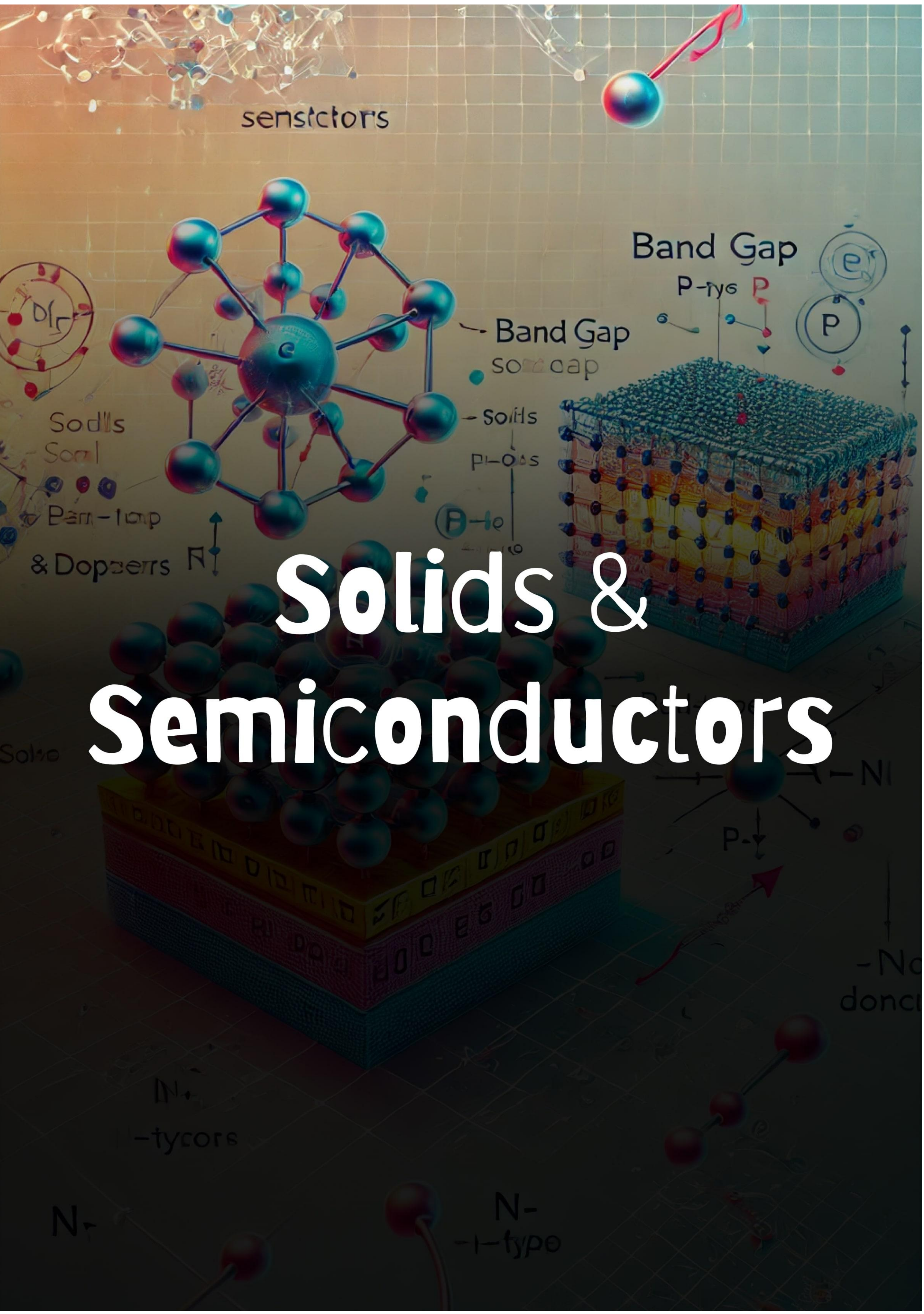


Solids & Semiconductors

Solids & Semiconductors

ENERGY BAND

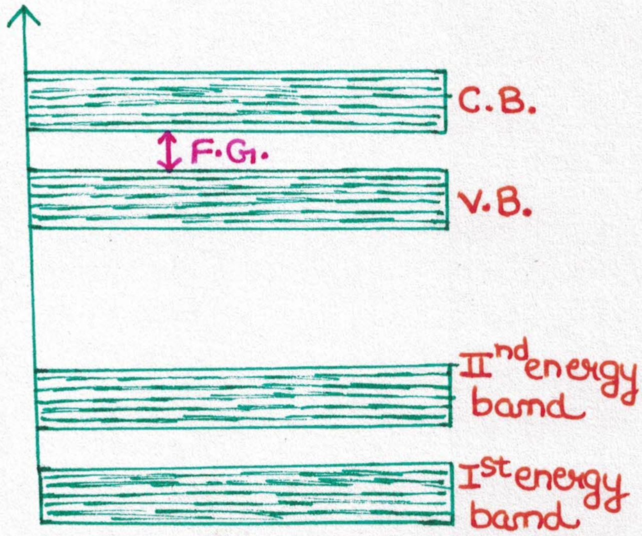
Electrons of same orbit having range of energies.

★ Isolated neutral gaseous atoms have fixed energy levels.

★ In solids, we draw 'ENERGY BAND DIAGRAM'.

VALENCE BAND

It is that energy band which has valence electrons.



CONDUCTION BAND

It is that energy band which has conduction OR free electrons.

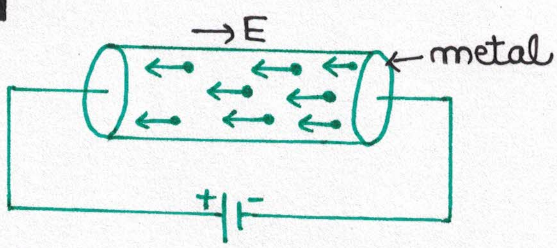
FORBIDDEN GAP

It is the energy gap b/w valence band and conduction band.

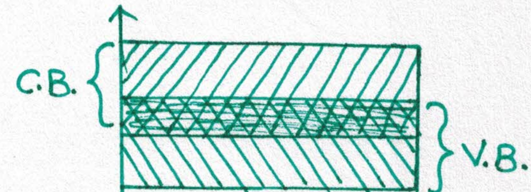
★ Every energy band has infinite energy levels.

CLASSIFICATION OF SOLIDS ON THE BASIS OF ENERGY BAND DIAGRAM

METAL

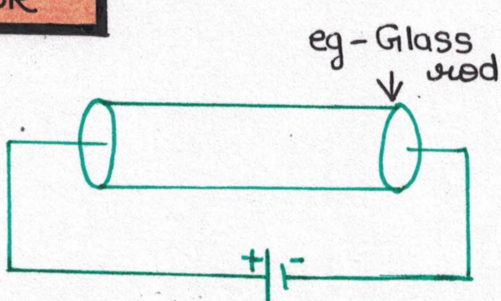


Large current flows

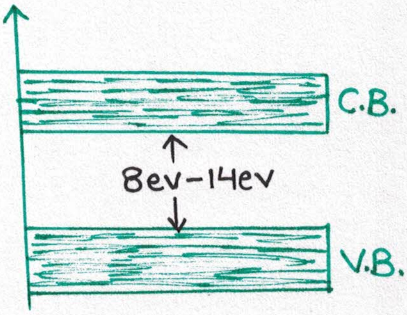


★ V.B. & C.B. are overlapping

INSULATOR



No current flows



Forward voltage is increased gradually in steps and the forward currents are noted.

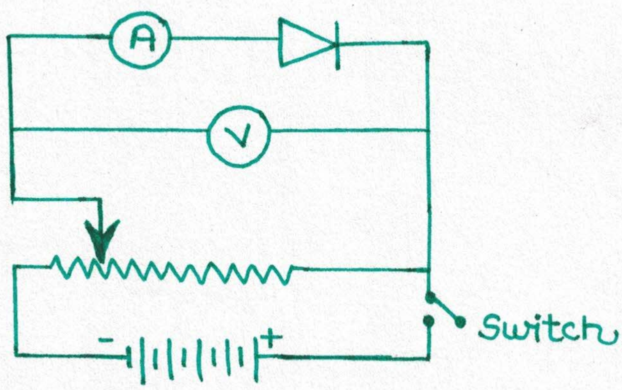
Then a graph is plotted b/w forward voltage & forward current.

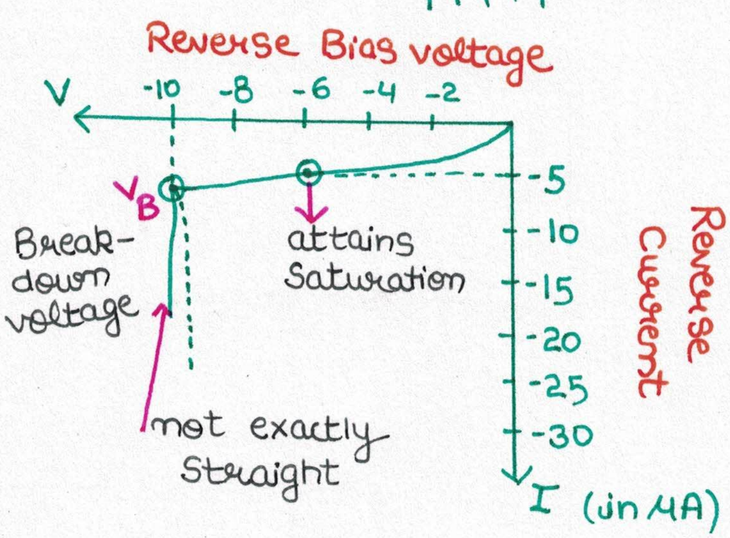
Observations: From the graph, we observe the following points:

1.) The forward current increases slowly with increase in forward bias voltage upto a certain voltage called 'Knee voltage'.

2.) After knee voltage, current increases rapidly & curve is almost linear.

REVERSE CHARACTERISTICS





Reverse voltage is increased gradually in steps, and the corresponding currents are noted. On plotting a graph b/w reverse voltage & reverse current, we get a graph as shown in figure.

Observations: The graph shows:-

1.) When the reverse voltage is increased from zero, the reverse bias current increases & reaches its maximum value, called the 'saturation current' for a small value of reverse voltage.

2.) When reverse voltage is further increased, the reverse current does not increase but remains constant.

3.) When the reverse voltage is increased beyond the value called 'breakdown voltage', the reverse current suddenly and sharp increases & the junction is said to be under breakdown. At this breakdown voltage, the curve indicates almost zero resistance.

4.) If the voltage is increased beyond breakdown voltage, the diode is likely to burn out.

NOTE: Zeaner Effect (OR Zeaner Breakdown)

It is a type of electrical breakdown in a reverse biased PN-junction in which the electric field enables tunnelling (lifting) of electrons from VB to CB of semiconductor, leading to a large no. of free minority carriers which suddenly increases the reverse current. This type of breakdown is used in Zeaner diode.

AVALANCHE BREAKDOWN

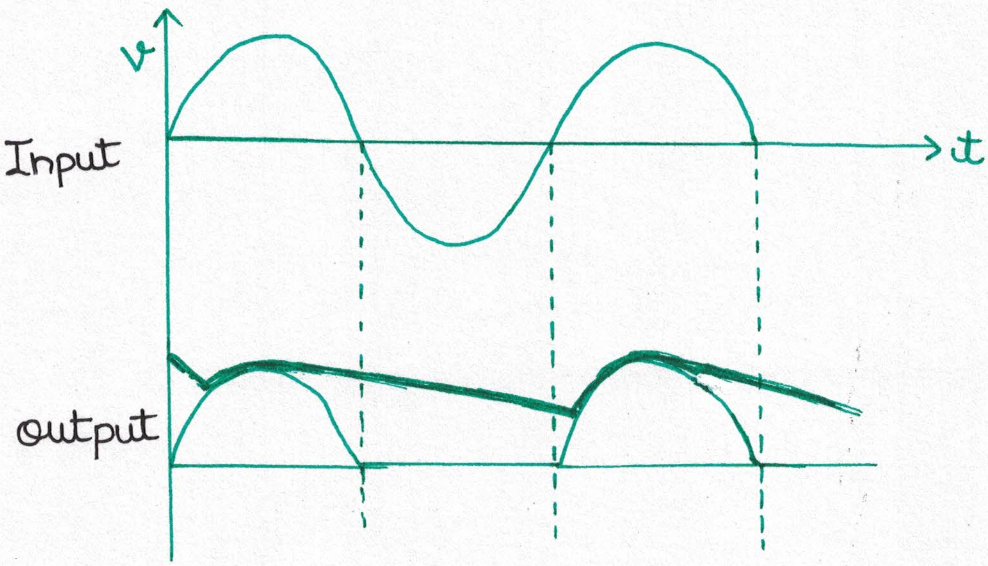
It is a form of electric current multiplication that can allow very large currents within such materials which are otherwise good insulators.

The avalanche process occurs when the carriers (i.e. e^-'s) in the depletion region are accelerated by the electric field, to energise sufficient to free e^- hole pairs via collision with bound electrons.

→ In case of reverse biasing, either only Zeaner breakdown occurs OR both Zeaner and Avalanche breakdown occur.

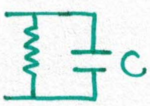
RECTIFIER: Rectifier is a device which converts AC into DC.

1.) P-N Junction as Half-Wave Rectifier:

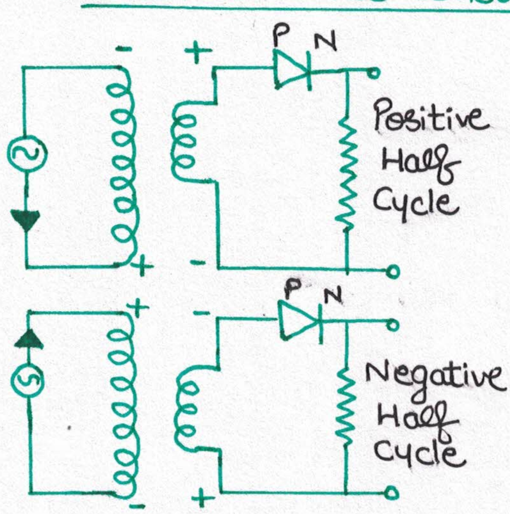


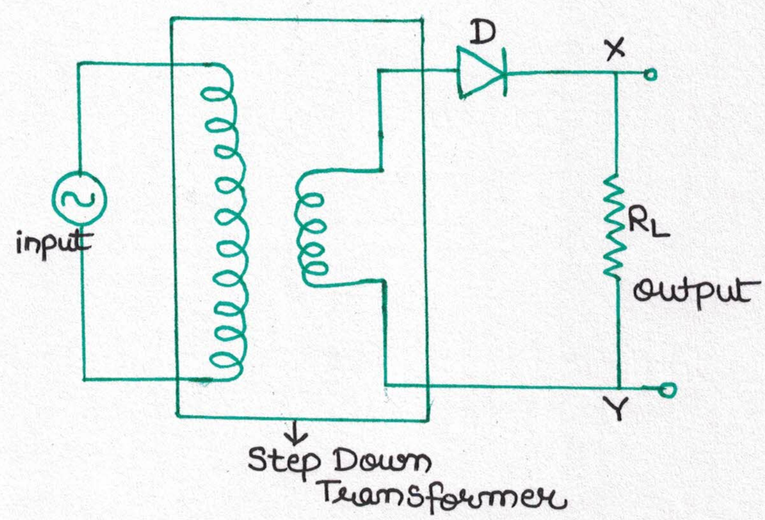
★ represents output if capacitor is connected with R_L

This output is pulsating DC



★ Unidirectional conductivity

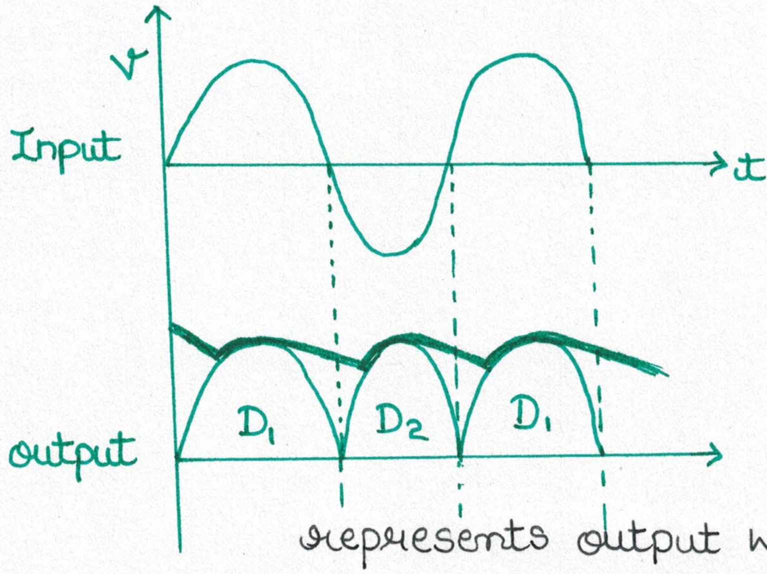




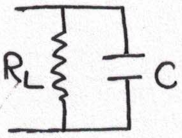
- When the positive half cycle of AC input is applied, the diode D is in forward bias, therefore it conducts.
- But when negative half cycle of AC input is applied, the diode D is in reverse bias, so it will not conduct.
- Hence, we get the output for +ve half cycle only.

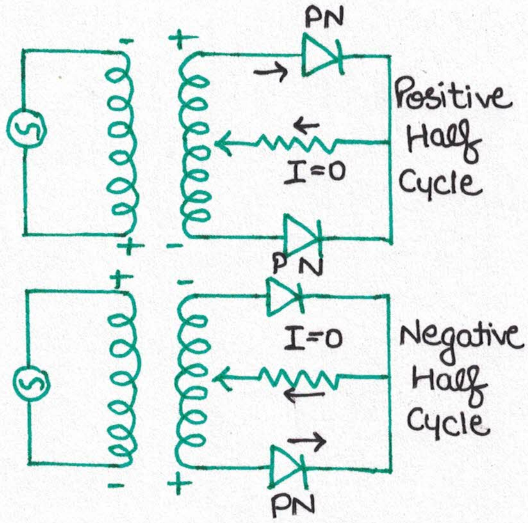
In half-wave rectifier, the frequency of input and output signals are same.

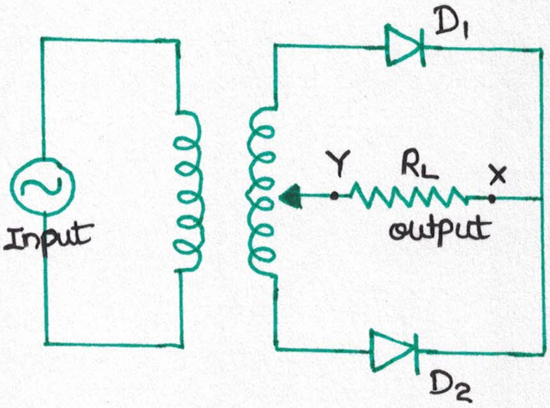
2:) P-N Junction as Full wave Rectifier:



represents output when



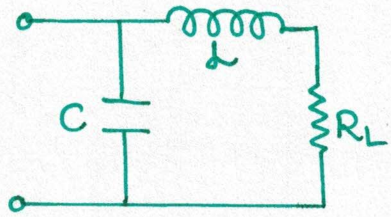




- In full wave rectifier, we make use of two diodes D_1 and D_2 and a centre tap transformer 'T'.
- When +ve half cycle of AC input is applied, the diode D_2 is in forward bias but D_2 is in reverse bias. So, D_1 will conduct but D_2 will not conduct.
  Hence we will get the output due to D_1 only.
- When -ve half cycle of AC input is applied the diode D_1 is in reverse bias but D_2 is in forward bias. So D_1 will not conduct but D_2 will conduct.
  Hence we will get the output due to D_2 only.

Therefore, we get the output due to D_1 and D_2 alternatively.

- Capacitor favours variation of current, which Inductor opposes. i.e. Capacitor opposes steadiness.
- Variable current prefers to go through capacitor.
- If we add more capacitors in parallel with resistor, variation in DC will be further reduced
- Inductor is placed in series with resistor to stop / oppose the varying current going through it.



TYPES OF DIODES

1. LED (LIGHT EMITTING DIODE)

- Materials used are GaP or GaAsP as they have high Forbidden Gap.
- An LED is a semiconductor light source.
- It is simply a forward biased P-N Junction which emits light when energised.

Principle: In a forward biased P-N Junction, electrons of N-region and holes of p-region are repelled towards the junction where e^--hole recombination takes place.
Now, the e^-'s are in higher conduction band on N-side & holes are in ~~lower~~ lower valence band on p-side. During the process of recombination, some ~~of~~ of this energy difference is used in the form of radiation (i.e. heat and light).

Ge & Si: In the case of Ge & Si junctions, greater percentage lies in infra-red region, so that the emitted light is insignificant.

GaP & GaAsP: In case of GaP & GaAsP, greater percentage of energy is released in the form of light.

→ The junction GaP emits mostly Red or Green light.

→ The junction GaAsP emits mostly Red and yellow light.

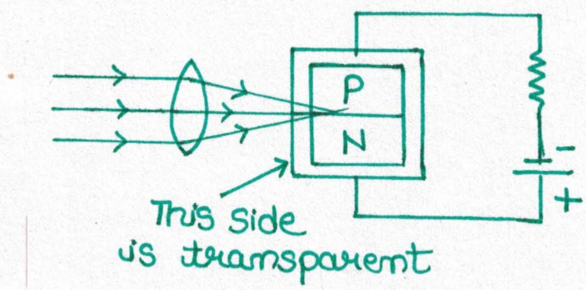
- LED is often small in area (less than 1 (mm)^2)
- LED's have many advantages over light source including lower energy consumption, longer lifetime, small size.
- LEDs are used in aviation lightning, automative lighting, advertising, general lighting and traffic signals.

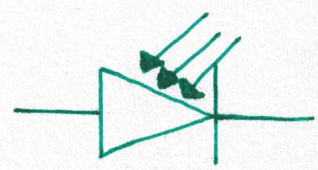
2. SEMI-CONDUCTOR PHOTODIODE

A semi-Conductor photo diode is simply a reverse biased PN-Junction, illuminated by radiation.

Principle: Basic principle of a Photo diode is that the current in a reverse biased PN junction varies almost linearly with the intensity of radiation.

Construction:





- To construct a photo diode, a PN-Junction is embedded in a glass OR clear plastic package.
- only one side of the package is kept transparent and all other sides are painted black.
- The entire unit is extremely small having dimensions of the order of 2.5mm.
- The PN-Junction is reverse biased and a converging lens is used to focus maximum light on the reverse biased junction.

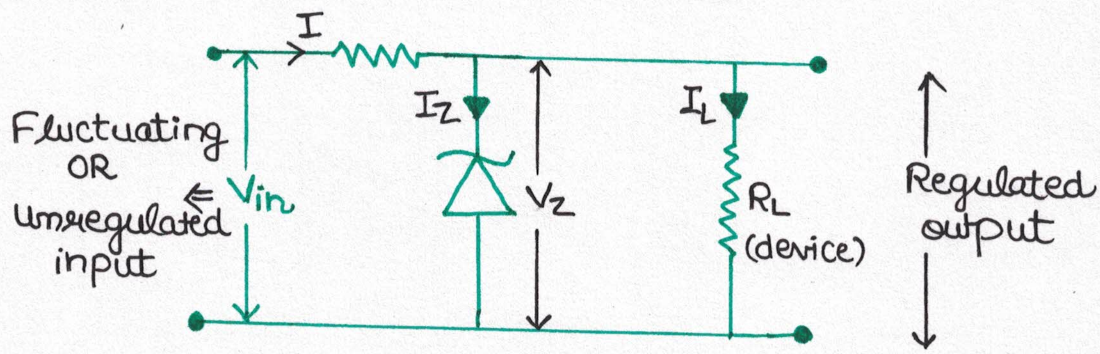
Working: when PN-junction is reversed and no light is made incident on it, then a small reverse Saturation current flows across, the junction. This is

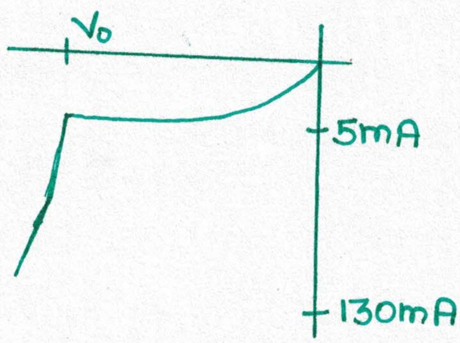
called dark current. Now if the light is made incident on the surface, addition of e⁻ hole pairs takes place.
As the concentration of majority charge carrier is much higher than minority carriers, therefore %age increase in majority charge carriers is much smaller than the minority carriers.

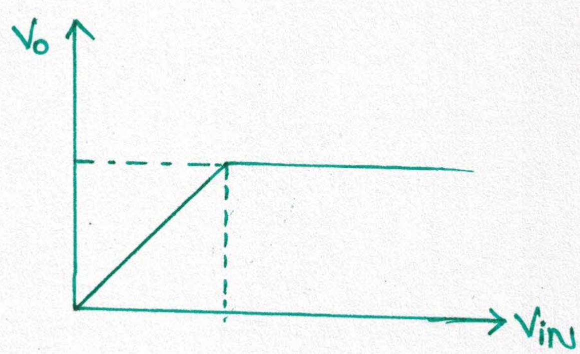
Hence, we may reflect the increase of majority charge carriers and consider the radiation solely as a minority charge carrier.
These newly created minority carriers defuse to the junction, cross it and create the current.
It is used in remotes and communication systems.

3. ZEANER DIODE

→ Heavily doped p-n.
→ So, depletion layer is very thin
→ So, breaks down very quickly.







$$I = I_Z + I_L$$

$$V_{in} - I(R_S) - V_Z = 0$$

$$\Rightarrow V_Z = V_{in} - I(R_S)$$

$$V_o = V_{in} - I(R_S)$$

- Z-diode is designed so that it may have greatly reduced breakdown voltage called **Zeaner Voltage.**
- The same can be achieved by changing thickness of depletion layer which is possible by doping both p & n sides heavily.
- Z-diode can be used in breakdown region continuously without being damaged, when I through ZD is controlled by external resistance.

Working: When input DC voltage across ZD increases beyond a certain limit ie Zeaner breakdown Voltage, the current through the circuit rises sharply, causing a sufficient increase in voltage-drop across the resistance R_S.
As a result, the voltage across ZD remains constant & hence output voltage also remains constant.

Que.) In a Zeaner regulated power supply, a zeaner with $V_Z = 6V$ is used, load current = 4mA and unregulated input = 10V. What should be the value of R_S?
Assume I_Z to be 5 times the load current.

$$I = I_Z + I_L$$
$$= 5(4) + 4$$
$$= 24\,mA$$

$$IR_S = V_{in} - V_Z$$
$$= 10 - 6 = 4V$$

$$R_S = \frac{4}{24 \times 10^{-3}}\,\Omega = \frac{1000}{6}\,\Omega$$

4. SOLAR CELL

→ It is basically a solar energy converter
→ It is a p-n junction device
→ It converts solar energy to electric energy.

Construction: A solar cell consists of either SiAs or GaAs pn-junction diode packed in a can with glass window on top.

- Upper layer is of P-type semi-conductor which is very thin so that the photolight e^-'s may easily reach the pn-junction.

- on the top face of p-layer, the metal finger electrodes are prepared in order to have enough spacing b/w the fingers for the light to reach the pn-junction thru the p-layer.

Working: ■ when photons of light (of energy $h\nu > E_g$) fall on the pn-junction, e⁻ hole pairs are generated in the depletion layer or near the pn-junction.

- The e⁻'s & holes produced, move in opposite direction due to junction field.
- The photo generated e⁻'s move towards n-side & the photo generated holes will move towards p-side.
- They will be collected at the two sides of the junction, giving rise to a photo voltage b/w the top & the bottom electrodes.
- The top metal contact acts as a positive electrode & the bottom metal contact acts as negative electrode.
- When an external load is connected, across the metal electrodes, a photo current flows.

Uses: → For charging storage battery during day time which can supply power during night.

→ In power traffic signals.

→ To produce electronic power ~~from the~~ in remote areas where power from the electric power supply units is unavailable.

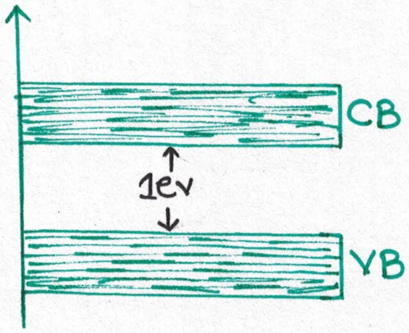
→ In artificial satellite to operate the various electrical instruments kept inside the satellite.

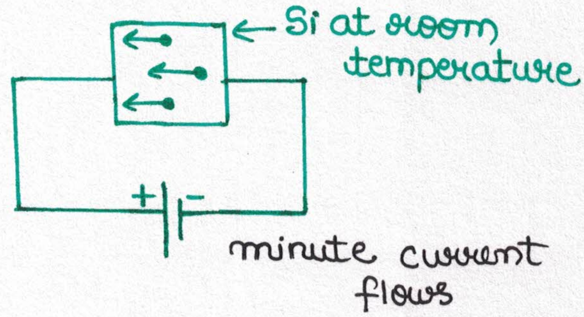
★ Energy of photon falling on the junction must be greater than the forbidden gap.

3. SEMI-CONDUCTORS

Eg - Silicon, Germanium

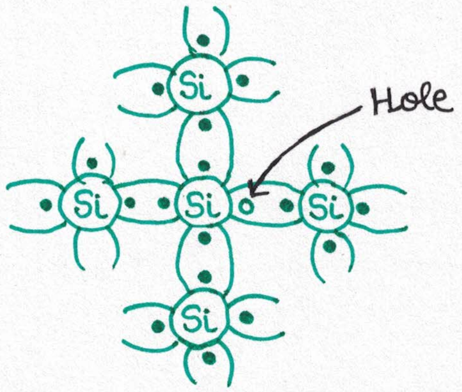
- Only some electrons jump from VB to CB ie. some e⁻'s are available in C.B.





- With increase in temp., conductivity of
  - 1.) metals decreases
  - 2.) semiconductors increases
- Because in semiconductors, more no. of electrons lift from VB to CB with heating.
- Semiconductors have negative temp. coefficient of resistance.
- At zero K temp., conductivity of semiconductors is zero, ie at 0 K temp., semiconductors behave as perfect insulators.

Crystal of Si:



★ HOLE:

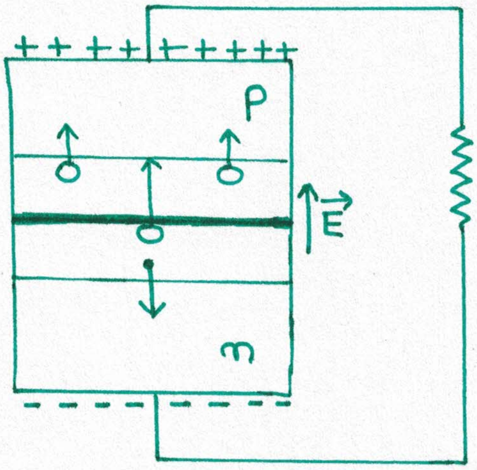
- Vacancy created in the VB, when an electron lifts from VB to CB.
- It is strongly positive & Charge on one hole = +e
- It attracts nearby electrons in the covalent bond.

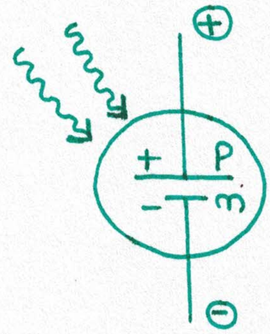
- When an electron comes to the hole, electron-hole recombination take place and the hole vanishes.
- Hole is always in the VB.

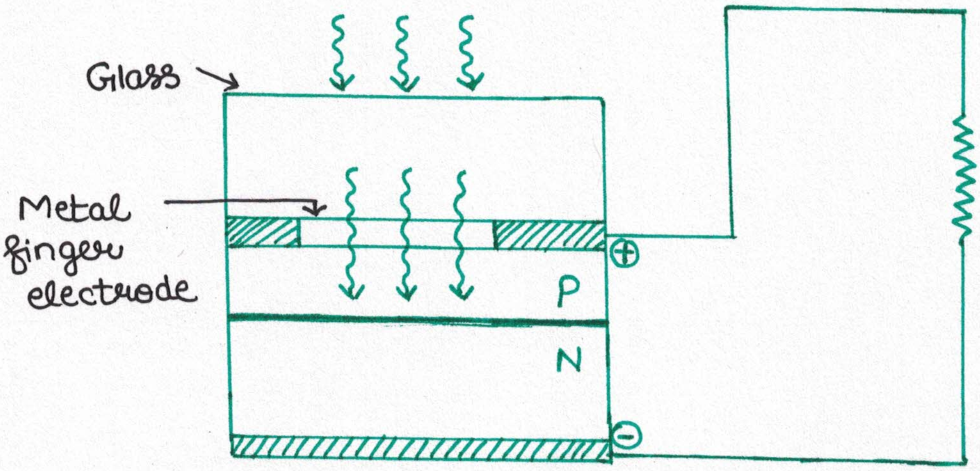
★ Charge carriers in Semiconductors:

1.) free electrons

2.) holes

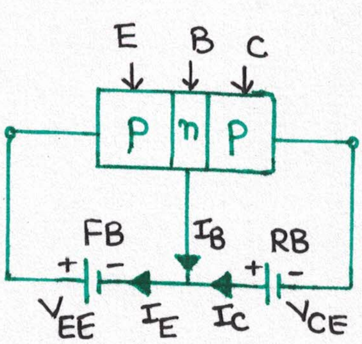


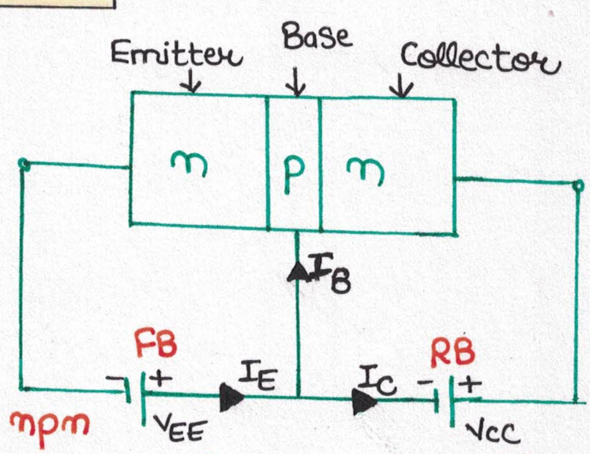




A p-n photodiode is fabricated from a semi-conductor with band gap of 2.8 eV. Can we detect wavelength of 600 nm ?

TRANSISTOR





Common Base Transistor

→ Consists of two pn-junctions connected back to back.

→ In one kind of transistor, a thin 'p-type' material is sandwiched b/w two 'N-type' material.

→ In other kind of transistor, a thin 'N-type' material is sandwiched b/w 'p-type' material.

→ Hence, there are two types of transistors:

(a) npn (b) pnp

★ In a transistor, there are three regions viz. emitter, base and collector.

→ Emitter is highly doped and not much large in size.

→ Base is lightly doped and thin.

→ Collector is moderately doped and large is size.

Hence, a transistor has three terminals & two pn-junctions

For npn & pnp

$(I_E = I_B + I_C)$

Emitter current = Base current + collector current.

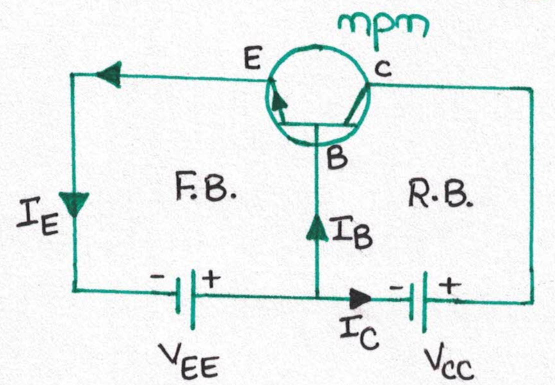
Transistor is used for power amplification:

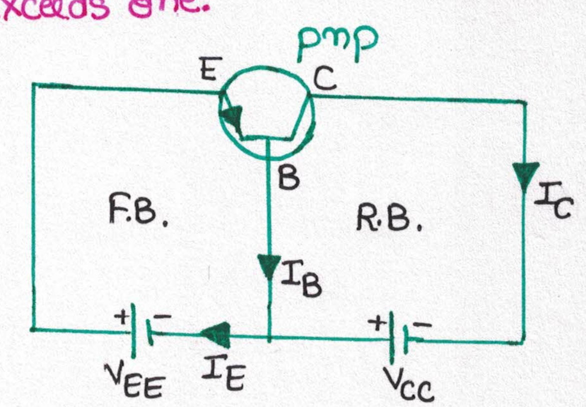
i.e. it increases (VI).

Batteries / cells used for its biasing are source of energy by which power of signal is amplified.

TRANSISTOR SYMBOL

voltage in FB is always in fraction & never exceeds one.

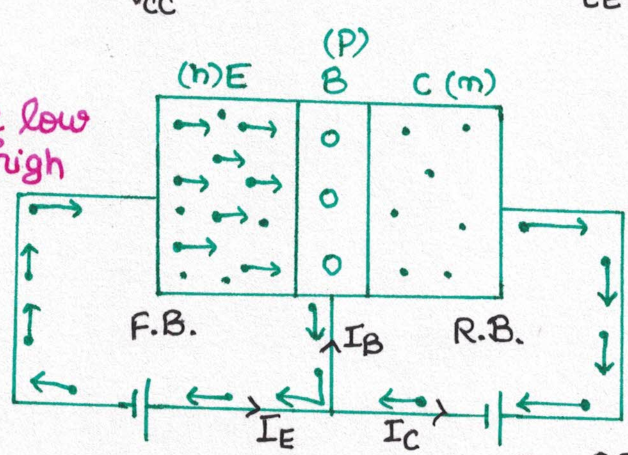




FB

(≃0.6V) Voltage low

(mA) Current high



RB

(20-60V) Voltage high

(μA) Current low

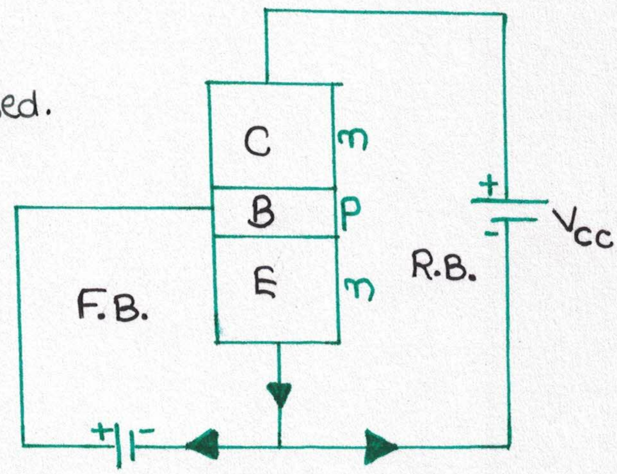
$I_B < 5\%$ of I_E , $I_C > 95\%$ of I_E

COMMON EMITTER CONFIGURATION

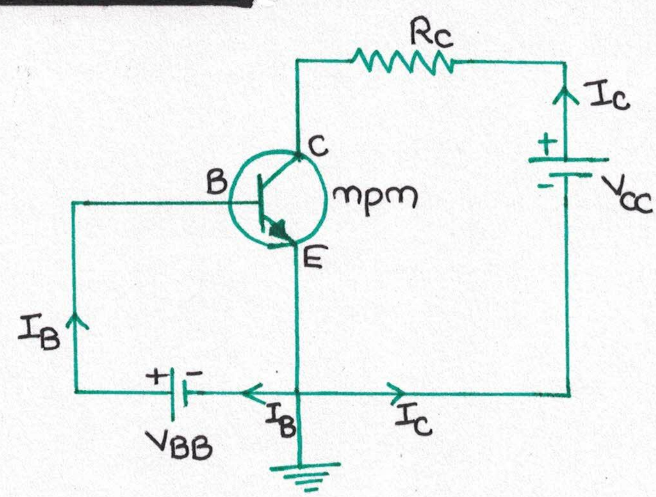
Common → Emitter
Input → Base
Output → Collector

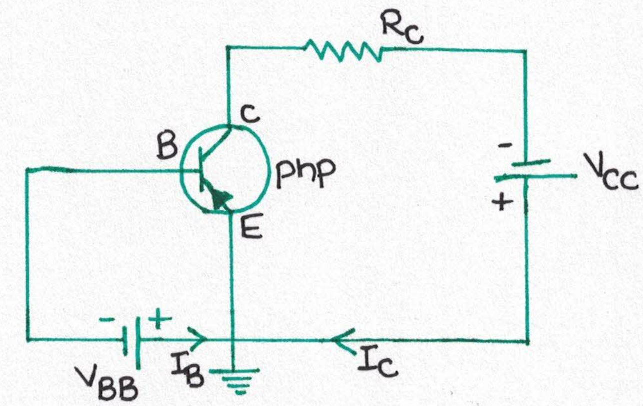
* Input is always forward biased.

* $I_E = I_B + I_C$

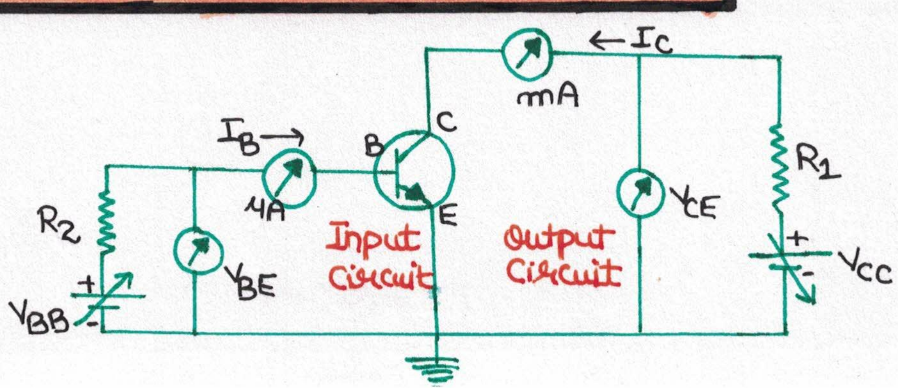


TRANSISTOR SYMBOL





CHARACTERISTICS OF A TRANSISTOR

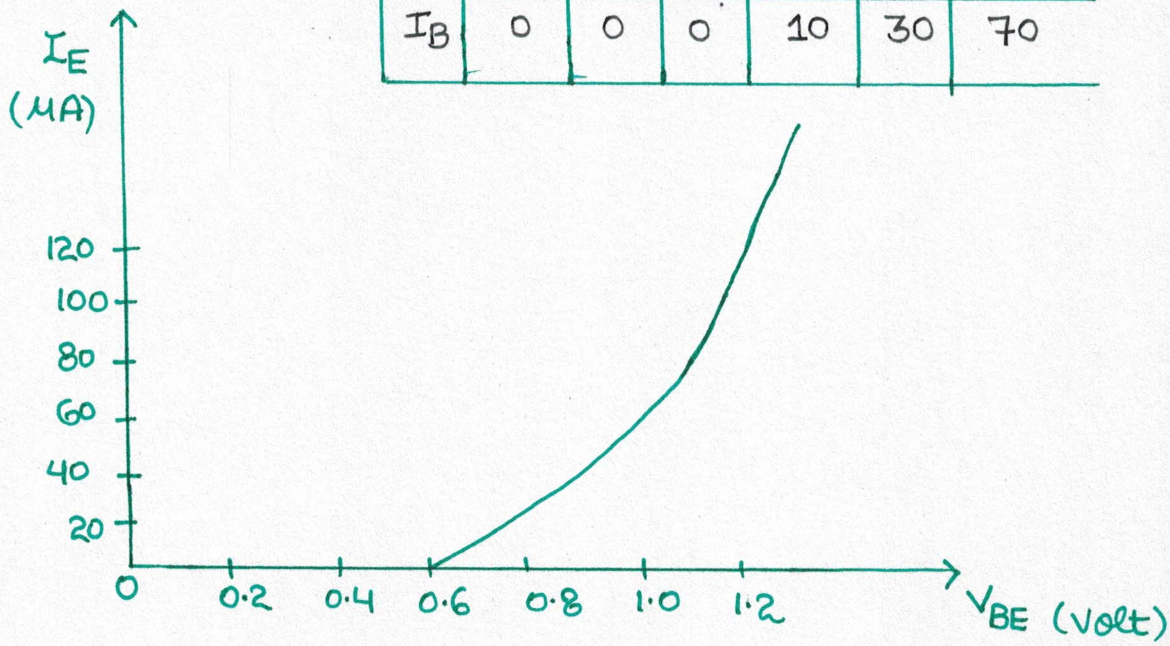


V_{BE} = measure p/d between base & emitter

INPUT CHARACTERISTICS

These characteristic curves are obtained by plotting the base current Vs base emitter voltage (V_{BE}) for fixed collector emitter voltage (V_{CE}).

V_{BE}	0.2	0.4	0.6	0.65	0.7	0.75
I_B	0	0	0	10	30	70



We draw the input characteristics when the transistor is in active state:

1.) The characteristics are similar to that of a forward-biased diode.

2.) The input- base current (I_B) increases with increase of base- emitter voltage (V_{BE})

3.) Input resistance is given by

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

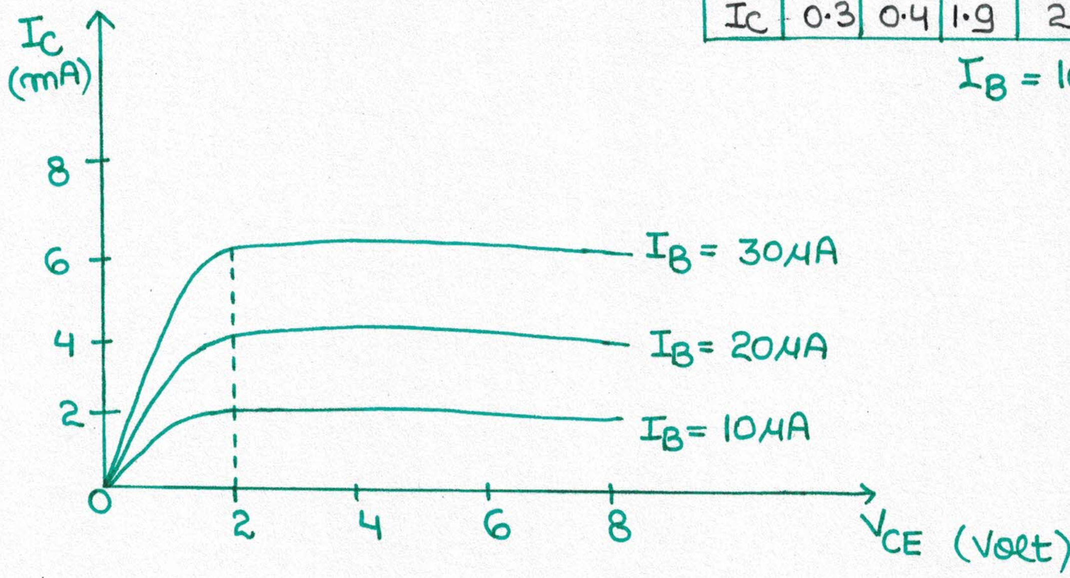
★ Such types of resistances, which are not constant & for whom, ohm's law is not applicable, are called dynamic resistances.

OUTPUT CHARACTERISTICS

These characteristics are obtained by plotting collector current (I_C) Vs collector- emitter voltage (V_{CE}) at fixed value of base current (I_B).

V_{CE}	0.5	0.8	1	2	4	6
I_C	0.3	0.4	1.9	2	2	2

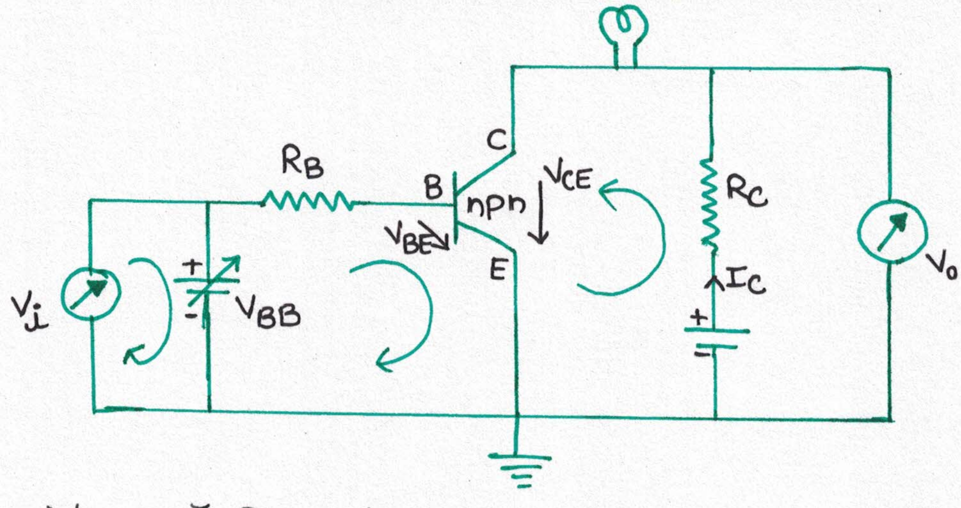
$I_B = 10\mu A$



These characteristic curves show that:
When V_{CE} is increased from zero, I_C increases as V_{CE} increases from 0 to 1 volt.
And, beyond 1 volt, I_C becomes almost independent of V_{CE}. Then output resistance

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

TRANSISTOR AS A SWITCH



$$V_{BB} - I_B R_B - V_{BE} = 0 \quad -(1)$$

$$V_i - V_{BB} = 0 \quad -(2)$$

From (1) & (2),

$$V_i = I_B R_B + V_{BE} \quad -(I)$$

$$V_{CC} - I_C R_C - V_{CE} = 0 \quad -(3)$$

$$V_{CE} = V_o \quad -④$$

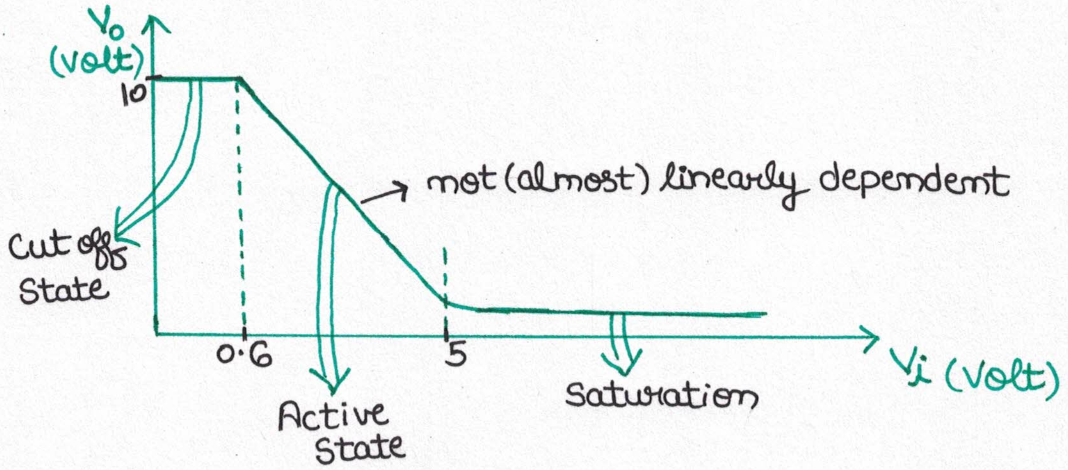
from ③ & ④,

$$V_o = V_{CC} - I_C R_C \quad -(II)$$

★ When $I_B = I_C = I_E = 0$, transistor is in 'cut-off' mode.

V_i	0.2	0.4	0.6	0.65	0.7	------- 5
V_o	10	10	10	9	8	------ 0.01
(μA) I_B	0	0	0	10	15	------ 100
(mA) I_C	0	0	0	2	3	------- 10

(taking $V_{CC} = 10V$)

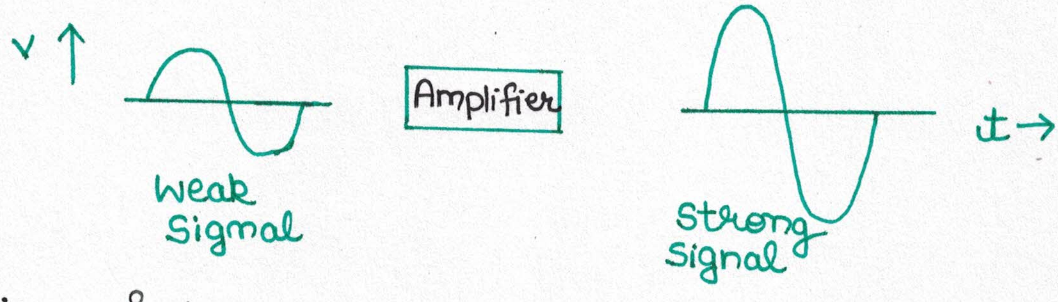


While using transistor as a switch, we use only two modes / states → cut-off and saturation.

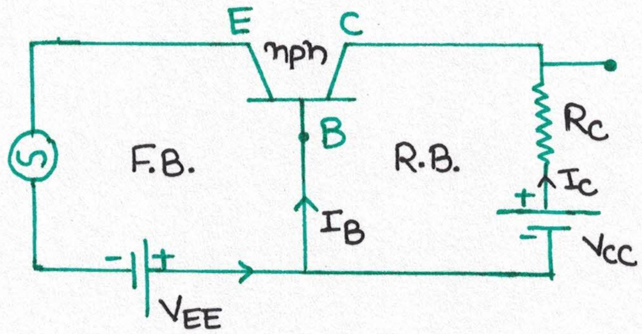
i.e. V_i is kept either less than 0.6 V.
or kept higher than 5 V.

★ Transistor is used as an amplifier in active state.

TRANSISTOR AS AN AMPLIFIER



Device which increases the strength of a weak signal.



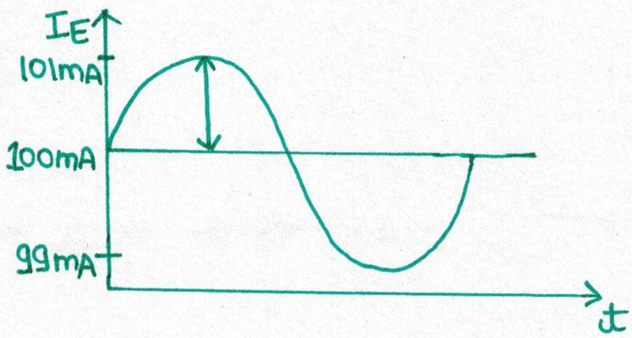
$I_E = I_B + I_C$

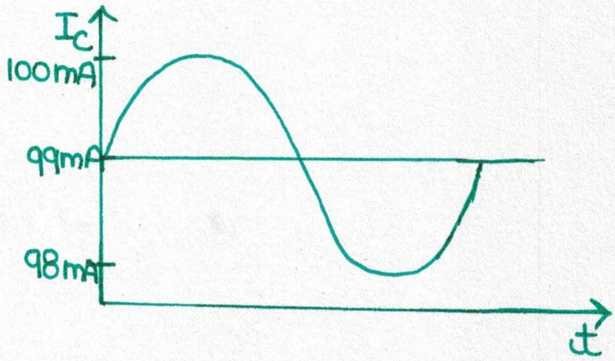
$\Delta I_E = \Delta I_B + \Delta I_C$

Since I_B is small

$\therefore \Delta I_B$ is negligible

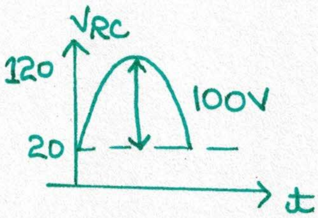
$\Delta I_E \simeq \Delta I_C$





$\Delta I_E = 1mA$

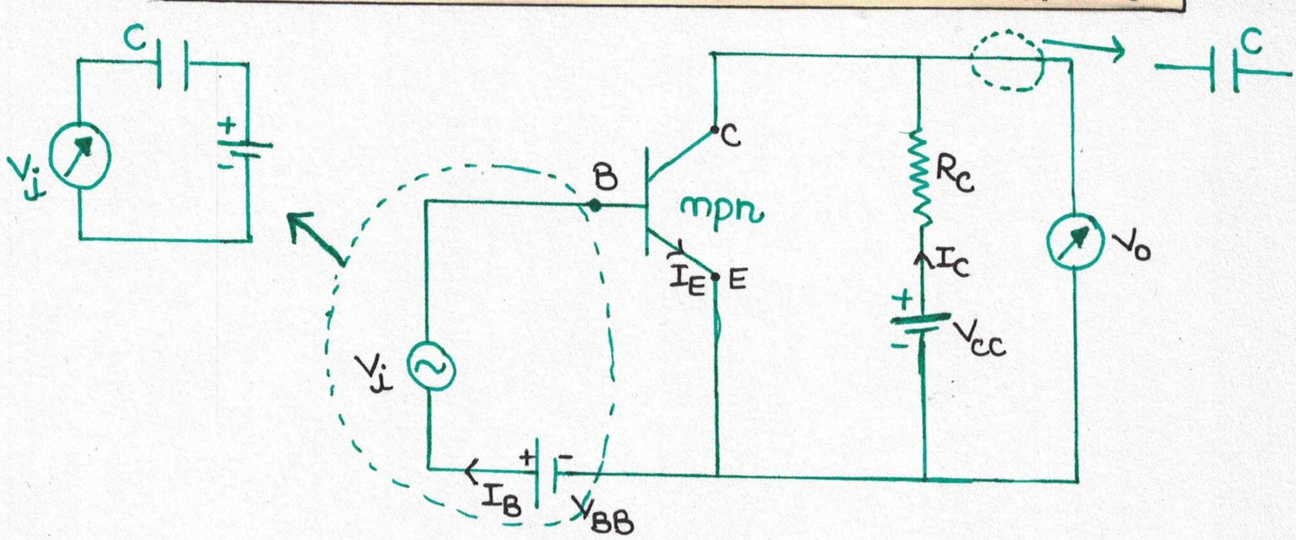
$\Delta I_C = 1mA$



- P/d across $R_C = (\Delta I_C)(R_C)$

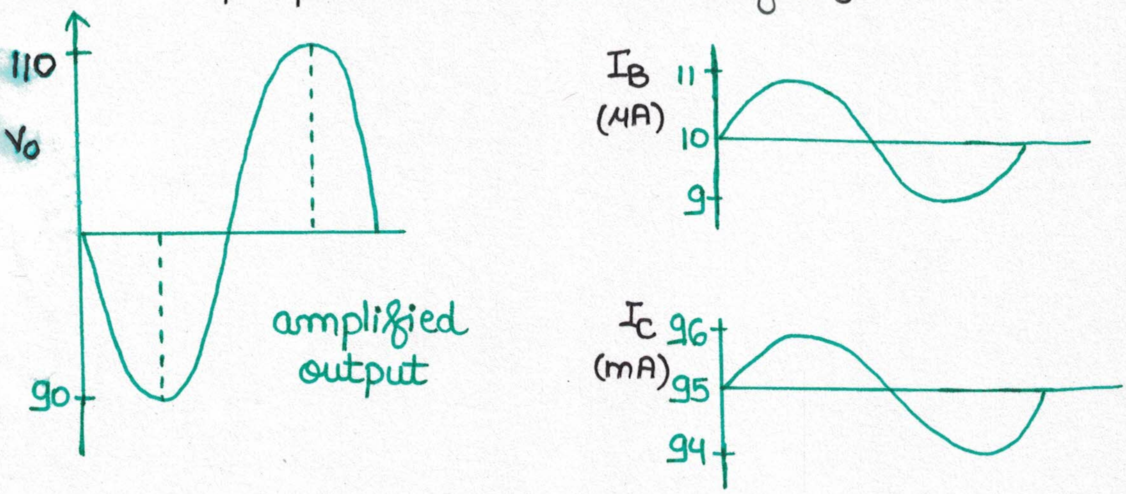
for $R_C = 100K\Omega$, $(P/d)_{R_C} = (1mA)(100K\Omega)$
$= 100V$

TRANSISTOR AS COMMON EMITTER AMPLIFIER



Working: If a weak sinusoidal voltage is superposed on the DC-based bias, in series with V_{BB}, then base current (I_B) will have sinusoidal variations superposed on the value of I_B.

As a consequence, collector will also have sinusoidal variations superposed on the value of I_C.



PHASE RELATION B/W INPUT & OUTPUT VOLTAGE

When the +ve half cycle of weak sinusoidal voltage comes, it favours the forward biasing of Base-emitter-circuit, due to which I_B increases and consequently, the collector current increases. As a result of this, output voltage (V_0) decreases.

Since the collector is connected to the +ve terminal of V_{CC} battery, therefore decreases in V_0 means collector will become less positive.

When the -ve half cycle of sinusoidal voltage comes, it opposes the forward biasing of B.E. circuit, due to which I_B decreases & consequently I_C decreases. As a result, output voltage (V_0) increases i.e. the collector becomes more +ve.

Hence in Common emitter amplifier, input & output signals are 180° (out of phase).

VARIOUS GAINS IN COMMON-EMITTER AMPLIFIER

CURRENT GAIN

(a) dc current gain

$$\beta = \frac{\text{output current}}{\text{Input current}} = \frac{I_C}{I_B}$$

(b) AC current gain

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

AC VOLTAGE GAIN

$$A_V = \frac{\text{Change in output voltage}}{\text{Change in Input voltage}} = \frac{\Delta V_o}{\Delta V_i}$$

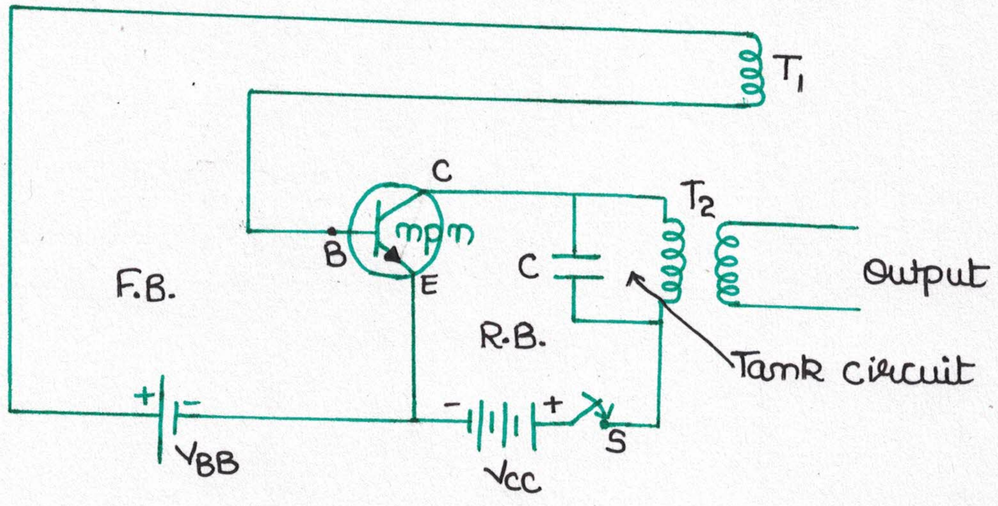
or $$A_V = \frac{\Delta I_C \times R_o}{\Delta I_B \times R_i}$$

$$A_V = \beta_{ac} \times \frac{R_o}{R_i}$$

AC POWER GAIN

$$A_P = (\beta_{ac})^2 \times \frac{R_o}{R_i}$$

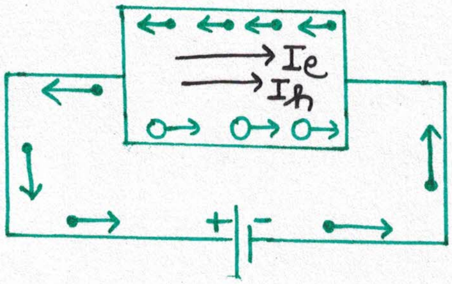
TRANSISTOR AS AN OSCILLATOR

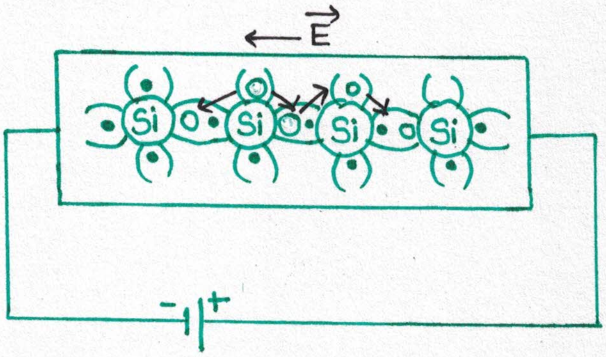


Inductive coupling : Binding of the inductors.
Here T_1 and T_2 are bind.

HOLE CURRENT

The apparent movement of hole through the semiconductor crystal constitutes hole current.





$$I = I_e + I_h$$

= (electronic current) + (Hole current)

INTRINSIC SEMICONDUCTORS

1.) extremely pure semiconductor
2.) No. of holes in V.B. = no. of free e^-'s in C.B.
3.) are poor conductor of charge carriers (electricity) due to low no. of charge carriers.

★ Conductivity is proportional to temperature and is a function of temperature only.

→ Current in a pure semiconductor is insignificant.

→ To increase their conductivity, we use DOPING.

DOPING:
The process of addition of small amount of impurity to a pure semiconductor crystal, in order to increase its conductivity.

EXTRINSIC SEMICONDUCTORS

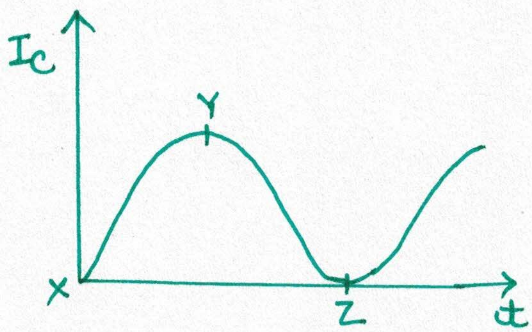
1.) Impure (or doped) semiconductor.
2.) No. of holes in V.B. ≠ no. of free e^-'s in C.B.
3.) are good conductors of electricity.

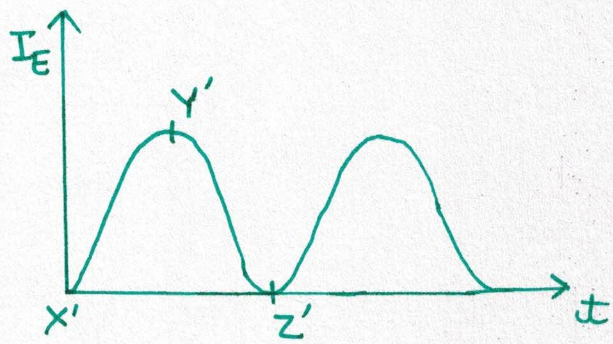
★ Conductivity depends both, on temperature & on the amount of doping.

1.) Let switch S is pressed to apply proper bias for the first time.

2.) A surge of collector current flows in the transistor. This collector current (I_C) flows through the coil T_2. This current does not reach full amplitude instantaneously but increases from X to Y as shown.

3.) The inductive coupling b/w coil T_2 and coil T_1, now causes a current to flow in the emitter circuit.
As a result of this positive feedback, the current (I_E) in T_1 also increases from 'X' to 'Y'.
The amount in T_2 connected in the collector circuit acquires the value 'Y' when the transistor becomes saturated.
Since there is no further change in I_C, the magnetic field around T_2 siezes to grow. Therefore, there is no feedback from T_2 to T_1. Consequently, I_E begins to fall & I_C also begins to fall from Y to Z. However, a decrease of I_C causes the magnetic field to decay around the coil T_2.





DECIMAL & BINARY SYSTEM

```
2 | 23
2 | 11 - 1
2 | 5 - 1
2 | 2 - 1
  | 1 - 0
```

$\therefore 23 = 10111_2$

$= (1\times2^4) + (0\times2^3) + (1\times2^2) + (1\times2^1) + (1\times2^0)$

$10 = 1010_2$