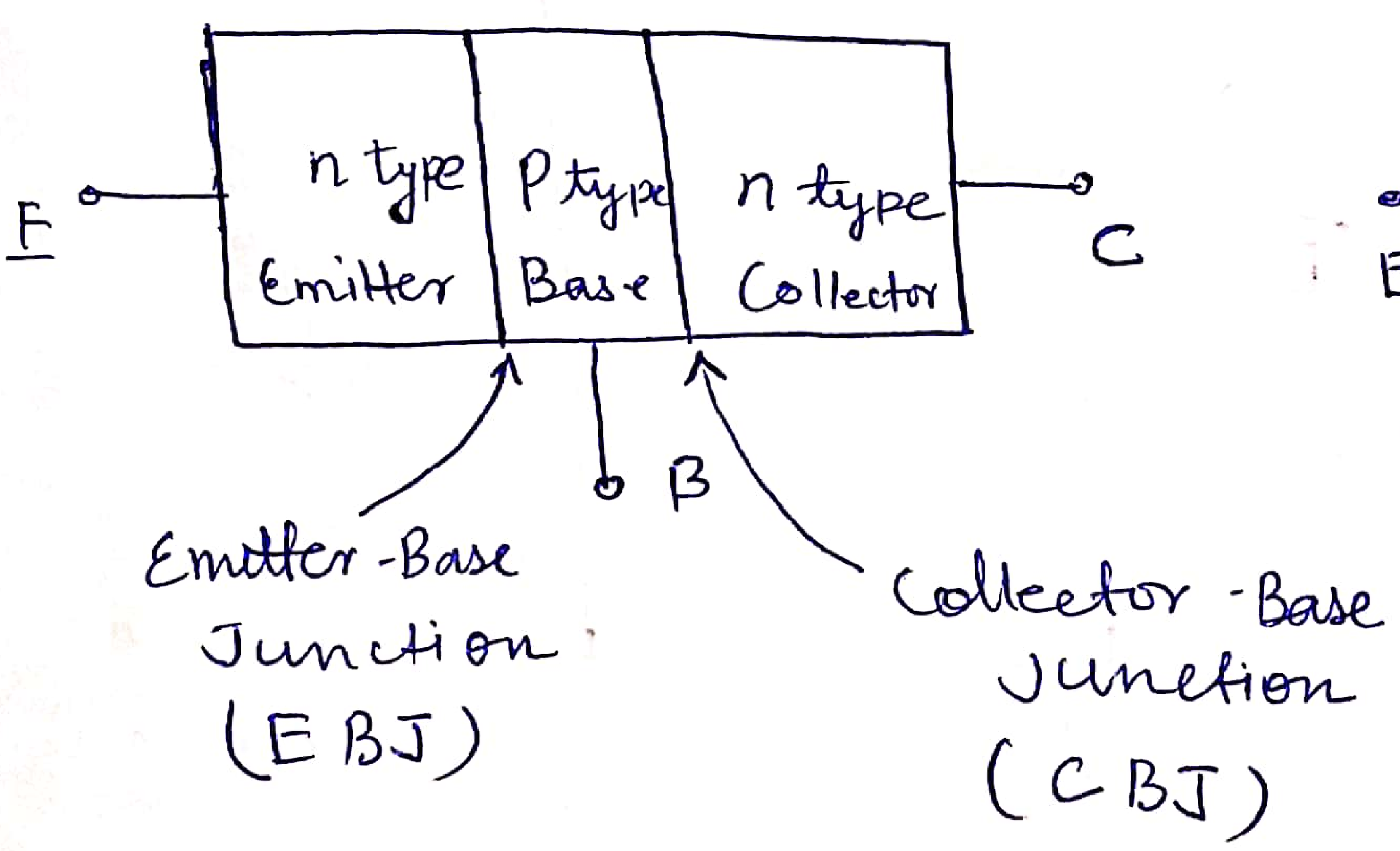
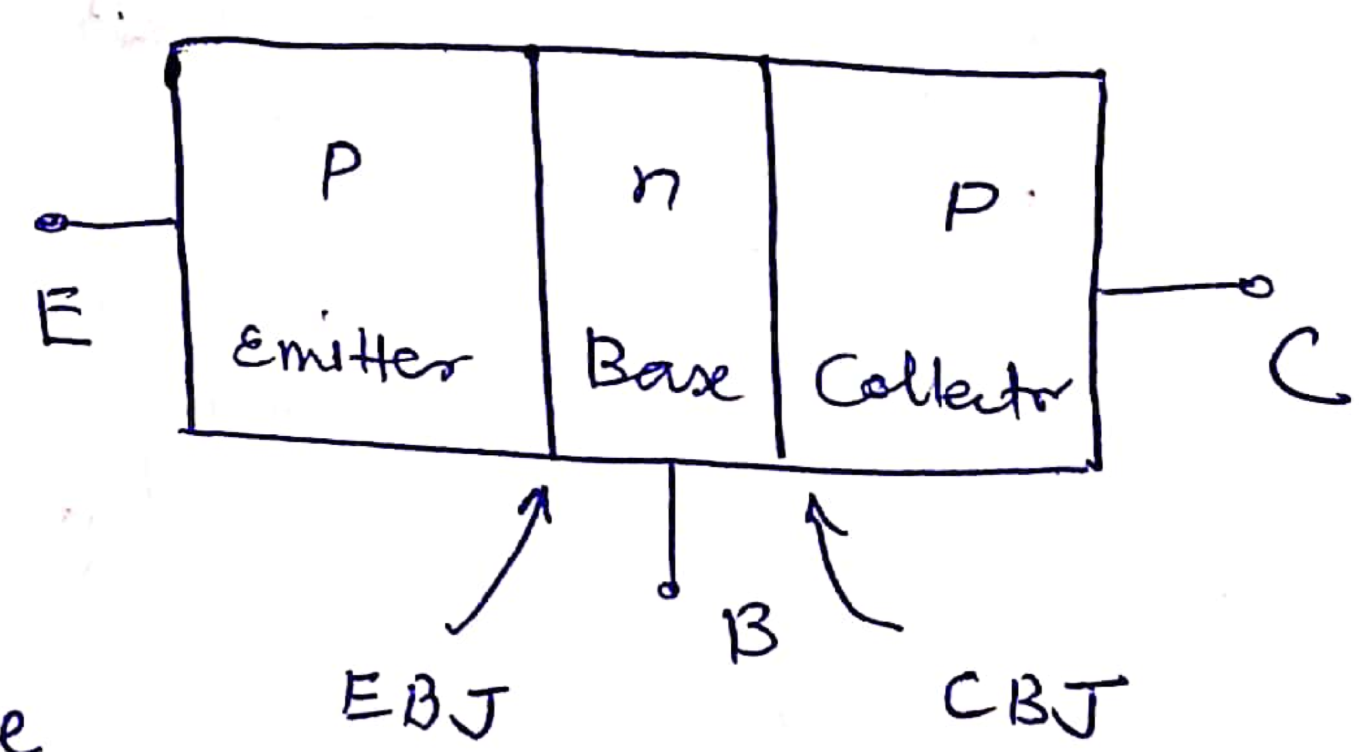
BIPOLAR JUNCTION TRANSISTOR (BJT)

* BJT is a three terminal device
* The voltage between two terminals ~~a~~ is used to control the current in third terminal.
  ~~They are also known as~~
  Therefore it works as Voltage controlled current Source (VCCS).
* Invented in 1948, at Bell Lab. { The inventors got the Nobel prize in 1956.
* Currently BJT has been almost completely replaced by other device MOSFET (we will study this later in this unit).
* However it is a popular choice for descrete circuit design
* Some other ~~area~~ applications:
  - Radio Frequency (RF) circuits
  - ECL - A high speed digital logic
  - BiCMOS - technology

DEVICE STRUCTURE

BJT
- npn
- pnp

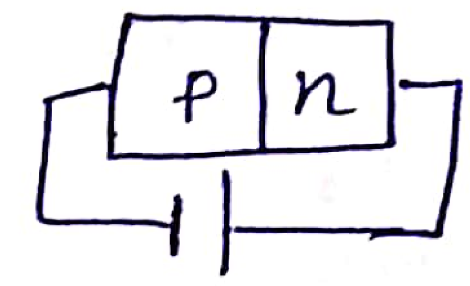




MODES OF OPERATION

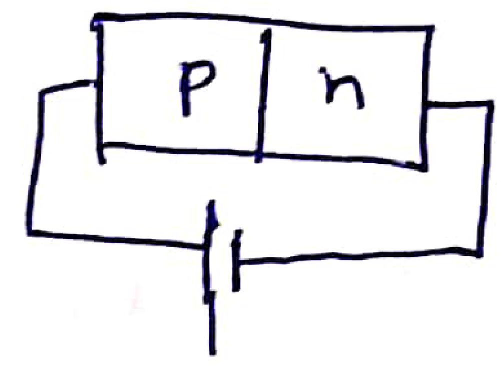
* Depending upon the Bais condition of two junction (EBJ & CBJ), different modes of operations are obtained

Mode	EBJ	CBJ
Cut-off	Reverse Bais	Reverse Bais
Active	F.B.	R.B
Revese Active	R.B.	F.B
Saturation	F.B.	F.B



R.B. = Revese Bais

F.B = Forward Bais



* Active mode (also known as forward active mode) is most important modes of operation. In this mode the ~~tran~~ BJT operates as an Amplifier

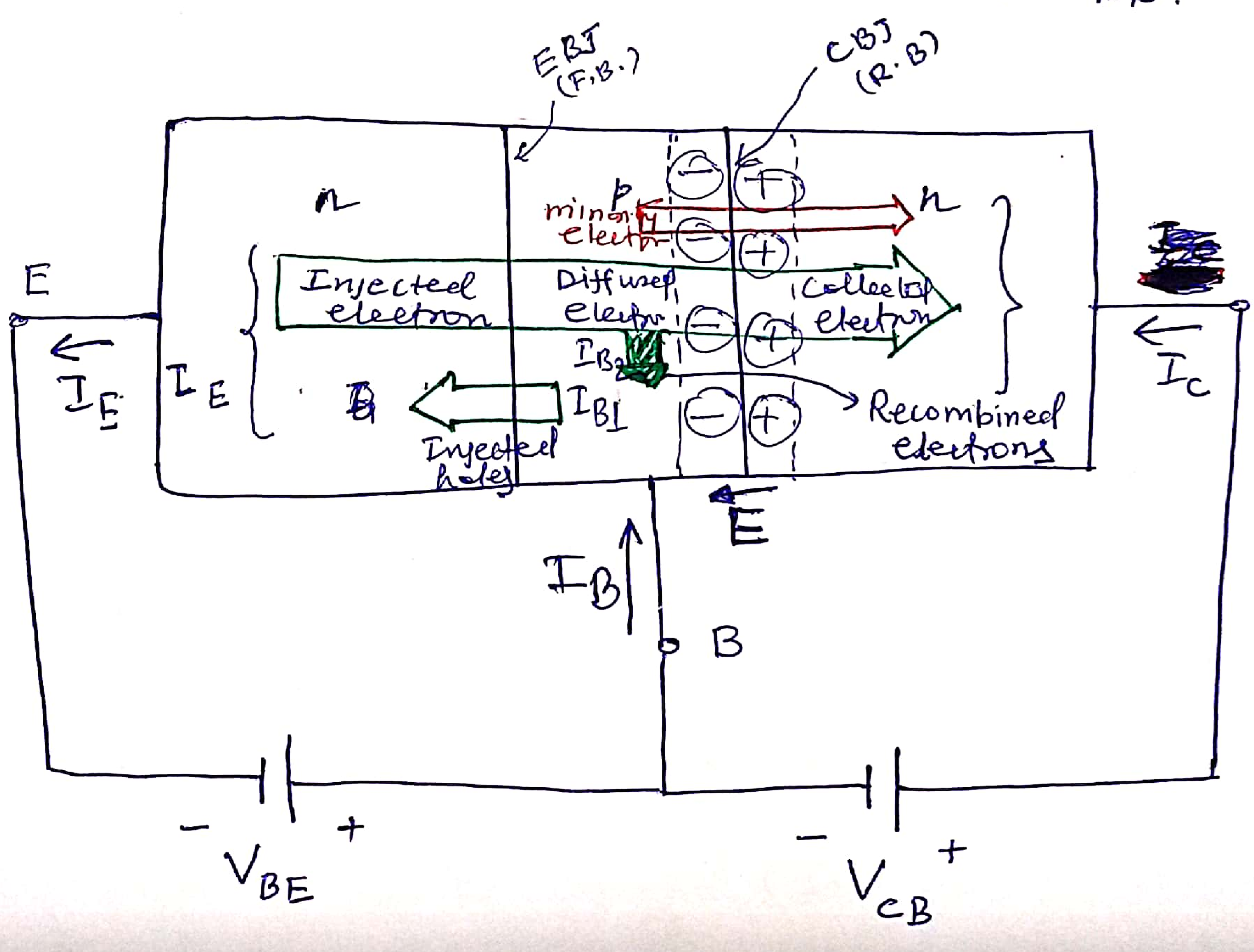
* BJT operates as switch in Cutoff & Saturation mode

Cutoff → Open Switch

Saturation → Closed switch

OPERATION OF npn TRANSISTOR

* We consider the Active Mode ie. EBJ → F.B. CBJ → RB



— minority electron
— majority e^-

Doping

E > C > B

Width

C > E > B

* The deplition width ~~of~~ at the EBJ is very thin (due to F.B.), hence it is not considerd. The R.B. at the CBJ will cause a wide deplition width, which shown in the figure.

* The majority e^- from E-region will be injected into B-region. Similarly majority holes from B-region will be injected in E-region. The two will consitutes a current I_E that will from out of the Emitter lead.

* Generally E-region is highly doped, therefore e^- component of Emitter current dominates.

* Since the Base region is very thin ~~very~~, most of the electrons (that are injected from E to B) will diffuse through the base region and will reach to the boundry of CBJ, where they will be easily swept by the $\vec{E}$.

* The e^- thus "collected" to the C-region will constitute the collector ~~region~~ current, I_C.

The collector current is given by

$$\boxed{I_C = I_S e^{V_{BE}/V_T}}$$

where, I_S (saturation current) $= \dfrac{\overset{\text{Emitter Area}}{A_E}\, q D_n n_i^2}{N_A \underset{\text{Effective Base width}}{W}}$

* Remark: (I) I_C is independent of V_{CB}!

The I_C depends on the diffused e^- (and hence injected e^- from E-region), and thus will not be affected by change in V_{CB}

(II) $I_C \propto A_E$

Larger the junction area larger will be I_C therefor I_S is also known as Scale current

* If we also consider the flow of minority e^- from B to C region, the I_C will combine the two component

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$

I_{CO} is minority current component and also known as leakage current and is very-very small as compared to majority component

* The ~~Base Current~~ is composed of two components

$$I_B = I_{B1} + I_{B2}$$

where I_{B1} is due to the holes enjected from B to E & I_{B2} is due to the holes that have been supplied by the External battery ~~to~~ ~~that is los are~~ to recombined with ~~from~~ few electrons travelling toward collector

* We can observe that I_B is a constant fraction of I_E (or I_C)

ie $\boxed{I_B = \frac{I_C}{\beta} = \frac{I_S}{\beta} e^{V_{BE}/V_T}}$

where β is called current gain (Range: 50-200)

* The emitter current can be given by

$$I_E = I_C + I_B \qquad (KCL)$$

$$I_E = I_C\left(1+\frac{1}{\beta}\right)$$

$$I_E = \left(\frac{\beta+1}{\beta}\right) I_C$$

~~or $I_E = \alpha I_C$~~ where, $\alpha = \frac{\beta}{\beta+1}$

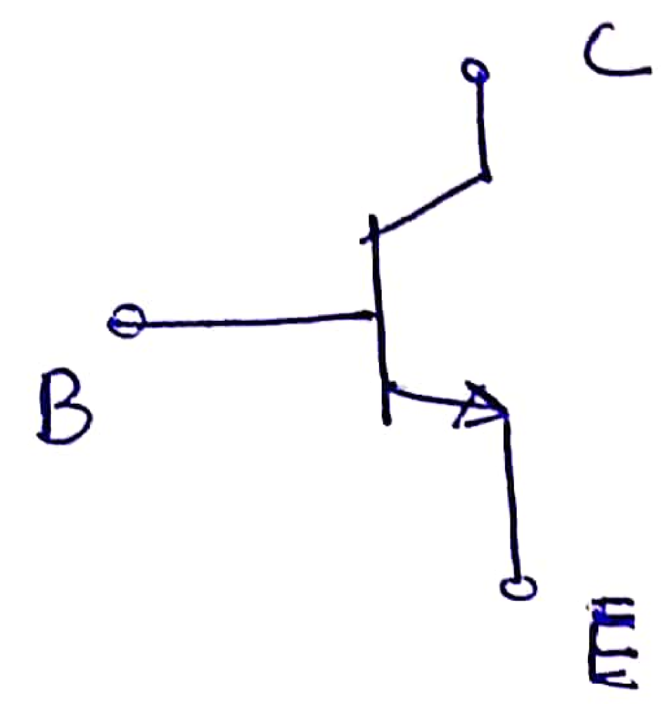
or, $\boxed{I_E = \frac{I_C}{\alpha} = \frac{I_S}{\alpha} e^{V_{BE}/V_T}}$

for $\beta = 100$

$\alpha = 0.99$

or $\boxed{\alpha \approx 1}$ for high β

Circuit Symbol & Conventions



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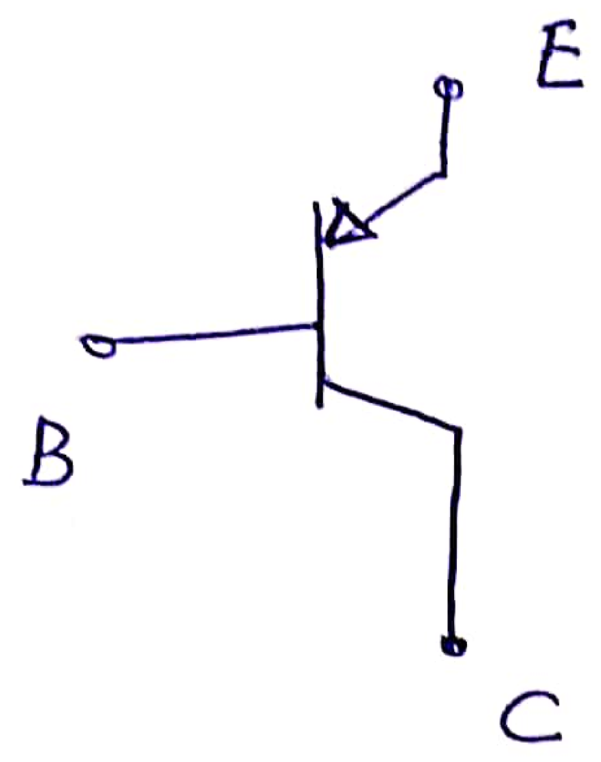

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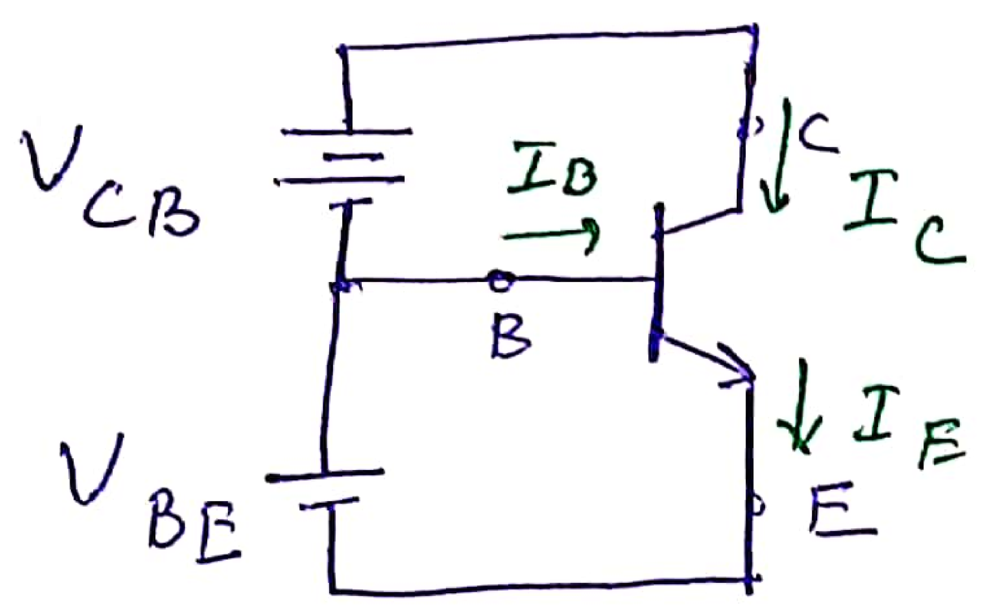
⇒ The arrowhead points in the direction of current flow in the emitter

Voltage polarity & current flow in active mode:



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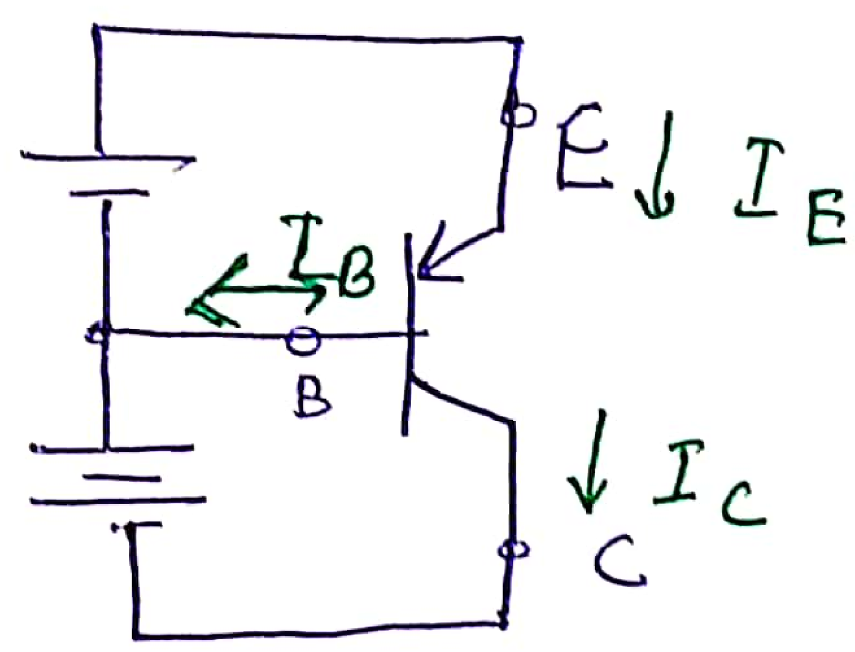

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Equation to Remember for solving Numericals

$$I_C = I_S e^{V_{BE}/V_T} \quad \text{——(1)}$$

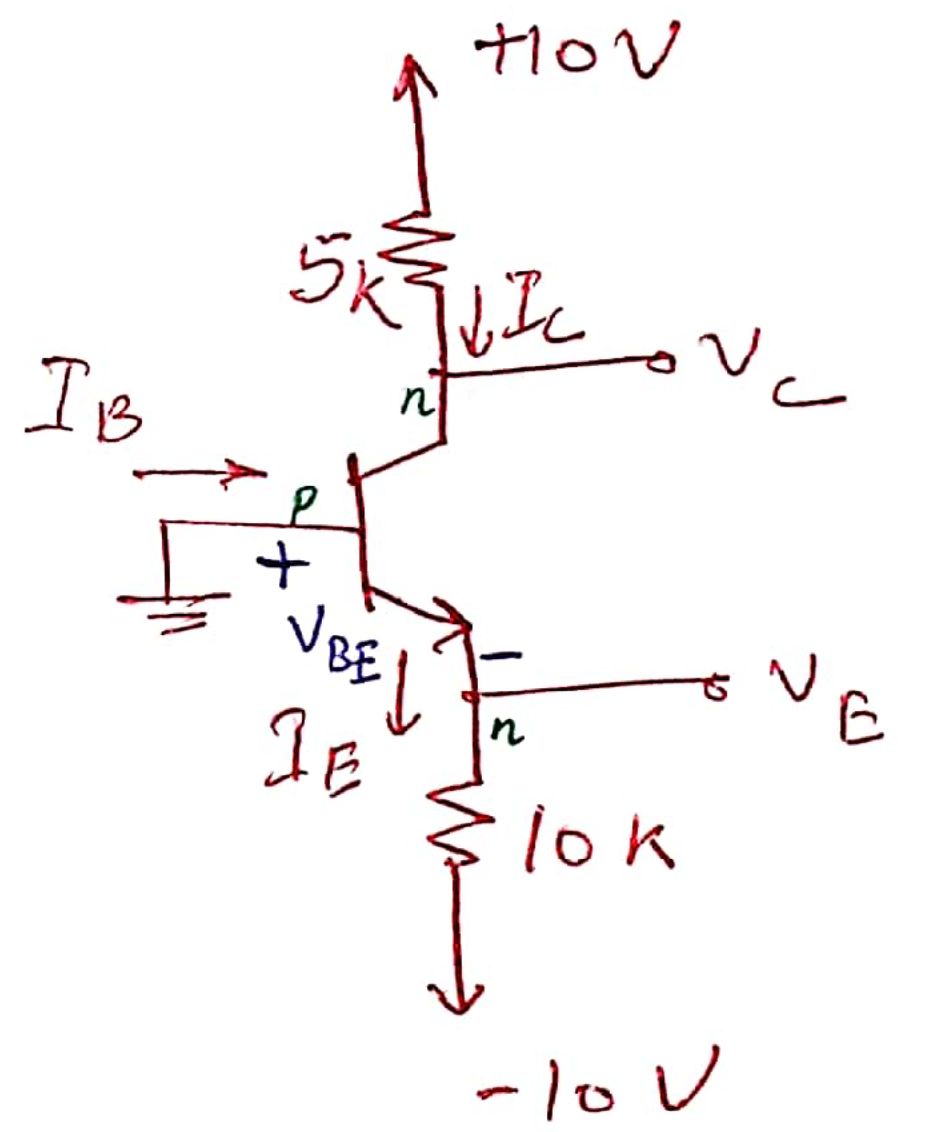
$$I_B = \frac{I_C}{\beta} \quad \text{——(2)}$$

$$I_E = \frac{I_C}{\alpha} \quad \text{——(3)}$$

$$I_E = I_C + I_B \quad \text{——(4)}$$

↳ for transistor operating in active mode

Ex-1 Determine I_E, I_B, I_C and V_C for the circuit shown. Assume $\beta = 50$, $V_{BE} = 0.7V$.



Check mode of operation ?

EBJ → F.B.

CBJ → R.B. (Since $V_C > 0$).

⇓

(Active mode)

Sol

$$V_{BE} = 0.7V$$

or, $0 - V_E = 0.7V$ $\boxed{V_E = -0.7V}$

$$\Rightarrow \quad I_E = \frac{V_E - (-10)}{10K} = \frac{-0.7+10}{10} = \underline{0.93\ mA}$$

Since $\beta = 50$, we can find $I_B = \frac{I_C}{50}$

or $I_C = 50\ I_B$

Put, $I_E = I_B + I_C$

$= I_B + 50\ I_B$

$= 51\ I_B$ $\Rightarrow$ $I_B = \frac{0.93mA}{51} = \underline{18.2\ \mu A}$

Then $I_C = 50 \times 18.2 = \underline{0.91\ mA}$

$V_C = 10 - 5 \times I_C$

$= 10 - 5 \times 0.91 = \underline{5.45\ V}$

Ques for further practice: –

① Solved Example: 3.1

② Excercise 3.11

③ Problems 3.21

All from Sedra/Smith "Microelectronic" Book 6th. Ed.