Physics (4300005) - Winter 2023 Solution

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Question 1(a) [3 marks]

Define: (a) Meter (b) Kelvin (c) Accuracy.

Solution

- **Meter**: The meter is the SI unit of length, defined as the distance traveled by light in vacuum during a time interval of 1/299,792,458 of a second.
- **Kelvin**: The kelvin is the SI unit of thermodynamic temperature, defined by setting the fixed numerical value of the Boltzmann constant k to 1.380649×10^{-23} J/K.
- **Accuracy**: Accuracy is the degree of closeness of a measured value to the true or standard value of the quantity being measured.

Mnemonic

"MKA - Meter measures Kilometers Accurately"

Question 1(b) [4 marks]

Explain construction of Vernier calipers with clean figure.

Solution

Diagram:

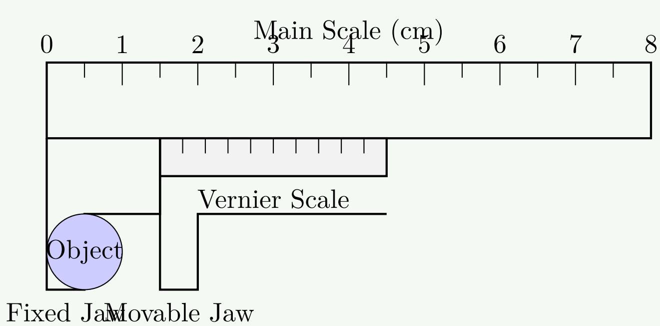

Figure 1. Vernier Calipers Construction

Vernier calipers consist of:

- **Main scale**: Fixed scale marked in standard units (mm or inches)
- **Vernier scale**: Movable scale that slides along the main scale
- **Fixed jaw**: Attached to the main scale
- **Movable jaw**: Connected to the vernier scale
- **Depth probe**: For measuring depth of cavities
- **External jaws**: For measuring outer dimensions

- **Internal jaws**: For measuring inner dimensions

Mnemonic

"FMMVJ - Fixed Main scale Makes Vernier Jaw move"

Question 1(c)(1) [4 marks]

What is physical quantities? Explain its types depending on direction.

Solution

A physical quantity is a measurable property of a physical system that can be quantified by measurement.
Types of physical quantities based on direction:

Table 1. Scalar vs Vector Quantities

Scalar Quantities	**Vector Quantities**
Have only magnitude	Have both magnitude and direction
Examples: mass, time, temperature, energy	Examples: displacement, velocity, force, acceleration
Represented by simple numbers	Represented by arrows or directed line segments
Addition follows simple arithmetic	Addition follows vector algebra (parallelogram law)
No directional properties	Completely specified by direction and magnitude

Mnemonic

"SMAVD - Scalars have Magnitude Alone, Vectors have Direction"

Question 1(c)(2) [3 marks]

Pitch of micrometer screw is 0.5 mm. If its circular scale is divided in equal 100 divisions, Calculate L.C.

Solution

Calculation:

$$\text{Least Count (L.C.)} = \frac{\text{Pitch}}{\text{Number of divisions on circular scale}}$$

$$\text{L.C.} = \frac{0.5 \text{ mm}}{100} = 0.005 \text{ mm}$$

Therefore, the least count of the micrometer screw gauge is 0.005 mm.

Mnemonic

"PDL - Pitch Divided gives Least count"

Question 1(c) OR [7 marks]

Explain errors of Micrometer screw gauge with figure.

Solution

Diagram:

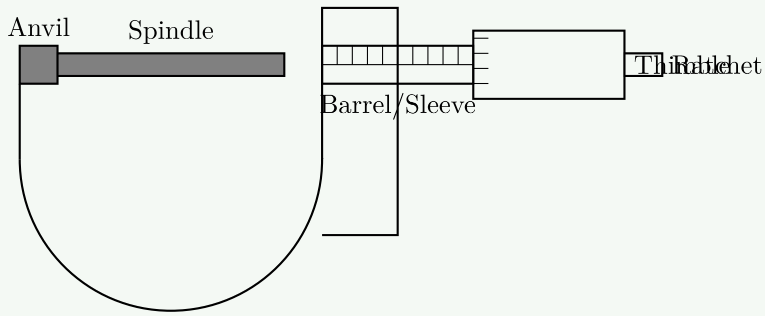

Figure 2. Micrometer Screw Gauge Components

Common errors in micrometer screw gauge:

- **Zero error**: When the measuring faces are in contact, the zero of thimble doesn't coincide with the datum line
  - **Positive zero error**: When the zero mark on thimble is below the datum line
  - **Negative zero error**: When the zero mark on thimble is above the datum line
- **Backlash error**: Play between the screw and nut, causes different readings in forward and backward movement
- **Instrumental error**: Due to manufacturing defects or wear and tear
- **Parallax error**: When line of sight isn't perpendicular to scale reading

Correction formula: True reading = Observed reading − Zero error

Mnemonic

"ZBIP - Zero, Backlash, Instrument and Parallax errors make measurements trip"

Question 2(a) [3 marks]

Explain Coulomb's inverse square law.

Solution

Coulomb's inverse square law states that the electrostatic force between two point charges is:

- Directly proportional to the product of the magnitudes of charges
- Inversely proportional to the square of the distance between them
- Acts along the line joining the two charges

Mathematical expression:

$$F = k\frac{q_1 q_2}{r^2}$$

Where:

- F = Electrostatic force between charges
- k = Coulomb's constant ($9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$)
- q_1, q_2 = Magnitudes of the two charges
- r = Distance between the charges

Mnemonic

"PDSA - Product of charges Directly, Square of distance inversely, Along the line"

Question 2(b) [4 marks]

Explain electrical potential difference.

Solution

Electrical potential difference (voltage) is the work done per unit charge in moving a positive test charge between two points in an electric field.
Mathematical expression:

$$V = \frac{W}{q}$$

Where:
- V = Potential difference (volts)
- W = Work done (joules)
- q = Charge (coulombs)

Key characteristics:
- Measured in volts (V)
- Scalar quantity (has magnitude only)
- Path independent (depends only on initial and final positions)
- Represents energy per unit charge

Mnemonic

"WPCS - Work Per Charge is what potential difference Says"

Question 2(c) [7 marks]

Explain equivalent capacitance of capacitors in series and in parallel combinations.

Solution

Series Combination:

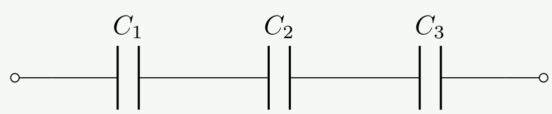

Figure 3. Capacitors in Series

- When capacitors are connected end-to-end
- Same charge on each capacitor: $Q = Q_1 = Q_2 = Q_3$
- Total potential difference: $V = V_1 + V_2 + V_3$
- Equivalent capacitance formula: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$
- Equivalent capacitance is less than the smallest individual capacitance

Parallel Combination:

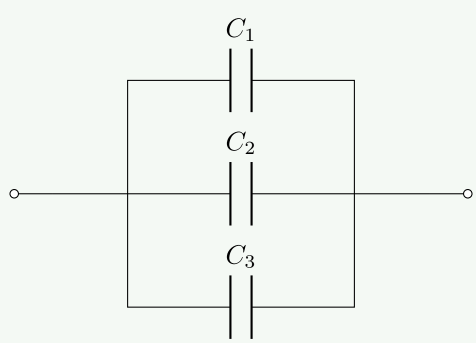

Figure 4. Capacitors in Parallel

- When capacitors are connected between the same two points
- Same potential difference across each: $V = V_1 = V_2 = V_3$

- Total charge: $Q = Q_1 + Q_2 + Q_3$
- Equivalent capacitance formula: $C_{eq} = C_1 + C_2 + C_3 + ...$
- Equivalent capacitance is greater than the largest individual capacitance

Comparison Table:

Table 2. Series vs Parallel Capacitors

Parameter	**Series**	**Parallel**
Charge	Same on all capacitors	Distributed as per capacitance
Voltage	Divided across capacitors	Same across all capacitors
Equivalent capacitance	$1/C_{eq} = 1/C_1 + 1/C_2 + ...$	$C_{eq} = C_1 + C_2 + ...$
Resulting capacitance	Smaller than any individual C	Larger than any individual C

Mnemonic

"RAPS - Reciprocals Add in Parallel Sum"

Question 2(a) OR [3 marks]

Write characteristics of electrical lines.

Solution

Characteristics of electric field lines:
- **Direction**: Always point from positive to negative charge
- **Nature**: Start from positive charge and end at negative charge
- **Continuity**: Never intersect each other
- **Density**: Closer lines indicate stronger electric field
- **Perpendicularity**: Always perpendicular to equipotential surfaces
- **Shape**: Straight lines for uniform fields, curved for non-uniform fields
- **Open/Closed**: Always open curves, unlike magnetic field lines

Mnemonic

"DNCPS - Direction, Never cross, Closeness shows strength, Perpendicular, Straight/curved"

Question 2(b) OR [4 marks]

Explain electric flux.

Solution

Electric flux is a measure of the electric field passing through a given area.

Mathematical expression:

$$\Phi_E = E \cdot A \cdot \cos\theta$$

Where:
- Φ_E = Electric flux ($\mathrm{N \cdot m^2/C}$ or $\mathrm{V \cdot m}$)
- E = Electric field strength (N/C or V/m)
- A = Area of the surface ($\mathrm{m^2}$)
- θ = Angle between electric field and normal to the surface

Key characteristics:
- Vector quantity

- SI unit is newton-meter-squared per coulomb ($N \cdot m^2/C$) or volt-meter ($V \cdot m$)
- Represents the number of field lines passing through a surface
- Maximum when field is perpendicular to surface ($\theta = 0°$)
- Zero when field is parallel to surface ($\theta = 90°$)

Mnemonic

"FACT - Flux = Area x Cos-theta x Field strength"

Question 2(c) OR [7 marks]

Explain capacitor and capacitance.

Solution

Capacitor: A capacitor is an electrical component designed to store electric charge and energy in an electric field.
Basic structure:

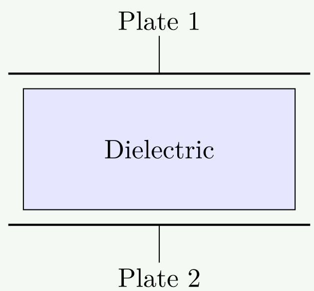

Figure 5. Parallel Plate Capacitor

Capacitance: The ability of a capacitor to store electric charge at a given potential difference.
Mathematical expression:

$$C = \frac{Q}{V}$$

Where:
- C = Capacitance (farads)
- Q = Electric charge (coulombs)
- V = Potential difference (volts)

For a parallel plate capacitor:

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

Where:
- ϵ_0 = Permittivity of free space (8.85×10^{-12} F/m)
- ϵ_r = Relative permittivity of dielectric
- A = Area of overlap between plates
- d = Distance between plates

Factors affecting capacitance:
- Increases with plate area
- Decreases with plate separation
- Increases with dielectric constant

Applications of capacitors:
- Energy storage
- Filtering in power supplies
- Timing circuits
- Coupling and decoupling
- Power factor correction

Mnemonic

"QVAD - Quotient of charge and Voltage, affected by Area and Distance"

Question 3(a) [3 marks]

Define: (a) Heat radiation (b) Kilocalorie (c) Thermometer.

Solution

- **Heat radiation**: The transfer of thermal energy in the form of electromagnetic waves without requiring a medium, occurring in vacuum or transparent media.
- **Kilocalorie**: A unit of heat energy equal to 1000 calories, where one calorie is the amount of heat required to raise the temperature of 1 gram of water by 1°C at standard conditions.
- **Thermometer**: An instrument used to measure temperature based on a physical property (like expansion of mercury) that changes with temperature.

Mnemonic

"RKT - Radiation needs no medium, Kilocalorie measures energy, Thermometer shows temperature"

Question 3(b) [4 marks]

Explain law of thermal conductivity.

Solution

The law of thermal conductivity (Fourier's law) states that the rate of heat transfer through a material is:

- Directly proportional to the area of the section
- Directly proportional to the temperature gradient
- Dependent on the material's thermal conductivity

Mathematical expression:

$$\frac{Q}{t} = -kA\frac{dT}{dx}$$

Where:

- Q/t = Rate of heat transfer (J/s or W)
- k = Thermal conductivity of material ($\mathrm{W/m \cdot K}$)
- A = Cross-sectional area ($\mathrm{m^2}$)
- dT/dx = Temperature gradient (K/m)
- Negative sign indicates heat flows from higher to lower temperature

Mnemonic

"GAKT - Gradient And area with K gives heat Transfer"

Question 3(c)(1) [3 marks]

A person has a fever of 102°F. So how much would it be in Celsius and Kelvin?

Solution

To convert from Fahrenheit to Celsius:

$$C = (F - 32) \times \frac{5}{9}$$

$$C = (102 - 32) \times \frac{5}{9}$$
$$C = 70 \times 0.555$$
$$C = 38.89°C$$

To convert from Celsius to Kelvin:

$$K = C + 273.15$$
$$K = 38.89 + 273.15$$
$$K = 312.04 \text{ K}$$

Therefore, $102°F = 38.89°C = 312.04$ K

Mnemonic

"FSK - From Fahrenheit Subtract 32, multiply by 5/9, then add 273.15 for Kelvin"

Question 3(c)(2) [4 marks]

Explain Celsius and Fahrenheit scale.

Solution

Comparison of Celsius and Fahrenheit Temperature Scales:

Table 3. Celsius vs Fahrenheit

Parameter	**Celsius Scale**	**Fahrenheit Scale**
Freezing point of water	0°C	32°F
Boiling point of water	100°C	212°F
Number of divisions	100 divisions	180 divisions
Developed by	Anders Celsius (1742)	Gabriel Fahrenheit (1724)
Used in	Most countries worldwide	Primarily USA and its territories
Relation	$C = (F - 32) \times 5/9$	$F = (C \times 9/5) + 32$

Diagram:

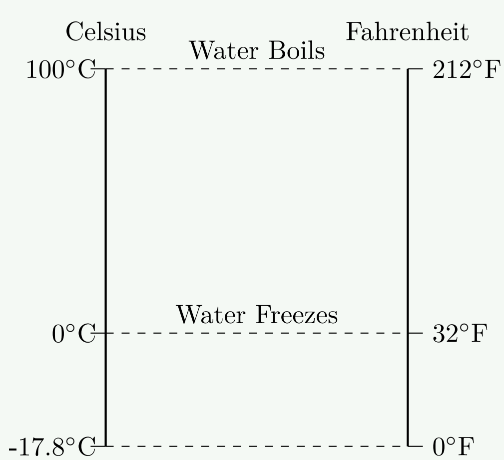

Figure 6. Temperature Scales Comparison

Mnemonic

"FBIC - Fahrenheit has Bigger numbers, Interval of 180, Conversion needs 5/9 or 9/5"

Question 3(a) OR [3 marks]

Write definition, formula and unit of Heat capacity.

Solution

Definition: Heat capacity is the amount of heat energy required to raise the temperature of an object by one degree (Celsius or Kelvin).
Formula:

$$C = \frac{Q}{\Delta T}$$

Where:
- C = Heat capacity (J/K or J/°C)
- Q = Heat energy supplied (joules)
- ΔT = Change in temperature (K or °C)

Units: Joules per kelvin (J/K) or joules per degree Celsius (J/°C)

Mnemonic

"QTC - Quotient of heat and Temperature Change gives heat capacity"

Question 3(b) OR [4 marks]

Explain Modes of Heat Transfer

Solution

Three modes of heat transfer:

Table 4. Modes of Heat Transfer

Mode	Definition	Examples	Medium Required
Conduction	Transfer of heat through direct molecular collision without bulk motion of matter	Heat through metal rod, cooking pan	Yes (solid preferred)
Convection	Transfer of heat by movement of heated particles from one region to another	Boiling water, room heater, sea breeze	Yes (fluid - liquid or gas)
Radiation	Transfer of heat via electromagnetic waves without requiring medium	Solar radiation, microwave heating, infrared heaters	No (works in vacuum)

Mnemonic

"CoCRa - Conduction needs Contact, Convection needs Currents, Radiation needs no medium"

Question 3(c) OR [7 marks]

Explain bimetallic thermometer.

Solution

Diagram:

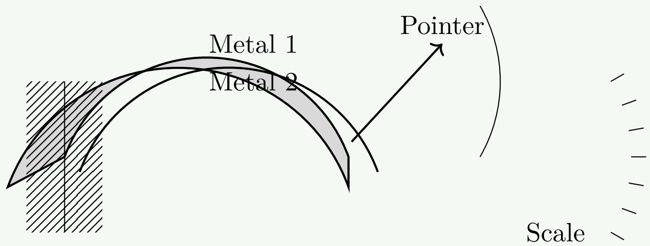

Figure 7. Bimetallic Strip Thermometer

Working principle:
- Based on differential thermal expansion of two different metals
- Two metal strips with different coefficients of thermal expansion are bonded together
- When heated, one metal expands more than the other
- This uneven expansion causes the strip to bend toward the metal with lower expansion
- The amount of bending is proportional to temperature change
- A pointer attached to the strip indicates temperature on a calibrated scale

Advantages:
- Simple, robust construction
- No liquid or gas required
- Wide temperature range
- Resistant to mechanical shocks
- Can be used to make thermostats

Applications: Thermostats, automobile cooling systems, oven controls, circuit breakers.

Mnemonic

"BENDS - Bimetallic strips Expand, Not equally, Different metals, Show temperature"

Question 4(a) [3 marks]

Define: (a) Frequency (b) Infrasonic waves (c) Echo.

Solution

- **Frequency**: The number of complete oscillations or cycles per unit time, measured in hertz (Hz).
- **Infrasonic waves**: Sound waves with frequencies below the lower limit of human hearing (below 20 Hz) that cannot be heard by humans but may be detected by other animals.
- **Echo**: A sound that is reflected back to the listener with sufficient time delay to be heard as a distinct repetition of the original sound.

Mnemonic

"FIE - Frequency counts cycles, Infrasonic is below hearing, Echo comes back after reflection"

Question 4(b) [4 marks]

Give distinction between Longitudinal and Transverse waves.

Solution

Comparison between Longitudinal and Transverse Waves:

Table 5. Longitudinal vs Transverse Waves

Parameter	Longitudinal Waves	Transverse Waves
Direction of particle motion	Parallel to wave propagation	Perpendicular to wave propagation
Example	Sound waves, P-waves	Light waves, ripples on water
Medium requirement	Solids, liquids and gases	Solids and surfaces of liquids (not gases)
Components	Compressions and rarefactions	Crests and troughs
Polarization	Cannot be polarized	Can be polarized
Visualization	Spring/Slinky	Rope moving up and down

Diagram:

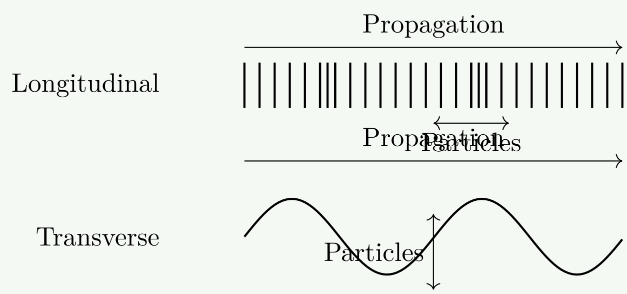

Figure 8. Wave Types

Mnemonic

"PPCP - Particles move Parallel in Longitudinal, Perpendicular in Transverse, Compressions vs Crests, Polarization only in Transverse"

Question 4(c)(1) [4 marks]

Give three properties and uses of ultrasonic waves.

Solution

Properties of ultrasonic waves:

- Frequency ranges above 20,000 Hz (beyond human hearing)
- Short wavelengths allow detection of small objects
- High directivity compared to audible sound
- High penetration in certain media
- Less diffraction around obstacles
- Cause cavitation in liquids

Uses of ultrasonic waves:

Table 6. Uses of Ultrasonic Waves

Field	Applications
Medical	Sonography, kidney stone destruction, physiotherapy
Industrial	Non-destructive testing, cleaning, welding, drilling
Navigation	SONAR, distance measurement, obstacle detection
Other	Dog whistles, pest control, echolocation

Mnemonic

"FWD-MNO - Frequency high, Wavelength short, Direction focused; Medical imaging, NDT testing, Ocean mapping"

Question 4(c)(2) [3 marks]

Derive relation between velocity, wavelength and frequency.

Solution

Derivation: Consider a wave traveling with:

- Wavelength (λ): Distance between consecutive similar points
- Frequency (f): Number of waves passing a point per second
- Time period (T): Time to complete one cycle

During one time period (T), the wave travels a distance equal to one wavelength (λ).

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}} = \frac{\lambda}{T}$$

Since frequency $f = 1/T$, we can write:

$$v = \lambda \times f$$

Where v is velocity (m/s), λ is wavelength (m), and f is frequency (Hz).

Diagram:

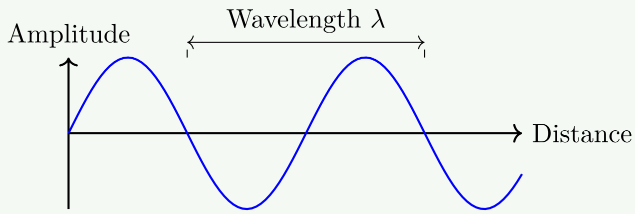

Figure 9. Wavelength Visualization

Mnemonic

"VLF - Velocity equals Lambda times Frequency"

Question 4(a) OR [3 marks]

Explain Sabine's formula for reverberation time.

Solution

Sabine's formula calculates the reverberation time in an enclosed space:

Formula:

$$RT_{60} = \frac{0.161 \times V}{A}$$

Where:
- RT_{60} = Reverberation time (seconds) for sound to decay by 60 dB
- V = Volume of the room (m^3)
- A = Total sound absorption (m^2 sabins)

Total absorption (A) is calculated as:

$$A = \sum \alpha_i S_i = \alpha_1 S_1 + \alpha_2 S_2 + ...$$

Where α_i is absorption coefficient and S_i is surface area.

Mnemonic

"VAS - Volume And Surface absorption determine reverberation time"

Question 4(b) OR [4 marks]

What is diffraction of light? Explain its types with diagram.

Solution

Definition: Diffraction is the bending of light waves around obstacles or through openings, showing the wave nature of light.

Types of diffraction:

1. **Fresnel Diffraction**: Source or screen at finite distance. Spherical wavefronts. Complex pattern.

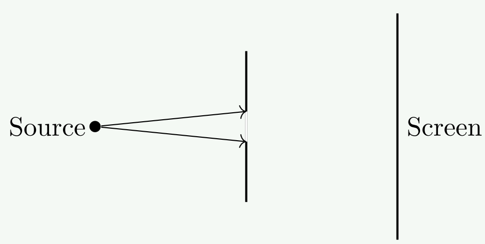

Figure 10. Fresnel Diffraction

2. **Fraunhofer Diffraction**: Source and screen at infinite distance. Plane wavefronts. Simple pattern.

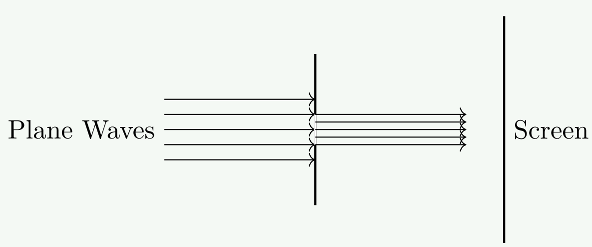

Figure 11. Fraunhofer Diffraction

Mnemonic

"FPSS - Fresnel has Finite distances, Spherical waves; Fraunhofer has Source at infinity, Straight (plane) waves"

Question 4(c)(1) OR [3 marks]

Find the wavelength of a radio wave if the frequency is 480 Hz and the speed of sound is 330 m/s.

Solution

Given:

- Frequency (f) = 480 Hz
- Speed (v) = 330 m/s

To find: Wavelength (λ)
Formula: $v = \lambda \times f \Rightarrow \lambda = v/f$
Calculation:

$$\lambda = \frac{330}{480} = 0.6875 \text{ m}$$

Therefore, the wavelength is 0.6875 m or 68.75 cm.

Mnemonic

"WFV - Wavelength equals Velocity divided by Frequency"

Question 4(c)(2) OR [4 marks]

Give properties of sound waves

Solution

Properties of sound waves:

Table 7. Sound Wave Properties

Property	Description
Wave nature	Mechanical, longitudinal wave requiring a medium
Frequency range	Audible range: 20 Hz to 20,000 Hz
Speed	343 m/s in air; fastest in solids
Reflection	Bounces off surfaces (echoes)
Refraction	Changes direction between media
Diffraction	Bends around obstacles
Interference	Constructive or destructive superposition
Resonance	Amplification at natural frequencies

Mnemonic

"WARDS-FIR - Wave needs medium, Audible range limited, Reflected, Diffracted, Speed varies, Frequency determines pitch, Intensity determines loudness, Resonates at natural frequencies"

Question 5(a) [3 marks]

State the meaning and properties of Laser.

Solution

LASER: Light Amplification by Stimulated Emission of Radiation
Properties of laser light:

- **Monochromatic**: Single wavelength
- **Coherent**: Waves are in phase
- **Directional**: Travels in straight line, low divergence
- **Intense**: High energy concentration
- **Collimated**: Rays are parallel

Mnemonic

"MCCDI - Monochromatic and Coherent, Collimated, Directional, Intense"

Question 5(b) [4 marks]

Give information about optical fiber.

Solution

Optical Fiber: Flexible, transparent fiber giving light signals through total internal reflection.
Structure:

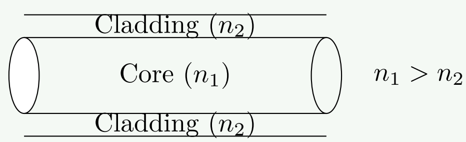

Figure 12. Optical Fiber Structure

Components:

- **Core**: Central region (high refractive index)
- **Cladding**: Outer optical material (lower refractive index)
- **Buffer coating**: Protective covering

Types: Single-mode (small core), Multi-mode (large core).

Mnemonic

"CCTLT - Core Carries light, Cladding keeps it in, Total internal reflection, Low loss transmission"

Question 5(c)(1) [7 marks]

Explain Snell's law.

Solution

Definition: Snell's law states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant.
Formula: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$
Diagram:

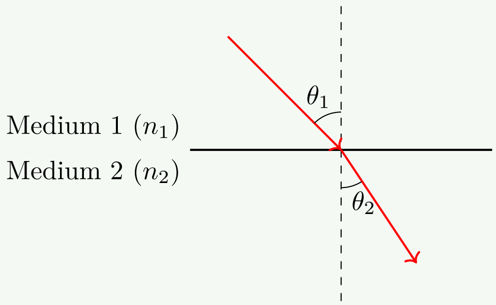

Figure 13. Refraction (Snell's Law)

Mnemonic

"SINS - Sine of incidence over sine of refraction equals N1 over N2"

Question 5(c)(2) [0 marks]

Explain the Acceptance angle.

Solution

Acceptance angle is the maximum angle at which light can enter an optical fiber and still experience total internal reflection.
Formula: $\theta_a = \sin^{-1}(NA)$ where $NA = \sqrt{n_1^2 - n_2^2}$
Diagram:

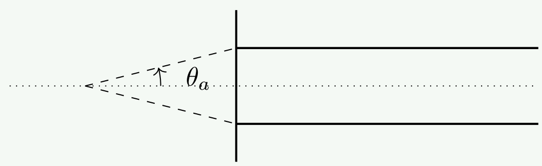

Figure 14. Acceptance Cone

Mnemonic

"CAP - Core and cladding indices Affect the acceptance angle"

Question 5(a) OR [3 marks]

Write the uses of Laser.

Solution

Uses of Laser:

Table 8. Laser Applications

Field	Applications
Medical	Surgery, eye treatment, cancer therapy
Industrial	Cutting, welding, 3D printing
Communications	Fiber optics
Scientific	Spectroscopy, holography
Consumer	Barcode scanners, printers
Military	Range finding, weapons

Mnemonic

"MICSM - Medical, Industrial, Communication, Scientific, Military"

Question 5(b) OR [4 marks]

Write a short note on total internal reflection of light.

Solution

Total Internal Reflection (TIR) occurs when light traveling in a denser medium hits the boundary with a less dense medium at an angle greater than the critical angle.

Conditions:

- Light must travel from denser to less dense medium ($n_1 > n_2$)
- Angle of incidence > Critical angle ($\theta_i > \theta_c$)

Critical angle formula: $\theta_c = \sin^{-1}(n_2/n_1)$

Diagram:

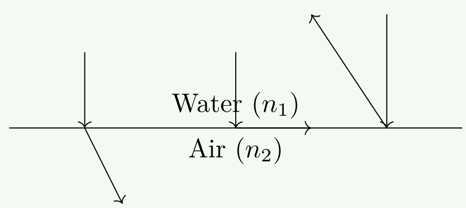

Figure 15. Total Internal Reflection

Mnemonic

"CANDO - Critical Angle, N1 Denser, Only when angle > Critical"

Question 5(c)(1) OR [3 marks]

If the speed of light in water is 2.25×10^8 m/s and in air is 3×10^8 m/s, find refractive index of water.

Solution

Given:

- $v_w = 2.25 \times 10^8$ m/s
- $v_a = 3 \times 10^8$ m/s

Formula: $n = c/v \Rightarrow n_w = v_a/v_w$

Calculation:

$$n_w = \frac{3 \times 10^8}{2.25 \times 10^8} = \frac{3}{2.25} = 1.33$$

Therefore, the refractive index of water is 1.33.

Mnemonic

"SVN - Speed in Vacuum divided by Speed in medium gives refractive iNdex"

Question 5(c)(2) OR [4 marks]

Write a note on step index fiber.

Solution

Step Index Fiber: Optical fiber where refractive index changes abruptly between core and cladding.

Characteristics:

- Abrupt change in index
- Single-mode or Multi-mode
- Simpler construction
- Higher modal dispersion in multi-mode

Diagram:

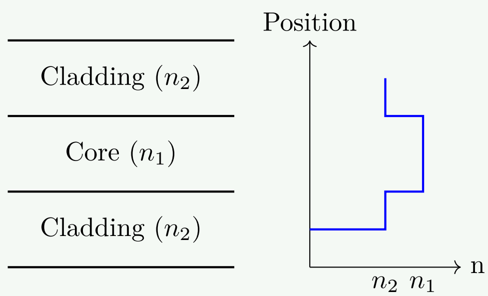

Figure 16. Step Index Fiber Profile

Mnemonic

"SACS - Step change, Abrupt profile, Core guides, Simple"