**1**

**(a) Define Surface Tension. Give some examples of Surface Tension in our practical experiences**

**(b) Show that the excess pressure inside a spherical liquid drop or an air bubble in a P = 2T / r - and inside a soap bubble is p = 4T / r, where the symbols have their conventional**

**meanings.**

**(c) (i) A student, using a circular loop of wire and a pan of soapy water, produces a soap bubble whose radius is 1.0 mm. The surface tension of the soapy water is T= 2.5 X 10^-2 N/m. Determine the pressure difference between the inside and outside of the bubble. (ii) The same soapy water is used to produce a spherical droplet whose radius is one-half that of the bubble, or 0.50 mm. Find the pressure difference between the inside and outside of the droplet.**

**2.**

**(a) Illustrate and explain seven crystal systems or structure with proper example.**

**(b) Write short note on: (i) Allotropy, (ii) Crystal Defect.**

**(c) Draw Miller planes for the given indexes: (111); (200). Interpret importance of Miller Planes.**

(a) Crystal Systems and Examples:

1. Cubic System:

- In the cubic system, all three axes are of equal length, and all angles between them are 90 degrees.

- Examples: Common salt (NaCl), diamond (carbon).

2. Tetragonal System:

- In the tetragonal system, two axes are of equal length, and the third is different and perpendicular to the other two.

- Example: Zircon (ZrSiO4).

3. Orthorhombic System:

- In the orthorhombic system, all three axes are of different lengths, and all angles between them are 90 degrees.

- Example: Sulfur (S8).

4. Hexagonal System:

- In the hexagonal system, there are four axes: three of equal length in the same plane and one perpendicular to that plane.

- Example: Graphite (carbon).

5. Monoclinic System:

- In the monoclinic system, all three axes are of different lengths, and only one angle is 90 degrees.

- Example: Gypsum (calcium sulfate).

6. Triclinic System:

- In the triclinic system, all three axes are of different lengths, and none of the angles between them are 90 degrees.

- Example: Albitite (feldspar).

7. Rhombohedral System:

- In the rhombohedral system, all three axes are of equal length, but the angles between them are not 90 degrees.

- Example: Calcite (calcium carbonate).

(b) Short Notes:

(i) Allotropy:

- Allotropy is the property of some chemical elements to exist in two or more different structural forms called allotropes.

- Allotropes of the same element have different physical and chemical properties.

- Example: Carbon has several allotropes, including diamond, graphite, and graphene.

(ii) Crystal Defect:

- Crystal defects are irregularities or deviations from the ideal crystal structure in a solid.

- They can be point defects (vacancies, interstitials), line defects (dislocations), or planar defects (grain boundaries, stacking faults).

- Crystal defects can influence the mechanical, electrical, and optical properties of materials.

(c) Miller Planes and Their Importance:

Miller indices are used to represent the orientation of planes and directions within crystals. They are crucial in crystallography and materials science. The Miller indices for the given planes are:

(111) - This represents a plane that intersects the crystal axes at fractions of 1/1 along all three axes. It's a high-density plane in a cubic system.

(200) - This represents a plane that intersects the crystal axes at fractions of 1/2 along one axis and 0 along the other two. It's a lower-density plane in a cubic system.

Importance of Miller Planes:

- Miller planes help describe the crystallographic orientation of faces and their spacing.

- They are used to understand the arrangement of atoms or ions in a crystal lattice.

- Miller indices are essential for characterizing and identifying crystal structures.

- They aid in studying material properties, such as mechanical behavior, electronic properties, and optical properties.

- Miller indices are used in X-ray crystallography to determine the structure of crystalline materials.

**3**

**(a) What is interference of light. Write down the conditions for interference.**

**(b) Describe Young's double-slit experiment and derive an expression for (i) intensity at a point on the screen, and (ii) fringe-width.**

**(c) Find the pit depth in a CD that has a plastic transparent layer with index of refraction of 1.60 and is designed for use in a CD player using a laser with a wavelength of 7.80x102 nm in air.**

(a) Interference of Light and Conditions:

Interference of light is a phenomenon that occurs when two or more coherent waves overlap and combine, resulting in the reinforcement or cancellation of their amplitudes. This leads to the formation of a pattern of alternating bright and dark regions. The conditions for interference to occur are:

Coherence: The sources of light must be coherent, which means that they have a constant phase relationship. In the context of interference, this ensures that the waves have a fixed phase difference.

Superposition: The waves from different sources must overlap at a point in space and time. The principle of superposition states that at any point, the displacement of the resultant wave is the algebraic sum of the displacements of the individual waves.

Similar Wavelengths: The interfering waves should have similar wavelengths. This ensures that they have comparable frequencies and can produce a visible interference pattern.

(b) Young's Double-Slit Experiment and Derivations:

Young's double-slit experiment is a classic experiment that demonstrates the interference of light. In this experiment, a beam of light is directed at a barrier with two narrow slits, and the light passing through the slits creates an interference pattern on a screen placed some distance away.

(i) Intensity at a Point on the Screen (I):

The intensity at a point on the screen in Young's experiment is given by:

I=I0cos⁡2(πdsin⁡θλ),I=I0​cos2(λπdsinθ​),

where:

II is the intensity at the point on the screen.

I0I0​ is the maximum intensity when both slits are illuminated equally.

dd is the distance between the two slits.

θθ is the angle between the line from the point on the screen to the center of the pattern and the line from that point to one of the slits.

λλ is the wavelength of the light used.

(ii) Fringe Width (Δy):

The fringe width (ΔyΔy) is the distance between two consecutive bright or dark fringes. It can be calculated as:

Δy=λDd,Δy=dλD​,

where:

ΔyΔy is the fringe width.

λλ is the wavelength of the light used.

DD is the distance between the double-slit and the screen.

dd is the distance between the two slits.

(c) Pit Depth in a CD:

To find the pit depth in a CD, we can use the following equation:

2nt=mλ2nt=mλ

Where:

nn is the refractive index of the plastic layer, which is 1.60.

tt is the pit depth.

mm is the order of the interference pattern (considering it as the first-order maximum, so m=1m=1).

λ is the wavelength of the laser in air, which is 7.80×10−77.80×10−7 m (as given in nanometers).

Solving for tt:

2(1.60)t=1(7.80×10−7 m)2(1.60)t=1(7.80×10−7m)

t=7.80×10−7 m2×1.60t=

2×1.607.80×10−7m​

**4**

**(a) Describe the diffraction of light waves by a narrow opening and an edge, and also describe the resulting interference pattern.**

**(b) With a sketch, describe the arrangement for a single-slit diffraction experiment.**

**(c) Monochromatic light from a helium—neon laser (2=632.8 tint) is incident normally on a diffraction grating containing 6.00x 103 lines/cm. Find the angles at which one would observe the first-order maximum, the second-order maximum, and so forth.**

(a) Diffraction of Light by a Narrow Opening and Edge: When light waves encounter a narrow opening or an edge, they undergo diffraction, which is the bending of light as it passes through the aperture. Diffraction patterns result from the interference of the diffracted waves. Here's how it works:

* **Narrow Opening (Single-Slit Diffraction):** When light passes through a narrow slit, the light wavefronts bend, and a central bright fringe is formed on the other side. Surrounding the central maximum, a series of alternating bright and dark fringes is observed. The angular width of these fringes depends on the slit width and the wavelength of light.
* **Edge (Knife-Edge Diffraction):** When light encounters the edge of an object, it also undergoes diffraction. A sharp edge creates a diffraction pattern with alternating bright and dark fringes, similar to single-slit diffraction. The pattern depends on the shape of the edge.

The resulting interference pattern for both cases consists of a central maximum (bright) and secondary maxima (bright) and minima (dark) on either side. The specific pattern and angular width of the fringes depend on the geometry of the diffracting object and the wavelength of light.

(b) Single-Slit Diffraction Experiment Arrangement (Sketch):

A single-slit diffraction experiment typically consists of the following components:

1. Light Source: A monochromatic light source, such as a laser, provides a narrow and well-defined wavelength of light.
2. Single Slit: A narrow slit or aperture is placed in an opaque barrier. The width of the slit can be adjusted.
3. Screen: A screen is placed a certain distance away from the slit, and it's where the diffraction pattern is observed.
4. Viewing Point: An observer's eye or a detector is positioned to view the diffraction pattern on the screen.

Light from the source passes through the single slit and produces a diffraction pattern on the screen.

(c) Diffraction Grating Angle Calculation: To find the angles at which one observes the first-order, second-order, etc., maxima in a diffraction grating, you can use the grating equation:

mλ=dsin(θ)

Where:

* m is the order of the maximum.
* λ is the wavelength of the incident light (632.8 nm = 632.8 x 10^(-9) m).
* d is the spacing between the lines of the diffraction grating (6.00 x 10^(3) lines/cm = 6.00 x 10^4 lines/m).
* θ is the angle at which the maximum is observed.

For the first-order maximum (m=1): 1(632.8x10(−9)m)=6.00x104lines/m∗sin(θ1​) sin(θ1​)=6.00x104lines/m632.8x10(−9)m​

Solve for θ1​.

For the second-order maximum (m=2): 2(632.8x10(−9)m)=6.00x104lines/m∗sin(θ2​)

Solve for θ2​.

You can continue this pattern for other orders of maxima.

**5**

**(a) State and explain Brewster's law. Show that at the polarizing angle of incidence, the reflected and refracted rays are mutually perpendicular to each other.**

**(b) Explain polarization of light by selective absorption, and hence the Malus law.**

**(c) Unpolarized light is incident upon three polarizers. The first polarizer has a vertical transmission axis, the second has a transmission axis rotted 30° with respect to the first, and the third has a transmission axis rotated 75° relative to the first. If the initial light intensity of the beam is Ib, calculate the light intensity after the beam passes through (i) the second polarizer, and (ii) the third polarizer.**

**(a) Brewster's Law: Brewster's law is a principle that relates to the polarization of light. It states that at a specific angle of incidence (known as the Brewster angle), the reflected light is completely polarized, and the refracted and reflected rays are mutually perpendicular to each other. Mathematically, Brewster's law is given as:**

tan(θB​)=n1​n2​​

Where:

* θ\_B is the Brewster angle (the angle of incidence at which polarization occurs).
* n\_1 is the refractive index of the initial medium (where the incident light is coming from).
* n\_2 is the refractive index of the medium the light is entering (e.g., a glass or water).

Explanation: At the Brewster angle, the reflected light is completely polarized, which means its electric field vector oscillates in a direction perpendicular to the plane of incidence. This happens because at this angle, the tangential component of the electric field of the incident light is zero for the reflected wave, which results in complete polarization.

(b) Polarization of Light by Selective Absorption and Malus's Law: Polarization of light by selective absorption occurs when certain materials selectively absorb light vibrations in one direction while allowing vibrations in other directions to pass through. This process leads to the partial or complete polarization of light.

Malus's Law describes the relationship between the intensity of polarized light and the angle between the polarizer's axis and the direction of polarization. It can be stated as:

I=I0​cos2(θ)

Where:

* I is the transmitted intensity of light.
* I\_0 is the initial intensity of unpolarized light.
* θ is the angle between the polarizer's transmission axis and the direction of polarization.

The law shows that the transmitted intensity is directly proportional to the square of the cosine of the angle between the polarizer's axis and the polarization direction.

(c) Calculation of Light Intensity After Passing Through Polarizers: (i) For the second polarizer (30° with respect to the first):

The angle between the transmission axis of the second polarizer and the first polarizer's axis is 30°. Using Malus's Law: I2​=I1​cos2(30°)=I1​(23

​​)2=43​I1​

(ii) For the third polarizer (75° relative to the first):

The angle between the transmission axis of the third polarizer and the first polarizer's axis is 75°. Using Malus's Law: I3​=I1​cos2(75°)=I1​(2

​1​)2=21​I1​

So, after passing through the second polarizer, the light intensity is 43​ of the initial intensity, and after passing through the third polarizer, the light intensity is 21​ of the initial intensity.

**6**

**(a) What is fission reactions? How does fission reactions occurs?**

**(b) Define spontaneous and induced fission.**

**(c) Write down the important characteristics of fission reactions. Write down short notes on each characteristic.**

**(d) Calculate excitation energy in fission process. Sketch a diagram for surface energy and Coulomb repulsion between the fission fragments those produce a potential barrier.**

(a) Fission Reactions: Fission reactions are nuclear reactions in which the nucleus of an atom splits into two or more smaller nuclei, along with the release of a significant amount of energy. Fission can occur naturally in some heavy isotopes, but it is primarily associated with nuclear reactors and atomic bombs. The most commonly studied fission reaction involves the nucleus of uranium-235 (U-235) splitting into two smaller nuclei, typically barium and krypton, along with the emission of neutrons and a release of energy.

Fission occurs when a heavy nucleus absorbs a neutron, becomes unstable, and splits into two or more smaller nuclei, releasing additional neutrons in the process. These neutrons can go on to induce further fission reactions in nearby nuclei, creating a chain reaction.

(b) Spontaneous and Induced Fission:

* **Spontaneous Fission:** Spontaneous fission is a natural, random process in which a heavy nucleus can undergo fission without any external influence, such as the absorption of a neutron. It is relatively rare and occurs spontaneously in some heavy radioactive isotopes.
* **Induced Fission:** Induced fission occurs when a heavy nucleus is prompted to undergo fission due to the absorption of a neutron. The neutron imparts the necessary energy to destabilize the nucleus and initiate the fission process. Induced fission is the basis for nuclear reactors and nuclear weapons.

(c) Important Characteristics of Fission Reactions:

1. **Release of Energy:** Fission reactions release a significant amount of energy, typically in the form of kinetic energy of the fission fragments and energy carried away by emitted neutrons.
2. **Production of Neutrons:** Fission reactions produce additional neutrons, which can go on to induce further fission reactions in a chain reaction.
3. **Two or More Fission Fragments:** Fission results in the formation of two or more smaller nuclei (fission fragments) along with the release of neutrons.
4. **Energy Barrier:** Fission requires overcoming a potential energy barrier to separate the positively charged protons within the nucleus. The barrier is overcome through the absorption of a neutron.
5. **Variability in Fission Products:** The specific fission products and their distribution depend on the nucleus that undergoes fission and the conditions of the reaction. This leads to a wide range of possible fission products.

(d) Excitation Energy in Fission and Diagram:

In a fission process, the excitation energy is the energy needed to overcome the potential energy barrier between the initial, highly deformed configuration of the nucleus and the separated fission fragments. The barrier arises from two main components:

1. **Surface Energy:** This is the energy required to increase the distance between the positively charged protons within the nucleus. As the nucleus deforms and elongates, this energy increases.
2. **Coulomb Repulsion:** The Coulomb repulsion arises from the electrostatic repulsion between the positively charged protons as they move further apart during fission. This energy also increases as the nucleus deforms.

The total potential energy barrier is the sum of the surface energy and the Coulomb repulsion. As the excitation energy of the nucleus exceeds this potential energy barrier, fission occurs. Below is a simplified diagram illustrating the potential energy barrier for fission:

The energy required to surmount this barrier is the excitation energy, and once it is exceeded, the nucleus undergoes fission.

**7**

**(a) Define effective neutron multiplication factor (k). Explain subcriticality, criticality and supercriticality with the value of k.**

**(b) What is nuclear reactors? Write down the types of nuclear reactors. Briefly discuss the sodium cooled fast reactor with schematic diagram.**

**(c) How does a nuclear power plant works? Briefly discuss its advantages and disadvantages.**

**(a) Effective Neutron Multiplication Factor (k) and Criticality:**

* **Effective Neutron Multiplication Factor (k):** The effective neutron multiplication factor (k) is a dimensionless quantity used to describe the behavior of neutrons in a nuclear reactor. It represents the ratio of the number of neutrons produced in one generation of fission reactions to the number of neutrons lost due to absorption in the previous generation. Mathematically, it can be expressed as: k=Neutrons absorbed in the previous generationNeutrons produced in one generation​
* **Subcriticality:** When k<1, the reactor is said to be in a subcritical state. In this condition, the number of neutrons produced is less than the number lost due to absorption, and the reactor cannot sustain a chain reaction. Neutron population decreases over time.
* **Criticality:** When k=1, the reactor is said to be in a critical state. In this condition, the number of neutrons produced is exactly equal to the number lost, leading to a self-sustaining chain reaction at a constant power level.
* **Supercriticality:** When k>1, the reactor is said to be in a supercritical state. In this condition, the number of neutrons produced is greater than the number lost, and the neutron population increases, resulting in an increasing power level.

(b) Types of Nuclear Reactors and Sodium Cooled Fast Reactor:

Nuclear reactors are devices that use controlled nuclear reactions to generate electricity or heat. There are several types of nuclear reactors, including pressurized water reactors (PWRs), boiling water reactors (BWRs), and fast breeder reactors. The sodium-cooled fast reactor is a type of fast breeder reactor.

**Sodium Cooled Fast Reactor (SFR):**

* SFRs use liquid sodium as a coolant, which has excellent heat transfer properties and is less likely to slow down fast neutrons.
* They are called "fast" reactors because they use fast neutrons (neutrons with high kinetic energy) to sustain the fission chain reaction.
* SFRs are capable of breeding fissile material (like plutonium) from fertile material (like uranium-238), making them highly efficient in terms of fuel utilization.
* They have the potential to reduce nuclear waste and maximize fuel resources.

**Schematic Diagram:** A simplified diagram of an SFR would show a core where nuclear reactions take place, surrounded by liquid sodium coolant. Heat is transferred to a secondary sodium loop, which then heats water to produce steam for electricity generation.

(c) How a Nuclear Power Plant Works, Advantages, and Disadvantages:

**How a Nuclear Power Plant Works:**

1. Nuclear fission occurs in the reactor core, releasing a tremendous amount of heat.
2. This heat is used to produce steam by heating a coolant (usually water or liquid sodium).
3. The steam drives a turbine, which turns a generator to produce electricity.
4. The generated electricity is transmitted for various uses.

**Advantages of Nuclear Power Plants:**

* Low Greenhouse Gas Emissions: Nuclear power is a low-carbon energy source.
* High Energy Density: A small amount of nuclear fuel produces a large amount of energy.
* Reliable and Continuous Power Generation: Nuclear plants operate 24/7.
* Long Fuel Supply: Uranium, a nuclear fuel, is available in significant quantities.

**Disadvantages of Nuclear Power Plants:**

* Radioactive Waste: Managing and disposing of nuclear waste is a challenge.
* High Initial Costs: Building nuclear power plants is expensive.
* Safety Concerns: Accidents (e.g., Chernobyl and Fukushima) can have catastrophic consequences.
* Limited Fuel Availability: Uranium reserves are finite.
* Security Risks: Nuclear materials pose security risks if not properly managed.