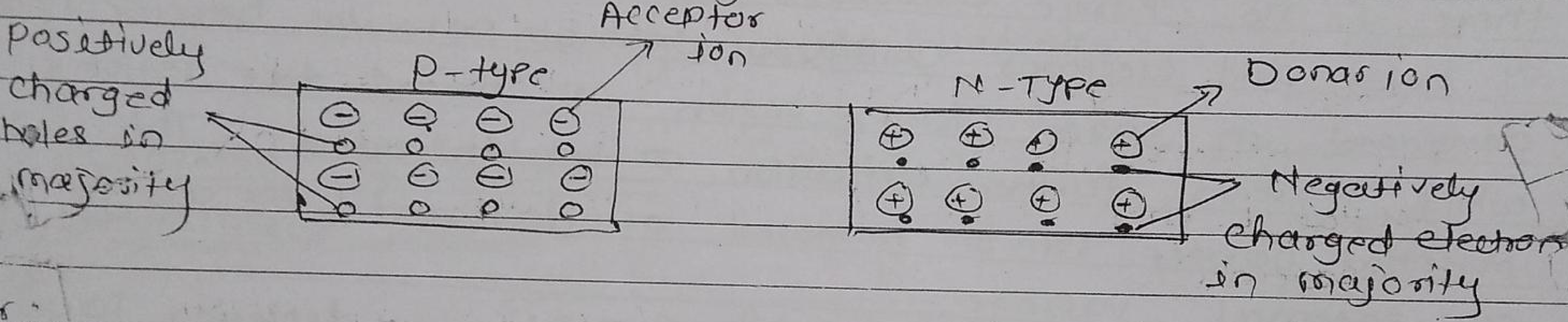
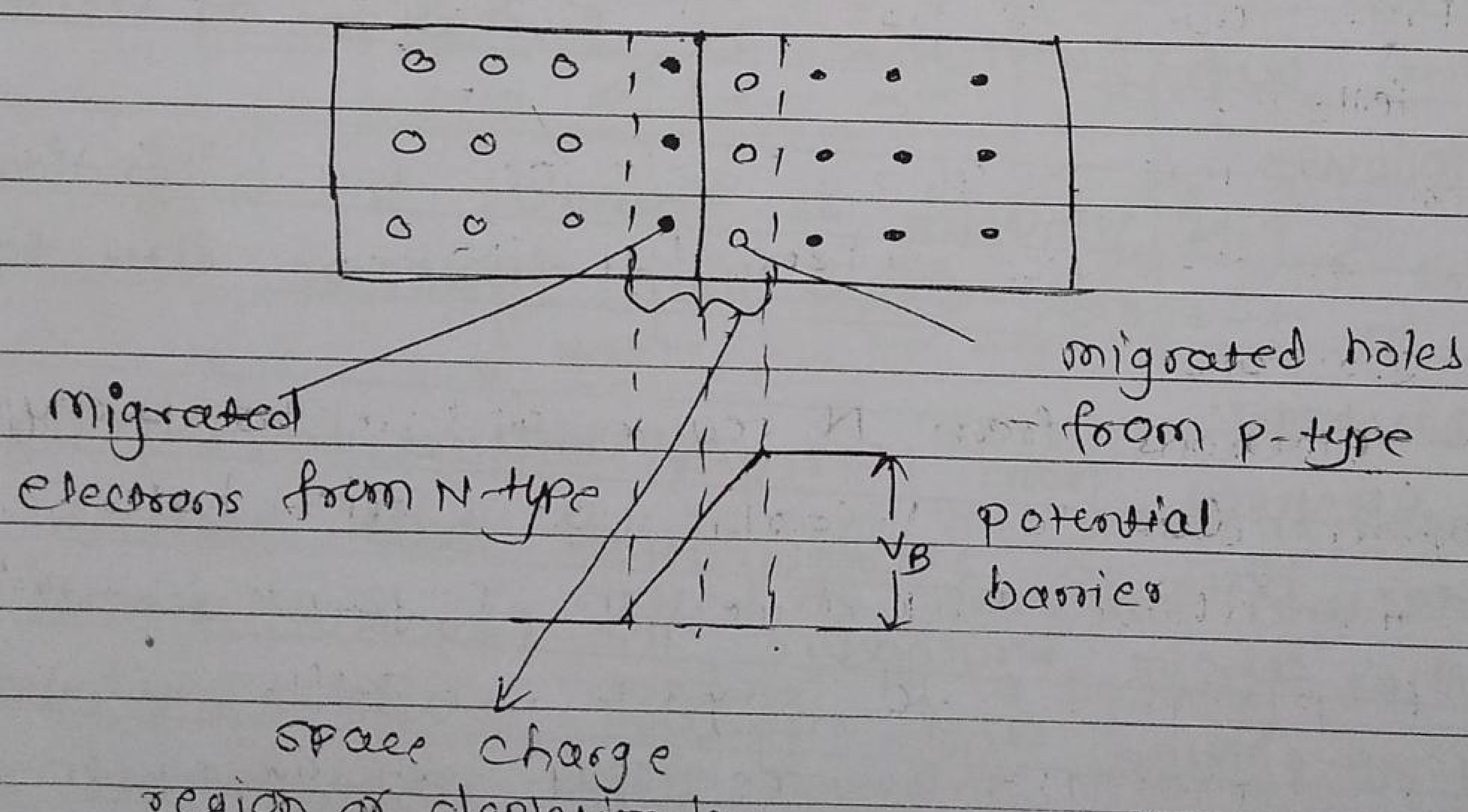
Unit No- 1

P-N junction diode

This is a two terminal device consisting of a P-N junction formed either in Ge or Si crystal. When a P-type material is intimately joined to N type, a P-N junction is formed. P-N junction is formed from a piece of semiconductor by diffusing P-type material to one half side and N-type material to other half side. The plane dividing the two zones is known as a junction.

Formation of depletion layer





Now let us consider that the two ~~pe~~ pieces are joined together. ~~As~~ shown in above figure. As P-type material has a high concentration of holes and N-type material has high concentration of free electrons and hence there is a tendency of holes to diffuse over to N-side and electrons to p-side. The process is known as diffusion so due to diffusion, some of the holes from p-side cross over to N-side where they combine with electrons and become neutral. Similarly, some of the electrons from N-side cross over to p-side where they combine with ~~electrons~~ hole and become neutral.

Thus a region is formed which is known as depletion layer or charged free region or space charge region because there is no charge available for conduction. The diffusion of holes and electrons continue till a potential barrier is developed in space charge region or charged free region which prevents further diffusion or neutralization. The potential barrier can be increased or decreased, by applyi an external voltage.

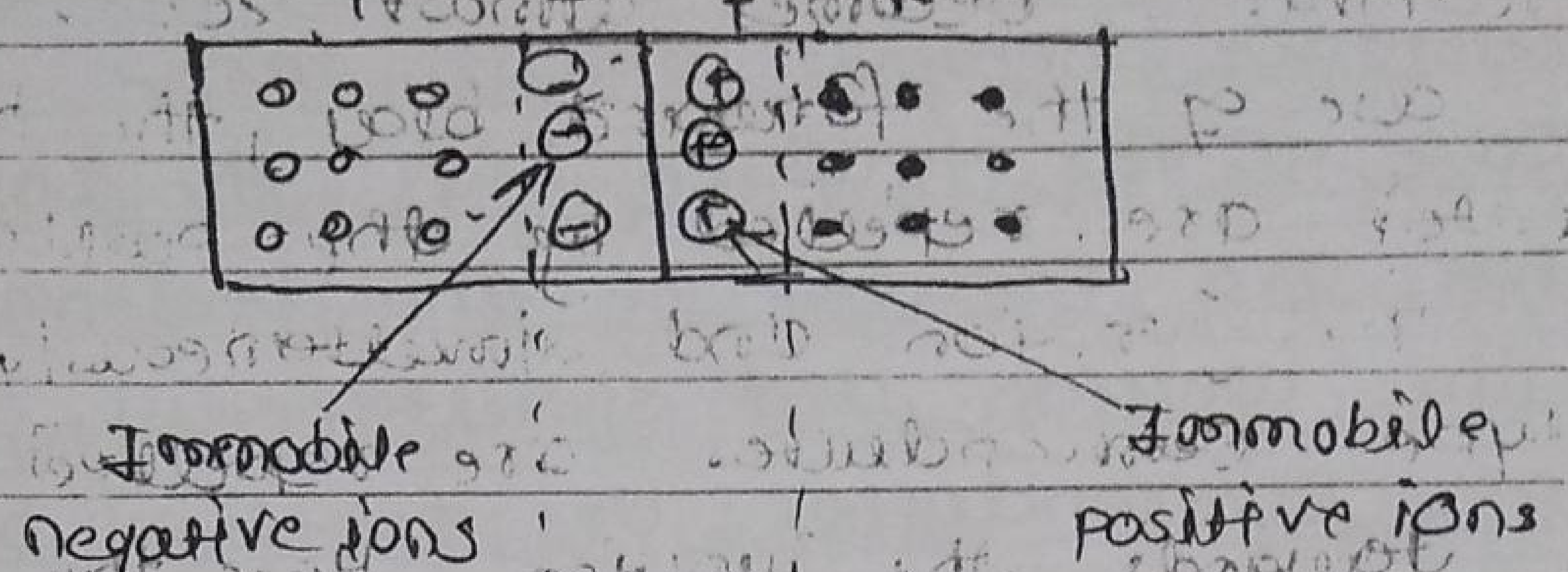
Now we summarise the formation of depletion laye as follows.

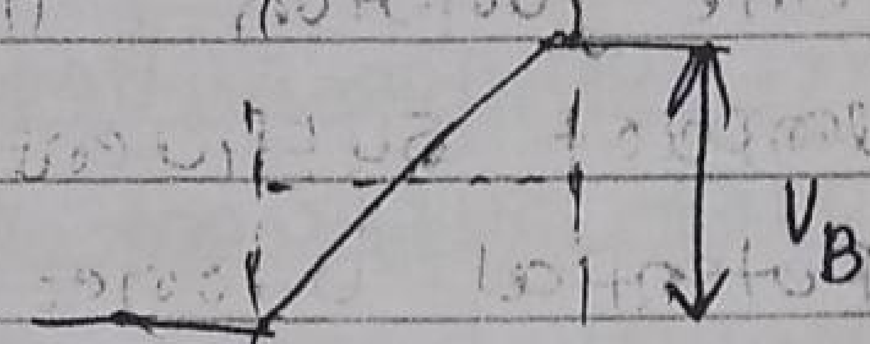
(i) When a P-N junction is formed, the holes from p-region diffuse to N-region where they disappear due to recombina with electrons.

(ii) The electrons from N-region diffuse to p-region where th disappear due to recombination with holes.

(iii) In the above procedure, the negative immobile accep ions in p-region and ~~negative~~ positive immobile don ions in N-region are left uncovered in the vici of junction

(iv) Now no further diffusion of holes and free electro takes place across the junction. The reason is tha the holes trying to diffuse to N-region are repelle immobile positive ions and the electrons trying to diff

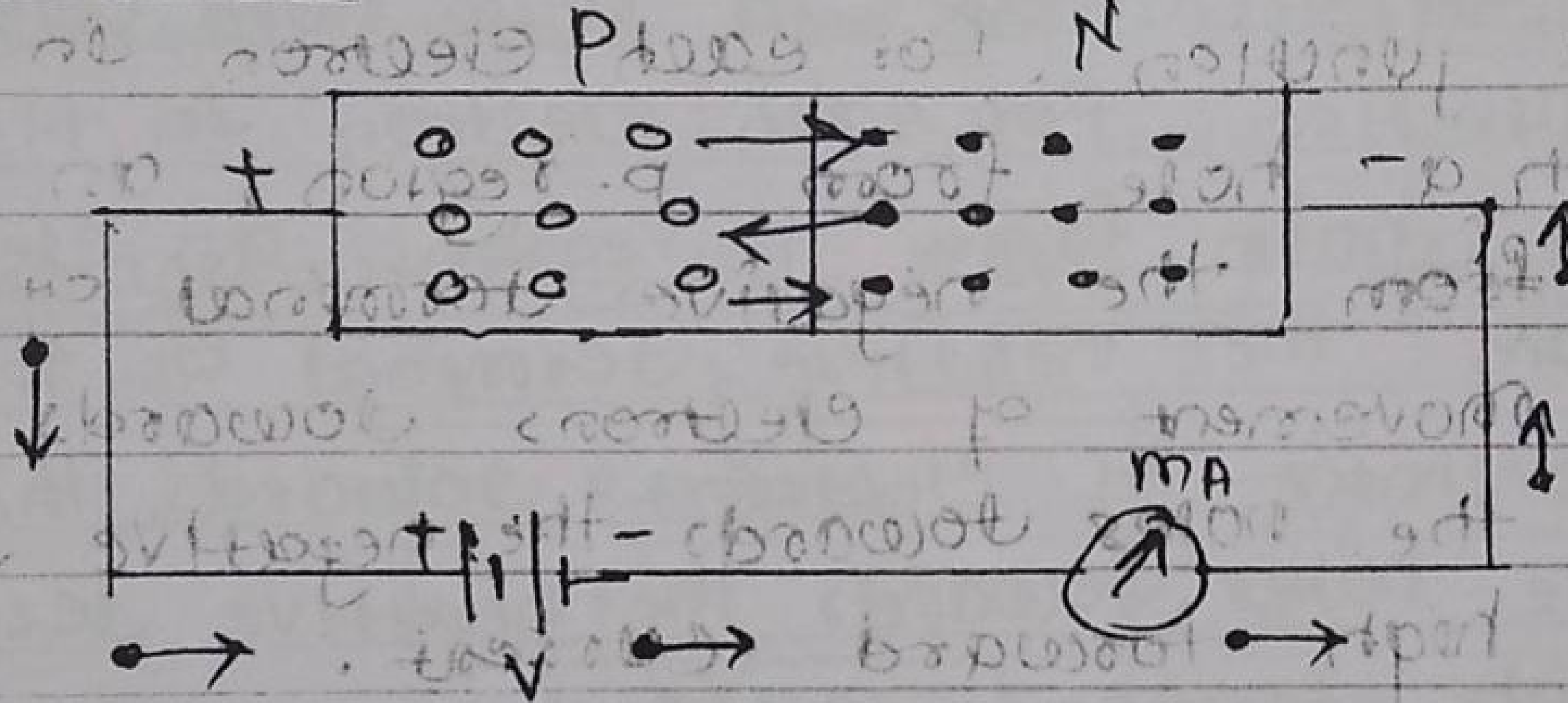




Showing junction voltage

Working of diode:-

1) **Forward Bias ⇒**

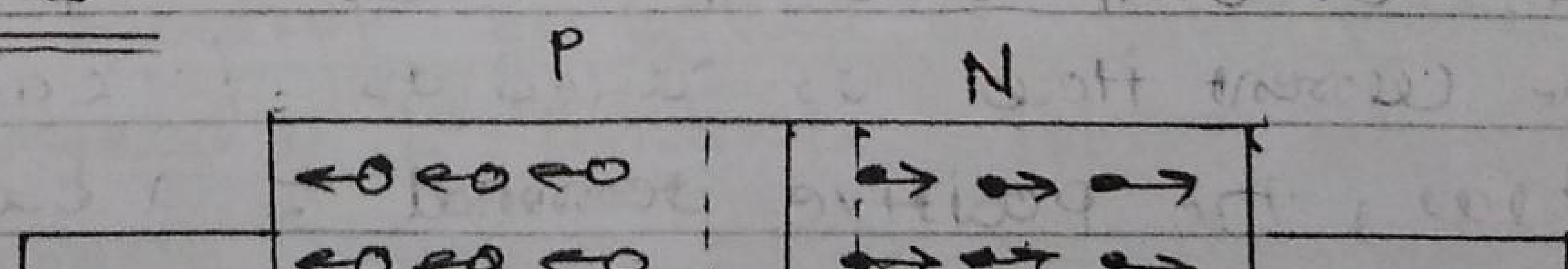


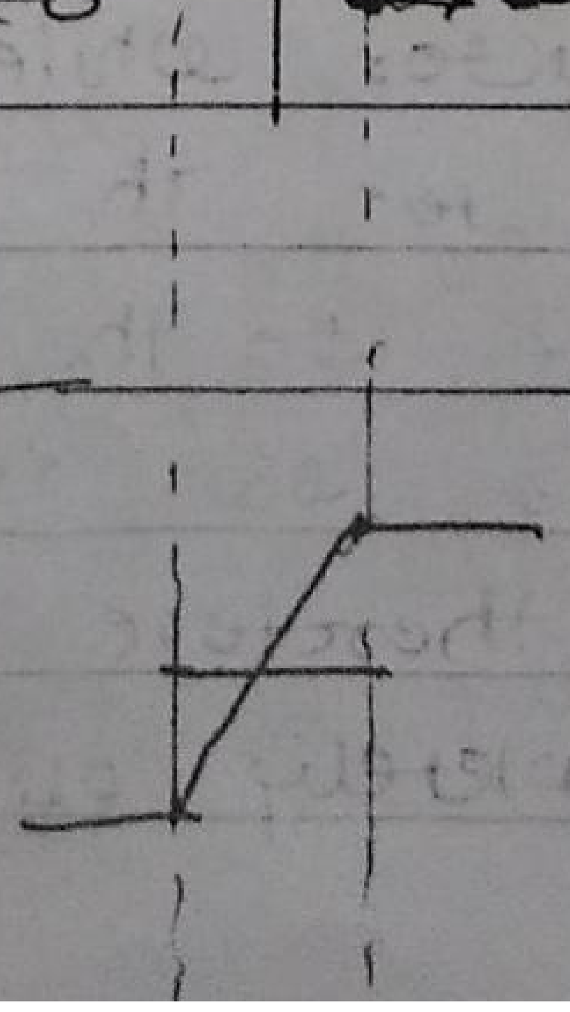
When an external voltage is applied to P-N junction in such a direction that it cancels the potential barrier and permits the current flow is called as forward bias. To apply a forward bias, the positive terminal of a battery is connected to p-type semiconductor while negative terminal is connected to N-type semiconductor. The applied potential establishes an electric field opposite to the potential barrier. Therefore the potential barrier is reduced. As the potential barrier very small, therefore a small forward voltage is cient to completely eliminate the barrier.

when Potential barrier is eliminated by the forward voltage junction resistance becomes almost zero.

In case of the forward bias, the holes from P-type semiconductor are repelled by the positive battery terminal towards the junction and simultaneously, the electrons in N-type semiconductor are repelled by negative battery terminal towards the junction. Here the battery voltage should be high to impart sufficient energy to these carriers to overcome the potential barrier at the junction and enable them to cross through it. When an electron hole combination takes place near the junction, a covalent bond near the positive terminal of battery breaks down. This causes the liberation of an electron which enters the positive terminal. This action creates a new hole which moves towards the junction. For each electron in N-region that combines with a hole from P-region, an electron enters the crystal from the negative terminal of the battery. The constant movement of electrons towards the positive terminal and the holes towards the negative terminal produces a high forward current.

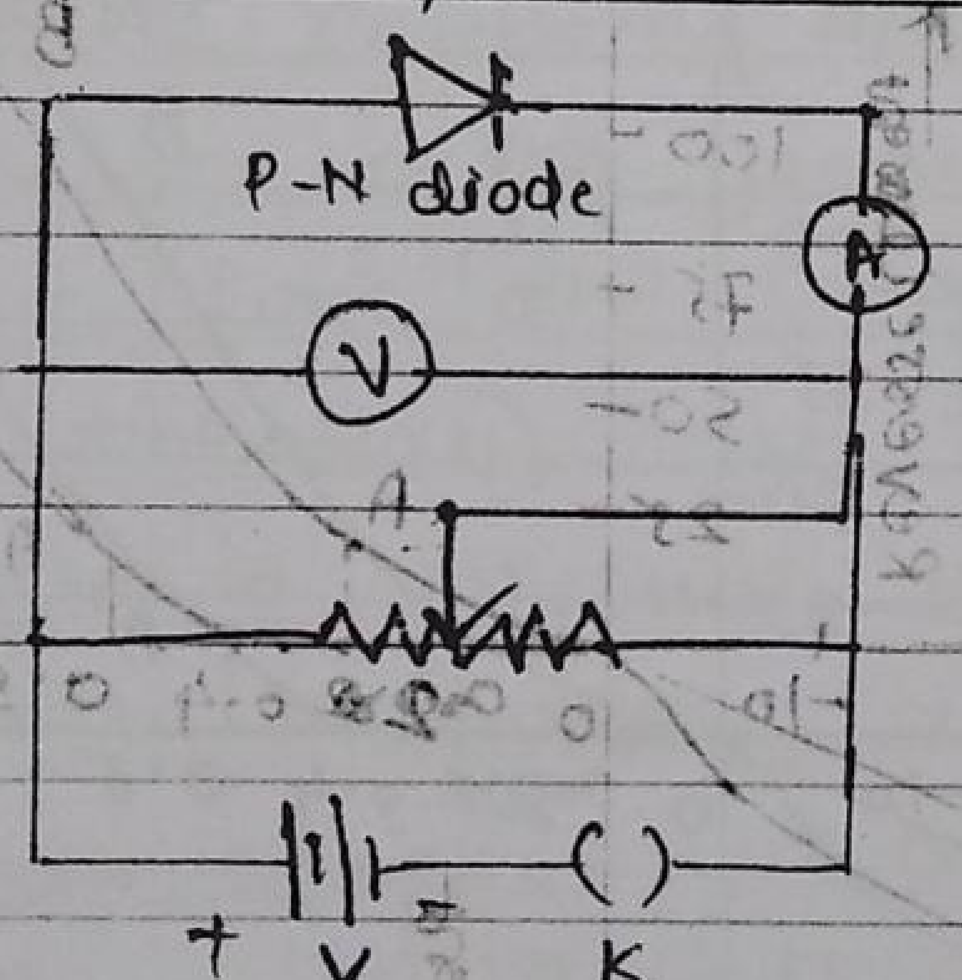
2) Reverse bias :-





when an external voltage is applied to P-N junction in such a direction that it increases the potential barrier then it is called as reverse bias. For reverse bias, the positive terminal of battery is connected to N-type semiconductor and negative terminal to P-type semiconductor. The applied reverse voltage establishes an electric field which acts in the same direction of potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier height is increased. This increased potential barrier prevents the flow of charge carriers across the junction. In this way high resistance path is established. When the junction is reversed biased, the electrons in N-type semiconductor and holes in P-type semiconductor are attracted away from the junction since there is no recombination of electron hole pairs, no current flows in the circuit.

V-I Characteristics of P-N Junction



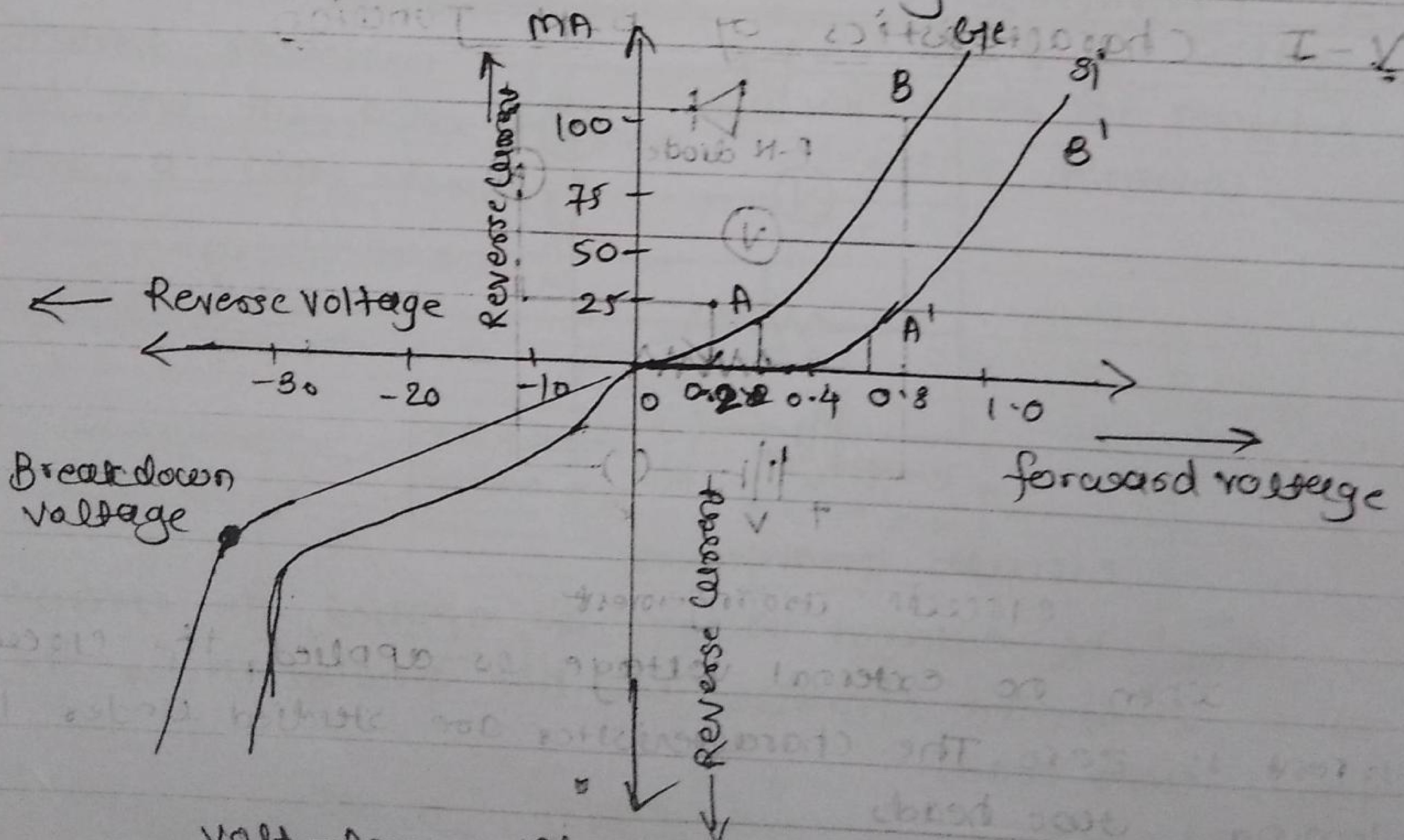
circuit arrangement

When no external voltage is applied, the circuit current is zero. The characteristics are studied under the following two heads

(i) Forward bias (ii) reverse bias

(i). Forward Bias ⇒

For the forward bias of a P-N junction, P-type is connected to the positive terminal while the N-type is connected to the negative terminal of a battery. The potential at P-N junction can be varied with the help of potential divider. At some forward voltage the potential barrier is altogether eliminated and current starts flowing. This voltage is known as threshold voltage (V_{th}) or cut in voltage or knee voltage. It is practically same as barrier voltage V_B. For $V < V_{th}$, the current flow is negligible. As the forward applied voltage increases beyond threshold voltage, the forward current rises exponentially as shown in fig. If the forward voltage is increased beyond a certain safe value, it produces an extremely large current which may destroy the junction due to overheating.



Volt-Ampere Characteristics of P-N junction

Important Terms

1) **Ideal diode** ⇒ An ideal diode is a two terminal device which has the following properties,
   - → Conducts with zero resistance when forward biased
   - → Offers an infinite resistance when reverse-biased.

2) **Knee Voltage** ⇒ Knee voltage is defined as the forward voltage at which the current through the junction starts increasing rapidly.

3) **Static and dynamic resistance of a diode** ⇒

It has been observed that a real diode does not offer zero resistance when it is forward biased and an infinite resistance when reverse-biased. This shows that when a real diode is forward biased has a definite resistance. This resistance is known as static forward resistance of diode. This is defined as the ratio of d.c. voltage across the diode to the d.c. current flowing through it. If V_F and I_F be the d.c. voltage across diode and d.c. current flowing through it resp. then static resistance R_F is given by,

$$R_F = \frac{V_F}{I_F}$$

(*) (The dynamic resistance or a.c. resistance of the diode at a particular d.c. voltage is defined as the reciprocal of the slope of the forward characteristics).

Let ΔI_F is the change in forward current corresponding to the change of forward voltage ΔV_F then,

$$\text{Slope of the forward Characteristics} = \frac{\Delta I_F}{\Delta V_F}$$

$$\therefore \text{ ac resistance } (r_{ac}) = \frac{1}{\text{Slope of forward characteristics}}$$

$$r_{ac} = \frac{1}{(\Delta I_F/\Delta V_F)}$$

$$r_{ac} = \frac{\Delta V_F}{\Delta I_F} \qquad r = \frac{\eta V_T}{I_0\, e^{V/\eta V_T}}$$

4) Reverse saturation current (I_s or I_0) ⇒

In reverse-biased diode, there is practically no current due to majority carriers, yet there is small current due to flow of minority carriers across the junction. The minority carriers are produced due to thermal agitation. The applied voltage drives these minority carriers across the junction. So the minority carriers constitute a small current called as reverse current or reverse saturation current. The reverse saturation current is extremely temperature dependent.

I_0 doubles for every 10°c rise for Ge and for every 6°c rise for si.

5) Junction breakdown ⇒

Under normal reverse voltage a very little reverse current flows through a P-N junction. But when the reverse voltage is increased a point is reached when the junction breaks down with sudden rise in reverse current. The critical value of the voltage is known as breakdown voltage. The breakdown voltage depends upon the width of the depletion region.

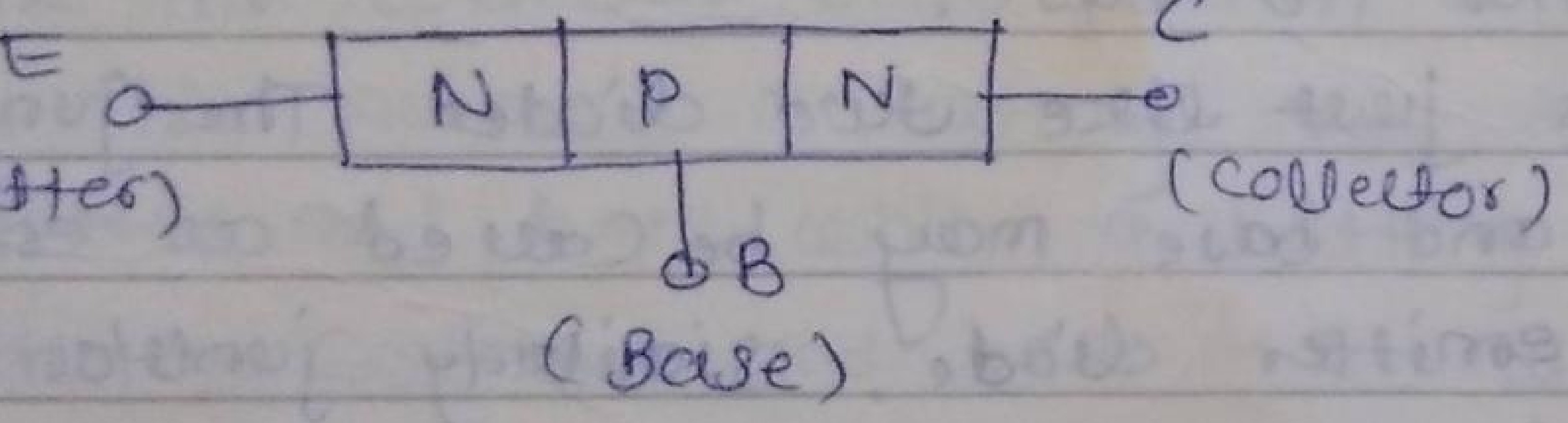
Bipolar Junction Transistor

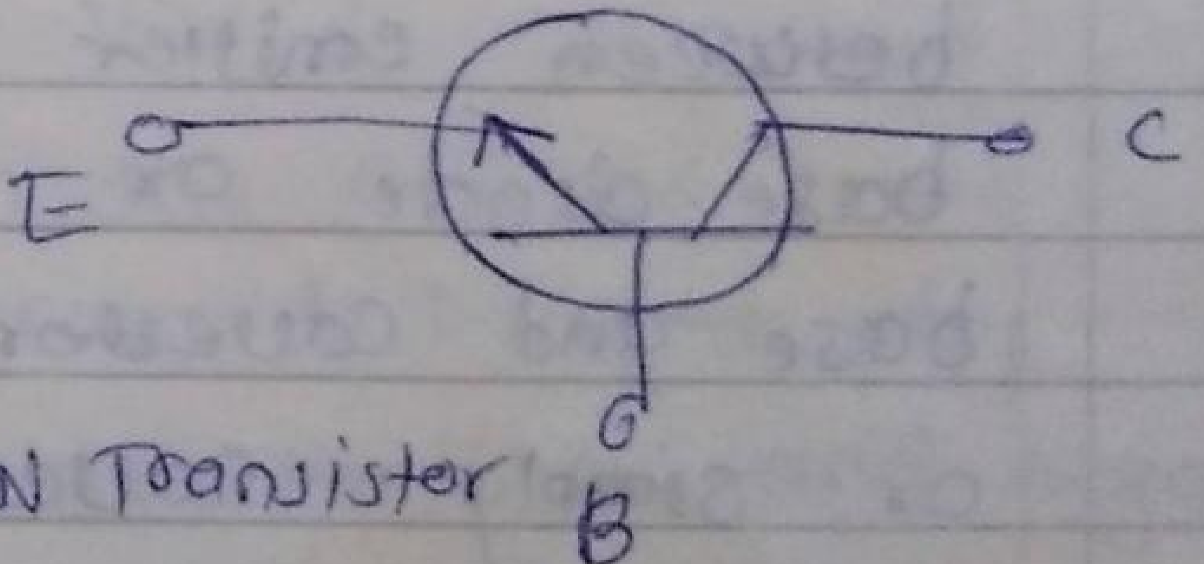
The transistor is a solid state device and is an essential ingredient of every electronic circuit. It is a current controlled device. Bipolar junction transistor is a three terminal, two junction device.

A junction transistor is simply a sandwich of one type of semiconductor material between two layers of the other type. Accordingly there are two types of transistors.

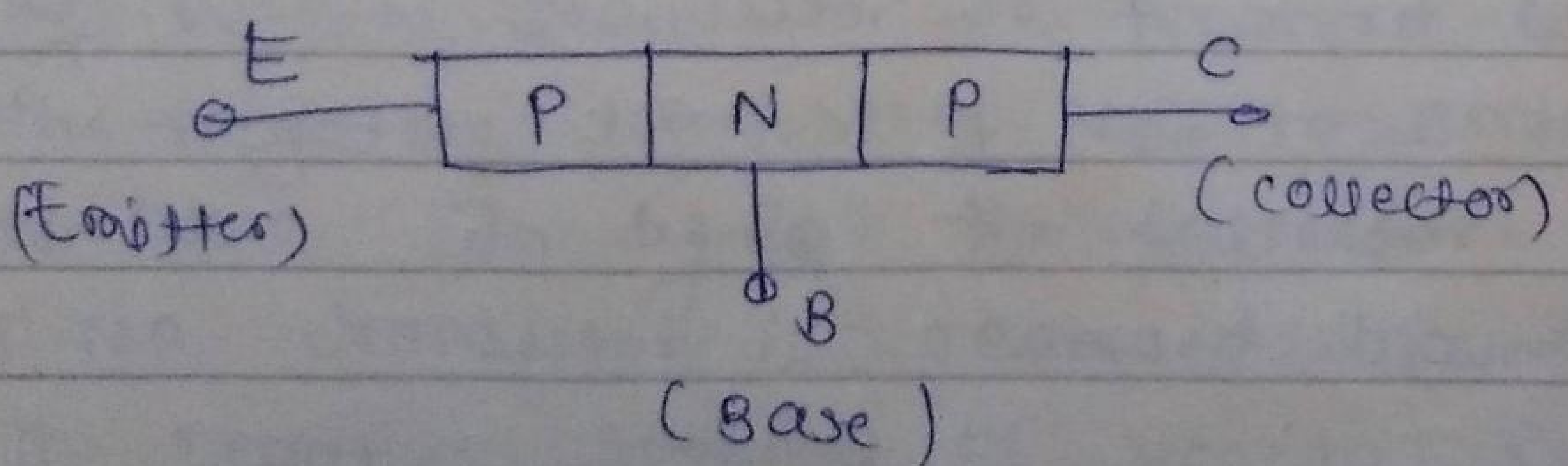
i) N-P-N transistor
ii) P-N-P transistor

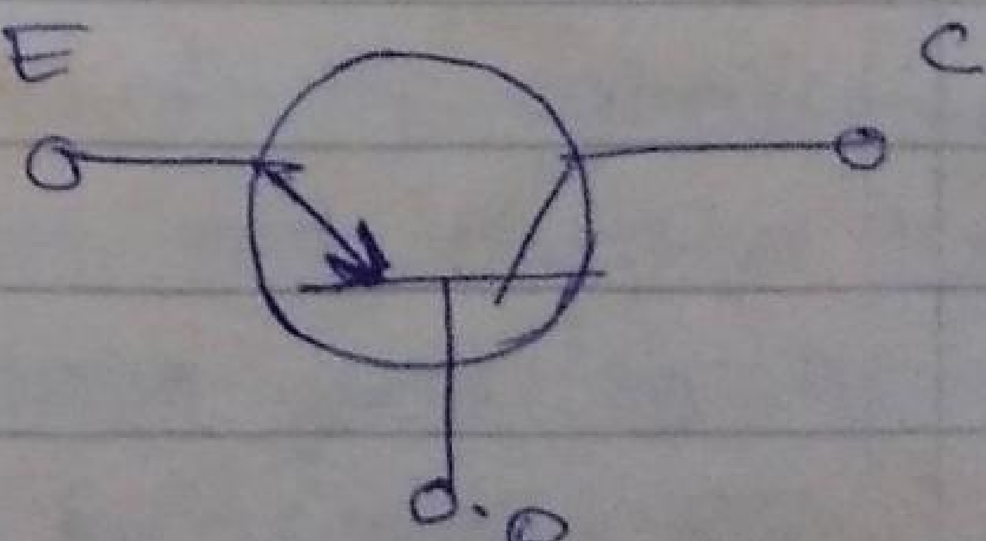
When a layer of P type material is sandwiched between two layers of N-type material, the transistor is known as N-P-N transistor. Similarly when a layer of N-type material is sandwiched between two layers of P-type material the transistor is known as P-N-P transistor. Transistors are made either from silicon or germanium crystal.





Structure & symbol of NPN Transistor





A transistor has the following sections,

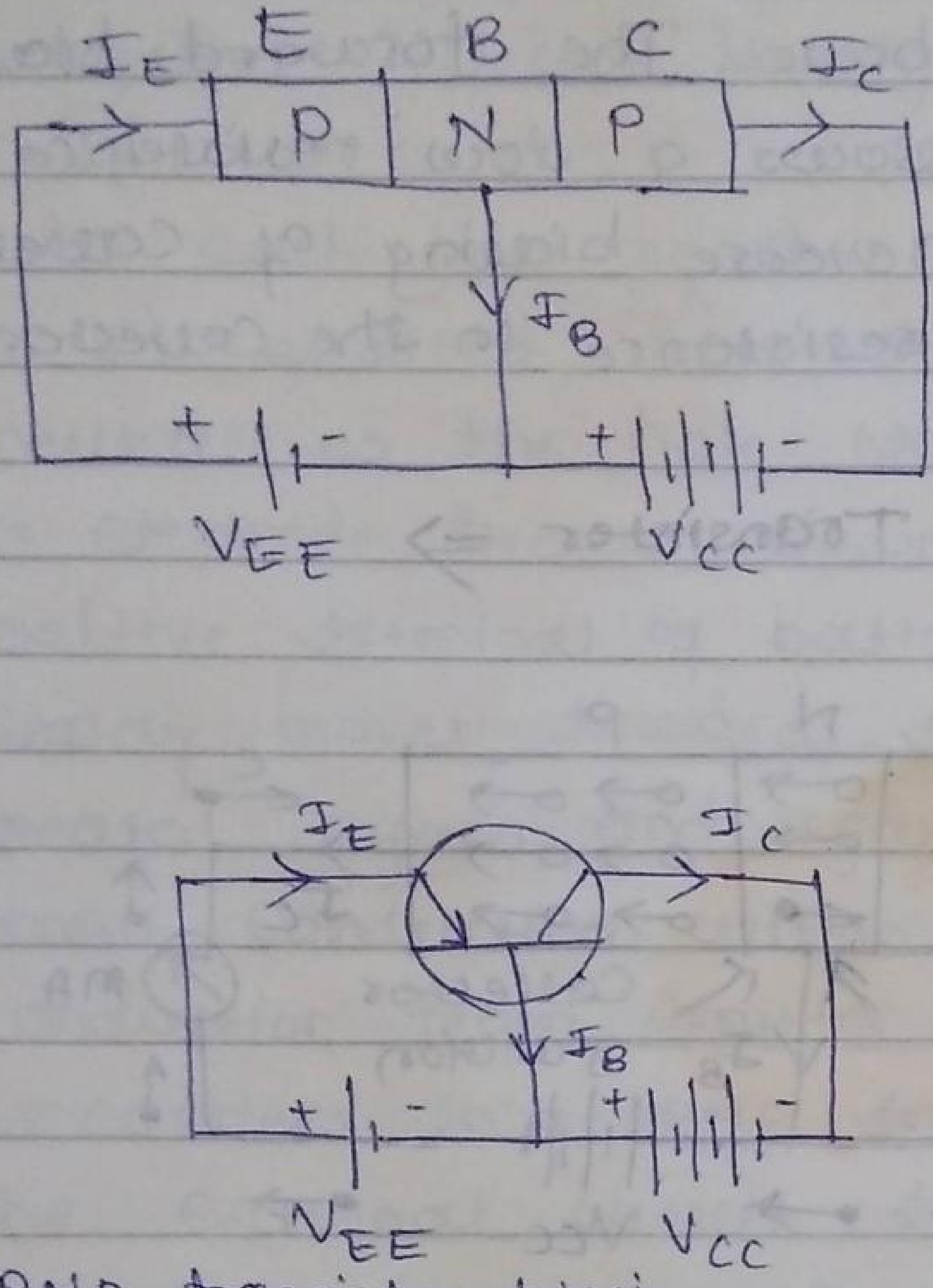
(i) Emitter :- This forms the left hand section or region of the transistor. The main function of this region is to supply majority charge carriers to the base and hence it is more heavily doped in comparision to other regions.

(ii) Base :- The middle section of the transistor is known as base. This is very lightly doped and is very thin ($10^{-6}m$) as compared to either emitter or collector so that it may pass most of the injected charge carriers to the collector.

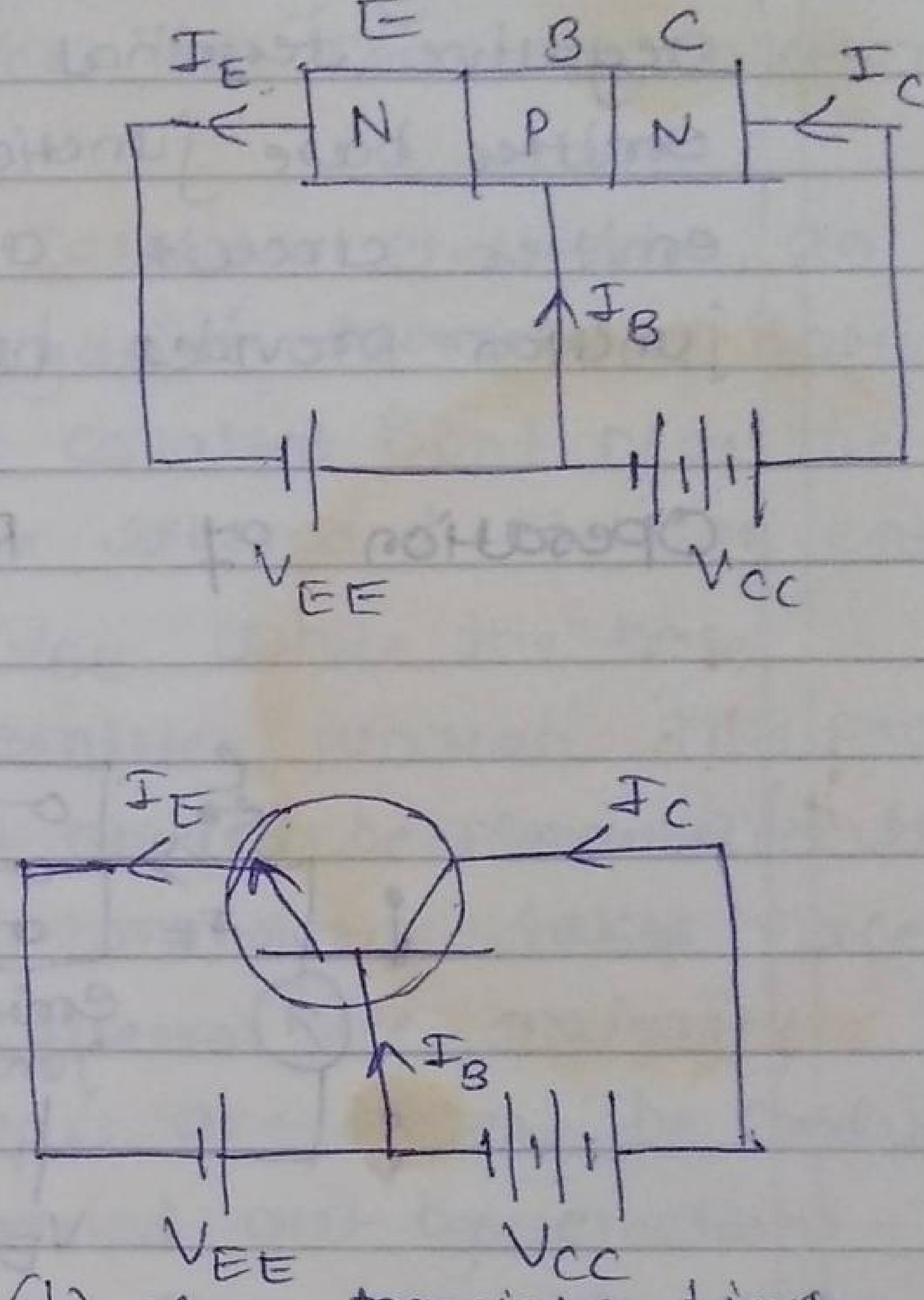
(iii) Collector :- The right hand section of the transistor is called as collector. The main function of the collector is to collect majority charge carriers through the base. This is moderately doped. Arrowhead is always at the emitter. The direction indicates the conventional direction of current flow i.e. in case of N-P-N transistor it is from base to emitter while in case of P-N-P it is from emitter to base.

Transistor is just like two diodes. The junction between emitter and base may be called as emitter base diode or emitter diode. Similarly junction between base and collector may be called as collector base diode or simply collector diode.

Transistor Biasing ⇒



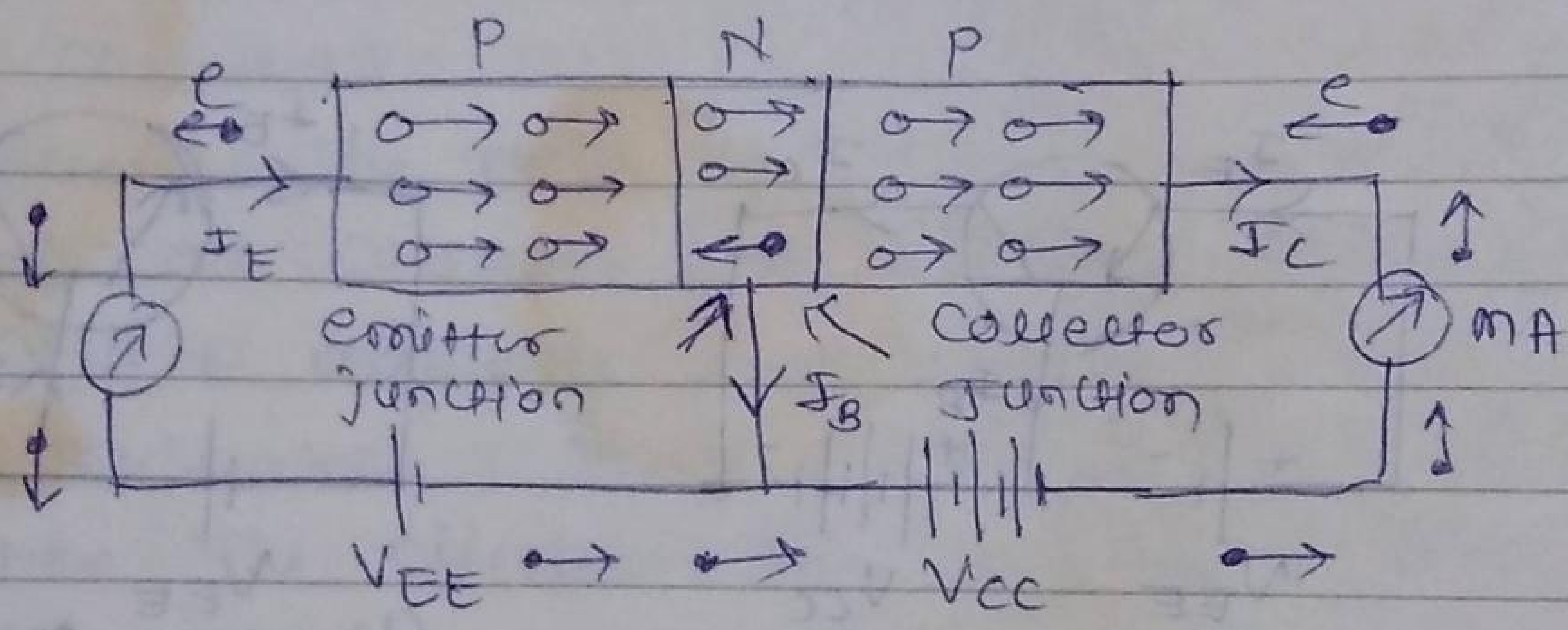
(a) PNP transistor biasing



(b) NPN transistor biasing

The emitter base junction is always forward-biased while the collector base junction is always reverse-biased. For this purpose a battery V_{EE} is connected in between emitter and base while a battery V_{CC} is connected between collector and base. In (a) the emitter base junction of P-N-P transistor is forward biased by connecting positive terminal of V_{EE} to emitter and negative terminal to base. Similarly in fig(b) the emitter base junction of N-P-N transistor is forward biased by connecting the negative terminal of V_{EE} to emitter and positive terminal to base. In fig (a) the collector base junction of a P-NP transistor is reversed biased by connecting the negative terminal of V_{CC} to collector while positive terminal to base. Similarly in fig(b) the Collector base junction of N-P-N transistor is reverse-biased by Connecting the positive terminal of Vcc to emitter while negative terminal to base. The forward biasing of emitter base junction allows a low resistance for emitter circuit and reverse biasing of Collector base junction provides high resistance in the Collector circuit.

Operation of PNP Transistor ⇒



above fig. shows PNP transistor with emitter base junction as forward biased and Collector base junction as reverse biased. The Operation of PNP transistor is as follows:

The holes of P region are repelled by the Positive terminal of battery V_{EE} towards base. The potential barrier at emitter junction is reduced as it is forward bias and hence the holes Cross this junction and penetrate into N-region. This constitute the emitter current I_E. The width of base region is very thin and it is lightly doped and hence 2 to 5% of the holes recombine with the free electrons of N region.

This constitute the base current I_B which is very small. The remaining holes (95% to 98%) are able to drift across the base and enter the collector region. They are swept up by the negative collector voltage $-V_{CC}$. This constitute collector current I_C.

As each hole reaches the collector electrode, an electron is emitted from the negative terminal of battery and neutralizes the hole. Now a covalent bond near the emitter electrode breaks down. The liberated electron enters the positive terminal of battery V_{EE} while the hole immediately moves towards the emitter junction. This process is repeated again and again. It should be remembered that

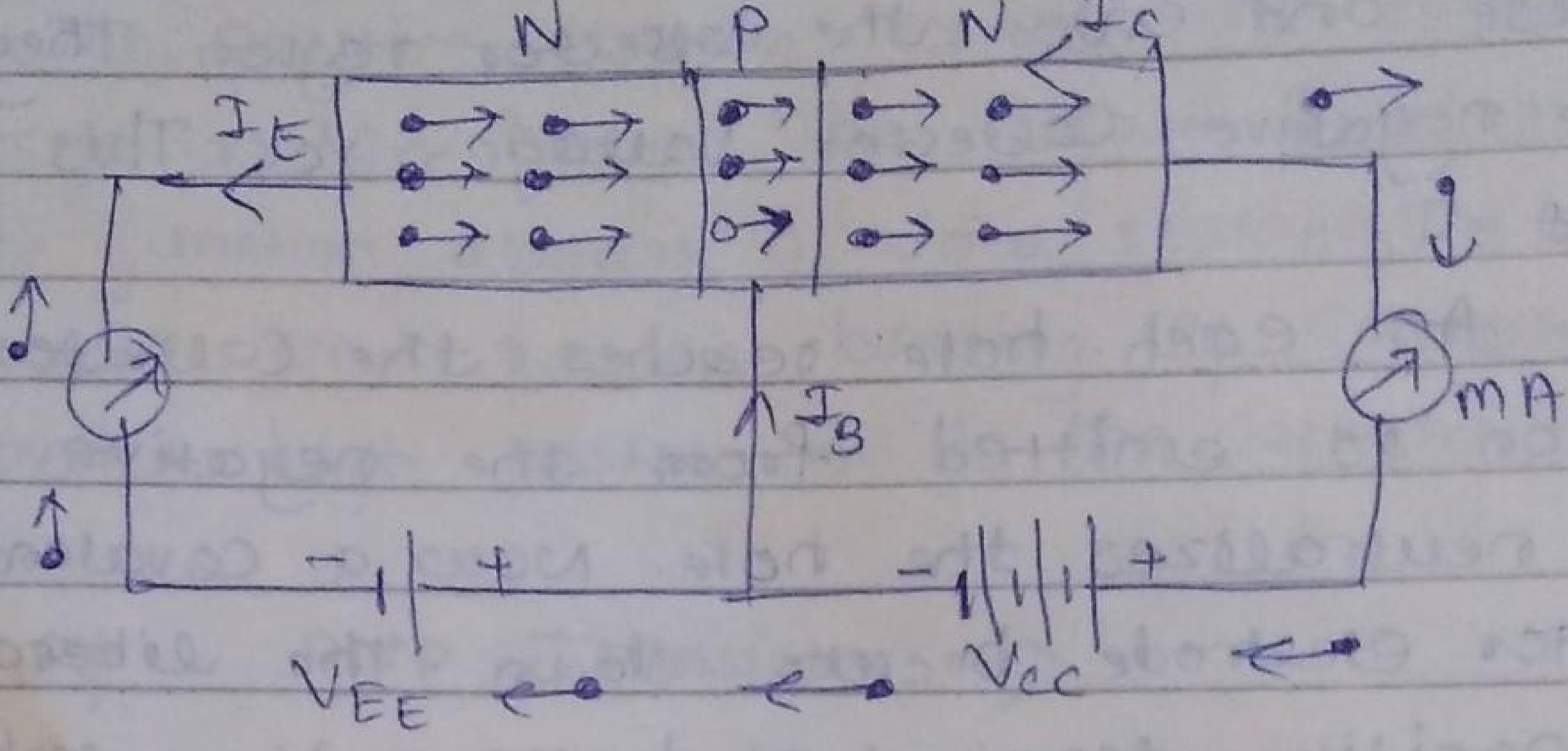
(i) Current conduction within PNP transistor takes place by hole conduction from emitter to collector i.e. majority charge carriers in a PNP transistors are holes. The conduction in the external circuit is carried out by electrons.

(ii) The collector current is slightly less than the emitter current. This is due to the fact that 2 to 5% of the holes are lost in recombination with electrons in base region. Thus the collector current is slightly less than emitter current.

(iii) The collector current is a function of emitter current i.e. with increase or decrease in the emitter current.

Beside the hole current, there is electron current which flows from base region to emitter region. This current depends upon emitter base potential. As the width of the base region is very small, the ratio of the hole current to electron current is very small. So for all practical purposes, the electron current may be neglected. Thus only the hole current plays the important role in the operation of PNP transistor.

Operation of NPN transistor ⇒



The emitter junction is forward biased because electrons are repelled from the negative emitter battery terminal V_{EE} towards the junction. The collector junction is reverse biased because electrons are flowing away from the collector junction towards the positive collector battery terminal Vcc.

The operation of NPN transistor is as follows ⇒

The electron in the emitter region are repelled from the negative terminal of battery towards the emitter junction. Since the potential barrier at the junction is reduced due to forward bias and base region is very thin and lightly doped, electrons cross the p-type base region. A few electrons combine with the holes in p-region and are lost as charge carrier. Now the electrons in N-region swept up by the positive collector voltage Vcc. For every electron flowing out the collector and entering the positive terminal of battery Vcc, an electron from negative emitter battery terminal enters the emitter region.

In this way electron Conduction takes place continuously so long as the two junctions are properly biased. so the current conduction in NPN transistor is carried out by electrons.

* Transistor as an Amplifier :→

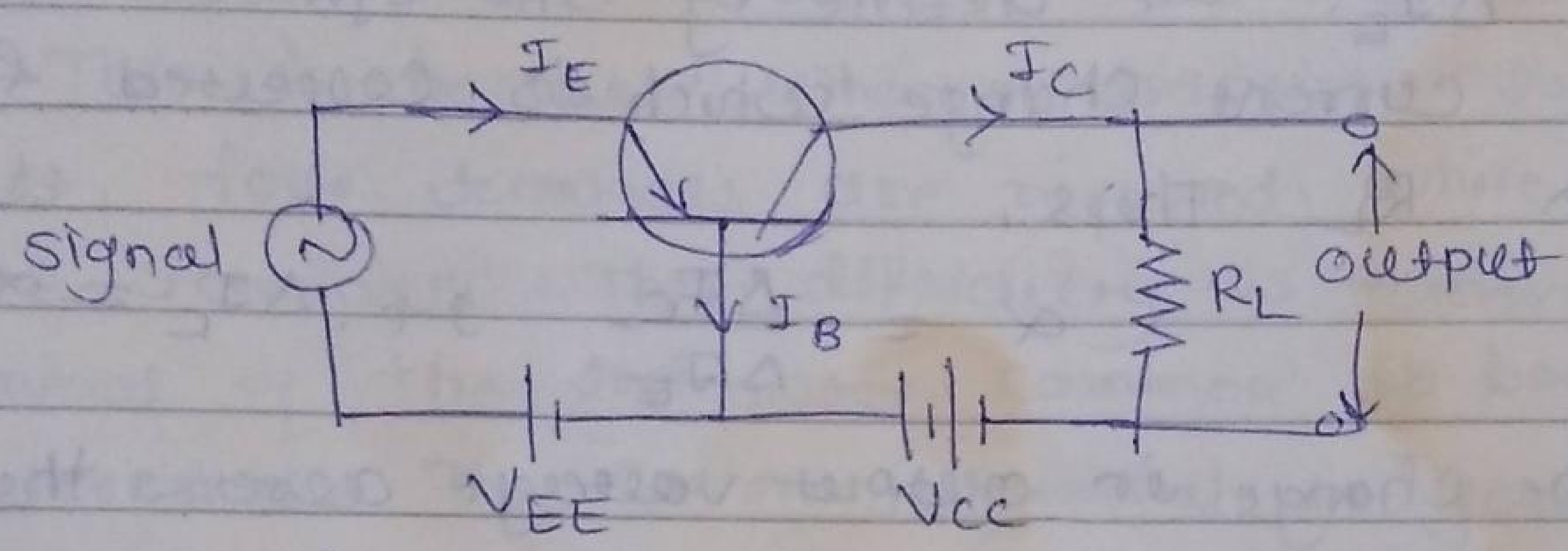


fig:- Transistor as an Amplifier

Here the weak signal to be amplified is applied betn emitter-base circuit and the output is taken across the load resistor R_L connected in the collector circuit. A d.c. voltage V_{EE} is also connected in the input circuit. If V_{EE} is not connected in the circuit. Now for the negative peak of the applied signal, the emitter base junction will be reversed biased. This is not desirable because to achieve faithful amplification, the input circuit should always remain forward biased. For this purpose, the emitter bias battery V_{EE} of such a magnitude that input circuit is always forward biased regardless of the polarity of the signal is connected.

A small change in signal voltage produces an appreciable change in emitter current because the input circuit has low resistance. Now due to the transistor action, the change in emitter current causes almost the same change in collector current. When the collector current flows through the load resistance R_L, a large voltage is developed across it. In this way, a weak signal applied in the input circuit appears in the amplified form across the output circuit.

Let a small voltage change ΔV_i between emitter and base causes a relatively large emitter-current change ΔI_E. We define by the symbol α that fraction of this current change which is collected & passes through R_L. Thus,

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{i.e. } \Delta I_C = \alpha \cdot \Delta I_E$$

The change in output voltage across the load resistor

$$\Delta V_o = R_L \times \Delta I_C$$

$$= R_L \times \alpha \times \Delta I_E$$

Under these circumstances, the voltage amplification is,

$$A = \frac{\Delta V_o}{\Delta V_i}$$

will be greater than unity and the transistor acts as an amplifier. If the dynamic resistance of the emitter junction be r_e, then $\Delta V_i = r_e \Delta I_E$

$$A = \frac{R_L \times \alpha \times \Delta I_E}{r_e \cdot \Delta I_E}$$

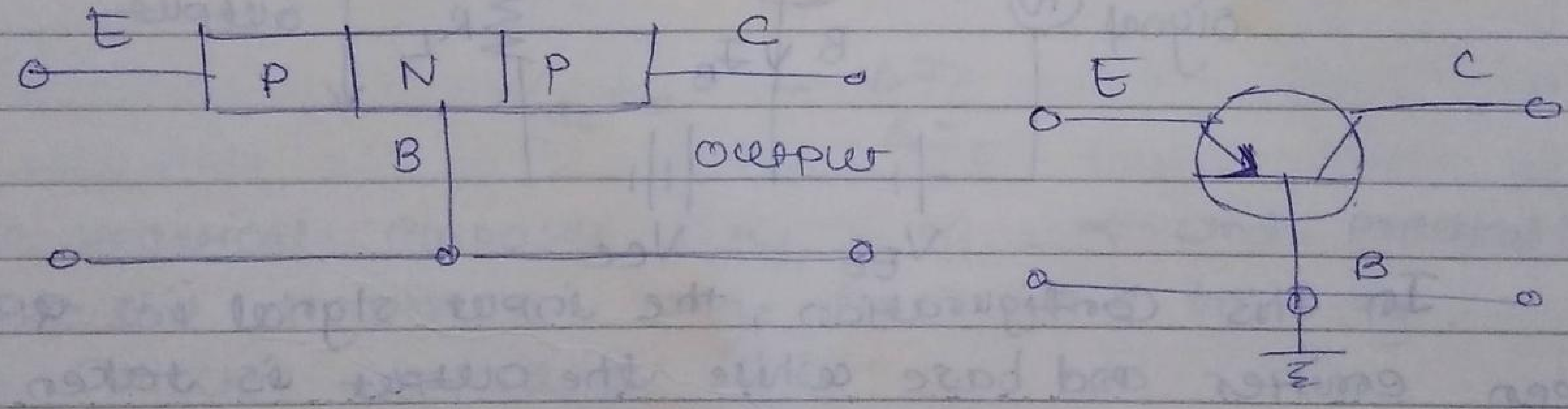
$$= \frac{\alpha R_L}{r_e}$$

Transistor Circuit Configurations

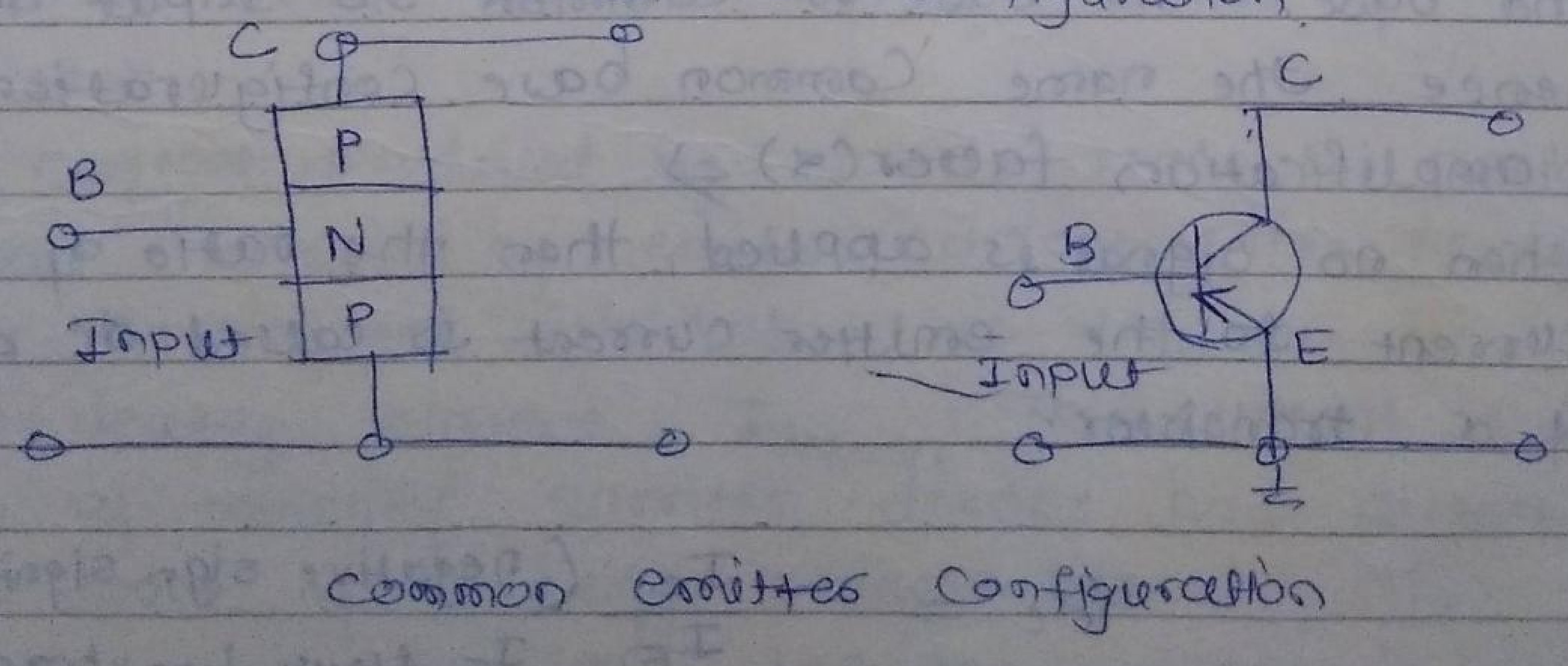
Following are the three types of transistor circuit configuration

1. Common-Base (CB)
2. Common-emitter (CE)
3. Common-Collector (CC)

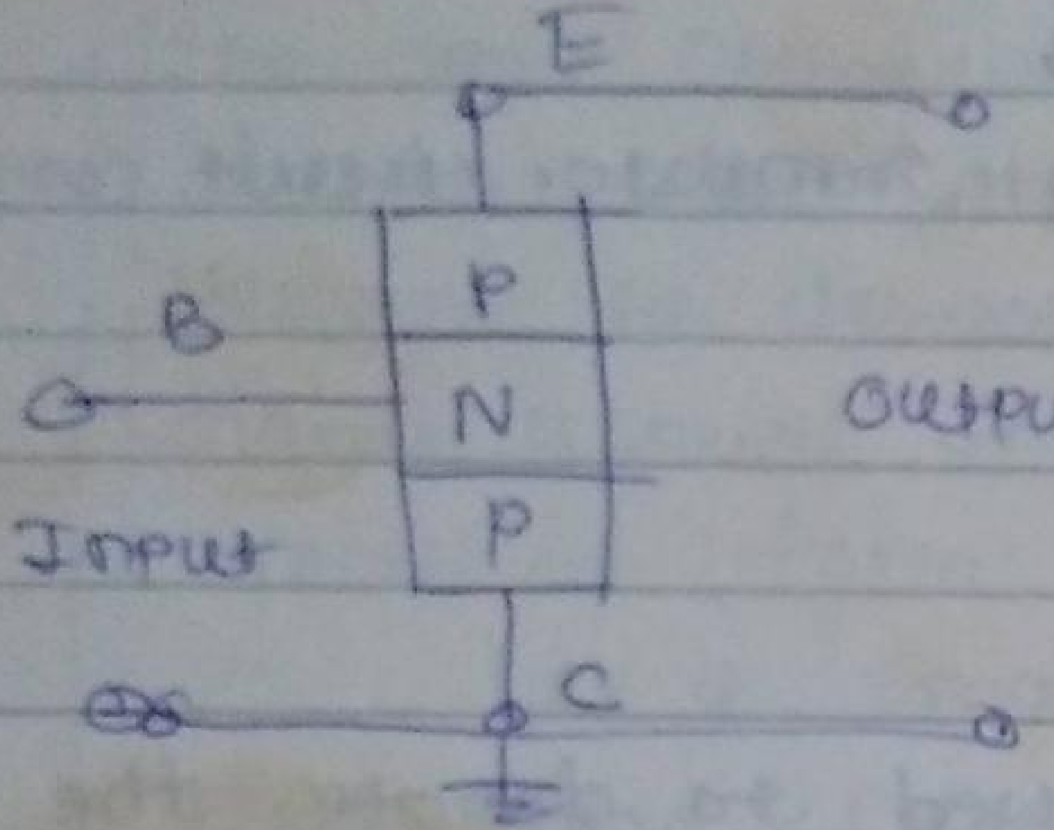
Here the term Common is used to denote the transistor lead which is common to the input and output circuit. This is because when a transistor is connected in a circuit, four terminals are required, while the transistor has three terminals. This difficulty is removed by making one terminal of the transistor 'common' to both input and output terminals. The common terminal is generally grounded.

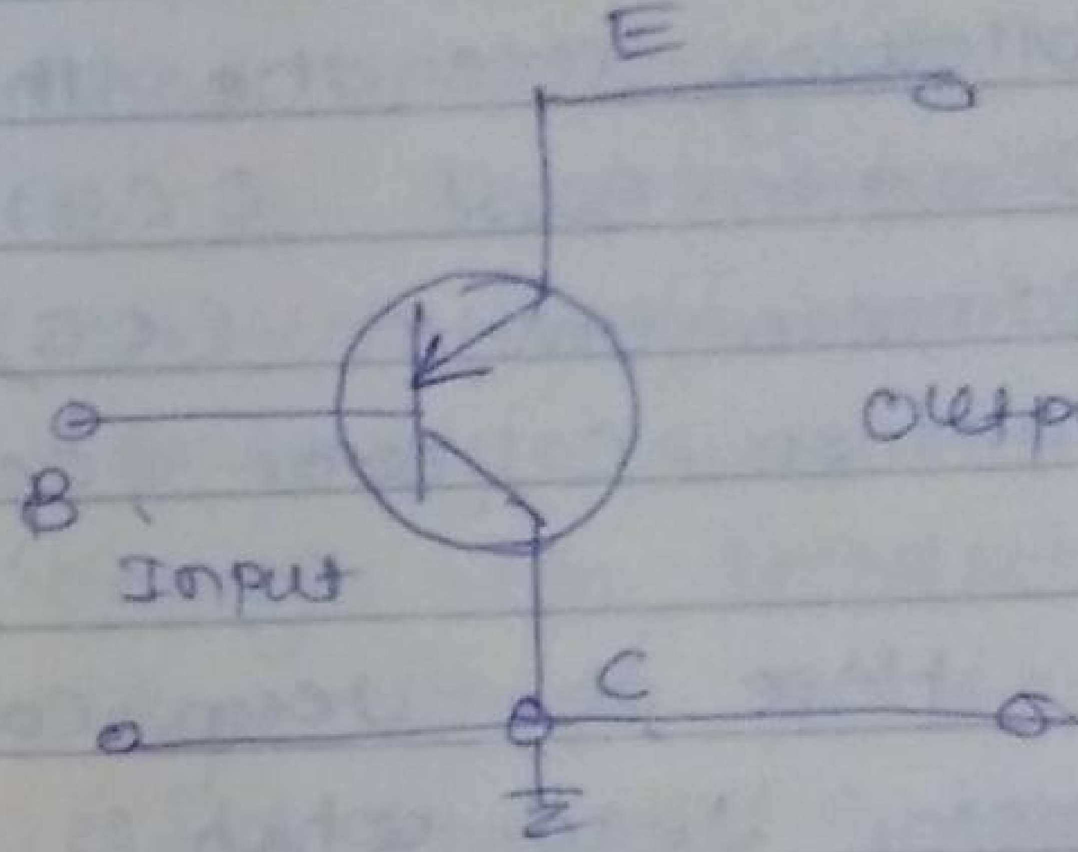


Common base Configuration



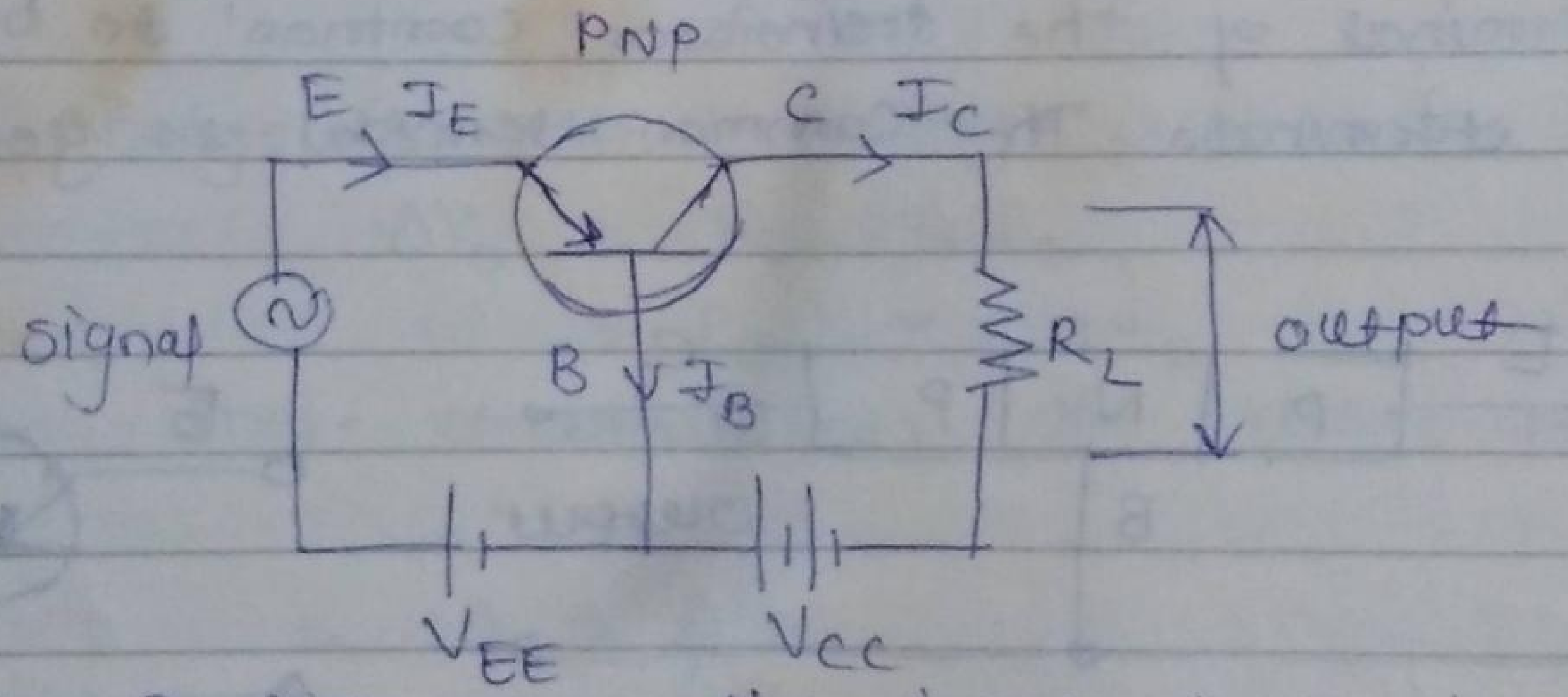
Common emitter Configuration





Common Collector (CC) configuration

Common Base (CB) Configuration



In this configuration, the input signal is applied between emitter and base while the output is taken from collector and base. As base is common to input and output circuits, hence the name Common base configuration.

Current amplification factor(α) $\Rightarrow$

When no signal is applied, then the ratio of the collector current to the emitter current is called dc alpha (α_{dc}) of a transistor.

$$\alpha_{dc} = -\frac{I_C}{I_E}$$ (negative sign signifies that I_E flows into transistor while I_C flows out of it)

If we write α_{dc} simply by α then

$$\alpha = -\frac{I_C}{I_E} \quad \text{--- (1)}$$

α of a transistor is a measure of the quality of a transistor. Higher is the value of α, better is the transistor in the sense that collector current approaches the emitter current.

from eqn (1) considering only magnitudes of the currents

$\therefore \quad I_C = \alpha I_E$ and hence $I_B = I_E - I_C$

$\therefore \quad I_B = I_E - \alpha I_E = I_E(1-\alpha)$

When signal is applied, the ratio of change in collector current to the change in emitter current at constant collector base voltage is defined as current amplification factor.

$$\alpha_{ac} = -\frac{\Delta I_C}{\Delta I_E}$$

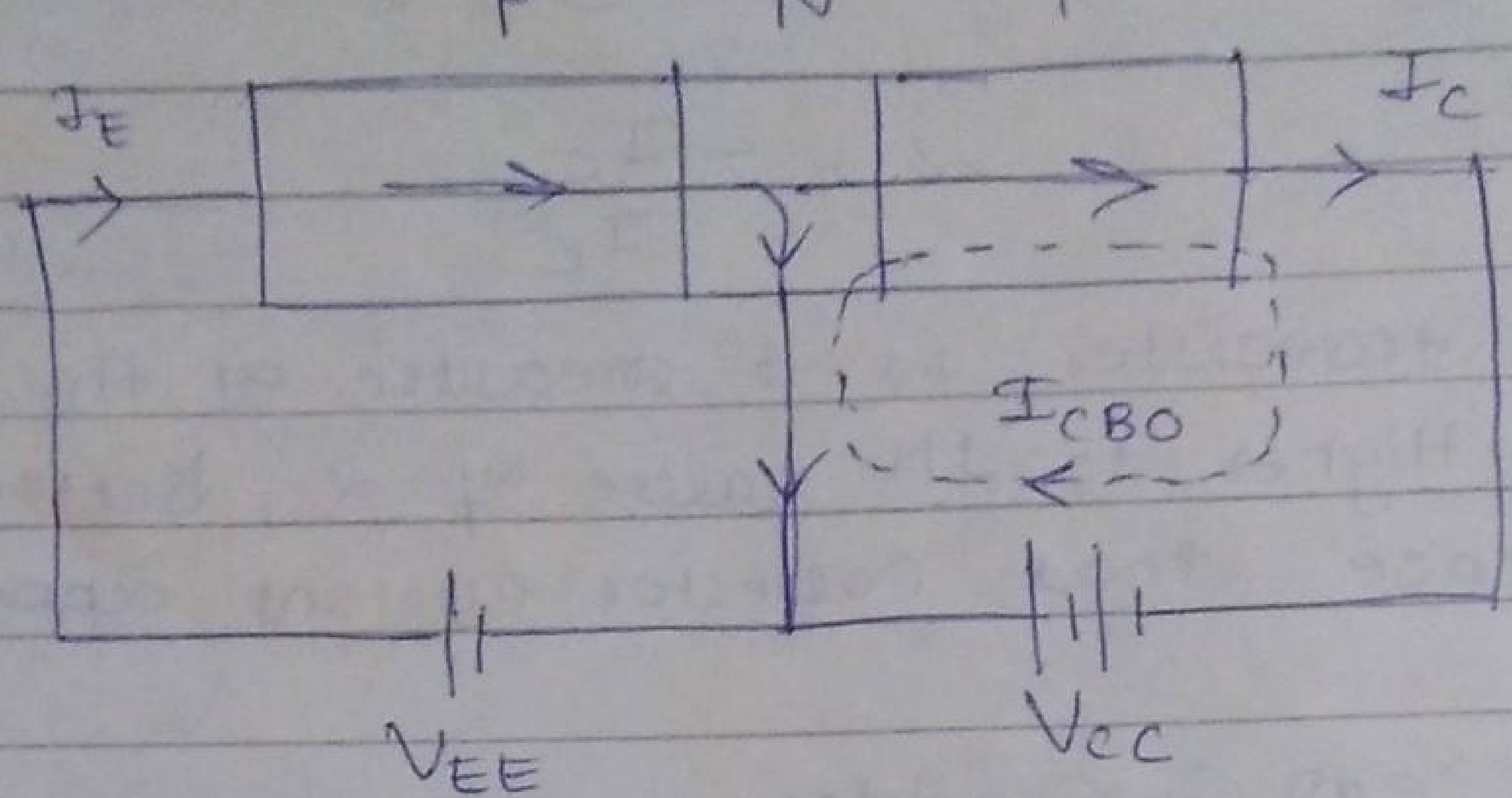
For all practical purposes, $\alpha_{dc} = \alpha_{ac} = \alpha$ and practical values in commercial transistors range from 0.9 to 0.99.

Total Collector current $\Rightarrow$

The total collector current consist of the following two parts $\Rightarrow$

(i) The current produced by normal transistor action i.e. component controlled by emitter current. This is due to the majority carrier and it's value is αI_E.

(ii) The leakage current $I_{leakage}$. This current is due to the motion of minority carriers across base-collector junction on account of it being reverse-biased. This is much smaller than αI_E. The leakage current is abbreviated as I_{CBO} i.e. collector base current with emitter open



showing leakage current

∴ Total collector current

$$I_C = \underset{\text{majority}}{\underbrace{\alpha I_E}} + \underset{\text{minority}}{\underbrace{I_{CBO}}}$$

if $I_E = 0$, even there will be small leakage current in the collector circuit. The current I_{CBO} is usually small and may be neglected in transistor circuit calculations.

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

or $$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

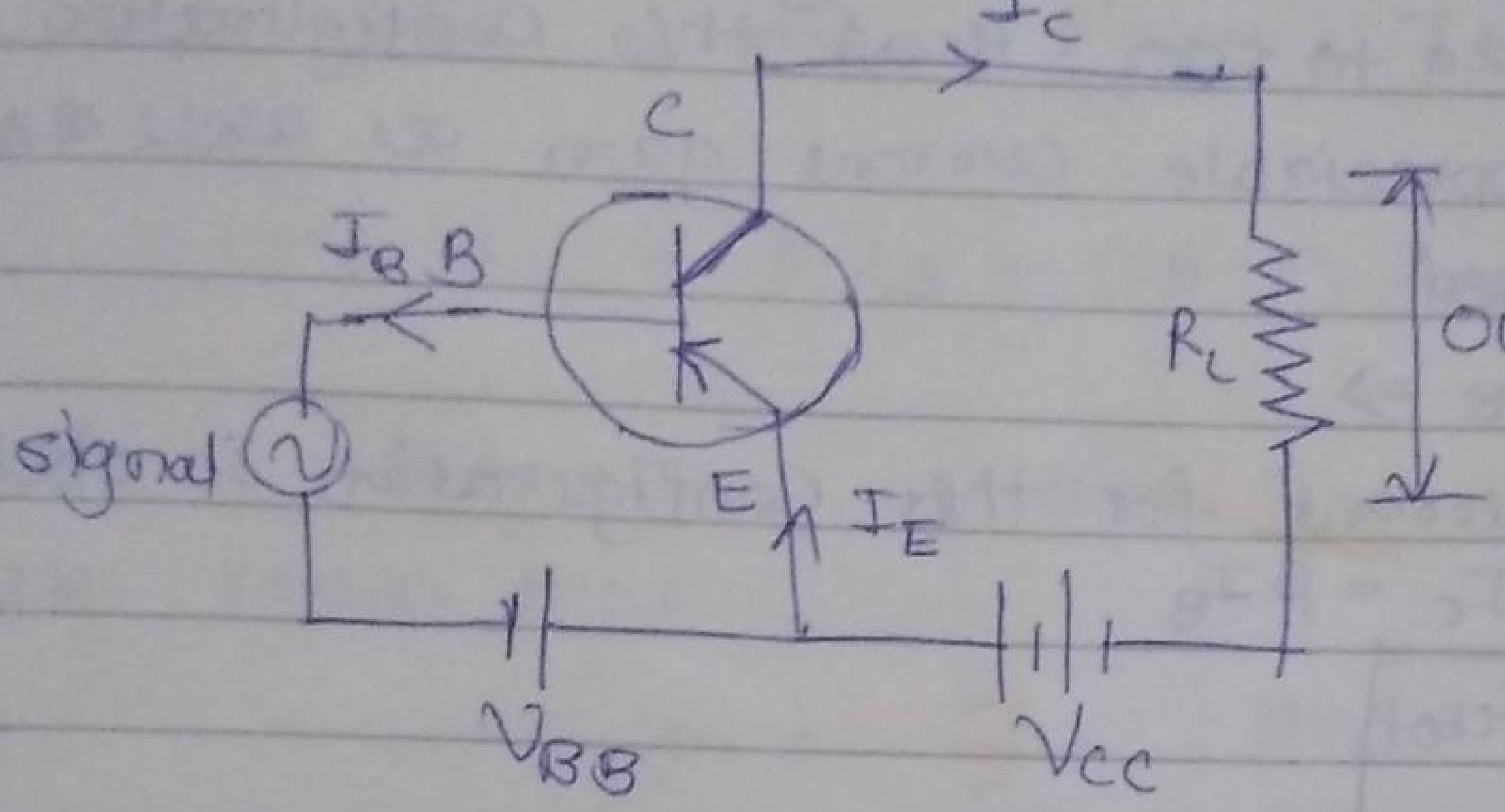
$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

The relation between α and β is given by

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

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

* Common - Emitter Configuration ⇒



In this configuration, the input signal is applied between base and emitter and the output is taken from collector and emitter. As emitter is common to input and output circuits, hence the name common emitter configuration.

Base current amplification factor (β):-

when no signal is applied, then the ratio of collector current to the base current is called dc beta (β_{dc}) of a transistor.

$$(\beta)_{dc} = \beta = \frac{I_C}{I_B} \quad \text{——— (1)}$$

when signal is applied, the ratio of change in collector current to the change in base current is defined as base current amplification factor. Thus

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

$$I_C = \beta I_B$$

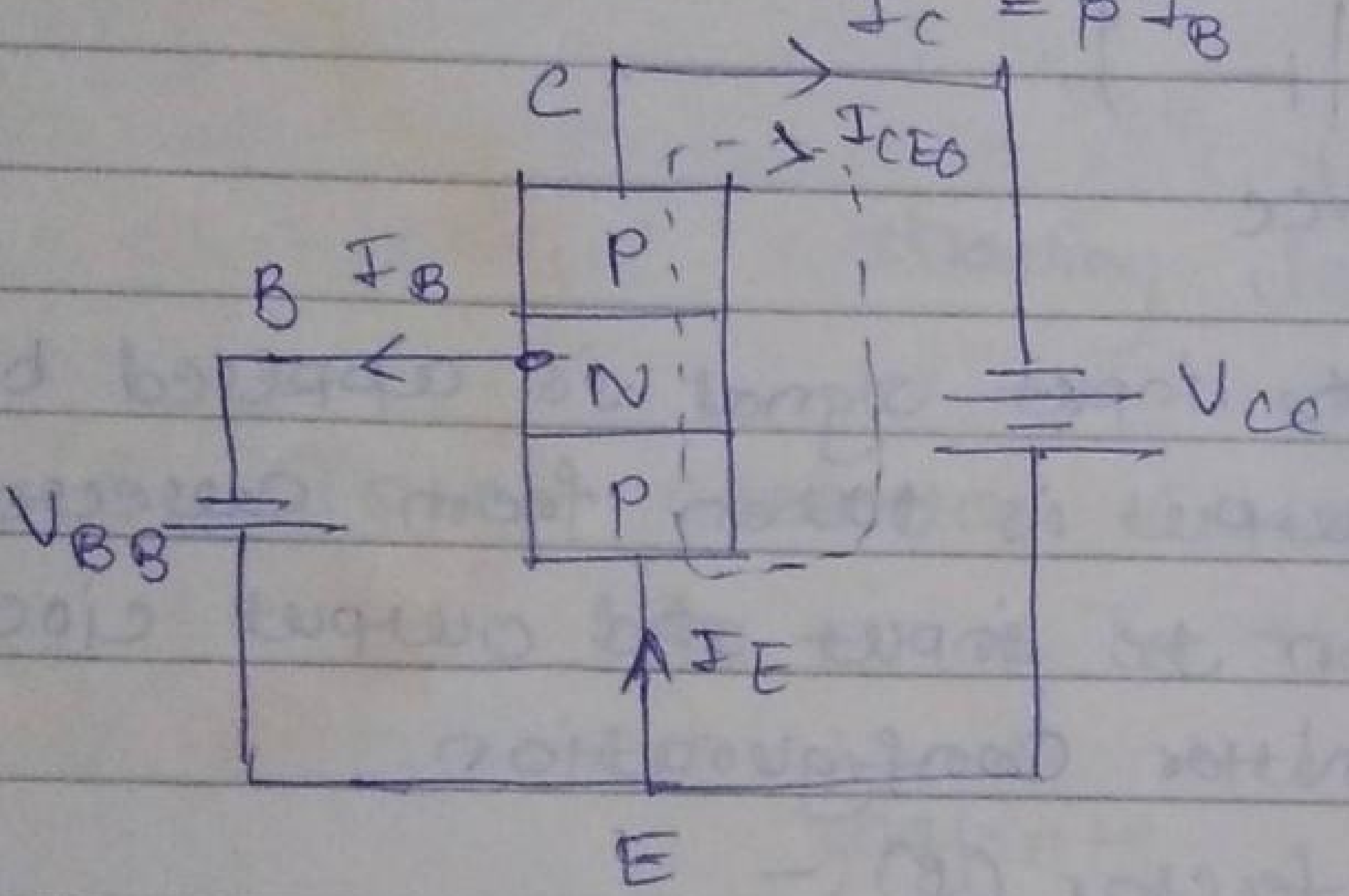
From eqn (1)

$$I_C = \beta I_B$$

Almost in all transistors, the base current is less than 5% of the emitter current. Due to this fact, β is generally greater than 20. Usually β ranges from 20 to 500. Hence this configuration is frequently used when appreciable current gain as well as voltage gain is required.

Total collector current ⇒

The leakage current for this configuration is shown below,



∴ Total collector current

$$I_C = \beta I_B + I_{CEO} \quad \text{--- (3)}$$

where I_{CEO} is the leakage current.

When $I_B = 0$ there is a leakage current from collector to emitter. It is called I_{CEO}, The subscript CEO stands for collector to emitter with base open.

We know that, $I_E = I_B + I_C$

$$\therefore \quad I_C = \alpha I_E + I_{CBO}$$

$$I_C = \alpha(I_B + I_C) + I_{CBO}$$

$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad \text{--- (4)}$$

Comparing eqn (3) & (4) we get,

$$\beta = \frac{\alpha}{1-\alpha} \quad \text{and} \quad I_{CEO} = \frac{1}{1-\alpha} I_{CBO} \quad \text{--- (5)}$$

Substituting the value of I_{CEO} in eqn (5) we get,

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

$$I_C = \beta I_B + (\beta + 1) I_{CBO} \quad \text{———} \quad (6)$$

Relation between α and β

we know that,

$$\alpha = \frac{I_C}{I_E} \quad \text{and} \quad \beta = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C \quad \text{or} \quad I_B = I_E - I_C$$

Now,
$$\beta = \frac{I_C}{I_E - I_C}$$

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

$$\boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{———} \quad (7)$$

Cross-multiplying eqn (7) we get,

$$\beta(1-\alpha) = \alpha$$

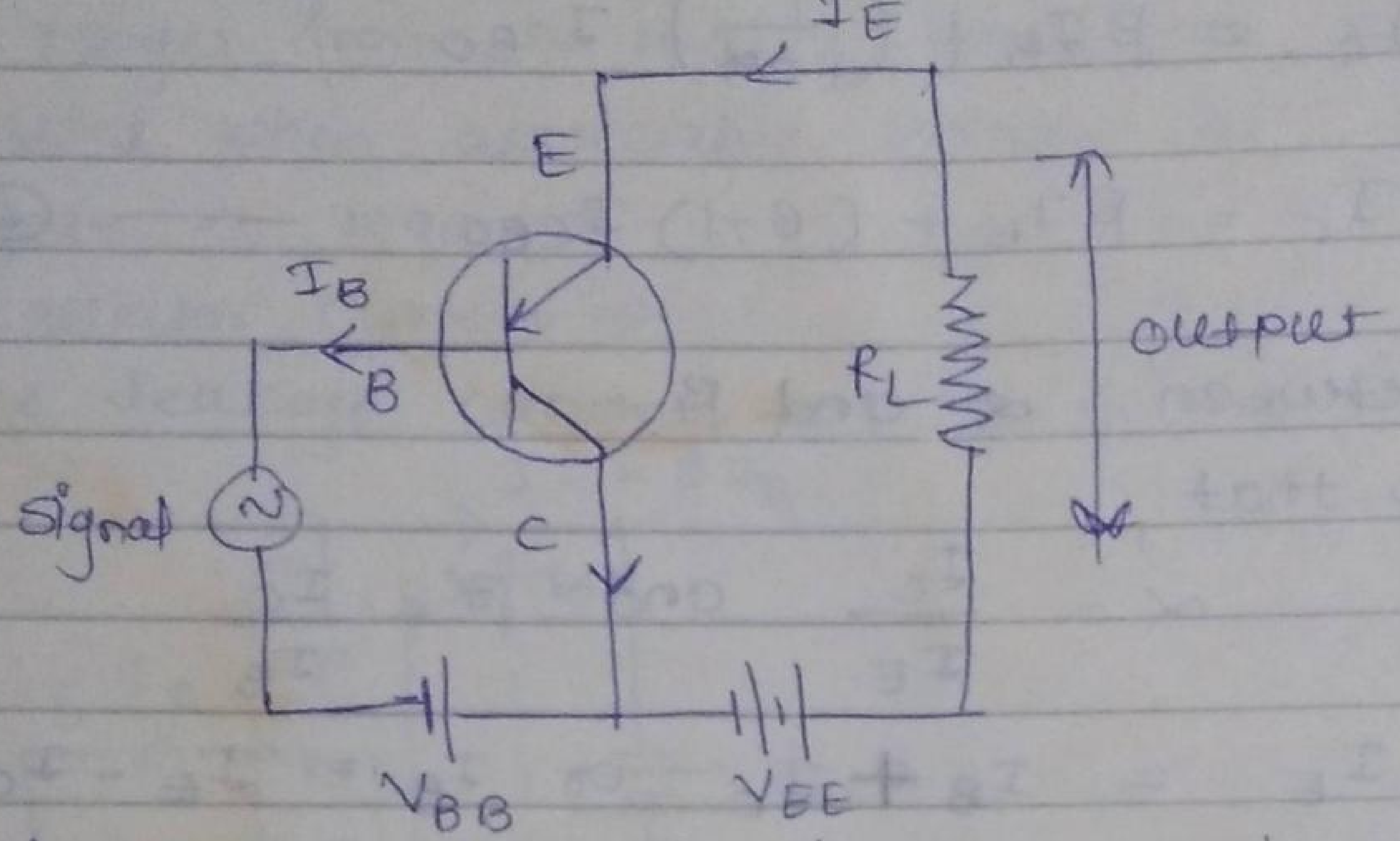
or $$\beta - \beta\alpha = \alpha$$

or $$\beta = \alpha(1+\beta)$$

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

$$\boxed{(1-\alpha) = \frac{1}{1+\beta}}$$

* Common - Collector (CC) configuration ⇒



In this configuration, the input signal is applied between base and collector and the output is taken from the emitter. As collector is common to input and output circuits hence the name common collector configuration.

Current Amplification factor (γ)

When no signal is applied, then the ratio of emitter current to the base current is called as dc gamma (γ_{dc}) of the transistor.

$$(\gamma_{dc}) = \gamma = \frac{I_E}{I_B}$$

When signal is applied, then the ratio of change in emitter current to the change in base current is known as current amplification factor (γ)

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

This configuration provides the same current gain as common emitter circuit as $\Delta I_E \simeq \Delta I_C$ but the voltage gain is always less than one.

Total emitter current ⇒

We know that $I_E = I_B + I_C$

Also, $I_C = \alpha I_E + I_{CBO}$

$\therefore$ $I_E = I_B + (\alpha I_E + I_{CBO})$

$= I_B + \alpha I_E + I_{CBO}$

$I_E(1-\alpha) = I_B + I_{CBO}$

$$I_E = \frac{I_B}{(1-\alpha)} + \frac{I_{CBO}}{(1-\alpha)}$$

or $I_E = (1+\beta) I_B + (1+\beta) I_{CBO}$

$$\because \frac{1}{(1-\alpha)} = (1+\beta)$$

Relation between γ and α

We know that $\gamma = \frac{I_E}{I_B}$ and $\alpha = \frac{I_C}{I_E}$

Also $I_B = I_E - I_C$

Now, $\gamma = \frac{I_E}{I_E - I_C}$

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

$$\gamma = \frac{1}{1-\alpha}$$

Relation betn γ and β

$$(1-\alpha) = \frac{1}{1+\beta}$$

$$\boxed{\gamma = \left(\frac{1}{1-\alpha}\right) = (1+\beta)}$$

Comparison of different characteristic in different Configuration

Characteristic	Common base	Common emitter	Common collector
Input resistance	low (about 100 Ω)	low (about 700 Ω)	very high
Output resistance	very high (about 400 kΩ)	high (about 50 kΩ)	low (about 50 Ω)
Voltage gain	about 150	about 500	less than 1
Applications	At high frequencies	At audio frequencies	impedance matching

Characteristics of Common Base circuit

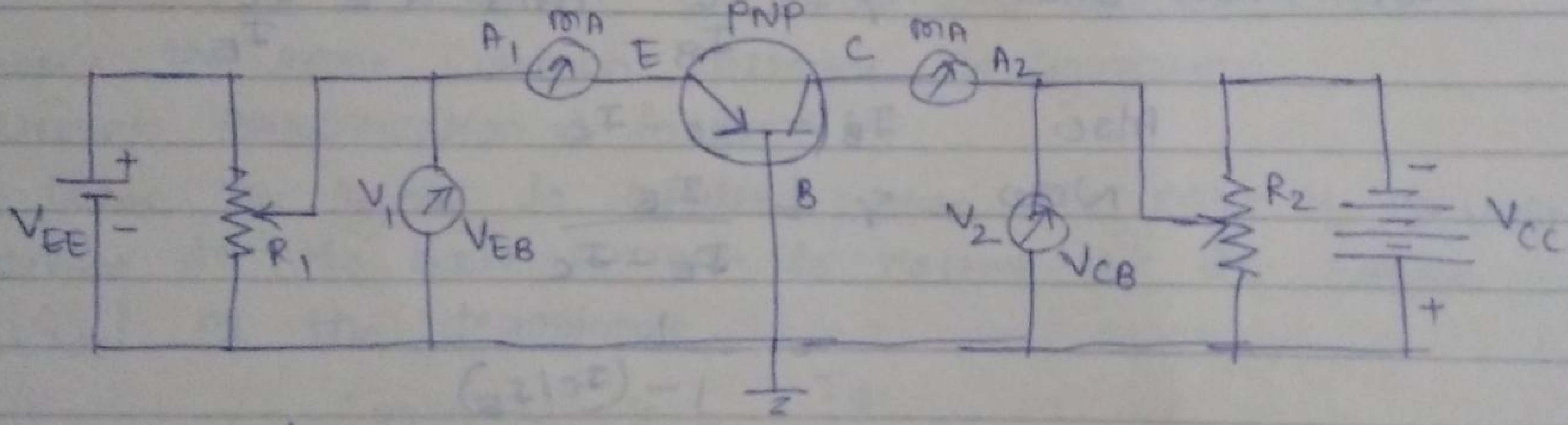
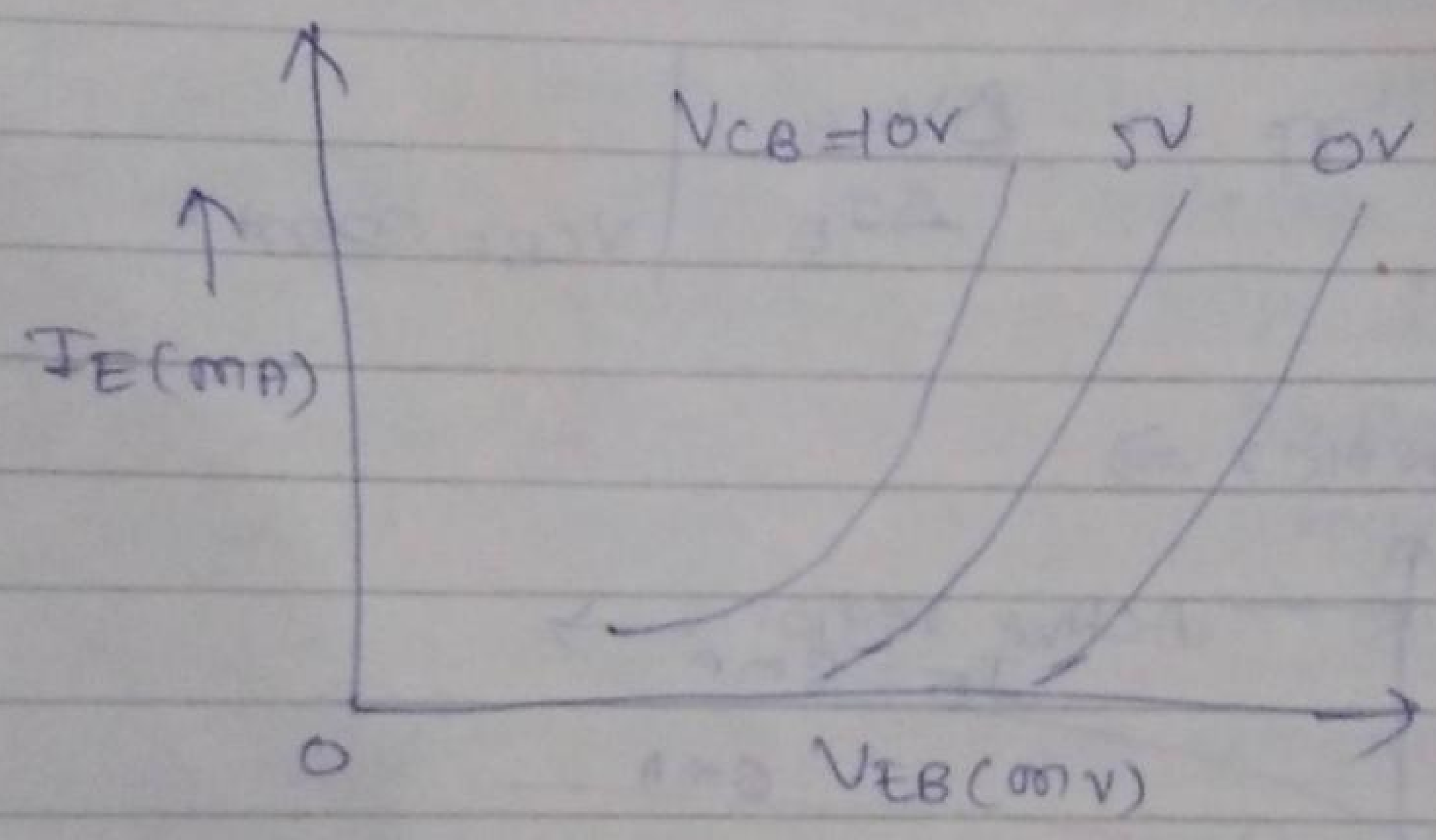


fig:- PNP transistor Connected in CB Configuration

The battery V_{EE} supplies forward bias to the emitter base junction through potential divider arrangement R_1. similarly the battery V_{CC} supplies reverse bias to the collector base junction through potential divider arrangement R_2.

In the circuit milliammeters are connected in series with emitter and collector to measure emitter current I_E and collector current I_C resp. similarly voltmeters are connected in parallel across E & B to measure the voltage V_{EB} and across C and B to measure the Voltage VCB resp. Here the quantities emitter to base voltage VEB and ~~collector~~ emitter current I_E correspond to input circuit. and collector to base voltage VCB and collector current I_C to the output circuit. The complete electrical behaviour of a transistor can be described by stating the relationship between different dc currents and voltages. These relationship can be displayed graphically and the curves thus obtained are known as characteristics of a transistor.

Input characteristics:-



Input characteristics.

The curve betn emitter current I_E and emitter base voltage VEB at constant collector base voltage VCB represents the input characteristics. For plotting the input characteristic, the collector base voltage VCB is kept fixed the emitter base voltage VEB is varied with the help of potential divider R_1 and emitter current is noted for each value of VEB. A graph of I_E against VEB is drawn. The curve is known as input characteristics. The experiment is repeated for other fixed values of VCB.

we noted from the characteristics that,

(i) There exists a cut in, offset or threshold voltage V_{EB} below which the emitter current is very small.

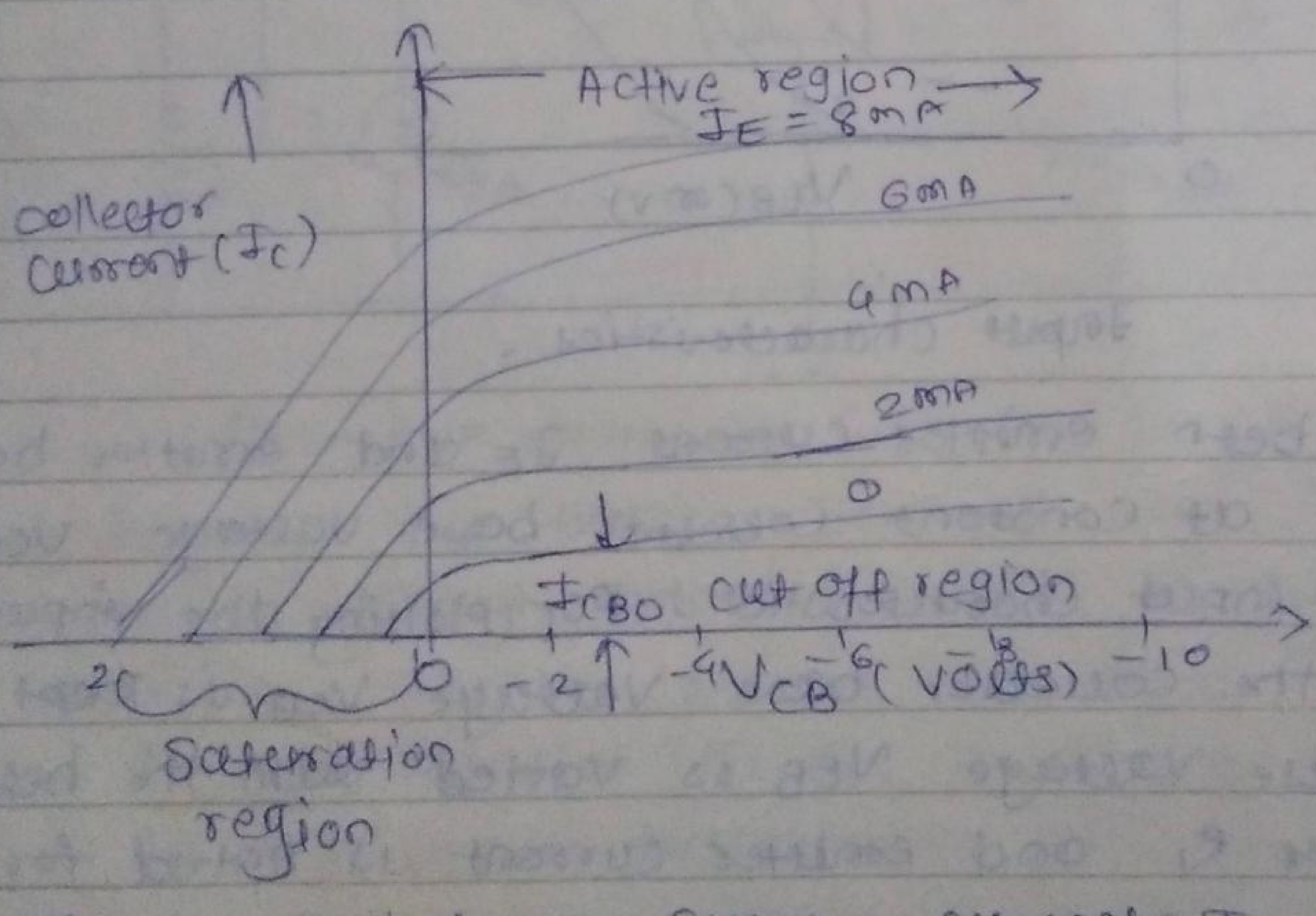
(ii) The emitter current I_E increases rapidly with small increase in emitter base voltage V_{EB}. This shows that the input resistance is very small.

Input resistance :-

The ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector base voltage (V_{CB}) is defined as input resistance

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

Output characteristics ⇒



The curve between collector current I_C and collector base voltage V_{CB} at constant emitter current I_E represents the output characteristics.

For plotting output characteristic, the emitter current I_E is kept fixed. With the help of potential divider R_2, the value of V_{CB} is varied in steps and the collector current I_C is noted for each value of V_{CB}. Now a graph is drawn between I_C and V_{CB}. The curve so obtained is known as output characteristic. The experiment is repeated for different values of emitter current I_E.

(i) In active region ⇒ The collector current is essentially independent of collector voltage and depends only upon the emitter current. Because α is less than, but almost equal to unity, the magnitude of collector current is slightly less than that of emitter current.

(ii) In the saturation region the collector current I_C flows even when $V_{CB} = 0$. Actually in PNP transistor, V_{CB} is slightly positive in this region & because of this forward biasing, there results large change in collector current with a small change in collector ~~current~~ voltage.

(iii) Cut off region ⇒ a small amount of collector current flows even when emitter current $I_E = 0$. This is the collector leakage current I_{CBO}

Output resistance :- The ratio of change in collector base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current (I_E) is defined as output voltage.

$$r_0 = \frac{\Delta V_{CB}}{\Delta I_C}\Bigg|_{I_E = \text{constant}}$$

Characteristics of Common Emitter Circuit :-

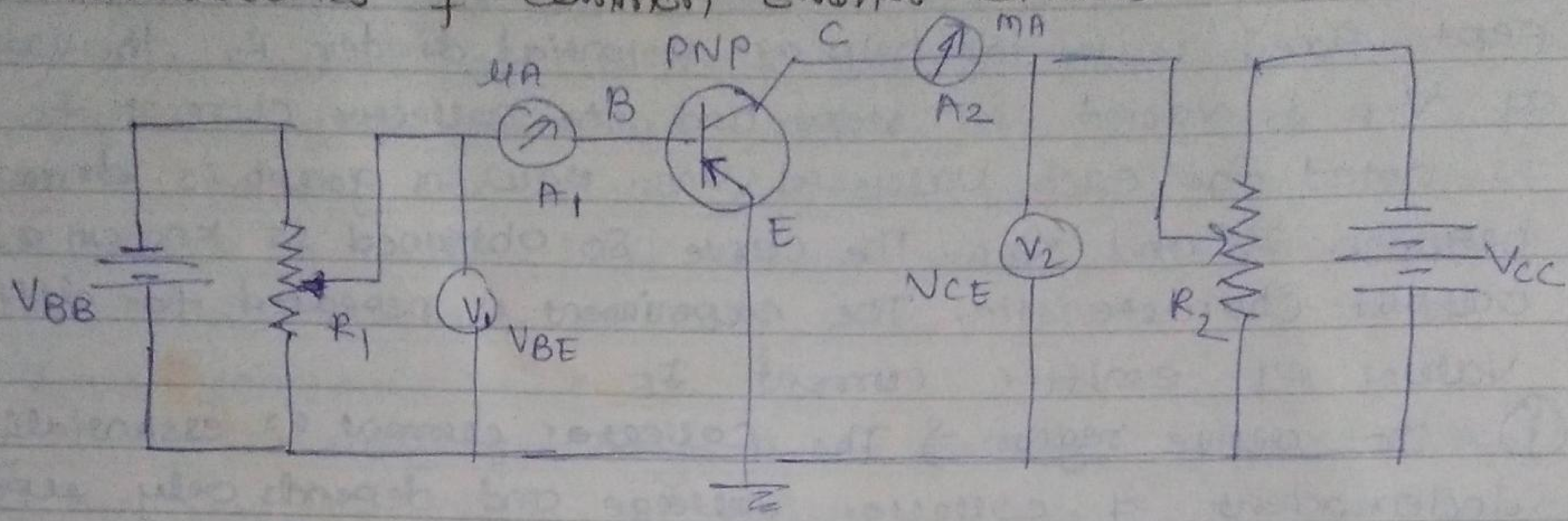
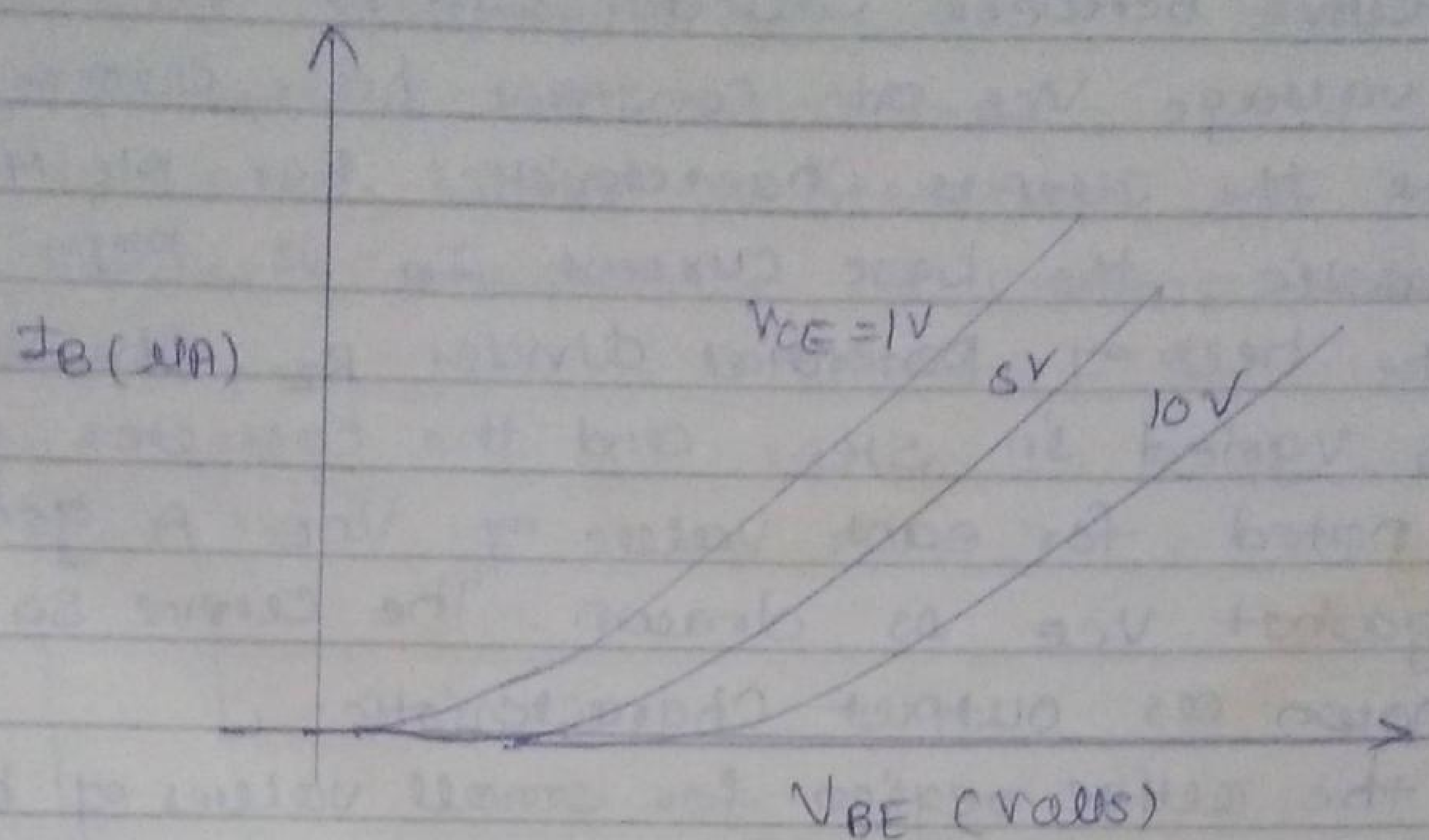


fig:- PNP transistor connected in Common emitter configuration

In the circuit the battery V_{BB} provides forward bias to emitter-base junction with the help of potential divider R_1. The Voltmeter V_1 measures the base-emitter voltage V_{BE}. The micro-ammeter A_1 measures the base current I_B. A battery V_{CC} is connected between collector and emitter through a potential divider R_2. The positive terminal of the battery is connected to emitter while the negative terminal is connected to the collector so that the collector is reverse-biased. The voltmeter V_2 measures the collector-emitter voltage V_{CE} and the milli-ammeter A_2 measures the collector current.

Input characteristics :→ The curve between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE} represents the input characteristics. For plotting the input characteristic, the collector-emitter voltage V_{CE} is kept fixed. The base emitter voltage V_{BE} is varied with the help of potential divider R_1 and base current I_B is noted for each value of V_{BE}. A graph of I_B against V_{BE} is drawn. The curve is so obtained is known as input characteristic.



Input characteristics

(i) The characteristic resembles that of a forward-biased diode curve. This is expected because the base-emitter section of transistor is a diode & it is forward biased.

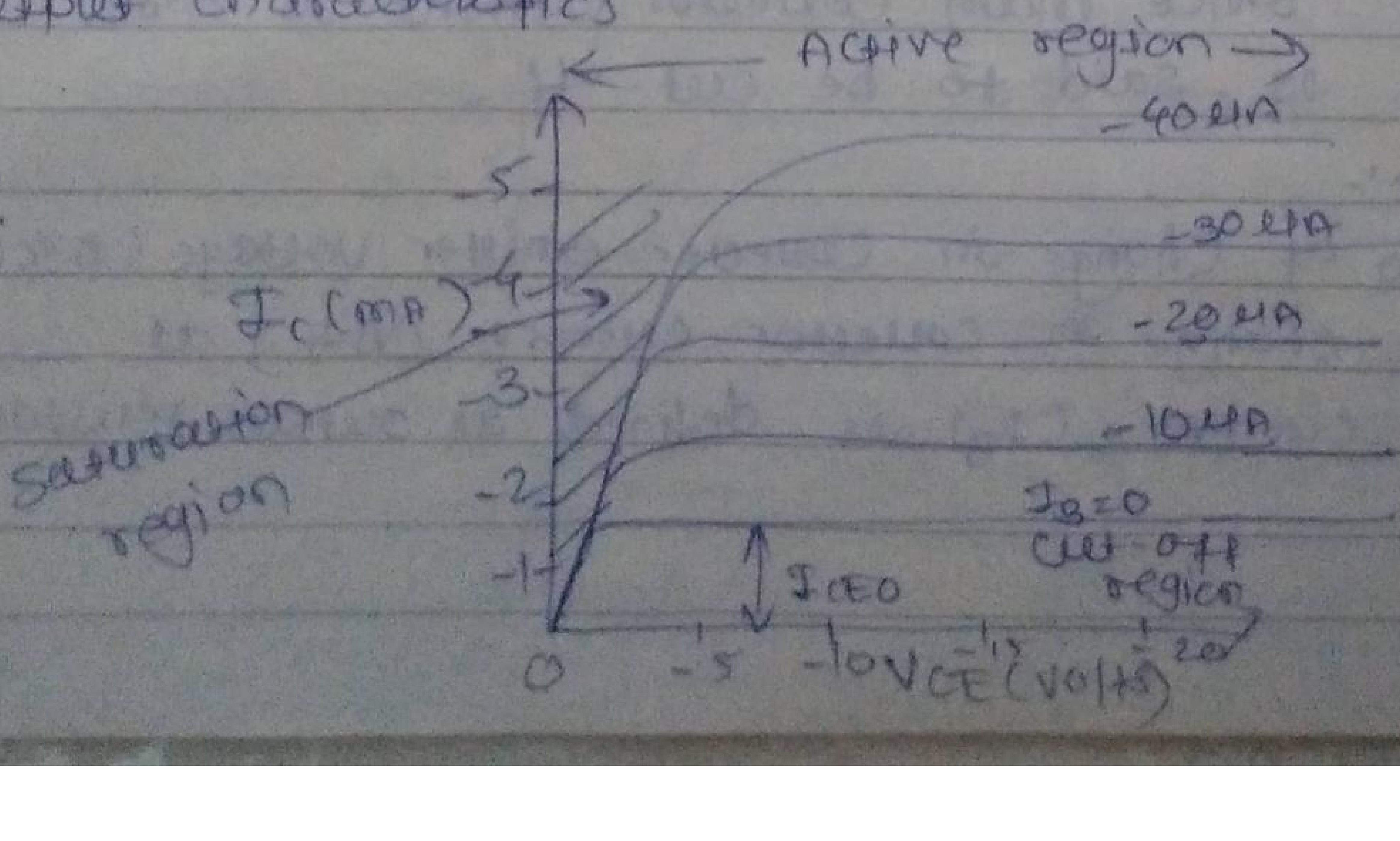
(ii) In this case, I_B increases less rapidly with V_{BE} as compared to common base configuration.

Input resistance :-

The ratio of change in base emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage (V_{CE}) is defined as input resistance

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

Output characteristics



The curve between collector current I_C and collector emitter voltage V_{CE} at constant base current I_B represents the output characteristics. For plotting output characteristic, the base current I_B is kept fixed. with the help of potential divider R_2, the value of V_{CE} is varied in steps and the collector current I_C is noted for each value of V_{CE}. A graph of I_C against V_{CE} is drawn. The curve so obtained is known as output characteristic.

(i) In the active region for small values of base current, the effect of collector voltage over collector current is small while for large base current values this effect increases. In this the collector is greater than base current. Thus the current gain of this configuration is greater than unity.

(ii) When V_{CE} has very low value, the transistor is said to be saturated and and it operates in saturation region of characteristic. In saturated region change in base current I_B does not produce a corresponding change in collector current I_C.

(iii) In the cut-off region a small amount of collector current flows even when base current $I_B = 0$. This is called I_{CEO}. Since main collector current is zero, the transistor is said to be cut-off.

output resistance:-

The ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current (I_B) is defined as output resistance.

Common-collector characteristics

Common collector Input characteristics

The common-collector input characteristics are quite different from either common-base or common-emitter input characteristics.

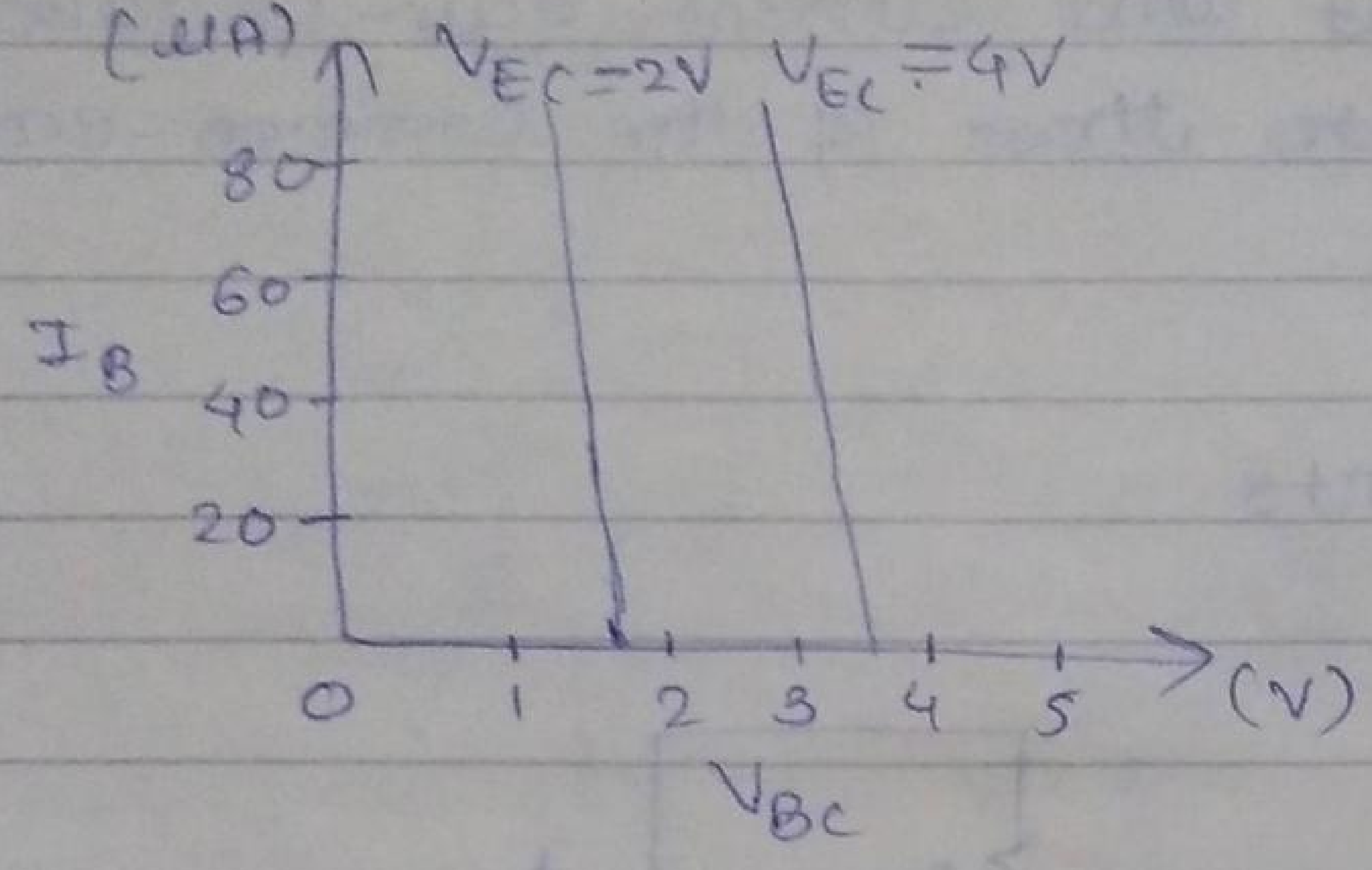


fig:- CC input characteristics

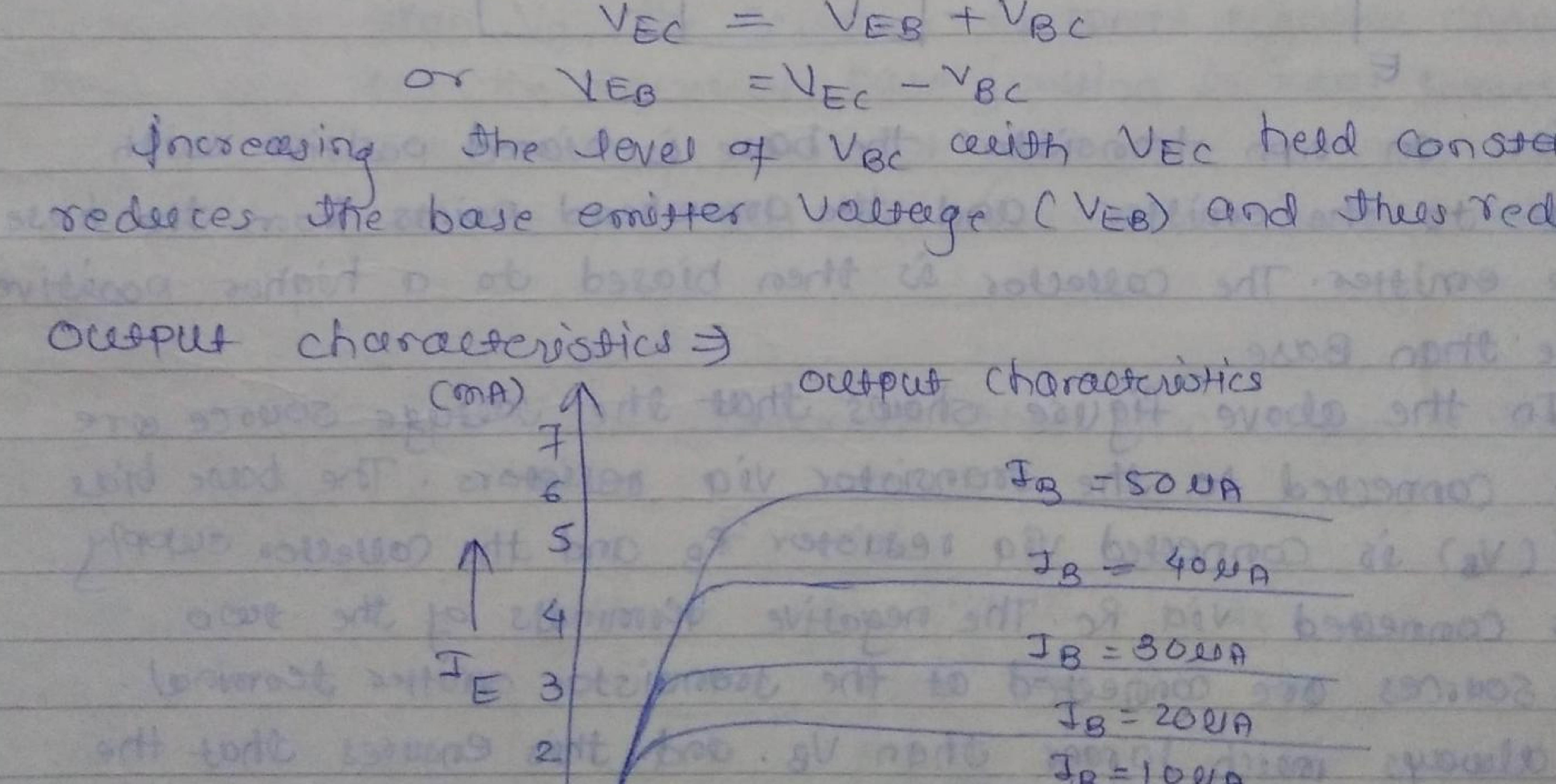
The difference is due to the fact that the input voltage (V_{BC}) is largely determined by the output voltage (V_{EC})

$$V_{EC} = V_{EB} + V_{BC}$$

$$\text{or} \quad V_{EB} = V_{EC} - V_{BC}$$

increasing the level of V_{BC} with V_{EC} held constant reduces the base emitter voltage (V_{EB}) and thus reduces I

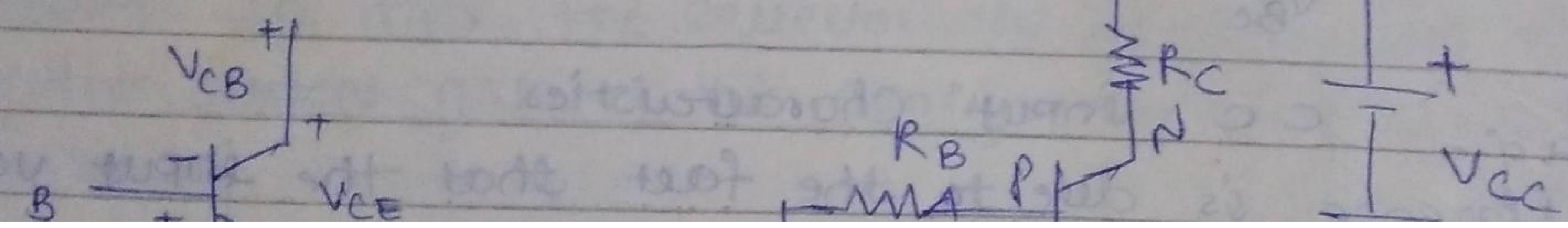
Output characteristics ⇒



The output characteristics are a plot of the emitter current (I_E) versus the emitter-collector voltage (V_{EC}) for several constant levels of base current (I_B). The current gain characteristics are I_E plotted versus I_B at constant V_{EC} voltage. Because I_C approximately equals I_E, the common collector output and current gain characteristics are practically identical to those of the common-emitter circuit.

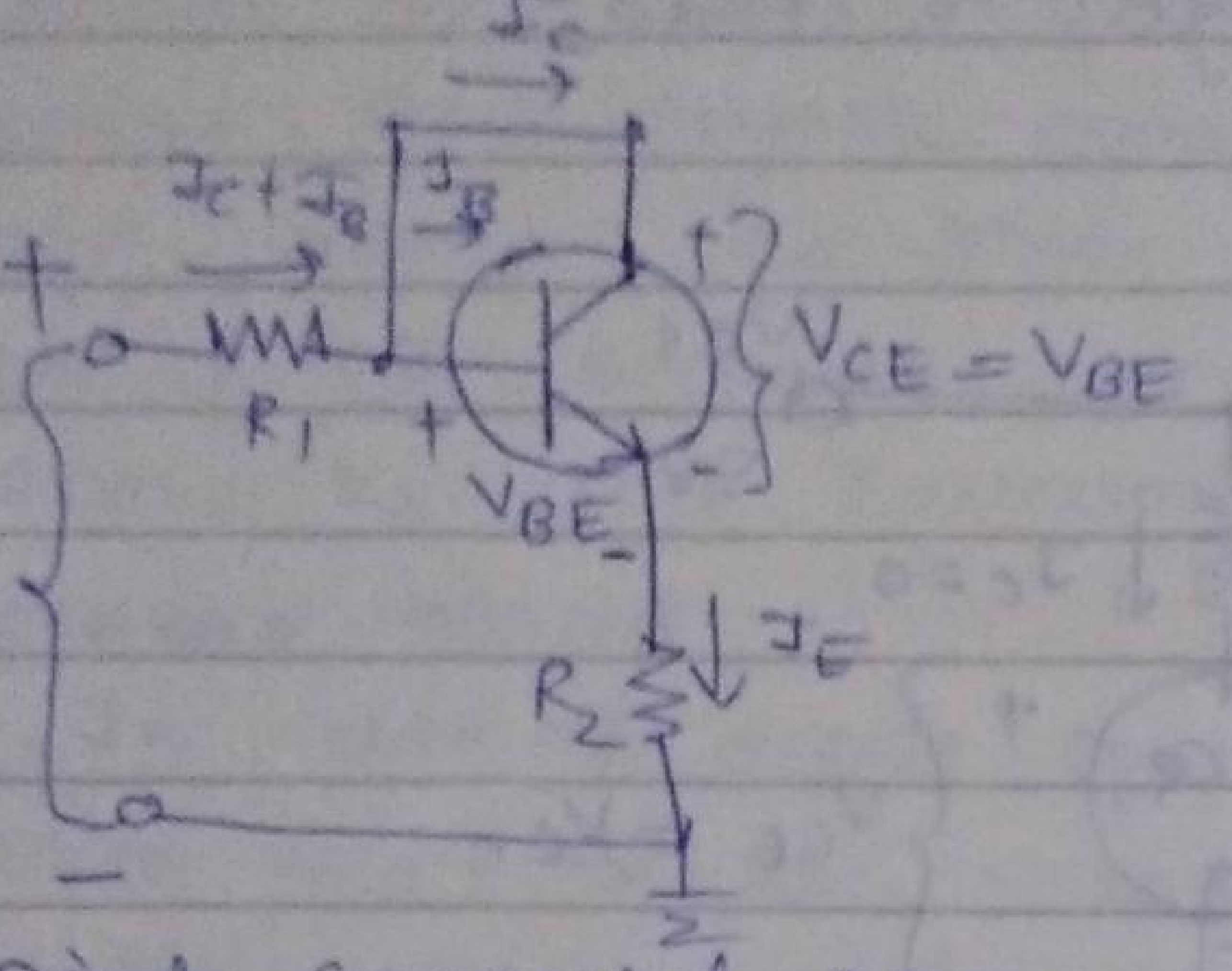
BJT Voltages and Currents

Transistor Voltages ⇒

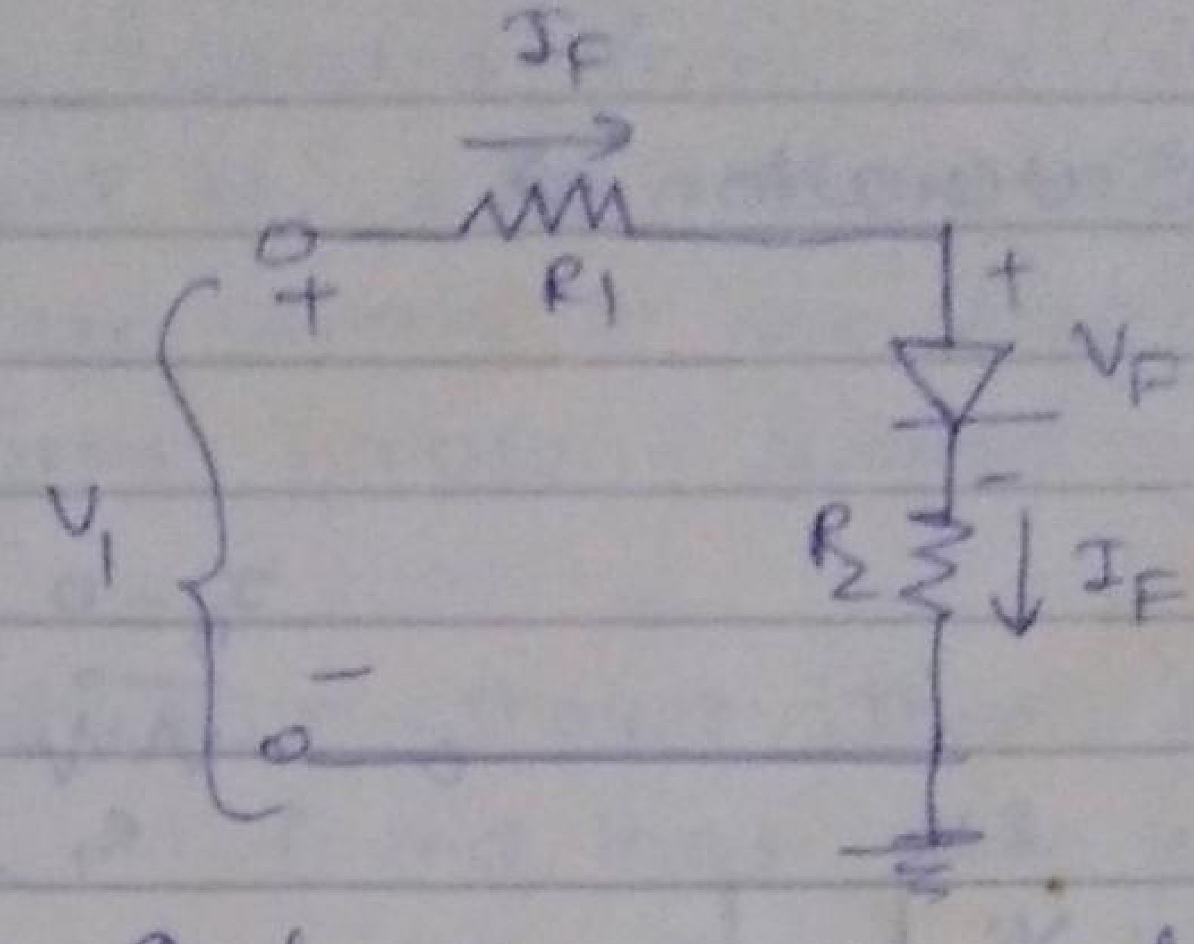


BJT Switching ⇒

Diode - Connected BJT



Diode Connected BJT



Q functions as a diode.

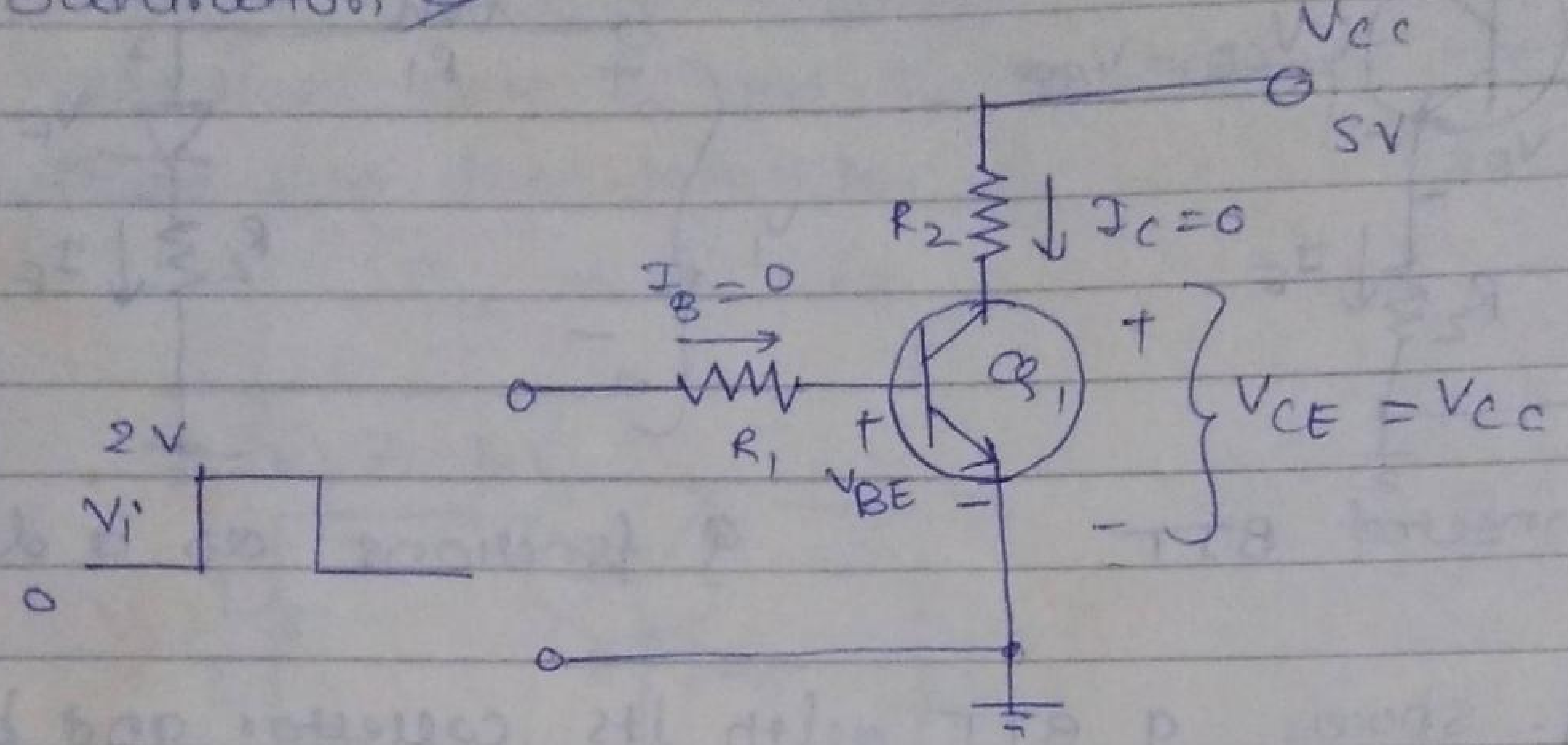
above fig. shows a BJT with its collector and base terminals connected together. This is referred as diode connected.

The total current into the base collector terminal is (I_C+I_B) which equals I_E flowing out of Q_1. The total voltage drop across the BJT is the normal base-emitter voltage (V_{BE}) which is typically 0.7V for a silicon device, so the device behaves exactly like a diode.

The charge carriers flow across the forward-biased base emitter junction. But since the collector base junction has a zero voltage external bias, how do charge carriers cross it to constitute a collector current? The barrier voltage is exist at an unbiased pn junction and that its polarity is Positive (+) on n side and negative (-) on p-side. The barrier voltage is the result of charge carriers crossing the junction to create the depletion region and it exists even when the collector and base terminals are connected together. Due to the barrier voltage polarity (+ on n, - on p) pulls minority charge carriers from the base into collector

So a collector current will flow when the ~~cutto~~ collector and base terminals are connected together. i.e. when the collector base voltage is zero.

BJT Saturation ⇒



BJT Connected as a switch.

A BJT may be used as a switch as well as for amplification. Fig 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 is also zero and hence I_C is zero and V_{CE} equals V_{CC}.

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

$$\text{with } I_C = 0, \quad V_{CE} = V_{CC}$$

When V_i is at positive level, a base current flows. In the 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 V_{CC}. with $I_C R_2 \cong V_{CC}$

$$V_{CE} \cong V_{CC} - I_C R_2$$

$$\cong 0$$

If V_{CE} went down to exactly zero volts, the collector base junction would become forward biased by 0.7V. Collector base barrier voltage would be overcome and charge carriers from emitter would be repelled from the collector base junction. So there would be zero collector current. But if I_C becomes zero, there would be no voltage drop across R_2 and collector-emitter junction would not be forward biased.

In case of diode connected BJT shows that I_C flows when V_{CB} equals zero. It is found that even when the collector base junction becomes partially forward biased, the barrier voltage is not completely overcome and I_C continues to flow. A silicon npn transistor typically passes substantial collector current when $V_{BC} \cong +0.5V$ which gives $V_{CE} \cong 0.2$ V. In this situation the collector emitter voltage is termed the saturation voltage ($V_{CE(sat)}$) and $V_{CE(sat)}$ is the minimum level of collector emitter voltage that exists when the voltage drop across the collector resistor R_2 tends to drive V_{CE} toward zero.