231PYS202T - PHYSICS FOR INFORMATION SCIENCE - QUESTION BANK

UNIT –I SEMICONDUCTOR PHYSICS

Part - A (2 Marks)

1. **What are elemental semiconductors? Give some important elemental semiconductors. (AU Nov 19)**

   Elemental semiconductors are made from single element of the fourth group elements of the periodic table.

   Example : Germanium and silicon.

2. **What are the properties of semiconductors? (AU APR 21)**
   - They are formed by covalent bond.
   - They have empty conduction band.
   - They have almost filled valence band.
   - These materials have comparatively narrow energy gap.

3. **What are compound semiconductors? Give some important compound semiconductors.**

   Semiconductors which are formed by combining third and fifth group elements or second and sixth group elements in the periodic table are called compound semiconductors.

S.No	Group	Compound semiconductor
1.	Combination of third and fifth group elements (III and V)	Gallium Phosphide (GaP) Gallium Arsenide (GaAs) Indium Phosphide (InP) Indium Arsenide (InAs)
2.	Combination of second and sixth group elements (II and VI)	Magnesium Oxide (MgO) Magnesium Silicon (MgSi) Zinc Oxide (ZnO) Zinc Sulphide (ZnS)

4. **What are the differences between elemental semiconductors and compound semiconductors?**

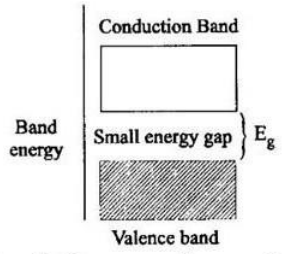
S.No	Elemental Semiconductors	Compound Semiconductors
1.	They are made of single element. Examples: Ge, Si	They are made of compounds. Examples: GaAs, GaP, MgO etc
2.	Heat is produced during recombination	The photons are emitted during recombination.
3.	They are used for the manufacture of diodes and transistors.	They are used for making LED's, Laser Diodes and IC's.

5. **Mention any four advantages of semiconducting materials.**
   - It behaves as insulator at 0 K and as conductor at high temperatures.
   - It has some properties of both conductor and insulator.
   - On doping, *n* and *p*-type semiconductors are produced with charge carriers of electrons and holes respectively.
   - It has many applications in electronic field such as manufacturing of diodes, transistors, LED's, IC etc.

6. **What is a semiconductor?**

   Semiconductor is a special class of material which behaves like an insulator at 0 K and acts as conductor at temperature other than 0 K. Its resistivity lies in between a conductor and an insulator.

7. **Draw the energy level diagram of a semiconductor. (EEC May 21)**



Energy band diagram of a semiconductor

8. **Write an expression for the concentration of electrons in the conduction band of an intrinsic semiconductor.**

   The concentration of electrons in the conduction band of an intrinsic semiconductor is given by

$$n = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2} e^{(E_F - E_C)/kT}$$

   Where m_e*→ effective mass of electronE_F→ Fermi energy level

   E_C→ Energy corresponds to the bottom of conduction band

9. **Write an expression for the concentration of holes in the valence band of an intrinsic semiconductor.**

   The concentration of holes in the valence band is given by

$$p = 2\left(\frac{2\pi\, m_h^* kT}{h^2}\right)^{3/2} e^{(E_v - E_F)/kT}$$

   m_h*→ effective mass of hole$T$→ absolute temperature

   E_F→ Fermi energy E_V→ Energy corresponds to the top of valence band

10. **Write an expression for carrier concentration in n-type semiconductor.**

The carrier concentration in n-type semiconductor is given by

$$n = (2N_d)^{1/2} \left[\frac{2\pi m_e^* kT}{h^2} \right]^{3/4} e^{-\Delta E/2kT}$$

Where ΔE → E_C-E_d = Ionisation energy of the donor m_e^* → Effective mass of an electron

N_d → Number of atoms per unit volume of the material. T → Absolute Temperature

11. **Write an expression for carrier concentration of holes in the valence band of p-type semiconductor.**

The carrier concentration in p-type is given by

$$p = (2N_a)^{1/2} \left[\frac{2\pi m_h^* kT}{h^2} \right]^{3/4} e^{-\Delta E/2kT}$$

Where ΔE = (E_v - E_a) → Ionisation of acceptor level

N_a → Number of acceptor atoms per unit volume of the material.

m_h^* → Effective mass of hole T → Absolute Temperature

12. Define Hall-effect.

When a conductor carrying a current (I) is placed in a transverse magnetic field (B), a potential difference is produced inside the conductor in a direction normal to the directions of the current and magnetic field.

13. Mention the uses of Hall Effect. (AU Nov 20)

- It is used to find type of semiconductor.
- It is used to measure carrier concentration.
- It is used to find mobility of charge carrier.
- It is used to measure the magnetic flux density using a semiconductor sample of known Hall coefficient.

14. What are the differences between intrinsic and extrinsic semiconductor?

S.No	Intrinsic Semiconductor	Extrinsic Semiconductor
1.	Semiconductor in pure form is called intrinsic semiconductor.	Semiconductors which are doped with impurity is called extrinsic semiconductor
2.	Here the charge carriers are produced only due to the thermal agitation.	Here, the charge carriers are produced due to impurities.
3.	Examples: Si, Ge, etc.	Examples: Si and Ge doped with Al, In, P, As, etc

15. **What is an n-type semiconductor?**

When a small amount of pentavalent impurity is added to pure semiconductor, it becomes extrinsic or semiconductor and it is known as n-type semiconductor.

16. **What is a p-type semiconductor?**

When a small amount of trivalent impurity is added to a pure semiconductor, it becomes extrinsic semiconductor or impure semiconductor and it is called p-type semiconductor.

17. **What is meant by doping and doping agent?**

The technique of adding impurities to a pure semiconductor is known as doping and the added impurity is called **doping agent.**

18. **Explain the concept of hole in semiconductor.**

In intrinsic semiconductor, charge carriers are created due to breaking of covalent bonds. When a covalent bond is broken, an electron escapes to the conduction band leaving behind an empty space in the valence band. This missing electron is called a hole.

19. **What is meant by donor and acceptor energy level?**

A pentavalent impurity when doped with an intrinsic semiconductor donates one electron which produces an energy level called **donor energy level.**

A trivalent impurity when doped with an intrinsic semiconductor accepts one electron which produces an energy level called **acceptor energy level.**

20. **Define Mobility. (EEC NOV 19)**

It is defined as the velocity of a charge carrier per unit electrical field strength.

$$\mu = \frac{v_d}{E}$$

21. **Define drift velocity.**

When an electrical field is applied in a semiconducting material, the free charge carriers such as free electrons and holes attain drift velocity v_d. The drift velocity attained by the carriers is proportional to the electrical field strength E.

$$\text{i.e.,} \quad v_d \propto E$$

$$v_d = \mu E$$

where μ is a proportionality constant and it is known as the mobility of the charge carrier.

22. **Define drift current.**

The electric current produced due to the motion of charge carriers under the influence of an external electric field is known as drift current.

23. **Define diffusion current.**

The non-uniform distribution of charge carriers creates the regions of uneven concentrations in the semiconductor. The charge carriers move from the regions of higher concentration to the regions of lower concentration. This process is known as diffusion. The current is known as diffusion current.

24. **What is ohmic contact?**

An ohmic contact is a type of metal semiconductor junction. It is formed by a contact of a metal with a heavily doped semiconductor. When the semiconductor has a higher work function than that of metal, then the junction formed is called the Ohmic junction.

25. **What is a schottky diode?**

It is a junction formed between a metal and n-type semiconductor. When the metal has a higher work function than that of n-type semiconductor then the junction formed is called schottky diode.

26. **What are advantages of schottky diodes?**

- In schottky diode, stored charges or depletion region is negligible. So a schottky diode has a very low capacitance.
- In schottky diode, the depleting region is negligible. So the schottky diode will immediately switch from ON to OFF state (fast recovery time).
- The depletion region is negligible in schottky diode. So applying a small voltage is enough to produce large current.
- It has high efficiency.
- It operates at high frequencies.
- It produces less noise.

27. **What are the application of schottky diode?**

- Schottky diode can be used for rectification of signals of frequencies even exceeding 300 MHz.
- It is commonly used in switching device at frequencies of 20 GHz.
- It is used in radio frequency (RF) applications.
- It is widely used in power supplies.

PART B & C

1. Obtain an expression for intrinsic carrier concentration in an intrinsic semiconductor. (AU Nov 2022)

2. Derive an expression for concentration of holes (absence of electrons) in intrinsic semiconductors.

3. Obtain an expression for the carrier concentration of electrons in an intrinsic semiconductor.

4. With energy band diagram, explain the variation of Fermi level with temperature in extrinsic semiconductor.

5. What is Hall Effect? Give the theory of Hall Effect. Describe the Hall Effect experiment to determine the Hall coefficient of semiconductor. (EEC NOV 2021)

6. Describe Principle, Construction and working of schottky diode.

UNIT II - LIGHT-SEMIONDUCTOR INTERACTION

PART A (2 MARKS)

1. What are optical materials?

The materials which are sensitive to light are known as Optical materials. These optical materials exhibit a variety of optical properties.

2. Classify the optical materials based on their interaction with visible light?

Generally, optical materials are classified into three types based on the nature of propagation of light namely,

(i) Transparent (ii) Translucent (iii) Opaque

3. Define scattering of light.

It is a process by which the intensity of the wave attenuates as it travels through a medium.

4. Define carrier generation and recombination.

The carrier generation is the process whereby electrons and holes are created. The recombination is the process whereby electrons and holes are annihilated.

5. What are types of carrier generations?

(i) Photogeneration (ii) Phonon generation (iii) Impact ionization

6. **What are types of recombination process?**

(a) Radiative Recombination (b) Shockley-Read-Hall Recombination
(c) Auger Recombination

7. What is LED?

It is a p-n junction diode which emits light when it is forward biased.

8. What is solar cell?

It is a *P* - *N* junction diode which converts solar energy (light energy) into electrical energy

9. Give the basic principle behold LED?

The injection of electrons into the p- region from n- region makes a direct transition from the conduction band to valence band. Then, the electrons recombine with holes and emits photons of energy E_g.

The forbidden gap energy is given by $E_g = hv$

10. Calculate the wavelength of radiation emitted by an LED with band gap energy of 2.8 eV.

Relationship between energy (E) and wavelength (λ) in photon emission

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

h = Planck's constant (6.626×10−34 J·s)
c = speed of light (3×108 m/s)
.

$$E=(2.8\ eV)\times(1.602\times10^{-19}\ J/eV)$$

$$E = 4.49\times10^{-19}\ J$$

Wavelength of radiation emitted by LED

Substitute above mentioned the values in formula, we can get λ = 4.42 x 10-7 m

11. Write any five advantages of LEDs?

- LEDs are smaller in size. A number of LEDs can be stacked together in a small space to form numerical display
- LED's can be turned ON and OFF in less than 1 nano second (10-9 second). So, they are known as fast devices.
- Variety of LEDs are available which emit light in different colours like red, green, yellow etc
- Light modulation can be achieved with pulse supply.
- It has long life time.
- It has low drive voltage and low noise.
- It is easily interfaced to digital logic circuits.
- It can be operated over a wide range of temperatures.

12. What are the disadvantages of LEDs?

- They require high power.
- Their preparation cost is high when compared to LCD.

13. List out the applications of LEDs?

- Because of their miniature size, they are widely used in numeric and alphanumeric display devices.
- They are used as indicator lamps.
- They are used as light sources in fiber-optic communication system.
- Infrared LEDs are used in burglar alarms.
- They are used in image sensing circuits used for picture phone.

14. Justify, why LEDs are preferred to have a hemispherical shape

LEDs are preferred to have a hemispherical shape primarily for their superior light distribution, providing uniform illumination in all directions. This shape also enhances viewing angles, reduces glare, and offers aesthetic appeal while maintaining mechanical strength and optical efficiency.

15. What is organic light emitting diode?

Organic light emitting diodes (OLEDs) are solid state devices made up of thin films of organic molecules that produce light with the application of electricity.

16. Specify the advantages of OLED?

- OLED's are tough enough to use in portable devices such as cellular phones, digital video cameras, DVD players, car audio equipment etc.,
- Can be viewed up to 160 degrees.
- High information applications including videos and graphics (Active matrix)
- OLEDs are paper-thin
- Upto 20% to 50% cheaper than LCD processes.
- Takes less power.

17. What are drawbacks of OLED?

- The biggest technical problem for OLEDs is the limited lifetime of the organic materials.
- The intrusion of water into displays can damage or destroy the organic materials.
- Color - The reliability of the OLED is still not upto the mark. After a month of use, the screen becomes non-uniform.

18. Mention some applications of OLED?

- OLED technology is used in commercial applications such as small screens for mobile phones and portable digital audio players (MP3 players), car radios, digital cameras and high-resolution micro displays for head-mounted displays.
- They can be used in television screens, computer displays, advertising, information and indication.
- OLEDs can also be used in light sources for general space illumination and large-area light-emitting elements.

19. How does OLED offer advantages over LED/LCD technology?

1) OLED is very thin and more flexible
2) Light emission is brighter than normal LED
3) They have large field of view

20. What is a laser diode?

It is a specially fabricated p - n junction diode. This diode emits laser light when it is forward - biased.

21. Mention some characteristics of Laser diodes?

1. It is coherent
2. It is monochromatic
3. It is collimated

22. Enumerate the benefits of Laser diodes?

- This laser is very small in size and compact
- It has high efficiency
- The laser output can be easily increased by increasing the junction current.
- It is operated with less power than ruby and CO2 lasers.
- It requires very little additional equipment.
- It emits a continuous wave output or pulsed output.

23. Mention any four applications of Laser diodes?

- Used in fiber optic communication.
- Used in various measuring devices such as range finders, bar-code readers.
- Used in printing industry both as light sources for scanning images and for resolution printing plate manufacturing.
- Infrared and red laser diodes are common in CD players, CD-ROM and DVD technology. Violet lasers are used in HD-DVD and Blue-ray technology
- High power laser laser diode is used in industrial applications such as heat treating, cladding, seam welding and for pumping other lasers.
- Used in laser medicine especially, dentistry.

24. What are the different types of optical data storage devices?

The Optical storage device types available in the market are

- CD-ROM (Compact Disc Read-Only Memory)
- DVD (Digital Versatile Disc)
- Blu-ray Disc (BD-ROM, BD-R, BD-RE)
- HD DVD (High Definition Disc Read-Only Memory – Part of a redefined DVD format not including optical layer and already obsolete since 2006)

25. Can you write down the fundamental idea behind a PIN photodiode?

This diode works in reverse bias. Under reverse bias when light is made to fall on the neutral or intrinsic region electron hole pairs are generated. These electrons and holes are accelerated by the external electric field, which results in photo current. Thus light is converted into electrical signal.

26. Name any three optical data storage techniques?

- Compact Disc (CD)
- Digital Versatile Disc (DVD)
- Blu-ray Disc (BD)
- Holographic Data Storage

27. What is meant by insulator?

Insulators are those substances through which electricity cannot flow are called insulators. Some common insulators are glass, plastic, rubber, and wood.

PART – B& C

1. Explain scattering of light in solids (EEC-NOV/DEC,2020), (EEC-APR/MAY,2020).

2. Describe absorption and emission of light in metal, insulator and semiconductor.

3. Explain carrier generation and recombination in semiconductor.

4. Describe the construction and working of photodiode.

5. Explain the construction and working of a solar cell.

6. Explain the construction and working of a LED with energy band diagram (AU-May 2003), (EEC-APR/MAY 2022).

7. What is OLED? Explain the basic concept of OLED, types, advantages, disadvantages and application (EEC-APR/MAY,2023).

8. Describe the construction and working of laser diodes. What are the advantages of these diodes?

9. Explain different types of optical data storage techniques.

Unit -3. BASIC QUANTUM MECHANICS

PART A (2 MARKS)

1. **Mention the physical significance of wave function of matter waves (or) deBroglie waves**.
   - A variable quantity which characterizes waves is known as wave function.
   - It relates the particle and the wave statistically.
   - It gives the information about the particle behavior.
   - It is a complex quantity.
   - It represents the probability density of the particle Ψ which is real and positive.

2. **What are the properties of photon?**
   - Energy of photon is E = hv
   - Speed of the photon is equal to the speed of light.
   - The mass of the photon is m=h/cλ
   - The momentum of photon is p=h/λ
   - Photons are electrically neutral and they are not affected by both electric and magnetic fields

3. **What are the drawbacks of classical theory?**
   - Interference, diffraction and polarization could not be explained
   - The concept of photo-electric effect, Compton effect and black body radiation cannot be explained
   - The electrical conductivity of semiconductor and insulator cannot be explained.
   - It fails to explain superconducting properties of metals.
   - It fails to explain the specific heat capacity of solids at lower temperature.
   - Ferromagnetism could not be explained by this theory

4. **State Stefan- Boltzmann's law**

   The area under the energy spectrum curve is directly proportion to forth power of the temperature of the body i.e. $E \alpha T^4$

5. **State Wien's displacement law**

   The product of wave length corresponding to maximum energy λm and absolute temperature is constant. i.e. λmT = constant.

6. **State Rayleigh-Jean's law.**

   The energy distribution of thermal spectrum at a given wavelength and temperature is given by

   $E_\lambda = 8\pi kT/ \lambda^4$

7. **What are meant by a degenerate state and Non-degenerate state?**

For various combinations of quantum numbers, if we get same eigen value but different eigen functions, it is called degenerate state. For various combinations of quantum numbers if we get same eigen value but same eigen functions, it is called Non-degenerate state.

8. **What are matter/de Broglie waves? Derive an expression for de Broglie wavelength.**

The waves associated with the matter particles when they travel with a velocity comparable with velocity of light are called matter waves or de Broglie waves".

Louis de Broglie derived an expression for the wavelength of matter waves based on Planck's theory of radiation.

$$E = h\upsilon = hc/\lambda \qquad (1)$$

where, c is the velocity of light and λ is the wavelength of light.

According to the Einstein mass-energy relation,

$$E = mc^2 \qquad (2)$$

From the eqns. (1) and (2), we get,

$$mc^2 = hc/\lambda \qquad (3)$$

$$\lambda = hc/mc^2 = h/mc = h/p \qquad (4)$$

Where, mc = p is the momentum of a photon.

9. **State Planck's hypothesis (or) What are the assumptions of quantum theory of black body radiation? (or) Give the special features of Quantum theory.**

(i) The electrons in the black body are assumed as simple harmonic oscillators.

(ii) The oscillators will not emit energy continuously.

(iii) The emit radiation in terms of quanta of magnitude 'hv', discretely.

i.e. E = nhv, where n = 0, 1, 2, 3, …..

10. **State de-Broglie hypothesis (or) Explain the concept of wave nature (or) What ismeant by matter waves? (or) Give the origin of concept of matter waves.**

The light exhibits the dual nature. It can behave as a particle and the wave. De-Broglie suggested that an electron which is a particle can also behave as a wave and exhibits the dual nature. Thus the waves associated with a material particle (electron) are called as matter waves. If 'v' is the velocity and 'm' is the mass of the particle,

de Broglie wavelength $\lambda = \frac{h}{mv}$

11. **What is black body and what are its characteristics?**

A perfect black body is the one which absorbs and also emits the radiations completely. Black body is said to be a perfect absorber, since it absorbs all the wavelengths of the incident radiation. The black body is the perfect radiator because it radiates the entire wavelength absorbed by it. This phenomenon is called black body radiation.

12. For a free particle moving within a one dimensional potential box, the ground state energy cannot be zero. Why?

For a free particle moving within a one dimensional potential box, when n = 0, the wave function is zero for all values of x, i.e., it is zero even within the potential box. This would mean that the particle is not present within the box. Therefore the state with n = 0 is not allowed. As energy is proportional to n2, the ground state energycannot be zero since n = 0 is not allowed.

13. State Kirchoff's law.

Kirchhoff stated that a good absorber is also a good radiator and the total energy radiated at all wavelengths is proportional to the area under the distribution curve.

$$E \propto A$$

14. **Peak emission of radiation from sun is at a wavelength of 500nm. Find the temperature of sum.** $\lfloor 2.898\times10^{-3}mk \rceil$

Solution:

$$\lambda m \ T = \text{constant}$$

$$T = \frac{2.898\times10^{-3}\times10^{-3}}{500\times10^{-9}}$$

$$T = 5796k$$

15. **What do you infer from the energy spectrum of black body?**

(i) Black body emits all kinds of radiation ranging from lower wavelength to higher wavelength.

(ii) The wavelength corresponding to maximum energy density gets shifted towards lower wavelength, with the increase of temperature.

(iii) If the temperature of black body is increased, the energy density also increases.

16. **What isHeisenberg's uncertainty principle**

Heisenberg's uncertainty principle states that it is impossible to measure or calculate exactly both the position and the momentum of an object. This principle is based on the wave-particle duality of matter.

$$\Delta x \times \Delta p \geq \hbar / 2\pi$$

17. **What is Born's interpretation to wave function**

Max Born's best known contribution to quantum mechanics was his proposal that the wave function, or rather its square modulus, should be interpreted as the probability density for finding the system in a given state at a given time.

PART – B& C

1. Explain Planck's quantum hypothesis. Deduce an expression for Planck radiation law, and also derive Wien's law and Rayleigh Jean's law.

2. What is Black body radiation? Explain the spectrum of black body radiation. Also state the various laws which explain black body spectrum.

3. Derive an expression for Schrödinger time dependent wave equation. Schrödinger time independent wave equation.

4. What is wave function? Explain the physical significance of wave function.

5. Derive a Schrödinger's wave equation for a particle in a one dimensional potential box.

6. What are matter/de Broglie waves? Derive an expression for de Broglie wavelength.

Unit -4. APPLIED QUANTUM MECHANICS

PART A (2 MARKS)

1. **What is a harmonic motion? (Jan 2022)**
   A particle undergoes harmonic motion if it experiences ("Hooke's law") restoring force, in which force is proportional to the displacement from equilibrium position.
   $F = -Kx$

2. **What is known as the zero point energy of a harmonic oscillator?**
   If a particle is confined to some region of space, the particle has a minimum kinetic energy, called the zero-point energy that is greater than zero. The smaller the region of space the particle is confined to, the greater its zero-point energy.
   $E = \frac{1}{2}\hbar\omega$

3. **Describe the significance of zero point energy**
   The lowest value of energy, called zero point energy. Even if the temperature reduces to absolute zero, the oscillator would still have an amount of energy 1/2 *hv*.

4. **Define barrier penetration.**
   The transmission of electrons through the barrier is known as barrier penetration. The phenomenon is also termed as the tunnel effect. The phenomenon of barrier penetration is entirely due to the wave nature of matter.

5. Explain the concept of quantum tunneling. (Jan 2022, Apr 2022)

Tunneling is a quantum phenomenon in which the particle of mass "m" having kinetic energy less than the potential energy barrier can penetrate through the barrier without overcoming the barrier is known as quantum tunneling.

6. What is the significance of tunneling effect?

- Tunneling is a very important physical phenomenon which occurs in certain semiconductor diodes. In such diodes electrons pass through potential barriers even though their kinetic energies are smaller than the barrier heights.

- The tunneling effect also occurs in the case of the alpha particles. The kinetic energy of alpha particle is only a few MeV but it is able to escape from a nucleus whose potential wall is perhaps 25 MeV high.

- The ability of electrons to tunnel through a potential barrier is used in the Scanning Tunneling Microscope (STM) to study surfaces on an atomic scale of size.

7. Define the term transmission coefficient (T).

Transmission coefficient is defined as ratio of transmitted wave to that of the incident wave. It is used to describe the probability of a particle tunneling through a barrier. It is inversely proportional to the barrier height and thickness.

8. Describe the working principle of tunneling microscope.

Scanning Tunneling microscope (STM) works under the principle of quantum barrier tunneling. The tunneling of electrons occurs between the sharp metallic tip of the probe and the surface of the sample.

9. Mention the advantages of STM.

- It can scan the positions and topography atom by atom or even electrons
- Accurate measurement can be obtained
- Magnification is up to nano-scale

10. Mention the disadvantages of STM.

- A small sound or vibration can disturb the measurement setup
- Tip can be easily damaged
- Cost is high

11. Mention the applications of STM.

- It is used to produce Integrated circuit
- It is used in biomedical devices
- It is used in material science to study the flat and bump surfaces

12. Define resonant tunneling.

When an electron (wave) is incident with energy equal to the energy level of a potential well of thin barrier, then the tunneling reaches its maximum value. This is known as resonant tunneling.

13. What is resonant diode?

It is a diode with a resonant tunneling structure in which the electrons tunnel through the resonant states at certain energy levels. When an external voltage is applied, the probability of electron tunneling increases due to resonance. It acts as a switching device.

14. Mention few applications of resonant diode.

- It is used in building oscillators and switching devices that operate at tera hertz frequencies.
- RTDs are very good rectifiers.
- They are used in digital logic circuits.
- They are also used in inverters, memory cells and transistors

15. What is known as Bloch theorem?

Bloch theorem is a mathematical statement of an electron wave function moving in a perfectly periodic potential. These functions are called Bloch functions.

$$\Psi x = e^{ikx}\, u_k\,(x)$$

16. **What is known as Finite potential well? (Apr/May 2022)**

The potential energy outside the box or well is finite and having some value V_0. This is called a finite potential well.

17. What is an energy band?

A set of closely spaced energy levels is called an energy band.

18. What is the conclusion of Kronig-Penny model?

It is a simple model which describes an electron in a one-dimensional periodic potential. The conduction electrons in periodic potentials of lattice ions possess the bands of allowed energy separated by forbidden regions.

PART – B& C

1. Derive an expression for the energy levels of the harmonic oscillator.

2. Explain the concepts of barrier penetration and quantum tunneling.

3. Discuss the principle, construction and working of scanning tunneling microscope with a neat diagram. (Apr/May 2022)

4. Write a short note on resonant diode and mention it's applications.
5. Discuss a particle in a finite potential well starting from Schrodinger wave equation.
6. Explain Bloch's theorem for particles in a periodic potential. (Jan 2022) (Apr/May 2022)
7. Discuss Kronig-Penney model and origin of energy band. (Jan 2022) (Apr/May 2022)

UNIT 5 - NANODEVICES AND QUANTUM COMPUTING

PART – A (2 MARKS)

1. **Define nano materials. (AU, Nov 20)**

   Nanophase materials are newly developed materials with grain size at the nanometre range (10-9 m), i.e., in the order of 1 - 100 nm. The particle size in a nano material is 1 - 100 nm.

2. **What is a quantum confinement? (AU, APR 18)**

   It is a process of reduction of the size of the solid such that the energy levels inside become discrete.

3. **What is quantum structure?**

   When a bulk material is reduced in its size, atleast one of its dimension, in the order of few nanometres, then the structure is known as quantum structure.

4. **What is quantum size-effect?(AU, APR 18)**

   When the size of a nanocrystal becomes smaller than the deBroglie wavelength, electrons and holes get spatially confined, electrical dipoles get generated, the discrete energy levels are formed. As the size of the material decreases, the energy separation between adjacent levels increases. The density of states of nanocrystals is positioned in between discrete (as that of atoms and molecules) and continuous (as in crystals). Quantum size effect is most significant for semiconductor nanoparticles.

5. **How quantum confinement leads to quantization of energy?**

   When a particle is confined to a small space, its position is known with a high degree of precision, which increases the uncertainty in its momentum.

6. **What is the formula for energy in quantum confinement?**

   First the energy levels in the model are discrete according to: $E_n = (h^2 n^2)/(8 m_c R^2)$, where n is an integer designating energy levels, h is Planck's constant, m_c is the effective mass of the electron and hole system, and R is the radius of the quantum dot (particle).

7. **What is the effect of quantum confinement on the density of states?**

Quantum confinement effects constitute the unique property of QDs, which becomes discrete the density of states near the band edges with the ability to determine the spacing between the energy bands in semiconductors.

8. **What are the three types of quantum confinement? (or) List the various low dimensional system. (AU, APR 19)**

It can be divided in to three ways: 1D confinement (free carrier in a plane) -Quantum Wells, 2D confinement (carriers are free to move down) - Quantum Wire and 3D-confinement (carriers are confined in all directions)

9. **Why does quantum confinement increase band gap?**

Due to quantum confinement effect, electrons and holes in the semiconductors in nanoscale are confined. Therefore, the energy difference between the filled states and the empty states increases or widen the band gap of the semiconductor

10. **What is the size of quantum dots?**

Quantum dots are small particles of semiconductors such as CdSe, CdS, etc. These particles usually have diameters of < 10 nm, and each particle has on the order of 1,000-10,000 atoms.

11. **Who discovered quantum dots?**

In 1980 a Russian physicist named Alexi Ekimov discovered quantum dots in glass crystals.

12. **What is single electron phenomena?**

Present day, transistors require 10,000 electrons. Rather than moving many electrons through transistors, it may very well be practical and necessary to move electrons one at a time. The phenomena in known as single electron phenomena.

13. **Define Coulomb - Blockade effect.**

The charging effect which blocks the injection or rejection of a single charge into or from a quantum dot is called Coulomb blockade effect.

14. **What is single electron tunneling? (AU, Nov 22)**

The quantization of charge can dominate and tunneling of single electrons across leaky capacitors carries the current. This is called single electron tunneling.

15. **What is a Single Electron Transistor? (AU, NOV 19)**

SET is three-terminal switching devices which can transfer electrons from source to drain one by one.

16. **What are the advantages of single electron transistor?**
    - The fast information transfer velocity between cells (almost near optic velocity) is carried out via electrostatic interactions only.
    - No wire is needed between arrays. The size of each cell can be as small as 2.5 nm. This made them very suitable for high density memory.
    - This can be used for the next generation quantum computer.

17. **What are the limitations of single electron transistor?**
    - In order to operate SET circuit at room temperature, the size of the quantum dot should be smaller than 10 nm.
    - It is very hard to fabricate by traditional optical lithography and semiconductor process. individual structures into logic circuits and these circuits.
    - The methods must be developed for connecting the must be arranged into larger 2D patterns.

18. **What are the applications of single electron Transistor?**
    - A variety of digital logic functions, including AND or NOR gates, is obtained based on SET operating at room temperature.
    - It is used for mass data storage.
    - It is used in highly sensitive electrometer.
    - SET can be used as a temperature probe, particularly in the range of very low temperatures.

19. **Define Classical Bits.**

    Classical bit is an abstraction of a physical system, anyone of two states, either '0' or '1'. Hence it can take the value 0 or 1. The bit is a smaller and simpler physical system It requires less energy to speedily process information and to store it. The physical system of bit is at atomic or subatomic level.

20. **What is a qubit?**

    A qubit is a mathematical model of microscopic physical system such as the spin of electron or the polarization of a photon. It also exists in a common intermediate states or superposition states.

21. **Define one-qubit quantum gates.**

    A one-qubit gate transforms an input qubit $|\psi) = \alpha|0) + \alpha \mid 1))$ into an output qubit $\mid \varphi) = \alpha \mid 0) + \alpha 1' \mid 1)$.

    Mathematically, a gate G is represented by a 2 × 2 transfer matrix with complex entries.

22. **Define Bloch Sphere.**(AU, APR 22)

    The Bloch sphere representation is useful in understanding the qubits. It provides a geometric picture of the qubit and of the transformations takes on the state of a qubit.

23. **What are the difference between bits and qubits? (AU APR 22)**

S.No	Bits	Qubits
1.	The device computes by manipulating those bits/manipulating those bits with the help of logical with gates (AND, OR, NOT).	The device computes by manipulating those bits with the help of quantum logic gates.
2.	A classical computer has a memory made up of bits where each bit hold either a one or zero	A qubits (quantum bitts) can hold a one, a zero or crucially a superposition of there.
3.	Bits are used in classical computers.	Qubits (Quantum bits) are used in quantum computer
4.	Information is stored in bits which take discrete values 0 and 1	Information is stored in quantum bits, or qubits. A qubit can be in states labelled $\|0\rangle$ and $\|1\rangle$, but it can also be in a superposition of these states, $a\|0\rangle$ and $b\|1\rangle$, where a and b are complex numbers. If we think of the state of a qubit as a vector,, then superposition of states is just vector addition.
5.	Processing of Bits are slow.	Processing of Qubits are faster.
6.	Its circuit behaviour is based on classical physics.	Its circuit behaviour is based on quantum mechanics.

24. **What are advantages of quantum computing over classical computing?**

- The quantum computers can solve the complex mathematical problems.
- Traditional computers find impossible to solve in a practical time frame.
- The computing power is sufficient to process excessively large amounts of data (2.5 Exabyte daily i.e. equal to 5 million laptops)
- It uses less amount of electricity, hence, reducing the power consumption upto 100 to 1000 times.
- A computer is "thousands of times" faster than any classical computer.
- It can work without being overheated.
- It can easily solve optimization problems such as finding the best route and scheduling trains and flights.
- The simulation efficiency is high in quantum computers than in classical computers.

25. **What are the disadvantages of quantum computing?**

- Due to advancements in quantum computers, the security of the existing Internet of Things (IoT) would fall down.
- Cryptographic techniques, Databases of defense systems can be hacked.

- The Quantum Computers will work as a different Since, classical computers are better at some places device and cannot replace classical computers entirely than quantum computers like email, excel, etc.
- It has not been invented completely yet as only parts are being implemented and people are still imaging how it would look.
- It is very delicate and error-prone. Any kind of vibrations affects subatomic particles like atoms and electrons. Due to which noise, faults, and even failures are possible.
- It leads to "Decoherence" which is a loss of coherence in quantum.

PART – B& C

1. Explain in detail, what is quantum confinement and how quantum structures, in nano materials are classified. (AU, NOV 22).
2. Describe single electron phenomena and single electron transistors with necessary diagram. (AU, NOV 22).
3. How does a CNOT gate work? (8) (AU, APR 22)
4. What is Coulomb blockade effect in nanomaterials? (8)(AU, APR 22)
5. List out the differences between Tunnel diode and normal diode.(8)(AU, APR 22)
6. Write a note on size dependence of Fermi Energy. (6) (AU, APR 2021)
7. Explain the construction and working of Tunnel diode.
8. Write a short note on Quantum gate. (8)
9. Give an outline on one-Qubit quantum gate.(10)

Prepared by:
Dr.M.Diivyabharathi
Dr.R.Thirumurugan
Dr.S.Vinothrathan
Dr.S.Baskar
Dr.K.Raju

Approved by

Course Coordinator

HoD/Physics