Junction Transistor

Objectives

After going through this module, the learners will be able to

- Understand the fabrication of a Junction transistor
- Know the two types of transistor *n-p-n* and *p-n-p*
- Use a multimeter to
  - Identify base of transistor
  - Distinguish between n-p-n and p-n-p type transistor
  - See the unidirectional flow of current in case of a diode and an LED
  - Check whether a given electronic component (e.g. diode, transistor) is in working order
- Draw and explain the basic details of the characteristics of a transistor
- Understand the use of n-p-n transistor in -common emitter configuration

Content Outline

- Unit Syllabus
- Module Wise Distribution of Unit Syllabus
- Words You Must Know
- Introduction
- Transistor: Structure
- Using a Multimeter to Identify a Transistor
- Working Principle
- Basic Transistor Circuit Configuration
- Common Emitter Transistor Characteristics
- Summary

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: I-V characteristics in forward and reverse bias, application of diode as a rectifier

Special Purpose *p-n* Junction 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 an 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

Module Wise Distribution Of Unit Syllabus 10 Modules

Module 1	● Energy bands in solids ● Forbidden gap ● Fermi level ● Energy bands in conductors, semiconductors and insulators
Module 2	● Uniqueness of semiconductors ● Charge carriers in semiconductors electrons and holes ● Intrinsic semiconductors ● Extrinsic semiconductors *p* and *n* type ● Why are *p* and *n* type semiconductors neutral?
Module 3	● *p-n* junction diode ● Potential barrier ● Depletion layer ● Characteristics of *p-n* junction diode ● Forward and reverse bias, knee voltage, magnitude of bias voltages ● To draw the IV characteristics curve for a *p-n* junction in forward bias and reverse bias

Module 4	● Application of diode ● Rectifier meaning and need of such a devise ● Half wave and full wave rectifier ● Rectifier in our homes ● Special purpose diode ○ *LED* ○ *Photodiode* ○ *Solar cells* ● Solar panels and future of energy
Module 5	● To identify a diode, an LED, a resistor and a capacitor ● Use a multimeter to i) See the unidirectional flow of current in case of a diode and an LED ii) Check whether a given diode is in working order
Module 6	● Zener diode ● Characteristics of Zener diode ● To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage ● How is a Zener diode different from other diodes? ● Zener diode as a voltage regulator ● Working of a Zener diode ● Zener diodes in our homes
Module 7	● Junction transistor ● Design of the transistor ● *n-p-n* and *p-n-p* ● Use a multimeter to ○ *identify base of transistor* ○ *distinguish between n-p-n and p-n-p type transistor*

	○ *check whether a given electronic component (e.g. diode , transistor, or IC) is in working order* ● Transistor action ● Characteristics of a transistor, n-p-n -common emitter
Module 8	● Understanding transistor characteristics and its applications ● To study the characteristics of a common emitter *n-p-n, p-n-p* transistor and to find the values of current and voltage gains. ● Transistor as switch ● Transistor as amplifier
Module 9	● Transistor as an amplifier ● Circuit diagram and understanding bias ● Input and output waveforms ● phase change
Module 10	● Analog signals ● logic gates ● truth tables OR gate AND gate NOT gate NAND gate NOR gate

Module 7

Words You Must Know

- **Conductors:** These are the materials which conduct electricity easily. They have a very large number of free electrons.
- **Insulators:** These are the materials which do not conduct electricity because they do not have free electrons.

- **Semiconductors:** These are the materials for which electrical conductivity values between conductors and insulators. The conductivities of semiconductors are highly temperature sensitive.
- **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 and termed as energy levels.
- **Valence Bands:** This band comprises energy of valence electrons. Electrons of this band do not contribute in conduction of electric current.
- **Conduction Band:** This band corresponds to energy of free electrons. Electrons of this band are responsible for conduction of electric current.
- **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.
- **Doping:** It is the deliberate and controlled addition of impurities in intrinsic semiconductors to enhance their electrical conductivity in a controlled manner.
- **Extrinsic Semiconductors:** Semiconductors to which impurities are added to increase conductivity are known as extrinsic semiconductors or impurity semiconductors.
- **Dopant:** two types of dopants used in doping the tetravalent Si or Ge element:
  - *Pentavalent dopants (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.*
  - *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.
- ***n*-type Semiconductors**, these are formed by doping elements like Si and Ge with pentavalent atoms.
- ***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 ($n \rightarrow p$).

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

  Due to this field, an electron on the p-side of the junction moves to the n-side and a hole on the 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:**

  I-V characteristics of a *p-n* junction diode during forward/reverse biasing is not a straight line. We therefore cannot have a unique (constant) value for the resistance of the diode. We can, however use the basic definition of resistance
- $resistance = \frac{change\ in\ potential\ difference}{corresponding\ change\ in\ current}$

  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.

  - $dynamic\, resistance = \frac{\Delta V}{\Delta I}$

- **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)

Introduction

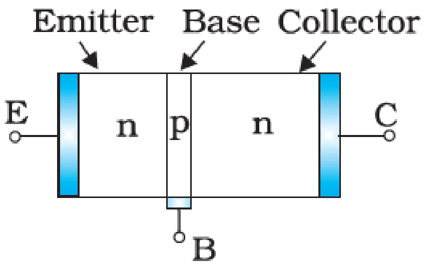
The credit of inventing the transistor in the year 1947 goes to J. Bardeen and W.H. Brattain of Bell Telephone Laboratories, U.S.A. That transistor was a point-contact transistor. The first junction transistor consisting of two back-to-back p-n junctions was invented by William Schockley in 1951. As long as only the junction transistor was known, it was known simply as a transistor. But over the years new types of transistors were invented and to differentiate it from the new ones it is now called the **Bipolar Junction Transistor (BJT)**. Even now, often the word transistor is used to mean BJT Since our study is limited to only BJT, we shall use the word transistor for BJT without any ambiguity.

Transistor Structure

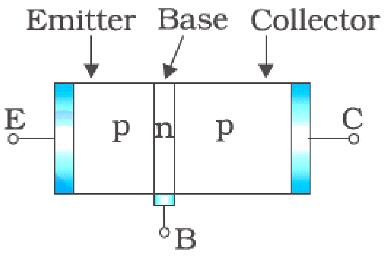
The transistor consists of two p-n junctions back to back and is obtained by sandwiching either *p*-type or *n*-type semiconductor between a pair of opposite type of semiconductors

Hence a transistor has three doped regions forming two *p-n* junctions between them. Obviously, there are two types of transistors,

- ***n-p-n* transistor**: Here two segments of *n*-type semiconductor (called the emitter and the collector) are separated by a segment of *p*-type semiconductor (called the base).



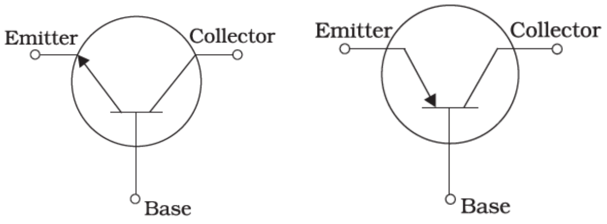
- ***p-n-p* transistor**: *Here two segments of p-type semiconductor (termed as emitter and collector) are separated by a segment of n-type semiconductor (termed as base).*



The schematic representations of an n-p-n and a p-n-p configuration

All the three segments of a transistor have different thickness and their doping levels are also different.

In the schematic symbols used for representing *p-n-p* and *n-p-n* transistors



Symbols for *n-p-n* and *p-n-p* transistors

(Trick to remember how to place the arrows for *n-p-n* means not pointing in or for *p-n-p* pointing in)The arrowhead shows the direction of conventional current in the transistor.

A brief description of the three segments of a transistor is given below:

Emitter:

- This is the segment on one side of the transistor.
- It is of moderate size.
- It is heavily doped.
- It supplies a large number of majority carriers for the current flow through the transistor.

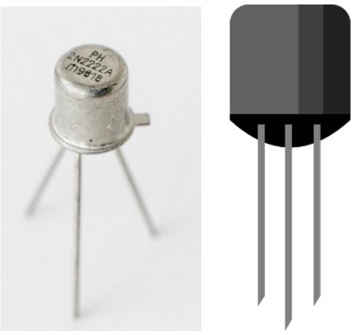
Base

- This is the central segment.
- It is very thin and ightly dopeD

Collector

- This segment collects a major portion of the majority charge carriers supplied by the emitter.
- The collector side is moderately doped and
- Larger in size as compared to the emitter.

Commercial Transistors



- It has three terminals each connected to the three different parts of the transistor.
- Emitter, base, collector can be checked with the help of a multimeter.
  In some transistors E, B, C are marked.
- A number on the transistor shows its operating voltages and performance using a Multimeter to Identify a Transistor.

Using a Multimeter to Identify a Transistor

- Identify base of transistor
- *Distinguish between n-p-n and p-n-p type transistor*
- *Check whether a given electronic component (e.g. diode, transistor or IC) is in working order.*

- Check the physical appearance of the given device, if it has three or four or more terminals it is an transistor or an IC (integrated circuit).

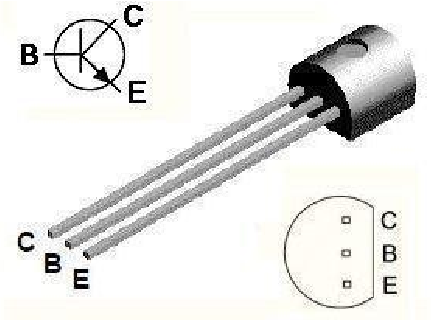
  If it has three terminals the component may be a transistor.

  To confirm
- Set the multimeter in **resistance mode**.
- Connect the black or common terminal to one of the extreme legs of the component, using the probe.
- Connect the second red wired probe (lead), or probe from the positive of the multimeter to the central leg.
- Check the multimeter deflection.
- Interchange the multimeter terminals across the two legs of the three-terminal component.
- If no deflection is observed, the component is a transistor.
- Repeat the test by connecting the multimeter terminals to the central leg and the other extreme leg of the component.
- If a similar behaviour is observed, the component is a transistor.

To check whether the component is *n-p-n or p-n-p* transistor?

Mostly in the case of transistors with pin terminals, the pins are marked.

In case they are not, the identification can be done by measuring the resistance values between different terminals



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Nature of resistance values between different transistor terminals. Here terminal 2 is taken as the base

For *n-p-n* transistor

s.no	Transistor terminal connected with the positive lead of multimeter	Transistor terminal connected with the negative lead of multimeter	Nature of resistance
1	1	2	Very high
2	1	3	Very high
3	2	1	low
4	2	3	low
5	3	1	Very high
6	3	2	Very high

For *p-n-p* transistor

s.no	Transistor terminal connected with the positive lead of multimeter	Transistor terminal connected with the negative lead of multimeter	Nature of resistance
1	1	2	low
2	1	3	Very high
3	2	1	Very high
4	2	3	Very high
5	3	1	Very high
6	3	2	low

In a transistor the junction joining the base region and the emitter region is called the **base emitter junction.**The junction joining the base region and the collector region is called the **base collector junction.**

Working Principle

We have seen earlier in the case of a *p-n* junction, that there is a formation of depletion regions across the junction. In case of a transistor depletion regions are formed at the emitter base-junction and the base collector junction.

For understanding the action of a transistor, we have to consider the nature of depletion regions formed at these junctions.

Transistors Action

- The charge carriers move across different regions of the transistor when proper voltages are applied across its terminals.

- The biasing of the transistor is done differently for different uses. The transistor can be used in two distinct ways.

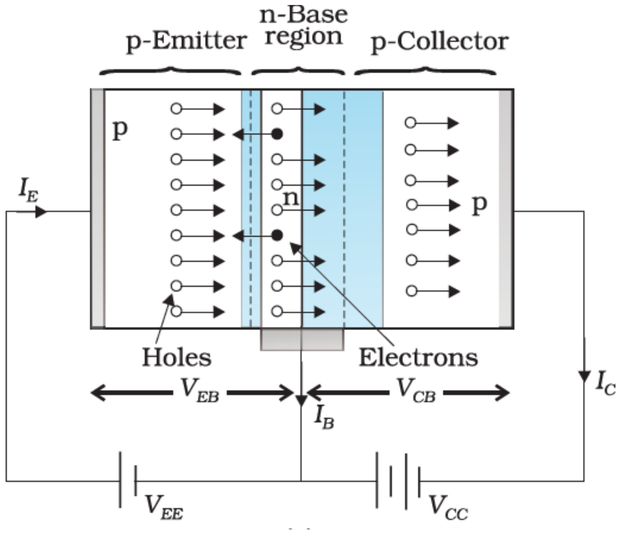
- Basically, it was invented to function as an amplifier; a device which produces an enlarged copy of a signal. But later its use as a switch acquired equal importance.

- We shall study both these functions and the ways the transistor is biased to achieve these mutually exclusive functions.

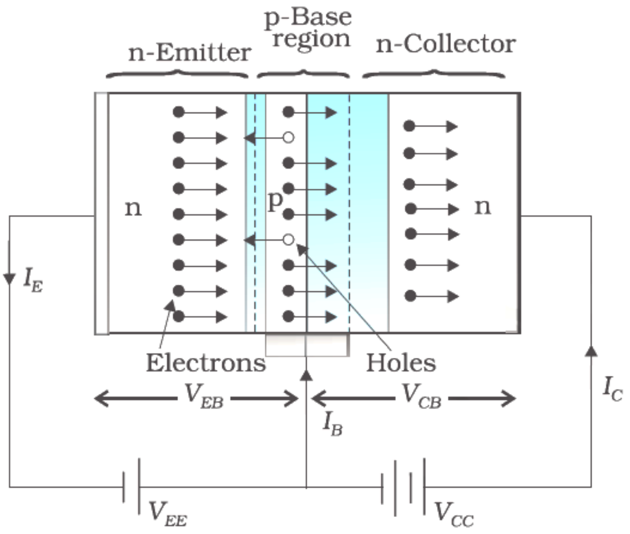
What Gives the Transistors its Amplifying Capabilities

The transistor works as an amplifier, when

- *the emitter-base junction is forward biased*
- *the base-collector junction is reverse biased.*



p-n-p transistor



n-p-n transistor

To explain the different value marked see the chart below

I_E	Emitter current
I_B	Base current
I_C	Collector current
V_{EE}	Emitter voltage

V_{CC}	Collector voltage
V_{EB}	Potential difference between emitter and base
V_{CB}	Potential difference between collector and base

Notice

- **There are two distinct circuits**
- **The current in one circuit (collector) is influenced/ controlled by the current in the other emitter circuit.**

When the transistor is biased, emitter base forward biased and base collector reverse biased, it is said to be in an **active state**.We represent the voltage between emitter and base as V_{EB} and that between the collector and the base as V_{CB}.

In the schematic Figure shown, the base is a common terminal for the two power supplies whose other terminals are connected to emitter and collector, respectively. This type of transistor circuit is known as its '**common base configuration**'.So the two power supplies are represented as V_{EE}, and V_{CC}, respectively.

In circuits, where the emitter is the common terminal, the power supply between the base and the emitter is represented as V_{BB} and that between collector and emitter as V_{CC}. This type of transistor circuit is known as its 'common emitter configuration'

Let us see now **the paths of current carriers in the transistor with emitter-base junction forward biased and base-collector junction reverse biased.**

The heavily doped emitter has a high concentration of majority carriers, which will be holes in a *p-n-p* transistor and electrons in an *n-p-n* transistor.

These majority carriers enter the base region in large numbers. The base is thin and lightly doped. So the majority carriers there would be few. In a *p-n-p* transistor the majority carriers in the base are electrons since the base is of *n*-type semiconductor.

The large number of holes entering the base from the emitter swamps the small number of electrons there.

As the base collector-junction is reverse biased, these holes, which appear as minority carriers at the junction, can easily cross the junction and enter the collector. The holes in the base could move either towards the base terminal to combine with the electrons entering from outside or cross the junction to enter into the collector and reach the collector terminal.

The base is made thin so that most of the holes find themselves near the reverse-biased base-collector junction and so cross the junction instead of moving to the base terminal.

It is interesting to note that due to forward bias a large current enters the emitter-base junction, but most of it is diverted to adjacent reverse-biased base-collector junction and the current coming out of the base becomes a very small fraction of the current that enters the junction I.

If we represent the hole current and the electron current crossing the forward biased junction by I_h and I_e respectively then the total current in a forward biased diode is
the sum $I_h + I_e$

We see that the **emitter current**

$$I_E = I_h + I_e$$

but the **base current**

$$I_B \ll I_h + I_e$$

Because a major part of I_E goes to collector instead of coming out of the base terminal

The base current is thus a small fraction of the emitter current.

The current entering into the emitter from outside is equal to the current I_E. Similarly, the current emerging from the base terminal is I_B and that from the collector terminal is I_C.

It is obvious from the above description and also from a straight forward application of **Kirchhoff's law**, that the emitter current is the sum of collector current and base current:

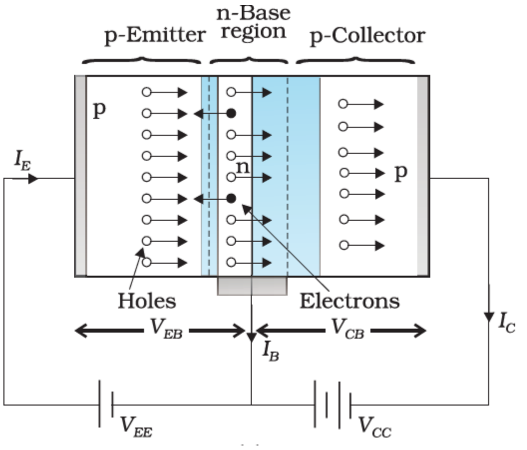
$$I_E = I_C + I_B$$

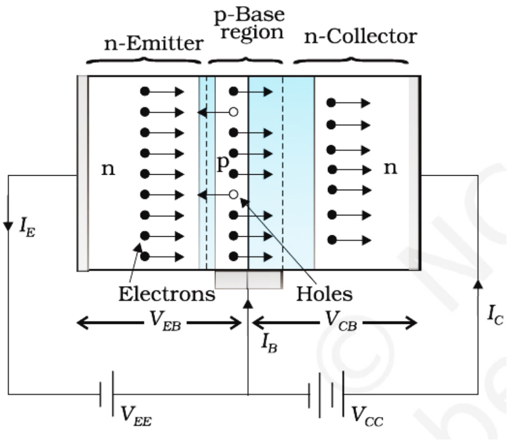
We see that since **I_B is small** **$I_C \approx I_E$.**

Our description of the direction of motion of the holes is identical with the direction of the conventional current. But the direction of motion of electrons is just opposite to that of the current.

Thus in a *p-n-p* transistor the current enters from the emitter into base whereas in a *n-p-n* transistor it enters from the base into the emitter. The arrowhead in the emitter shows the direction of the conventional current.

The description about the paths followed by the majority and minority carriers in a *n-p-n* is the same as that for the *p-n-p* transistor. But the current paths are exactly opposite, as shown in the two circuits





For *n--p-n* transistor the electrons are the majority carriers supplied by the *n*-type emitter region. They cross the thin p-base region and are able to reach the collector to give the collector current, I_C.

From the above description we can conclude that in the active state of the transistor the emitter-base junction acts as a low resistance while the base collector acts as a high resistance.

It appears that the resistance has increased or got transferred hence the name transistor

Bassics Transistors Circuit Configurations

In a transistor, only three terminals are available, viz., *Emitter* (E), *Base* (B) and *Collector* (C).

Therefore, in a circuit the input/output connections have to be such that one of these (E, B or C) is common to both the input and the output. Accordingly, the transistor can be *connected* in any of the following **three configurations:**

- *Common Emitter (CE), Fig (a)*
- *Common Base (CB), Fig (b)*
- *Common Collector (CC), Fig (c)*

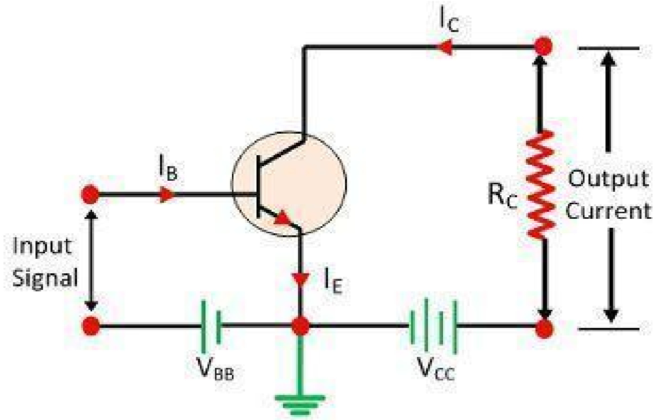


Fig (a)

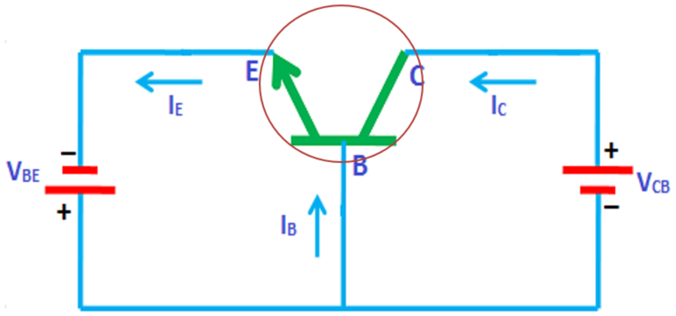


Fig (b)

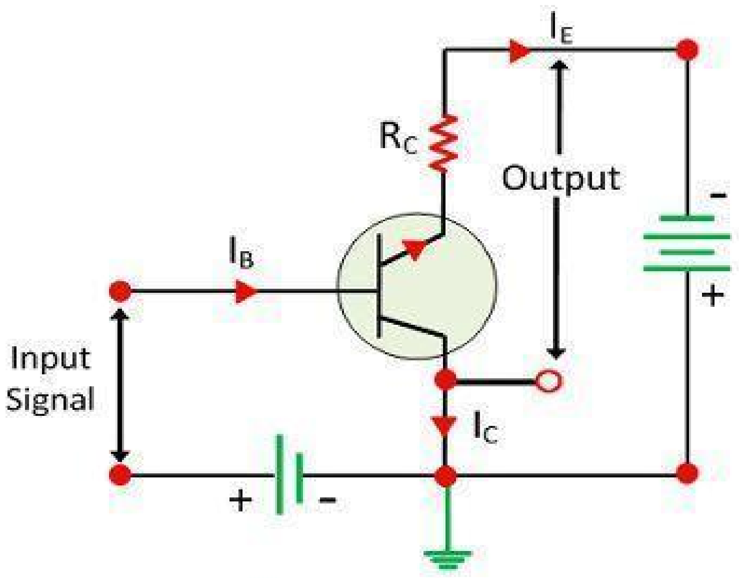


Fig (c)

The transistor is most widely used in the CE configuration and we shall restrict our discussion to only this configuration.Since more commonly used transistors are the *n-p-n* transistors, made from Si.

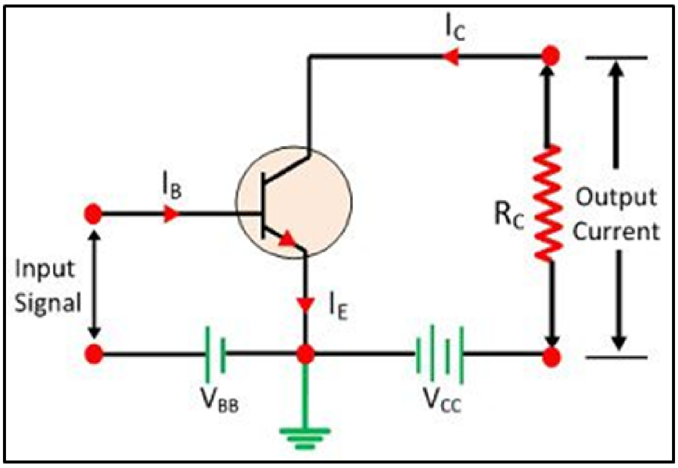
We shall confine our discussion to such transistors only.

With *p-n-p* transistors the polarities of the external power supplies are to be inverted.

Common Emitter Transistor Characteristics

The characteristics of a transistor when the emitter is kept as a common terminal (and grounded), the base as the input terminal and the collector as the output terminals, are called **common emitter characteristics**.

When a transistor is used in CE configuration, the input is between the base and the emitter and the output is between the collector and the emitter. The idea of input and output implies what we will ‘feed ‘to the transistor and what will ‘come out of it’

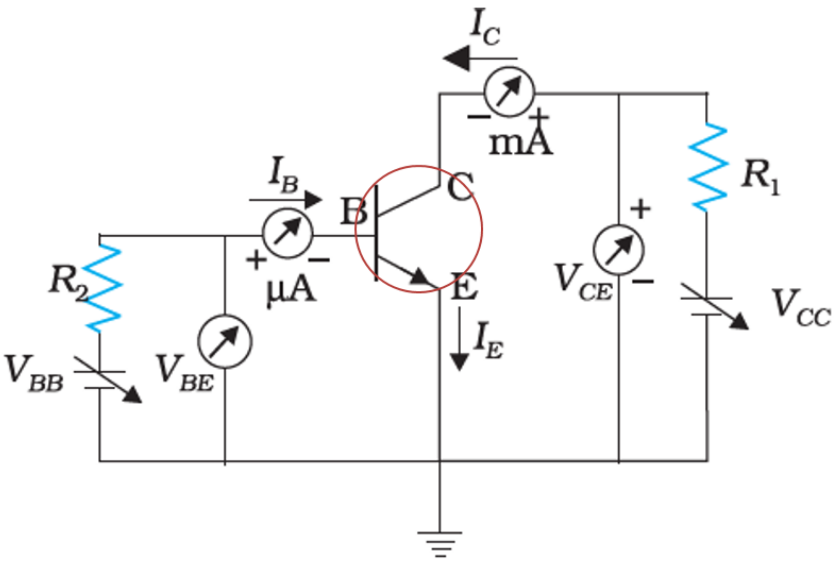


The variation of the base current I_B with the base-emitter voltage V_{BE}, keeping V_{CC} constant is called the input characteristic.

The variation of the collector current I_C with the collector-emitter voltage V_{CE}, keeping I_B constant is called the output characteristic.

You will see that the input characteristics control the output characteristics.
This implies that the collector current changes with the base current.
The **input and the output characteristics of an n-p-n transistors** can be studied by using the circuit as shown in the following circuit diagram.

Note
To our basic circuit, we have added micro ammeters, milli ammeters and voltmeters to record the values of current and voltages.
In addition we have added devices to change the bias input , output voltages in order to study the pattern of output across the load resistance .



Circuit arrangement for studying the input and output characteristics of n-p-n transistor in CE configuration

Input Characteristics

To study the input characteristics of the transistor in C*E* configuration

The collector-emitter voltage V_{CE} is kept fixed while studying the dependence of I_B on V_{BE}

We are interested to obtain the input characteristic when the transistor is in active state.

So the **collector-emitter voltage V_{CE} is kept large enough to make the base collector junction reverse biased, and measurable I_B and I_C are obtained.**

Since

$$V_{CE} = V_{CB} + V_{BE}$$

and for Si transistor V_{BE} is 0.6 to 0.7 V,

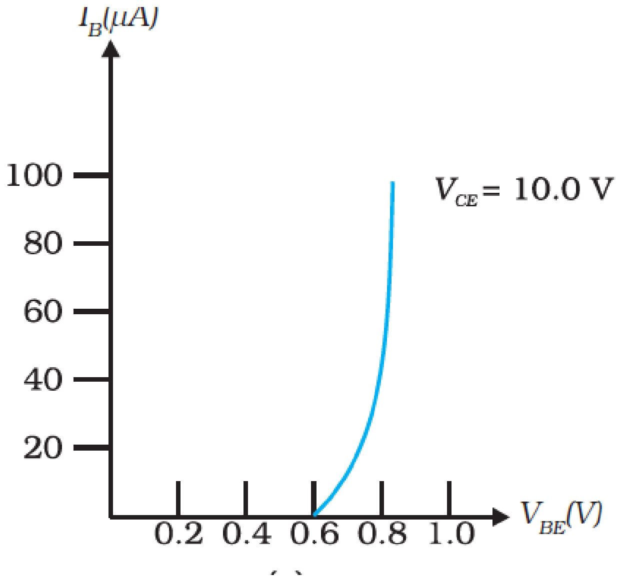
V_{CE} must be sufficiently larger than 0.7 V.

As long as the input voltage V_{BE} is less than the knee voltage, current is small and beyond that the current I_B rises, this also means that the junction behaves like the p-n junction in forward bias.

Also notice that a **micro ammeter is needed to read I_B** since the base currents are small.

Since the transistor is operated as an amplifier over a large range of V_{CE}, the reverse bias across the base collector junction is high most of the time.

Therefore, the input characteristics may be obtained for V_{CE} somewhere in the range of 3 V to 20 V.



A curve is plotted between the base current I_B against the base-emitter voltage V_{BE}. Typical input characteristics Since

- **The increase in V_{CE} appears as an increase in V_{CB}, its effect on I_B is negligible.**

- **Consequently, input characteristics for various values of $V_{CR|E}$ will give almost identical curves.**

Hence, it is enough to determine only one input characteristic.

The Input Resistance

The linear segments of the input characteristics can be used to calculate an important parameter of transistors, its input resistance**.**

Input resistance r_i is defined as the ratio of change in base – emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B).

Also it is defined as the reciprocal of slope at a fixed point on the input characteristics curve

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

The value of r_i is of the order of a few hundred to a few thousand ohms.

We can conclude

- **The base current remains almost zero so long the base – emitter voltage V_{BE} is less than the barrier voltage (~ 0.3 V or so) as soon as the V_{BE} exceeds the barrier voltage current increases first slowly and then rapidly. This resembles a forward biased diode.**
- **The input characteristics are only slightly dependent upon collector to emitter voltage V_{CE}**
- **The input resistance is given by**

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

- **As the input characteristics are nonlinear the input resistance varies. At any point it is given by the reciprocal of the slope of the curve at that point.**
- **The input resistance is of the order of kilo ohms**

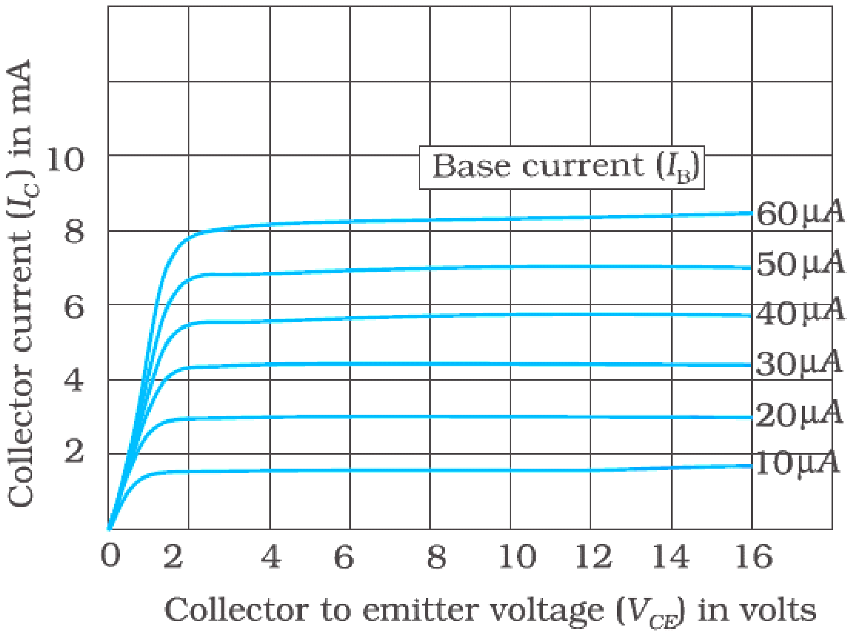
Output Characteristics

The curves showing the variation in output collector current I_C with output voltage V_{CE} for different values of input current I_B are called output characteristics.

The output characteristic is obtained by observing the **variation of I_C as V_{CE} is varied keeping I_B constant.**

It is obvious that if V_{BE} **is increased by a small amount, both hole current from the emitter region and the electron current from the base region will increase. As a consequence, both I_B and I_C will increase simultaneously.**

This shows that when I_B increases I_C also increases.So there will be different output characteristics corresponding to different values of I_B



The linear segments of the output characteristics can be used to calculate the output resistance.

Output Resistance

This is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at a constant base current I_B

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

The values of output resistance r_0 are of the order of 50 to 100 k ohms

We find that

- **The collector current I_C varies rapidly with collector–emitter voltage for 0-1 volt only. The value of V_{CE} upto which I_C changes is the knee voltage.**
- **Above knee voltage, current I_C is almost constant , varying very slightly and almost linearly with V_{CE}**
- **For a given value of V_{CE} the collector current I_C increases with increasing I_B**

- **There is a small collector current even when the base current I_B is zero. This is due to intrinsic conduction inherent to semiconductors and this current is highly temperature dependent,**
- **The output resistance is defined by**

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

- **The values of output resistance are of the order of 50 to 100 k ohms.**

Think About These

- **It is sufficient to plot only one input characteristic curve but several curves are required to completely describe the output characteristics**

  It is obvious that if V_{BE} is increased by a small amount, both hole current from the emitter region and the electron current from the base region will increase.

  As a consequence, both I_B and I_C will increase simultaneously. This shows that when I_B increases I_C also increases.

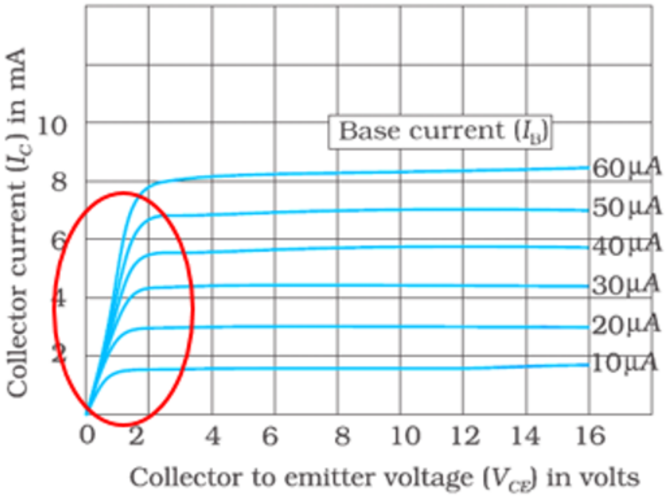
  The plot of I_C versus V_{CE} for different fixed values of I_B gives one output characteristic.

  So there will be different output characteristics corresponding to different values of I_B

- ***Why is the output resistance so high?***

  The high magnitude of the output resistance (of the order of 100 kΩ) is due to the reverse-biased state of this diode

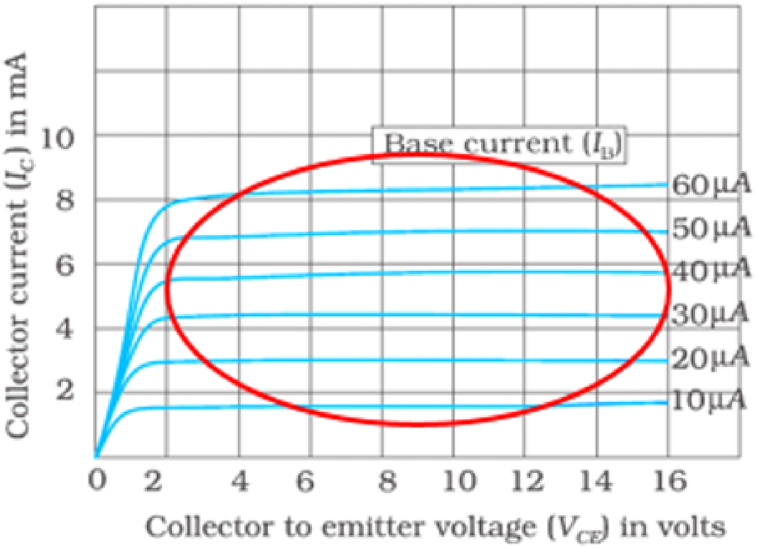
- ***Why does the current I_C increase almost linearly before showing a saturation value?***



The output characteristics show that initially for very small values of V_{CE}, I_C increases almost linearly.

This happens because the base-collector junction is not reverse biased enough and the transistor is not in active state. In fact, the transistor is in the saturation state and the current is controlled by the supply voltage V_{CC} ($=V_{CE}$) in this part of the characteristic.

Why is there hardly any change in I_C when V_{CE} is high enough?



The output characteristic is obtained by observing the variation of I_c as V_{CE} is varied.

keeping I_B constant. It is obvious that if V_{BE} is increased by a small amount, both hole current from the emitter region and the electron current from the base region will increase. As a consequence, both I_B and I_C will increase proportionately. This shows that when I_B increases I_C also increases. The plot of I_C versus V_{CE} for different fixed values of I_B gives one output characteristic. So there will be different output characteristics corresponding to different values of I_B.

Current amplification factor (β):

This is defined as t**he 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 dc β of the transistor.

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

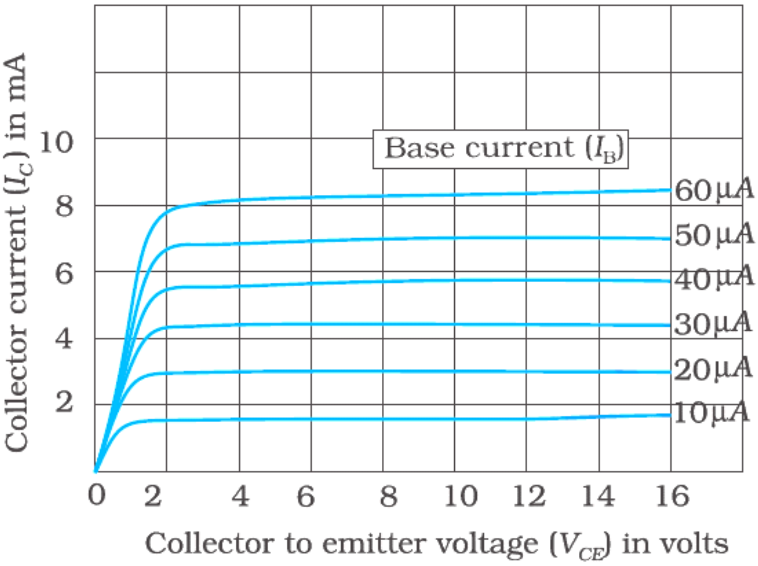
Hence,

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

So, for most calculations βdc can be used.

Example:

From the output characteristics shown



Calculate the values of β_{ac} and β_{dc} of the transistor when V_{CE} is 10 V and I_C = 4.0 mA.

Solution:

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

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

For determining βac and βdc at the stated values of V_{CE} and I_C one can proceed as follows. Consider any two characteristics for two values of I_B which lie above and below the given value of I_C. Here I_C = 4.0 mA. (Choose characteristics for I_B = 30 and 20 μA.

At V_{CE} = 10 V we read the two values of I_C from the graph. Then

$$\Delta I_B = (30 - 20)\mu A = 10\mu A, \qquad \Delta I_C = (2.5 - 3.0)mA = 1.5mA$$

$$therefore\ \beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}} = \frac{1.5mA}{10\mu A} = 150$$

We can find β_{dc} for two characteristics chosen and find a mean

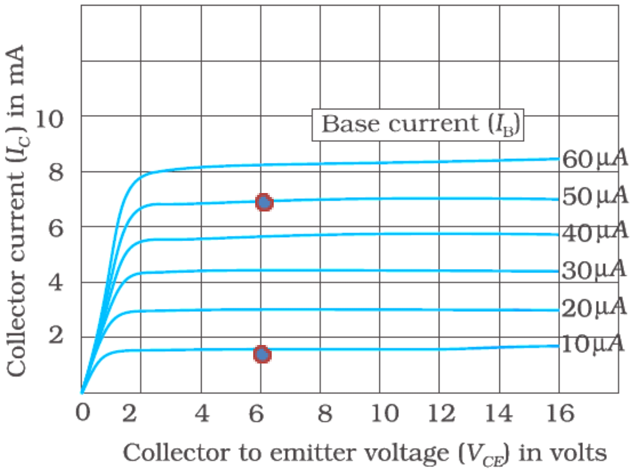
$$\beta_{dc} = \frac{4.5mA}{30\mu A} = 150$$

And for I_C =3.0mA and I_B=20 μA

$$\beta_{dc} = \frac{3.0mA}{20\mu A} = 150$$

Example:

From the output characteristics



a) calculate the value of current

b) amplification of the transistor when V_{CE} is 6 V

Solution:

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

Consider any characteristics for any two values of I_B

say, 10 and 50 μA from the graph $\Delta I_B = (50 - 10)\mu A = 40\mu A$

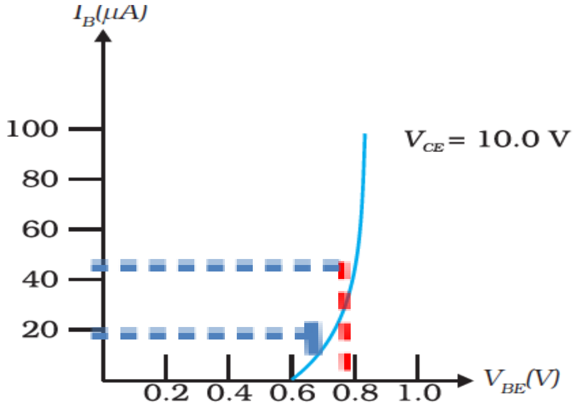
$$\Delta I_C = (7.0 - 1.8)mA = 5.2mA$$

$$\beta = \frac{5.2mA}{40\mu A} = 13$$

Example:

Calculate the input resistance of a transistor operating at

V_{CE} = 10V in common emitter configuration having the input characteristics as shown



Solution:

From the graph

$$\Delta V_{BE} = (0.8 - 0.7)V$$

$$\Delta I_B = (40 - 15)\mu A$$

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

$$r_i = \left(\frac{0.1V}{25\mu A}\right) = 4000\ ohms$$

Example:

In a silicon transistor a change of 0.2 V in base to emitter voltage produces a change of 20 μ*A* in the base current and change of 2 mA in the collector current . Find the input resistance and current gain β.

Solution:

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

$$r_i = \left(\frac{0.2V}{20\mu A}\right) = 1000\ ohms$$

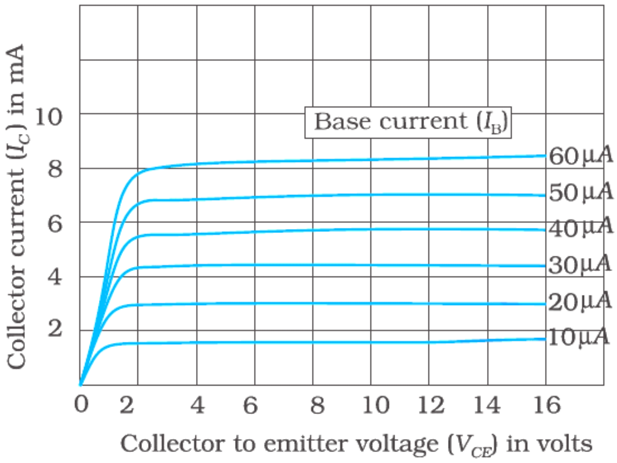
And

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right) = \frac{2mA}{20\mu A} = 100$$

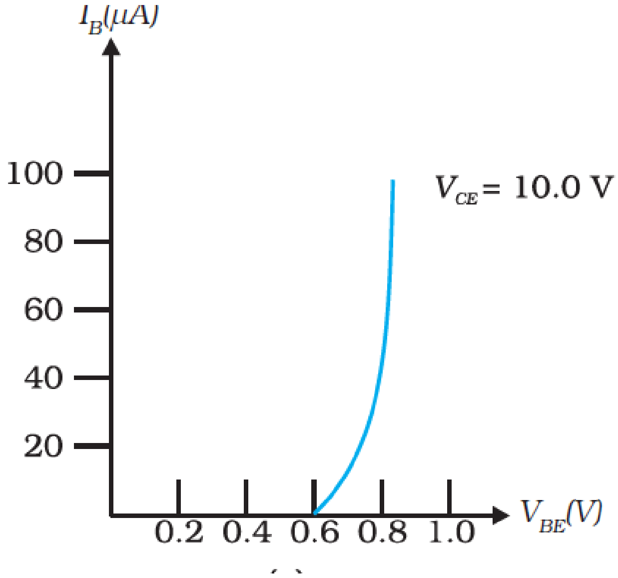
Summary

We have learnt

- *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 the 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 (µA) 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 the 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).
- **CE-configuration** is most commonly used.
- The plot between I_C and V_{CE} for fixed I_B is called output characteristics while



- The plot between I_B and V_{BE} with fixed V_{CE} is called input characteristics.



- The important transistor parameters for **CE-configuration** are

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

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

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