

Subject Name Solutions

4300005 – Winter 2023

Semester 1 Study Material

Detailed Solutions and Explanations

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 $1.380649 \times 10^{-23} \text{ J/K}$.
- **Accuracy:** Accuracy is the degree of closeness of a measured value to the true or standard value of the quantity being measured.

Mnemonic

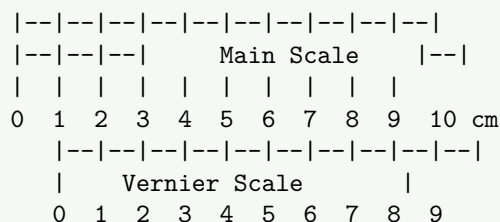
“MKA - Meter measures Kilometers Accurately”

Question 1(b) [4 marks]

Explain construction of Vernier calipers with clean figure.

Solution

Diagram:



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:

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: Least Count (L.C.) = Pitch / Number of divisions on circular scale
 $L.C. = 0.5 \text{ mm} / 100 = 0.005 \text{ mm}$

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

Mnemonic

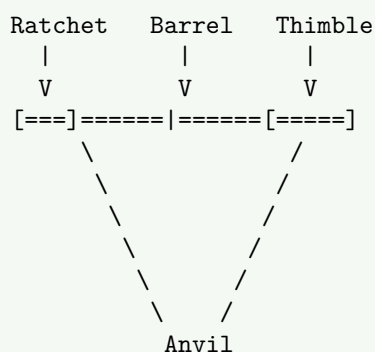
“PDL - Pitch Divided gives Least count”

Question 1(c) OR [7 marks]

Explain errors of Micrometer screw gauge with figure.

Solution

Diagram:



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: $F = k(q_1q_2)/r^2$

Where:

- F = Electrostatic force between charges
- k = Coulomb's constant ($9 \times 10^9 Nm^2/C^2$)
- 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: $V = W/q$

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:

Diagram:

-----||-----||-----||-----
 $C_{\{1\}}$ $C_{\{2\}}$ $C_{\{3\}}$

- When capacitors are connected end-to-end

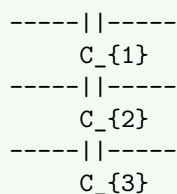
- Same charge on each capacitor:

$$Q = Q_1 = Q_2 = Q_3$$

- Total potential difference: $V = V_1 + V_2 + V_3$
- Equivalent capacitance formula: $1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3 + \dots$
- Equivalent capacitance is less than the smallest individual capacitance

Parallel Combination:

Diagram:



- 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: $C_{eq} = C_1 + C_2 + C_3 + \dots$
- Equivalent capacitance is greater than the largest individual capacitance

Comparison Table:

Parameter	Series	Parallel
Charge	Same on all capacitors	Distributed as per capacitance
Voltage	Divided across capacitors	Same across all capacitors
Equivalent capacitance	$1/C_{eq} = 1/C_1 + 1/C_2 + \dots$	$C_{eq} = C_1 + C_2 + \dots$
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: $\Phi_e = EA \cos \theta$

Where:

- $\Phi_e = \text{Electric flux (Nm}^2/\text{C or Vm)}$
- $E = \text{Electric field strength (N/C or V/m)}$
- $A = \text{Area of the surface (m}^2\text{)}$
- $\theta = \text{Angle between electric field and normal to the surface}$

Key characteristics:

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

Mnemonic

"FACT - Flux = Area \times Cos \times Fields Trength"

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:

Plate 1	Plate 2
////////	////////
////////	//////// - Dielectric
////////	////////
////////	////////

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

Mathematical expression: $C = Q/V$

Where:

- $C = \text{Capacitance (farads)}$
- $Q = \text{Electric charge (coulombs)}$
- $V = \text{Potential difference (volts)}$

For a parallel plate capacitor: $C = \epsilon_0 A/d$

Where:

- $\epsilon_0 = \text{Permittivity of free space (8.85} \times 10^{-12} \text{ F/m)}$
- $\epsilon_r = \text{Relative permittivity of dielectric}$
- $A = \text{Area of overlap between plates}$
- $d = \text{Distance between plates}$

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 1st 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: $Q/t = -kA(dT/dx)$

Where:

- Q/t = Rate of heat transfer (J/s or W)
- k = Thermal conductivity of material (W/m · K)
- A = Cross-sectional area (m²)
- 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. So how much would it be in Celsius and Kelvin?

Solution

To convert from Fahrenheit to Celsius: $C = (F - 32) \times 5/9$ $C = (102 - 32) \times 5/9$

$C = 70 \times 5/9$

$C = 38.89$

To convert from Celsius to Kelvin: $K = C + 273.15$ $K = 38.89 + 273.15$ $K = 312.04$ K

Therefore, $102 = 38.89 = 312.04$ 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:

Parameter	Celsius Scale	Fahrenheit Scale
Freezing point of water	0	32
Boiling point of water	100	212
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:

Celsius	Fahrenheit	
100 [°] C	-- 212 [°] F	(Water boils)
0 [°] C	-- 32 [°] F	(Water freezes)
-17.8 [°] C	-- 0 [°] F	

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: $C = Q/\Delta T$

Where:

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

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

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:

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

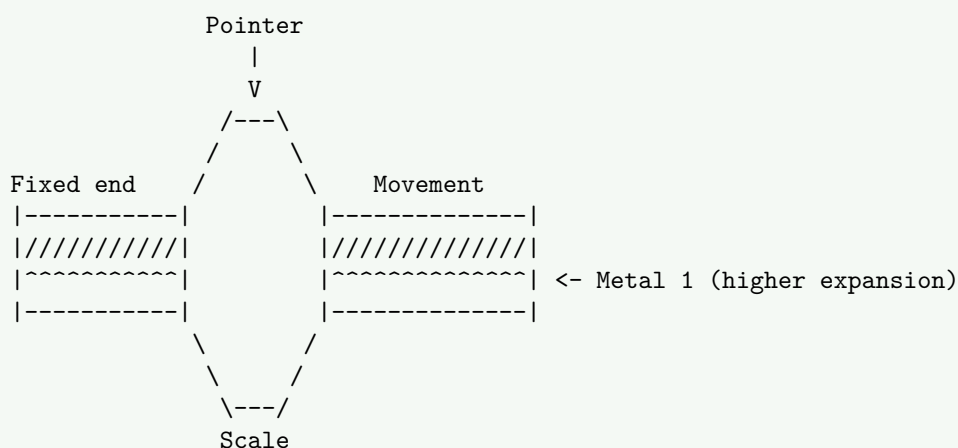
“CoCRa - Conduction needs Contact, Convection needs Currents, Radiation needs no medium”

Question 3(c) OR [7 marks]

Explain bimetallic thermometer.

Solution

Diagram:



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

Limitations:

- Less accurate than liquid-in-glass thermometers
- Slower response to temperature changes
- Subject to mechanical fatigue over time

Applications:

- Thermostats in home heating/cooling systems

- Automobile cooling systems
- Oven temperature 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:

Parameter	Longitudinal Waves	Transverse Waves
Direction of particle motion	Parallel to wave propagation	Perpendicular to wave propagation
Example	Sound waves, P-waves in earthquakes	Light waves, ripples on water surface, S-waves in earthquakes
Medium requirement	Can travel through solids, liquids and gases	Can travel through solids and surfaces of liquids but not through gases
Components	Compressions and rarefactions	Crests and troughs
Polarization	Cannot be polarized	Can be polarized
Visualization	Like a spring or slinky compressed and expanded	Like a rope being moved up and down

Diagram:

Longitudinal: -->-->-->-->--> (Direction of propagation)
 <--><--><--><--> (Particle movement)

Transverse: -->-->-->-->--> (Direction of propagation)
 ↑ ↓ ↑ ↓ (Particle movement)

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:

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).

Therefore, velocity = distance/time = λ/T

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

$$v = \lambda \times f$$

Where:

- v = velocity of the wave (m/s)
- λ = wavelength (m)
- f = frequency (Hz)

Diagram:



$$v = \lambda \times f$$

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: $RT_{60} = 0.161 \times V/A$

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)
- 0.161 = Constant (for calculation in metric units)

Total absorption (A) is calculated as: $A = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \dots + \alpha_n S_n$

Where:

- α = Absorption coefficient of material i
- S = Surface area of material i (m^2)

Applications:

- Acoustic design of concert halls, auditoriums, recording studios
- Determination of required acoustic treatment
- Evaluation of acoustic quality of existing spaces

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

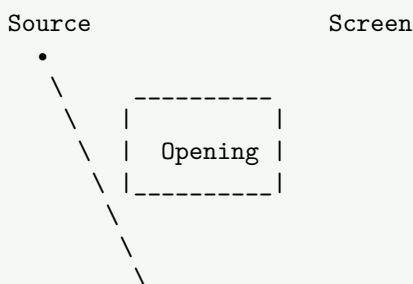
Definition: Diffraction is the bending of light waves around obstacles or through openings, showing the wave nature of light.

Types of diffraction:

1. Fresnel Diffraction:

- Source or screen (or both) at finite distance from the obstacle
- Spherical wavefronts
- More complex interference pattern

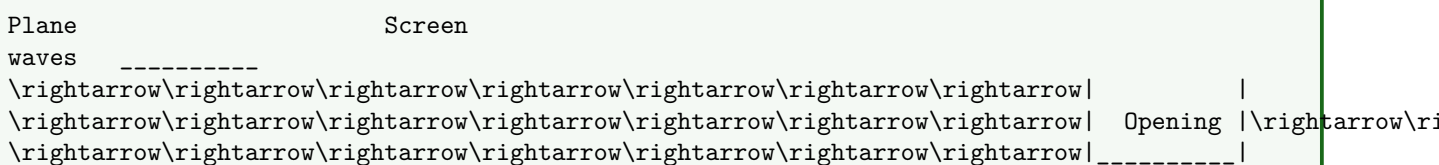
Diagram:



2. Fraunhofer Diffraction:

- Source and screen at infinite distance (or effectively using lenses)
- Plane wavefronts
- Simpler interference pattern
- More commonly studied in elementary physics

Diagram:



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 of sound (v) = 330 m/s

To find: Wavelength ()

Formula: $v = \lambda \times f$

Calculation: $\lambda = v/f = 330 \text{ m/s} \div 480 \text{ Hz} = 0.6875 \text{ m} = 68.75 \text{ cm}$

Therefore, the wavelength of the radio wave 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:

Property	Description
Wave nature	Sound is a mechanical, longitudinal wave requiring a medium
Frequency range	Audible range for humans: 20 Hz to 20,000 Hz
Speed	~343 m/s in air at room temperature; varies with medium
Reflection	Bounces off surfaces, creating echoes and reverberation
Refraction	Changes direction when passing between media of different densities
Diffraction	Bends around obstacles and through openings
Interference	Waves can superimpose to create constructive or destructive interference
Resonance	Amplification at natural frequencies of objects

Factors affecting speed of sound:

- Increases with temperature in gases
- Faster in liquids than gases
- Fastest in solids
- Independent of frequency and amplitude in a given medium

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 or very narrow band of wavelengths
- **Coherent:** All waves are in phase with each other
- **Directional:** Low divergence, travels in a straight line with minimal spreading
- **Intense:** High energy concentration in a small area
- **Collimated:** Light rays are parallel with minimal divergence

Mnemonic

“MCCDI - Monochromatic and Coherent, Collimated, Directional, Intense”

Question 5(b) [4 marks]

Give information about optical fiber.

Solution

Optical Fiber: A flexible, transparent fiber made of glass or plastic that transmits light signals through total internal reflection.

Structure:

Core	$n_{\{1\}}$ (Higher refractive index)
Cladding	$n_{\{2\}}$ (Lower refractive index)
Protective coating	

Components:

- **Core:** Central region where light travels (higher refractive index)
- **Cladding:** Outer optical material surrounding the core (lower refractive index)
- **Buffer coating:** Protective outer covering

Types:

- **Single-mode:** Small core (8-10 μm), carries only one mode
- **Multi-mode:** Larger core (50-100 μm), carries multiple modes
 - **Step-index:** Abrupt change in refractive index
 - **Graded-index:** Gradual change in refractive index

Advantages:

- High bandwidth and data transmission rates
- Immune to electromagnetic interference
- Low signal attenuation over long distances
- Small size and lightweight
- Enhanced security (difficult to tap)

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

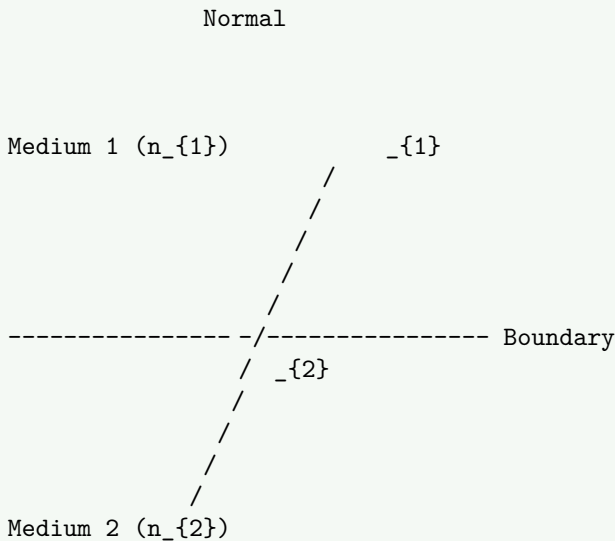
Definition: Snell's law (law of refraction) states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any two specific media.

Formula: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

Where:

- n_1 = Refractive index of medium 1
- θ_1 = Angle of incidence
- n_2 = Refractive index of medium 2
- θ_2 = Angle of refraction

Diagram:



Examples:

- Light bending when entering water from air
- Apparent displacement of objects underwater
- Formation of rainbow
- Design of lenses and prisms

Special cases:

- When light travels from less dense to more dense medium ($n_1 < n_2$), it bends toward the normal ($\theta_1 > \theta_2$)
- When light travels from more dense to less dense medium ($n_1 > n_2$), it bends away from the normal ($\theta_1 < \theta_2$)
- When angle of incidence equals 0° (normal incidence), no refraction occurs

Mnemonic

“SINS - Sine of incidence over sine of refraction equals $N_1 \text{ over } N_2$ ”

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:

- θ_a = Acceptance angle
- NA = Numerical aperture

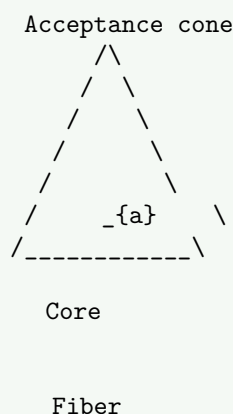
Numerical Aperture (NA): $NA = \sqrt{n_1^2 - n_2^2}$

Where:

- n_1 = Refractive index of the core

- $n_2 = \text{Refractive index of the cladding}$

Diagram:



Significance:

- Determines the light-gathering capacity of the fiber
- Larger acceptance angle means more light can enter the fiber
- Related to the fiber's information-carrying capacity
- Critical for coupling efficiency with light sources

Mnemonic

“CAP - Core and cladding indices Affect the acceptance angle which determines the Path light can take”

Question 5(a) OR [3 marks]

Write the uses of Laser.

Solution

Uses of Laser:

Field	Applications
Medical	Surgery, eye treatment, cancer therapy, dermatology, dental procedures
Industrial	Cutting, welding, drilling, marking, material processing, 3D printing
Communications	Fiber optic data transmission, free-space optical communication
Scientific	Spectroscopy, holography, nuclear fusion, particle acceleration
Consumer	Barcode scanners, DVD/Blu-ray players, laser pointers, printers
Military	Range finding, target designation, guidance systems, weapons

Mnemonic

“MICSMM - Medical procedures, Industrial cutting, Communication systems, Scientific research, Military applications”

Question 5(b) OR [4 marks]

Write a short note on total internal reflection of light.

Solution

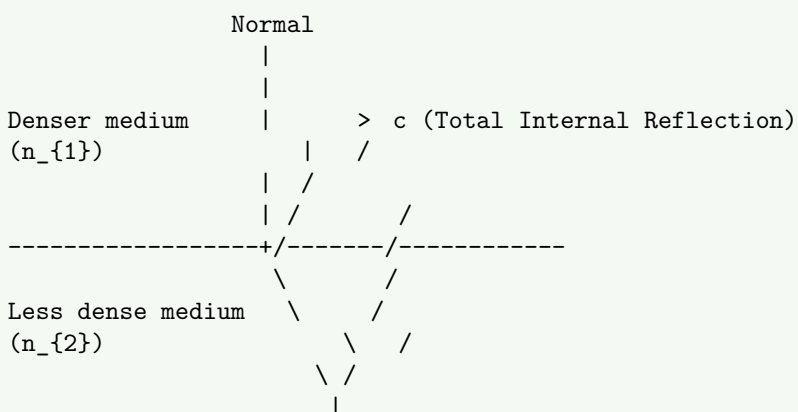
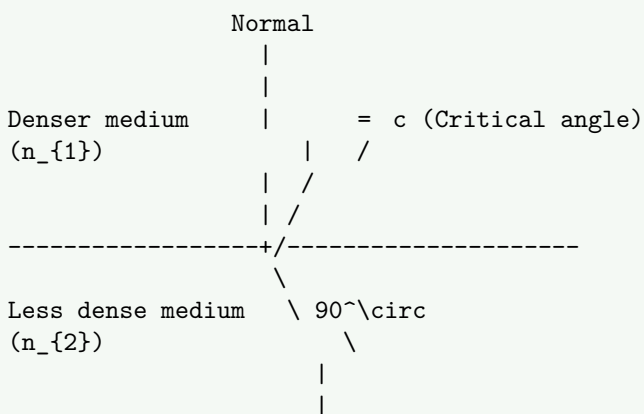
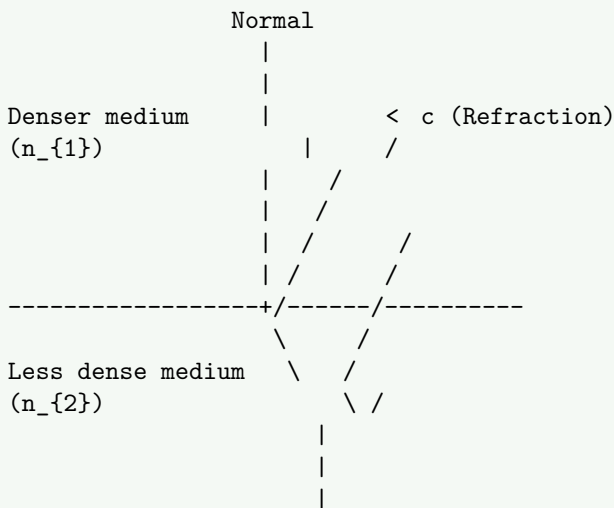
Total Internal Reflection (TIR) is an optical phenomenon that occurs when light traveling in a denser medium hits the boundary with a less dense medium at an angle greater than the critical angle.

Conditions required for TIR:

- Light must travel from a denser medium to a less dense medium ($n_1 > n_2$)
- The angle of incidence must exceed the critical angle ($i > c$)

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

Diagram:



Applications:

- Optical fibers for communication
- Prisms and binoculars
- Diamond brilliance
- Mirage formation
- Endoscopes for medical imaging

Mnemonic

“CANDO - Critical Angle needed, n_1 must be Denser than n_2 , Only works when angle is greater than critical, Angle determined by $n_1 \sin \theta_c = n_2$ ”

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

If the speed of light in water is $2.25 \times 10^8 \text{ m/s}$ and the speed of light in air is $3 \times 10^8 \text{ m/s}$, find the refractive index of water.

Solution

Given:

- Speed of light in water (v_w) = $2.25 \times 10^8 \text{ m/s}$
- Speed of light in air (v_a) = $3 \times 10^8 \text{ m/s}$

To find: Refractive index of water (n_w)

Formula: $n = c/v$

For calculation of refractive index of water relative to air: $n_w = v_a/v_w$

Calculation: $n_w = 3 \times 10^8 \text{ m/s} \div 2.25 \times 10^8 \text{ m/s} = 3 \div 2.25 = 1.33$

Therefore, the refractive index of water is 1.33.

Mnemonic

“SVN - Speed of light in Vacuum divided by Speed in medium gives refractive iNdex”

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

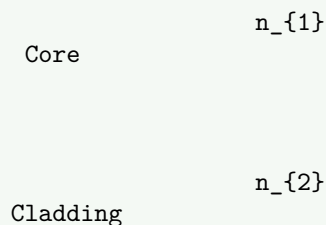
Write a note on step index fiber.

Solution

Step Index Fiber: A type of optical fiber where the refractive index changes abruptly between the core and cladding.

Structure:

Diagram:



Refractive Index Profile:

n_{1}

n_{2}

Core Cladding

Characteristics:

- Abrupt change in refractive index at core-cladding boundary
- Available in both single-mode and multi-mode configurations
- Simpler construction than graded-index fiber
- More modal dispersion in multi-mode configuration

Types:

- Single-mode step index fiber:
 - Very small core diameter (8-10 μm)
 - Only allows one mode of light propagation
 - Low signal distortion

- Used for long-distance communication
- Multi-mode step index fiber:
 - Larger core diameter (50-100 μ m)
 - Allows multiple light paths
 - Higher modal dispersion
 - Suitable for shorter distances

Advantages:

- Simpler and cheaper manufacturing
- Good for short-distance applications
- Easier to couple light into multi-mode versions
- Less sensitive to bending losses than single-mode fibers

Limitations:

- Higher modal dispersion in multi-mode configuration
- Bandwidth limitations due to different path lengths
- Not ideal for high-speed, long-distance transmission

Mnemonic

“SACS - Step change at boundary, Abrupt index profile, Core guides light, Simple construction”