10.1 Introduction

The prefix 'nano' means a billionth (10^{-9}). The field of nanotechnology deals with various structures of matter having dimensions of the order of a billionth of a meter. These particles are called nanoparticles. Nanotechnology is based on the fact that particles which are smaller than about 100 nm give rise to new properties of nanostructures built from them. Particles which are smaller than the characteristic length for a particular phenomenon show different physical and chemical properties than the particles of larger sizes. For example, mechanical properties, optical properties, conductivity, melting point and reactivity have all been observed to change when particles become smaller than the characteristic length. Gold and silver nanoparticles were used in window glass panes to obtain a variety of beautiful colours. Nanotechnology has wide range of applications like producing lighter but stronger materials, constructing faster switches for computers, improving drug delivery to specific organs of the body, etc.

10.2 Nanoparticles

The radii of atoms and most of the molecules are less than a nanometer. Nanoparticles are generally considered to have radius in the range of 1 nm to 100 nm which can have 25 to 10^6 atoms. A cluster of 1 nm radius has approximately 25 atoms. This definition of nanoparticles based on size does not distinguish between molecules and nanoparticles as many organic molecules contain more than 25 atoms.

Nanoparticles can be more appropriately defined as an aggregate of atoms between 1 nm and 100 nm with dimensions less than the characteristic length of some physical phenomena.

When particle size is less than the characteristic length of some physical phenomena, the particles show different properties. The nanoparticles show unique properties that change with their size. Classical mechanics is able to explain properties of bulk materials but is unable to explain properties of nanoparticles. Quantum mechanical principles have to be used to explain properties of the nanoparticles.

10.3 Properties of Nanoparticles

May-09,10,11,12, Dec.-09,10

As discussed earlier, the properties of nanoparticles are different from the bulk material. The properties of nanoparticales also vary with size and shape. Hence different properties can be obtained by changing the size and shape of the nanoparticles. Some of the properties of nanoparticles are as follows :

1) Optical properties : The colour of nanoparticles is different from the bulk material. When a bulk material is reduced in size to a few hundred atoms, the energy band structure of the bulk material changes to a set of discrete energy levels. Atomic ısters of different sizes will have different energy level separations. As clusters of ffferent sizes have different energy level separations, the colour of the clusters (which e due to transitions between the energy levels) will depend on their size. Hence the ze of the cluster can be altered to change the colour of a material. For example, gold in ılk form appears yellow but gold nanoparticles appear bright red in colour. The edieval glass makers produced tinted glass with beautiful variety of colours by ssolving metal particles like gold, silver, cobalt, iron etc. Due to these metal ınoparticles, the glasses appear coloured.

In semiconductor nanoparticles (which are used in quantum dots) there is significant ift in the optical absorption spectra towards blue as the particle size is reduced.

2) Electrical properties : The resistivity in bulk matter is mainly due to scattering of ectrons by ions and crystal defects. In nanostructures, the resistivity mainly depends ı scattering from boundaries of nanoparticles when particle size becomes less than the ean free path between collisions. Thus smaller particle size increases the resistivity.

Various types of defects in the lattice also increase the resistivity by limiting the ean free path. But many nanostructures are too small to have internal defects.

Another effect of reduced size is the confinement of conduction electrons. In bulk ınductors, the electrons move freely throughout the entire conductor. The situation ıanges when one or more dimensions of the conductor are made very small. Consider flat conducting plate with large length and width but small thickness in the range of a w nanometers. In this configuration, called a **quantum well**, the electron will be ınfined along one dimension but will move freely along the remaining two dimensions. a conducting wire has a long length but very small diameter, the electrons can move eely along the length but will be confined in two mutually perpendicular transverse irections. This configuration is known as a **quantum wire**. If all the three dimensions of ie conductor are in nanometer range, the configuration is called a **quantum dot** and the ectron is confined in all the three dimensions. Confinement of electrons to small mensions leads to quantization of energy as discussed in chapter 8. The level of oping in semiconductors gives rise another important phenomenon. or typical doping levels of 1 onor impurity atom in 10^8 atoms semiconductor atoms, a quantum ot of 10^7 semiconductor atoms ould have an average of 10^{-1} ectrons. In other words, on an erage, one quantum dot in 10 will ive a free electron. These result in e phenomena of single-electron

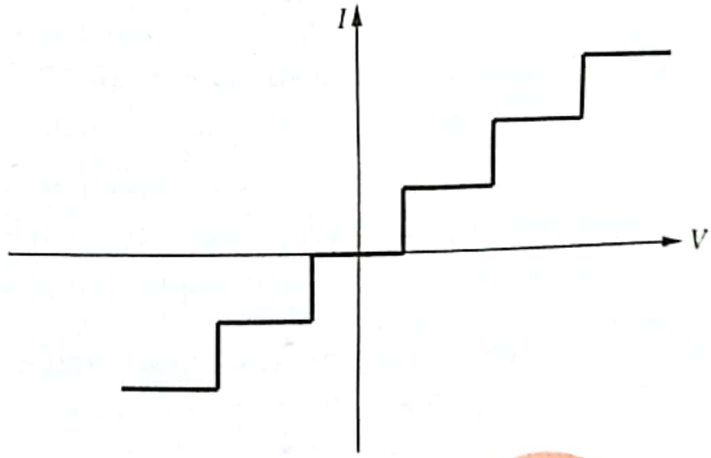


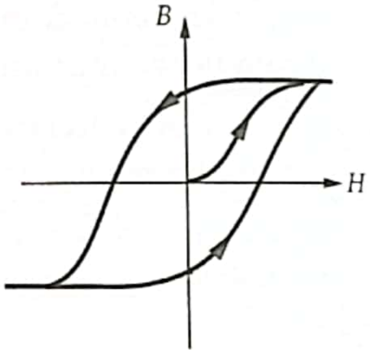
Fig. 10.3.1

tunneling and coulomb blockade. The conduction is due to tunneling of electrons through the quantum dot. The electrons are blocked from tunneling except at discrete voltage change positions. This phenomenon is called coulomb blockade. The *I-V* characteristic shown in Fig. 10.3.1 is called coulomb staircase.

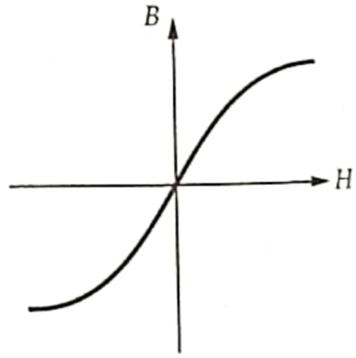
3) Magnetic properties : Magnetic properties are basically due to the orbital and spin motions of electrons around the nucleus. Every electron in an atom has spin and orbital magnetic moment which, when added, give the total magnetic moment of the electron. The vector sum of all the moments of electrons give the total moment of the atom. In most of the atoms the net magnetic moment is zero. However, atoms like iron, cobalt and manganese, have a net magnetic moment. Crystals of these atoms become ferromagnetic when magnetic moments of all atoms are aligned in the same direction.

The magnetic moment of magnetic nanoparticles are observed to be less than the value for perfect alignment of all moments. The net magnetic moment is observed to decrease with increasing temperature. This is due to thermal vibration of atoms in the cluster which disturbs the alignment of magnetic moments.

In bulk ferromagnetic materials, the magnetic moment is less than the moment the material would have if every atomic moment were aligned in the same direction. This is due to presence of 'domains' which are regions in which all atomic moments are in one direction but moments of different domains are in different directions. When bulk ferromagnetic materials are subjected to alternating magnetic fields, they show hysteresis for which the *B-H* curve is as shown in Fig. 10.3.2 (a). In nanosized ferromagnetic particles, essentially consisting of a single domain, there is no hysteris and the *B-H* curve is as shown in Fig. 10.3.2 (b). These particles are said to be superparamagnetic.



(a)



(b)

Fig. 10.3.2

The saturation magnetization is observed to increase significantly on decreasing the particle size. Another interesting property of nanoparticles is that clusters made up of nonmagnetic atoms like rhenium show magnetic moment which increases with the decrease in particle size.

4) Structural properties : The structure of small nanoparticles can be entirely different from that of the bulk material. The crystal structure of large nanoparticles is observed to be same as the bulk material but with different lattice parameters. As a result of the changed structure, the electronic structure changes which in turn leads to changes in optical properties and reactivity.

5) Mechanical properties : Mechanical properties like hardness, elasticity and ductility depend upon the bonds between atoms. Imperfections in the crystal structure and impurities result in changes in these properties. As the nanoparticles are highly pure and free from imperfections, they show different mechanical properties than the bulk material. It has been observed that the Young's modulus decreases in metallic nanocrystals with decrease in particle size. The yield stress has been observed to increase with the decrease in grain size in bulk materials with nanosized grains. Hence stronger materials can be produced by making materials with nanosized grains. The carbon nanotubes are estimated to be about 20 times stronger than steel.

University Questions

1. *Explain the optical and electrical properties of nanoparticles.* **May-09,10,11, Marks 6**

   [Marking scheme : Optical properties - 3 Marks, Electrical properties - 3 Marks]

2. *Explain any two properties of nanomaterials.* **Dec.-09,10, May-12, Marks 6**

   [Marking scheme : For each property - 3 Marks]

10.4 Methods of Synthesis of Nanoparticles **May-09,10,11,12,Dec.-09,10**

A large number of techniques are available for the synthesis of nanomaterials, in different forms like colloids, clusters, powders, tubes, wires, thin films etc. The nanoparticles can be synthesized either by using the 'top-down' approach in which a bulk material is cut down or the 'bottom-up' approach in which the individual atoms are accumulated to form the nanoparticle. The different methods for synthesis of nanomaterials can be classified into physical, chemical, biological and hybrid methods.

10.4.1 Physical Methods

1) Mechanical method : This method is used to make nanoparticles of metals and alloys in the form of powder. Hardened steel balls are put in containers along with powder of the bulk material. The containers are made to move in circular paths around a central axis and also rotate around their own axis. This motion is similar to motion of planets which revolve around the sun and also rotate about their own axis. Hence it is called a 'planetary ball mill'. If larger balls are used for the milling process, smaller particle sizes can be obtained.

2) Vapour deposition method : In this method the material is evaporated and then blown towards a cold finger (a cool cylinder) where the particles are deposited. The set-up is shown in Fig. 10.4.1.

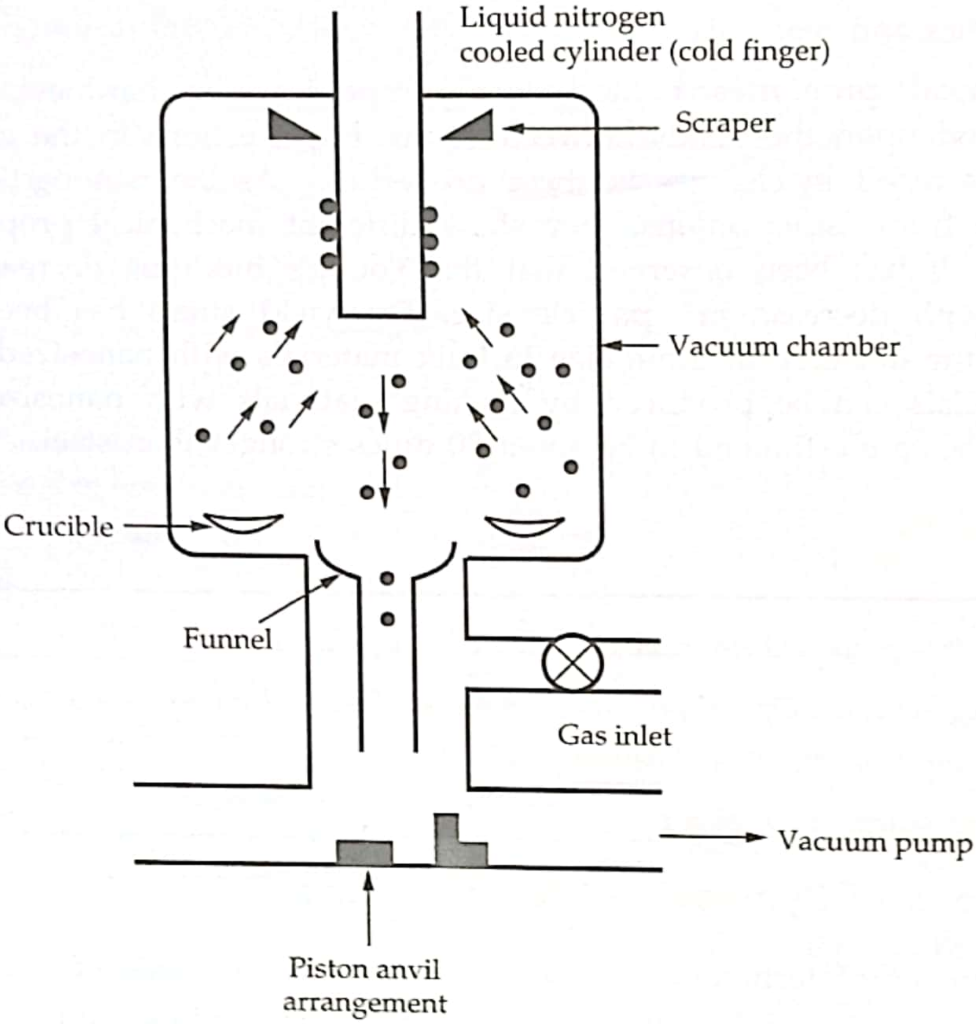


Fig. 10.4.1

The material kept in crucibles is evaporated. As the density of vapour is high close to the crucibles, the small particles start interacting to form larger particles. To avoid formation of large particles, an inert gas is used to blow the particles away from the crucibles towards the cold finger. The particles condense on the cold finger. The particles grow while travelling from the crucibles to the cold finger. Hence the particle size can be controlled by changing the distance between the crucibles and the cold finger and by changing the inert gas pressure. The particles collected on the cold finger are scraped off using scrapers. The particles fall into the funnel. A piston anvil arrangement is used to compact the nanoparticle powder in pellet form.

10.4.2 Chemical Method

Chemical methods use colloidal solutions of nanoparticles which are filtered or entrifuged and dried. Colloids contain two or more phases, out of the three phases olid, liquid and gas, coexist. Colloids can contain two or more phases of the same or ifferent materials. Nanoparticles of metals are generally insoluble in organic or norganic solvents but they can be prepared in colloidal form. Colloidal dispersions in rganic liquids are called **organosols** and dispersions in water are called **hydrosols**. The olloidal particles are generally charged. The particles are kept in suspension by epulsive electrostatic forces between them.

Synthesis of colloids : An arrangement for synthesis of nanoparticles by colloidal method is shown in Fig. 10.4.2. The synthesis is carried out in a trinecked glass flask in n inert gas environment to avoid oxidation of nanoparticles. The reactants are ntroduced into the flask by a pipette. A magnetic stirrer is used to mix the reactants. he reactant temperature is controlled by a heater.

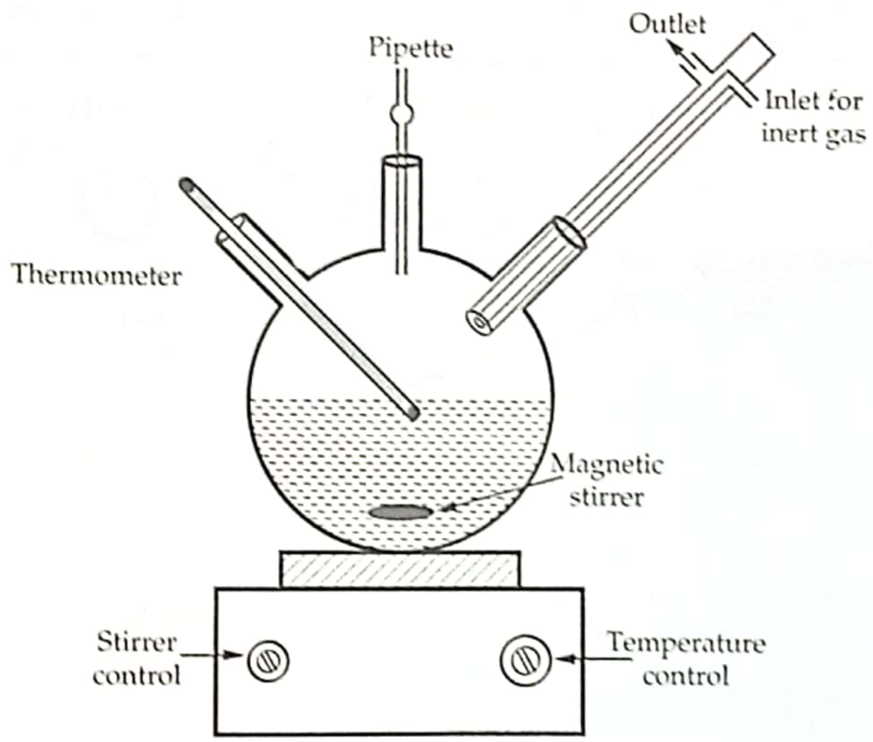


Fig. 10.4.2

Nanoparticles of nearly the same size can be obtained by controlling the ncentration of reactants in the solution. The effect of concentration on particle size can understood using the Lamer diagram shown in Fig. 10.4.3. The formation of nuclei gins when a certain concentration C_O is reached. The nucleation increases upto a ncentration C_N above which there is supersaturation. The rate of nucleation is aximum when the concentration is C_N. The rate of nucleation decreases when ncentration decreases from C_N to C_O. As the concentration falls below C_O, no new nuclei are formed but the nuclei grow in size. The concentration has to be adjusted s that new nuclei are not formed during the growth of nuclei as the different nuclei wi be in different stages of their growth and hence be of different sizes.

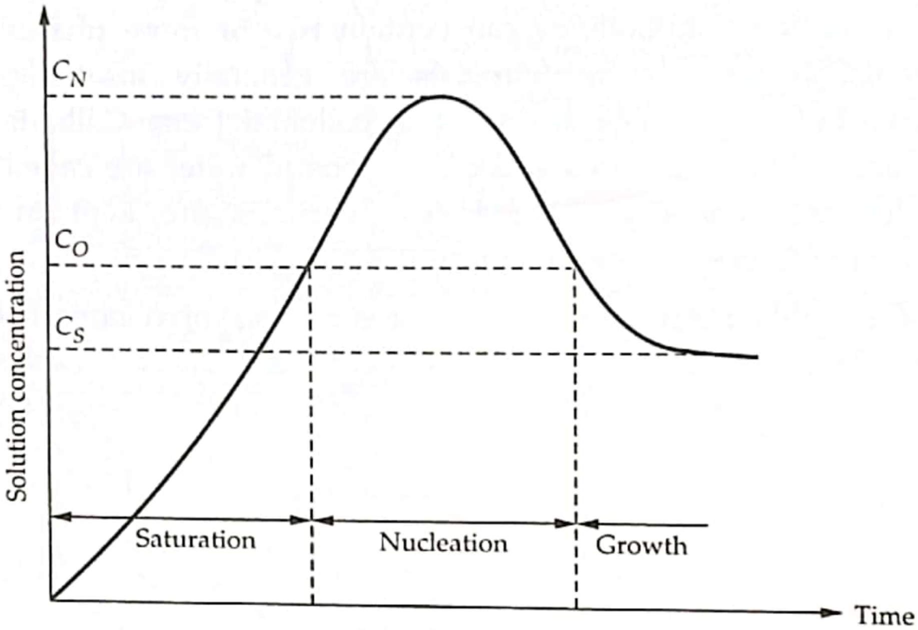
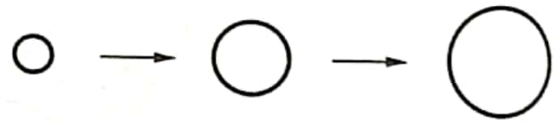
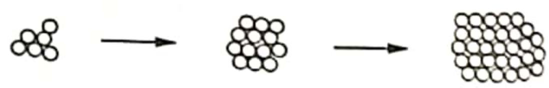


Fig. 10.4.3

Larger particles have smaller surface energy. hence particles keep growing to larger sizes. This is called 'Ostwald ripening'. The surface energy is also reduced when some particles come together to form an aggregate. Thus in Ostwald ripening, the particle size increases whereas in aggregation, particles come together without increase in the individual particle size as shown in Fig. 10.4.4. The two processes take place simultaneously.



(a) Ostwald ripening



(b) Aggregation

Fig. 10.4.4

Synthesis of metal nanoparticles by colloidal route :

Colloidal metal nanoparticles can be produced by reduction of metal salt or aci Highly stable gold nanoparticles are obtained by reducing chloroauric acid ($HAuCl$ with trisodium citrate ($Na_3C_6H_5O_7$).

Gold nanoparticles are formed by nucleation and condensation. The particles grow b reduction of Au^+ on the surface.

The particles are stabilized by oppositely charged citrate ions by Coulomb force. Th formation of gold nanoparticles is shown in Fig. 10.4.5.

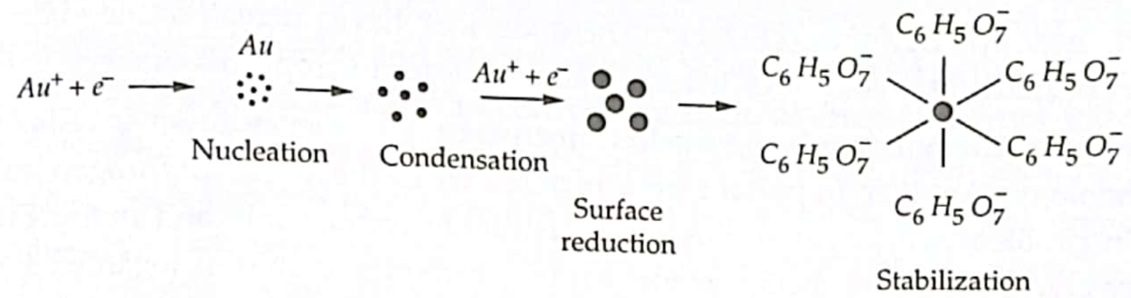


Fig. 10.4.5

10.4.3 Biological Methods

Biological methods use microorganisms, like fungi, yeast, bacteria etc. or plant xtracts and enzymes to produce inorganic nanomaterials. Viruses, diatoms, DNA and membranes are also used in some methods.

10.4.4 Hybrid Method - Chemical Vapour Deposition (CVD)

In this method, chemicals in vapour phase are deposited on a substrate in the form of thin film. The vapour of reactant is transported to the substrate which is kept at a igh temperature. The reactant gets adsorbed on the surface of the substrate and ndergoes chemical reaction. A thin film of nanoparticles gets deposited on the ubstrate.

University Questions

1. *Explain the synthesis of metal nanoparticles by colloidal route.* **May-09,10,11,12, Marks 5**

   [Marking scheme : Synthesis of colloids - 2 Marks, Synthesis of metal nanoparticles - 3 Marks]

2. *Explain briefly how colloids are synthesized by a chemical route.* **Dec.-09, Marks 3**

   [Marking scheme : Chemical method - 3 Marks]

3. *Explain chemical vapour deposition method for manufacturing nano particles.* **Dec.-10, Marks 6**

   [Marking scheme : Description - 6 Marks]

10.5 Applications of Nanotechnology **Dec.-09,10**

Nanotechnology has found wide ranging applications in many fields. Some of these pplications are discussed below.

1) Electronics : Nanosized electronic components show unique properties which are ifferent from the larger semiconductor components. The semiconductor devices are sed on the concept of charge transport only whereas the nanosized components work the concept of charge as well as spin transport of electrons. This has been used in devices like spin FET, spin LED etc. These devices have increased the data storag capacities of hard disks and have led to small and faster microprocessors.

2) Energy : Attempts are being made to increase the efficiency of solar cells by usin nanotechnology. Another important area of research is the use of hydrogen as a fue The main problem with hydrogen is that it is highly combustible and hence cannot b stored easily. Efforts are being made to use carbon nanotubes to trap and stor hydrogen.

Nanoparticles are also being used to increase the energy density of rechargeab batteries. Which are used in laptops and mobile phones.

3) Automobiles : Nanotube composites have better mechanical strength compared t steel but are costly at present. Efforts are being made to develop cheaper nanotub composites that can replace steel which is used to construct the body structure o automobiles. Use of nanoparticles in paints provides thin and smooth coatings.

Nanoparticles are being used to develop light weight and less rubber consumin tyres for automobiles which will increase the mileage of the automobiles. The use o carbon nanotubes for storing hydrogen is being explored so that the automobiles can b run on hydrogen as a fuel.

Nanonmaterial catalysts can be used as catalysts to convert the harmful emission from automobiles to less harmful gases.

4) Space and defence : Aerogels are porous materials with nanosized pores. The have very low density and are poor conductors of heat. They can be used in spacecraft light weight suits and jackets.

Polymer composites using silica fibers and nanoparticles have larger mechanic strength and low temperature coefficient of expansion. They can be used in spacecraf which have to withstand high temperature and stress conditions during launching an re-entry into the earth's atmosphere.

Satellites and spacecrafts use solar energy.

The efficiency of solar cells can be increased using nanoparticles. The use o nanoparticles will also make the solar cells smaller in size and light weight.

5) Medical : Nanoparticles can be used for detection and treatment of cancers an tumours. The nanoparticles are injected into the body and guided towards a specif part. Drugs can be encapsulated in nanocapsules and guided towards any specific pa where the drug can be delivered in a controlled manner by opening the capsule at desired rate using magnetic fields or infrared light. This targeted drug delivery do not affect the healthy organs. Nanotechnology based tests are being developed for fa detection of viruses and antibodies.

6) Environmental : Nanoparticle based sensors are capable of detecting water and air pollution due to toxic ions and pesticides with a very high sensitivity. Nanomaterial catalysts can be used as catalysts to convert the harmful emissions from industries and automobiles to less harmful gases.

Nanotubes can be used to store hydrogen fuel which, when used in automobiles, will reduce harmful emissions.

7) Textiles : The use of nanotechnology in textile industry has led to the development of water repellent and wrinkle free clothes.

8) Cosmetics : Zinc oxide and titanium oxide nanoparticles are used in sunscreen lotions which protect the skin from the ultraviolet radiations. These nanoparticles absorb ultraviolet radiations. Nanoparticle based dyes and colours are harmless to the skin and hence are used in hair creams, gels and hair dyes.

University Questions

1. *Discuss any one application of nanotechnology.* **Dec.-09, Marks 3**

   *[**Marking scheme :** Any one application - 3 Marks]*

2. *Explain applications of nano particles in the field of medicine and electronics.* **Dec.-10, Marks 4**

   *[**Marking scheme :** 2 Marks each]*

❑❑❑

6.1 Introduction

The term laser in an acronym for light amplification by stimulated emission of radiation. Laser is a device that produces a highly coherent, monochromatic, intense beam of light with very small divergence. The first laser was built by T.H. Maiman in 1960 and since then extensive research has been carried out on the development of lasers due to their wide ranging applications.

The basic principles involved in the development of laser are discussed in the next few sections which is followed by a discussion on semiconductor, ruby and helium-neon lasers.

6.2 Coherence

Two waves are said to be coherent if the phase difference between them remains constant.

If the phase difference between two points along any ray remains constant, the coherence is called temporal coherence. The distance along the ray over which the phase difference remains constant is called coherence length and the corresponding time is called coherence time.

If the phase difference between two points in a plane normal to the ray direction remains constant the coherence is called spatial or lateral coherence.

Temporal and spatial coherence require the waves to have the same phase difference, speed and wavelength. Two waves having the same wavelength are called monochromatic.

Coherent sources of light are required for producing good and steady interference and diffraction patterns. Lasers being highly coherent, give the best interference and diffraction patterns.

6.3 Energy Levels of Atoms and Molecules

According to predictions of quantum mechanics, the energy of an atom or a molecule can take only discrete values. Transitions from lower levels to higher are accompanied by absorption of radiation whereas transitions from higher levels to lower are accompanied by emission of radiation.

In atoms, the electrons make transition from one level to another. In a molecule, in addition to the atomic energy levels of atoms constituting the molecule, there are vibrational and rotational energy levels. The vibrational energy levels correspond to the vibrations of atoms in the molecule whereas the rotational energy levels correspond to the rotational motion of the molecule. The energy difference between atomic energy levels is much larger than that between the vibrational and rotational energy levels. The atomic transitions from higher to lower levels give rise to radiation mainly in infrared and visible regions and hence are utilized in lasers.

6.4 Energy States of Atoms

Ground state : It is the lowest possible energy state of an atom which is the most stable state. Atoms can remain in this state for unlimited time.

Excited state : These are the possible energy states of an atom which are higher than the ground state. Atoms remain in such energy states for a very short time called life time typically of the order of 10^{-8} s.

Metastable states : These are excited states of an atom with relatively larger life times of the order of 10^{-3}s. As these energy states are neither as stable as ground state nor as unstable as the other excited states, they are known as metastable states.

6.5 Absorption and Emission of Radiation by Matter

Induced or stimulated absorption : If a photon is incident on an atom in its ground state E_1, the atom absorbs the photon and is raised to its excited energy state E_2 provided the photon energy is $E_2 - E_1$. If the photon energy is not equal to the energy difference between the excited state and the ground state, the photon is not absorbed and the atom remains in its ground state. This process of raising the atom to its excited state by a photon is known as induced or stimulated absorption and is shown in Fig. 6.5.1.

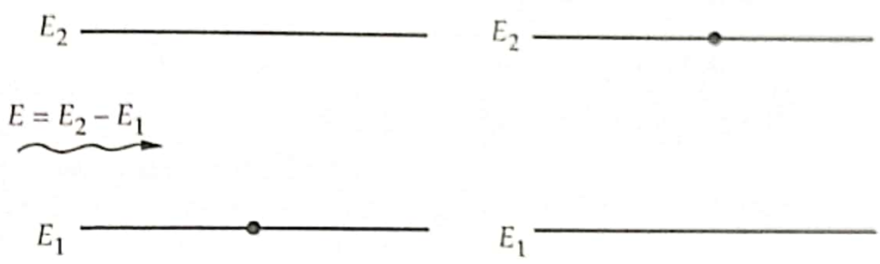


Fig. 6.5.1

Emission of radiation : If an atom is in the excited energy state E_2, it makes a transition to its ground state by emitting a photon having energy $E_2 - E_1$. The transition of atom from higher energy state E_2 to lower energy state E_1 can either take place spontaneously or the transition can be forced by stimulating the atom using a photon having energy $E_2 - E_1$. These, processes of emission of radiation are called spontaneous and stimulated emission respectively.

Spontaneous emission of radiation : When an atom in its excited energy state E_2 makes a transition to the ground state E_1 on its own, without any external stimulus, it emits a photon of energy $E_2 - E_1$ as shown in Fig. 6.5.2. This is known as spontaneous emission of radiation.

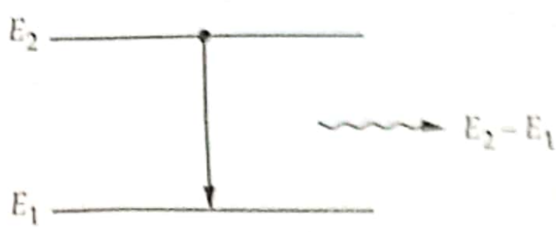


Fig. 6.5.2

When a large group of atoms emit radiation spontaneously, the emitted radiation contains photons which have randomly distributed phases, directions and polarization states, even though they have the same energy and wavelength.

Stimulated emission of radiation : If a photon having energy $E_2 - E_1$ interacts with an atom in the energy state E_2, the photon forces the atom to undergo transition to the ground state E_1 giving rise to another photon of the same energy $E_2 - E_1$ as shown in Fig. 6.5.3. The emitted photon has the same phase wavelength, direction and polarization as that of the stimulating photon. Hence the light produced by stimulated emission is coherent.

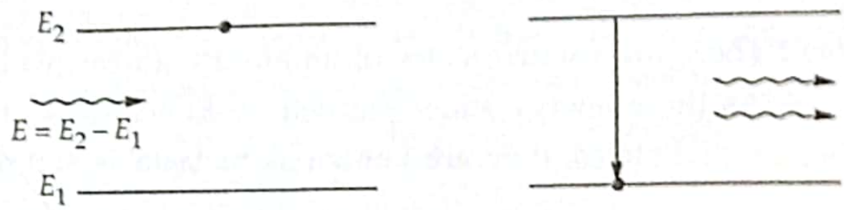


Fig. 6.5.3

Stimulated emission of radiation is possible from atoms in metastable states. Spontaneous emission of radiation takes place from excited states with very small life times.

6.6 Population Inversion

According to Maxwell-Boltzmann distribution, the number of atoms per unit volume, N, in an excited energy level E for a gas in thermal equilibrium is given by

$$N = N_0 e^{-E/kT} \quad \ldots (6.6.1)$$

where N_0 is a constant, k is Boltzmann constant and T is the absolute temperature. For larger values of the energy E, the number of atoms per unit volume is smaller i.e. the atoms tend to occupy the lower energy states.

Consider two energy states E_1 and E_2 where $E_2 > E_1$ then

$$N_1 = N_0 e^{-E_1/kT} \quad \ldots (6.6.2)$$

and

$$N_2 = N_0 e^{-E_2/kT} \quad \ldots (6.6.3)$$

$$\therefore \quad \frac{N_2}{N_1} = e^{-(E_2-E_1)/kT} \quad \ldots (6.6.4)$$

As $\quad E_2 > E_1 \quad , \quad e^{-(E_2-E_1)/kT} < 1$

$$\therefore \quad N_2 < N_1$$

i.e., the number of atoms is more in the lower energy state than that in the higher energy state.

If a photon having energy $E_2 - E_1$ is incident on such a gas, the probability of induced absorption is more than the probability of stimulated emission. To increase the probability of stimulated emission, the number of atoms in the higher energy state must be made greater than the number of atoms in the lower energy state. This state, in which there is a larger number of atoms in the higher energy state than the lower, is called population inversion. Population inversion ensures amplification of light. A system in which population inversion is achieved is called active system.

In a state of population inversion, for $E_2 > E_1$, $N_2 > N_1$. Therefore, from equation (6.6.4), $T < 0$. Hence the state of population inversion is also known as a negative temperature state. It should be noted that the temperature is actually not negative, but the inverted population, created artificially, corresponds to a negative temperature state. The state of population inversion is not an equilibrium state of the system.

6.7 Pumping

To achieve a state of population inversion, the atoms in the lower energy state have to be 'pumped' to the higher energy state by providing energy. The process of raising the atoms from a lower energy state to higher, to create population inversion, is called pumping.

Energy can be supplied to atoms in different forms. In optical pumping, light energy from gas discharge is used to raise atoms to higher energy states. In electrical pumping, which is suitable for gases, the gas is ionized by applying a suitable potential difference across it. The atoms in the ionized gas collide with free electrons causing transfer of energy. Other atoms and molecules can also be introduced into the gas to transfer energy through inelastic collisions, as in He – Ne laser. Chemical pumping uses exothermic chemical reactions to pump the atoms to higher energy levels.

6.8 Resonant Cavity

Cavities can be constructed using different types of mirrors such that the light rays return to their original location and orientation after travelling through the cavity for a certain number of times. Such cavities are known as resonant cavities. For example, in a cavity formed by two parallel mirrors as shown in Fig. 6.8.1 (a), photons travelling along the axis bounce back and forth whereas those photons that do not travel along the axis escape from the cavity after a few reflections. When the active system is placed in a resonant cavity, the intensity of light builds up along the axis. As a result, the laser beam has a very high degree of uni-directionality.

One of the mirrors of the resonant cavity is completely silvered and the other partially silvered. The laser beam emerges from the resonant cavity through the partially silvered mirror.

Further, stationary waves are formed and the cavity resonates when the distance 'L' between the mirrors is an integer multiple of $\frac{\lambda}{2}$ where λ is the wavelength of the radiation in the active system. i.e.,

$$L = n\frac{\lambda}{2}$$

If $\quad v = $ Velocity of light in the active system

and $\quad \nu = $ Frequency,

$$v = \nu\lambda$$

$$\therefore \quad \lambda = \frac{v}{\nu}$$

$$\therefore \quad L = \frac{n\,v}{2\nu}$$

$$\therefore \quad \nu = \frac{n\,v}{2L}$$

Hence the cavity resonates and amplifies only in a very narrow frequency region due to which the laser is highly monochromatic.

A few resonant cavity configurations in common use are shown in Fig. 6.8.1.

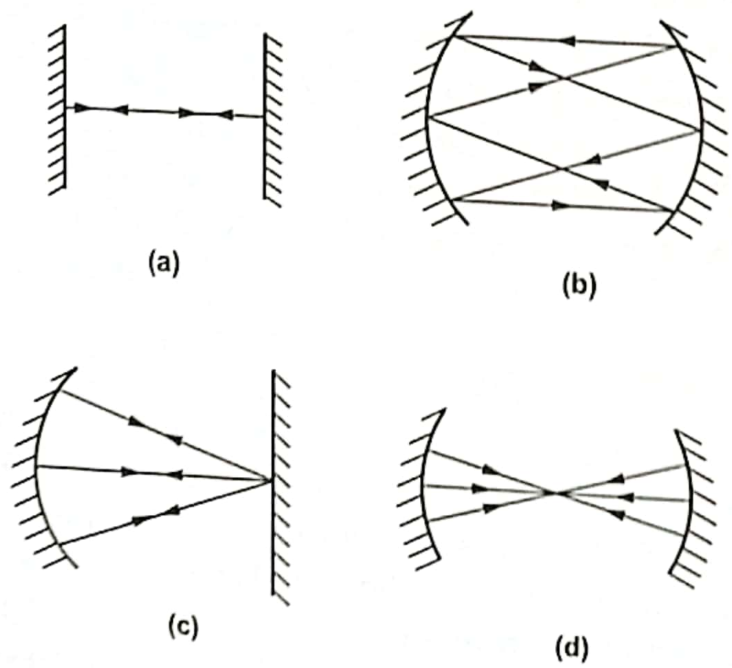
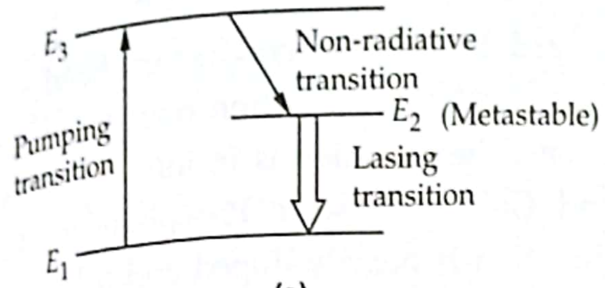


Fig. 6.8.1

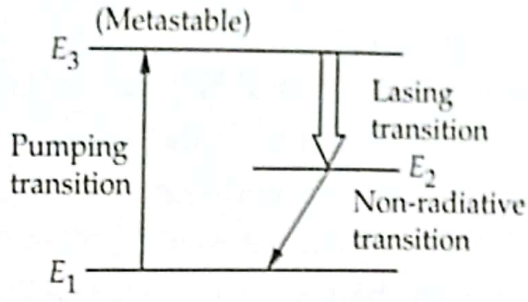
6.9 Various Levels of Laser Systems

May-06,07,08,09,10,11, Dec.-05,06,07,09,10

a) Three level laser system : In these systems three energy levels are involved in the laser action. The atoms are pumped from the ground state E_1 to E_3. Out of the two transitions from E_3 to E_2 and from E_2 to E_1, one is a non-radiative spontaneous transition and the other is the lasing transition as shown in Fig. 6.9.1 (a) and (b). The Ruby laser is an example of three level laser system.



(a)



(b)

Fig. 6.9.1

b) Four level laser systems : Pumping transition takes the atoms from E_1 to E_4 from where there is a spontaneous transition to E_3. The lasing transition is from E_3 to E_2 which is then followed by another spontaneous transition to E_1 as shown in Fig. 6.9.2. Nd-YAG laser is an example of the four level laser system.

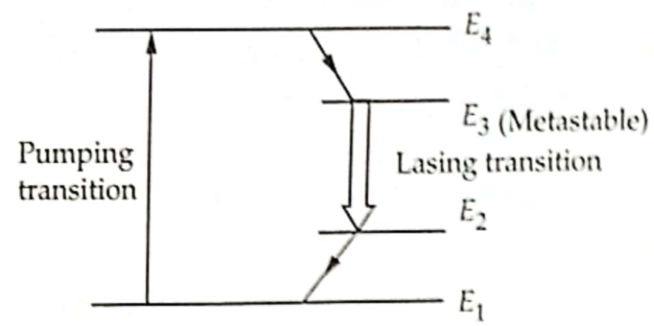


Fig. 6.9.2

University Questions

1. *Explain i) Spontaneous emission ii) Stimulated emission.* **Dec.-05,06,07, Marks 4**

   *[**Marking scheme** : 2 Marks each.]*

2. *Explain : i) Population inversion ii) Optical pumping iii) Active system.* **May-06, Marks 3**

   *[**Marking scheme** : 1 Mark each.]*

3. *Explain : i) Stimulated emission of radiation ii) Optical pumping iii) Metastable state.* **May-07, Marks 3**

   *[**Marking scheme** : 1 Mark each.]*

4. *Define and explain the terms : i) Pumping ii) Active system* **May-08, Marks 4**

   *[**Marking scheme** : 2 Marks each.]*

5. *Define the following terms : i) Spontaneous emission ii) Stimulated emission iii) Pumping iv) Population inversion.* **May-09, Dec.-09, Marks 4**

   *[**Marking scheme** : 1 Mark each.]*

6. *Explain the terms - Optical pumping and Resonant cavity.* **May-10, Marks 2**

   *[**Marking scheme** : 1 Marks each]*

7. *Explain the terms - Optical pumping, Population inversion* **Dec.-10, May-11, Marks 4**

   *[**Marking scheme** : 2 Marks each]*

6.10 Semiconductor Laser

May-06,07,08,10,12, Dec.-09,11

Principle : When a P-N junction is forward biased, the conduction band electrons from N-type combine with the valence band holes in the depletion region and radiation is emitted. For silicon and germanium junctions, the radiation is in infrared whereas for materials like Gallium Arsenide (GaAs) and Gallium Arsenic Phosphide (GaAsP) the radiation is in the visible region. The P-N junction is heavily doped and a large current is made to flow through the junction to create population inversion. Laser can be obtained by using a resonant cavity for such a junction.

Construction : Metallic contacts are provided to the P and N types in a heavily doped P-N junction diode. Two opposite faces which are perpendicular to the plane of the junction are polished and made parallel to each other. These parallel faces constitute the resonant cavity and laser is obtained through these faces as shown in Fig. 6.10.1. The remaining two faces are roughened to prevent lasing action in that direction.

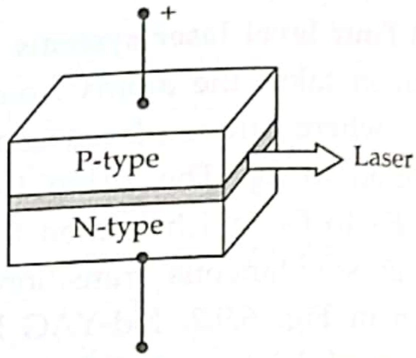


Fig. 6.10.1

Working : As the P and N types are heavily doped, the Fermi level (E_F) in N type lies in the conduction band and in P-type it lies in the valence band. The Fermi level is uniform throughout the unbiased diode as shown in Fig. 6.10.2 (a).

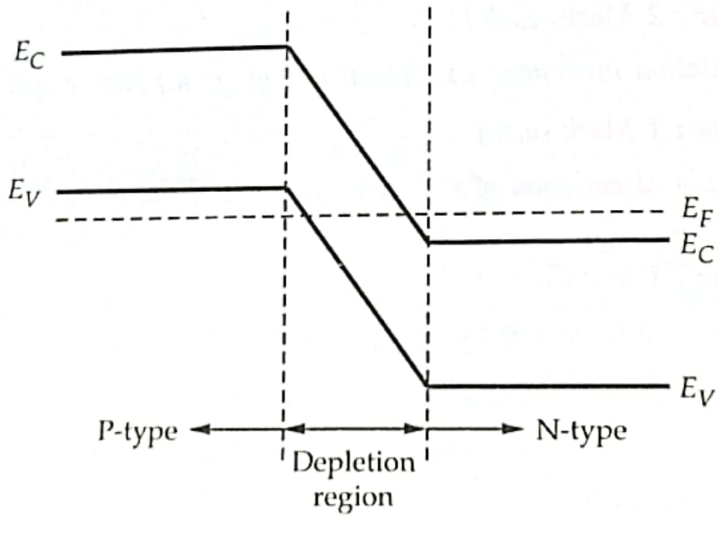


Fig. 6.10.2 (a)

The Fermi level is discussed in detail in chapter 7. When the junction is forward biased, the energy levels shift as shown in Fig. 6.10.2 (b). The width of depletion region decreases due to injection of electrons and holes. At low forward currents, the electron-hole recombination causes spontaneous emission of radiation and the diode acts as a LED. When current is increased and reaches a threshold value, population inversion is achieved in the depletion region due to large concentration of electrons in conduction

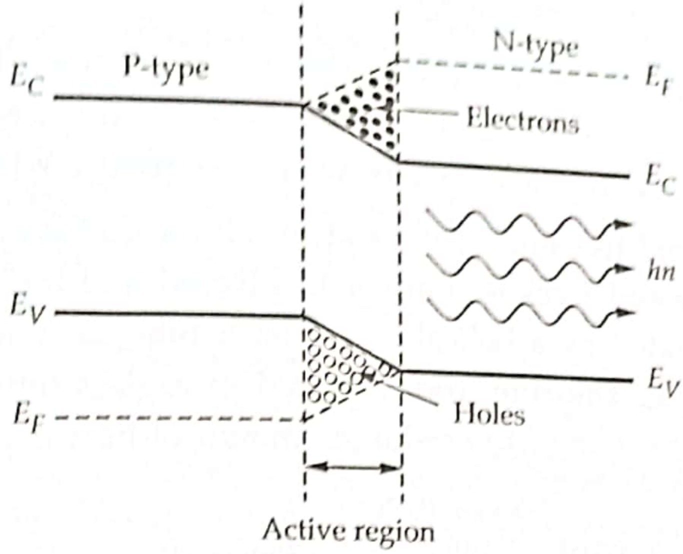


Fig. 6.10.2 (b)

band and holes (i.e. vacancies) in valence band. The narrow region where population inversion is achieved becomes the active region where lasing action takes place. The forward bias applied to the junction is thus the pumping mechanism which produces population inversion. The photons travelling in the junction along the resonant cavity stimulate recombination of electron-hole pairs due to which the intensity of coherent light builds up along the axis of the cavity.

The semiconductor lasers have low power consumption are compact and highly efficient. But the laser output is less monochromatic and more divergent compared to other lasers.

University Questions

1. *Explain in brief the working of a semiconductor laser.* **May-06,07, Dec.-09, Marks 4**

   ***[Marking scheme :** Diagram - 1 Mark, Explanation - 3 Marks.]*

2. *With the help of neat diagram explain the lasing action of a semiconductor laser.* **May-08,10, Marks 7**

   ***[Marking scheme :** Diagram - 1 Mark, Energy level diagram - 1 Mark, Explanation - 5 Marks]*

3. *State and explain advantages of diode/Semiconductor laser over He-Ne laser.* **Dec.-11, Marks 4**

   ***[Marking scheme :** 2 advantages - 2 Marks each.]*

4. *Explain the construction and working of semiconductor laser with the help of energy band diagram.* **May-12, Marks 6**

   ***[Marking scheme :** Construction - 2 Marks, Energy band diagram - 1 Mark,*

6.11 Ruby Laser

May-04,09,10,11, Dec.-05,06,07,09,10

Ruby laser is the first successfully developed laser in 1960 by Maiman. Ruby is a crystal of Al_2O_3 in which a few aluminium atoms are replaced by chromium atoms. The chromium atoms have metastable states which are used for lasing action.

Construction : The end faces of a ruby rod in the form of a cylinder are polished flat and parallel. One of the end faces is completely silvered and the other partially silvered. The ruby rod is surrounded by a helical xenon flash tube as shown in Fig. 6.11.1 which provides optical pumping. The ruby rod is placed in a glass tube through which liquid nitrogen is circulated for cooling as very large amount of heat is produced.

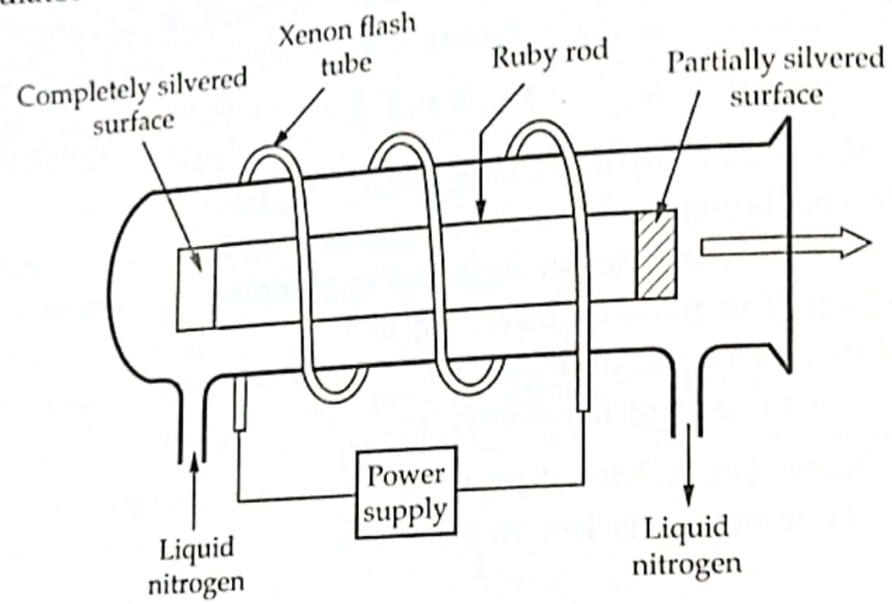


Fig. 6.11.1

Working : An intense flash of light is produced by the xenon flash tube. The chromium atoms in ground state absorb this light in the wavelength region of 5500 A° and are raised to a wide band of energy levels as shown in Fig. 6.11.2.

The mean life time of atoms in these states is very small (of the order of 10^{-8}s). Some atoms from this energy band jump back to the ground state whereas some drop to intermediate metastable states E_3 and E_4. A very intense flash from the xenon tube produces population inversion in these states where the mean life time is a few milliseconds. The transition of atoms from E_2 to E_3 and E_4 is non-radiative as this energy is converted into vibrational energy of atoms in the crystal.

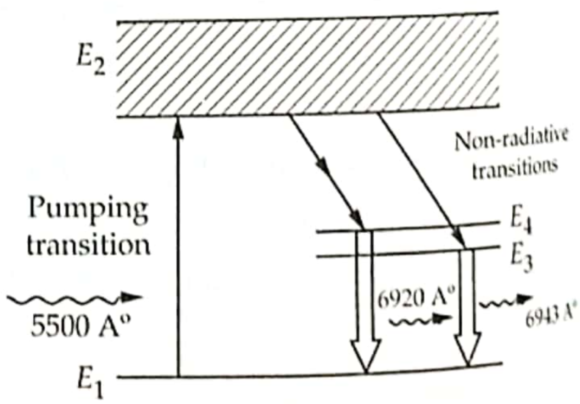


Fig. 6.11.2

Some atoms in state E_3 emit photons spontaneously by falling to the ground state. Some of these photons which travel along the axis of resonant cavity produce stimulated emission due to which intensity of light builds up along the axis of the cavity. The laser is transmitted through the partially silvered surface. Each flash of light from the xenon lamp is used to produce a pulse of laser. Hence the ruby laser is a pulsed laser.

The ruby laser is a high power pulsed laser in the visible region but the efficiency of the laser is very low.

University Question

1. *Explain the operation of solid state ruby laser with a neat labelled diagram.* **May-04,09,10,11; Dec.-05,06,07,09,10, Marks 6**

[Marking scheme : Diagram of laser - 1 Mark, Energy level diagram - 1 Mark, Description - 4 Marks]

6.12 Helium-Neon Laser

May-04,05,06,07,09,10,11,12

It is the first gas laser to be successfully operated. A mixture of Helium (*He*) and Neon (*Ne*) is used. Lasing transition in Ne is utilized to produce laser and He atoms are used to transfer energy to Ne atoms.

Construction : The *He-Ne* laser consists of a glass tube of length 10 cm to 100 cm and few millimetre in diameter. Two electrodes are inserted in the tube as shown in Fig. 6.12.1. One end of the tube is completely silvered and the other partially silvered. The tube is filled with *He* to pressure of 1 Torr and *Ne* to a pressure of 0.1 Torr. This mixture contains about 85 % of He atoms and 15 % *Ne* atoms. A high voltage D.C. source is connected across the electrodes to strike discharge in the gas.

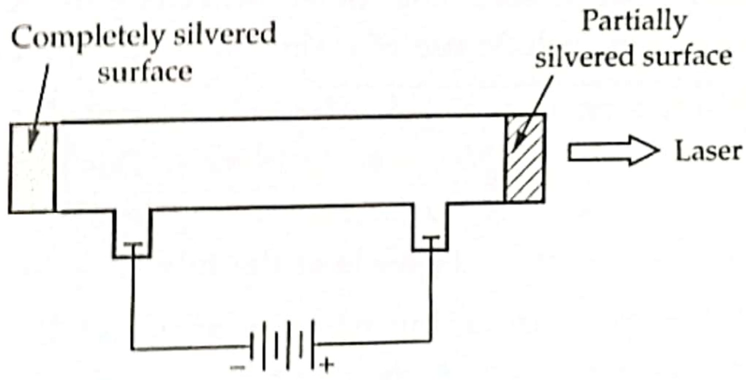


Fig. 6.12.1

Working : The high voltage applied across the electrodes ionizes the gas. The electrons gain energy more easily than the ions due to smaller mass and transfer this energy to *He* and *Ne* atoms by collision. Transfer of energy to *He* is more due to its smaller mass. The He atoms accumulate in He_2 and He_3 states which are metastable. These *He* atoms transfer energy to *Ne* atoms through inelastic collisions to raise them to Ne_4 and Ne_6 levels which have same energy as He_2 and He_3 states respectively as shown in Fig. 6.12.2. Due to large number of *He* atoms in the mixture, *Ne* atoms are continuously excite to Ne_4 and Ne_6 levels and population inversion in these levels can be maintained at all times.

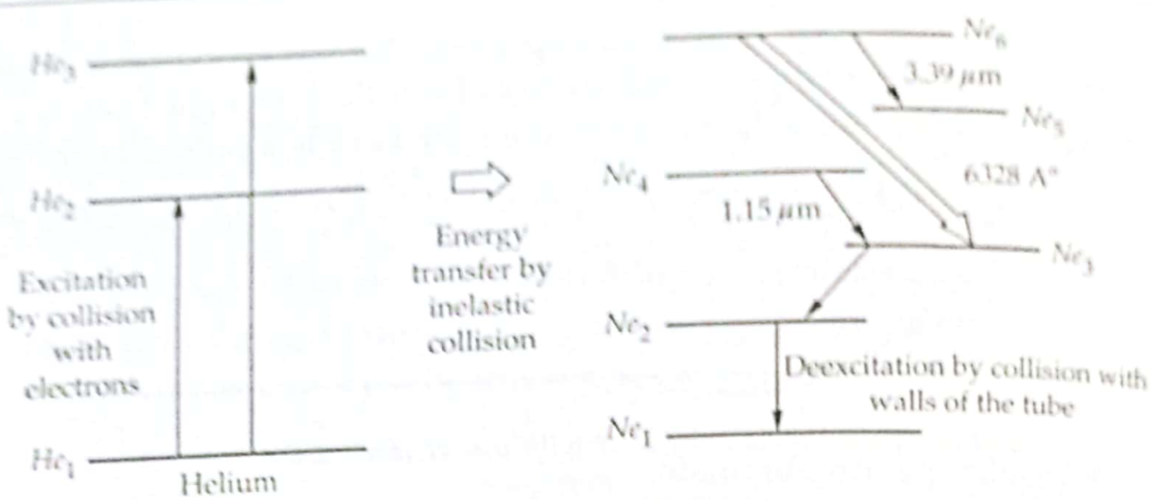


Fig. 6.12.2

Ne_2, Ne_4 and Ne_6 are the metastable states in *Ne* atoms. The transitions from Ne_6 to Ne_5 and Ne_3 give rise to 3.39 μm and 6328 A° wavelengths respectively whereas transition from Ne_4 to Ne_3 gives radiation of wavelength 1.15 μm.

The laser can be operated at any of these wavelengths but is more commonly operated at 6328 A° which is in the visible region. Stimulated emission at other wavelengths can be suppressed by using highly reflecting coatings at 6328 A° on the mirrors that absorb the other wavelengths. Other methods of suppressing certain wavelengths include use of etalons and variation of the length of resonant cavity.

Neon atoms in Ne_2 level can get excited to Ne_3 level disturbing the population inversion between Ne_3 and Ne_6 levels. This can be avoided by decreasing the diameter of the tube so that the atoms in Ne_2 level lose energy and come down to Ne_1 level through collisions with walls of the tube.

When population inversion is achieved between the Ne_3 and Ne_6 levels a few spontaneously emitted photons travelling along the axis of the resonant cavity stimulate emission of the 6328 A° wavelength. The intensity of coherent radiation builds up along the axis of the resonant cavity and the laser is transmitted through the partially silvered surface.

He-Ne laser is a low power continuous laser. It is highly monochromatic as the energy levels in gaseous state have very small spread in energy due to negligible interaction between different atoms.

University Questions

1. *Explain the construction and working of He-Ne low power gas laser with neat labelled diagram.* **May-04,05,06,07,09,11,12 Marks 6**

[Marking scheme : Diagram of laser - 1 Mark, Energy level diagram - 1 Mark, Description - 4 Marks.]

2. With the help of neat energy level diagram explain the technique used to achieve population inversion in He-Ne Laser. **May-10, Marks 4**

[Marking scheme : Energy level diagrams - 2 Marks, Explanation - 2 Marks]

...13 Properties of Lasers

May-05,06, Dec.-05,06,07,09

The following important properties of laser make it different from other ordinary ...urces of light :

i) **Monochromaticity :** The laser beam is highly monochromatic. The light is emitted a very narrow frequency band.

ii) **Coherence :** The laser is highly coherent due to stimulated emission of radiation.

iii) **Unidirectionality :** The laser beam has very small divergence due to the resonant ...vity. Hence light intensity does not decrease as fast with distance as it does in ...dinary sources of light.

iv) **Brightness :** Light from laser is much more brighter than other ordinary sources light.

...iversity Question

1. State important properties of lasers. **May-05,06, Dec.-05,06,07,09, Marks 4**

[Marking scheme : 1 Mark for each property.]

...14 Applications of Lasers

Industrial and Engineering Applications

i) **Welding :** The two metal plates to be welded are held in contact at their edges as shown in Fig. 6.14.1 and a high power laser is focussed on the line of contact. The metal at the line of contact melts and solidifies on cooling which causes the two plates to stick together. As the laser can be focussed to a very sharp point, the heat affected area is very small. Hence laser welding does not cause distortion of the plates. Also, it is a contact - less procedure. Hence there is no possibility of introducing impurities. Laser welding is commonly used in automobile, ship building and aircraft manufacturing industries. CO_2 and NdYAG lasers are used for this purpose.

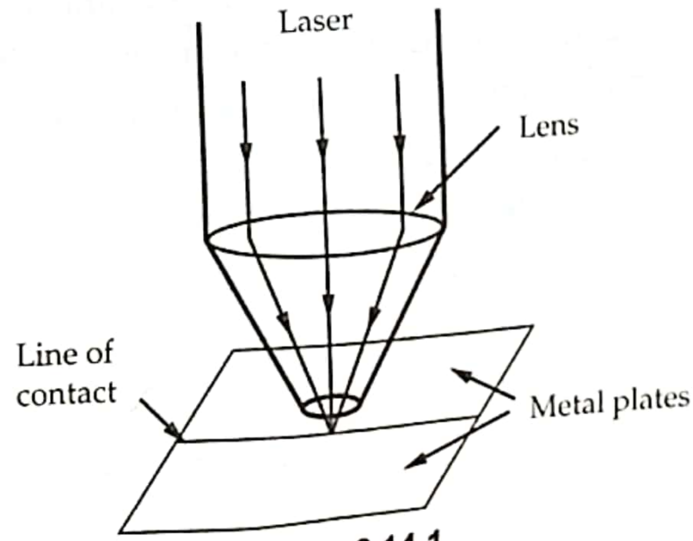


Fig. 6.14.1

ii) **Cutting :** Cutting of metal sheets is achieved using high power lasers like *NdYAG* or CO_2 lasers. The laser is focussed on the metal sheet and a jet of oxygen is blown on the spot. A significant part of the energy required for cutting is supplied by burning of the metal in oxygen. The oxygen jet also blows away the vapourized metal and also cools the adjacent edges. An arrangement of gas laser cutting is shown in Fig. 6.14.2 Higher cutting speeds have been achieved with lasers compared to other conventional methods. Laser cutting produces higher quality of the cut edges.

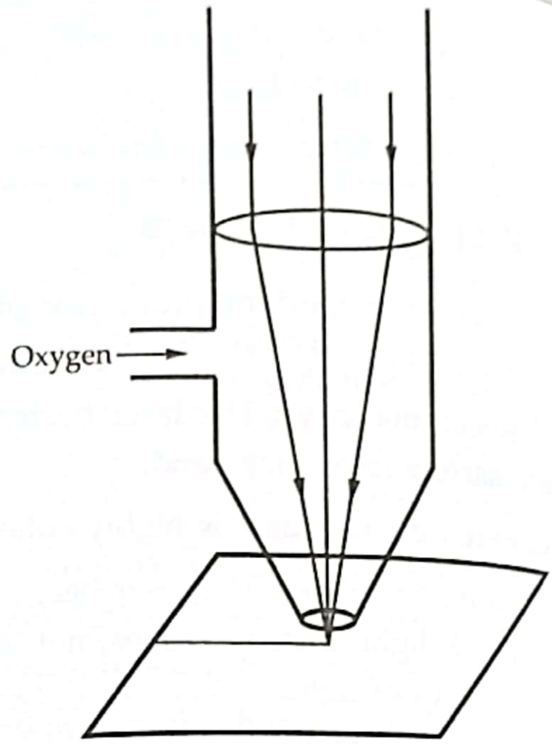


Fig. 6.14.2

iii) **Drilling :** Holes can be drilled into materials using high power pulsed lasers of 10^{-4} to 10^{-3} s duration. The laser pulse evaporates the material which leaves a hole in its place. *NdYAG* laser is commonly used for this purpose. Laser drilling has a very high degree of precision and holes can be drilled in any direction. As the laser can be focussed to a very fine spot, very small holes can be drilled having diameters of the order of a few microns. As there are no mechanical vibrations, holes can be drilled very close to the edges without damaging the metal plates.

iv) **Measurement of atmospheric pollution levels :** Pollution in the atmosphere is due to suspended particulate matter like dust, smoke, flash, aerosols, etc. and non-particulate matter like carbon monoxide, sulphur dioxide, etc. Conventional method for measurement of pollution levels require collection of sample and then its chemical analysis. This is a time consuming process and does not give real time data. Using lasers, we can get real time data by transmitting the laser beam in atmosphere and then observing either the reflected or transmitted beam.

LIDAR (Light detection and ranging) is used to measure concentration of suspended particulate matter in the atmosphere. A pulse of laser is transmitted into the atmosphere and the back-scattered light is recorded using photodiode. This gives information regarding concentration of suspended particulate matter.

Absorption of certain wavelengths by some gases is used to study their presence in the atmosphere by transmitting a lasers beam through the atmosphere and recording the transmitted intensity.

The presence of different gaseous pollutants is best studied by means of Raman backscattering. The backscattered laser contains the transmitted wavelength as well as longer and shorter wavelengths than the transmitted wavelength. The change in wavelength from the original transmitted wavelength is knows as Raman shift and is specific for particular gas. Hence these gases can be detected.

v) Lasers are used in surveying and ranging. Very long distances can be measured using lasers as their attenuation is less compared to other sources of light.

vi) Lasers are used in laser printers. They are also used in CD read and write devices.

vii) Lasers are used in optic fibre communication systems which will be discussed in detail in the next section.

viii) Lasers are used in holography.

5) Medical Applications

i) Lasers are used in eye surgeries as they can be focussed to very fine spot. It is used to weld detached retinas.

ii) Lasers are used in bloodless cancer surgeries.

iii) Lasers are used in painless dental surgeries.

iv) Lasers are used in plastic surgeries for treating skin diseases.

6.15 Application of Laser in Optic Fibre Communication System

May-04,12, Dec.-04,05,10,11

Optic fibers consist of a central core of a transparent material surrounded by cladding of another transparent material as shown in Fig. 6.15.1. The refractive index of the core is greater than that of the cladding. When light travelling in the core is incident on the core-cladding interface at angle of incidence greater than the critical angle, $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$, there is total internal reflection. Due to multiple total internal reflections, light is confined to the core and can travel long distances without significant attenuation.

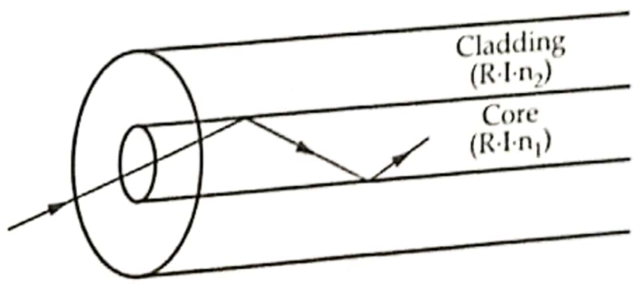


Fig. 6.15.1

A general block diagram of a communication system based on optic fibres is shown in Fig. 6.15.2. A non-electrical signal like sound, in telecommunication, is converted into electrical signal by a transducer. The signal is amplified, modulated and then fed to a

2. *Explain communication through optical fibres. Give any five advantages of optical fibres for communication purposes.* **Dec.-05, Marks 7**

[Marking scheme : Concept of total internal reflection - 1 Mark, Block diagram of communication system - 1 Mark, Description - $2\frac{1}{2}$ Marks, Five advantages - $\frac{1}{2}$ Mark each.]

3. *Describe propagation mechanism of light wave in optical fibres.* **Dec.-10, Marks 6**

[Marking scheme : Concept of total internal, reflection with critical angle - 4 Marks, Construction of optical fibre - 1 Mark, Propagation light - 1 Mark.]

4. *Draw a block diagram of the fibre optics communication system and explain the role of any four components in the system.* **Dec.-11, Marks 6**

[Marking scheme : Block diagram - 2 Marks, Explanation of role of four components 1 - Mark each.]

6.16 Holography

May-04,05,08, Dec.-04,07

Holography is a technique of producing three dimensional images. In conventional photography, two dimensional images are formed as only the amplitude of light coming from an object is recorded on a photographic plate. In holography, the amplitude as well as the phase of light waves coming from the object are stored in the form of an interference pattern. The technique involves two steps-recording and reconstruction. Best interference patterns are produced using lasers which are the most coherent sources.

Recording : Coherent light from a laser is partly reflected from a mirror (known as reference beam) and partly reflected from the object (known as object beam). The interference pattern of these two beams is recorded on a photographic plate as shown in Fig. 6.16.1. The developed photographic plate is known as hologram. It consists of alternate bright and dark fringes.

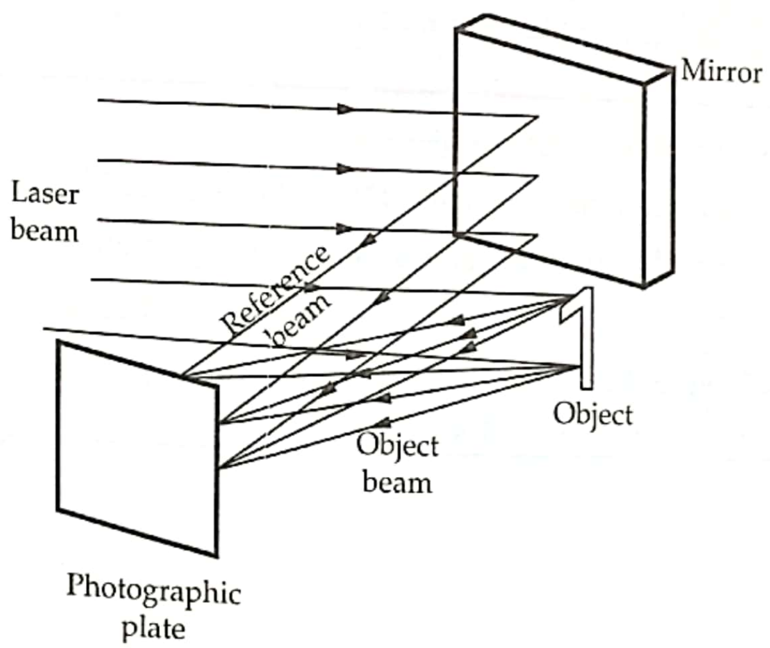


Fig. 6.16.1

Reconstruction : To see the three dimensional image of the object, the hologram illuminated by the reference beam only or a laser beam with the orientation of th reference beam with respect to the hologram. The hologram acts as a diffraction gratin One of the first order diffracted beam produces a real three dimensional and inverte image and the other first order diffracted beam produces a virtual three dimension image which is formed at the same place where the object was kept during recording a shown in Fig. 6.16.2.

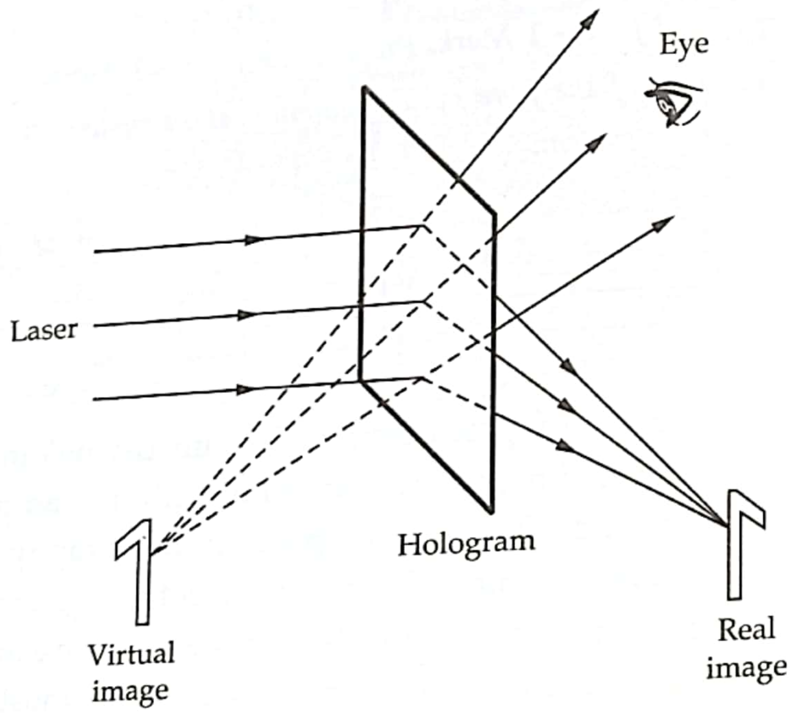


Fig. 6.16.2

Holography is used to produce three dimensional images. Holograms can store larg amount of data and are used in ROM devices. Microscopic holography is used to stud three dimensional structures of micro-organisms.

University Questions

1. *Write a short note on holographic recording.* **May-04, Marks 3**

   *[**Marking scheme :** Diagram - 1 Mark, Description - 1 Mark]*

2. *What is holography ? Explain the process of holography recording and reconstruction.* **Dec.-04,07, May-05,08; Marks 6**

   *[**Marking scheme :** Definition - 1 Mark, Recording process with diagram - 2 Marks, Reconstruction (with diagram) - 3 Marks.]*

Reconstruction : To see the three dimensional image of the object, the hologram is illuminated by the reference beam only or a laser beam with the orientation of the reference beam with respect to the hologram. The hologram acts as a diffraction grating. One of the first order diffracted beam produces a real three dimensional and inverted image and the other first order diffracted beam produces a virtual three dimensional image which is formed at the same place where the object was kept during recording as shown in Fig. 6.16.2.

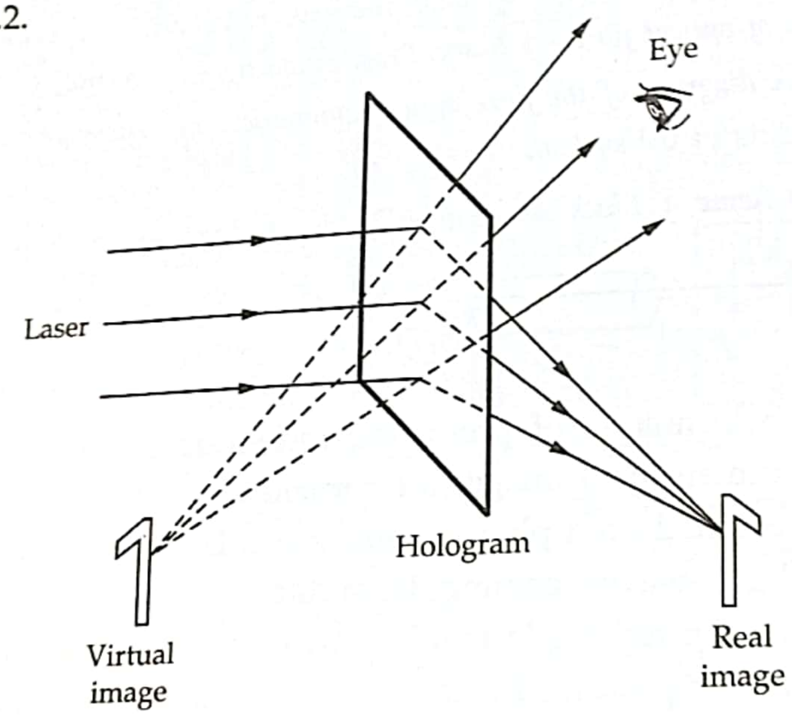


Fig. 6.16.2

Holography is used to produce three dimensional images. Holograms can store large amount of data and are used in ROM devices. Microscopic holography is used to study three dimensional structures of micro-organisms.

University Questions

1. *Write a short note on holographic recording.* **May-04, Marks 3**

   [Marking scheme : Diagram - 1 Mark, Description - 1 Mark]

2. *What is holography ? Explain the process of holography recording and reconstruction.* **Dec.-04,07, May-05,08; Marks 6**

   [Marking scheme : Definition - 1 Mark, Recording process with diagram - 2 Marks, Reconstruction (with diagram) - 3 Marks.]

Objective Questions & Answers for Online Examination

The emission of photon without being aided by any external agency is called ______.

[a] light amplification
[b] induced absorption
[c] stimulated emission
[d] spontaneous emissions

Q.2 If n_1 is the number density of lower energy E_1 and n_2 is the number density of higher energy E_2 then $n_2 > n_1$ is called ______.

[a] thick population
[b] inverted population
[c] normal population
[d] no population

Q.3 Supply of energy to atoms for excitation is called ______.

[a] glowing
[b] bombarding
[c] incidenting
[d] pumping

Q.4 Important characteristic of laser beam is ______.

[a] interference
[b] diffraction
[c] dispersion
[d] coherence

Q.5 Pumping process used in diode laser is ______.

[a] optical pumping
[b] forward bias
[c] electric discharge
[d] none of these

Q.6 The life time of an atom on a metastable state is of the order, ______.

[a] a few seconds
[b] unlimited
[c] a nanosecond
[d] few millisecond

Q.7 The purpose of the optical resonator in a laser is ______.

[a] to provide cover to the active medium
[b] to provide path for atoms
[c] to provide selectivity of photons
[d] to send laser in specified direction

Q.8 In He - Ne lasers, the ratio of He - Ne is in the order, ______.

[a] 1 : 10
[b] 1 : 1
[c] 10 : 1
[d] 100 : 1

Q.9 From a broken hologram which is 10 % of the original, if reconstruction of image being done, then ______.

a) only 10 % of information of the object can be obtained
b) complete information of the object obtained
c) no information of the object can be obtained
d) none of these

Q.10 Population inversion ensures that there will be ______.

a) stimulated emission
b) light amplification
c) spontaneous emission
d) coherence

Q.11 Image is stored on a hologram in the form of ______.

a) interference pattern
b) diffraction pattern
c) photograph
d) none of the above

Q.12 Rate of induced absorption depends on ______.

a) number of atoms in lower energy state
b) the energy density
c) number of atoms in higher energy state
d) both A and B

Q.13 The required condition to achieve laser action in a system is ______.

a) state of population inversion
b) existence of metastable state
c) a resonant cavity
d) all the three

Q.14 In recording the image on the photographic plate the reference beam and the object beam undergo __________ at the photographic plate.

a) diffraction
b) reflection
c) interference
d) polarization

Q.15 Wavelength of a Laser beam can be used as a standard of ______.

a) time
b) temperature
c) angle
d) length

Q.16 Which event is likely to takes place, when a photon of energy equal to the difference in energy between two levels is incident in a system ______.

a) absorption
b) emission
c) absorption and emission
d) none of these

Q.17 Holography records ______.

a) only amplitude
b) only phase
c) both amplitude and phase
d) neither amplitude nor phase

Q.18 Photography records ______.

a. only amplitude
b. only phase
c. both amplitude and phase
d. neither amplitude nor phase.

Q.19 Stimulated emission of radiation in laser is responsible for its ______.

a. unidirectionality
b. high intensity
c. high frequency
d. coherence

Q.20 The He - Ne laser is a ______.

a. high power continuous laser
b. high power pulsed laser
c. low power continuous laser
d. low power pulsed laser

Answers

Q.No.	Answer	Q.No.	Answer	Q.No.	Answer	Q.No.	Answer	Q.No.	Answer	Q.No.	Answer
1.	d	2.	b	3.	d	4.	d	5.	b	6.	d
7.	d	8.	c	9.	b	10.	b	11.	a	12.	d
13.	d	14.	c	15.	d	16.	c	17.	c	18.	a
19.	d	20.	c								

2. Explain photovoltaic effect. How is the fill factor obtained for a solar cell from its I-V characteristics ? **Dec.-06, Marks 6**

[Marking scheme : Photovoltaic effect - 3 Marks, I-V graph - 1 Mark, Procedure for calculation of fill factor - 2 Marks.]

3. Explain the construction and working of solar cell. Explain its characteristics curve. **May-09, Marks 6**

[Marking scheme : Construction - 2 Marks, Working - 2 Marks, I-V characteristics curve - 2 Marks.]

Exercise

1. *Calculate the conductivity of pure Germanium at room temperature when the concentration of carriers is 2.5×10^{13} per cm^3. Take $\mu_e = 3600\, cm^2/V$ - s and $\mu_h = 1700\, cm^2/V$ - s*

(Ans. : 2.12 mho/m)

2. *Calculate the conductivity of copper for which $\mu_e = 34.8\, cm^2/V$ - s and density $= 8.9\, gm/cm^3$. Assume that there is one free electron per atom. Atomic weight of copper = 63.5. If an electric field of 10 V/cm is applied, find the average velocity of free electrons.*

(Ans. : 47.02×10^{-4} mho/cm, 348 cm/s)

Objective Questions & Answers for Online Examination

Q.1 An electron can exist in ______.

a) valence band b) conduction band
c) forbidden band d) both a) and b)

Q.2 A free electron exists in ______.

a) valence band b) conduction band
c) forbidden band d) both a) and b)

Q.3 A hole in an intrinsic semiconductor exists in ______.

a) valence band b) conduction band
c) forbidden band d) both a) and b)

Q.4 The forbidden energy gap in a semiconductor is of the order of ______.

a) 0 eV b) 1 eV
c) 6 eV d) none of the above

Q.5 The forbidden energy gap in an insulator is of the order of ______.

a) 0 eV b) 1 eV
c) 6 eV d) none of the above

Q.6 Energy bands are formed in ______.

a) solids b) liquids
c) gases d) all the above

Q.7 Conductivity of conductors near room temperature ______ with increasing temperature.

a) increases b) decreases
c) remains constant d) initially increases and then decreases

Q.8 Conductivity of semiconductors near room temperature ______ with increasing temperature.

a) increases b) decreases
c) remains constant d) initially increases and then decreases

Q.9 Conductivity of conductors ______ on adding impurities.

a) increases b) decreases
c) remains constant d) initially increases and then decreases

Q.10 Mobility of holes is ______ mobility of free electrons in an intrinsic semiconductor.

a) less than b) equal to
c) more than d) can be more or less than

Q.11 Donor impurity levels lie ______.

a) in the valence band b) just above the valence band
c) in the conduction band d) just below the conduction band

Q.12 Acceptor impurity levels lie ______.

a) in the valence band b) just above the valence band
c) in the conduction band d) just below the conduction band

Q.13 If the mobility of electron in a metal increases, the resistivity

a) decreases b) increases
c) remains constant d) none of these.

Q.14 The Fermi factor for $E = E_F$ at $T > 0$ K is

a) 1 b) $\frac{1}{2}$
c) 0 d) 2

Q.15 Which of the following relations is correct for current density ?

a $J = neAv_d$

b $J = \frac{neA}{v_d}$

c $J = nev_d$

d $J = \frac{1}{nev_d}$

Q.16 The value of Fermi distribution function at absolute zero (T = 0 K) is 1 under the condition ______.

a $E = E_F$

b $E > E_F$

c $E >> E_F$

d $E < E_F$

Q.17 The electron energies in quantum free electron theory follow ______.

a Maxwell-Boltzmann statistics

b Fermi-Dirac statistics

c Bose-Einstein statistics

d none of the above

Q.18 Position of Fermi level in intrinsic semiconductor is ______.

a just above the valence band

b just below the conduction band

c at the center of forbidden band

d in the conduction band

Q.19 Position of Fermi level in p - type semiconductor is ______.

a just above the valence band

b just below the conduction band

c at the center of forbidden band

d in the conduction band

Q.20 Position of Fermi level in n - type semiconductor is ______.

a just above the valence band

b just below the conduction band

c at the center of forbidden band

d in the conduction band

Q.21 When forward bias is applied to a p-n junction diode, the Fermi level in n-type ______ with respect to the Fermi level in p-type.

a rises

b falls

c remains at the same level

d initially rises and then falls

Q.22 When reverse bias is applied to a p-n junction diode, the Fermi level in n-type ______ with respect to the Fermi level in p-type.

a rises

b falls

c remains at the same level

d initially rises and then falls

Q.23 Generation of e.m.f across an open circuited p-n junction when light is made incident on it is known as ______ effect.

a photoconductive

b photoelectric

c photovoltaic

d none of the above

4 When light is incident on a solar cell, the electron - hole pairs get separated due to ________.

a applied voltage
b incident light
c electric field in depletion region
d all the above

25 Hall effect can be used to determine ________ of charge carriers.

a polarity
b density
c mobility
d all the above

26 Ohm's law relates to the electric field E, conductivity σ and current density J as

a $J = \frac{E}{\sigma}$
b $J = \sigma E^2$
c $J = \frac{\sigma}{E}$
d $J = \sigma E$

27 The mobility of electrons in a conductor is $4 \times 10^{-3} m^2 V^{-1} s^{-1}$. Then the drift velocity of the electron in the presence of applied electric field of strength 100 Vm^{-1} is

a 4 ms^{-1}
b 10 ms^{-1}
c 0.4 ms^{-1}
d 0.04 ms^{-1}

Q.28 Electrons cannot have energy greater than the fermi energy at temperature of ______.

a 0 K
b 273.16 K
c 300 K
d 325 K

Answers