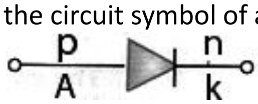
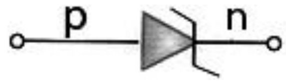
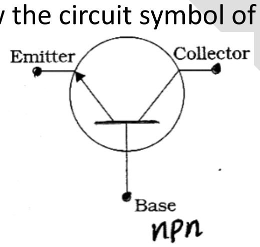
Chapter No: 14	
Chapter:	**Semiconductor Electronics: Materials, Devices And Simple Circuits**

(ONE MARK QUESTIONS)

1. What is an electronic device?
   Ans. It is a device in which controlled flow of electrons takes place either in vacuum or in semiconductors.
2. What is an energy band in a solid?
   Ans. Energy band is a group of close by energy levels with continuous energy variation.
3. What is a valence band?
   Ans. Valence band is the energy band which includes the energy levels of the valence electrons. It is the range of energies possessed by valence electrons.
4. What is conduction band?
   Ans. Conduction band is the energy band which includes the energy levels of conduction electrons or free electrons.
5. What is energy gap or energy band gap?
   Ans. The gap (spacing) between the top of the valence band (E_V) and the bottom of the conduction band (E_c) is called the energy band gap (E_g) or energy gap.
6. What is the order of energy gap in a semiconductor?
   Ans. 1eV
7. At what temperature would an intrinsic semiconductor behave like a perfect insulator?
   Ans. 0 K (absolute zero temperature)
8. What is an intrinsic semiconductor?
   Ans. It is a pure semiconductor in which electrical conductivity is solely due to the thermally generated electrons and holes.
9. What is doping?
   Ans. The process of adding suitable impurity atoms to the crystal structure of pure semiconductor like Ge or Si to enhance their electrical conductivity is called doping.
10. What is a hole?
    Ans. The vacancy of an electron(of charge -e) in the covalent bond with an effective positive charge +e is called a hole.
11. What is an extrinsic semiconductor?
    Ans. The semiconductor obtained by doping a pure semiconductor like silicon with impurity atoms to enhance its conductivity is called an extrinsic or doped semiconductor.
12. Name one dopant which can be used with germanium to form an n-type semiconductor.
    Ans. Phosphorus.
13. What are dopants?
    Ans. The impurity atoms added to pure semiconductors like germanium to increase their electrical conductivity are called dopants.
14. Name the majority charge carriers in p-type semiconductors.
    Ans. Holes.
15. What is depletion region in a p-n junction?
    Ans. The space charge region at the p-n junction which consists only of immobile ions and is depleted of mobile charge carriers is called depletion region.
16. How does the width of the depletion region of a p-n junction change when it is reverse biased?
    Ans. The depletion region width increases.
17. What is the forward resistance of an ideal p-n junction diode?
    Ans. Zero.
18. Draw the circuit symbol of a semiconductor diode.
    Ans. 

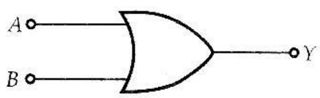
19. Name any one optoelectronic device.
Ans. Photodiode / Light emitting diode / photovoltaic cell or solar cell.
20. Draw the circuit symbol of a Zener diode.
Ans.


22. What is rectification?
Ans. The process of converting AC (alternating current) to pulsating DC is called rectification.
23. How does the conductivity of a semiconductor change with rise in its temperature?
Ans. The conductivity increases exponentially with temperature.
24. Is the ionisation energy of an isolated free atom different from the ionization energy E_g for the atoms in a crystalline lattice?
Ans. Yes. It is different since in a periodic crystal lattice each bound electron is influenced by many neighbouring atoms.
25. Which process causes depletion region in a p-n junction?
Ans. The diffusion of majority charge carriers i.e., free electrons and holes across the p–n junction causes the depletion region.
26. What is the order of the thickness of the depletion layer in an unbiased p-n junction?
Ans. micrometer (10^{-6} m).
27. What is a photodiode?
Ans. It is a special purpose p-n junction diode whose reverse current strength varies with the intensity of incident light.
28. Under which bias condition a Zener diode is used as a voltage regulator?
Ans. Reverse bias.
29. How is the band gap E_g of a photodiode related to the maximum wavelength λ_m that can be detected by it?
Ans. $E_g = \frac{hc}{\lambda_m}$ h : Planck's constant

c : speed of light in vacuum.
30. What is a solar cell?
Ans. It is a photovoltaic cell which is basically a p-n junction which generates emf when solar radiation falls on it.
31. Draw the circuit symbol of an npn transistor.


Ans.
32. Define current gain or current amplification factor of transistor in CE mode.
Ans. The current gain (β) is defined as the ratio of change in collector current to corresponding change in base current at constant collector–emitter voltage.
33. What kind of biasing will be required to the emitter and collector junctions when a transistor is used as an amplifier?
Ans. Emitter-base junction is forward biased while collector-base junction is reverse biased.
34. Which region of the transistor is made thin and is lightly doped?
Ans. Base.
35. Under what condition a transistor works as an open switch?
Ans. When the transistor is in cut off state it works as an open switch.

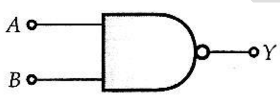
36. What is an oscillator?
Ans. It is an electronic device which is used to produce sustained electrical oscillations of constant frequency and amplitude without any external input.
37. What type of feedback is used in an oscillator?
Ans. Positive feedback.
38. What is an analogue signal?
Ans. An electrical signal (current or voltage) which varies continuously with time is called an analogue signal.
39. What is a digital signal?
Ans. A signal (current or voltage) which takes only discrete values is called digital signal.
40. What is a logic gate?
Ans. A logic gate is a digital circuit that follows certain logical relationship between the input and output signals and works on the principles of Boolean algebra.
41. Draw the logic symbol of an OR gate.
Ans.



42. Write the truth table for a NOT gate.
Ans.

A	$y=\bar{A}$
0	1
1	0

43. Draw the logic symbol of NAND gate
Ans.



(TWO MARKS QUESTIONS)

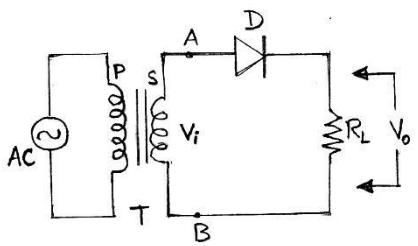
1. Name the charge carriers in the following at room temperature: (i) conductor (ii) semiconductor.
Ans. (i) conductor: Electrons are charge carriers
(ii) semiconductor: electrons and holes are charge carriers
2. Name the factors on which electrical conductivity of a pure semiconductor depends at a given temperature.
Ans. (i) The width of the forbidden band.
(ii) Intrinsic charge carrier concentration.
3. Mention the necessary conditions for doping.
Ans. 1. The dopant (impurity atom) should not distort the original pure semiconductor lattice.
2. The size of the dopant atom should be nearly the same as that of the semiconductor (host) atoms.
4. Name one impurity each, which when added to pure Si produces (i) n-type and (ii) p-type semiconductor.
Ans. (i) n-type→impurity to be added – phosphorus / antimony
(ii) p-type→impurity to be added – aluminium / boron.
5. Give two differences between intrinsic and extrinsic semiconductors.
Ans.

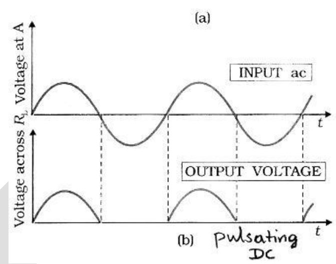
Intrinsic semiconductors	**Extrinsic semiconductors**
1. Electrical conductivity depends only on temperature	1. Electrical conductivity depends on both temperature and dopant concentration
2. The number of free electrons is equal to the number of holes	2. The number of free electrons is not equal to number of holes

6. Give two differences between n-type and p-type semiconductors.
   Ans.

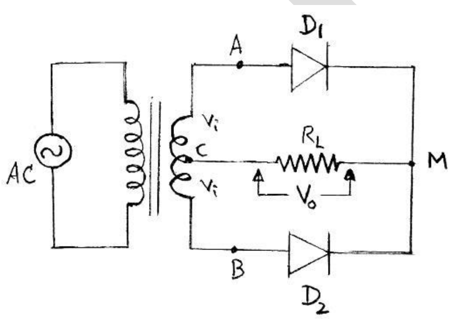
n-type semiconductor	**p-type semiconductor**
1. These are extrinsic semiconductors obtained by doping Ge or Si crystals with pentavalent dopants like Phosphorus.	1. These are extrinsic semiconductors obtained by doping Ge or Si crystals with trivalent dopants like aluminium.
2. Free electrons are the majority charge carriers and holes are minority charge carriers	2. Free electrons are minority charge carriers and holes are majority charge carriers.

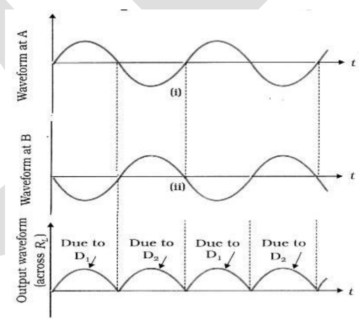
7. What happens to the width of the depletion layer of a p-n junction when it is (i) forward biased? (ii) reverse biased?
   Ans. (i) The depletion layer width decreases when p-n junction is forward biased.
   (ii) The depletion layer width increases when p-n junction is reverse biased.
8. Draw a labelled diagram of a half wave rectifier. Draw the input and output waveforms.
   Ans.





9. Draw a labelled diagram of a full wave rectifier. Draw the input and output waveforms.
   Ans.





10. Zener diodes have higher dopant densities as compared to ordinary p-n junction diodes. How does it effect: (i) the width of the depletion layer? (ii) the junction field?
    Ans. (i) The width of the depletion layer becomes small.
    (ii) The junction electric field becomes large.
11. Explain why a photodiode is usually operated under reverse bias.
    Ans. During reverse bias the reverse saturation current due to minority charge carriers is small. When light is incident the fractional increase in minority charge carrier concentration is significant and is early measurable. If the photodiode is forward biased, under illumination the fractional increase in charge carriers is insignificant and is difficult to measure. Hence photodiode is usually operated in reverse bias.

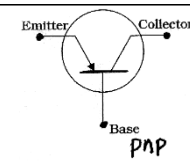
12. What is an LED? Mention two advantages of LED over conventional incandescent lamps.
Ans. LED (Light emitting diode) is a heavily doped p-n junction which under suitable forward bias emits spontaneous radiation.
The advantages of LEDs over incandescent lamps.
(i) LEDs operate at low voltages and consume less power.
(ii) LEDs have long life, are rugged and have fast switching (on-off) capability.

13. Mention the factor which determines the (i) frequency and (ii) intensity of light emitted by LED.
Ans. (i) The frequency of light emitted by an LED depends on the band gap of the semiconductor used in LED.
(ii) The intensity of light emitted depends on the doping level of the semiconductor used.

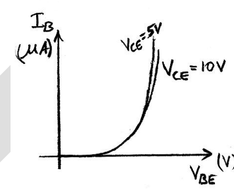
14. Give two operational differences between light emitting diode (LED) and photodiode.
Ans.

LED	**PHOTODIODE**
1. It is forward biased	1. It is reverse biased
2. Recombination of electrons and holes takes place at the junction and light is emitted ($h\nu$)	2. Light energy ($h\nu$) falling on the p-n junction creates electron-hole pair which increases photocurrent.

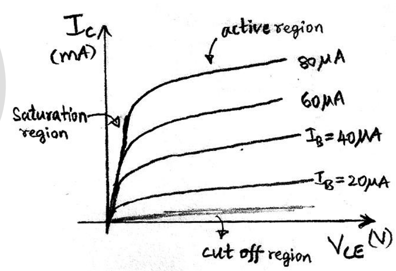
15. What is a transistor? Draw the circuit symbol of pnp transistor.
Ans. Transistor is a three terminal two junction semiconductor device whose basic action is amplification.



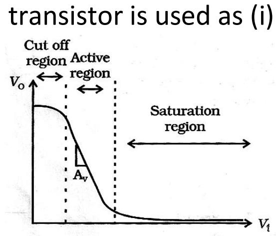
16. Draw input characteristics of a transistor in CE mode and define input resistance.
Ans. The input resistance r_i of the transistor in CE mode is defined as the ratio of change in base-emitter voltage to the corresponding change in base current at constant collector-emitter voltage.



17. Draw output characteristics of a transistor in CE mode and define output resistance.
Ans. Output resistance(r_0) is the ratio of the change in collector-emitter voltage to the corresponding change in collector current at a constant base current

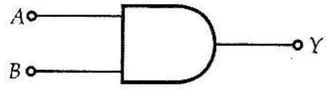


18. Draw the transfer characteristics of base-biased transistor in CE configuration and indicate the regions of operation when transistor is used as (i) an amplifier (ii) a switch.



Ans.
(i) Transistor is used as an amplifier in the active region
(ii) Transistor is used as a switch in the cut-off region and saturation region

19. Draw the logic symbol of AND gate and write its truth table.
Ans.

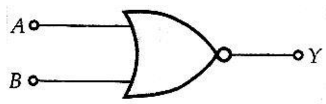


Truth Table: AND gate

A	B	y=A.B
0	0	0
0	1	0
1	0	0
1	1	1

20. Draw the logic symbol of NOR gate and write its truth table.

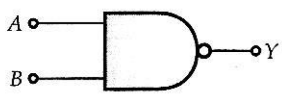
Ans.



Truth table: NOR gate		
A	B	$y = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

21. Draw the logic symbol of NAND gate and write its truth table.

Ans.



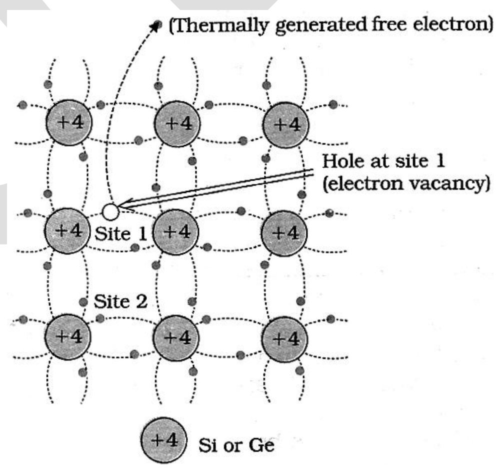
Truth table: NAND gate

A	B	$y = \overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

(THREE MARKS QUESTIONS)

1. What is intrinsic semiconductor? Explain the formation of a hole in the covalent bond structure of a Ge crystal.

Ans. Intrinsic semiconductor is a pure semiconductor in which electrical conductivity is solely dependent on thermally generated charge carriers. Example: pure crystals of germanium (Ge) or Silicon (Si)



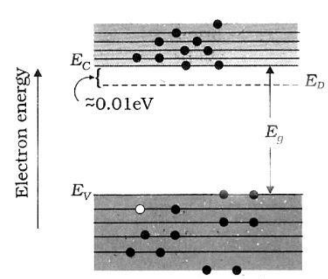
Si or Ge are tetravalent. In their crystalline structure every Si (or Ge) atom tends to share each one of its four valence electrons with its neighbours. This leads to covalent bonding.

Near absolute zero temperature, ideally all covalent bonds are intact and no electron is free. Hence the semiconductor may act like an insulator. As temperature increases, due to thermal energy acquired, some electrons break free (bond may be disrupted) – and become free electrons to conduct electricity.

An electron (-e) which becomes free leaves behind a vacancy in the covalent bond with an effective positive charge +e. The vacancy of an electron in the bond with an effective positive charge +e is called a hole. It behaves as an apparent free particle with effective positive charge.

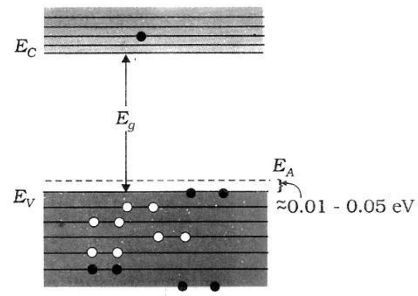
2. How is an n-type semiconductor formed? Name the majority charge carriers in it. Draw the energy band diagram of an n-type semiconductor.

Ans.: n-type semiconductor is obtained by doping pure semiconductors like Si or Ge with a pentavalent dopant like phosphorus. The majority charge carriers are electrons.



3. How is a p-type semiconductor formed? Name the majority charge carriers in it. Draw the energy band diagram of a p-type semiconductor.

Ans. p-type semiconductor is obtained by doping pure semiconductors like Ge or Si with a trivalent impurity like aluminium. The majority charge carriers are holes.

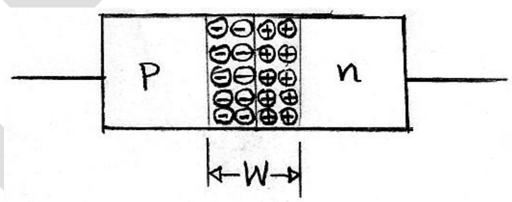


4. Distinguish between n-type and p-type semiconductors on the basis of energy band diagrams.
Ans. Refer answer in question no. 2 and 3.

5. Explain the formation of the depletion region in a p-n junction. How does the width of this region change when the junction is (i) forward biased? and (ii) reverse biased?

Ans. In the p-region holes are majority charge carriers and in the n-region electrons are the majority charge carriers. During the formation of p-n junction, due to this concentration gradient (number density gradient) the majority charge carriers diffuse across the junction. Holes diffuse from p-region to n-region (p→n) while electrons diffuse from n-region to p-region (n→p).

When an electron diffuses from n to p-region, it leaves behind an immobile positive ion (donor ion) on the n-side. As electrons continue to diffuse a layer of positive charge (positive space charge region) develops on the n-side of the junction.



Similarly when a hole diffuses from p-region to n-region it leaves behind an immobile negative ion (acceptor ion) on the p-side. As the holes continue to diffuse, a layer of negative charge (negative space charge region) develops on the p-side of the junction.

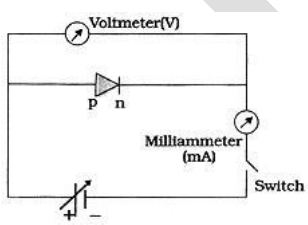
The space charge region at the p-n junction which consists only of immobile ions and is depleted of mobile charge carriers is called depletion region.

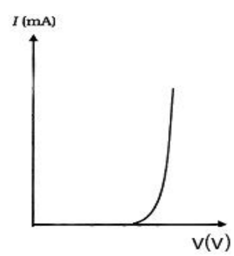
(i) The depletion region width decreases when the p-n junction is forward biased

(ii) The depletion region width increases when the p-n junction is reverse biased

6. What is forward bias? Draw a circuit diagram for the forward biased p-n junction and sketch the voltage-current graph for the same.

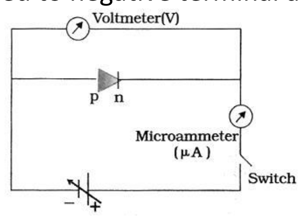
Ans. A p-n junction or diode is said to be forward biased when an external voltage is applied such that p-side is connected to positive terminal and n-side is connected to negative terminal of the battery.

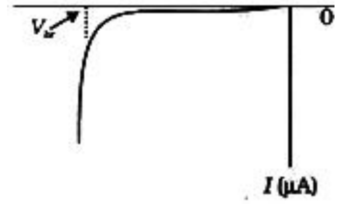




7. What is reverse bias? Draw a circuit diagram for the reverse biased p-n junction and sketch the voltage-current graph for the same.

Ans. A p-n junction or diode is said to be reverse biased when an external voltage is applied such that p- side is connected to negative terminal and n-side is connected to positive terminal of the battery.

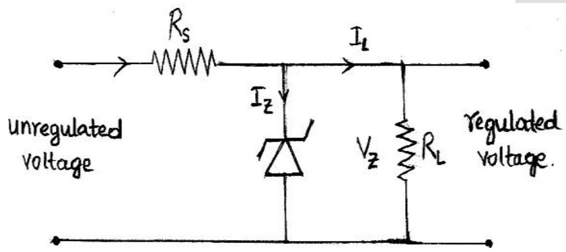


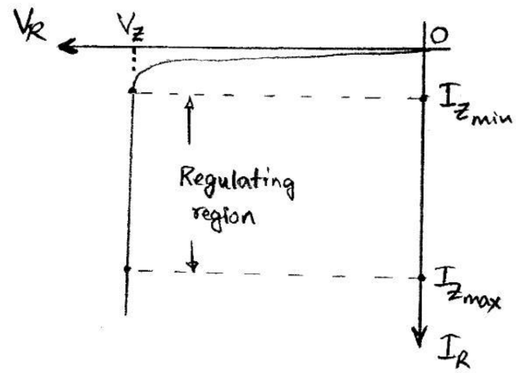


8. With the help of a circuit diagram explain the use of Zener diode as a voltage regulator.
Ans.

A DC power supply which maintains the output voltage constant irrespective of AC mains fluctuations or load variations is known as regulated DC power supply.

Zener diode voltage regulator





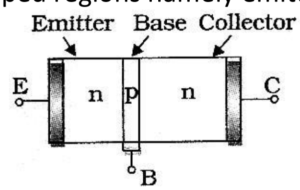
A zener diode is used to obtain a constant DC voltage from DC unregulated output of a rectifier. The unregulated DC voltage is connected to the zener diode through a series resistance R_s such that the zener diode is reverse biased.

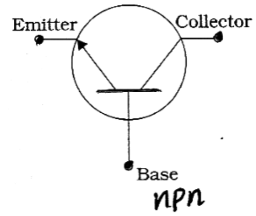
When the input voltage increases, the current through R_s and that through the zener diode will increase. This increases the voltage drop across R_s but the voltage across the zener diode remains same. This is because in the breakdown region, the zener voltage remains constant even though the zener current varies (between I_{Zmin} to I_{zmax}). Similarly if the input voltage decreases, the currents through R_s and zener will decrease but zener voltage V_z will remain constant. Thus the zener diode acts as a voltage regulator.

9. What is a transistor? Describe the various regions of a transistor.

Ans.: Junction transistor consists of two back to back p-n junctions. It is also called bipolar junction transistor (BJT).

A transistor is a three terminal, two semiconductor-junction device whose basic action is amplification. It has three doped regions namely emitter, base and collector.





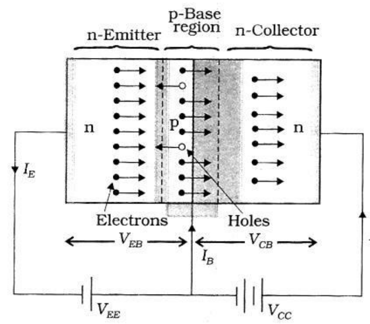
The arrowhead on the emitter shows the direction of the conventional current in the transistor.

Emitter: It is moderate in size and heavily doped. It supplies large number of majority charge carriers.

Collector: It is larger in size compared to emitter and is moderately doped.

Base: It is the Central region which is very thin and lightly doped.

10. Describe briefly with the help of a circuit diagram, the paths of current carriers in an npn transistor with emitter-base junction forward biased and collector-base junction reverse biased.



Ans.

For the effective working of a transistor its junctions have to be properly biased. When the transistor is used as an amplifier the emitter-base junction is forward biased while the collector-base junction is reverse biased. The transistor is then said to be in active state.

Basic action of a transistor (npn): Consider an npn transistor with its emitter- base junction forward biased and collector-base junction reverse biased. The heavily doped n-type emitter has a high concentration of electrons (majority carriers). The electrons cross the emitter base junction and enter the base region in large number as it offers least resistance due to its forward biased condition. This gives rise to emitter current $I_{E.}$

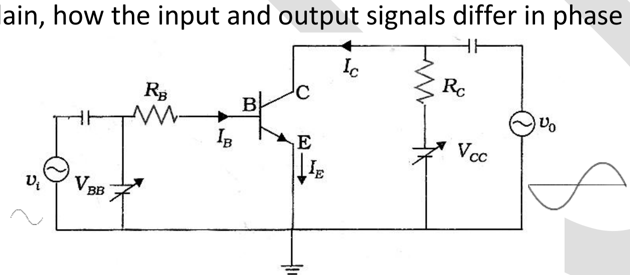
As the p-type base is very thin and lightly doped only few holes are present in base. As such very few electrons from the emitter combine with the holes of base, giving rise to base current I_B. The remaining large number of electrons in the base region are minority carriers there and hence can easily cross the reverse-biased collector- base junction to enter the collector. This gives rise to collector current I_c

The base current is only a small fraction of the emitter current. It is seen that the emitter current is the sum of base current and collector current.

$I_E = I_B + I_C$

I_E and I_C are of the order of mA such that $I_E > I_C$. I_B is of the order of μA.

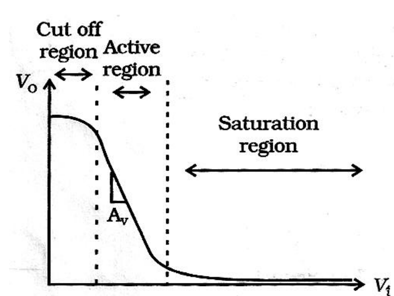
11. Draw a circuit diagram of a transistor amplifier in the common-emitter configuration. Briefly explain, how the input and output signals differ in phase by 180°.



Ans.

When an AC signal is fed to the input circuit, its positive half cycle increases the forward bias of the circuit which, in turn, increases the emitter current and hence the collector current. The increase in collector current increases the potential drop across R_L, which makes the output voltage V_0 less positive or more negative. So as the input signal goes through its positive half cycle, the amplified output signal goes through a negative half cycle. Similarly, as the input signal goes through its negative half cycle, the amplified output signal goes through its positive half cycle. Hence in a common emitter amplifier, the input and output voltages are 180°out of phase or in opposite phases.

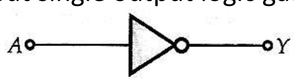
12. Draw the transfer characteristic curve of a base biased transistor CE configuration. Explain how the active region of the V_o versus V_i curve is used for amplification.



Ans.

The slope of the linear part of the active region of the V_0 versus V_i curve gives the rate of change of output with the input. If ΔV_0 and ΔV_i are the changes in the output and input voltages, then $\Delta V_0 / \Delta V_i$ will be the small signal voltage gain A_V of the amplifier. If the forward V_{BB} is fixed at the midpoint of the active region, then the base biased CE transistor will behave as an amplifier with voltage gain $\Delta V_0 / \Delta V_i$. Thus the linear portion of the active region of the transistor can be used for the purpose of amplification.

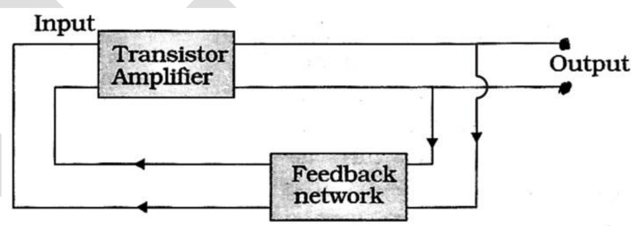
13. What is a logic gate? Draw the symbol of a NOT gate and write its truth table.
Ans.
A logic gate is a digital circuit that follows certain logical relationship between the input and output signals. It works on the principles of Boolean algebra.
NOT gate
It is a single input single output logic gate whose output is the logical inversion of its input.



Truth table: NOT gate

A	$y=\bar{A}$
0	1
1	0

14. With the help of a block diagram, briefly explain the principle of transistor oscillator.
Ans.
Transistor as an oscillator
An oscillator is an electronic device which produces sustained electrical oscillations (ac signal) of constant frequency and amplitude without any external input.



Principle of a transistor oscillator
In an oscillator a portion of the output power is returned (feedback part) back to the input in phase with the input or starting power. An oscillator may be regarded as a self sustained transistor amplifier with a positive feedback. (in-phase feedback).
A tank circuit produces oscillations. These oscillations may get damped due to energy loss. The transistor amplifier amplifies the oscillations. The feedback circuit returns or feeds back a fraction of the output power of the amplified output from the amplifier to the tank circuit in phase with the input signal to that energy loss due to damping is compensated. This produces undamped, self sustained oscillations.

(**FIVE MARKS QUESTIONS**)

1. What is energy band? On the basis of energy band diagrams, distinguish between metals, insulators and semiconductors.
Ans.
Energy band is a group of close by energy levels with continuous energy variation.
Valence band is the energy band which includes the energy levels of the valence electrons. It is the range of energies possessed by valence electrons.
It is the energy band which is completely filled at absolute zero temperature.

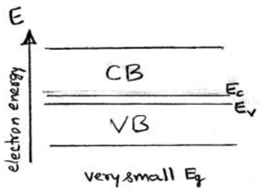
Conduction band is the energy band which includes the energy levels of conduction electrons or free electrons. This band lies above the valence band. This energy band is completely empty at absolute zero temperature or it may be partially filled at higher temperatures.

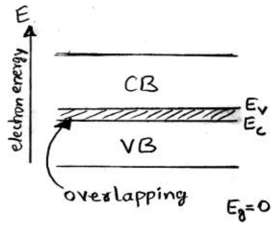
The lowest energy level in the conduction band is E_c and the highest energy level in the valence band is E_v. The gap between the top of the valence band (E_v) and the bottom of the conduction band (E_c) is called the energy band gap (E_g) or energy gap or forbidden energy band.

Distinction between metals, insulators and semiconductors:

Metals:

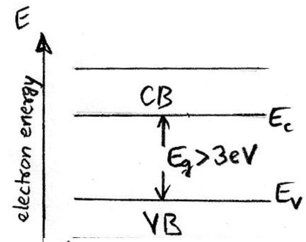
In metals either the conduction band is partially filled (as in Li, Na etc) or the conduction band can overlap the valence band (as in Be, Mg etc) with no energy gap. A large number of free electrons are available for conduction and hence metals have high conductivity.





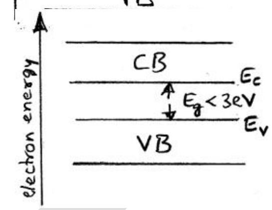
Insulators:

In insulators the energy gap is very large (E_g>3eV). The valence band is completely filled while the conduction band is empty. Electrons cannot be excited from valence band to conduction band by applying electric field. Hence electrical conduction is not possible. (Diamond $E_g \approx 6$eV)



Semiconductors:

In semiconductors the energy gap is less than 3eV. At absolute zero temperature (0K) the valence band is filled and conduction band is empty and the material acts as an insulator. At room temperature some electrons from valence band get thermally excited to conduction band. Hence at higher temperature semiconductors acquire some conductivity.

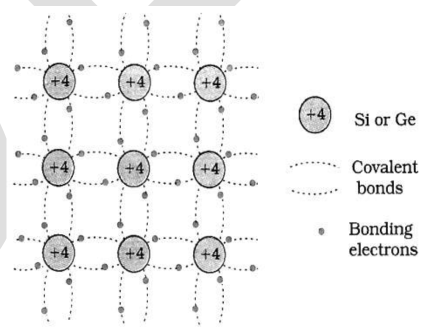


2. What are intrinsic semiconductors? Explain the formation of a hole in an intrinsic semiconductor. Draw the energy level diagram.

Ans.

Intrinsic semiconductors

These are pure semiconductors in which electrical conductivity is solely dependent on thermally generated charge carriers. Example: pure crystals of germanium (Ge) or Silicon (Si)



Si or Ge are tetravalent. In their crystalline structure every Si (or Ge) atom tends to share each one of its four valence electrons with its neighbours. This leads to covalent bonding.

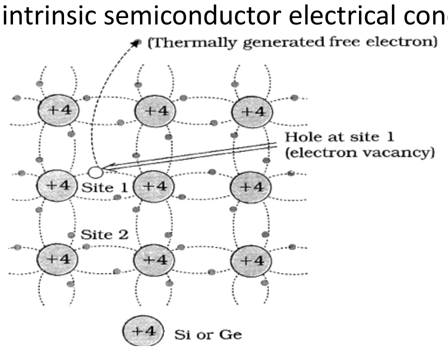
Near absolute zero temperature, ideally all covalent bonds are intact and no electron is free. Hence the semiconductor may act like an insulator. As temperature increases, due to thermal energy acquired, some electrons break free (bond may be disrupted) – and become free electrons to conduct electricity.

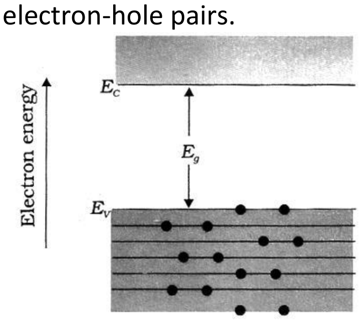
An electron (-e) which becomes free leaves behind a vacancy in the covalent bond with an effective positive charge +e. The vacancy of an electron in the bond with an effective positive charge +e is called a hole. It behaves as an apparent free particle with effective positive charge.

In intrinsic semiconductors the number of free electrons (n_e) is equal to the number of holes (n_h).

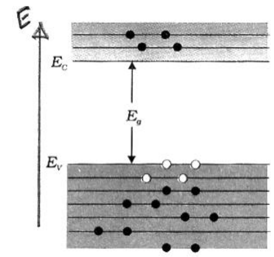
$n_e=n_h=n_i$ n_i is called intrinsic carrier concentration.

In an intrinsic semiconductor electrical conduction is due to electron-hole pairs.



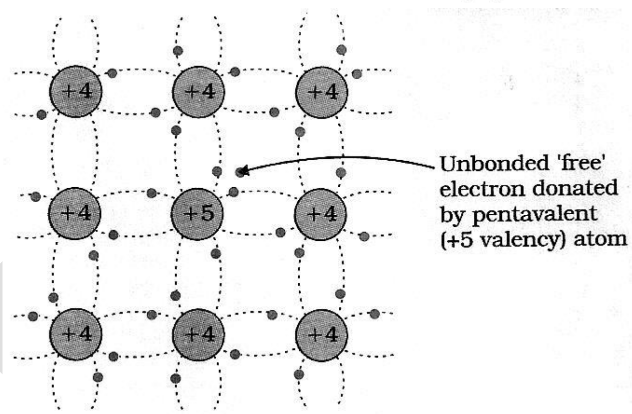


At absolute zero temperature (0K) the valence band is completely filled while conduction band is empty. Hence the semiconductor acts like an insulator at T = 0K. At higher temperature (T > 0K) some electrons from the valence band gain energy to move to conduction band creating equal number of holes in the valence band. Both free electrons and the holes take part in conductivity.



3. What is extrinsic semiconductor? Distinguish between n-type and p-type semiconductors. Draw relevant energy level diagrams.

Ans.

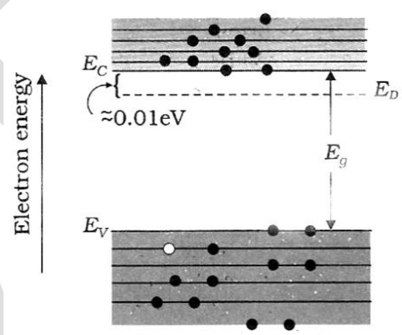


Extrinsic semiconductors

These are semiconductors obtained by doping pure semiconductors like silicon with suitable impurity atoms (like phosphorus indium etc) to enhance their electrical conductivity. The impurity added is called as dopant.

Extrinsic semiconductors are of two types based on the type of dopants used. n-type semiconductors and p – type semiconductors.

n-type semiconductor



This is obtained by doping pure semiconductors like Si or Ge with a pentavalent dopant like phosphorus. When a pentavalent impurity atom like P occupies position in the lattice of Ge, four of its electrons form covalent bond with the host Ge atoms while the fifth one remains weakly bound to the parent atom. Even thermal energy at room temperature is sufficient to free it.

For Ge, this ionization energy is ≈0.01eV and Si it is ≈0.05eV.

The impurity atom is known as donor impurity since it is donating one extra electron for conduction. The doping level determines the concentration of dopant contributed electrons while the total number of conduction electrons n_e is due to the contribution by donors as well as thermally generated (intrinsic) electrons while the total number of holes n_h is only due to intrinsic (thermal) source.

Also rate of recombination of holes increases as the number of electrons is more. As a result the number of holes get reduced further.

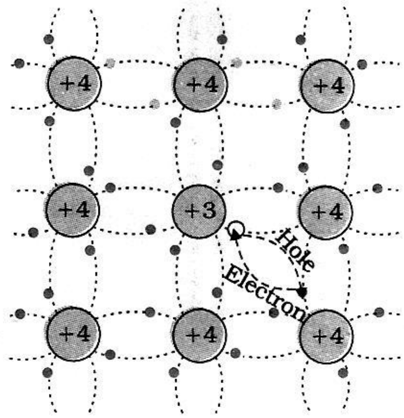
Hence in extrinsic semiconductors doped with pentavalent impurities electrons are majority charge carriers while holes are minority charge carriers. Thus they are called n type semiconductors ($n_e >> n_h$).

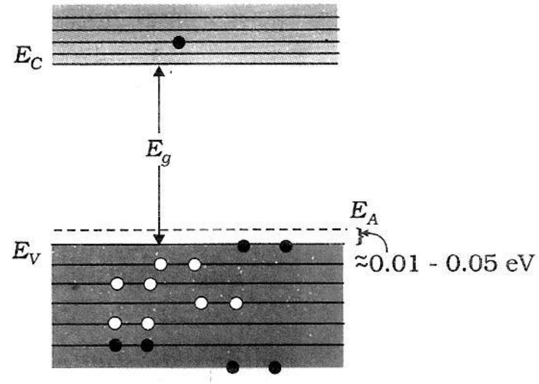
p – type semiconductor

This is obtained by doping pure semiconductors like Ge or Si with a trivalent impurity like aluminium.

The trivalent dopant atom forms bonds with three host Ge atoms while the bond between the fourth neighbour and the trivalent atom has a vacancy or hole.

An electron from a neighbouring atom may jump to fill this vacancy, leaving a vacancy or hole at its own site. Thus a hole is available for conduction. Each acceptor atom gives one hole to the semiconductor. In addition holes and free electron pairs are created by thermal energy (intrinsic)





In semiconductors doped with trivalent impurities, holes are majority charge carriers while electrons are minority charge carriers. Hence they are called p type semiconductors. ($n_h >> n_e$)

4. What is a p-n junction? Explain the formation of the depletion region in a p-n junction. How does the width of this region change when the junction is (i) forward biased? (ii) reverse biased? Explain.
Ans.

p-n junction

It is a junction between p-type and n-type semiconductors such that the crystal structure remains continuous at the boundary.

Formation of p-n junction

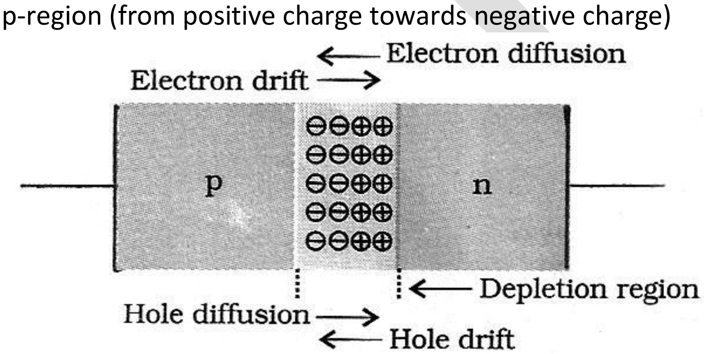
In the p-region holes are majority charge carriers and in the n-region electrons are the majority charge carriers. During the formation of p-n junction, due to this concentration gradient (number density gradient) the majority charge carriers diffuse across the junction giving rise to diffusion current (I_{df}) Holes diffuse from p-region to n-region ($p \rightarrow n$) while electrons diffuse from n-region to p-region ($n \rightarrow p$).

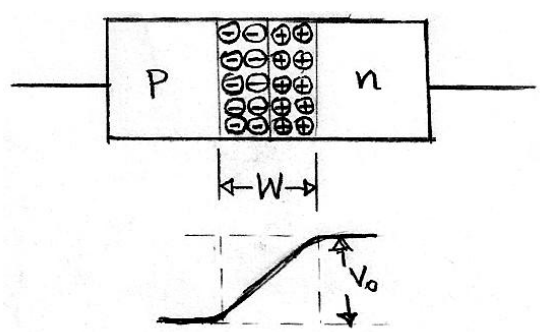
When an electron diffuses from n to p region, it leaves behind an immobile positive ion (donor ion) on the n-side. As electrons continue to diffuse a layer of positive charge (positive space charge region) develops on the n-side of the junction.

Similarly when a hole diffuses from p-region to n-region it leaves behind an immobile negative ion (acceptor ion) on the p-side. As the holes continue to diffuse, a layer of negative charge (negative space charge region) develops on the p-side of the junction.

The space charge region at the p-n junction which consists only of immobile ions and is depleted of mobile charge carriers is called depletion region. The thickness of the depletion region is nearly a micrometer or less (1 μm or 0.1 μm). The depletion region prevents further diffusion of majority charge carriers.

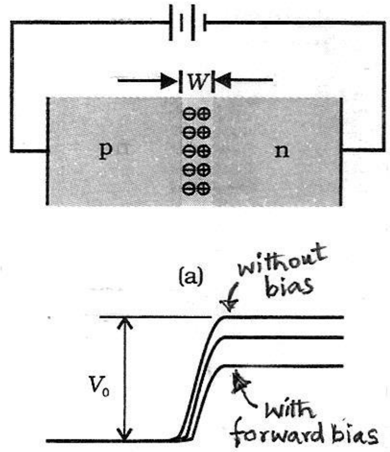
Due to this space charge region an electric field E is developed which is directed from n-region to p-region (from positive charge towards negative charge)



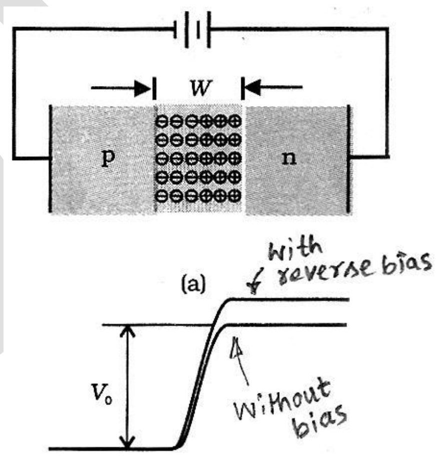


The depletion region has a layer of positive charge on n-side and layer of negative charge on the p-side. This results in a potential gradient and hence an electric field across the junction. The n-region has lost electrons and p-region has gained electrons. Thus n-side is positive relative to p-side. This potential tends to prevent the movement of majority charge carriers and is often called barrier potential V_o (junction potential). It is nearly 0.3V for germanium p-n junction and 0.7V for silicon p-n junction.

P-n junction under forward bias



A p-n junction or diode is said to be forward biased when an external voltage is applied such that p-side is connected to positive terminal and n-side is connected to negative terminal of the battery. The applied voltage falls across the depletion region as other parts offer negligible resistance and is directed opposite to the junction potential V_0. Due to forward bias, the depletion region width decreases and the potential barrier height is reduced,the effective barrier height now being (V_0 – V), where V is the forward bias voltage



As V increases the majority charge carriers i.e., electrons from n-side and holes from p-side diffuse across the junction since the barrier height decreases. The effective resistance of the p-n junction decreases..

p-n junction under reverse bias

A p-n junction (diode) is said to be reverse biased when an external voltage is applied such that p- side is connected to negative terminal and n-side is connected to positive terminal of the battery.

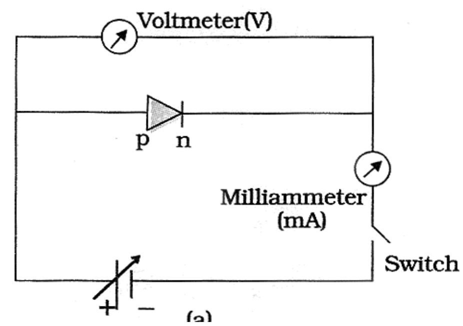
Due to reverse bias voltage V the depletion region width increases and the potential barrier height also increases (V_0 + V) – the direction of V being the same as that of V_0. The majority charge carriers move away from the junction increasing the width of the depletion layer – the resistance of the p-n junction becomes very large.

5. Draw the circuit diagrams of a p-n junction diode in (i) forward bias and (ii) reverse bias. Draw the I-V characteristics for the same and discuss the resistance of the junction in both the cases. Ans.

V–I CHARACTERISTICS OF p-n JUNCTION DIODE

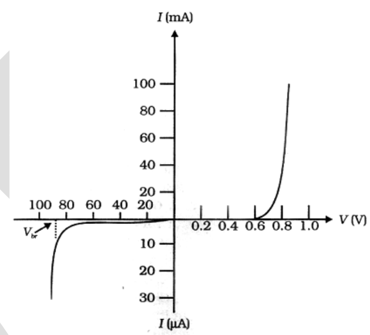
A graph showing the variation of current through a semiconductor diode with the applied voltage is called V-I (voltage – current) characteristics.

Forward bias characteristics



The arrangement for forward bias is as shown

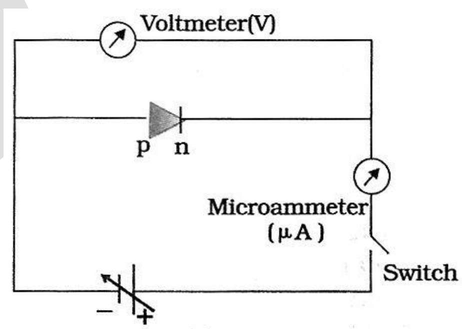
The battery is connected to the diode through potentiometer or rheostat for varying the voltage across the diode. For different values of forward voltage V_f the corresponding forward current I_f is noted from milliammeter. The graph of V-I so obtained is called forward characteristic. Initially the current is negligible till the voltage V_f crosses a certain threshold voltage or cut-in voltage V_c ($V_c \approx 0.3V$ for germanium diode and $V_c \approx 0.7V$ for silicon diode) – after which the current increases rapidly and exponentially even for small change in voltage. The diode resistance in forward bias is low. The dynamic resistance r_d of a diode is defined as the ratio of small change in voltage (ΔV) to the corresponding change in current (ΔI)



$$r_d = \frac{\Delta V}{\Delta I} \ldots\ldots\ldots\ldots\Omega$$

Reverse –bias characteristics

In reverse bias polarities of the cell and meters are reversed while a microammeter is used to measure reverse current I_r.



When the reverse bias voltage (V_r) is increased a small reverse saturation current I_r of the order of μA results. The reverse bias resistance of the diode is very large. Even when the voltage is increased considerably the current does not increase significantly. Only at the breakdown voltage (V_{br}) The current increases sharply even for small increase in voltage.

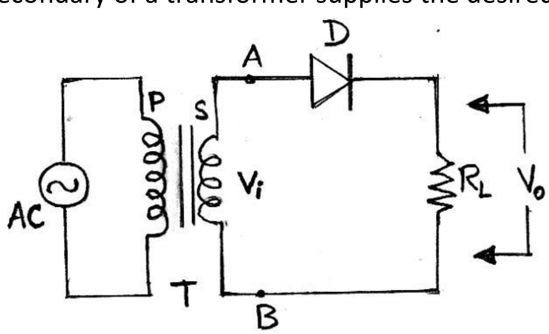
6. With a neat circuit diagram, explain the working of a half wave rectifier employing a semiconductor diode. Draw the relevant waveforms.

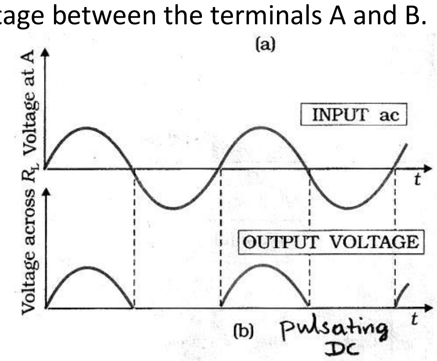
Ans.

Half wave rectifier (HWR)

It is a circuit or device which converts AC to pulsating DC in which the output current flows (output voltage is obtained) only during one half cycle of the input AC signal.

The secondary of a transformer supplies the desired AC voltage between the terminals A and B.

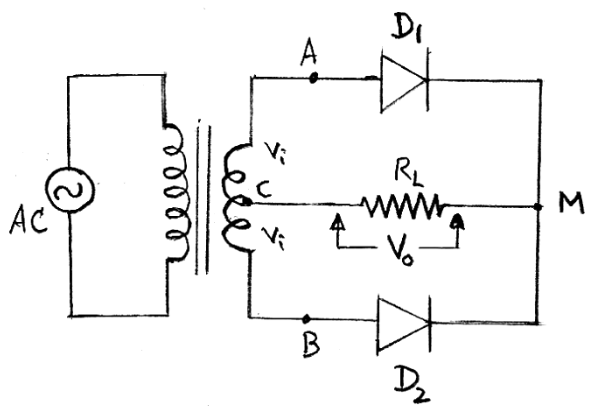


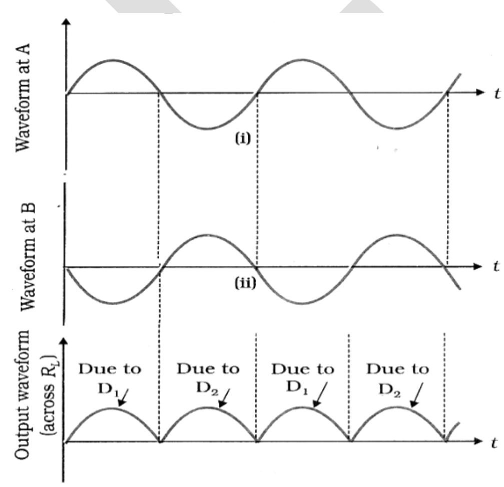


During positive half cycle of the input AC, A is positive and B is negative and the diode D is forward biased. It conducts and an output voltage V_0 is obtained across the load resistance R_L.
During negative half cycle of the input AC, A is negative and B is positive – now the diode D is reverse biased. It does not conduct. Hence no output voltage is obtained across R_L during this half cycle.

During the next positive half cycle of the input AC again output voltage V_0 is obtained. Thus the output voltage, still varying, is restricted to one direction and hence is said to be rectified. Since the rectified output is only for one half cycle of the input AC it is called half wave rectification and the device is called half wave rectifier.

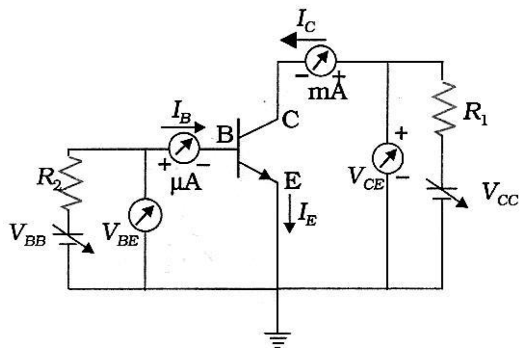
7. With a neat circuit diagram, explain the working of a full wave centre-tap rectifier using junction diodes. Draw the input and output waveforms.
Ans.
Full wave rectifier (FWR)
A full wave rectifier is a device or circuit which converts AC to pulsating DC in which the output current flows (output voltage V_0 is obtained) during the entire cycle of the input AC.
In the full wave rectifier circuit shown a centre tap transformer is used which provides equal AC inputs V_i between centre tap C and the terminals A and B.
Here two diodes D_1 and D_2 are used with their anodes connected to secondary terminals A and B while their cathodes are connected to a common point M. The load resistance R_L is connected between M and C.





During positive half cycle of the input AC the end A is positive and B is negative with respect to C. D_2 is reverse biased and it does not conduct while D_1 is forward biased and it conducts. The output current flows through R_L and hence output voltage V_0 is obtained due to D_1.
During negative half cycle of the input AC A is negative while B is positive with respect to C. D_1 is reverse biased and it does not conduct while D_2 is forward biased and it conducts. The output current flows through R_L and hence output voltage V_0 is obtained due to D_2.
Thus every positive half cycle of input AC D_1 gives the output voltage while during negative half cycle D_2 gives the output voltage. Hence we get full wave rectification.

8. Draw the circuit arrangement for studying the input and output characteristics of an npn transistor in CE configuration. Draw these characteristics and define input resistance and output resistance.



Ans.

Common emitter (CE) transistor characteristics

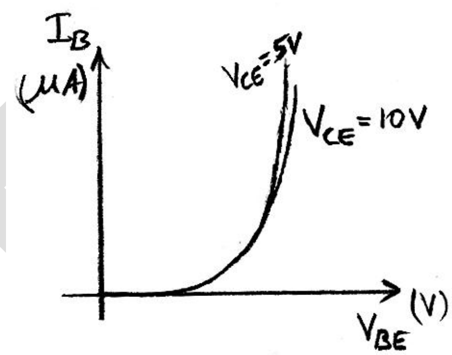
In the CE mode the input is between base and emitter terminals while the output is between collector and emitter terminals.

Input characteristic

The graphical representation of the variation of base current I_B with the base-emitter voltage V_{BE} for a fixed value of collector- emitter voltage V_{CE} is called input characteristic.

V_{CE} is kept fixed, V_{BE} is varied and the variation in I_B noted in regular intervals. For small values of V_{BE} the base current I_B is negligible. When V_{BE} exceeds barrier voltage I_B increases sharply even with small increase in V_{BE}.

Increase in V_{CE} appears as increase in V_{CB} hence its effect on I_B is negligible. Hence different values of V_{CE} give almost identical curves.

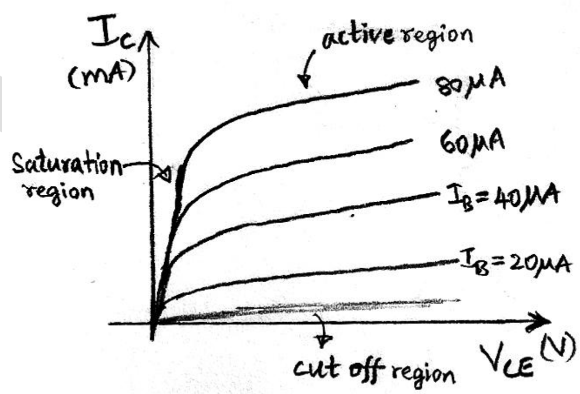


The input resistance r_i of the transistor in CE mode is defined as the ratio of change in base-emitter voltage to the corresponding change in base current at constant collector-emitter voltage.

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

r_i ranges from few hundred ohm to few thousand ohm.

Output characteristics: The graphical representation of the variation of collector current I_C with the collector-emitter voltage V_{CE} for a fixed value of base current I_B is called output characteristic.



Initially for very small values of V_{CE}, I_C increases almost linearly – this is since collector- base junction is not reverse biased and the transistor is not in active state.

The transistor is in the saturation state and current is controlled by V_{CC} (equal to V_{CE}) in this region.

When V_{CE} is increased further, I_C increases marginally (very small change) with V_{CE} for a given base current I_B. The output resistance r_0 of the transistor is very high – of the order of 100kΩ or more. It is seen that larger the value of I_B larger is the value of I_c for a given V_{CE}.

Output resistance(r_0)

It is the ratio of the change in collector-emitter voltage to the corresponding change in collector current at a constant base current.

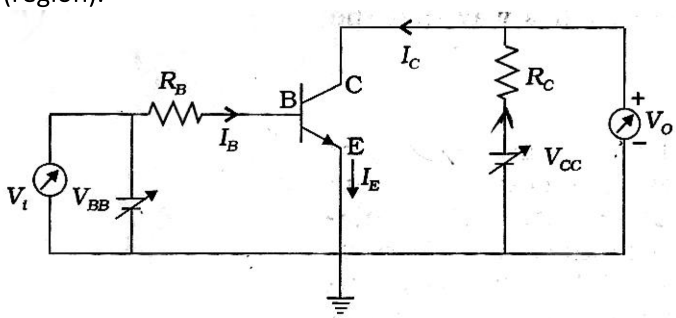
$$r_0 = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B = \text{constant}}$$

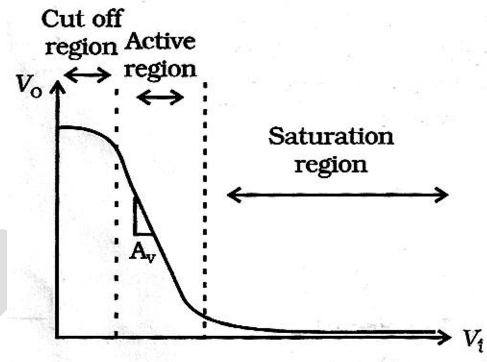
9. With the help of a circuit diagram explain the action of a npn transistor in CE configuration as a switch. Draw the transfer characteristics and indicate the relevant regions of operation.

Ans.:

Transistor as a switch

The transistor acts as a switch when it is used in the cut-off state (region) and in the saturation state (region).





Consider the transistor in CE configuration which is base-biased.

Applying Kirchhoff's voltage law (KVL) to the input side.

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

Taking V_{BB} as DC input voltage V_i,

$V_i = I_B R_B + V_{BE}$ …………(1)

Applying KVL to the output side

$V_{CE} = V_{CC} – I_C R_C$

Taking V_{CE} as DC output voltage V_o,

$V_o = V_{CC} – I_c R_c$ …………(2)

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

Thus $V_O = V_{CC}$, from eqn 2

Hence when low input is given the transistor is switched off (it goes to cut-off state) while output voltage V_o is maximum at V_{CC}.. When a high input V_i is given such that it is enough to drive the transistor into saturation the transistor will be switched ON – while the output voltage V_0 will be very low.

$V_O = V_{CC} - I_C R_C$

In saturation region I_C will be large hence V_o is very small.

LOW input V_i switches the transistor OFF.

While HIGH input V_i switches the transistor ON –

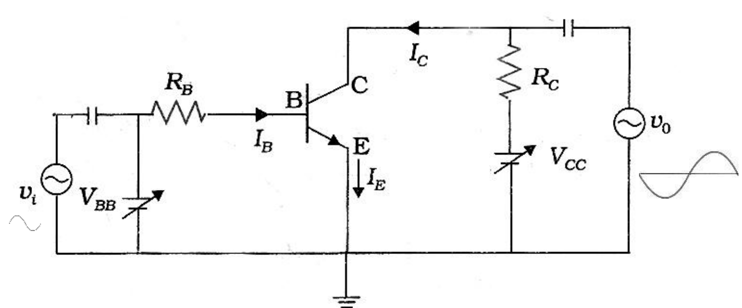
Thus a transistor acts as a switch.

10. Describe with a circuit diagram the working of an amplifier using an npn transistor in CE configuration. Draw relevant waveforms and obtain an expression for the voltage gain.

Ans.

Transistor amplifier in CE configuration

The circuit of CE amplifier employing npn transistor is as shown. Here C_1 and C_2 are coupling capacitors which block DC and allow only AC.



The transistor operating point is fixed in the middle of the active region. This fixes DC base current I_B and the corresponding collector current I_c while DC voltage V_{CE} would remain constant. The operating values of V_{CE} and I_B

determine the operating point of the amplifier.

A small sinusoidal voltage of amplitude v_i is superposed on the DC base bias. The base current will have sinusoidal variations superimposed on I_B. The collector current also will have AC variations superimposed on I_c. This produces corresponding change in the value of output voltage V_o.

During the positive half cycle of the input AC signal the emitter-base voltage increases. As a result the input current I_B and hence the output current I_C also increases. Consequently the voltage drop across R_L increases. The output voltage V_0 taken across collector and emitter becomes less positive (or more negative) – i.e., the amplified output signal goes through a negative half cycle.

Similarly during negative half cycle of the input AC, input voltage decreases, I_B and I_C decreases. As a result voltage across R_L also decreases. But the output voltage V_0 goes through a positive half cycle. Thus the output voltage $V_0=V_{CE}$ is out of phase by 180° with the input voltage V_i.

In the absence of input AC signal v_i, applying Kirchhoff's voltage law to the input loop,

$V_{BB} = V_{BE} + I_BR_B$.

When the signal v_i is superposed,

$V_{BB} + V_i = V_{BE} + I_BR_B + \Delta I_B (R_B + r_i)$

$V_i = \Delta I_B (R_B + r_i)$

$V_i = \Delta I_B r$ …………………(1)

Where r_i is input resistance and $r = (R_B + r_i)$

Applying Kirchhoff's voltage law to the output part,

$V_{CC} = V_{CE} + I_CR_C$

The change in I_B causes change in I_c which in turn causes change in V_{CE}. Voltage drop cross R_c also is changed – since V_{CC} is fixed.

$\Delta V_{CC} = O$

$O = \Delta V_{CE} + R_C\Delta I_C$

$\Delta V_{CE} = - R_c\Delta I_c$

This is the output voltage V_o, which is taken between collector and the ground.

$V_o = - R_C\Delta I_C$ ……………..(2)

The voltage gain of the amplifier,

$$A_v = \frac{V_o}{V_i} = \frac{-R_c\Delta I_c}{r\Delta I_B} = -\left(\frac{\Delta I_c}{\Delta I_B}\right)\frac{R_c}{r}$$

$$A_v = -\beta_{ac}\left(\frac{R_c}{r}\right)$$

Where $r = R_B + r_i$

The negative sign indicates that the output voltage is out of phase with the input voltage.