

## 1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics-04 (Physics Part 2, Class XII)
Module Name/Title	Unit-09, Module-09: Common emitter Transistor amplifier Chapter-14: Semiconductor Electronics: Materials, Devices and Simple Circuits
Module Id	leph_201409_eContent
Pre-requisites	Semiconductors, semiconductor diode, p-n junction diode characteristics, transistor characteristics, n-p-n common emitter characteristics, input and output resistances.
Objectives	<p>After going through this module, the learner will be able to :</p> <ul style="list-style-type: none"> <li>• <b>Understand</b> the working of the Transistor as an amplifier</li> <li>• <b>Draw</b> the relevant circuit diagram and understand the need for proper biasing for voltage gain</li> <li>• <b>Differentiate</b> between input signal and output signal waveforms</li> <li>• <b>Learn about and explain</b> the phase change of the output signal</li> </ul>
Keywords	transistor amplifier, phase change between the output and the input signal, input and output waveforms

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**1. UNIT SYLLABUS****Unit-09: Electronic Devices****Chapter-14: Semiconductor electronic material, devices and simple circuits.**

Energy bands in conductors, semiconductors and insulators (qualitative only)  
semiconductors intrinsic and extrinsic

Semiconductor diode -IV characteristics in forward and reverse bias, application of diode as a rectifier

Special purpose p-n diodes LED, photodiode, solar cell and Zener diode and their characteristics, Zener diode as a voltage regulator

Junction transistor, transistor action, characteristics of a transistor and transistor as amplifier common emitter configuration

Basic idea of Analog and Digital signal, logic gates OR, AND, NOR, NOT, NAND

**Keeping the needs of state boards in mind we have not changed the content**

**2. MODULE WISE DISTRIBUTION OF UNIT SYLLABUS 10 MODULES**

<b>Module 1</b>	<ul style="list-style-type: none"> <li>• Energy bands in solids</li> <li>• Forbidden gap</li> <li>• Fermi level</li> <li>• Energy bands in conductors, semiconductors and insulators</li> </ul>
<b>Module 2</b>	<ul style="list-style-type: none"> <li>• Uniqueness of semiconductors</li> <li>• Charge carriers in semiconductors electrons and</li> </ul>

	<p>holes</p> <ul style="list-style-type: none"> <li>• Intrinsic semiconductors</li> <li>• Extrinsic semiconductors p and n type</li> <li>• Why are p and n type semiconductors neutral?</li> </ul>
Module 3	<ul style="list-style-type: none"> <li>• p-n junction diode</li> <li>• Potential barrier</li> <li>• Depletion layer</li> <li>• Characteristics of p-n junction diode</li> <li>• Forward and reverse bias, knee voltage, magnitude of bias voltages</li> <li>• To draw the IV characteristics curve for a p-n junction in forward bias and reverse bias</li> </ul>
Module 4	<ul style="list-style-type: none"> <li>• Application of diode</li> <li>• Rectifier meaning and need of such a device</li> <li>• half wave and full wave rectifier</li> <li>• rectifier in our homes</li> <li>• Special purpose diode</li> <li>LED</li> <li>Photodiode</li> <li>Solar cells</li> <li>• Solar panels and future of energy</li> </ul>
Module 5	<ul style="list-style-type: none"> <li>• To identify a diode, an LED, a resistor and a capacitor</li> <li>• use a multimeter to <ul style="list-style-type: none"> <li>i. <i>see the unidirectional flow of current in case of a diode and an LED</i></li> <li>ii. <i>check whether a given diode is in working order</i></li> </ul> </li> </ul>
Module 6	<ul style="list-style-type: none"> <li>• Zener diode</li> <li>• Characteristics of Zener diode</li> <li>• To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage</li> <li>• How is Zener diode different from other diodes?</li> <li>• Zener diode as a voltage regulator</li> <li>• Working of a Zener diode</li> <li>• Zener diodes in our homes</li> </ul>
Module 7	<ul style="list-style-type: none"> <li>• Junction transistor</li> <li>• Design of the transistor</li> <li>• n-p-n and p-n-p</li> <li>• Use a multimeter to <ul style="list-style-type: none"> <li>i. <i>identify base of transistor</i></li> </ul> </li> </ul>

	<p>ii. <i>distinguish between n-p-n and p-n-p type transistor</i></p> <p>iii. <i>check whether a given electronic component (e.g. diode , transistor, or IC) is in working order</i></p> <ul style="list-style-type: none"> <li>• Transistor action</li> <li>• Characteristics of a transistor, n-p-n common emitter</li> </ul>
Module 8	<ul style="list-style-type: none"> <li>• Understanding transistor characteristics and its applications</li> <li>• To study the characteristic of a common emitter n-p-n, p-n-p transistor and to find the values of current and voltage gains.</li> <li>• Transistor as switch</li> <li>• Transistor as amplifier</li> </ul>
Module 9	<ul style="list-style-type: none"> <li>• Transistor as an amplifier</li> <li>• Circuit diagram and understanding bias</li> <li>• Input and output waveforms</li> <li>• phase change</li> </ul>
Module 10	<ul style="list-style-type: none"> <li>• Analog signals</li> <li>• logic gates</li> <li>• truth tables</li> </ul> <p>OR</p> <p>AND</p> <p>NOT</p> <p>NAND</p> <p>NOR</p>

### MODULE 9

#### 3. WORDS YOU MUST KNOW

**Conductors:** These are the materials which conduct electricity easily. They have very large number of free electrons. conductors: material capable of carrying electric current, i.e. material which has “mobile charge carriers” and are therefore capable of electric current (e.g. electrons, ions.) e.g. metals, liquids with ions (water, molten ionic compounds), plasma !

**Insulators:** These are the materials which do not conduct electricity because they do not have free electrons. Quartz, most covalent and ionic solids, plastics

**Semiconductors:** These are the materials for which electrical conductivity values less than conductors but more than that of insulators. The conductivities of semiconductors are highly temperature sensitive.

**Semiconductors:** Materials germanium Ge, silicon Si, GaAs, GaP, InP have useful characteristic properties.

**Superconductors:** certain materials have zero resistivity at very low temperature, but are quite like normal conductors at room temperature

**Energy level:** As per Bohr's theory electrons revolve around the nucleus only in some specific orbits called stationary orbits. Energy of electrons in these orbits is constant; are termed as energy levels.

**Energy bands theory** in solid material, electron energy levels 'merge' to form bands of allowed energies. A band is a collection of a large number of close energies. The bands are separated by forbidden bands.

**Valence bands:** This band comprises of energy of valence electrons. it is the outermost highest filled band with electrons of this band do not contribute in conduction of electric current.

**Conduction band:** This is a higher band to valence band, it may be empty or partially filled in metals or in good conductors this band is filled

**Forbidden energy gap ( $E_g$ ):** It is the minimum energy required to take an electron from valence band to conduction band. Insulators have highest  $E_g$  and conductors have least  $E_g$ .

**Intrinsic semiconductors:** these are pure semiconductors without any impurity. They show very small electrical conductivity at room temperature.

The gap between the valence band and conduction band is relatively small. These are covalent bonded materials such as Si and Ge the forbidden gap width in Si is 1.1 eV and for Ge it is 0.7 eV

Electrons moving to conduction band leave "hole" (covalent bond with missing electron) behind; under influence of applied electric field, neighbouring electrons can jump into the hole, thus creating a new hole, etc.  $\Rightarrow$  holes can move under the influence of an applied electric field, just like electrons; both contribute to conduction., in pure Si and Ge, there are equally many holes as there are conduction electrons

**Doping:** It is the deliberate and controlled addition of impurities in intrinsic semiconductors to enhance their electrical conductivity in a controlled manner.

**Extrinsic semiconductors:** Initially pure semiconductor to which an appropriate /designed impurities is added to increase its conductivity are known as extrinsic semiconductors or impurity semiconductors

**Dopant** two types of dopants used in doping the tetravalent Si or Ge element:

(i) Pentavalent dopants (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

(ii) Trivalent dopants (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

**p-type semiconductors**, these are formed by doping elements like Si and Ge with trivalent atoms. Like B, Al, Ga, In, such that only 3 of the 4 covalent bonds get filled. A hole or vacancy is created because of the unfilled fourth covalent bond. there are more holes as compared to electrons in p type extrinsic semiconductor.

**n-type semiconductors**, these are formed by doping elements like Si and Ge with pentavalent atoms in this case impurity or dopant having 5 valence electrons like P, As, Sb is added to a sample of initially pure semiconductor.. of these 4 electrons get used by the covalent bond of the surrounding Si or Ge atoms The fifth electron is unpaired or left loosely bound. Hence only a small amount of energy is needed to lift it into the conduction band (0.5 eV for Si) n type semiconductors have more conduction electrons and fewer holes. example; doping fraction of 1 in  $10^8$  Sb in Si yield about  $5 \times 10^{16}$  conduction electrons per  $\text{cm}^3$  at room temperature which is a gain of  $5 \times 10^5$  conduction electrons over intrinsic Si.

**Advantage of doped semiconductors is we can alter conductivity by choice of doping fraction and choose majority carriers**

**p-n junction** A p-n junction is a boundary, or interface, between the two types of semiconductors, (p-type and n-type), inside a single crystal

**Diffusion current** holes diffuse from p-side to n-side ( $p \rightarrow n$ ) and electrons diffuse from n-side to p-side ( $n \rightarrow p$ ). Diffusion means movement due to difference in concentration, from higher to lower concentration; in absence of electric field across the junction, holes “diffuse” towards and across boundary into n type and capture electrons. Electrons diffuse across boundary, fall into holes (“recombination of majority carriers”) which forms a depletion region, **a region without free charge carriers) around the boundary**, charged ions are left behind (cannot move): the negative ions left on p-side give a net negative charge on p-side of the junction; the positive ions left on n-side give a collection of net positive charge on n-side of the junction. The potential barrier so created as electric field across junction, prevents further diffusion.

**Potential barrier:** Initially both the sides were electrically neutral. Now, because of diffusion of electrons and the holes, there are immobilised additional ions on both the sides.

From the n side, electrons have diffused to p side, so there are positive immobile ions on the n side, from the p side, holes have diffused to the n side, so there are negative immobile ions on the p side. These immobile ions near the junction create a potential difference across the junction.

**Drift current** Due to the positive space-charge region on n-side of the junction, and negative space charge region on p-side of the junction, an electric field, directed from positive charge towards negative charge develops.

- *Due to this field, an electron on p-side of the junction moves to n-side and a hole on n-side of the junction moves to p-side.*
- *The motion of charge carriers due to the electric field is called drift.*

*A drift current, which is opposite in direction to the diffusion current is set up.*

**Forward bias** when an external voltage V is applied across a semiconductor diode such that p-side is connected to the positive terminal of the battery and n-side to the negative terminal it is said to be forward biased.

**Reverse Bias:** The positive terminal of the battery is connected to the n-side of the semiconductor and negative terminal is connected to the p-side. This way of connecting a diode with a battery is called Reverse Biasing.

### Characteristics of a p-n junction diode

When a bias is placed across a conductor, its characteristic curves show the dependence of current on voltage placed across the conductor

**Knee voltage** the special value of forward voltage beyond which the current increases with increase in the voltage is known as the knee Voltage.

### Dynamic resistance of a junction diode

The I-V characteristics of a p-n junction diode during forward /reverse biasing) is not a straight line. We therefore cannot have a have a unique (constant) value for the resistance of the diode. We can, however use the basic definition of resistance

$$\text{resistance} = \frac{\text{change in potential difference}}{\text{corresponding change in current}}$$

We can use it to define

Dynamic resistance of a junction diode (for a particular value of the applied /current flowing) is defined as the ratio of small change in the applied potential across the diode to the corresponding small change in the junction current.

$$\text{dynamic resistance} = \frac{\Delta V}{\Delta I}$$

**Rectifier** is a device which converts an alternating current (AC) into a direct current (DC).

**Filter circuit:** The ripples in the DC can be reduced by allowing the output to pass through a filter circuit.

**Photodiodes** used for detecting optical signals (photodetectors).

**Light emitting diodes (LED)** which convert electrical energy into light.

**Photovoltaic devices** which convert optical radiation into electricity (**solar cells**)

**Transistors (bipolar) transistor** combination of two diodes that share middle portion, called “base” of transistor; other two sections: “emitter” and “collector”; usually, base is very thin and lightly doped. Two kinds of bipolar transistors: p-n-p and n-p-n transistors

**Transistor action p-n-p transistor** if emitter-base junction is forward biased, “holes flow” from battery into emitter, move into base, some holes annihilated with electrons in n-type base, but because base thin and lightly doped, most holes make it through base into collector, holes move through collector into negative terminal of battery; i.e. “collector current” flows whose size depends on how many holes have been captured by electrons in the base. This depends on the number of n type carriers in the base which can be controlled by the size of the base current, which is allowed to flow from the base to the emitter. The base current is usually very small. Small changes in base current can cause big difference in collector current.

Since due to chosen biasing the emitter base junction has lower resistance as compared to base collector hence resistance increases so it is called transistor or transfer of resistance.

**Common emitter n-p-n input characteristics of a transistor:** The variation of the base current  $I_B$  with the base-emitter voltage  $V_{BE}$  is called the input characteristic

**Input resistance:** This is dynamic (ac resistance) and as can be seen from the input characteristic, its value varies with the operating current in the transistor

$$r_i = \left( \frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE}}$$

The value of  $r_i$  can be anything from a few hundreds to a few thousand ohms.



**Output characteristics of a transistor:** The variation of the collector current  $I_C$  with the collector-emitter voltage  $V_{CE}$  is called the output characteristic

**Output resistance ( $r_o$ ):** This is defined as the ratio of change in collector-emitter voltage ( $\Delta V_{CE}$ ) to the change in collector current ( $\Delta I_C$ ) at a constant base current  $I_B$ .

$$r_o = \left( \frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B}$$

**Current amplification factor ( $\beta$ ):** This is defined as the ratio of the change in collector current to the change in base current at a constant collector-emitter voltage ( $V_{CE}$ ) when the transistor is in active state.

$$\beta_{ac} = \left( \frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE}}$$

This is also known as small signal current gain and its value is very large.

If we simply find the ratio of  $I_C$  and  $I_B$  we get what is called  $\beta_{dc}$  of the transistor.

Hence

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

Since  $I_C$  increases with  $I_B$  almost linearly and  $I_C = 0$  when  $I_B = 0$ , the values of both  $\beta_{dc}$  and  $\beta_{ac}$  are nearly equal.

So, for most calculations  $\beta_{dc}$  can be used. Both  $\beta_{ac}$  and  $\beta_{dc}$  vary with  $V_{CE}$  and  $I_B$  (or  $I_C$ ) slightly

**Transfer characteristics of a transistor** plot transfer characteristics to show the variation of output voltage with input voltage called transfer as voltage is transferred from input to output.

**Cut-off region:** In the case of Si transistor, as long as input  $V_i$  is less than 0.6 V, the transistor will be in cut off state and current  $I_C$  will be zero.

Hence  $V_o = V_{CC}$

**Saturation state:** With increase of  $V_i$ ,  $I_C$  increases almost linearly and so  $V_o$  decreases linearly till its value becomes less than about 1.0 V.

Beyond this, the change becomes non-linear and transistor goes into saturation state.

With further increase in  $V_i$  the output voltage is found to decrease further towards zero though it may never become zero

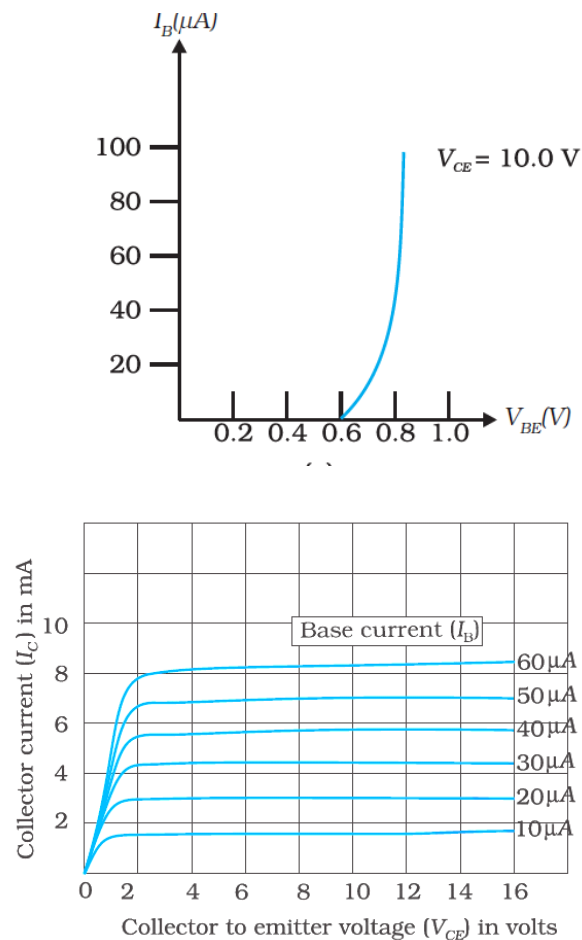
**Active region** When  $V_i$  becomes greater than 0.6 V the transistor is in active state with some current  $I_C$  in the output path and the output  $V_o$  decreases

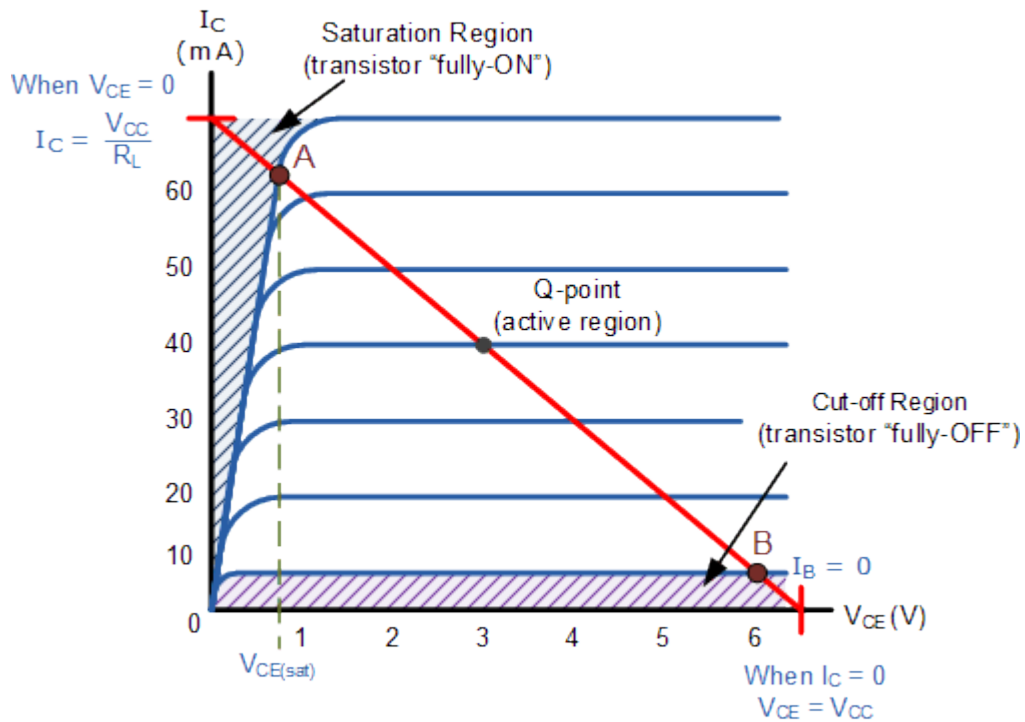
**Switch and amplifier** When the transistor is used in the cut off or saturation state it acts as a switch. On the other hand for using the transistor as an amplifier, it has to operate in the active region.

#### 4. INTRODUCTION

In the previous modules in this unit we have understood solid state devices. In our study we have focused on semiconductors, a class of solid materials that have conductivities between conductors and insulators.

#### INPUT AND OUTPUT CHARACTERISTIC CURVES AND TRANSFER CHARACTERISTICS

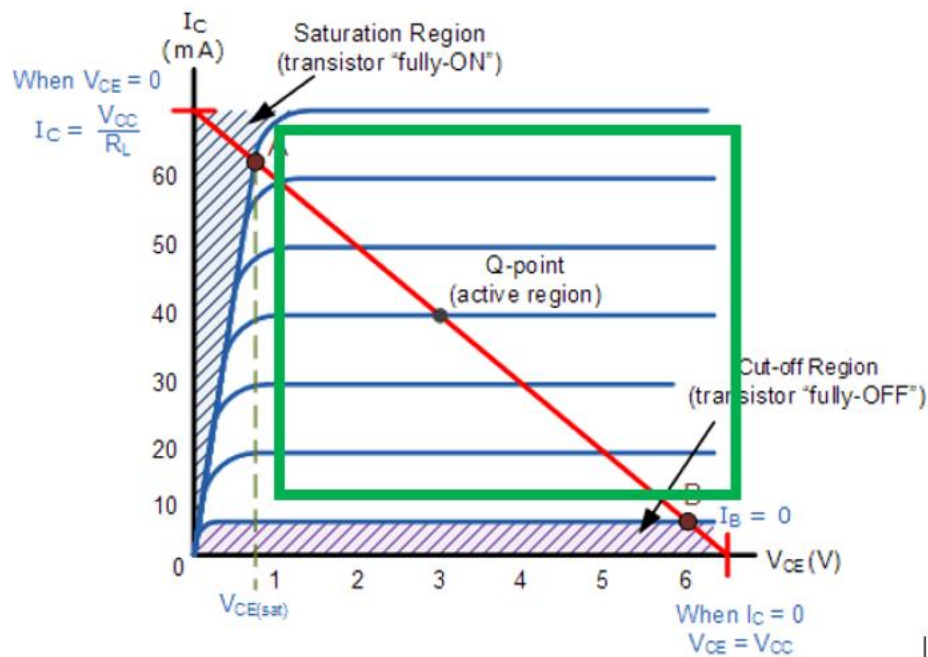




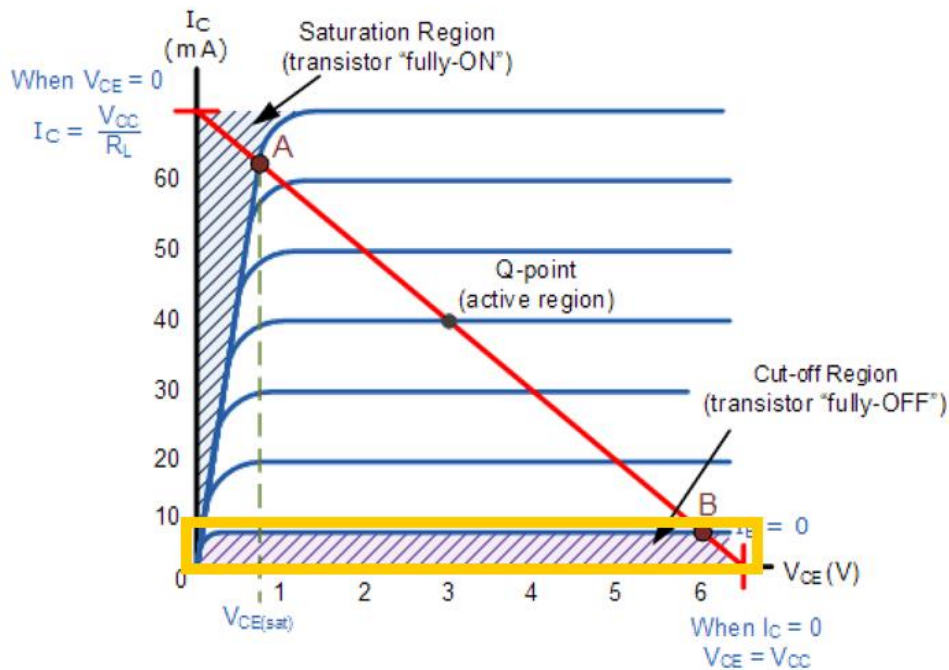
<https://i.stack.imgur.com/UuO7V.gif>

### FROM THE GRAPH

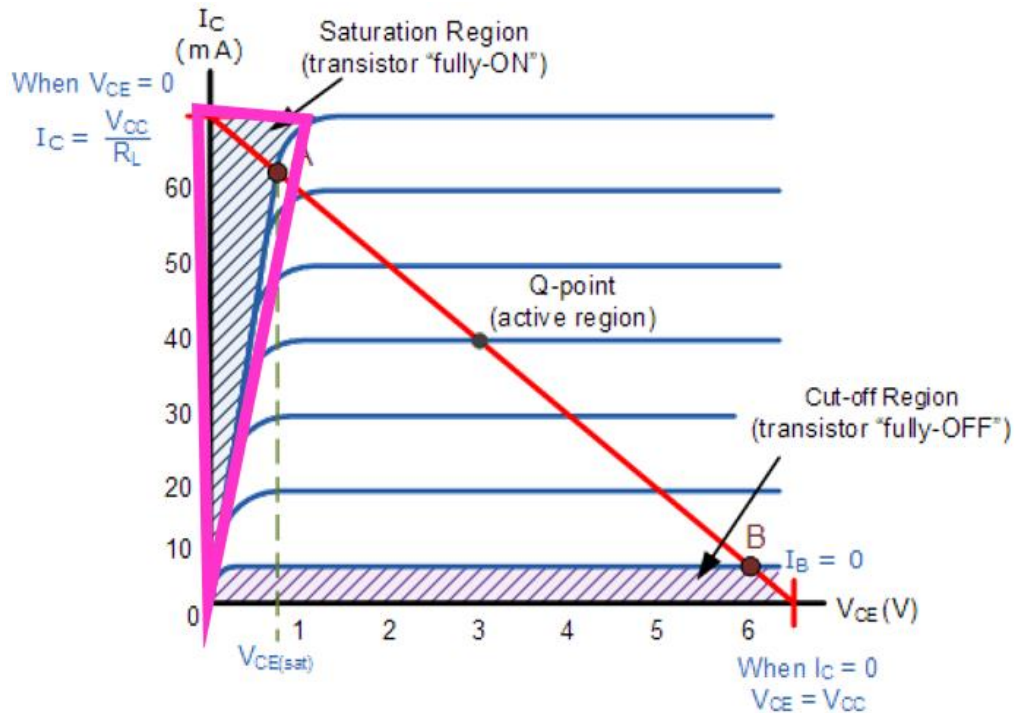
- **Region 1**-In linear portion of the graph for different  $I_B$  the transistor is **active**, region, the response is:  $I_C = \text{const.}$



- Region 2- In Cut off region**, Response is:  $I_C = 0$ .
  - No matter how large the increase in  $V_{CE}$ ,  $I_C$  is still zero. It is Similar to Air gap in the plug type key in the laboratory.



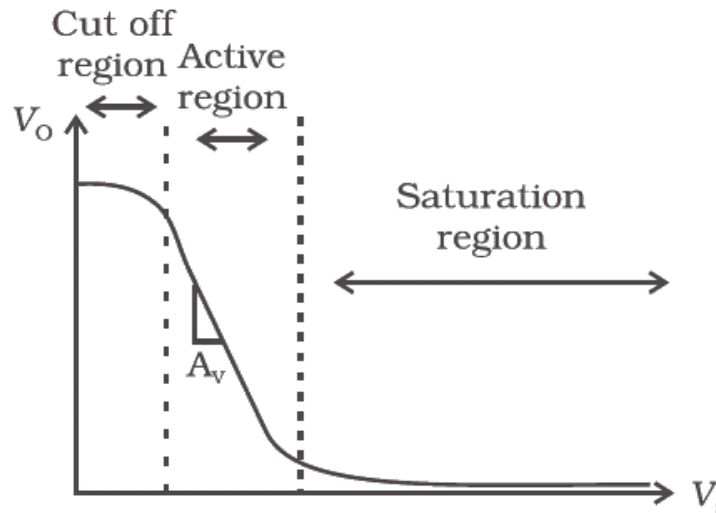
- Region 3- In Saturation region**, Response is:  $I_C = \text{const.}$   $V_{CE}$  is constant being the slope of the curve.



We

can plot a TRANSFER **CHARACTERISTIC CURVE**

The above graphs when plotted to show the variation of output voltage with input voltage give transfer characteristics, which means how the voltage is 'transferred' from input to output.



**This is called transfer characteristics**

**The cut off region corresponds to input voltages lower than knee voltage for the emitter base forward bias.**

## 5. TRANSISTOR AS AN AMPLIFIER (CE-CONFIGURATION)

To operate the transistor as an amplifier it is necessary to fix its operating point somewhere in the middle of its active region.

If we fix the value of  $V_{BB}$  corresponding to a point in the middle of the linear part of the transfer curve then the dc base current  $I_B$  would be constant and corresponding collector current  $I_C$  will also be constant.

The dc voltage

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

would also remain constant

**The operating values of  $V_{CE}$  and  $I_B$  determine the operating point, of the amplifier.**

**If a small sinusoidal voltage with amplitude  $V_s$  is superposed on the dc base bias by connecting the source of that signal in series with the  $V_{BB}$  supply, then the base current will have sinusoidal variations superimposed on the value of  $I_B$ .**

**As a consequence the collector current also will have sinusoidal variations superimposed on the value of  $I_C$ , producing in turn corresponding change in the value of  $V_O$ .**

We can measure the ac variations across the input and output terminals by blocking the dc voltages by large capacitors.

In the description of the amplifier given above we have not considered any ac signal.

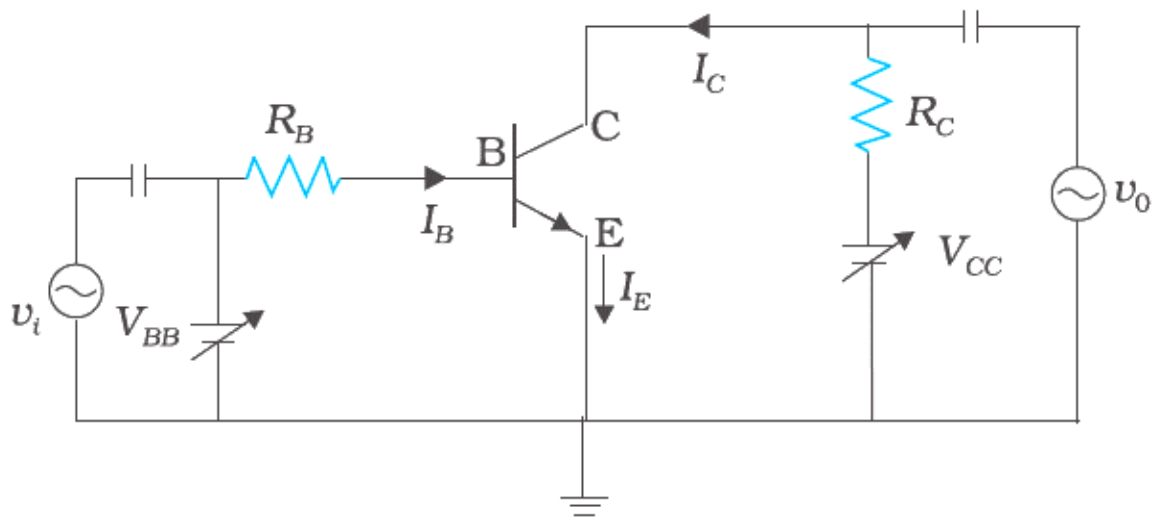
In general, amplifiers are used to amplify alternating signals.

Now let us superimpose an ac input signal  $v_i$  (to be amplified) on the bias  $V_{BB}$  (dc) as shown in the circuit diagram

The **output is taken between the collector and the ground.**

The working of an amplifier can be easily understood,

if **we first assume that  $v_i = 0$** . Then applying Kirchhoff's law to the output loop,



$$V_{CC} = V_{CE} + I_C R_L$$

Likewise, the input loop gives

$$V_{BB} = V_{BE} + I_B R_B$$

**When  $v_i$  is not zero, we get**

$$V_{BE} + v_i = V_{BE} + I_B R_B + \Delta I_B (R_B + r_i)$$

The change in  $V_{BE}$  can be related to the input resistance  $r_i$  and the change in  $I_B$ .  
Hence

$$\begin{aligned} v_i &= \Delta I_B (R_B + r_i) \\ &= r_i \Delta I_B \end{aligned}$$

The change in  $I_B$  causes a change in  $I_C$ . We define a parameter  $\beta_{ac}$ , which is similar to the  $\beta_{dc}$  as

$$\beta_{AC} = \frac{\Delta i_C}{\Delta i_B} = \frac{i_C}{i_B}$$

which is also known as the **ac current gain  $A_i$** .

Usually  $\beta_{ac}$  is close to  $\beta_{dc}$  in the linear region of the output characteristics.

The change in  $I_C$  due to a change in  $I_B$  causes a change in  $V_{CE}$  and the voltage drop across the resistor  $R_L$  because  $V_{CC}$  is fixed.

These changes are

$$\Delta V_{CC} = \Delta V_{CE} + R_L \Delta I_C = 0$$

$$\text{Or } \Delta V_{CE} = -R_L \Delta I_C$$

The change in  $V_{CE}$  is the output voltage  $v_o$ . We get

$$v_o = \Delta V_{CE} = -\beta_{ac} R_L \Delta I_B$$

The **voltage gain of the amplifier** is

$$\begin{aligned} A_o &= \frac{v_o}{v_i} = \frac{\Delta V_{CE}}{r \Delta I_B} \\ &= -\frac{\beta_{ac} R_L}{r} \end{aligned}$$

The negative sign represents that output voltage is opposite with phase with the input voltage.

From the discussion of the transistor characteristics you have seen that there is a current gain  $\beta_{ac}$  in the CE configuration.

Here we have also seen the voltage gain  $A_v$ .

Therefore the power gain  $A_p$  can be expressed as the product of the current gain and voltage gain.

Mathematically

$$A_p = \beta_{ac} \times A_v$$

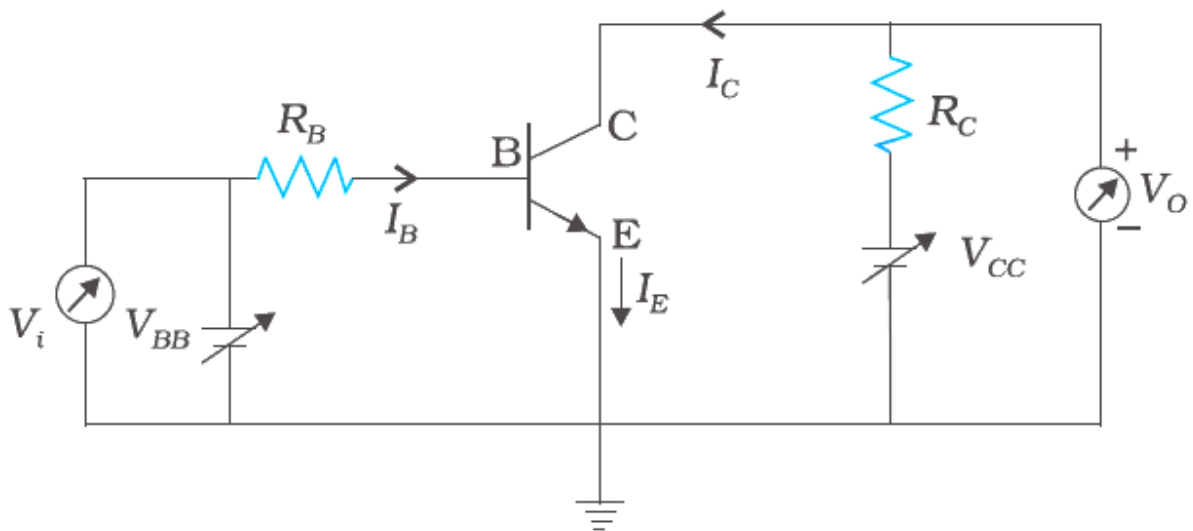
Since  $\beta_{ac}$  and  $A_v$  are greater than 1, we get ac power gain.

However, it should be realised that transistor is not a power generating device.

The energy for the higher ac power at the output is supplied by the battery.

### EXAMPLE

In



The  $V_{BB}$  supply can be varied from 0V to 5.0 V.

The Si transistor has  $\beta_{dc} = 250$  and

$R_B = 100 \text{ kW}$ ,  $R_C = 1 \text{ KW}$ ,  $V_{CC} = 5.0\text{V}$ .

Assume that when the transistor is saturated,

$V_{CE} = 0\text{V}$  and  $V_{BE} = 0.8\text{V}$ .

**Calculate**

(a) The minimum base current, for which the transistor will reach saturation. Hence,

(b) Determine  $V_i$  when the transistor is 'switched on'.

(c) Find the ranges of  $V_i$  for which the transistor is 'switched off' and 'switched on'.

### SOLUTION

Given at saturation

$$V_{CE} = 0\text{V and } V_{BE} = 0.8\text{V}$$

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

$$I_C = \frac{V_{CC}}{R_C} = \frac{5.0\text{V}}{1.0\text{kohm}} = 5.0\text{mA}$$

Therefore

$$I_B = \frac{I_C}{\beta} = \frac{5.0\text{mA}}{250} = 20\mu\text{A}$$

The input voltage at which the transistor will go into saturation is given by

$$v_i = V_{BB} = I_B R_B + V_{BE}$$

$$= 20\mu\text{A} \times 100\text{kohm} + 0.8\text{V} = 2.8\text{V}$$

The value of input voltage below which the transistor remains cut off is given by

$$V_{i\text{lowest}} = 0.6\text{V}, V_{i\text{highest}} = 2.8\text{V}$$

Between 0.0V and 0.6V, the transistor will be in the 'switched off' state.

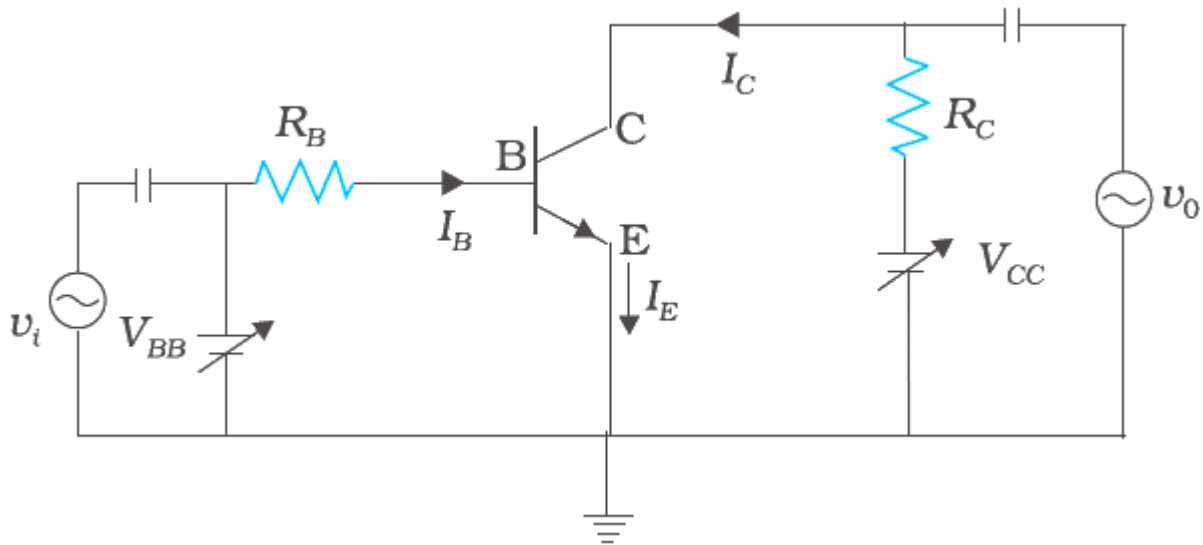
Between 2.8V and 5.0V, it will be in 'switched on' state.



Note that the transistor is in active state when  $I_B$  varies from 0.0mA to 20mA. In this range,  $I_C = \beta I_B$  is valid. In the saturation range,  $I_C \leq \beta I_B$

### EXAMPLE

For a CE transistor amplifier, the audio signal voltage across the collector resistance of 2.0 kW is 2.0 V. Suppose the current amplification factor of the transistor is 100, What should be the value of  $R_B$  in series with  $V_{BB}$  supply of 2.0 V if the dc base current has to be 10 times the signal current. Also calculate the dc drop across the collector resistance.



### SOLUTION

The output ac voltage is 2.0 V.

So, the ac collector current  $I_C = 2.0/2000 = 1.0$  mA.

The signal current through the base is, therefore given by

$$I_B = I_C / \beta = 1.0 \text{ mA} / 100 = 0.010 \text{ mA}.$$

The dc base current has to be  $10 \times 0.010 = 0.10$  mA.

$$R_B = (V_{BB} - V_{BE}) / I_B.$$

Assuming  $V_{BE} = 0.6$  V,

$$R_B = (2.0 - 0.6) / 0.10 = 14 \text{ kohm}.$$

The dc collector current  $I_C = 100 \times 0.10 = 10$  mA.

### EXAMPLE

For transistor action, which of the following statements are correct?

- (a) Base, emitter and collector regions should have similar size and doping concentrations.
- (b) The base region must be very thin and lightly doped.
- (c) The emitter junction is forward biased and collector junction is reverse biased.
- (d) Both the emitter junction as well as the collector junction is forward biased.

### SOLUTION

Both (b) and (c)

### EXAMPLE

For a transistor amplifier, the voltage gain

- (a) *Remains constant for all frequencies.*
- (b) *Is high at high and low frequencies and constant in the middle frequency range.*
- (c) *Is low at high and low frequencies and constant at mid frequencies.*
- (d) *None of the above.*

### SOLUTION

(c)

Because of the presence of junction and external capacitances the voltage gain of a transistor depends upon frequency. The gain decreases both at low as well as high frequencies

### EXAMPLE

For a CE-transistor amplifier, the audio signal voltage across the collector resistance of 2 kW is 2 V.

Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 kW.

### SOLUTION

$$V_i = 0.01 \text{ V} \quad I_B = 10 \text{ mA}$$

### EXAMPLE

Two amplifiers are connected one after the other in series (cascaded).

The first amplifier has a voltage gain of 10 and the second has a voltage gain of 20. If the input signal is 0.01 volt, calculate the output ac signal.

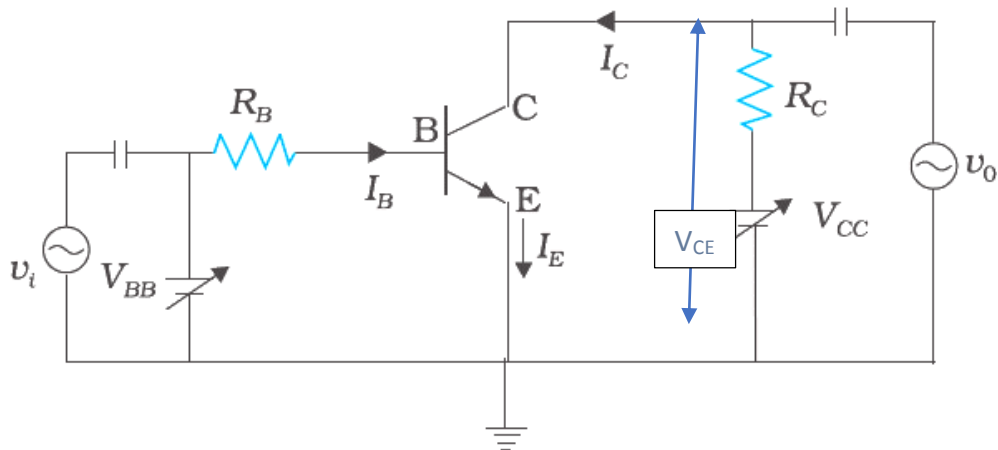
### SOLUTION

2 V

## 6. PHASE RELATION BETWEEN INPUT AND OUTPUT VOLTAGES

In a common emitter amplifier, the output voltage signal obtained across the collector and the emitter is  $180^\circ$  out of phase with the input voltage signal applied across the base and the emitter.

Let us try and understand why this happens



Suppose

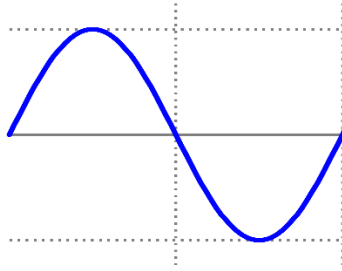
### Positive half input cycle

- The first half cycle of the input signal is positive. it reduces the forward biasing of the base emitter circuit.
- The emitter current decreases and so does the collector current. The decrease in collector current results in increase in collector voltage  $V_{CE}$ .
- Since the collector is connected to the negative terminal of battery  $V_{CC}$ , an increase in collector voltage means that the collector becomes more negative ,
- Thus during the positive half-cycle of the ac input voltage signal, the output voltage signal at the collector undergoes a negative half cycle.

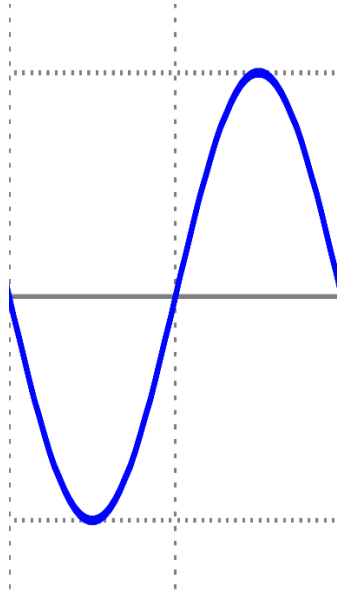
### Negative half input cycle

- The negative half cycle of the input voltage signal supports and hence increases the forward biasing of the base emitter circuit.
- Therefore the emitter current  $I_E$  and corresponding collector current  $I_C$  increases. As a result, the collector voltage  $V_{CE}$  decreases, that is, the collector becomes less negative.
- Thus, during the negative half cycle of the ac input voltage signal, the output voltage signal at the collector undergoes a positive half cycle.

So if the input signal is as shown



**Output signal will be**

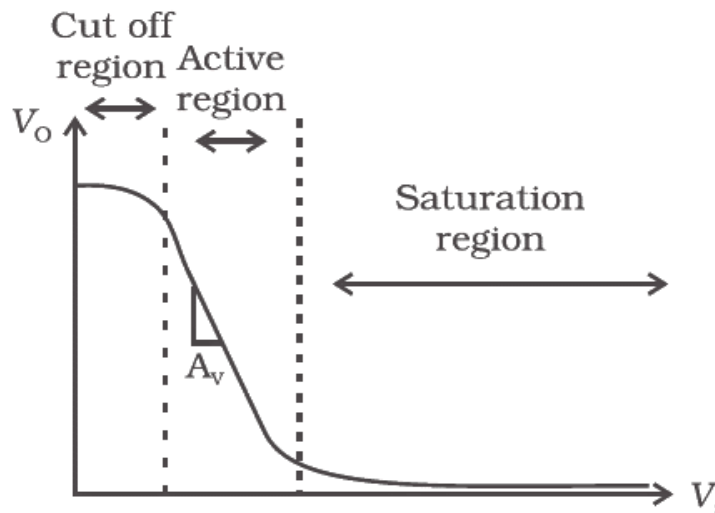


- The frequency of the signal does not change
- Amplitude increases
- Phase is reversed
- Output is extracted across emitter collector terminals of the transistor
- The input is fed into base emitter circuit.

**7. *EXPLANATION OF PHASE REVERSAL USING TRANSFER CHARACTERISTICS OF THE TRANSISTOR IN COMMON EMITTER MODE***

**Observe the transfer characteristics**

**The transistor operates as an amplifier in the active region of the graph**



Draw an input ac waveform along the x axis. Note the signal should vary the emitter base forward bias but never make it within the cut off or saturation regions

The variation in  $v_i$  result in variation in  $v_o$

Observe the output voltage curve to understand phase reversal of  $V_o$  with  $V_i$

The frequency remains unaffected. The amplitude and phase change

## 8. SUMMARY

**We have learnt in this module**

- p-n junction is the 'key' to all semiconductor devices.
- When such a junction is made, a 'depletion layer' is formed consisting of immobile ion-cores devoid of their electrons or holes. This is responsible for a junction potential barrier.
- By changing the external applied voltage, junction barriers can be changed. In forward bias (n-side is connected to negative terminal of the battery and p-side is connected to the positive), the barrier is decreased while the barrier increases in reverse bias. Hence, forward bias current is more (mA) while it is very small ( $\mu\text{A}$ ) in a p-n junction diode.
- Transistor is an n-p-n or p-n-p junction device.
- The central block (thin and lightly doped) is called 'Base' while the other electrodes are 'Emitter' and 'Collectors'.
- The emitter-base junction is forward biased while collector-base junction is reverse biased.
- The transistors can be connected in such a manner that either C or E or B is common to both the input and output. This gives the three configurations in which a transistor is used: Common Emitter (CE), Common Collector (CC) and Common Base (CB).
- The plot between  $I_C$  and  $V_{CE}$  for fixed  $I_B$  is called output characteristics

- The plot between  $I_B$  and  $V_{BE}$  with fixed  $V_{CE}$  is called input characteristics.
- The important transistor parameters for CE-configuration are:
- Input resistance  $r_i = \left( \frac{\Delta V_{BE}}{\Delta I_B} \right)$  *keeping  $V_{CE}$  constant*
- Output resistance  $r_o = \left( \frac{\Delta V_{CE}}{\Delta I_C} \right)$  *keeping  $I_B$  constant*
- Current amplification factor  $\beta = \left( \frac{\Delta I_C}{\Delta I_B} \right)$  *keeping  $V_{CE}$  constant*
- Transistor can be used as an amplifier and oscillator. In fact, an oscillator can also be considered as a self-sustained amplifier in which a part of output is feed-back to the input in the same phase (positive feedback). The voltage gain of a transistor amplifier in common emitter configuration is:

$$A_v = \left( \frac{v_o}{v_i} \right) = \beta \frac{R_C}{R_B}$$

Where  $R_C$  and  $R_B$  are the resistances in collector and base sides of the circuit

- When the transistor is used in the cut off or saturation state, it acts as a switch.