage and ac signal source is applied to the transistor base.

When the input voltage $V_i$ is at zero level, the base current $I_B$ is zero and consequently $I_C$ is zero




$$V_{CE} = V_{CC} - I_C R_2$$

With $I_C = 0$ $=$ $V_{CE} = V_{CC}$

When $V_i$ is at a +ve level, a base current flows. In a switching circuit $I_B$ is made large enough to produce an $I_C$ level that will cause the voltage drop across $R_1$ to approximately equal the supply voltage ($I_C R_2 \approx V_{CC}$).

$$V_{CE} \approx V_{CC} - I_C R_2$$
$$\approx 0$$

If $V_{CE}$ went down to exactly zero volts, the C-B junction would become forward biased by 0.7V. In this case, collector base barrier voltage would be overcome and charge carriers from the emitter would be repelled from the collector-base junction. Consequently there would be zero collector current. But if $I_C$ becomes zero, there would be no voltage drop across $R_2$ and the collector emitter junction would not be forward biased. So $I_C$ does flow, but it does not become large enough to make $V_{CE}$ equal zero.

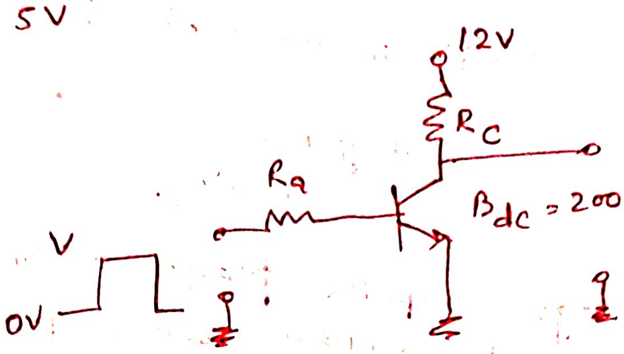
Q Calculate $I_C$, $I_B$ and $h_{FE}$ for switching circuit when $Q_1$ is switched into saturation. {Take $V_i = 2V$}

$$I_C = \frac{V_{CC} - V_{CE(sat)}}{R_2} = \frac{5 - 0.2}{4.7k\Omega}$$
$$= 1.02mA.$$

$$I_B = \frac{V_i - V_{BE}}{R_1} = \frac{2 - 0.7}{12k\Omega} = 108\mu A.$$

$$h_{FE} = \frac{I_C}{I_B} = 9.4$$

Determine $R_B$ and $R_C$ for a transistor inverter shown in fig. $I_{C(sat)}$ = 5mA and $V_{CE(sat)}$ = 0.2V , V = 5V




$$R_C = \frac{V_{CC} - V_{CE\,sat}}{I_{C(sat)}}$$

$$= \frac{12 - 0.2}{5\times10^{-3}} = 2.7k\Omega$$

$$I_{B(min)} = \frac{I_C}{\beta_{dc}} = \frac{5\times10^{-3}}{200} = 25\mu A$$

$I_B > I_{B(min)}$ for saturation region.

$$R_B = \frac{V_B - V_{BE}}{I_{B(min)}}$$

$$= \frac{5 - 0.7}{25\times10^{-6}} = 172k\Omega.$$