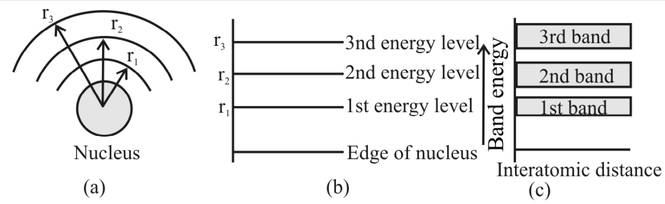
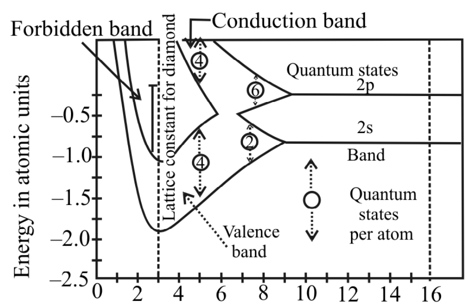
1. ENERGY BANDS IN SOLIDS

- However, an atom in solid is influenced by the presence of neighbouring atoms so that electron in any orbit may now have a range of energies than a single energy.
- The range of energy possessed by an electron in a solid is known as its energy band. Several energy levels overlap to form a band.

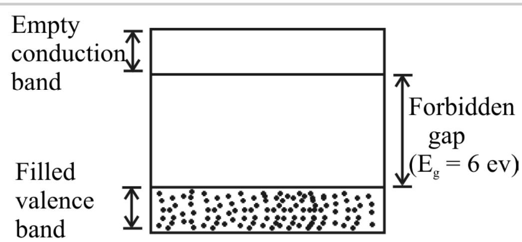


Semiconductor Electronics: Materials, Devices and Simple Circuits



Lattice constant in Angstrom

- **Valence band:** The range of energies possessed by valence electrons.
- **Conduction band:** The range of energies possessed by conduction / free electrons.
- The conduction band lies above the valence band.

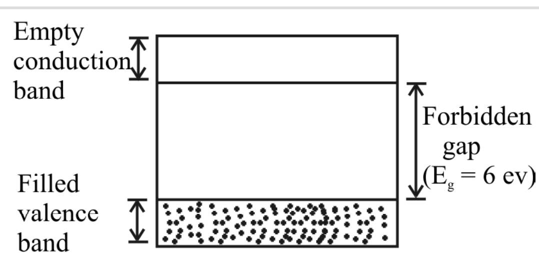


- **Forbidden energy gap:** The energy difference between the top of the valence band and the bottom of the conduction band is known as forbidden energy gap (E_g). In order to push an electron from valence band to conduction band, this much energy is to be supplied externally. The greater the energy gap, more tightly the valence electrons are bound to the nucleus.

2. CONDUCTORS, INSULATORS AND SEMICONDUCTORS

On the basis of energy band diagrams, solids can be classified as conductor, semiconductor and insulator.

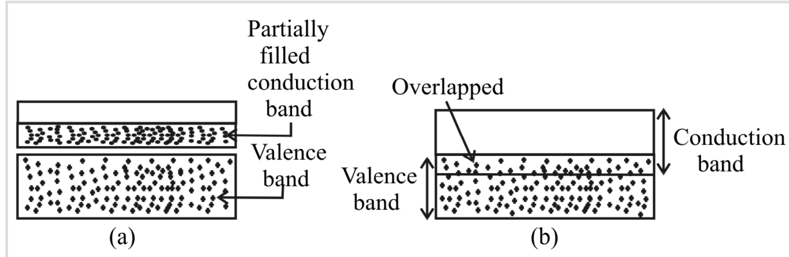
Insulators



- These are materials in which valence electrons are bound very tightly to the parent atoms, thus requiring very large electric field to remove them from. (*e.g.*, woods, glass etc)
- There is large energy gap (~ 6 eV) between them.
- They do not have free charge carriers for conduction, available with them under normal conditions.
- The resistance of an insulator decreases with the increase in temperature and vice-versa, *i.e.*, an insulator has negative temperature coefficient of resistance.

Conductors

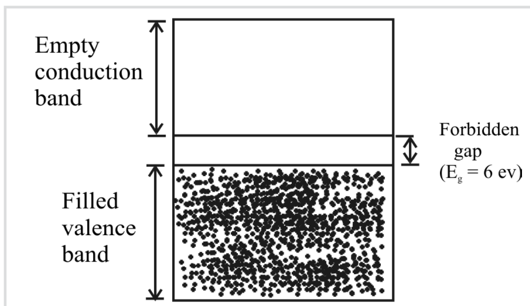
- These materials are very rich in free electrons (*e.g.*, copper, aluminium).
- The valence band can be completely filled and the conduction band partially filled with extremely small energy gap between them (*e.g.*, sodium) as shown in figure (*a*) below.



- For metals like zinc, the valence band and conduction band overlap each other as shown in the figure (*b*) below.
- They have positive temperature coefficient of resistance.

Semiconductors

- There are certain materials whose conductivity lies between those of insulators and conductors. (e.g. silicon, germanium)
- The size of forbidden energy band is much smaller (of the order of 1 eV).

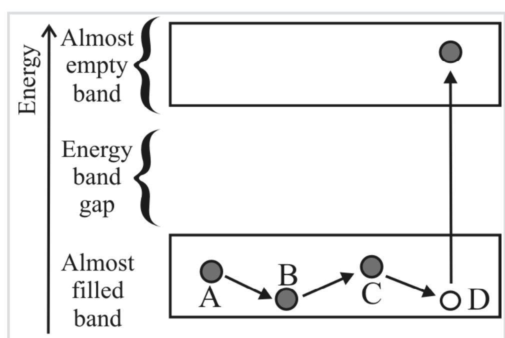


- At low temperature, the valence band is completely filled and conduction band is completely empty. At room temperature some electrons cross over to the conduction band, thereby, imparting little conductivity.
- As the temperature is increased, more electrons reach to the conduction band and the conductivity increases. Hence, the resistance of a semiconductor decreases with the increase in temperature and vice-versa, i.e. a semiconductor has negative temperature coefficient of resistance.
- A vacancy of electrons creates a hole in the valance band. Thus holes conduct in the valance band.

3. INTRINSIC SEMICONDUCTOR

Hole Concept: When a covalent bond is broken due to thermal energy, in a semiconductor, the removal of one electron leaves a vacancy behind it, i.e. a missing electron in the bond. This vacancy of electron is called a hole.

As shown in the above figure, when thermal energy is given, an electron jumps from valence band to conduction band leaving a vacancy at point D. Now the valance electron at C comes to fill the hole at D. This results in the disappearance of hole from D and appearing at C. Next, the valence electron at B moves into the hole at C. Consequently, hole is created at B. Thus, the electrons move along the path ABCD whereas the hole moves in the opposite direction (path DCBA).



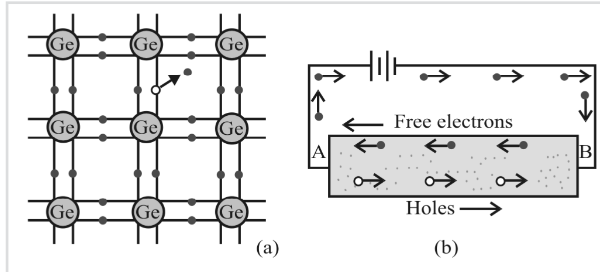
Intrinsic Semiconductor

- A semiconductor in an extremely pure form is known as an intrinsic semiconductor.
- In tetravalent atoms like germanium and silicon, the four valence electrons of each atom are shared with the four adjacent atoms.
- Each electron pair is a covalent bond and in the figure below; a pair of parallel lines between the respective atoms represents the covalent bonds.
- These covalent bonds serve to keep the atoms together in the crystal formation.

- When, some of the covalent bonds are broken, electron-hole pairs are generated.
- The number of free electrons (in conduction band) and holes (in valence band) is exactly equal in an intrinsic semiconductor.

  $$n_e = n_h = n_i$$

  where n_e and n_h are the number densities of electrons in the conduction band and that of holes in the valence band respectively while n_i is the number density of intrinsic carriers (electrons or holes) in a pure semiconductor.

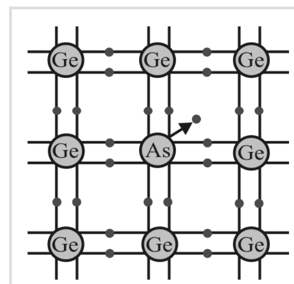


4. EXTRINSIC SEMICONDUCTOR

Doping is the process of addition of certain specific impurity atoms to a pure semiconductor in order to modify its conductivity in a controlled manner. The impurity added may be 1 in 10^{10}.

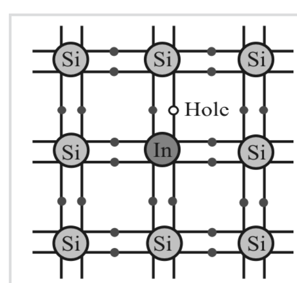
***n*-Type Semiconductor**

- When a semiconductor sample is doped with a pentavalent impurity such as phosphorus, arsenic etc. an *n*-type semiconductor is formed.
- The sample will have free electrons in excess to holes.
- Only four of the five valence electrons form covalent bonds with four adjacent atoms of the semiconductor, leaving one valence electron, free to wander about at random in the crystal.
- Since the pentavalent impurity atoms responsible for introducing or donating free electrons into the crystal, they are termed as donors; and a crystal doped with such impurity becomes n-type (that is, negative type) semiconductor.
- At room temperature, some of the covalent bonds may get ruptured, thereby producing free holes in the n-type semiconductor. But overall, the total number of holes in n-type semiconductor is relatively low.
- Thus, it is seen that the current conduction in n-type semiconductor is predominantly by free electrons or the electrons are majority carriers and holes are minority carriers.



***p*-Type Semiconductor**

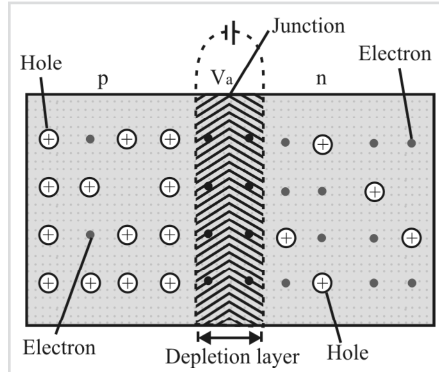
- When a semiconductor sample is doped with a trivalent impurity such as indium, gallium etc. a p-type semiconductor is formed.
- The sample will have holes in excess to free electrons.
- A trivalent atom can form covalent bonds with only three neighbouring semiconductor atoms.
- In the fourth covalent bond, only the semiconductor atom contributes one valence electron and there is the deficiency of an electron to complete the covalent bond. This missing electron creates a hole.
- Since the trivalent impurity atoms easily accept free electrons, they are called acceptors; and a crystal doped with such impurity becomes p-type (that is, positive type) semiconductor.
- At room temperature, some of the covalent bonds may get ruptured, thereby producing free electrons and holes in the p-type semiconductor. But overall, the total number of electrons in p-type semiconductor is relatively low.
- The current conduction in p-type semiconductor is predominantly by holes or holes are majority carriers and electrons are minority carriers.



5. PN JUNCTION

A PN junction is formed when a p-type semiconductor is suitably joined to an n-type semiconductor.

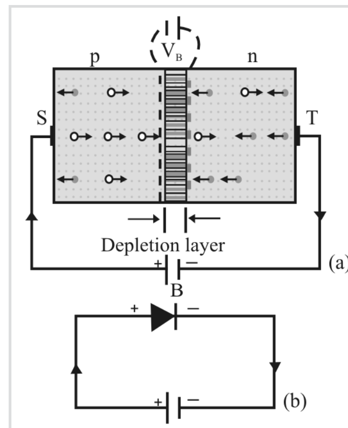
Depletion Layer in *p-n* Junction



- The p-region has mobile holes and the same number of immobile negative ions. The n-region has mobile electrons and the same number of immobile positive ions.
- Some of the holes diffuse across the boundary into the *n*-type region and electrons into the *p*-type region. As a result of diffusion of charges, the *n*-region of the junction will have its electrons neutralised by holes from the p-region, leaving only immobile ionised donor atoms (positive charges). Similarly, the p-region of the junction will have immobile ionised accepted atoms (negative charges).
- The accumulation of charges of opposite polarities in the two regions near the junction produces an electric field across these regions which oppose the further flow of electrons across the junction and the potential corresponding to this field is called a potential barrier.
- The region of immobile charges, devoid of free charges is known as the depletion region.

  Biasing of a p-n junction: A potential differences across a p-n junction or junction diode can be applied in two ways, namely forward bias and reverse bias.

Forward Bias

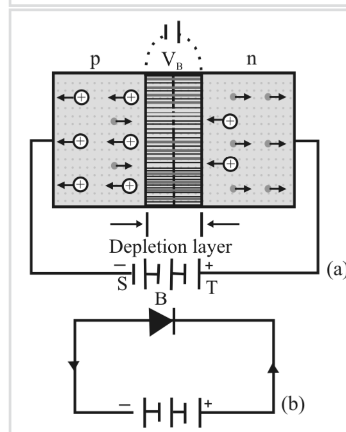


When an external voltage applied across a p-n junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward bias.

To apply forward bias, the positive terminal of the battery is connected to the p-type and negative terminal to n-type.

The holes in the p-region are repelled by positive terminal of the battery and the electrons by the negative terminal, towards the junction. On crossing the region of junction, the free electrons and the holes combine. Thus, all the majority holes of p-type and electrons of the n-type move towards the negetive and positive terminal of the battery respectively. Consequently, a forward current flows through the junction. The width of the depletion region as well as the resistance of the junction gets reduced.

Reverse Bias



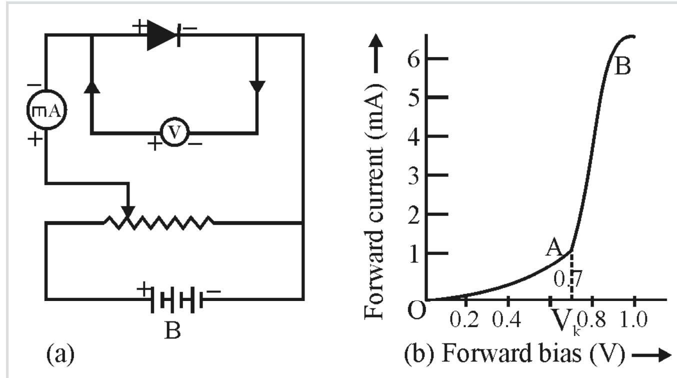
When the external voltage applied to junction is in such a direction that potential barrier is increased, it is called reverse bias.

A p-n junction is said to be reverse biassed, if the positive terminal of the external battery is connected to n-side and the negative terminal of battery is connected to the p-side of the junction.

The holes in the p-side are attracted towards the negative electrode while the free electrons are attracted towards the positive electrode. The depletion region becomes thick and offers high resistance to the flow of current. Practically, no current (that due to majority carriers) flows across the junction. Consequently, the junction behaves as an insulator. However, due to the thermally generated electron-hole pair, a small current known as reverse current or leakage current, (few microamperes) still flows.

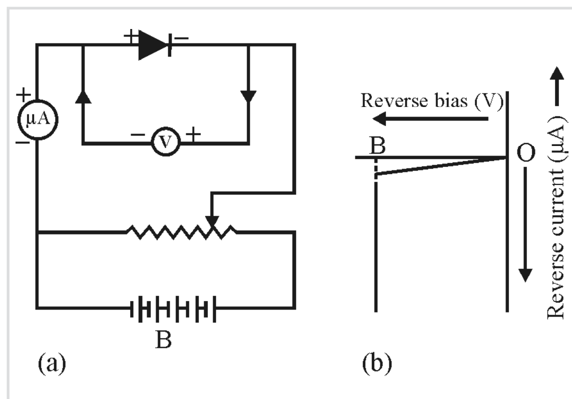
6. SEMICONDUCTOR DIODE

Forward Characteristics of *p-n* Junction Diode



- The graphical representation of the relation between the voltage applied across the junction and the current through the junction when the diode is in forward bias is called the forward characteristics.
- When the applied forward voltage is low, practically no current flows through the junction diode, as the potential barrier opposes the applied voltage.
- When voltage is increased, a small forward current flows (due to minority charges) till the applied voltage becomes equal to the potential barrier. Portion OA in the figure shows this.
- The forward current increases almost linearly beyond certain forward voltage, called the knee voltage, at which the applied voltage overcomes the barrier potential.

Reverse Characteristics of *p-n* Junction Diode



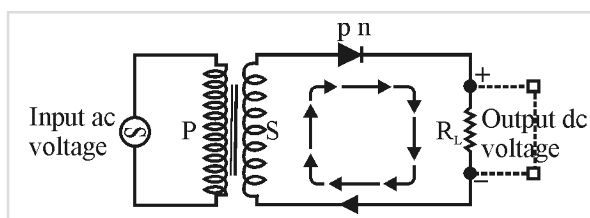
- Reverse characteristics depict the graphical relation between reverse bias voltage applied to the junction and the reverse current through the junction.
- The reverse bias voltage opposes the majority carriers but allows the minority carriers to constitute a small current (of the order of micro-amperes) which remains more or less constant.
- When the reverse voltage reaches a particular value called the Zener voltage or breakdown voltage (OB in the figure), the breakdown of the junction occurs and current increases abruptly.

7. JUNCTION DIODE AS A RECTIFIER

Rectifier is a device that converts alternating current into unidirectional current.

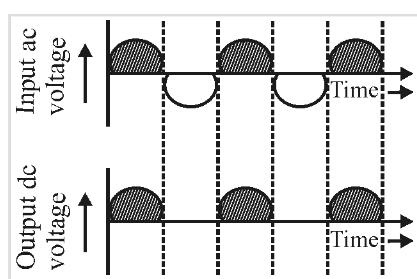
Principle: p-n junction admits current through it when it is in forward bias and offers very high resistance when in reverse bias. Therefore, p-n diodes can be used as rectifiers.

Half-wave rectifier: A single diode that rectifies only one-half of the input ac signal is called a half-wave rectifier.



Circuit: The ac supply is fed across the primary coil P of a step-down transformer. The secondary coil of the transformer S is connected to the junction diode. The output dc voltage is obtained across the load resistance RL.

Working

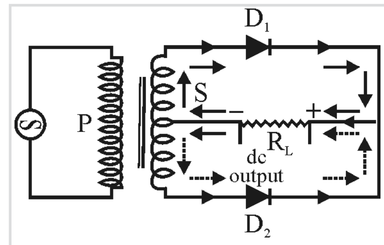


- When ac input signal is applied, the diode gets forward biased during one half of the ac cycle (usually positive half cycle) and reverse biased during the other half cycle (negative).
- The output is obtained only at alternate half cycles of the input. Therefore, the output will be discontinuous.
- The output across RL will change according to the ac input. Therefore, it is a pulsating dc.
- The ratio of r.m.s value of ac component to the dc component in the rectifier output is knows as ripple factor

Full-Wave Rectifier

A rectifier that rectifies both halves of the input ac signal is called a full-wave rectifier. Two diodes are used in a full-wave rectifier.

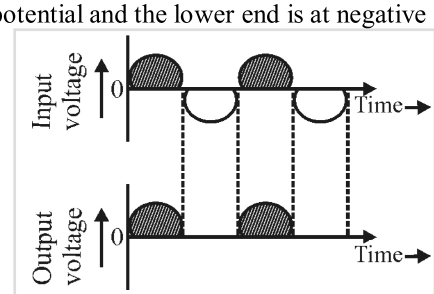
The two diodes are arranged in such a manner that one diode is forward biased during the first half of ac input and the other one is reverse biased. In the next half cycle, the situation is reversed. Thus, output is obtained at every half cycle of the ac input.



Circuit: As shown in the figure below, the ac supply is fed across the primary coil P of a step down transformer. Both ends of the secondary coil of the transformer S are connected to the p-section of junction diodes D1 and D2. A load resistance RL is connected to the n-section of the two diodes and the central tapping of the secondary coil as shown in the figure. The output dc voltage is obtained across RL.

Working

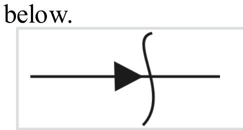
- During first half of the input cycle, the upper end of coil S is at positive potential and the lower end is at negative potential. D_1 gets forward biased, while D_2 reverse biased. D_1 alone conducts and the current is shown by the continuous arrows in the figure.
- In the second half cycle, D_2 gets forward biased and D_1 reverse biased. D_2 alone conducts and dotted arrows show the current due to D_2.
- The right end of R_L will be at positive potential with respect to the left end. Therefore, the output during both half cycles will be of the same nature. As the output depends on the input, dc will be fluctuating. The ripples can be smoothened using a filter circuit.



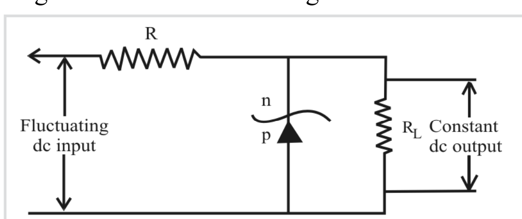
8. SPECIAL PURPOSE OF P-N JUNCTION DIODES

Zener Diode

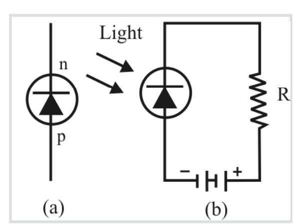
- These diodes are specially designed junction diodes, which can operate in the reverse breakdown voltage region continuously without getting damaged.
- The symbol of a Zener diode is shown below.



- It can be used as a voltage regulator as shown in the figure below.



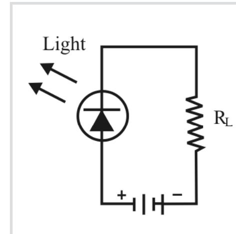
- When Zener diode is forward-biased, it acts as a normal diode.
- At a small reverse voltage, the current is the sum of the surface leakage current and the normal current due to thermally generated holes and electrons. As the reverse voltage is increased, for a particular reverse voltage, the current suddenly rises very rapidly. This occurs after breakdown of the junction due to the abrupt increase in the number of charge carriers. This is referred to as the avalanche effect.
- The voltage across the regulator diode after breakdown is called the reference voltage and its value for a given diode is practically constant over a wide range of current, provided the maximum permissible junction temperature is not exceeded.



Photodiode

- Photodiodes are specially designed p-n junctions from photosensitive semiconductor materials. The symbol of photodiode is shown in figure (*a*).

- They can be used in two ways – in a photovoltaic mode (*e.g.*, solar cell) or photoconductive mode.
- In photoconductive mode, the photodiode is reverse biased [figure (*b*)], but the voltage applied is less than the breakdown voltage.



- It will allow a current to flow when it is illuminated with a light of suitable frequency resulting in the movement of energised electrons from valence band to conduction band.
- As the intensity of incident light is increased, the current also increases till it reaches a maximum value known as the saturation value.
- Photodiodes are used in sound films, computers, tapes, reading of computer cards and in light driven switches.

Light Emitting Diode (LED)

- All diodes emit some light when in forward biased mode. LEDs are made of special semiconductors (like gallium arsenide or indium phosphide) that optimise this light output.
- LEDs rarely burn out unless their current limit is exceeded.
- When current is flowing through an LED, the voltage on the positive side is higher than the voltage on the negative side by about 1.4 V. (This varies with LED type).
- A resistor must be used in series with the LED to avoid damaging it. The recombination of holes and electrons causes the release of energy in the form of light.
- The merits of LEDs are as follows:
  - They operate with low voltage and less power.
  - They emit light very quickly. No warm-up time is required. Also, they have fast on-off switching capability.
  - The bandwidth of emitted light is such that the light is nearly monochromatic.
  - They have long life and ruggedness.
- LEDs are used in calculators, telephones, switchboards, etc.

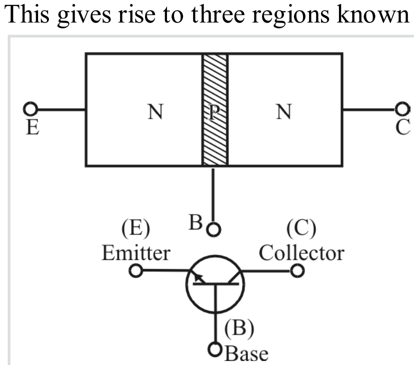
Solar Cell

- Solar cell converts light energy into electric energy. The working of solar cell is based on the production of voltage by sunlight.
- Basically, solar cell is a junction diode in which one of the p- or n-type sections is made very thin. Thus the light energy falling on the diode does not get absorbed to a great extent before reaching the junction.
- The solar energy reaching the junction produces a voltage across it there by converting light energy into electrical energy.
- Solar cells can be used to charge batteries during daytime. These batteries can be then used as sources of electrical energy during the nighttime. It can also be used in cooking food by using generated electrical energy.

9. JUNCTION TRANSISTOR

A junction transistor is a three-terminal semiconductor device and it is obtained by growing a thin layer of one type of semiconductor in between two thick layers of the other type of semiconductor. This gives rise to three regions known as emitter, base and collector. Base is the thin middle region.

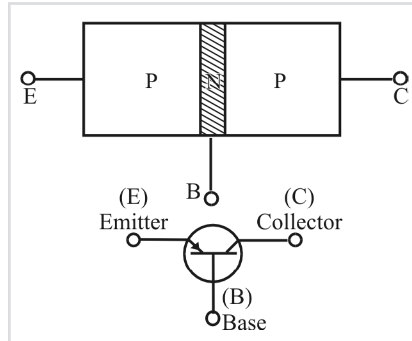
***n-p-n* Transistor and *p-n-p* Transistor**



n-p-n transistor is obtained when a p-type thin layer is sandwiched between two n-type layers. The figure given below shows the n-p-n transistor along with its symbol.

p-n-p transistor is obtained when an n-type thin layer is sandwiched between two p-type layers. The figure given below shows the p-n-p transistor along with its symbol

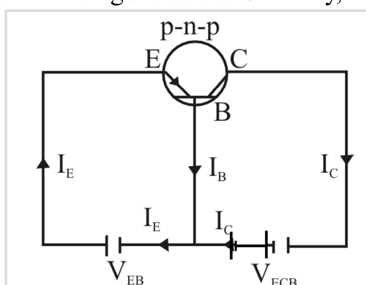
- Transistors have two p-n junctions. When included in a circuit, one of these junctions will be forward biased and the other reverse biased. The heavily doped thick layer associated to the forward biased junction is called the emitter. The thick layer associated with the reverse biased junction is called collector. The two junctions are named emitter-base junction and collector-base junction.



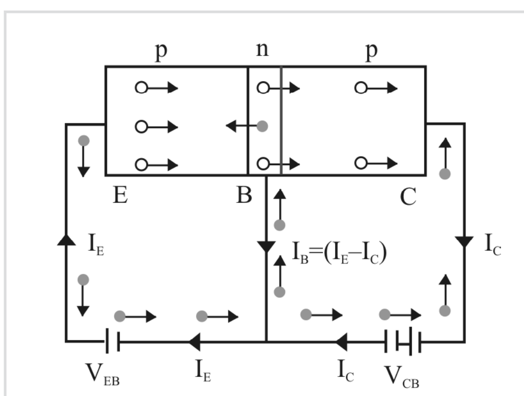
- In symbols, the arrowhead is always shown for the emitter and its direction indicates the direction of conventional current. For n-p-n transistor, the arrowhead for the emitter is outwards and for p-n-p transistor, it is inwards.
- The base is very lightly doped so that it can allow majority carriers to pass through it without any loss. It provides the proper interaction between emitter and collector.
- Collector collects majority charge carriers emitted by emitter. It is made physically larger than emitter region because it has to dispatch much greater power.
- Transistor is a current controlled device, in which emitter current controls the collector current.

Working of *p-n-p* Transistor

Emitter-base junction is forward biased by connecting *p*-type emitter to the positive terminal of the battery and *n*-type base to the negative terminal as shown in the figure below. Similarly, the collector-base junction is reverse biased.



The holes in the emitter region are repelled towards the base due to the forward bias, resulting in emitter current. As base is thin and lightly doped, only few numbers of holes (5%) gets neutralised by electron-hole recombination, resulting in current. The loss of electrons due to recombination is compensated by the flow of electron from the negative terminal of battery to the base region. Most of the holes (~ 95%) reach the collector under the influence of high reverse bias, resulting in collector current. Hence, the current in *p-n-p* transistor is carried by the holes and at the same time their concentration is maintained as explained in the diagrammatical representation given below.



The relation between the three currents is

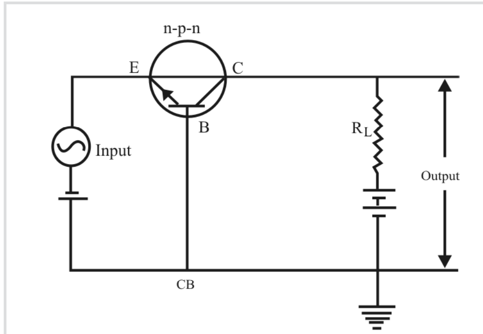
$$I_E = I_B + I_C$$

The above equation is valid for n-p-n transistor also.

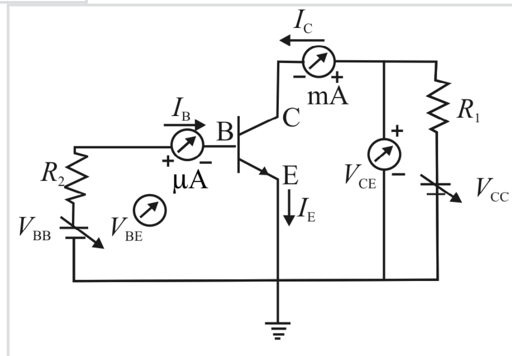
Transistor Configurations

Any one of the three terminals of the transistor can be grounded, which would be common to the other two terminals. Therefore, the transistor can be used in three different modes, called configurations.

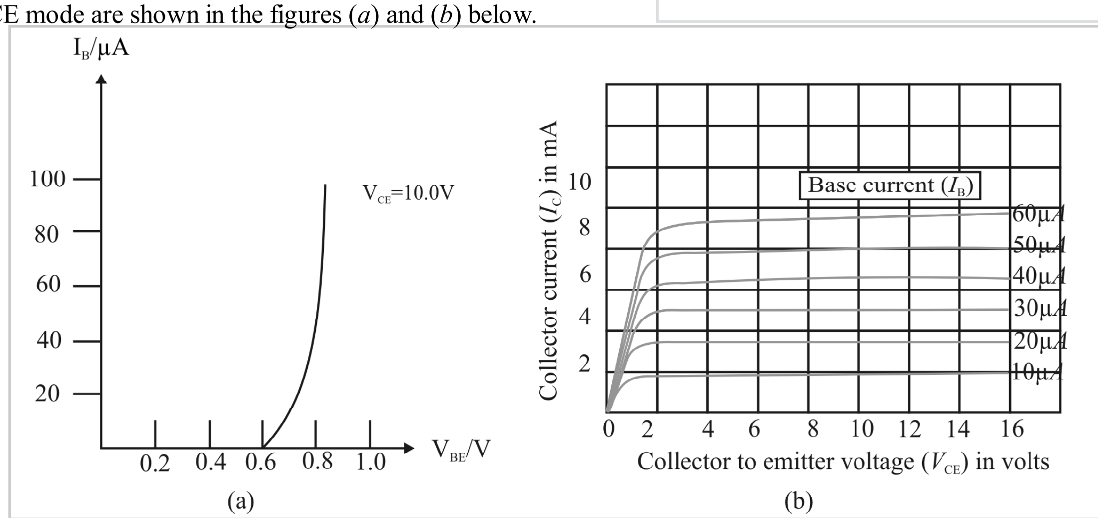
(*i*) The figure given below represents common base configuration (CB). In this mode, base is common to the emitter and collector.



(*ii*) The figure given below represents common emitter configuration (CE). In this mode, emitter is common to the base and collector. Transistor is used for a variety of applications in this configuration.



- The variation of the base current (I_B) with the base-emitter voltage (V_{BE}) is called the input characteristics in CE configuration.
- Similarly, the variation of the collector current (I_C) with the collector-emitter voltage (V_{CE}) is called the output characteristics.
- Typical input and output characteristics of an n-p-n transistor in CE mode are shown in the figures (*a*) and (*b*) below.



The ac input resistance of the transistor in a common emitter configuration is defined as the ratio of small change in the base voltage to the small change produced in the base current at constant collector voltage. It is represented by R_i and equal to the slope of the curve.

At constant collector voltage, $R_i = \left(\dfrac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$

Where, ΔV_{-BE} is the small change in the base voltage and ΔI_B is the small change produced in the base current at constant collector voltage.

The ac output resistance of the transistor in a common emitter configuration is defined as the ratio of small change in the collector voltage to the small change produced in the collector current at constant base current. It is represented by R_o and equal to the slope of the curve.

At constant base current, $R_o = \left(\dfrac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$

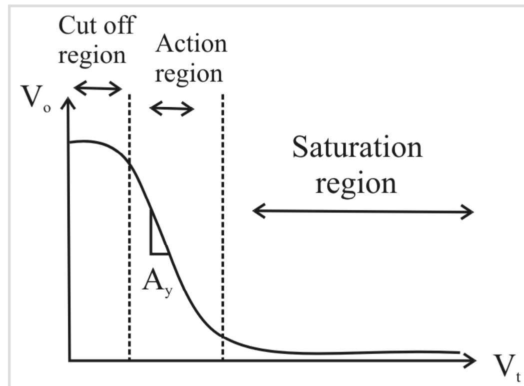
Where, ΔV_{CE} is the small change in the collector voltage and ΔI_C is the small change produced in the collector current at the constant base current.

(*iii*) In common collector configuration, the collector is common to the emitter and base. Common collector is also known as an emitter follower circuit.

10. TRANSISTOR AS A DEVICE

Transistor as a Switch

The transfer characteristic of a transistor in CE configuration is shown below:

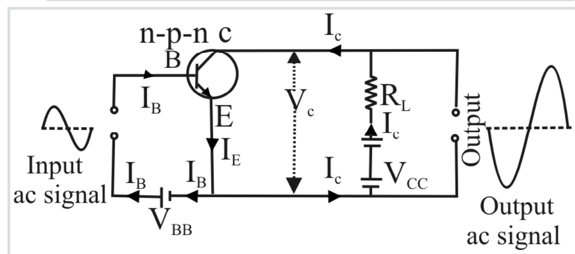


At low values of V_i, it is unable to forward bias the transistor. Then V_o is high. The transitor is not conducting and it is said to be in the cut off region. At high values of V_i, the transitor is driven to saturation. Then V_o is very low. When the transistor is not conducting it is said to be switched off and when it is driven into saturation it is said to be switched on. We can define these low voltage and high voltage states and thus use the transistor as a switching device.

Transistor as an Amplifier

Amplifier is a device to strengthen weak signals. Transistor can serve as an amplifier.

Common Emitter Amplifier Using *n–p–n* Transistor



The figure given below shows the common emitter amplifier circuit using an n-p-n transistor. The emitter is common to both the input and output circuits.

The emitter-base junction (input circuit) is forward biased by using battery V_{BB}. This makes the resistance of input circuit low. The collector (output) is reverse biased by using V_{CC}. The low input ac signal is applied in the base-emitter circuit (input circuit) and the amplified output is obtained across the collector-emitter junction. The arrowheads in the circuit represent the hole current or the conventional current.

The relation between emitter current, base current and collector current is,

$I_E = I_B + I_C$

By Kirchhoff's voltage law, corresponding to collector current I_C, the collector voltage V_C will be

$V_C = V_{CE} - I_C R_L$

The variation in the input voltage signal causes the variation in emitter current, which in turn produces collector current and hence, in turn collector voltage. The variation in collector voltage appears as an amplified output voltage. Here, the input voltage and the output voltage are out of phase.

Gains (Amplification Factor) in Common Emitter Amplifier

Direct Current Gain: It is the ratio of collector current I_C to the base current I_B. It is denoted by Mathematically,

$$\beta = \frac{I_C}{I_E}$$

Alternate Current Gain: The ratio of change in collector current to change in base current at constant collector voltage is termed the alternate current gain. Mathematically,

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

Its value lies between 15 and 50.

Alternating Voltage Gain

It is the ratio of change in output voltage to change in input voltage. Mathematically,

$$A_v = \frac{\Delta V_C}{\Delta V_B}$$

If R_{out} and R_{in}, be the resistance of input and output circuits, respectively, then

$$A_v = \frac{\Delta I_C \times R_{out}}{\Delta I_E \times R_{in}} = \beta_{ac} \times \frac{R_{out}}{R_{in}}$$

or $$A_v = \beta_{ac} \times \text{Resistance gain}$$

$\Delta I_C >> \Delta I_B$. Also $R_{out} > R_{in}$. Therefore, the voltage gain in common emitter amplifier is very large.

Alternating Power Gain

It is defined as the ratio of change in output power to change in input power. Mathematically,

$$A_P = \frac{P_{out}}{P_{in}} = \frac{\Delta V_C \times R_{out}}{\Delta V_B \times R_{in}}$$

$$Or,\ A_P = A_v \times \text{Resistance gain}$$

Since A_v and resistance gain are large, ac power gain in common emitter amplifier is extremely large.

Relation between α and β

In common base amplifier, the input and output currents are I_E and I_C respectively.
The direct current gain in this mode is given by,

$$\alpha = \frac{I_C}{I_E} \qquad \ldots (i)$$

In common emitter amplifier, the direct current gain is given by, $\beta = \frac{I_C}{I_B}$ $\ldots (ii)$

For both type of amplifiers, the relation between emitter current, base current and collector current is
$I_E = I_B + I_C$
Dividing both sides by I_C,

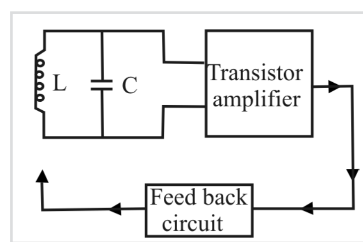
$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1 \qquad \ldots (iii)$$

From (*i*), (*ii*) and (*iii*), $\frac{1}{\alpha} = \frac{1}{\beta} + 1$ Or, $\alpha = \frac{\beta}{\beta + 1}$ Or, $\beta = \frac{\alpha}{1 - \alpha}$

The above equation shows the relation between the current gains of common base and common emitter amplifiers.

11. OSCILLATOR

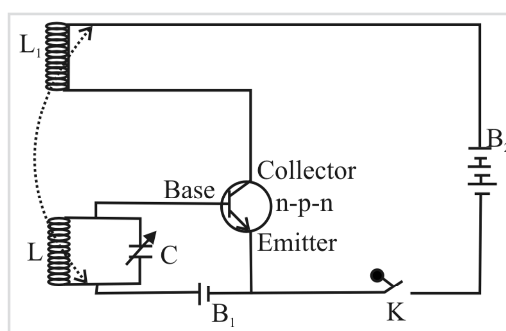
Oscillator is a device used to produce undamped electromagnetic oscillations of desired frequency. The figure given below shows the basic block diagram of oscillator using transistor.



An LC circuit is coupled with the transistor such that there is a positive feedback to the LC circuit. In this way, there is a proper supply of energy at the proper time and the energy of the LC circuit remains the same throughout the oscillations. The frequency of the LC oscillation is given by,

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

Circuit Diagram of Transistor as an Oscillator



The figure given below shows the circuit for *n-p-n* transistor as an oscillator in the common emitter configuration.

The LC circuit is inserted in the emitter base circuit. Emitter base junction is forward biased by using battery B_1, and battery B_2 is connected in series with a high impedance coil L_1 in collector-emitter circuit. Coil L_1 is coupled with coil L such that if the magnetic flux is linked with coil L increases then it will support the forward bias of emitter-base circuit and if it decreases, it will oppose the forward bias of the emitter-base circuit.

Working

On closing the key K, the collector gets positive potential and very small collector current flows through the coil, which increases with time. As the coil L is inductively coupled to the coil L_1, there is a change of flux due to change in current and a small voltage is induced in the coil L. This charges the upper plate of the capacitor with forward charge. As a result, it will provide support to the forward biasing of the emitter base circuit. This leads to an increase in small emitter current and causes the corresponding increase in the collector current. This makes the growing magnetic flux linked with the coil L_1 increase the induced voltage across the coil L. This, in turn, will further increase the forward bias of the emitter-base circuit. This further increases the emitter current and hence the collector current. This way, collector current goes on increasing, until it attains the saturation point.

After that the current stops varying. This stops the flux changing. The capacitor C gets discharged through the inductor L. Due to this, the emitter current that was being sustained by the induced voltage in L begins to decrease causing the collector current to decrease as well. As a result the flux linked with the coil L_1 and hence with the coil L decreases. Due to mutual induction, an induced emf is linked with coil L, which will charge the lower plate of capacitor C with positive charge. This causes opposition to the forward biasing of emitter base circuit. It results in further decreasing emitter current and hence, collector current. This process will continue till the collector current becomes zero. The condenser gets discharged through the inductor L. Due to this, the opposition to the forward biasing of emitter base circuit is withdrawn, which in turn increases the emitter current and enhances the collector current. The process repeats. Thus, it can be said that collector current oscillates between a maximum and a zero value.

It is known to us that in common emitter circuit, an ac signal voltage applied to the emitter base circuit suffers a phase variation of 180° in the collector emitter circuit. Now, in the given circuit by coupling coil L_1 with L, a further phase change of 180° is produced. Thus, the energy that is supplied to the LC circuit is in proper phase. Undamped oscillations are produced which oscillates with the frequency expressed as $v = \dfrac{1}{2\pi\sqrt{LC}}$

This frequency can be varied by changing the value of capacitance by variable capacitors.

12. LOGIC GATES

- A logic gate is an electronic circuit that operates according to certain logic rules. It has one output and one or more inputs.
- Truth table is a table that shows all input and output possibilities for a logic gate.

Boolean Expressions: In Boolean algebra, the variables used can assume only one of the two values, *i.e.* 0 or 1. The true value is denoted by 1 and the false value by 0. It was first applied to switching circuits, as a switch is a binary device (on or off).

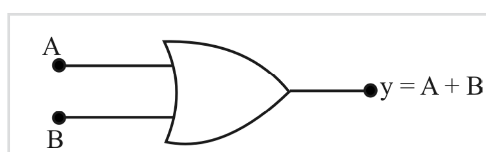
- The addition symbol (+) is referred to as OR.
  $y = A + B$ implies y equals A OR B.
- The dot symbol (.) is referred to as AND.
  $y = A.B$ implies y equals A AND B.
- The bar symbol (–) is referred to as NOT.
  $y = \overline{A}$ implies y equals NOT A.

(The not operation is also called negation or inversion.)

OR Gate

The OR gate has two or more inputs and one output.

The electronic symbol for a two-input OR gate is shown in the figure below.



The two inputs have been marked A and B and the output as y. The OR gate has an output of 1 when either A or B or both are 1. The output would be 0 if and only if both its inputs are 0. The OR gate represents the Boolean equation $A + B = y$.

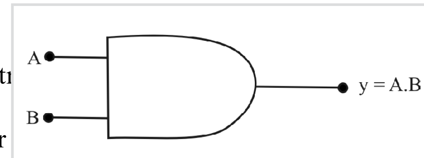
The truth table of the OR gate is shown below.

A	B	$y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

AND gate

The AND gate has two or more inputs and one output.

The AND gate gives its output only when all its inputs are present. The electronic symbol of a two input AND gate is shown in the figure.



The AND gate has an output 1 when both A and B are 1. For all other combinations, the output is 0.

The truth table of the AND gate is shown below.

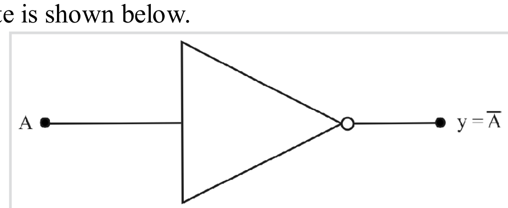
A	B	$y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

NOT Gate

The NOT gate has only one input and one output.

It is a complementary operation and its symbol is an over bar (can be denoted by $y = \overline{A}$).

The electronic symbol of NOT gate is shown below.



Its logical operations can be summarised with the help of the truth table.

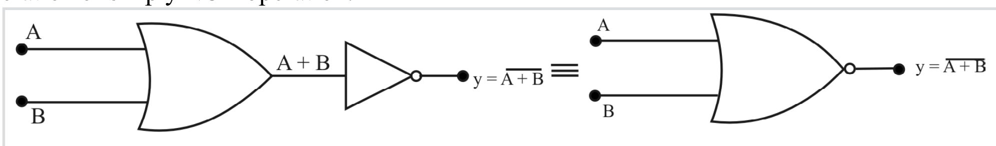
A	$y = \overline{A}$
0	1
1	0

The NOT gate is also called an inverter.

NOR Gate

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

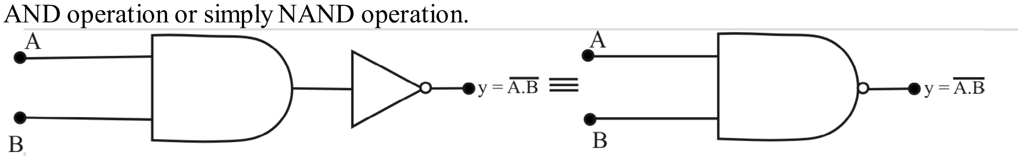
NOR gate has two or more inputs and one output. An OR operation followed by a NOT operation gives rise to a NOT – OR operation or simply NOR operation.



Its truth table is given as follows:

NAND Gate

NAND gate has two or more inputs and one output. A NOT operation performed after an AND operation gives rise to a NOT – AND operation or simply NAND operation.



Its truth table is given as follows:

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

13. INTEGRATED CIRCUITS

- An entire conventional electronic circuit that consists of many resistors, capacitors, inductors etc. fabricated on a small single semiconductor chip is known as an integrated circuit (IC).
- Integrated circuits are more reliable. They are small devices which are light and require only less space. Also they are of low cost and operate at less power.
- ICs are classified, according to the number of circuit components and logic gates, as follows:

  (*i*) Small scale integration, SSI (number of logic gates upto 10)

  (*ii*) Medium scale integration, MSI (number of logic gates upto 100)

  (*iii*) Large scale integration, LSI (number of logic gates upto 1000)

  (*iv*) Very large scale integration, VLSI (number of logic gates above 1000)

Previous Years Questions

2012

1. The current in the forward bias is known to be more $(\sim \text{mA})$ than the current in the reverse bias $(\sim \mu\text{A})$. What is the reason, then, to operate the photodiode in reverse bias.

2. Draw a simple circuit of a CE transistor amplifier. Explain its working. Show that the voltage gain, Av, of the amplifier is given by $A_v = \frac{\beta_{ac} R_L}{r_i}$, where β_{ac} is the current gain, R_L is the load resistance and r_i is the input resistance of the transistor. What is the significance of the negative sign in the expression for the voltage gain?

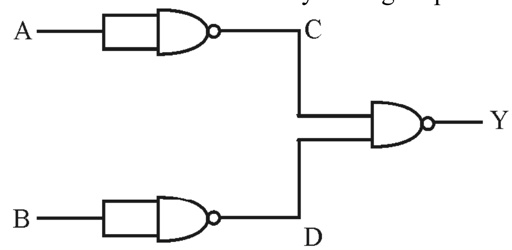
2011

1. In a transistor, doping level in base is increased slightly. How will it affect (i) collector current and (ii) base current.

2. Explain how a depletion region is formed in a junction diode.

3. Draw the transfer characteristic curve of a base biased transistor in CE configuration. Explain clearly how the active region of the V_0 versus V_i curve in a transistor is used an an amplifier.

4. Write the truth table for the logic circuit shown below and identify the logic operation performed by this circuit.

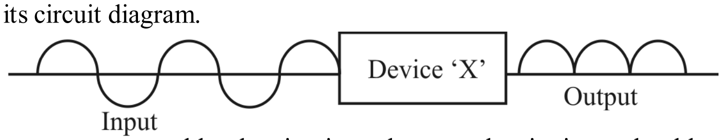


2010

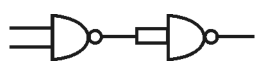
1. Draw the circuit diagram of an illuminated photodiode in reverse bias. How is photodiode used to measure light intensity ?

2. (*a*) Explain the formation of depletion layer and potential barrier in a p – n junction.

(*b*) In the figure given below the input waveform is converted into the output waveform by a device ‘X’. Name the device and draw its circuit diagram.



(*c*) Identify the logic gate represented by the circuit as shown and write its truth table.



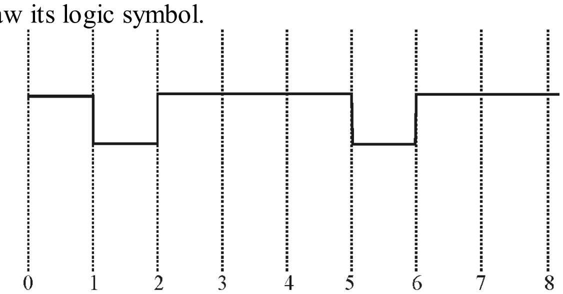
[Ans.

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

]

2009

1. The following figure shows the input waveforms (A, B) and the output waveform (Y) of a gate. Identify the gate, write its truth table and draw its logic symbol.



2. (*i*) Draw a circuit diagram to study the input and output characteristics of an *n-p-n* transistor in its common emitter configuration. Draw the typical input and output characteristics.

(*ii*) Explain, with the help of a circuit diagram, the working of *n-p-n* transistor as a common emitter amplifier.

Or

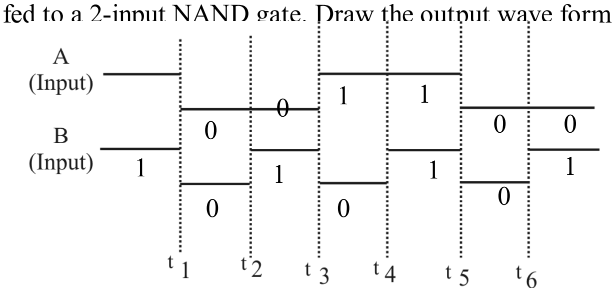
How is a zener diode fabricated so as to make it a special purpose diode. Draw I-V characteristics of zener diode and explain the significance of breakdown voltage.

Explain briefly, with the help of a circuit diagram, how a *p-n* junction diode works as a half wave rectifier.

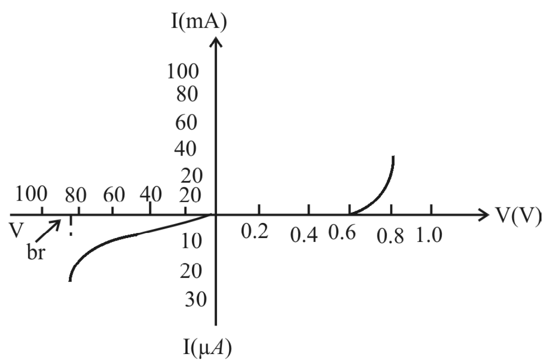
2008

1. Distinguish between an intrinsic semiconductor and P-type semiconductor. Give reason, why, a P-type semiconductor crystal is electrically neutral, although $n_h >> n_e$.

2. The given inputs A, B are fed to a 2-input NAND gate. Draw the output wave form of the gate.



3. The figure below shows the V-1 characteristic of a semiconductor diode.



(*i*) Identify the semiconductor diode used.

(*ii*) Draw the circuit diagram to obtain the given characteristic of this device.

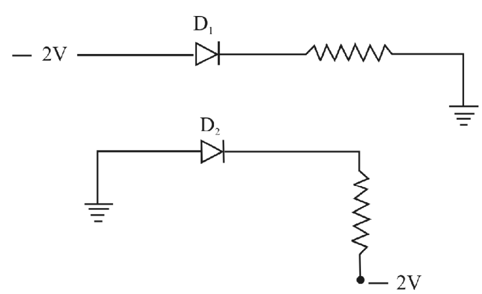
(*iii*) Briefly explain how this diode can be used as a voltage regulator.

2007

1. What will be the values of input A and B for the Boolean expression $\left(\overline{A+B}\right).\left(\overline{A.B}\right)=1$. **[Ans. A = 0, B = 0]**

2. Which one of the two diodes D_1 and D_2 in the given figures is

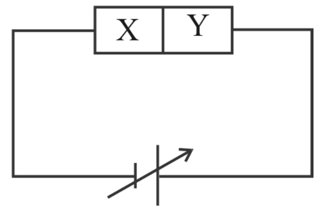
(*i*) Forward biased (*ii*) Reverse biased.



3. The output of an OR gate is connected to both the inputs of a NAND gate. Draw the logic circuit of this combination of gates and write its truth table.

4. The output of a 2-input NOR gate is fed to a NOT gate. Draw the logic circuit of this combination of gates and write the truth table for the output of the combination for all inputs.

5. Two semiconductor materials X and Y shown in the given figure, are made by doping germanium crystal with indum and arsenic respectively. The two are joined end to end and connected to a battery as shown.



(*i*) Will the junction be forward biased or reverse biased.
(*ii*) Sketch a V-I graph for this arrangement.

6. Explain, with the help of a schematic diagram, the principle and working of a Light Emitting Diode. What criterion is kept in mind while choosing the semiconductor material for such a device. Write any two advantages of Light Emitting Diode over conventional incandescent lamps.

7. Draw the circuit diagram of a common emitter amplifier using n-p-n transistor. What is the phase difference between the input signal and output voltage. State two reasons why a common emitter amplifier is preferred to a common base amplifier.

8. Explain the formation of energy band in solids. Draw energy band diagram for
(*i*) a conductor,
(*ii*) an intrinsic semiconductor.

9. State the principle of working of p-n diode as a rectifier. Explain, with the help of a circuit diagram, the use of *p-n* diode as a full wave rectifier. Draw a sketch of the input and output waveforms.

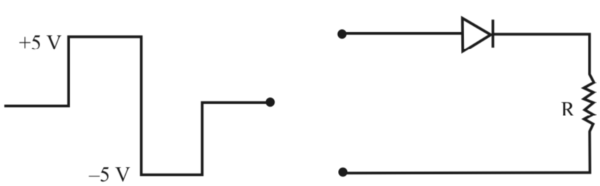
10. Draw the symbolic representation of a (*i*) *p-n-p*, (*ii*) *n-p-n* transistor. Why is the base region of transistor thin and lightly doped. With proper circuit diagram, show the biasing of a *p-n-p* transistor in common base configuration. Explain the movement of charge carriers through different parts of the transistor in such a configuration and show that $I_E = I_B + I_C$.

11. Explain, with the help of a circuit diagram, the use of an n-p-n transistor as an amplifier in common-emitter configuration. Write the expression for voltage gain of the transistor.
Draw the frequency response curve of this amplifier.
How will the current gain of a transistor be affected if its base region is made thicker as compared to a usual transistor and why.

12. Draw energy band diagrams for
(*i*) an intrinsic semiconductor,
(*ii*) *p*-type semiconductor.
Draw symbolic representation of a zener diode. Draw its V-I characteristics and explain, with the help of a circuit diagram, its use as a voltage regulator.

2006

1. Draw and explain the output waveform across the load resistor R, if the input waveform is as shown in the given figure.



[Ans.  **]**

2. Explain how the width of depletion layer in a p-n junction diode changes when the junction is
(*i*) forward biased
(*ii*) reverse biased.

3. What is an intrinsic semiconductor. How can this material be converted into (*i*) P-type (*ii*) N-type extrinsic semiconductor. Explain with the help of energy band diagrams.

4. Draw a circuit diagram for use of npn transistor as an amplifier in common emitter configuration. The input resistance of a transistor is $1000\,\Omega$. On changing its base current by $10\ \mu A$, the collector current increases by 2 mA. If a load resistance of $5\,k\Omega$ is used in the circuit, calculate:
(*i*) the current gain (*ii*) voltage gain of the amplifier

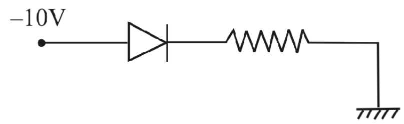
5. Explain
(*i*) forward biasing,
(*ii*) reverse biasing of a p-n junction diode. With the help of a circuit diagram, explain the use of this device as a half-wave rectifier.

6. What are energy bands. How are these formed. Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagram.

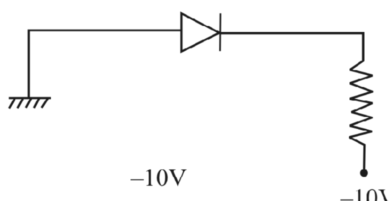
7. Explain the function of base region of a transistor. Why is this region made thin and lightly doped.
Draw a circuit diagram to study the input and output characteristics of n-p-n transistor in a common emitter (CE) configuration. Show these characteristics graphically. Explain how current amplification factor of the transistor is calculated using output characteristics.

2005

1. Explain, with the help of a circuit diagram, how the thickness of depletion layer in a p-n junction diode charges when it is forward biased. In the following circuit, which one of the two diodes is forward biased and which is reverse biased.

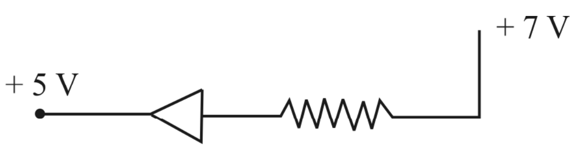
(i)


[Ans. Forward]

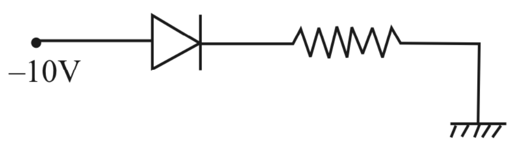
(ii)


[Ans. Backrward]

2. Explain, with the help of a circuit diagram, how the thickness of depletion layer in a *p-n* junction diode charges when it is forward biased. In the following circuit, which one of the two diodes is forward biased and which is reverse biased.

(i)


[Ans. Backrward]

(ii)


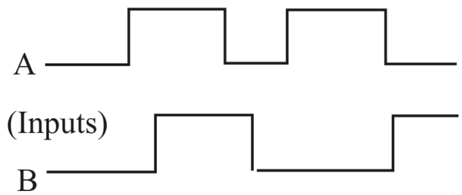
[Ans. Forward]

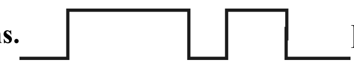
3. (*a*) Distinguish between metals, insulators and semiconductors on the basis of their energy bands.
(*b*) Why are photodiodes used preferably in reverse bias condition. A photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 6000 nm. Justify.

4. (*a*) Explain briefly, with the help of circuit diagram, how V – I characteristics of a *p-n* junction diode are obtained in
(*i*) forward bias, and
(*ii*) reverse bias.
Draw the shape of the curves obtained.
(*b*) A semiconductor has equal electron and hole concentration of 6×10^{8} m^{-3}. On dopingwith certain impurity, electron concentration increases to 9×10^{12} m^{-3}.
(*i*) Identify the new semiconductor obtained after doping.
(*ii*) Calculate the new hole concentration.

2004

1. Draw the voltage current characteristic of a Zener diode.
2. Give the logic symbol for an OR gate. Draw the output wave form for input wave forms A and B for this gate.



[Ans. ]

3. With the help of a diagram, show the biasing of a light emitting diode (LED). Give its two advantages over conventional incandescent lamps.
4. Write the symbol and truth table of an AND gate.
5. Draw the circuit diagram of a common-emitter amplifier using an n-p-n transistor, Draw the Input and 1p waveforms of the signal. Write the expression for its voltage gain.
6. With the help of a labelled circuit diagram, explain how an n-p-n transistor can be used as an amplifier in common-emitter configuration. Explain how the input and output voltages are out of phase by 180° for a common-emitter transistor amplifier.
7. (*a*) For an n-p-n transistor in the common-emitter configuration, draw a labelled circuit diagram of an arrangement for measuring the collector current as a function of collector-emitter voltage for at least two different values of base current. Draw the shape of the curves obtained.
   (*b*) Define the terms:
   (*i*) output resistance
   (*ii*) current amplification factor

