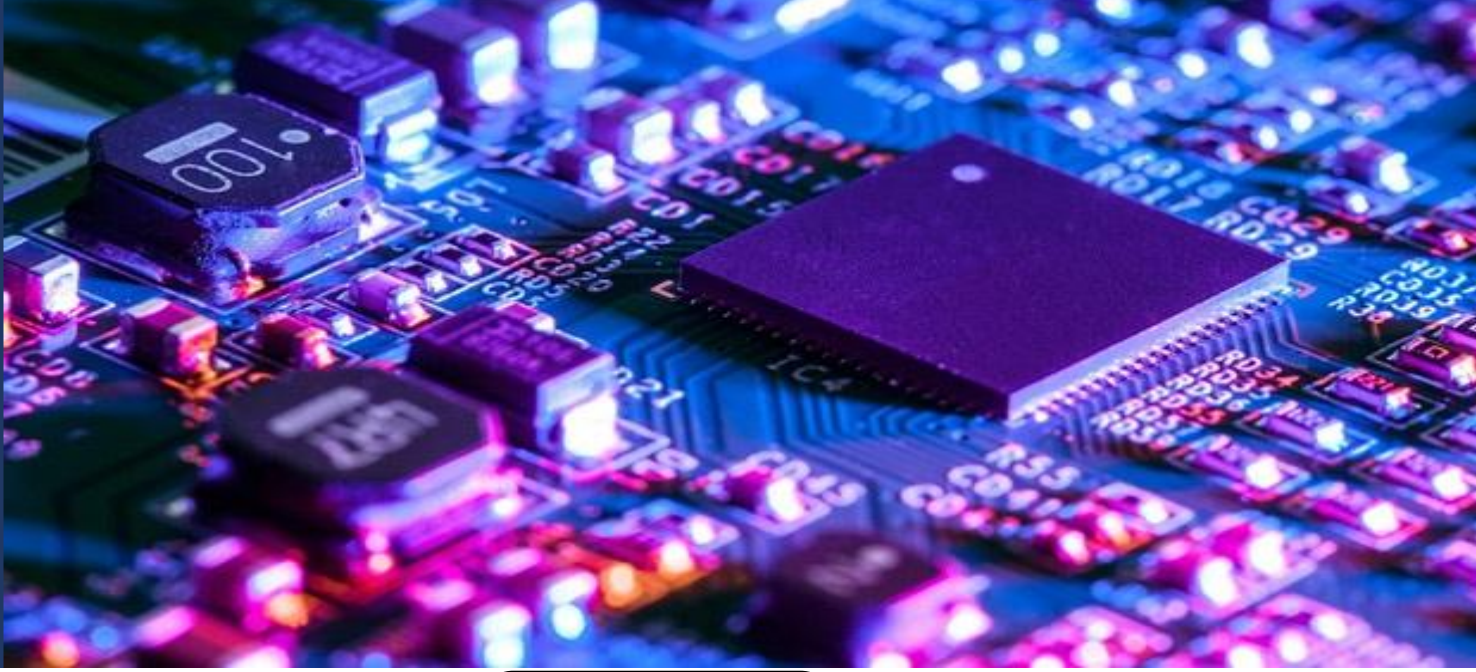


CHAPTER – 14

SEMICONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

The word "electronics' is derived from electron + dynamics which means the study of the behavior of an electron under different conditions of externally applied field. This field of science deals with electronic devices and their utilization. An electronic device is a device in which conduction takes place by the movement of electron - through a vacuum, a gas or a semiconductor. Main application of electronic is computer which is used in every field. All electronics equipment required D.C. supply for operation (not A.C. supply).

Energy Band

The energy levels of an isolated atom are clearly defined. However, these individual energy levels overlap and undergo substantial modification when numerous such atoms combine to create a real solid.

The energy values of electrons are not discrete but rather fall within a range. An energy band is thought to be formed by the accumulation of these densely grouped energy levels. Valence Band and Conduction Band are two terms used to describe these types of bands that form in solids. The Valence Band is made up of filled energy levels, while the Conduction Band is made up of partially filled or unfilled energy levels. A space known as the energy gap or forbidden gap typically separates the two bands.

Classification Of Solids According to Energy Band Theory

According to energy band theory, solids are conductor, semiconductor and insulator:

Conductor

In some solids conduction band and valence band are overlapped so there is no band gap between them, it means $\Delta E_g = 0$.

Due to this a large number of electrons are available for electrical conduction and therefore its resistivity is low ($\rho = 10^{-2} - 10^{-8}$U–m) and conductivity is high [$\sigma = 10^{2} - 10^{8}\ (\Omega\text{–m})^{-1}$].

Such materials are called conductors. For example, gold, silver, copper, etc.

Insulator

In some solids energy gap is large ($E_g > 3$eV). So, in conduction band there are no electrons and so no electrical conduction is possible. Here energy gap is so large that electrons cannot be easily excited from the valence band to conduction band to conduction band by any external energy (electrical, thermal or optical)

Such materials are called as "insulator". Their U > $10^{11}\ \Omega$–m and $\sigma < 10^{-11}$ (Q–m)$^{-1}$

Semiconductor

In some solids a finite but small band gap exists ($E_g < 3$eV). Due to this small band gap some electrons can be thermally excited to "conduction band".

These thermally excited electrons can move in conduction band and can conduct current. Their resistivity and conductivity both are in medium range, $\rho \simeq 10^{-5} - 10^{6}\ \Omega$–m and $\sigma \simeq 10^{-6} - 10^{5}\ \Omega\text{–m}^{-1}$

Example of semiconducting materials

Elemental semiconductor: Si and Ge

Compound semiconductor

Inorganic: CdS, GaAs, CdSe, InP etc.

Organic: Anthracene, Doped pthalocyanines etc.

Organic Polymers: Poly pyrrole, Poly aniline, polythiophene

Properties Of Semiconductor

Negative temperature coefficient (a.), with increase in temperature resistance decreases. Crystalline structure with covalent bonding [Face centered cubic (FCC)]. Conduction properties may change by adding small impurities

Position in periodic table - IV group (Generally}

Forbidden energy gap (0.1 eV to 3 eV)

Charge carriers: electron and hole.

There are many semiconductors but few of them have practical application in electronics.

Holes

Due to external energy (temperature or radiation) when electron goes from valence band to conduction band (i.e., bonded electrons become free), vacancy of free e^- creates in valence band. The electron vacancy called as "hole" which has same charge as electron but positive. This positively charged vacancy move randomly in semiconductor solid.

Properties of holes

- It is missing electron in valence band.
- It acts as positive charge carrier.
- Its effective mass is more than electron.
- Its mobility is less than electron.

Holes acts as virtual charge, although there is not physical charge on it.

Q. Find the maximum wavelength of electromagnetic radiation, which can create a hole-electron pair in germanium. Given that forbidden energy gap in germanium is 0.72eV.

Sol. Here, $E_g = 0.72\text{eV} = 0.72 \times 1.6 \times 10^{-19}$

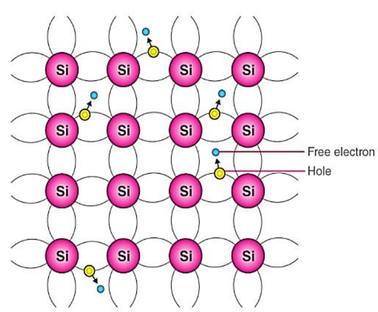
The maximum wavelength of radiation, which can create a hole-electron pair in germanium is given by $E_g = \frac{hc}{\lambda}$

Or

$$\lambda = \frac{hc}{E_g} = \frac{6.62\times10^{-34}\times3\times10^{8}}{0.72\times1.6\times10^{-19}} = 1.724 \times 10^{-6}\text{ m}$$

Intrinsic Semiconductor

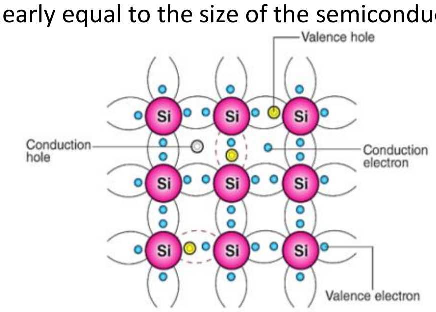
Pure semiconductors are in which the conductivity is caused due to charge carriers made available from within the material are called intrinsic semiconductors. There are no free charge carriers available under normal conditions. However, when the temperature is raised slightly, some of the covalent bonds in the material get broken due to thermal agitation and few electrons become free. In order to fill the vacancy created by absence of electron at a particular location, electron from other position move to this location and create a vacancy (absence of electron) at another place called hole. The movement/shifting of electrons and holes within the material results in conduction.



An intrinsic semiconductor behaves as a perfect insulator at temperature 0 K

Extrinsic Semiconductors

Extrinsic semiconductors are semiconductors that are doped with specific impurities. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors. While adding impurities, a small amount of suitable impurity is added to pure material, increasing its conductivity by many times. Extrinsic semiconductors are also called impurity semiconductors or doped semiconductors. The process of adding impurities deliberately is termed as doping and the atoms that are used as an impurity are termed as dopants. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors. The dopant added to the material is chosen such that the original lattice of the pure semiconductor is not distorted. Also, the dopants occupy only a few of the sites in the crystal of the original semiconductor, and it is necessary that the size of the dopant is nearly equal to the size of the semiconductor atoms.



Q. Distinguish between intrinsic and extrinsic semiconductors?

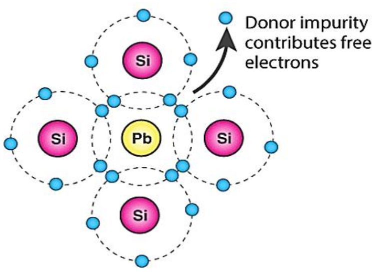
Sol. A semiconductor free from all types of impurities is called an intrinsic semiconductor. At room temperature, a few covalent bonds break up and the electrons come out. In the bonds, from which electrons come out, vacancies are created. These vacancies in covalent bonds are called holes. In an intrinsic semiconductor, holes and electrons are equal in number and they are free to move about in the semiconductor. On the other hand, a semiconductor doped with a suitable impurity (donor or acceptor) so that it possesses conductivity much higher than that of pure semiconductor is called an extrinsic semiconductor. The extrinsic semiconductor may be of n-type or p-type.

Q. Why is a semiconductor damaged by a strong current?

Sol. A strong current, when passed through a semiconductor, heats up the semiconductor and the covalent bonds break up. It results in a large number of free electrons. The material then, behaves just as a conductor. As now the semiconductor no longer possesses the property of low conductor it is said to be damaged.

n-type semiconductor

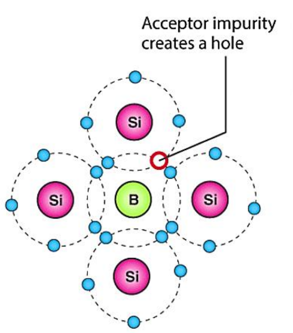
When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb) then four electrons out of the five valence electrons of impurity take part in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donor's impurity (N_0). Here free e^- increases very much so it is called as "N" type semiconductor. Here impurity ions known as "Immobile Donor positive Ion". "Free e^-" called as "majority" charge carriers and "holes" called as "minority" charge carriers.



n - type

p- type semiconductor

When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In) then the outermost three electrons of the valence band of impurity, take part in covalent bonding with four silicon atoms surrounded by it. This shows that there remains a vacancy in the band. To fill this vacancy, an electron is accepted from the neighboring atom leaving a hole from its own site. Thus, an extra hole is formed. These impurity atoms accepting bonded e^- from valence band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as "P" type semiconductor. Here impurity ions known as "Immobile Acceptor negative Ion", Free e^- are called as minority charge carries and holes are called as majority charge carriers.



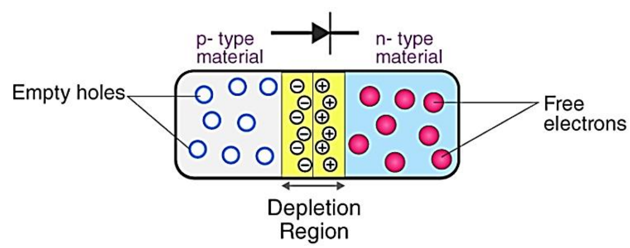
p - type

P-N Junction

A P-N junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.

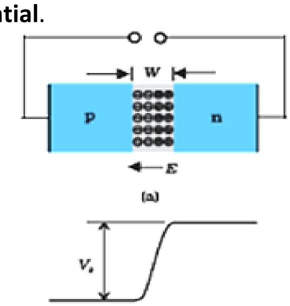
Formation of P-N Junction

As we know, if we use different semiconductor materials to make a P-N junction, there will be a grain boundary that would inhibit the movement of electrons from one side to the other by scattering the electrons and holes and thus, we use the process of doping. We will understand the process of doping with the help of this example. Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both the p-type region and the n-type region and a junction between these two regions. The processes that follow after forming a P-N junction are of two types – diffusion and drift. There is a difference in the concentration of holes and electrons at the two sides of a junction. The holes from the p-side diffuse to the n-side, and the electrons from the n-side diffuse to the p-side. These give rise to a diffusion current across the junction.



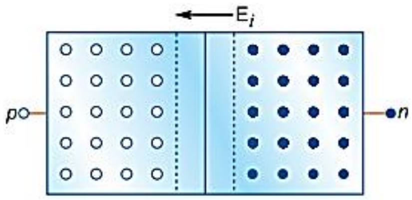
Direction of diffusion current: P to N side and drift current: N to P side

If there is no biasing then | diffusion current | = | drift current |So total current is zero. In junction N side is at high potential relative to the P side. This potential difference tends to prevent the movement of electron from the N region into the P region. This potential difference is called **Barrier potential**.

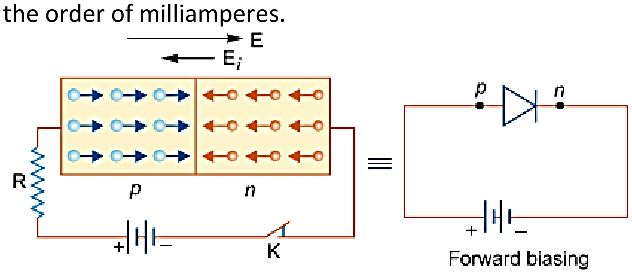


p-n junction diode under forward bias

In this arrangement the positive terminal of battery is connected to p-end and negative terminal to n-end of the crystal, so that an external electric field E is established directed from p to n-end to oppose the internal field, E_i. Thus, the junction is said to conduct.



Under this arrangement the holes move along the field E from p-region to n-region and electrons move opposite to field E from n-region to p-region; eliminating the depletion layer. A current is thus set up in the junction diode. The following are the basic features of forward biasing. Within the junction diode the current is due to both types of majority charge carriers but in external circuit it is due to electrons only. The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.

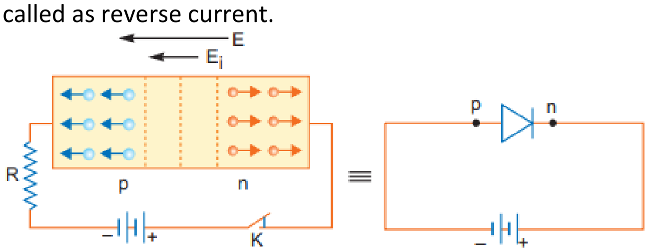


p-n junction diode under reverse bias

In this type of biasing we apply a potential difference such that P-side is at low potential and N-side is at high potential as shown in the diagram.

The applied voltage is same side of to the junction barrier potential. Due to this effective potential barrier increased, junction width also increased, so no majority carriers will be allowed to flow across junction.

Only minority carriers are drifted. It means the current flow in Principledly due to minority charge carries and is very small (UA) called as reverse current.



(c) Reverse current

Reverse biasing

The current under reverse bias is essentially voltage independent up to a critical reverse bias voltage, known breakdown voltage (E_i). When V = E_i, the diode reverses current increases sharply. Even a slight increase in the bias voltage causes large change in the current. This phenomenon is known as **Breakdown**.

Application of Junction Diode

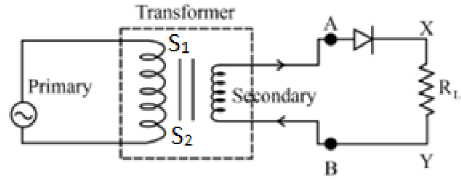
Rectifier

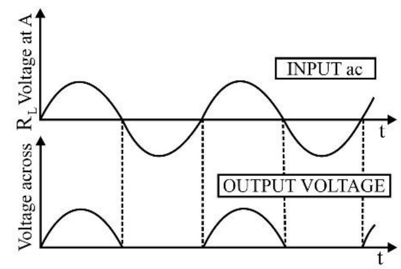
It is device which is used for converting alternating current into direct current.

(i) Half wave rectifier:

It rectifies only half of the ac input wave.

During the first half (positive) of the input signal, S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained across the R_L.





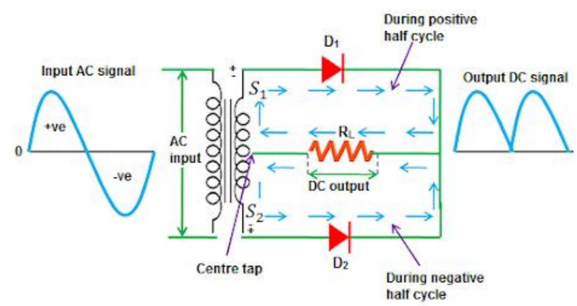
During the second half (negative) of the input signal, S_1 is at negative potential and S_2 is at positive potential. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output across the RL.

Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output called rectified output.

Full Wave Rectifier

It rectifies both the cycles of input ac wave. It is of two types (fundamentally).

Centre tape rectifier: Figure shows the experimental arrangement for using diode as full wave rectifier. When the alternating signal is fed to the transformer, the output signal appears across the load resistance R_L.



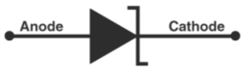
During the positive half of the input signal: S_1 positive and S_2 negative. In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

During the negative half of the input signal: S_1 is negative and S_2 is positive. So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conduct and hence the current flows through the load resistance R_L again from A to B.

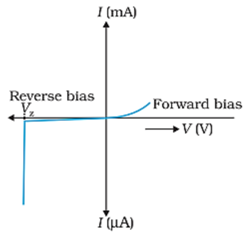
It is dear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and thus output is called full wave rectified.

Zener Diode

It is a special purpose diode, designed to operate under the reverse bias in the breakdown region and used in voltage regulation. Symbol of Zener diode is

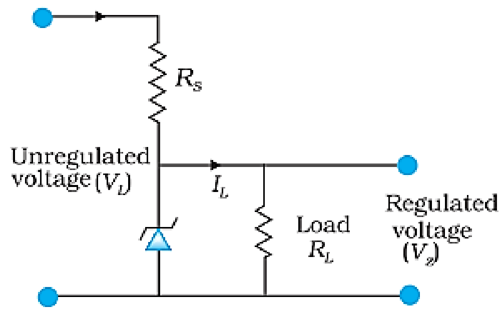


In reverse bias of Zener diode after the breakdown voltage V_z, a large change in the current can be produced by almost insignificant change in the reverse bias voltage. In other words, Zener voltage remains constant, even though current through the Zener diode varies over a wide range. This property of the Zener diode is used for regulating voltage.



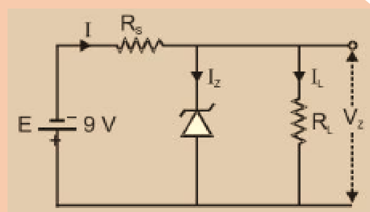
Zener diode as a voltage regulator

The unregulated de voltage (filtered output of a rectifier) is connected to the Zener diode through a series resistance R_S such that the Zener diode is reverse biased. If the input voltage increases, the current through R_S and Zener diode also increases. This increases the voltage drop across R_S without any change in the voltage across the Zener diode. This is because in the breakdown region, Zener voltage remains constant even though the current through the Zener diode changes. Similarly, if the input voltage decreases, the current through R_S and Zener diode also decreases.



The voltage drop across R_S decreases without any change in the voltage across the Zener diode. Thus, any increase/decrease in the input voltage results in, increase/decrease of the voltage drop across R_S without any change in voltage across the Zener diode. Thus, the Zener diode acts as a voltage regulator.

Q. A Zener diode of voltage $V_Z(= 6\text{ V})$ is used to maintain a constant voltage across a load resistance $R_L(= 1000\Omega)$ by using a series resistance $R_S(= 100\Omega)$. If the e.m.f. of source is $E(= 9\text{ V})$, calculate the value of current through series resistance, Zener diode and load resistance. What is the power being dissipated in Zener diode.



Sol. Here, $E = 9\text{ V}; V_Z = 6; R_L = 1000\Omega$ and $R_S = 100\Omega$,

Potential drop across series resistor $V = E - V_Z = 9 - 6 = 3V$

Current through series resistance R_S is $I = \frac{V}{R} = \frac{3}{100} = 0.03\text{ A}$

Current through load resistance R_L is $I_L = \frac{V_Z}{R_L} = \frac{6}{1000} = 0.006\text{ A}$

Current through Zener diode is $I_Z = I - I_L = 0.03 - 0.006 = 0.024\text{amp}$.

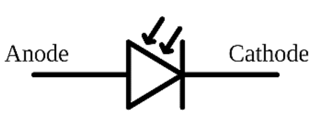
Power dissipated in Zener diode is $P_z = V_z I_z = 6 \times 0.024 = 0.144$ Watt

Optoelectronic Junction Devices

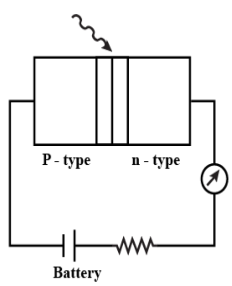
Photodiode

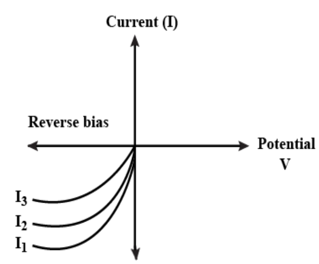
It is a special purpose junction diode used to sense and measure incident light. It is operated under reverse bias.

Its symbol is-



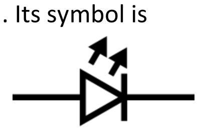
When light of energy "hv" falls on the photodiode (Here hv > energy gap) more electrons move from valence band to conduction band, due to this current in circuit of photodiode in "Reverse bias'', increases. As light intensity is increased, the photo current goes on increasing. So, photo diode is used "to detect light intensity". Example used in "Video camera".





Light Emitting Diode

It is a heavily doped P-N junction which under forward bias emits spontaneous radiation. Its symbol is



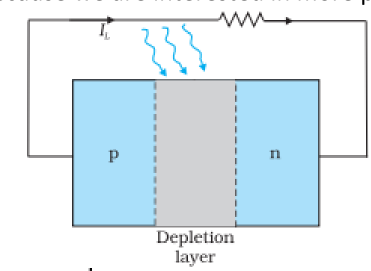
when LED is forward biased then electrons move from N⟶P and holes move from PYN. At the junction boundary these are recombined. On recombination, energy is released in the form of photons of energy equal to or slightly less than the band gap.

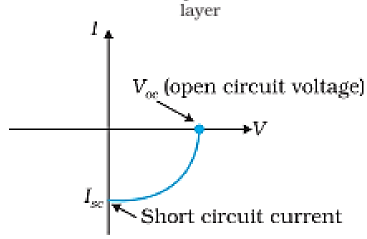
When the forward current of the diode is small, the intensity of light emitted is small. As the forward current increases, intensity of light increases and reaches a maximum. Further increase in the forward current results in decrease of light intensity. LEOs are biased in such a way that the light emitting efficiency should be maximum.

In case of Si or Ge diodes, the energy released in recombination lies in infra-red region. Therefore, to form LED, such semiconductors are to be used which have band gap from 1.8 eV to 3 eV. Hence $GaAs_{1-x}P_x$ is used in forming LED.

Solar Cell

A p-n junction which generates emf when solar radiation falls on it, called solar cell. It works on the same principle (photovoltaic effect) as the photodiode, except that no external bias is applied and the junction area is kept much larger for solar radiation to be incident because we are interested in more power.





When light falls on, emf generates due to the following three basic processes: generation, separation and collection-

(i) generation of e-h pairs due to light (with hν > E_g) in junction region.

(ii) separation of electrons and holes due to electric field of the depletion region. Electrons are swept to n-side and holes to p-side by the junction field.

(iii) On reaching electrons at n-side and holes on at p-side. Thus n-side becomes negative and p-side becomes positive potential and giving rise to photovoltage

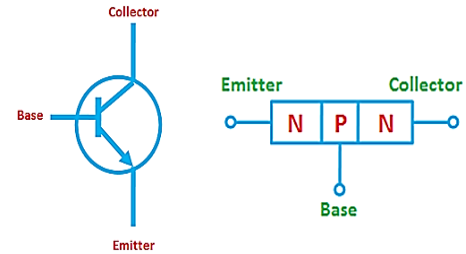
Transistor

Transistor is a three terminal device which transfers a signal from low resistance circuit to high resistance circuit. It is formed when a thin layer of one type of extrinsic semiconductor (P or N type) is sandwiched between two thick layers of other type of extrinsic semiconductor.

Transistors are of two types

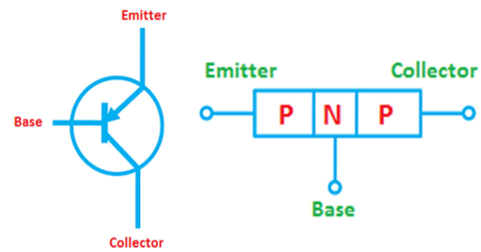
- **N-P-N Transistor**

If a thin layer of P-type semiconductor is sandwiched between two thick layers of N-type semiconductor, then it is known as NPN transistor.



- **P-N-P Transistor**

  If a thin layer of N-type of semiconductor is sandwiched between two thick layer of P-type semiconductor, then it is known as PNP transistor.



Each transistor has three terminals and these are:

(i) **Emitter:** It is the left most part of the transistor which emits the majority carriers towards base. It is **highly doped** and **medium in size**.

(ii) **Base:** It is the middle part of transistor which is sandwiched by emitter (E) and collector (c). It is **lightly doped** and **very thin in size**.

(iii) **Collector:** It is right part of the transistor which collects the majority carriers which is emitted by emitter. It has **large size** and **moderate doping**.

Every transistor has following two junctions

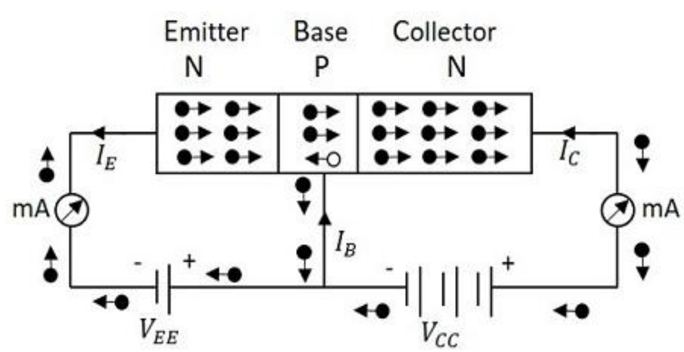
(i) The junction between emitter and base is known as emitter-base junction **(J_{EB})**.

(ii) The junction between base and collector is known as base-collector junction **(J_{BC})**.

Working of Transistor

Working of NPN Transistor

The emitter base junction is forward biased and base collector junction is reversed biased to study the behavior of transistor. It is called active state of transistor. N-P-N transistor in circuit and symbolic representation is shown in figure.



In active state of n-p-n transistor majority electrons in emitter are sent towards base.

The barrier of emitter base junction is reduced because of forward bias therefore electrons enter into the base.

About 5% of these electrons recombine with holes in base region results very small current (I_B) in base.

The remaining electron ($\approx$95%) enters into the collector region because these are attracted towards the positive terminal of battery results collector current (I_C).

The base current is the difference between I_E and I_C and proportional to the number of electron hole recombination in the base.

$I_E = I_B + I_C$

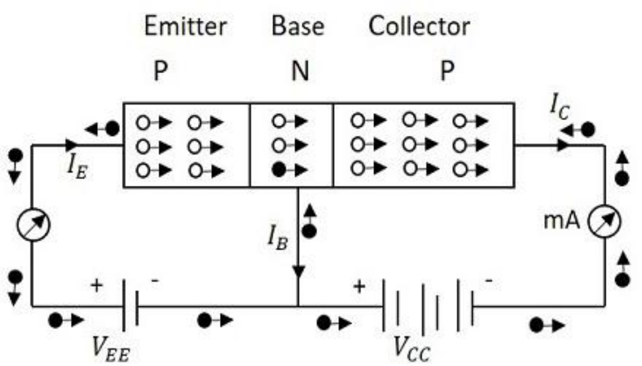
We also see $I_E \simeq I_C$ because I_B is very small.

Working of PNP Transistor

When emitter-base junction is forward biased, holes (majority carriers) in the emitter are repelled towards the base and diffuse through the emitter base junction. The barrier potential of emitter-base junction decreases and hole enters into then-region (i.e. base). A small number of holes

($\approx$ 5%) combine with electrons of base-region resulting small current (I_B). The remaining holes

($\approx$ 95%) enter into the collector region because these are attracted towards negative terminal of the battery connected with the collector-base junction. These holes constitute the collector current (I_C).



Operation of a PNP transistor

8/As one hole reaches the collector, it is neutralized by the battery. As soon as one electron and a hole is neutralized in collector, a covalent bond is broken in emitter region and an electron hole pair is produced. The released electron enters the positive terminal of battery and holes moves towards the collector. So $I_E = I_B + I_C$

Configurations Of A Transistor And Its Characteristics

The transistor is connected in either of the three ways in circuit.

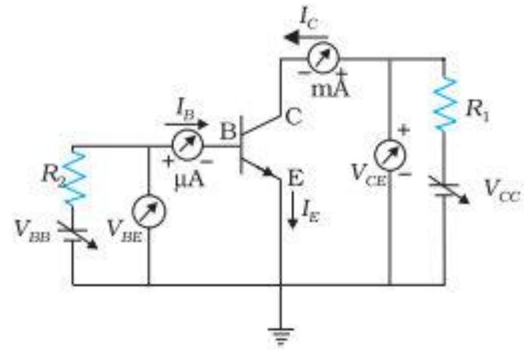
(i) Common base configuration

(ii) Common emitter configuration

(iii) Common collector configuration

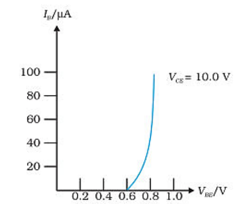
In these three, common emitter is widely used and common collector is rarely used.

Common emitter transistor characteristics



Input Characteristics

The variation of base current (I_B) (input) with base emitter voltage (V_{EB}) at constant collector emitted voltage (V_{CE}) is called input characteristic.



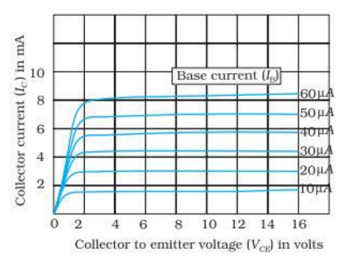
(i) Kept the collector-emitter voltage (V_{CE}) constant (say V_{CE} = 10V)

(ii) Now change emitter base voltage V_{BE} in steps of 0.1 volt and note the corresponding values of base current (I_B).

(iii) Plot the graph between V_{BE} and I_B.

Output characteristics

The variation of collector current I_C (output) with collector-emitter voltage (V_{CE}) at constant base current (I_B) is called output characteristic.



(i) Keep the base current (I_B) constant (say I_B = 10 μA)

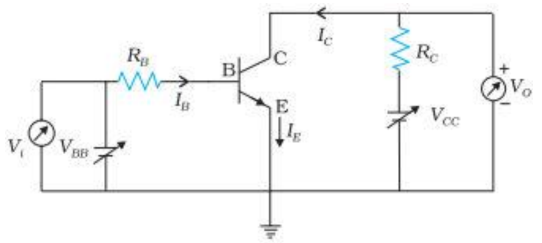
(ii) Now change the collector-emitter voltage (V_{CE}) and not the corresponding values of collector current (I_C) .

(iii) Plot the graph between V_{CE} and I_C.

(iv) A set of such curves can also be plotted at different fixed values of base current (say 20 μA, 30 μA etc.)

Transistor as a switch

When a transistor is used in the cut off (off state) or saturation state (on state) only, it acts as a switch. To study this behavior, we understand base biased CE transistor circuit.

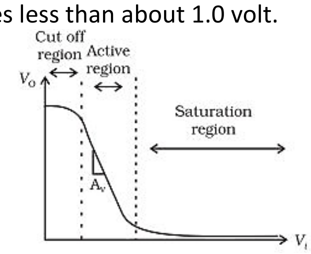


Applying Kirchhoff's voltage rule to the input and output sides of this circuit we get

$V_i = I_BR_B + V_{BE}$ (V_i = dc input voltage)

and $V_O = V_{CC} - I_C R_C$ (V_O = dc output voltage)

Now we can analyse how V_O changes as V_i increase from zero onwards. In case of Silicon transistor, if V_i is less than 0.6 V, I_B will be zero, hence I_C will zero and transistor will be said to be in cut-off state, and $V_O = V_{CC}$. When V_i become greater than 0.6 V, some I_B flows, so some I_C flows (transistor is in active state now) and output V_O decreases as the term $I_C R_C$ increase. With increase in V_i the I_C increase almost linearly and so V_O decreases linearly till its value becomes less than about 1.0 volt.



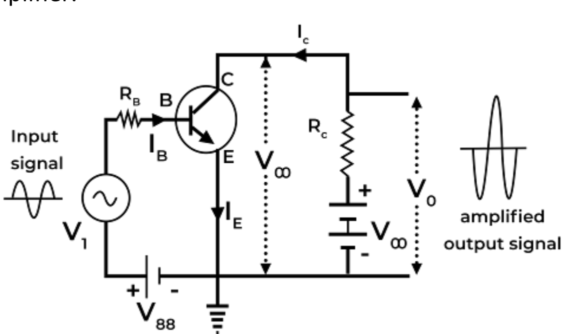
Beyond this, the change becomes nonlinear and transistor goes into saturation state. With further increase in V_i the output voltage is found to decrease further forwards zero (however, it may never become zero).

It we draw the V_O versus V_i curve called transfer characteristic (see figure), we see that between cut off state and active state and also between active state and saturation state there are regions of non-linearity showing that the transition from cut-off state to active state and from active state to saturation state are not sharply defined.

Transistor as an amplifier

The process of increasing the amplitude of input signal without distorting its wave shape and without changing its frequency is known as amplification.

A device which increases the amplitude of the input signal is called amplifier.



common emitter amplifier NPN transistor

To operate the transistor as an amplifier it is necessary to fix its operating point somewhere in the middle of its active region. If we fix the value of V_{BB} corresponding to a point in the middle of the linear part of the transfer curve then the de base current I_B would be constant and corresponding collector current I_C will also be constant. The dc voltage $V_{CE} = V_{CC} - I_CR_C$ would also remain constant. The operating values of V_{CE} and I_B determine the operating point, of the amplifier.

If a small sinusoidal voltage with amplitude υ_i is superposed in series with the V_{BB} supply, then the base current will have sinusoidal variations superimposed on the value of I_B. As a consequence, the collector current also will have sinusoidal variations superimposed on the value of I_C producing in turn corresponding change in the value of V_0.

Mathematical Analysis:

From KVL equation of base biased CE transistor circuit

$V_i = I_BR_B + V_{BE}$

$\Rightarrow \Delta V_i = (\Delta I_B)R_B + \Delta V_{BE} \quad \because \quad \Delta V_{BE} = 0$

$\Rightarrow \Delta V_i = (\Delta I_B)R_B$

Similarly $V_o = V_{CC} - I_CR_C$

$\Rightarrow \Delta V_o = V_{CC} - (\Delta I_C)R_C$

$\because \Delta V_{CC} = 0$

$\Rightarrow \Delta V_o = -(\Delta I_C)R_C$

So voltage gain of CE amplifier

$$A_V = \frac{\Delta V_o}{\Delta V_{in}} = \frac{-(\Delta I_C)R_C}{(\Delta I_B)R_B} = -\beta\frac{R_C}{R_B}$$

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

Power gain (A_p) = current gain × voltage gain = $\beta_{ac} \times A_V \Rightarrow A_P > 1$

Feedback amplifier

When some part of output signal is fed back to the input of amplifier then this process is known as feedback. Feedback of two types:

- **Positive feedback**

  When input and output are in the same phase then positive feedback is there. It is used in oscillators. Voltage gain after feedback $A_f = \dfrac{A}{1-A\beta}$

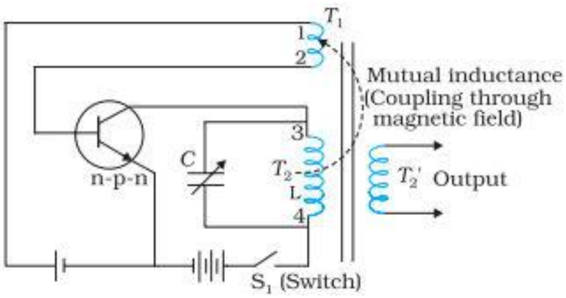
- **Negative feedback**

  If input and output are out of phase and some part of that is feedback to input then it is known as negative feedback. It is used to get constant gain amplifier.

  Voltage gain after feedback $A_f = \dfrac{A}{1+A\beta}$

  Oscillator is device which delivers ac output wave form of desired frequency without any external input wave form.

  The electric oscillations are produced by. L–C circuit (i.e., tank circuit containing inductor and capacitor). These oscillations are damped one i.e., their amplitude decrease with the passage of time due to the small resistance of the inductor. In other words, the energy of the L-C oscillations decreases. If this loss of energy is compensated from outside, then undamped oscillations (of constant amplitude) can be obtained.



This can be done by using feedback arrangement and a transistor amplifier in the circuit.

Oscillating frequency of oscillator is given by $f = \frac{1}{2\pi\sqrt{LC}}$

Advantages of semiconductor devices over vacuum tubes

Advantage

- Semiconductor devices are very small in size as compared to the vacuum tubes. Hence the circuits using semiconductor devices are more compact.
- In vacuum tubes, current flows when the filament is heated an starts emitting electrons. So, we have to wait for some time for the operation of the circuit. One the other hand, in semiconductor devices no heating is required and the circuit begins to operate as soon as it is switched on.
- Semiconductor devices required low voltage for their operation as compared to the vacuum tube. So a lot of electrical power is saved.
- Semiconductor devices do not produce any humming noise which is large in case of vacuum tube.
- Semiconductor devices have longer life than the vacuum tube. Vacuum tube gets damaged when its filament is burnt.
- Semiconductor devices are shock proof.
- The cost of production of semiconductor-devices is very small as compared to the vacuum tubes.
- Semiconductor devices can be easily transported as compared to vacuum tube.

Disadvantages

- Semiconductor devices are heat sensitive. They get damaged due to overheating and high voltages. So they have to be housed in a controlled temperature room.
- The noise level in semiconductor devices in very high.
- Semiconductor devices have poor response in high frequency range.

Integrated circuit (IC)

An integrated circuit (ICs), sometimes called a chip or microchip, is semiconductor wafer on which thousands or millions of tiny resistors, capacitors and transistors are fabricated. An IC can function as an amplifier, oscillator, timer, counter, computer memory, or microprocessor. ICs can be made very compact, having up to several billion transistors and other electronic components in an area the size of a fingernail. The most widely used technology is the Monolithic Integrated Circuit. The word monolithic is a combination of two Greek words, monos mean single and lithos means stone. This, in effect means that the entire circuit is formed on a single silicon crystal (or chip). The chip dimensions are as small 1 mm × 1 mm or it could even be smaller.

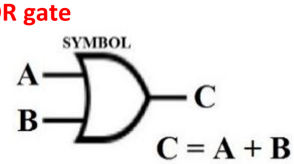
Depending upon the level of integration (i.e., the number of circuit components or logic gates), the ICs are termed as small integration, SSI (logic gates < 10); Medium Scale Integration, MSI (logic gates< 100); Large Scale Integration, LSI (logic gates < 1000) and very Large-Scale integration, VLSI (logic gates > 1000). The technology of fabrication is very involved but large-scale industrial production has made them very inexpensive.

Basic Logic Gates

There are three basic logic gates. They are (a) OR gate (b) AND gate, and (c) NOT gate.

The OR gate: The output of an OR gate attains the state 1 if one or more inputs attain the state1.

Logic symbol of OR gate



B, read as C equals A OR B.

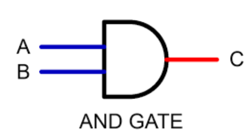
Truth table of a two-input OR gate

INPUT		OUTPUT
A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

The AND gate

The output of an AND gate attains the state 1 if and only if all the inputs are in state 1.

Logic symbol of AND gate



The **Boolean expression** of AND gate is C = A.B.
It read as C equals A AND B.

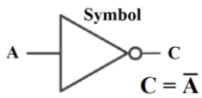
Truth table of a two-input AND gate

INPUT		OUTPUT
A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

The NOT gate

The output of a NOT gate attains the state 1 if and only if the input does not attain state 1.

Logic symbol of NOT gate



The **Boolean expression is** $C = \bar{A}$, read as C equals NOT A.

Truth table of NOT gate

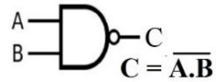
INPUT	OUTPUT
A	NOT A
0	1
1	0

Combination Of Gates

The three basis gates (OR, AND and NOT) when connected in various combinations give us logic gates such as NAND, NOR gates, which are the universal building blocks of digital circuits.

The NAND gate

Logic symbol of NAND gate



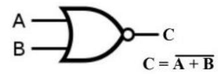
The **Boolean expression** of NAND gate is $C = \overline{A.B}$

Truth table of a NAND gate

INPUT		OUTPUT
A	B	A NAND B
0	0	1
0	1	1
1	0	1
1	1	0

The NOR gate

Logic symbol of NOR gate



The **Boolean expression** of NOR gate is $C = \overline{A + B}$

Truth table of a NOR gate

INPUT		OUTPUT
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

SUMMARY

- **Intrinsic Semiconductor:**
The pure semiconductors in which the electrical conductivity is totally governed by the electrons excited from the valence band to the conduction band and in which no impurity atoms are added to increase their conductivity are called intrinsic semiconductors and their conductivity is called intrinsic conductivity. Electrical conduction in pure semiconductors occurs by means of electron-hole pairs. In an intrinsic semiconductor,
$n_e = n_h = n_i$
where n_e = the free electron density in conduction band, n_h = the hole density in valence band, and n_i = the intrinsic carrier concentration.
- **Extrinsic Semiconductors:**
A Semiconductor doped with suitable impurity atoms so as to increase its conductivity is called an extrinsic semiconductor.
- **Types of Extrinsic Semiconductors:**
Extrinsic semiconductors are of two types
i) n-type semiconductors
ii) p-type semiconductors
- **n-type semiconductors:**
The pentavalent impurity atoms are called donors because they donate electrons to the host crystal and the semiconductor doped with donors is called n-type semiconductor. In n-type semiconductors, electrons are the majority charge carriers and holes are the minority charge carriers. Thus,
$n_e >> n_h$
- **p-type semiconductors:**
The trivalent impurity atoms are called acceptors because they create holes which can accept electrons from the nearby bonds. A semiconductor doped with acceptor type impurities is called a p-type semiconductor. In p-type semiconductor, holes are the majority carriers and electrons are the minority charge carriers Thus,
$n_h >> n_e$
- **Holes:**
The vacancy or absence of electron in the bond of a covalently bonded crystal is called a hole. A hole serves as a positive charge carrier.
- **Mobility:**
(a) The drift velocity acquired by a charge carrier in a unit electric field is called its electrical mobility and is denoted by μ.
$$\mu = \frac{V_d}{E}$$
(b) The mobility of an electron in the conduction band is greater than that of the hole (or electron) in the valence band.
- **Electrical conductivity of a Semiconductor:**
(a) If a potential difference V is applied across a conductor of length L and area of cross-section A, then the total current I through it is given by,
$I = eA(n_e v_e + n_h v_h)$
where n_e and n_h are the electron and hole densities, and v_e and v_h are their drift velocities, respectively.
(b) If μ_h are the electron and hole mobilities, then the conductivity of the semiconductor will be,
$\rho = e(n_e \mu_e + n_h \mu_h)$ and the resistivity will be,
$$\rho = \frac{1}{e(n_e\mu + n_h\mu_h)}$$
(c) The conductivity of an intrinsic semiconductor increases exponentially with temperature as,
$$\sigma = \sigma_0 \exp\left(-\frac{E_g}{2k_BT}\right)$$
- **Forward Biasing of a pn-junction:**
If the positive terminal of a battery is connected to the p-side and the negative terminal to the n-side, then the pn-junction is said to be forward biased. Both electrons and holes move towards the junction. A current, called forward current, flows across the junction. Thus, a pn-junction offers a low resistance when it is forward biased.
- **Reverse Biasing of a pn-junction:**
If the positive terminal of a battery is connected to the n-side and negative terminal to the p-side, then pn-junction is said to be reverse biased. The majority charge carriers move away from the junction. The potential barrier offers high resistance during the reverse bias. However, due to the minority charge carriers a small current, called reverse or leakage current flows in the opposite direction. Thus, junction diode has almost a unidirectional flow of current.
- **Action of a transistor:**
When the emitter-base junction of an npn-transistor is forward biased, the electrons are pushed towards the base. As the base region is very thin and lightly doped, most of the electrons cross over to the reverse biased collector. Since few electrons and holes always recombine in the base region, so the collector current I_c is always slightly less then emitter current I_E.
$I_E = I_C + I_B$
Where I_B is the base current.
- **Three Configurations of a Transistor:**
A transistor can be used in one of the following three configurations:
(a) Common-base (CB) circuit.
(b) Common-emitter (CE) circuit.
(c) Common-collector (CC) circuit.
- **Current Gains of a Transistor:**
Usually low current gains are defined:
(a) Common base current amplification factor or ac current gain α:
It is the ratio of the small change in the collector current to the small change in the emitter current when the collector-base voltage is kept constant.

$$\alpha = \left[\frac{\delta I_C}{\delta I_E}\right]_{V_{CB=\text{Constant}}}$$

(b) **Common emitter current amplification factor or ac current gain β:**

It is the ratio of the small change in the collector current to the small change in the base current when the collector emitter voltage is kept constant.

$$\beta = \left[\frac{\delta I_C}{\delta I_B}\right]_{V_{CE=\text{Constant}}}$$

- **Relations between α and β:**

  The current gains α and β are related as,

  $$\alpha = \frac{\beta}{1+\beta} \text{ and } \beta = \frac{\alpha}{1+\alpha}$$

- **Transistor as an amplifier:**
  An amplifier is a circuit which is used for increasing the voltage, current or power of alternating form. A transistor can be used as an amplifier.

- **AC Current Gain:**
  AC current gain is defined as,

  $$\beta_{ac} \text{ or } A_i = \left[\frac{\delta I_C}{\delta I_B}\right]_{V_{CE=\text{constant}}}$$

- **DC Current Gain:**
  DC current gain is defined as,

  $$\beta_{dc} = \left[\frac{I_C}{I_B}\right]_{V_{CE=\text{constant}}}$$

- **Voltage Gain of an Amplifier:**
  It is defined as,

  $$A_v = \frac{V_0}{V_i} = \frac{A \text{smallchangeinoutputvoltage}}{A \text{smallchangeininputvoltage}}$$

  $$A_V = \frac{\delta V_{CE}}{\delta V_{BE}}$$

  $$A_V = \beta_{ac} \cdot \frac{R_{out}}{R_{in}} = A_i . A_r$$

  i.e., Voltage gain = Current gain X Resistance gain

- **Power Gain of an Amplifier:**
  It is defined as,

  $$A_p = \frac{\text{Outputpower}}{\text{Inputpower}} = \text{current x voltage gain}$$

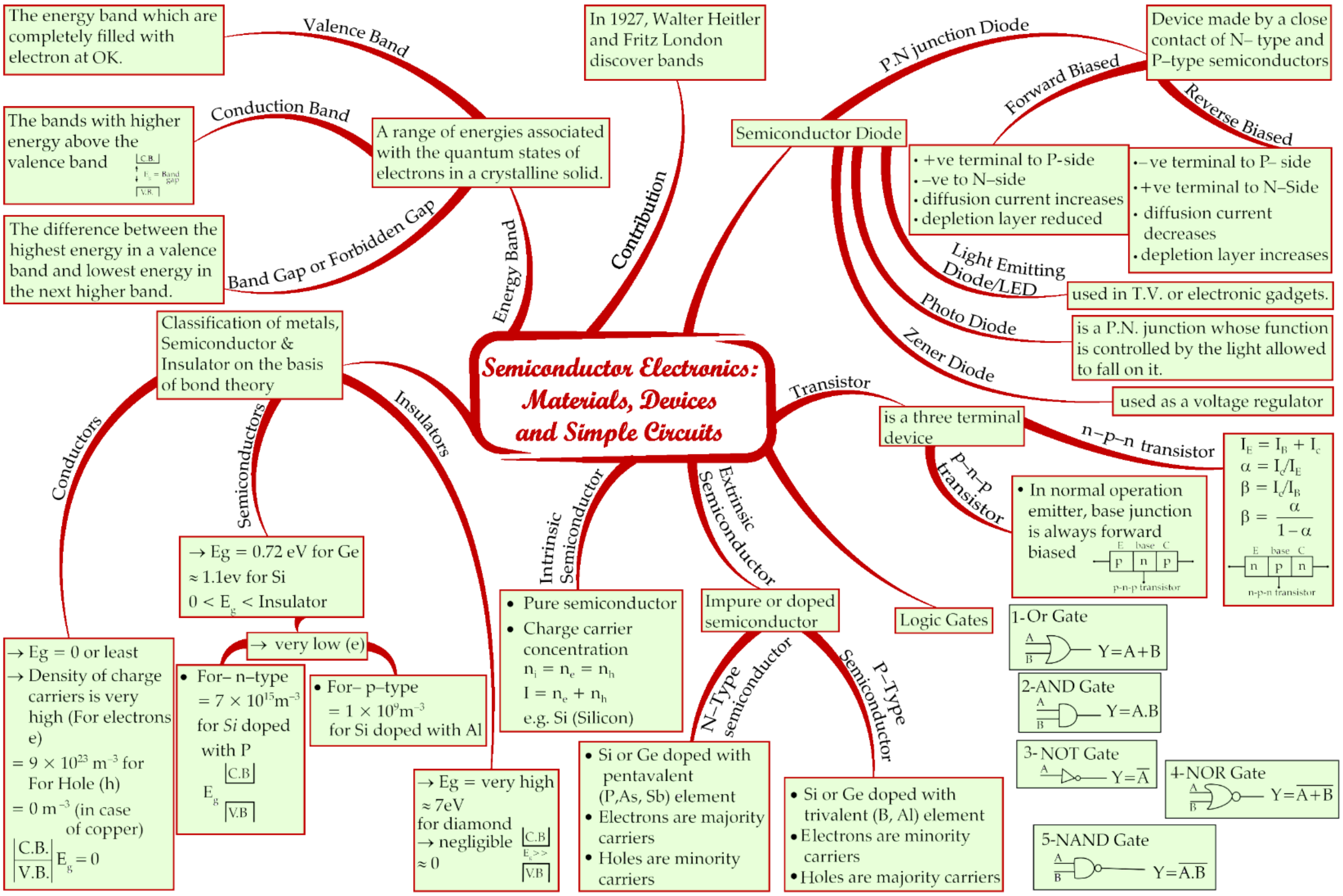
  or

  $$A_p = A_i . A_v = \beta_{ac}^2 \cdot \frac{R_{out}}{R_{in}}$$

- **Logic Gate:**
  A logic gate is a digital circuit that has one or more inputs but only one output. It follows a logical relationship between input and output voltage.
- **Truth Table:**
  This table shows all possible input combination and the corresponding output for a logic gate.
- **Boolean Expression:**
  It is a shorthand method of describing the function of a logic gate in the form of an equation or an expression. It also relates all possible combination of the inputs of a logic gate to the corresponding outputs.
- **Positive and Negative Logic:**
  If in a system, the higher voltage level represents 1 and the lower voltage level represent 0, the system is called a positive logic. If the higher voltage represents 0 and the lower voltage level represents 1, then the system is called a negative logic.
- **OR Gate:**
  An OR gate can have any number of inputs but only one output. It gives higher output (1) if either input A or B or both are high (1), otherwise the output is low (0).
  A + B = Y
  Which is read as 'A or B equals Y'.
- **AND gate:**
  An AND gate can have any number of inputs but only one output. It gives a high output (1) if inputs A and B are both high (1), or else the output is low (0). It is described by the Boolean expression.
  A. B = Y
  Which is read as 'A and B equals Y'.

- **NOT Gate:**
  A NOT gate is the simplest gate, with one input and one output. It gives as high output (1) if the input A is low (0), and vice versa.
  Whatever the input is, the NOT gate inverts it. It is described by the Boolean expression:
  $\bar{A}$ = Y
  Which is read as 'not A equal Y'.
- **NAND (NOT+AND) gate:**
  It is obtained by connecting the output of an AND gate to the input of a NOT gate. Its output is high if both inputs A and B are not high. If is described by the Boolean expression.
  A.B = Y or *AB = Y*
  Which is read as 'A and B negated equals Y'.
- **NOR (NOT+OR) Gate:**
  It is obtained by connecting the output of an OR gate to the input of a NOT gate. Its output is high if neither input A nor input B is high. It is described by the Boolean expression.
  A + B = Y
  Which is read as 'A and B negated equals Y'.
- **XOR or Exclusive OR gate.** The XOR gate gives a high output if either input A or B is high but not when both A and B are high or low. It can be obtained by using a combination of two NOT gates, two AND gates and one OR gate. It is described by Boolean expression:
  Y = AB + AB
  The XOR gate is also known as difference gate because its output is high when the inputs are different.
- **Integrated Circuits:**
  The concept of fabricating an entire circuit (consisting of many passive components like R and C and active devices like diode and transistor) on a small single block (or chip) of a semiconductor has revolutionized the electronics technology. Such a circuit is known as Integrated Circuit (IC).

MIND MAP


Semiconductor Electronics: Materials, Devices and Simple Circuits
Energy Band
A range of energies associated with the quantum states of electrons in a crystalline solid.
Valence Band
The energy band which are completely filled with electron at OK.
Conduction Band
The bands with higher energy above the valence band
C.B.
V.B.
Band Gap or Forbidden Gap
The difference between the highest energy in a valence band and lowest energy in the next higher band.
Contribution
In 1927, Walter Heitler and Fritz London discover bands
Classification of metals, Semiconductor & Insulator on the basis of bond theory
Conductors
→ Eg = 0 or least
→ Density of charge carriers is very high (For electrons e)
= 9 × 10²³ m⁻³ for For Hole (h)
= 0 m⁻³ (in case of copper)
C.B.
V.B.
E_g = 0
Semiconductors
→ Eg = 0.72 eV for Ge
≈ 1.1ev for Si
0 < E_g < Insulator
→ very low (e)
• For– n–type = 7 × 10¹⁵m⁻³ for Si doped with P
• For– p–type = 1 × 10⁹m⁻³ for Si doped with Al
C.B
E_g
V.B
Insulators
→ Eg = very high ≈ 7eV for diamond
→ negligible ≈ 0
C.B
V.B
Intrinsic Semiconductor
• Pure semiconductor
• Charge carrier concentration
n_i = n_e = n_h
I = n_e + n_h
e.g. Si (Silicon)
Extrinsic Semiconductor
Impure or doped semiconductor
N–Type semiconductor
• Si or Ge doped with pentavalent (P,As, Sb) element
• Electrons are majority carriers
• Holes are minority carriers
P–Type Semiconductor
• Si or Ge doped with trivalent (B, Al) element
• Electrons are minority carriers
• Holes are majority carriers
Semiconductor Diode
P.N junction Diode
Device made by a close contact of N– type and P–type semiconductors
Forward Biased
• +ve terminal to P-side
• –ve to N–side
• diffusion current increases
• depletion layer reduced
Reverse Biased
• –ve terminal to P– side
• +ve terminal to N–Side
• diffusion current decreases
• depletion layer increases
Light Emitting Diode/LED
used in T.V. or electronic gadgets.
Photo Diode
is a P.N. junction whose function is controlled by the light allowed to fall on it.
Zener Diode
used as a voltage regulator
Transistor
is a three terminal device
n–p–n transistor
I_E = I_B + I_C
α = I_C/I_E
β = I_C/I_B
β = α / (1 – α)
n-p-n transistor
p–n–p transistor
• In normal operation emitter, base junction is always forward biased
p-n-p transistor
Logic Gates
1-Or Gate
Y=A+B
2-AND Gate
Y=A.B
3-NOT Gate
Y=Ā
4-NOR Gate
Y=$\overline{A+B}$
5-NAND Gate
Y=$\overline{A.B}$

PRACTICE EXCERCISE

MCQ

Q1. In a p-n junction having depletion layer of thickness 10^{-6} m the potential across it is 0.1 V. The electric field is

(a) $\frac{10^7 \text{ V}}{\text{m}}$ (b) $\frac{10^{-6} \text{ V}}{\text{m}}$

(c) $\frac{10^5 \text{ V}}{\text{m}}$ (d) $\frac{10^{-5} \text{ V}}{\text{m}}$

Q2. In a reverse biased diode when the applied voltage changes by 1 V, the current is found to change by $0.5\mu A$. The reverse bias resistance of the diode is

(a) $2 \times 10^5 \Omega$ (b) $2 \times 10^6 \Omega$

(c) 200Ω (d) 2Ω.

Q3. When the forward bias voltage of a diode is changed from 0.6 V to 0.7 V, the current changes from 5 mA to 15 mA. Then its forward bias resistance is

(a) 0.01Ω (b) 0.1Ω

(c) 10Ω (d) 100Ω

Q4. A diode having potential difference 0.5 V across its junction which does not depend on current, is connected in series with resistance of 20Ω across source. If 0.1 A current passes through resistance then what is the voltage of the source?

(a) 1.5 V (b) 2.0 V

(c) 2.5 V (d) 5 V

Q5. If the forward bias on p-n junction is increased from zero to 0.045 V, then no current flows in the circuit. The contact potential of junction i.e. V_B is

(a) zero (b) 0.045 V

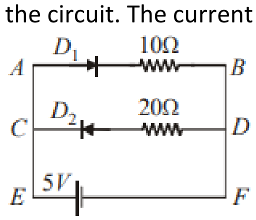
(c) more than 0.045 V (d) less than 0.045 V

Q6. The peak voltage in the output of a half-wave diode rectifier fed with a sinusoidal signal without filter is 10V. The d.c. component of the output voltage is

(a) $20/\pi$ S V (b) 10/ 2 V

(c) $10/\pi$ V (d) 10V

Q7. Two ideal diodes are connected to a battery as shown in the circuit. The current supplied by the battery is



(a) 0.75 A (b) zero

(c) 0.25 A (d) 0.5 A

Q8. Hole in semiconductor is

(a) an anti – particle of electron

(b) a vacancy created when an electron leaves a covalent bond

(c) absence of free electrons

(d) an artificially created particle

Q9. In the half wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be

(a) 25 Hz (b) 50 Hz

(c) 70.7 Hz (d) 100 Hz

Q10. Addition of trivalent impurity to a semiconductor creates many

(a) hole (b) bound electrons

(c) free electrons (d) valence electrons

Q11. In a full wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be

(a) 25 Hz (b) 50 Hz

(c) 70.7 Hz (d) 100 Hz

Q12. What bonds are present in a semiconductor?

(a) Monovalent (b) Bivalent

(c) Trivalent (d) Covalent

Q13. What happens to the forbidden energy gap of a semiconductor with the fall of temperature?

(a) Decreases

(b) Increases

(c) Unchanged

(d) Sometimes decreases and sometimes increases

Q14. In a p-type semiconductor, the current conduction is due to

(a) Holes (b) Atoms

(c) Electrons (d) Protons

Q15. What is the main function of a transistor?

(a) Simplify (b) Amplify

(c) Rectify (d) All of the above

Q15. In a semiconductor, what is responsible for conduction?

(a) Electrons only

(b) Holes only

(c) Both electrons and holes

(d) Neither electrons nor holes

Q17. What happens to the resistance of semiconductors on heating?

(a) Increases

(b) Decreases

(c) Remains the same

(d) First increases later decrease

Q18. In intrinsic semiconductors at room temperature, the number of electrons and holes are

(a) Unequal (b) Equal

(c) Infinite (d) Zero

Q19. Which of the following is not a universal gate?

(a) NOT (b) AND

(c) OR (d) NAND

Q20. Electric conduction in a semiconductor takes place due to

(a) electrons only

(b) holes only

(c) both electrons and holes

(d) neither electrons nor holes

ASSERTION AND REASONING

Directions: Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

(a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.

(b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion

(c) Assertion is correct, reason is incorrect

(d) Assertion is incorrect, reason is correct

Q1. Assertion: NAND or NOR gates are called digital building blocks. Reason: The repeated use of NAND (or NOR) gates can produce all the basis or complicated gates.

Q2. Assertion: A transistor amplifier in common emitter configuration has a low input impedance.
Reason: The base to emitter region is forward biased.

Q3. Assertion: A *p-n* junction diode can be used even at ultra-high frequencies.
Reason: Capacitive reactance of *p-n* junction diode increases as frequency increases.

Q4. Assertion: The diffusion current in a p-n junction is from the p-side to the n-side.
Reason: The diffusion current in a p-n junction is greater than the drift current when the junction is in forward biased.

Q5. Assertion: When the temperature of a semiconductor is increased, then its resistance decreases.
Reason: The energy gap between valence and conduction bands is very small for semiconductors.

SHORT ANSWER QUESTIONS

Q1. In a transistor, reverse bias is quite high as compared to the forward bias. Why? A transistor is a temperature sensitive device. Explain.

Q2. The use of a transistor in common-emitter configuration is preferred over the common-base configuration. Explain why?

Q3. A transistor is a temperature sensitive device. Explain

Q4. Explain why the emitter is forward biased and the collector is reverse biased in a transistor?

Q5. Why a transistor cannot be used as a rectifier?

NUMERICAL TYPE QUESTIONS

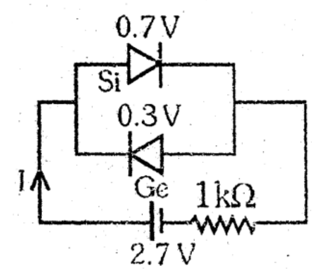
Q1. A P type semiconductor has acceptor level 57 meV above the valance band. What is maximum wavelength of light required to create a hole?

Q2. A silicon specimen is made into a p-type semiconductor by doping on an average one indium atom per 5×10^7 silicon atom. If the number density of atoms in the silicon specimen is 5×10^{28} atoms/ m^3; find the number of acceptor atoms in silicon per cubic centimetre.

Q3. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium n_h increases to 3×10^{22} m^{-3}. Calculate n_e in the doped Si.

Q4. What will be conductance of pure silicon crystal at 300 K temperature? If electron hole pairs per cm^3 is 1.075×10^{10} at this temperature, $\mu_e = 1350$ cm^2 / volt-s & $\mu_h = 480$ cm^2 / volt-s.

Q5. What is the value of current I in given circuits?



Q6. In a transistor, the value of β is 50. Calculate the value of α.

Q7. In an NPN transistor 10^{10} electrons enter the emitter in 10^{-6} s and 2% electrons recombine with holes in base, then find the value of α and β.

Q8. The transfer ratio of a transistor is 50. The input resistance of the transistor when used in the common-emitter configuration is 1 kΩ. Then find the peak value for an A.C input voltage of 0.01 V peak.

Q9. Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5eV, 2eV and 3eV, respectively. Which ones will be able to detect light of wavelength 6000Å A?

Q10. The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes.

Q11. A photodetector is made from a semiconductor with E_g = 0.75 eV. Calculate the maximum wavelength which it can detect?

HOMEWORK EXERCISE

MCQ

Q1. When a semiconductor is heated, its resistance
(a) decreases
(b) increases
(c) remains unchanged
(d) nothing is definite

Q2. In the case of constants α and β of a transistor
(a) $\alpha = \beta$
(b) $\beta < 1, \alpha > 1$
(c) $\alpha = \beta^2$
(d) $\beta > 1, \alpha < 1$

Q3. The forbidden energy band gap in conductors, semiconductors and insulators are EG_1, EG_2 and EG_3 respectively. The relation among them is
(a) $EG_1 = EG_2 = EG_3$
(b) $EG_1 < EG_2 < EG_3$
(c) $EG_1 > EG_2 > EG_3$
(d) $EG_1 < EG_2 > EG_3$

Q4. Which statement is correct?
(a) N-type germanium is negatively charged and P-type germanium is positively charged
(b) Both N-type and P-type germanium is neutral
(c) N-type germanium is positively charged and P-type germanium is negatively charged
(d) Both N-type and P-type germanium is negatively charged

Q5. Let n_h and n_e be the number of holes and conduction electrons respectively in a semiconductor. Then
(a) $n_h > n_e$ in an intrinsic semiconductor
(b) $n_h = n_e$ in an extrinsic semiconductor
(c) $n_h = n_e$ in an intrinsic semiconductor
(d) $n_e > n_h$ in an intrinsic semiconductor

Q6. Wires P and Q have the same resistance at ordinary (room) temperature. When heated, resistance of P increases and that of Q decreases. We conclude that
(a) P and Q are conductors of different materials
(b) P is n-type semiconductor and Q is p-type semiconductor
(c) P is semiconductor and Q is conductor
(d) P is conductor and Q is semiconductor

Q7. In an NPN transistor circuit, the collector current is 10 mA. If 90% of the electrons emitted reach the collector, the emitter current (i_E) and base current (i_B) are given by
(a) i_E = –1mA, i_B = 9mA
(b) i_E = 9mA, i_B = –1mA
(c) i_E = 1mA, i_B = 11mA
(d) i_E = 11mA, i_B = 1mA

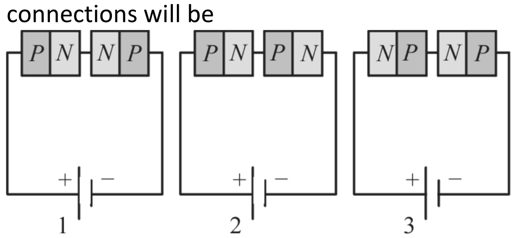
Q8. At zero Kelvin a piece of germanium
(a) becomes semiconductor
(b) becomes good conductor
(c) becomes bad conductor
(d) has maximum conductivity

Q9. The intrinsic semiconductor becomes an insulator at
(a) 0°C (b) –100°C
(c) 300 K (d) 0 K

Q10. Energy bands in solids are a consequence of
(a) Ohm's Law
(b) Pauli's exclusion principle
(c) Bohr's theory
(d) Heisenberg's uncertainty principle

Q12. Choose the correct statement
(a) When we heat a semiconductor, its resistance increases
(b) When we heat a semiconductor, its resistance decreases
(c) When we cool a semiconductor to 0 K then it becomes super conductor
(d) Resistance of a semiconductor is independent of temperature

Q13. Two PN-junctions can be connected in series by three *different* methods as shown in the figure. If the potential difference in the junctions is the same, then the correct connections will be



(a) In the circuit (1) and (2)
(b) In the circuit (2) and (3)
(c) In the circuit (1) and (3)
(d) Only in the circuit (1)

Q14. The approximate ratio of resistances in the forward and reverse bias of the PN-junction diode is
(a) $10^2 : 1$ (b) $10^{-2} : 1$
(c) $1 : 10^{-4}$ (d) $1 : 10^4$

Q15. The dominant mechanisms for motion of charge carriers in forward and reverse biased silicon P-N junctions are
(a) Drift in forward bias, diffusion in reverse bias
(b) Diffusion in forward bias, drift in reverse bias
(c) Diffusion in both forward and reverse bias
(d) Drift in both forward and reverse bias
In reverse biasing diffusion becomes more difficult so net current (very small) is due to the drift.

Q16. In a triclinic crystal system
(a) $a \neq b \neq c, \alpha \neq \beta \neq \gamma$
(b) $a = b = c, \alpha \neq \beta \neq \gamma$
(c) $a \neq b \neq c, \alpha \neq \beta = \gamma$
(d) $a = b = c, \alpha = \beta = \gamma$

ASSERTION AND REASONING

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(b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
(c) Assertion is correct, reason is incorrect
(d) Assertion is incorrect, reason is correct

Q1. Assertion: A pure semiconductor has negative temperature coefficient of resistance.
Reason: In a semiconductor on raising the temperature, more charge carriers are released, conductance increases and resistance decreases.

Q2. Assertion: A p-type semiconductors is a positive type crystal.
Reason: A p- type semiconductor is an uncharged crystal.

Q3. Assertion: When two semiconductors of p and n type are brought in contact, they form p-n junction which act like a rectifier.
Reason: A rectifier is used to convent alternating current into direct current.

Q4. Assertion: The number of electrons in a P-type silicon semiconductor is less than the number of electrons in a pure silicon semiconductor at room temperature.
Reason**:** It is due to law of mass action.

Q5. Assertion: We can measure the potential barrier of a PN junction by putting a sensitive voltmeter across its terminals.
Reason**:** The current through the PN junction is not same in forward and reversed bias

Q6. Assertion**:** The resistivity of a semiconductor decreases with temperature.
Reason**:** The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing its resistivity.

SHORT ANSWER QUESTIONS

Q1. Why we prefer transistor over the vacuum tubes in the portable radio receivers?

Q2. How is a light emitting diode fabricated? Briefly state it's working. Write any two important advantages of LEDs over the conventional incandescent low power lamps.

Q3. How is forward biasing different from reverse biasing in a p-n junction diode?

Q4. Explain why elemental semiconductor cannot be used to make visible LEDs.

Q5. Why are elemental dopants for Silicon or Germanium usually chosen from group 13 or group 15?

CASE STUDY BASED QUESTIONS

Q1. A student performs an experiment for drawing the static characteristic curve of a triode valve in the laboratory. The following data were obtained from the linear portion of the curves:

Grid voltage V_g (volt)	–2.0	–3.5	–2.0
Plate voltage V_p (volt)	180	180	120
Plate current I_p (mA)	15	7	10

(i). Calculate the plate resistance r_p of the triode valve?
(a) 0.12×10^4 ohm (b) 1.2×10^4 ohm
(c) 1.3×10^4 ohm (d) 1.4×10^4 ohm

(ii). Calculate the mutual conductance g_m of the triode valve?
(a) 5.33×10^{-3} ohm^{-1} (b) 53.3×10^{-3} ohm^{-1}
(c) 4.32×10^{-3} ohm^{-1} (d) 5.00×10^{-3} ohm^{-1}

(iii). Calculate the amplification factor μ, of the triode valve?
(a) 64 (b) 52
(c) 54 (d) 62

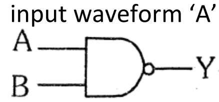
NUMERICAL TYPE QUESTIONS

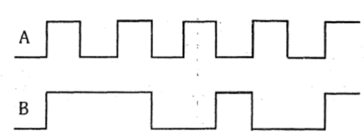
Q1. Calculate the emitter current for which I_B = 20 μA, β = 100

Q2. The base current is 100 μA and collector current is 3 mA.
(a) Calculate the values of β, I_E and α.
(b) A charge of 20 μA in the base current produces a change of 0.5 mA in the collector current. Calculate $\beta_{a.c.}$.

Q3. In a transistor connected in common emitter mode R_0 = 4 kΩ, R_i = 1 kΩ, I_C = 1 mA and I_B = 20 μA. Find the voltage gain.

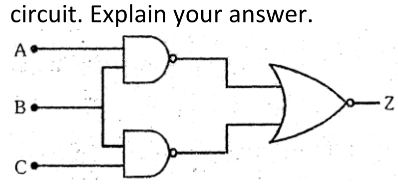
Q4. In the figures below, circuit symbol of a logic gate and two input waveform 'A' and 'B' are shown.





(a) Name the logic gate & Write its Boolean expression.
(b) Write its truth table.
(c) Give the output wave from.

Q5. Write down the equivalent function performed by given circuit. Explain your answer.



Q6. In a half wave rectifier, what is the frequency of ripple in the output if the frequency of input ac is $50 \mathrm{~Hz}$? What is the output ripple frequency of a full wave rectifier?

Q7. The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes. Given that $n_1 = 1.5 \times 10^{16} \mathrm{~m}^{-3}$. Is the material n-type or p-type?

Q8. A $p - n$ photodiode is fabricated from a semiconductor with band gap of $2.8 \mathrm{eV}$. Can it detect a wavelength of $6000 \mathrm{~nm}$?

Q9. A p-n photodiode is fabricated from a semiconductor with a bandgap of $2.8 \mathrm{eV}$. Can it detect a wavelength of $6000 \mathrm{~nm}$?

Q10. The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}$ per m^3. Is the material n-type or p-type?

SOLUTIONS MULTIPLE CHOICE

MCQ

S1. **(c)** $E = \frac{V}{d} = \frac{0.1}{10^{-6}} = 10^5$ V/m

S2. (b)
Reverse resistance
$= \frac{\Delta V}{\Delta I} = \frac{1}{0.5 \times 10^{-6}} = 2 \times 10^6 \Omega$

S3. (c)
Forward bias resistance $= \frac{\Delta V}{\Delta I}$
$= \frac{(0.7-0.6)V}{(15-5)mA} = \frac{0.1}{10 \times 10^{-3}} = 10\Omega$

S4. (c)
$V' = V + IR = 0.5 + 0.1 \times 20 = 2.5$ V

S5. (c)
When no current flows at the junction plane, then contact potential of junction plane is equal to the forward voltage applied $= 0.045$ V

S6. (c)
$V = \frac{V_0}{\pi} = \frac{10}{\pi} V$

S7. (d) Here D_1 is in forward bias and D_2 is in reverse bias so, D_1 will conduct and D_2 will not conduct. Thus, no current will flow through DC.

$$I = \frac{V}{R} = \frac{5}{10} = \frac{1}{2} \text{Amp.}$$

S8. (b) a vacancy created when an electron leaves a covalent bond. Because- anti particle of electron is positron (i.e. e+), there is no presence of free electron in semiconductor and hole is not created. It is just the absence created when an electron jumps to the conduction band from the valence band leaving an empty spot in the semiconductor. Electron breaks the covalent bond and a blank is created which is called hole.

S9. (b) In half wave rectifier, we get the output only in one half cycle of input a.c. therefore, the frequency of the ripple of the output is same as that of input a.c. i.e., 50 Hz

S10. (a) holes
In a pure semiconductor, each atom is surrounded by four atoms and is engaged in chemical bond with all of them. This is because a pure semiconductor has four valence electrons. A trivalent impurity has 3 valence electrons. When it is added, one atom of it forms bonds with three atoms of the semiconductor. Only three atoms are engaged in bonding. There is an empty space between the atom of impurity and the fourth atom of pure semiconductor. Such an empty space is called as hole which is available for conduction. Thus a semiconductor with trivalent impurity has many holes.

S11. (d) In full wave rectifier, we get the output for the positive and negative cycle of input a.c. Hence the frequency of the ripple of the output is twice than that of input a.c. i.e. 100 Hz

S12. (d) Covalent Covalent bonds are present in a semiconductor.

S13. (b) Increases The forbidden energy gap of a semiconductor increases with the fall of temperature.

S14. (a) Holes In a p-type semiconductor, the current conduction is due to holes.

S15. (b) Amplify
The main function of a transistor is to amplify.

S16. (c) Both electrons and holes
Both electrons and holes are responsible for conduction in a semiconductor.

S17. (b) decreases
The resistance of semiconductors decreases on heating.

S18 **(b)** Equal
In intrinsic semiconductors, the number of electrons and holes are equal.

S19. (d) NAND
NAND is not a universal gate.

S20. (c) Electric conduction, in a semiconductor occurs due to both electrons & holes.

ASSERTION AND REASONING

S1. (a) These gates are called digital building blocks because using these gates only (either NAND or NOR) we can compile all other gates also (like OR, AND, NOT, XOR)

S2. (a) Input impedance of common emitter configuration.

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

where ΔV_{BE} = voltage across base and emitter (base emitter region is forward biased)

S3. (c) Here Assertion is correct but Reason is wrong. As capacitive reactance, $X_c = 1/(\omega C) = 1/(2\pi v C)$. It decreases as v increases.

S4. (b) Diffusion current is due to the migration of holes and electrons into opposite regions, so it will be from p-side to n-side. Also, in forward bias it will increases.

S4. (a) Assertion is right because with increase in temperature, the resistance of semiconductor decreases. Due to small gap between valence band and conduction band, electrons jump into conduction band and increases conduction.

SHORT ANSWER QUESTIONS

S1. In a transistor, charge carriers (electrons or holes) move from emitter to collector through the base. The reverse bias on collector is made quite high so that it may exert a large attractive force on the charge carriers to enter the collector region. These moving carriers in the collector constitute a collector current.

S2. The current gain and voltage gain in the common-emitter configuration is more one. So maximum power gain in common emitter configuration

S3. In a transistor, conduction is due to the movement of current carriers' electrons and holes. When temperature of the transistor increases, many covalent bonds may break up resulting in the formation of more electron, and holes. Thus, the current will increase in the transistor. This current gives rise to the production of more heat energy. The excess heat causes complete breakdown of the transistor.

S4. In a transistor, the charge carriers move from emitter to collector. The emitter sends the charge carriers and collector collects them. This can happen only if emitter is forward biased and the collector is reverse biased so that it may attract the carriers.

S5. If transistor is to be used as a rectifier, then either emitter-base or base-collector has to use as diode. For equated working of the said set of diodes, the number density of charge carriers in emitter and base or base and collector must be approximately same. As base is lightly doped and comparatively thin, so transistor cannot work as a rectifier

NUMERICAL TYPE QUESTIONS

S1. $E = \frac{hc}{\lambda}$

$$\Rightarrow \quad \lambda = \frac{hc}{E} = \frac{6.62\times10^{-34}\times3\times10^{8}}{57\times10^{-3}\times1.6\times10^{-19}} = 217700 \text{ Å}$$

S2. The doping of one indium at6m in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been clopped per 5 × 10^7 silicon atoms, so number density of acceptor atoms in silicon

$$= \frac{5\times10^{28}}{5\times10^{7}} = 10^{21} \text{ atom/m}^3 = 10^{15} \text{ atom/cm}^3$$

S3. For a doped semi-conductor in thermal equilibrium

$n_e n_h = n_i^2$ (Law of mass action)

$$n_e = \frac{n_i^2}{n_h} = \frac{(1.5\times10^{16})^2}{3\times10^{22}} = 7.5\times10^{9}\,\text{m}^{-3}$$

S4. $\sigma = n_i e\mu_e + n_i e\mu_h = n_i e(\mu_e + \mu_h)$

$= 1.072 \times 10^{10} \times 1.6 \times 10^{-19} \times (1350 + 480)$

$= 3.14 \times 10^{-6}$ mho/cm

S5. $I = \frac{27-0.7}{1\times10^{3}} = 2\ mA$

S6. $\beta = \frac{\alpha}{1-\alpha} \quad \Rightarrow \quad 50 = \frac{\alpha}{1-\alpha}$

$\Rightarrow 50 - 50\alpha = \alpha \Rightarrow \quad \alpha = \frac{50}{51} = 0.98$

S7. Emitter current $I_e = \frac{Ne}{t} = \frac{10^{10}\times1.6\times10^{-19}}{10^{-6}} = 1.6$ mA

Base current $I_b = \frac{2}{100}\times 1.6 = 0.032$ mA

But, $I_e = I_c + I_b$

$\therefore I_c = I_e - I_b = 1.6 - 0.032 = 11.568$ mA

$\therefore \alpha = \frac{I_c}{I_e} = \frac{1.568}{1.6} = 0.98$ and $\beta = \frac{I_c}{I_b} = \frac{1.568}{0.032} = 49$

S8. $\beta = 50, R = 1000\Omega, V_i = 0.01V$

$\beta = \frac{i_c}{i_b}$ and $i_b = \frac{V_i}{R_i} = \frac{0.01}{10^3} = 10^{-5}A$

Hence $i_c = 50 \times 10^{-5}A = 500\ \mu A$

S9. Energy of incident light photon,

$$E = hv = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{6\times10^{-7}\times1.6\times10^{-19}} = \mathbf{2.06eV}$$

For the incident radiation to be detected by the photodiode, energy of incident radiation photon should be greater than the band gap. This is true only for D_2. Therefore, only D_2 will detect this radiation.

S10. Following values are given in the question:

Number of silicon atoms, $N = 5\times10^{28}$ atoms $/\text{m}^3$

Number of arsenic atoms, $n_{AS} = 5\times10^{22}$ atoms $/\text{m}^3$

Number of indium atoms, $n_{\text{In}} = 5\times10^{22}$ atoms $/\text{m}^3$

$n_i = 1.5\times10^{16}$ electrons $/\text{m}^3$

$n_e = 5\times10^{22} - 1.5\times10^{16} = 4.99\times10^{22}$

Let us consider the number of holes to be n_h

In the thermal equilibrium, $n_e n_h = n_i^2$

Calculating, we get

$n_h = 4.51\times10^{9}$

Here, $n_e > n_h$, therefore the material is a n-type semiconductor.

S11. $\lambda \frac{hc}{E_g} \frac{6.62\times10^{-34}\times3\times10^{8}}{0.75\times1.6\times10^{-19}}$ max

HOMEWORK EXERCISE SOLUTIONS

MULTIPLE CHOICE QUESTIONS

S1. (a) With temperature rise conductivity of semiconductors increases.

S2. (d) α is the ratio of collector current and *emitter* current while β is the ratio of collector current and base current.

S3. (b) In insulators, the forbidden energy gap is very large, in case of semiconductor it is moderate and in conductors the energy gap is zero.

S4. (b) Both P-type and N-type semiconductors are neutral because neutral atoms are added during doping.

S5. (c) In intrinsic semiconductors, the creation or liberation of one free electron by the thermal energy creates one hole. Thus, in intrinsic semiconductors $n_e = n_h$

S6. (d) Conductor has positive temperature coefficient of resistance but semiconductor has negative temperature coefficient of resistance.

S7. (d) $i_C = \frac{90}{100} \times i_E \Rightarrow 10 = 0.9 \times i_E \Rightarrow 11mA$
Also $\mathrm{i_E = i_B + i_C \Rightarrow i_B = 11 - 10 = 1mA}$

S8. (c) At zero Kelvin, there is no thermal agitation and therefore no electrons from valence band are able to shift to conduction band.

S9. (d) At 0K temperature semiconductor behaves as an insulator, because at very low temperature electrons cannot jump from the valence band to conduction band

S10. (b) Formation of energy bands in solids are due to Pauli's exclusion principle.

S12. (b) With rise in temperature, conductivity of semiconductor increases while resistance decreases.

S13. (b) Because in case (1) N is connected with N. This is not a series combination of transistor

S14. (d) Resistance in forward biasing $R_{fr} \approx 10\Omega$ and resistance in reverse biasing
$R_{Rw} \approx 10^5\Omega \Rightarrow \frac{R_{fr}}{R_{Rw}} = \frac{1}{10^4}$

S15. (b) In forward biasing the diffusion current increases and drift current remains constant so not current is due to the diffusion.

S16. (a) In a triclinic crystal $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma \neq 90°$

ASSERTION AND REASONING

S1. (a) In semiconductors, by increasing temperature, covalent bond breaks and conduction hole and electrons increase.

S2. (d) There is no charge on P-type semiconductor, because each atom of semiconductor is itself neutral.

S3. (b) Study of junction diode characteristics shows that the junction diode offers a low resistance path, when forward biased and high resistance path when reverse biased. This feature of the junction diode enables it to be used as a rectifier

S4. (a) According to law of mass action, $n_i^2 = n_e n_h$. In intrinsic semiconductors $n_i = n_e = n_h$ and for P-type semiconductor n_e would be less than n_i, since n_h is necessarily more than n_i.

S5. (c) We cannot measure the potential barrier of a PN-junction by connecting a sensitive voltmeter across its terminals because in the depletion region, there are no free electrons and holes and in the absence of forward biasing, PN-junction offers infinite resistance.

S6. (d) Resistivity of semiconductors decreases with temperature. The atoms of a semiconductor vibrate with larger amplitudes at higher temperatures there by increasing its conductivity not resistivity.

SHORT ANSWER QUESTIONS

S1. This is because of two reasons:
(a) Transistor is compact and small in size than the vacuum tube.
(b) Transistor can operate even at low voltage which can be supplied with two or three dry cells.

S2. LED is fabricated by
(i) heavy doping of both the p and n regions.
(ii) providing a transparent cover so that light can come out. Working: When the diode is forward biased, electrons are sent from n→ p and holes from p→ n. At the junction boundary, the excess minority carriers on either side of junction recombine with majority carriers. This releases energy in the form of photon hv = Eg.
GaAs (Gallium Arsenide): Band gap of semiconductors used to manufacture LED's should be 1.8 eV to 3 eV. These materials have band gap which is suitable to produce desired visible light wavelengths.

Advantages-
(i) Low operational voltage and less power consumption.
(ii) Fast action and no warm-up time required

S3. Forward Bias:
(i) Within the junction diode the direction of applied voltage is opposite to that of built-in potential.
(ii) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.
(iii) The diode offers very small resistance in the forward bias.

Reverse Bias:
(i) The direction of applied voltage and barrier potential is same.

(ii) The current is due to leakage of minority charge carriers through the junction and is very small of the order of nA

(iii) The diode offers very large resistance in reverse bias.

S4. Elemental semiconductor's band-gap is such that electromagnetic emissions are in infrared region.

S5. The size of dopant atoms should be such as not to distort the pure semiconductor lattice structure and yet easily contribute a charge carrier on forming covalent bonds with Si or Ge.

CASE STUDY BASED QUESTIONS

S (i). (b)

$$r_p = \frac{\Delta V_p}{\Delta I_p} = \frac{(180-120)}{(15-10)\times 10^{-3}} = 1.2\times 10^4\ ohm$$

S (ii). (a)

$$g_m = \frac{\Delta I_p}{\Delta V_g} = \frac{(15-7)\times 10^{-3}}{(-2.0)-(-3.5)} = 5.33\times 10^{-3}\ \text{ohm}^{-1}$$

S (iii). (a)

$$\mu = r_p \times g_m = (1.2\times 10^4)\times(5.33\times 10^{-3}) = 64$$

NUMERICAL TYPE QUESTIONS

S1. $I_C = \beta\, I_B = 100 \times 20 \times 10^{-6} = 2000\ \mu A$

$I_E = \beta\, I_B + I_C = 20 + 2000 = 2020\ \mu A = 2.02 \times 10^{-3}$ A = 2.02 mA

S2. (a) $\beta = \dfrac{I_C}{I_B} = \dfrac{3\times 10^{-3}}{100\times 10^{-6}} = 30$

$\alpha = \frac{\beta}{1+\beta} = \frac{30}{1+30} = \frac{30}{31} = 0.97$ and $I_E = \frac{I_C}{\alpha} = \frac{3\times 31}{30} = 3.1\ mA$

(b) $\Delta I_B = 20\ \mu A = 0.02$ mA,

$\Delta I_C = 0.5$ mA

$\therefore\ \beta_{ac} = \frac{\Delta I_C}{\Delta I_B} = \frac{0.5}{0.02} = 25$

S3. Voltage gain

$$A_V = \beta\left(\frac{R_0}{R_i}\right) = \left(\frac{I_C}{I_B}\right)\left(\frac{R_0}{R_i}\right) = \left(\frac{1\times 10^{-3}}{20\times 10^{-6}}\right)\left(\frac{4}{1}\right) = 200$$

S4. (a) NAND gate: $Y = \overline{A.B}$

(b) Truth table

Input A	*Input B*	*Output Y*
0	0	1
0	1	1
1	0	1
1	1	0

(c) Output waveform

S5. AND gate, $A = \overline{\overline{A\cdot B} + \overline{B\cdot C}} = \overline{\overline{AB}\cdot\overline{BC}} = \overline{\overline{ABC}} = ABC\ \ (\because\ \bar{X} + \bar{Y} = \overline{X\cdot Y}$

S6. In half wave rectifier, the output ripple frequency is 50 Hz.

In full wave rectifier, the output ripple frequency is twice of input frequency of ac i.e., $2\times 50 = 100$ Hz

S7. The following values are given in the question:

Number of silicon atoms, $N = 5\times 10^{28}$ atoms $/m^3$

Number of arsenic atoms, $n_{AS} = 5\times 10^{22}$ atoms $/m^3$

Number of indium atoms, $n_{In} = 5\times 10^{22}$atoms$/m^3$

$n_i = 1.5\times 10^{16}$ electrons $/m^3$

$n_e = 5\times 10^{22} - 1.5\times 10^{16} = 4.99\times 10^{22}$

Let us consider the number of holes to be n_h

In the thermal equilibrium, $n_e n_h = n_i^2$

Calculating, we get

$n_h = 4.51\times 10^9$

Here, $n_e > n_h$, therefore, the material is an n-type semiconductor.

S8. Energy corresponding to wavelength 6000 nm is

$E = = \frac{hc}{\lambda}$

$= \frac{6.6\times 10^{-34}\times 3\times 10^8}{6000\times 10^{-9}}$ joule $= 3.3\times 10^{-20}$ J

$= \frac{3.3\times 10^{-20}}{1.6\times 10^{-19}} = 0.2$Ev

The photon energy ($E = 0.2$eV) of given wavelength is much less than the band gap $\left(E_g = 2.8\text{eV}\right)$, hence it cannot detect the given wavelength.

S9. No, the photodiode cannot detect the wavelength of 6000 nm because of the following reason:

The energy bandgap of the given photodiode, $E_g = 2.8$eV

The wavelength is given by $\lambda = 6000$ nm $= 6000\times 10^{-9}$ m

We can find the energy of the signal from the following relation:

$E = hc/\lambda$

In the equation, h is Planck's constant $= 6.626\times 10^{-34}$ J and c is the speed of light $= 3\times 10^8$ m/s

Substituting the values in the equation, we get

$E = (6.626\times 10^{-34}\times 3\times 10^8)/6000\times 10^{-9} = 3.313\times 10^{-20}$ J

But, 1.6×10^{-19} J $=$ 1eV

Therefore, $E = 3.313\times 10^{-20}$ J $= 3.313\times 10^{-20}/1.6\times 10^{-19} = 0.207$eV

The energy of a signal of wavelength 6000 nm is 0.207eV, which is less than 2.8eV - the energy band gap of a photodiode. Hence, the photodiode cannot detect the signal.

S10. Arsenic is n-type impurity and indium is p-type impurity.

Number of electrons, $n_e = n_D - n_A$

$= 5\times 10^{22} - 5\times 10^{20} = 4.95\times 10^{22}$ m^{-3}

Also $n_i^2 = n_e n_h$

Given $n_i = 1.5\times 10^{16}$ m^{-3}

Number of holes, $n_h = \frac{n_i^2}{n_e} = \frac{\left(1.5\times 10^{16}\right)^2}{4.95\times 10^{22}}$

$\Rightarrow\ n_h = 4.54\times 10^9$ m^{-3}

As $n_e > n_h$; so the material is an n-type semiconductor