CHAPTER - 2

BIPOLAR JUNCTION TRANSISTORS

→ Transistor is three terminal device. Three terminals are collector, base & emitter.

→ "Transistor" word was derived from "transfer" and "Resistor".

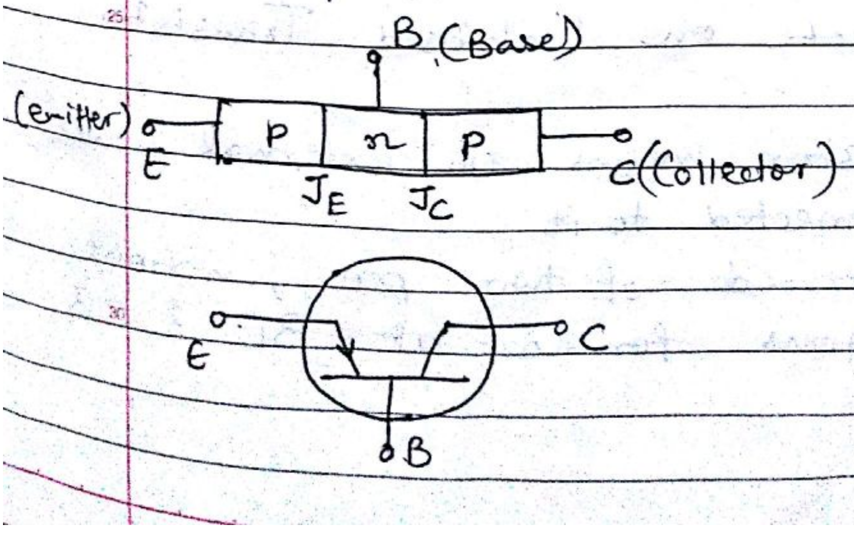
→ This means it describes the operation of transistor. It transfers input signal current from a low resistance circuit to a high resistance circuit.

→ Why it is called "Bipolar Junction Transistor."
conduction in BJT takes place due to both electrons and holes, this is why it is called bipolar junction transistor.

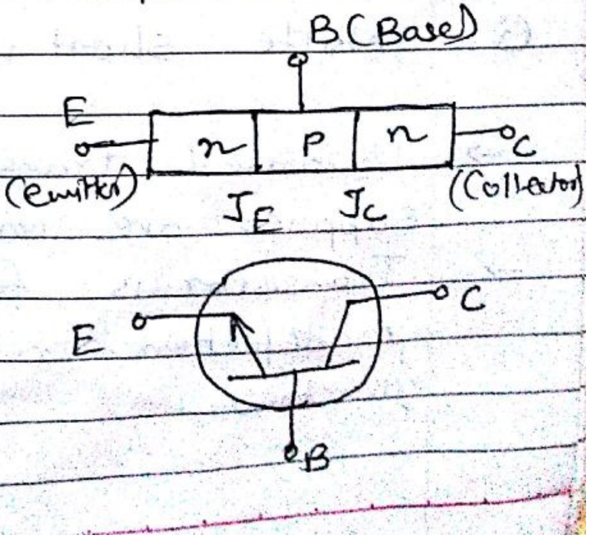
BJT types:

1. p-n-p transistors
2. n-p-n transistors.

1. p-n-p transistor



2. n-p-n transistor



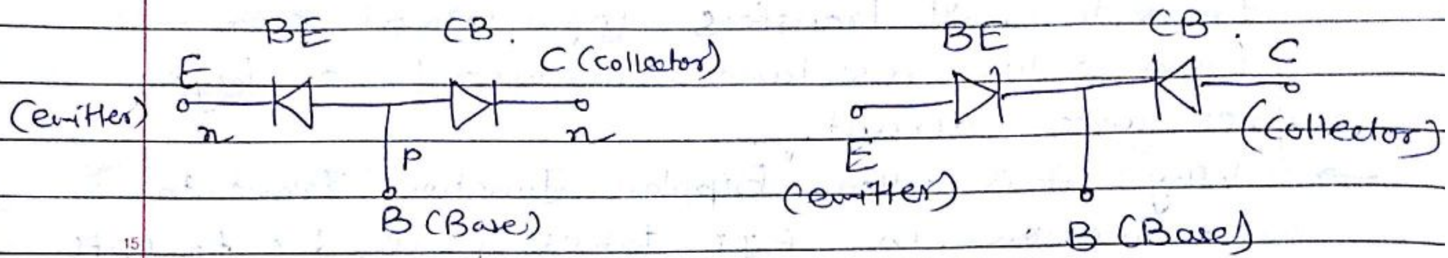
→ In Bipolar junction transistor Base is always thin and lightly doped.

→ Emitter & collector are much wider than base & are heavily doped.

→ Emitter is heavily doped (most heavily doped) because it has to emit or inject electrons & collector area is larger than emitter.

→ Collector area is larger, because it is required to dissipate more heat.

→ Transistor has two p-n junctions



equivalent circuit for n-p-n transistor.

→ Transistor has two junctions BE (Base to emitter) junction & CB (collector to Base junction)

→ In actual practice we can not replace the transistor by back to back connected diodes, because it can not give integrated effect of transistor

Q. Write short note on Unbiased Transistor

→ Unbiased transistor means no external power supplies are connected to it.

→ Transistor is formed of two p-n junctions. so depletion regions formed at BE & CB junctions.

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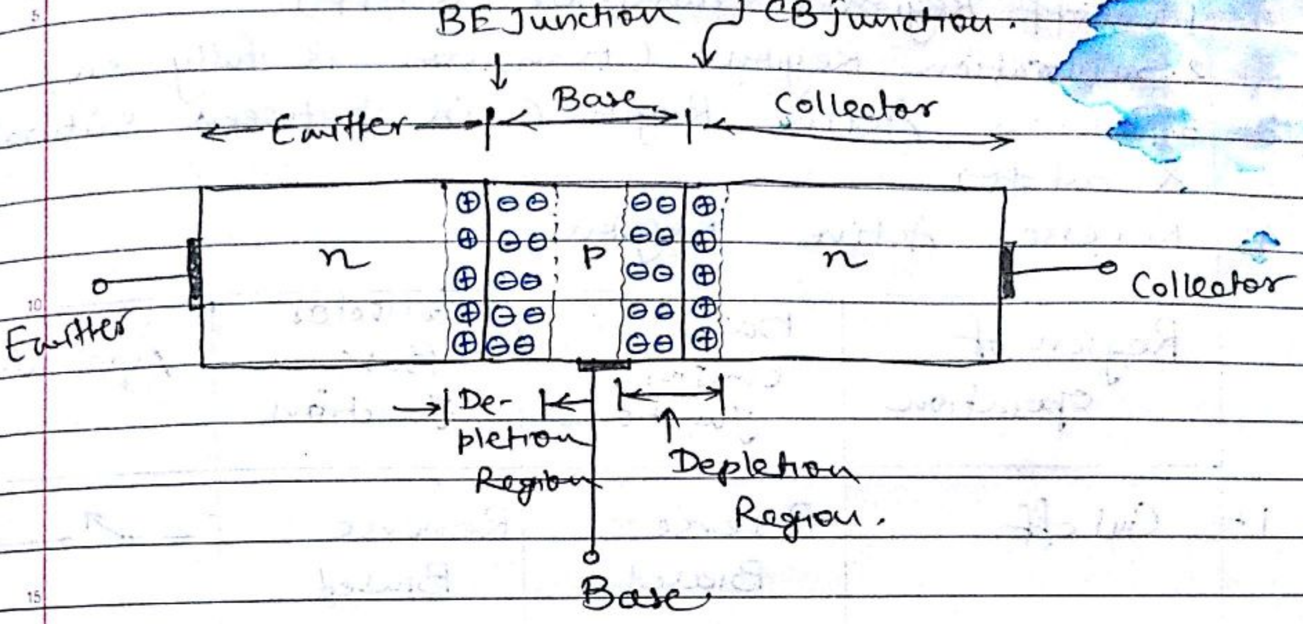
Penetration of Depletion Regions:

→ The width of depletion region is not same on both the side of the junction.



→ As emitter is heavily doped as compare to Base so more number of electrons will cross the junction & holes crossing from base to emitter is less due to lightly doped base, so penetration of depletion region is more in lightly doped Base. Same is for base to collector junction.

* Explain four region of operation of bipolar junction transistor.

OR

Draw and explain transistor current component when it is biased in active Region.

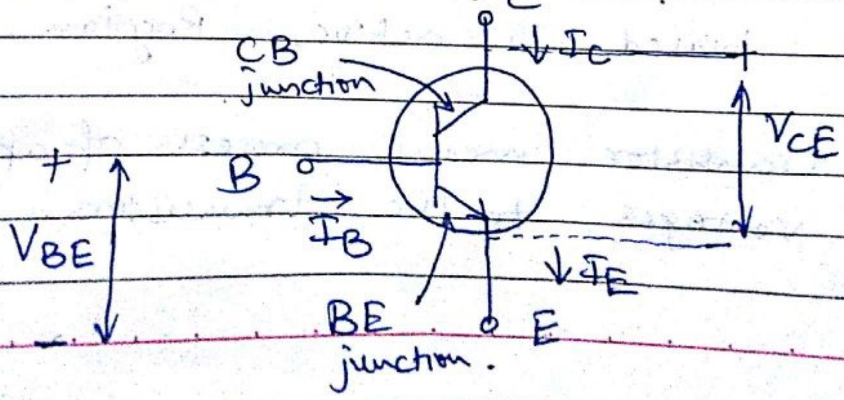
→ Biasing transistor means process of applying external voltages to the transistors.

→ BJT is capable of operating in four different regions, depending on the way in which is biased.

1. cutoff Region (transistor is OFF)
2. Saturation Region (transistor is fully on)
3. Forward Active Region (in between saturation & cutoff)
4. Reverse Active Region.

	Region of operation	Base Emitter Junction	Collector Base Junction	Application
1.	Cut off	Reverse Biased	Reverse Biased	
2.	Forward Active Region	Forward biased	Reverse biased	Amplifier
3.	Saturation Region	Forward Biased	Forward Biased	
4.	Reverse Action	Reverse Biased	Forward Biased	—

→ Biasing of transistor for active region is shown below. In this transistor acts as an amplifier.



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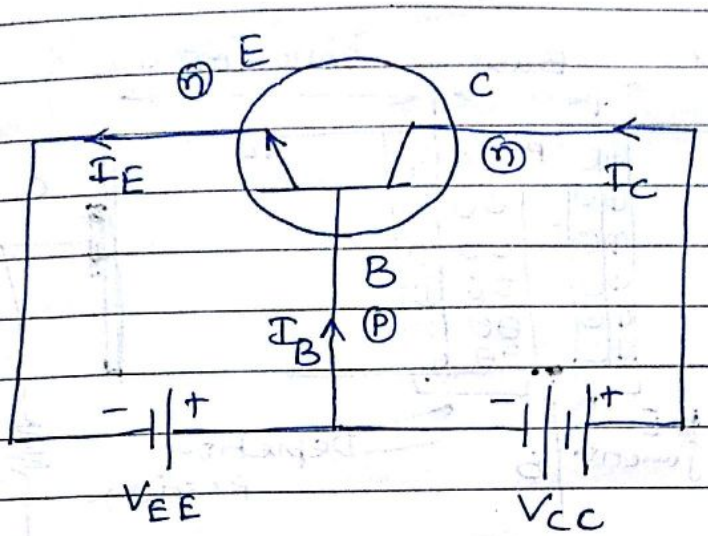
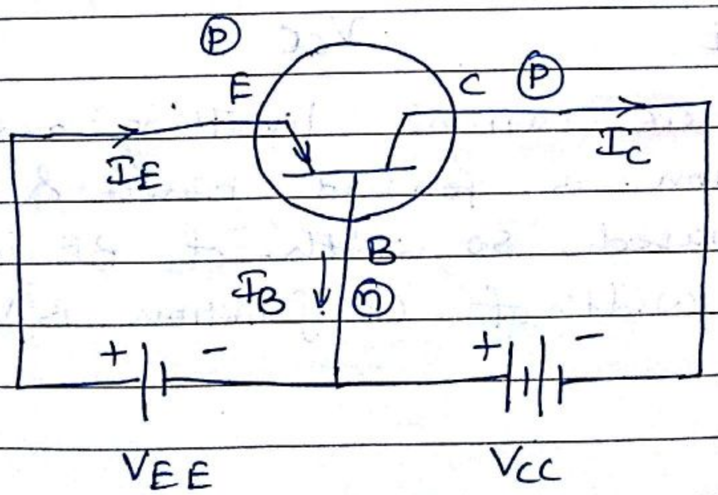
→ Directions of currents I_B, I_E & I_C are shown in fig. polarities of Voltages V_{BE} & V_{CE} is also shown in fig.

→ Biasing of n-p-n transistor in active region is shown below.



Biasing of n-p-n transistor



Biasing of p-n-p transistor.

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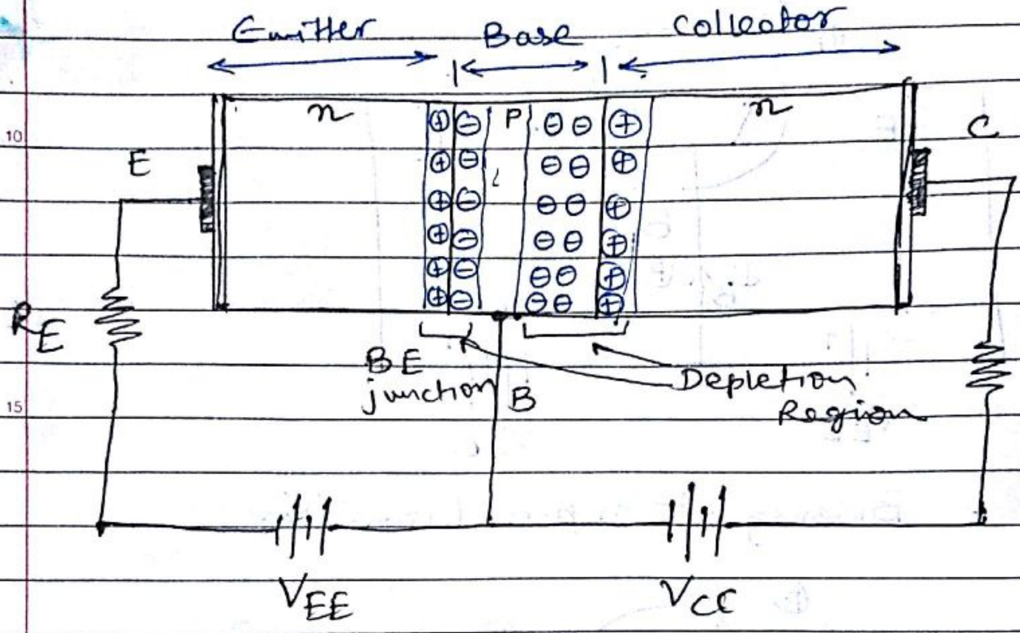
Q. Write short note on Operation of transistor. (Biasing of transistor).

n-p-n transistor is biased in active region due to emitter junction is forward biased & collector to Base junction is reverse Biased.



→ R_C & R_E are current limitting resistors.

→ BE junction is forward biased. & CB junction is reverse biased. so width of BE junction will reduced, & width of CB junction is large.

Operation:

1. The electrons i.e. majority charge carriers of emitter starts flowing towards the p-type base. This will constitutes emitter current I_E.

2. Electrons moving from emitter to Base have three options.

(A) → They recombines with the holes present in the base. As Base is lightly doped & twin number of holes is few. So out of total injected electrons from emitter very few recombine with holes in base. This is called current I_B.

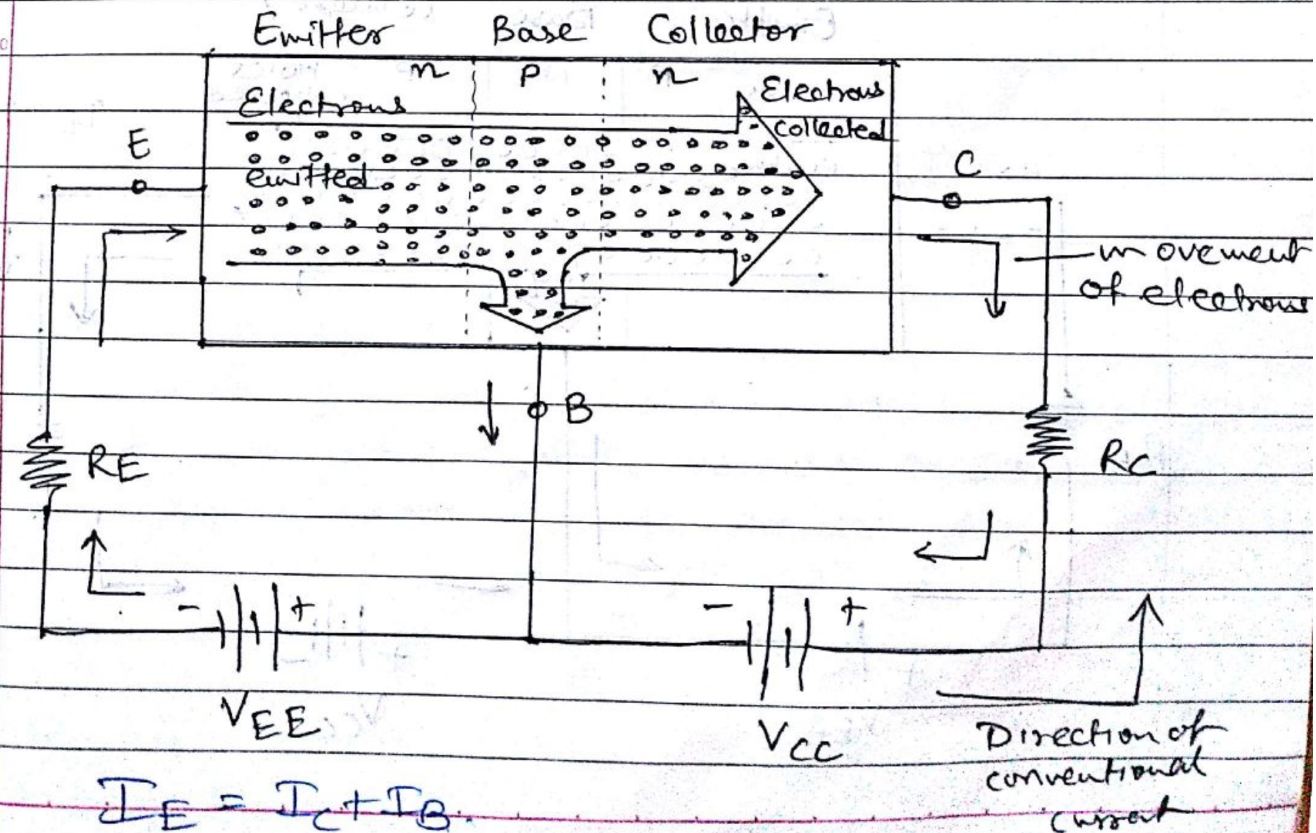
→ So I_B is due to recombination of electrons & holes in base. so I_B is small.

(B)→ Some electrons diffuse through the base & out of base connection.

(C)→ The remaining large number of electrons will pass through the depletion region CB junction & pass through collector region to the positive end of the external power supply V_{CC}.

I_C (collector current) is much larger than the Base current (About 98% of the total I_E.

operation of n-p-n transistor.



$I_E = I_C + I_B$

Q. Indicate & Briefly explain various current components flowing in p-n-p transistor with forward biased emitter junction & reversed bias collector junction

Explain

Q. Operation of p-n-p transistor in Detail.

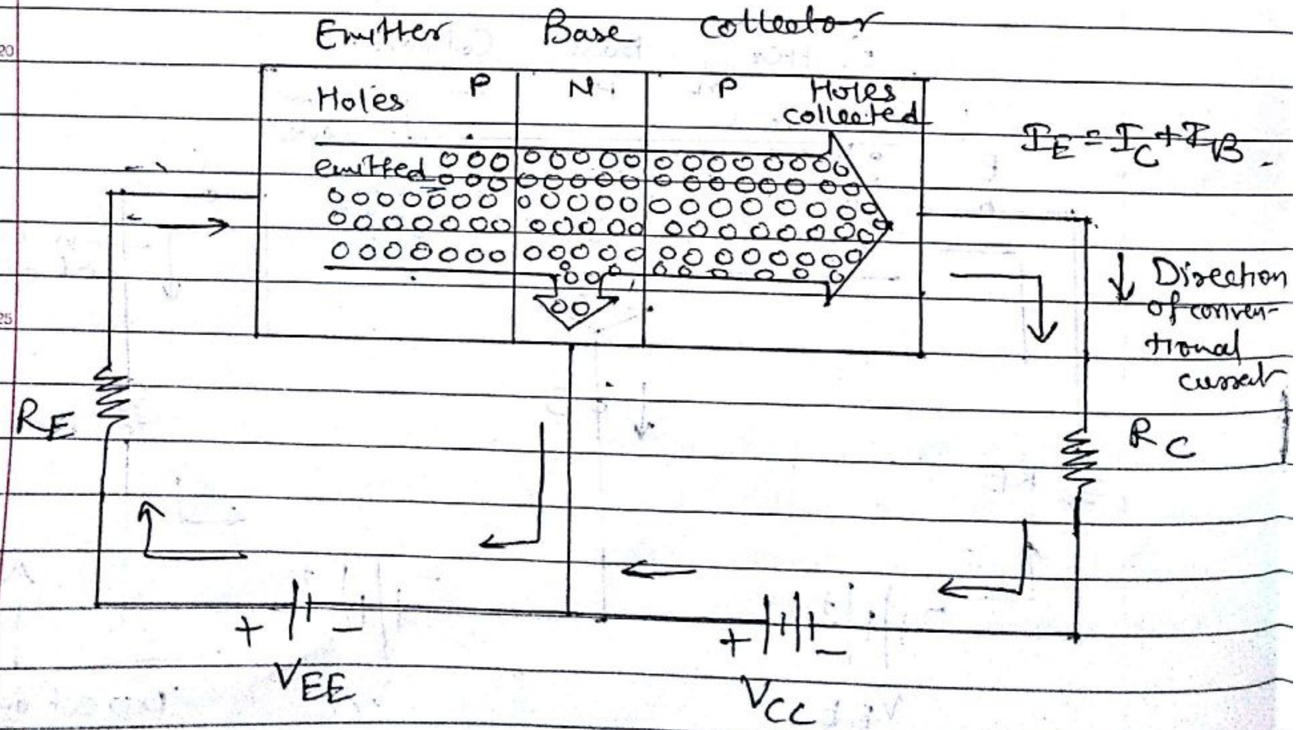
p-n-p transistor behaves exactly in same ways as n-p-n transistor.

Only difference is, the majority charge carriers are holes instead of electrons.

As shown in fig. holes are emitted from p-type emitter across forward biased BE junction in to the Base.

→ In lightly doped base there are few number of electrons available for recombination.

→ only 2% of emitted holes will flow out via the base terminal & remaining are drawn across the collector by the electric field of reversed biased Base collector junction.



$$I_E = I_C + I_B.$$

Q. Define various currents & voltages of BJT & α & β.

→ electrons injected from emitter into Base constitutes the emitter current (I_E)

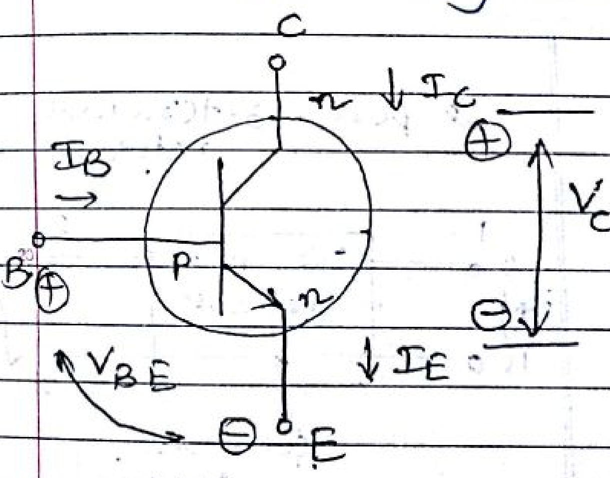
→ Out of these electrons very few will recombine with the holes in this base, it constitutes the Base current (I_B)

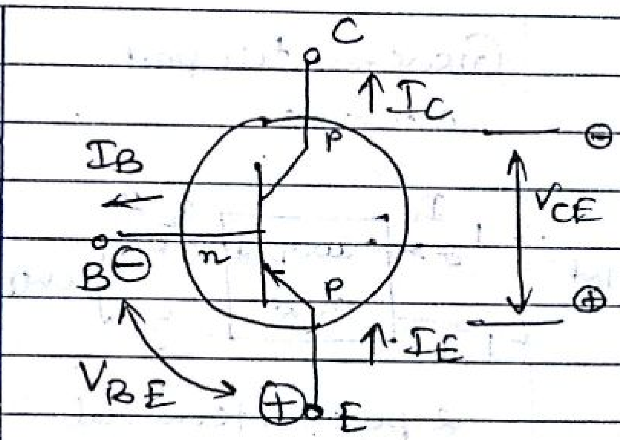
→ The remaining electrons pass through the collector region & then to the positive terminal of V_{CC}, it constitutes collector current (I_C)

So, we can write

$$I_E = I_C + I_B.$$

→ Here I_B is very small. so $I_C \simeq I_E$





(α_{dc}) Alpha :

→ α or CB current gain defined as ratio of dc collector current & dc emitter current

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

→ α_{dc} is less than but close to 1. This is because $I_C \simeq I_E$. α_{dc} ranges from 0.95 to 0.995

β_{dc} (Beta)

→ β_{dc} or CE current gain of transistor is defined as the ratio of dc collector current I_C and the dc base current I_B.

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

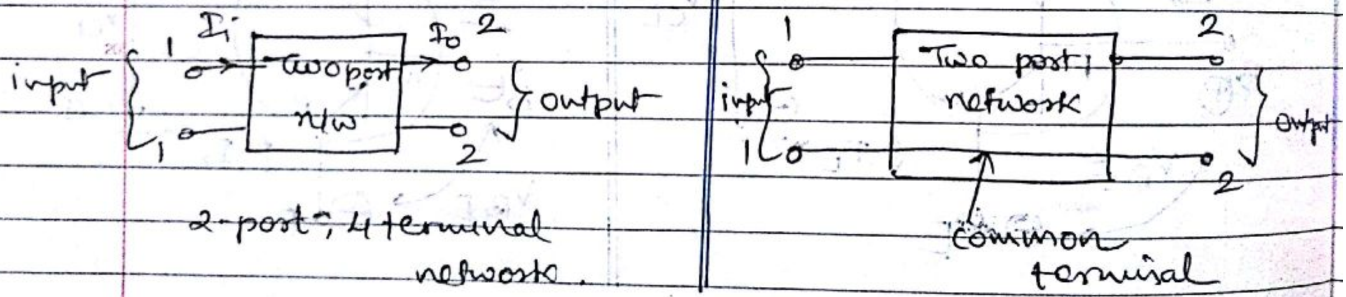
→ I_B is very small compare to I_C, so β_{dc} is large compare to α_{dc}

→ β_{dc} is CE (common emitter current gain) it's values ranges from 20 to 300.

Transistor Configurations:

General two port network.

2-port, 3-terminal network.



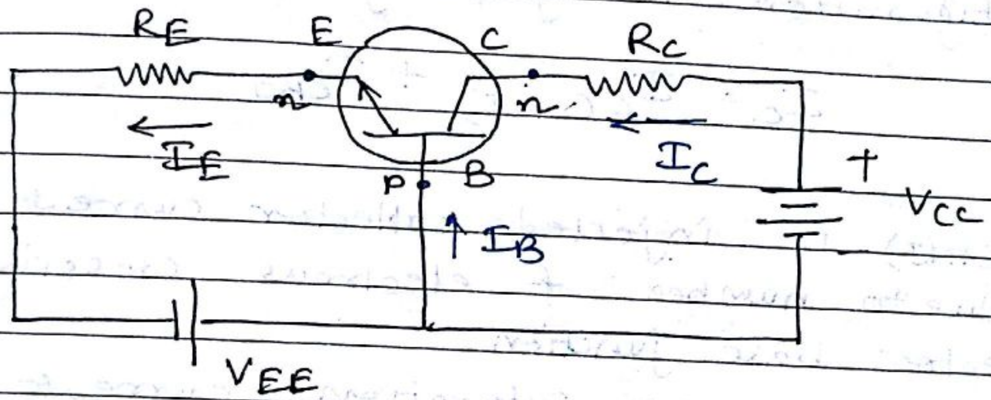
→ Depending on which terminal is made common between input & output there are three possible configurations of transistor.

1) Common Base Configuration (CB)
2) Common Emitter " (CE)
3) Common collector " (CC)

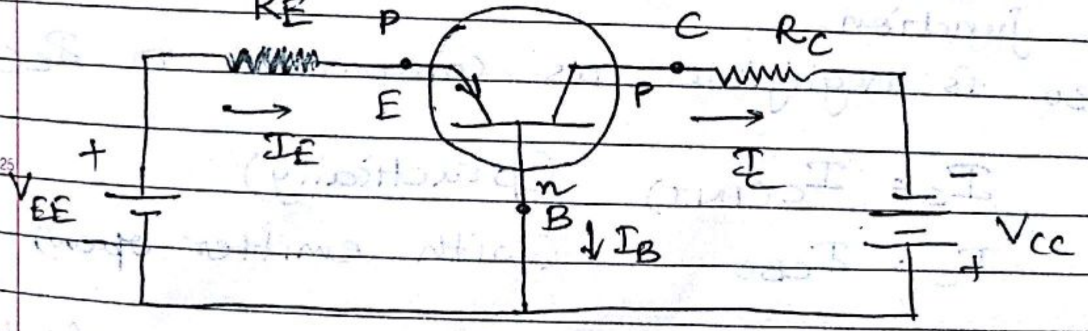
→ In all these configurations emitter base junction is forward bias & collector base junction is reversed biased to operate transistor in active region.

Q. Write short note on Common Base (CB) Configuration.

→ common base configuration for the n-p-n & p-n-p transistor is shown in figure below.



Common Base configuration for n-p-n transistor.



Common Base configuration for p-n-p transistor

→ In common base configuration input is applied between emitter & Base.

→ The base acts as common terminal between input & output ports. Input voltage is V_{EB} & input current I_E.

→ The output is taken between collector and base. Therefore the output voltage is V_{CB} & output current is I_C.

→ Current Relations in CB configuration.

Collector current I_C of common base configuration is given by

$$I_C = I_{C(INJ)} + I_{CBO}$$

→ $I_{C(INJ)}$ is injected collector current, which is due to number of electrons crossing the collector base junction.

→ I_{CBO} is reverse saturation current flowing due to the minority charge carriers between collector & base when emitter is open. I_{CBO} flows due to reverse biased collector base junction.

→ I_{CBO} is negligible as compared to $I_{C(INJ)}$ so.

$$I_C = I_{C(INJ)} \quad \text{(practically)}$$

$$I_C = I_{CBO} \quad \text{(with emitter open)}$$

→ Current Gain (α_{dc}) (Current Amplification factor)

→ for CB configuration $I_{C(INJ)}$ is output current & I_E is input current.

$$\alpha_{dc} = \frac{I_{C(INJ)}}{I_E}$$

→ α_{dc} is always less than 1, because $I_{C(INJ)} < I_E$

$$I_{C(INJ)} = \alpha_{dc} I_E$$

→ $$I_C = I_{C(INJ)} + I_{CBO}$$
$$I_C = \alpha_{dc} I_E + I_{CBO}$$

→ I_{CBO} is negligibly small.

$$I_C \simeq \alpha_{dc} I_E \quad , \text{ so } \alpha_{dc} = \frac{I_C}{I_B}.$$

→ Expression for I_B :

$$I_E = I_C + I_B$$

$$I_E = (\alpha_{dc} I_E + I_{CBO}) + I_B$$

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

$$-I_B = \alpha_{dc} I_E - I_E + I_{CBO}$$

$$I_B = -\alpha_{dc} I_E + I_E - I_{CBO}$$

neglecting I_{CBO}

we get $\boxed{I_B = (1-\alpha_{dc}) I_E}$

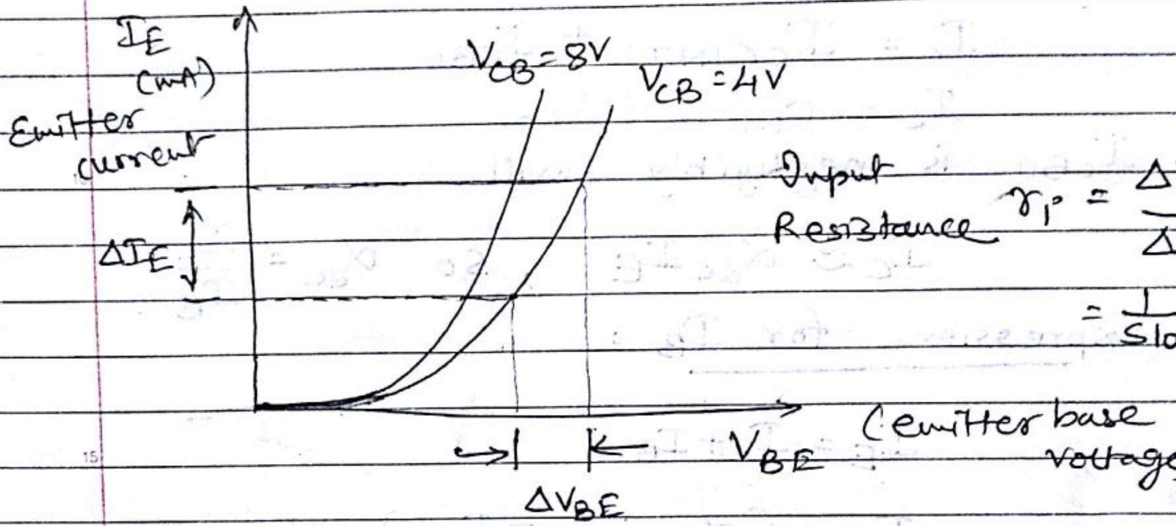
Q. Explain Input, output characteristics of Common Base configuration.

A.3) Input Characteristics :

Input characteristic is always a graph of input current versus input voltage.

→ for CB configuration input current is I_E (emitter current) & input voltage is V_{BE} emitter to base voltage

→ Input characteristics is plotted at a constant output voltage V_{CB}.



Input Resistance $r_i = \dfrac{\Delta V_{BE}}{\Delta I_E}$

$= \dfrac{1}{\text{Slope}}$

→ Input characteristics is identical to forward I-V characteristics of P-N junction diode, because there exsist P-N junction between the emitter & base of a transistor.

→ Up to cut in voltage, I_E is negligible but after cut in voltage it increases rapidly with a small increase in the input voltage V_{BE}.

→ The input resistance r_i

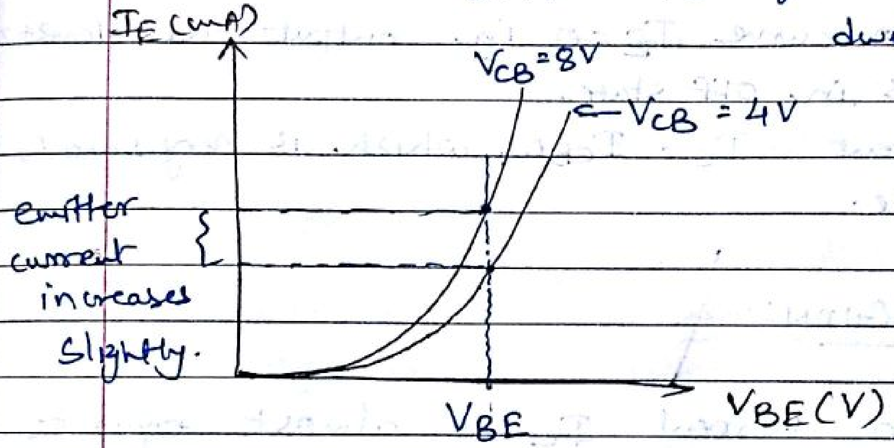
$$r_i = \left.\frac{\Delta V_{BE}}{\Delta I_E}\right|_{\text{Constant } V_{CB}}$$

→ The input resistance r_i is obtained from the input characteristics.

→ ΔI_E (change in input current) is very large for small change in input voltage (ΔV_{BE}) so r_i is small.

→ Effect of V_{CB} (output voltage) on the input characteristics:

→ emitter current increases slightly with increase in output voltage V_{CB}. This happens due to "early effect."

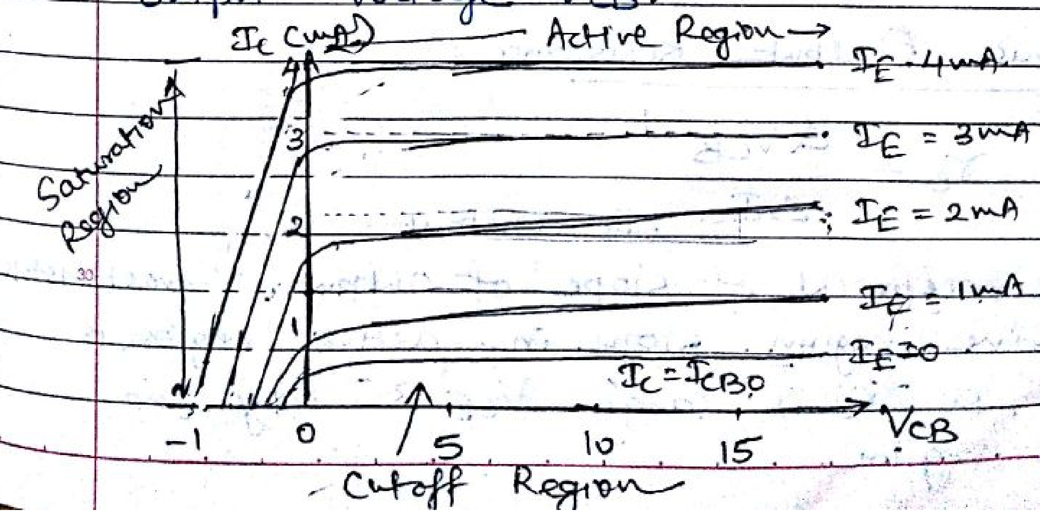


Output characteristics: (CB configuration)

→ output characteristics is always a graph of output current versus output voltage.

→ output current I_C

→ output voltage V_{CB}.



→ Transistor can be operated in three Regions:

1. Cutoff Region
2. Active Region
3. Saturation Region

CUTOFF REGION:

→ Emitter base Junction & collector base junction both reverse biased.
→ Region below curve $I_E = 0$ in output characteristics
→ Transistor is in off state.
→ Output current $I_C = I_{CBO}$, which is very small in magnitude.

ACTIVE REGION:

→ The collector current I_C is almost equal to emitter current I_E & it almost remains constant if I_B is held constant.
→ If I_E is constant I_C remains constant irrespective of variation of V_{CB}.
→ Transistor is said to operate as "constant current source.

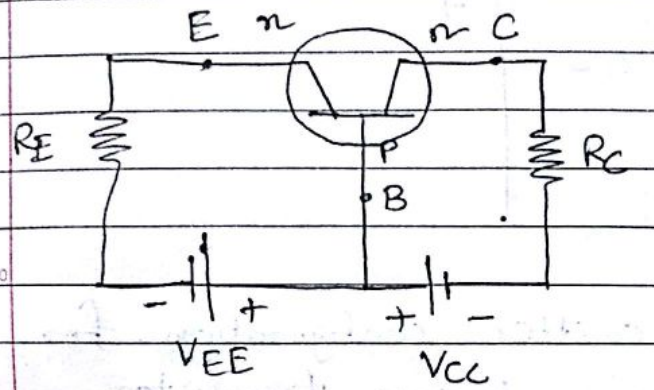
Dynamic Output Resistance:

$$r_o = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E \text{ constant}}$$

→ r_o is reciprocal of slope of output characteristics in active region. slope in active region is Small, so r_o is large. V_{CE} is large in Active region

SATURATION REGION:

→ In saturation region both junctions are forward bias, so V_{CB} is negative.



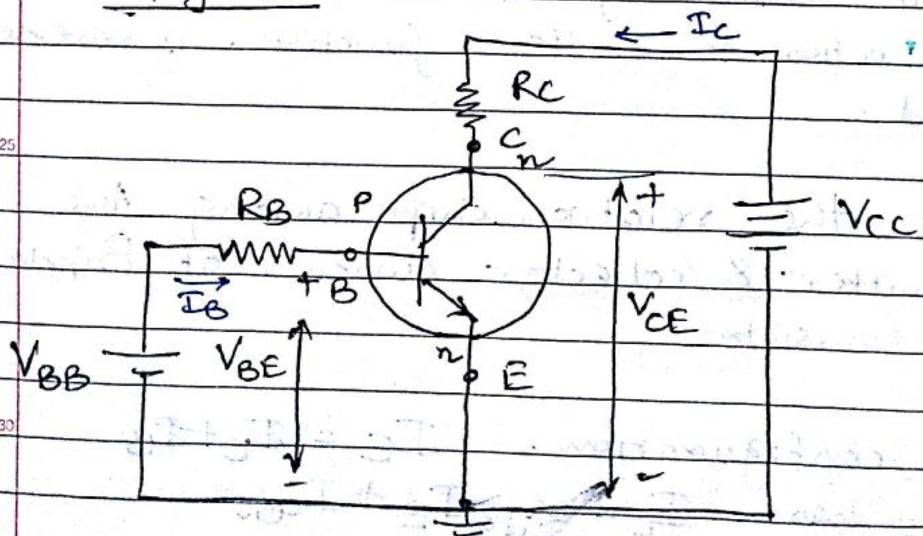
→ here I_C is not constant but increases exponentially with increase in V_{CB} towards zero.

→ slope of characteristic is high.

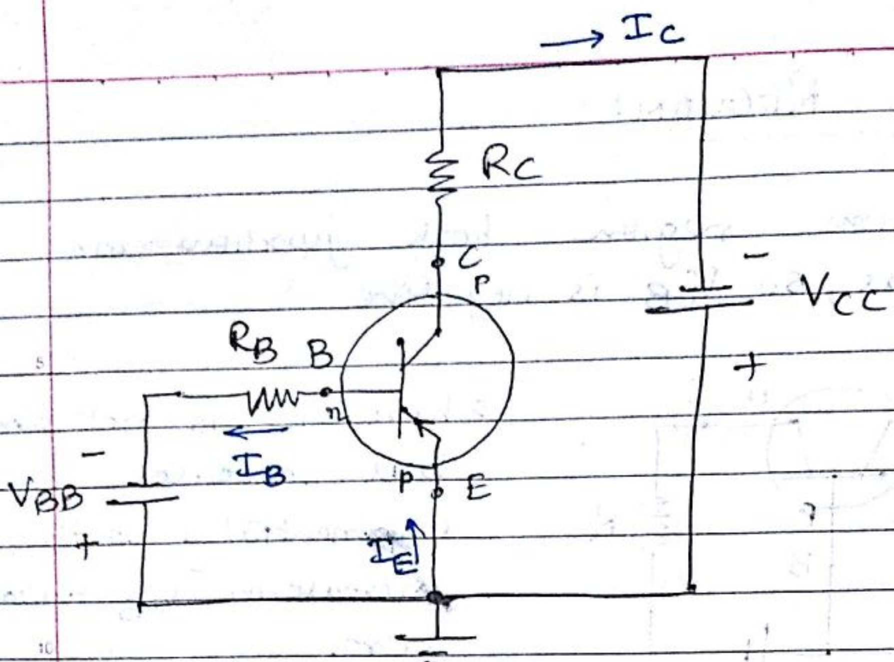
→ So, r_o (dynamic output Resistance) is small. so, V_{CE} is small.

→ Transistor is "current controlled" or "current operated" device because in active region I_C does not depends on V_{CB}. It depends only on I_E (input current)

Q. Write short note on common Emitter (C.E) Configuration.



common emitter configuration for n-p-n transistor



Common emitter configuration for p-n-p transistor

→ In CE configuration

1. emitter acts as a common terminal between input & output. Input voltage is V_{BE} (Between base & emitter). Input current is I_B
2. Output is taken between collector & emitter i.e. (V_{CE}), output current is I_C.
3. To operate transistor in active region base to emitter junction is forward bias & collector to emitter junction is reverse biased.

Q. Describe the relationship among the base, emitter & collector currents of Bipolar Junction transistor.

→ for CB configuration $I_E = I_C + I_B$

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

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

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

$$\frac{I_C}{\alpha_{dc}} - I_C = I_B + \frac{I_{CBO}}{\alpha_{dc}}$$

$$I_C\left(\frac{1}{\alpha_{dc}} - 1\right) = I_B + \frac{I_{CBO}}{\alpha_{dc}}$$

$$I_C = \left(\frac{\alpha_{dc}}{1-\alpha_{dc}}\right) I_B + \frac{I_{CBO}}{(1-\alpha_{dc})}$$

→ As β_{dc} is ratio of output current to input current I_B, it is called "common emitter current amplification" or "current gain"

→ Thus transistor acts as current amplifier

$$\beta_{dc} = \left(\frac{\alpha_{dc}}{1-\alpha_{dc}}\right)$$

$$I_C = \beta_{dc} I_B + \frac{I_{CBO}}{(1-\alpha_{dc})} \quad \text{(A)}$$

$$1 + \beta_{dc} = \left(\frac{\alpha_{dc}}{1-\alpha_{dc}}\right) + 1$$

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

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

equate in eq. (A)

$$I_C = \beta_{dc} I_B + (1+\beta_{dc}) I_{CBO}.$$

$$I_C = \beta_{dc} I_B + I_{CEO}.$$

I_{CEO} is the reverse saturation current for CE configuration

$$I_{CEO} = (1+\beta_{dc}) I_{CBO}.$$

→ If α_{dc} is 0.99 then $\beta = 99$

<u>Reverse Leakage current in CE configuration</u> (I_{CEO})

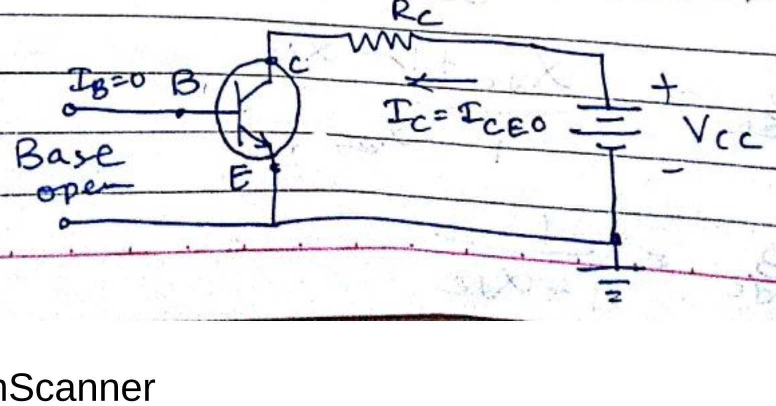
→ I_{CEO} is reverse leakage current (CE configuration)

$$I_{CEO} = (1+\beta_{dc}) I_{CBO}.$$

→ As $\beta_{dc} >> 1$ so, $I_{CEO} >> I_{CBO}$.

→ If $I_B = 0$ then $I_C = I_{CEO}$ & Reverse saturation current increases with increase in the temperature.

→ This current flows in same direction as I_C. so, I_C increases with temperature even when I_B is constant.



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COMMON EMITTER CURRENT GAIN (β_{dc})

$$I_C = \beta_{dc} I_B + I_{CEO}$$

I_{CEO} is large But much smaller than $\beta_{dc} I_B$

so, $I_C = \beta_{dc} I_B$

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

Q. Derived Relation between α_{dc} & β_{dc} for a transistor or

Q. Draw CE configuration of transistor & Derive $\alpha = \frac{\beta}{\beta+1}$.

A, we know that $\alpha_{dc} = \frac{I_C}{I_E}$

$$I_E = I_C + I_B$$

$$\alpha_{dc} = \frac{I_C}{I_C + I_B}$$

$$\alpha_{dc} = \frac{I_C/I_B}{(1 + I_C/I_B)}$$

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

$$\boxed{\alpha_{dc} = \frac{\beta_{dc}}{1 + \beta_{dc}}}$$

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

$$I_B = I_E - I_C$$

$$\beta_{dc} = \frac{I_C}{I_E - I_C}$$

$$\beta_{dc} = \frac{I_C/I_E}{(1 - I_C/I_E)}$$

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

$$\alpha_{dc} = \frac{\beta_{dc}}{1+\beta_{dc}} , \quad \beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}$$

Q. Draw & explain input & output characteristic of common emitter configuration.

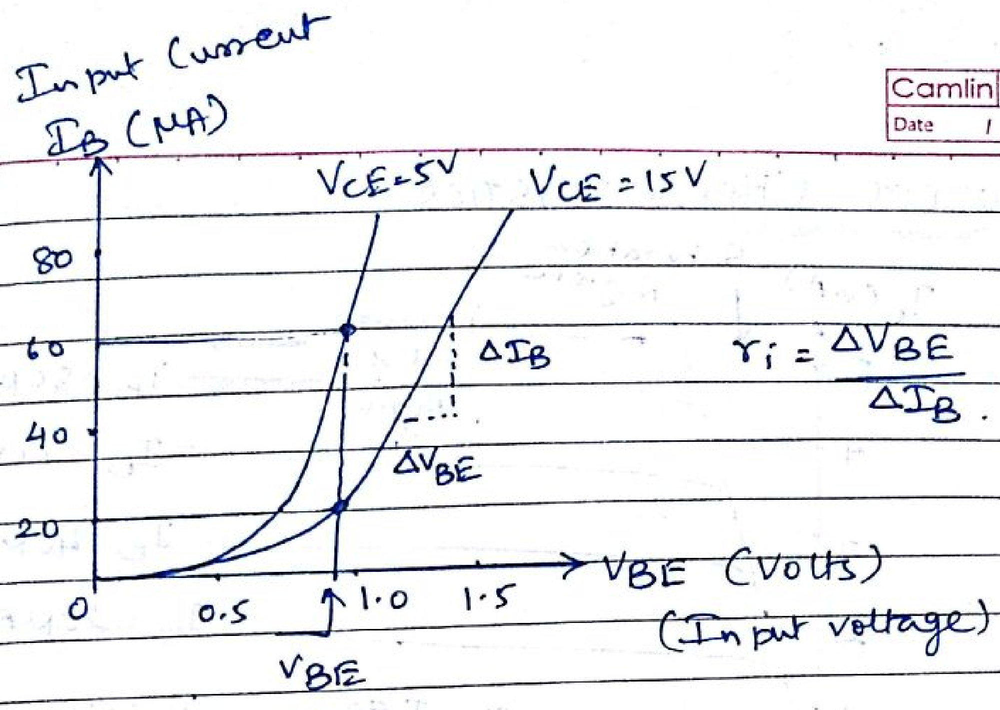
Q. Draw & explain base curve for BJT.

Input characteristics: (The Base curve)

→ Input characteristic or a base curve is graph of input current I_B versus input voltage V_{BE} at constant output voltage (V_{CE})

→ At constant V_{CE} input characteristics is similar to p-n junction diode forward characteristics.

→ when V_{BE} is greater than cut in voltage base current increases rapidly.



→ Dynamic input Resistance.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}\bigg|_{V_{CE}\ \text{constant}}$$

→ Value of r_i is low (As slope is high) approximately 1 kΩ, for CE configuration but not low as that of CB configuration.

Effect of change in V_{CE} on the input characteristics

→ here I_B decreases with increase of V_{CE}

→ As V_{CE} increases CB junction is more reversed biased

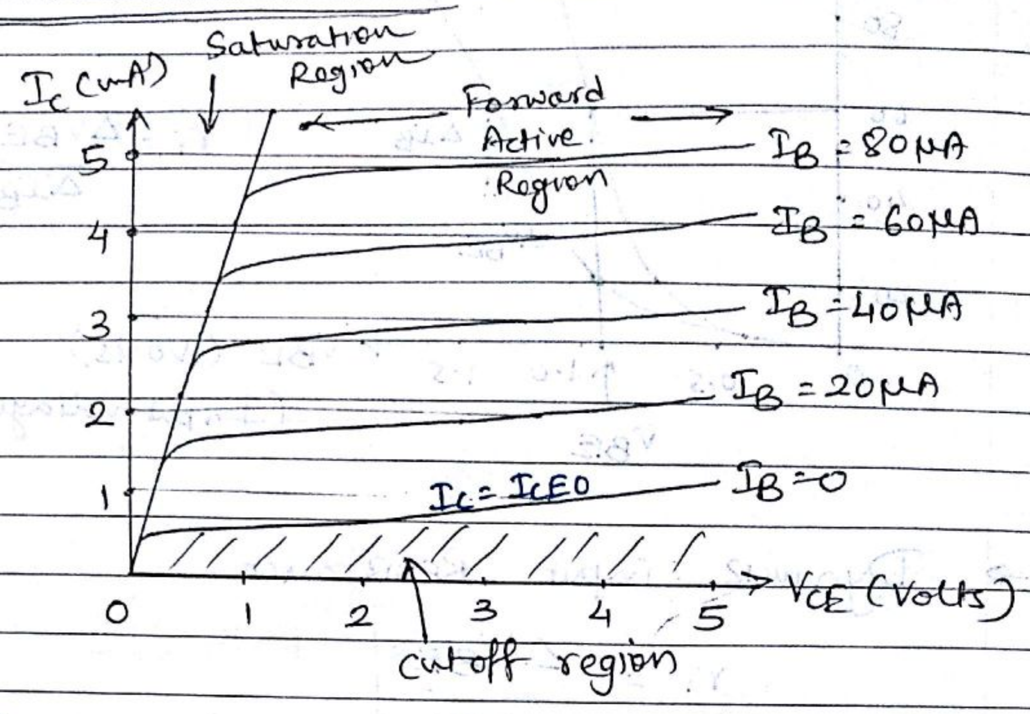
→ So depletion region at CB junction penetrates more in to Base region.

→ This reduce electrical width of Base.

→ so chance of recombination in Base reduces.

→ so I_B will reduce

OUTPUT CHARACTERISTICS



→ Output characteristics is graph of I_C verses V_{CE} for CE configuration.

→ output characteristics of n-p-n transistor is shown in fig.

1) CUTOFF REGION:

→ Both CB & B-E junctions are reversed biased.

→ $I_B = 0$

→ & collector current is equal to I_{CEO}.

→ Region below $I_B = 0$ is cutoff region.

2) ACTIVE REGION:

→ BE junction is forward biased & CB junction is reversed biased.

→ At constant Base current collector current increases slightly with increases of V_{CE}.

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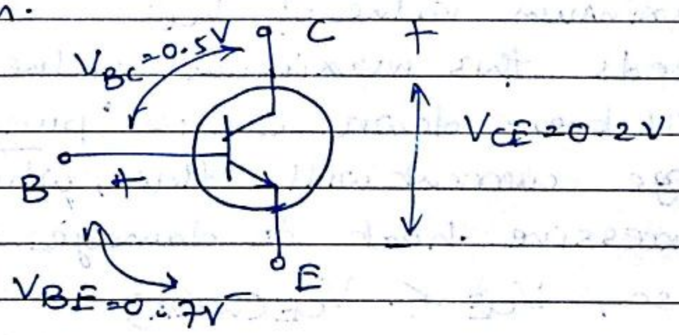
→ Collector current largely depends on I_B.

→ If I_B is increases I_C increases substantially.
→ This is because $I_C = \beta_{dc} I_B$. This is true for Active Region.

3) SATURATION REGION:

→ BE & CB, both junctions are forward biased.
→ CB junction can be forward biased if V_{CE} drops down to about 0.2 V. & $V_{BE} = 0.7$ will forward bias the BE junction.
→ Saturation voltage of transistor $V_{CE}(sat)$ is between 0.1 to 0.3 V.
→ I_C rises rapidly with increase in V_{CE}.
→ here I_C independent of I_B, but function of V_{CE}.
→ Transistor is operated as switch (ON) in this region.



Dynamic output Resistance

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \Big|_{\text{constant } I_B}$$

→ r_o is large in Active region As ΔI_C small in Active region.

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* Define β_{ac} :

→ value of β_{dc} is obtained from the output characteristics. At any point in characteristics we can calculate β_{dc}.

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

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\Bigg|_{V_{CB}\ \text{constant}}$$

→ β_{dc} & β_{ac} are nearly same.

* Maximum V_{CE} & Break down :

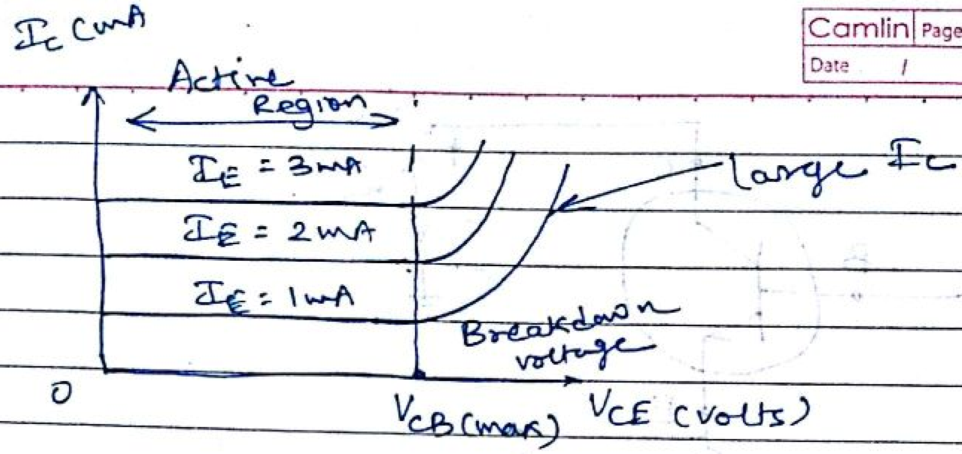
→ In active region the collector junction is reverse bias, so there is a limit on the maximum value of V_{CE}

→ If V_{CE} exceeds this maximum value, collector junction will break down due to "punch through" effect, large current will flow, which will generate excessive heat to damage the transistor. so, $V_{CE} < V_{CE(max)}$

* Breakdown voltage

→ we have to limit the maximum value of output voltage V_{CB} a certain value so as to ensure safe operation of transistor.

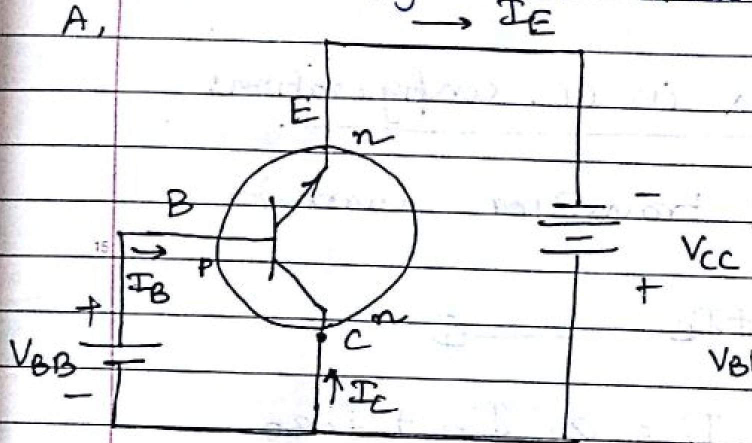
→ $V_{CB(max)}$ decided by breakdown voltage of reverse biased collector base Junction.



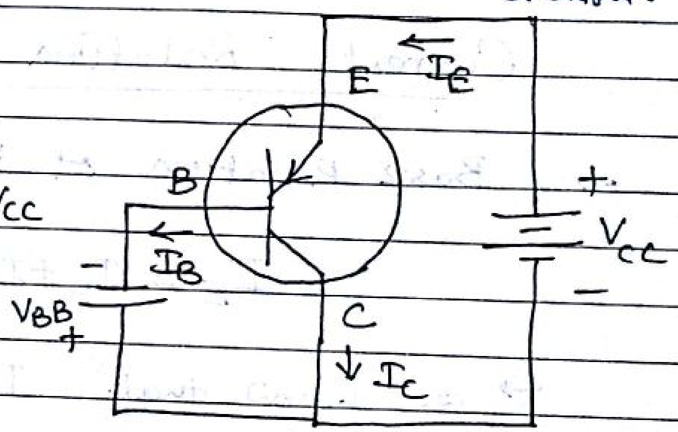
Q. Write short note on Common collector (CC) configuration.

→ in CC configuration collector terminal is common bet^n input & output.

A,



CC configuration for n-p-n transistor



CC configuration for p-n-p transistor.

→ Here V_{BC} is input voltage & I_B is input current

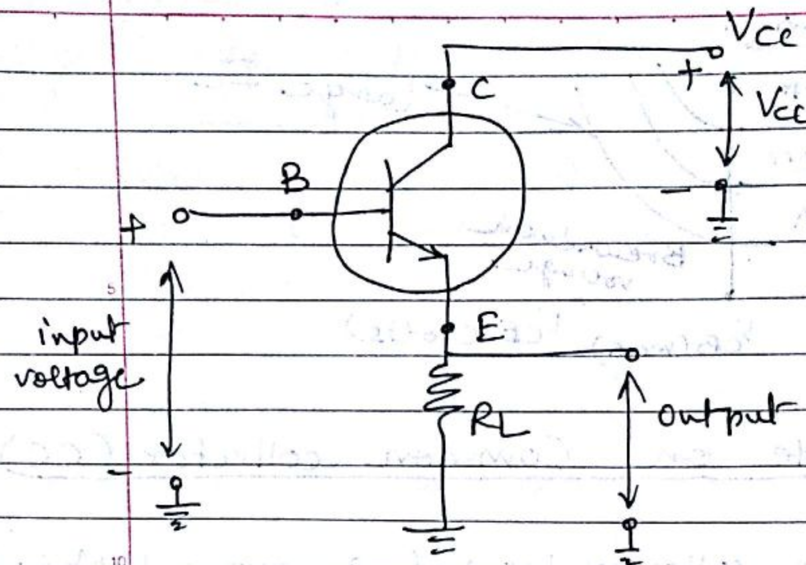
→ V_{EC} is output voltage & I_E output current

→ This configuration also called "emitter follower"

→ CC configuration is used for impedance matching, because it has high input impedance & low output impedance.

→ Practical way to Draw CC configuration

→ CC configuration with load is shown in fig. load is connected to emitter terminal.



Current Relation in CC configuration:

→ Basic Relation of transistor current

$$I_E = I_C + I_B \quad \text{—— (1)}$$

→ we know that $I_C = \alpha_{dc} I_E + I_{CBO}$.
Substitute in eq. (1).

$$I_E = \alpha_{dc} I_E + I_B + I_{CBO}.$$

$$(1-\alpha_{dc}) I_E = I_B + I_{CBO}.$$

$$\boxed{I_E = \frac{I_B}{(1-\alpha_{dc})} + \frac{I_{CBO}}{(1-\alpha_{dc})}} \quad \text{—— (2)}$$

→ now we know that $\beta_{dc} = \dfrac{\alpha_{dc}}{1-\alpha_{dc}}$

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

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But $\alpha_{dc} = \frac{\beta_{dc}}{1+\beta_{dc}}$

So, $(1-\alpha_{dc}) = \frac{\cancel{\beta_{dc}}}{(1+\beta_{dc})\cancel{\beta_{dc}}} = \frac{1}{(1+\beta_{dc})}$

$$\frac{1}{1-\alpha_{dc}} = (1+\beta_{dc})$$

substitute above in eq. 2.

$$I_E = (1+\beta_{dc}) I_B + (1+\beta_{dc}) I_{CBO}.$$

→ neglecting I_{CBO}

$$I_E = (1+\beta_{dc}) I_B.$$

$\frac{I_E}{I_B} = 1+\beta_{dc}$ = current gain for CC configuration

→ Current Gain of CC configuration:

$$\gamma = \frac{I_E}{I_B} = 1+\beta_{dc}$$

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

$$\gamma = 1 + \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{1}{1-\alpha_{dc}}$$

$\boxed{\gamma = \frac{1}{1-\alpha_{dc}}}$ ← relation between γ & α_{dc}

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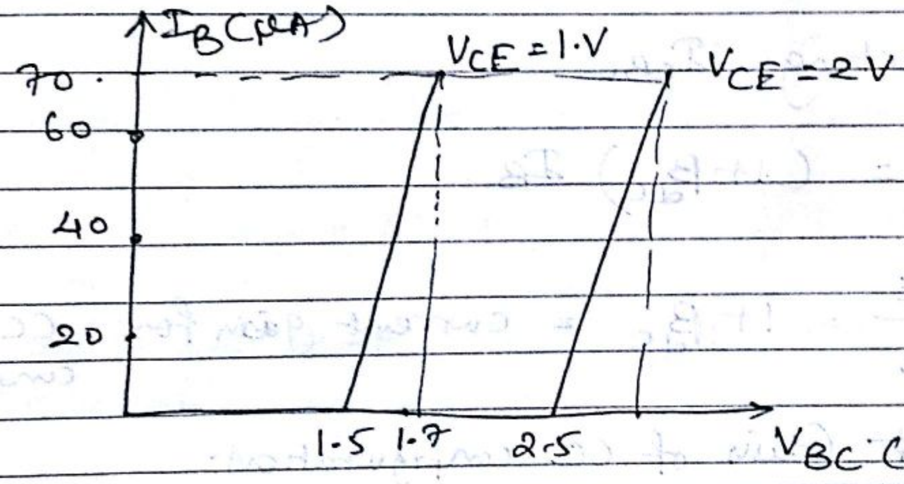
→ Voltage Gain of CC configuration is always less than 1, in order to forward bias Base emitter junction forward bias, V_{BE} must be higher than V_{EE}

Input characteristics

→ Graph of I_B (input current) versus V_{BC} input voltage for different fix value of output voltage V_{EC}.

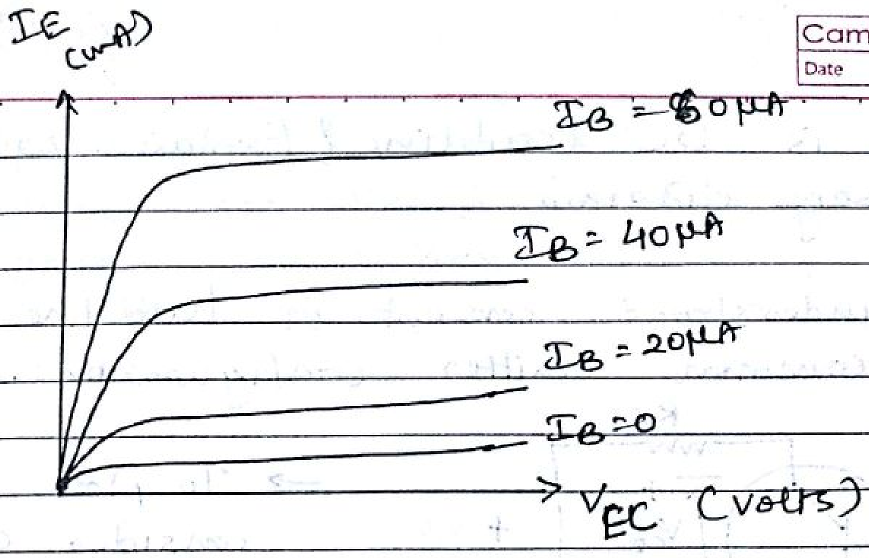


→ consider $V_{EC} = 1V$, so, base emitter junction is not forward biased upto $V_{BC} = 1.5$

→ for $V_{EC} = 2V$, Base emitter junction is not forward bias upto $V_{BC} = 2.5V$.

Output characteristics:

→ Output characteristic is plote of output current I_E versus output voltage V_{EC} for constant value of input current.



Give
Q. Comparision All configurations of Transistor.

Sr. No	Parameter	CB	CE	CC
1.	Common terminal betn input & output	Base	Emitter	collector.
2.	Input current	I_E	I_B	I_B
3.	output current	I_C	I_C	I_E
4.	Current Gain	$\alpha_{dc} = \frac{I_C}{I_E}$	$\beta_{dc} = \frac{I_C}{I_B}$	$\gamma = \frac{I_E}{I_B}$ $= 1+\beta_{dc}$
5.	Input voltage	V_{EB}	V_{BE}	V_{BC}
6.	Output voltage	V_{CB}	V_{CE}	V_{EC}
7.	Voltage Gain	Medium	Medium	Less than 1
8.	Input Resistance	Very low (20Ω)	Low (1kΩ)	High (500kΩ)
9.	Output Resistance	Very high (1MΩ)	High (40kΩ)	Low (50Ω)
10	Application	As pre amplifier	Audio Amplifier	For impedance matching