Physics (4300005) - Summer 2023 Solution

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Question 1(a) [3 marks]

Write base units with their symbols in SI.

Solution

Table 1. SI Base Units

Physical Quantity	Base Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Mnemonic

“”Learn Measurements Through Accurate Techniques Like Modern Scientists””

Question 1(b) [4 marks]

Explain construction and working of a vernier caliper. Explain its least count and zero error.

Solution

Construction of Vernier Caliper:

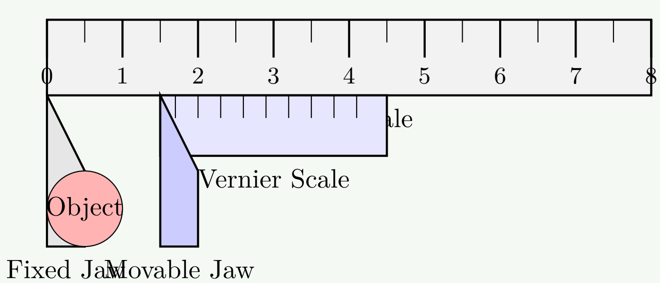


Figure 1. Vernier Caliper Construction

- **Main scale**: Fixed scale with millimeter divisions

- **Vernier scale**: Sliding scale with divisions slightly smaller than main scale
- **Fixed jaw**: Connected to main scale
- **Movable jaw**: Attached to vernier scale
- **Depth rod**: For measuring depths
- **Locking screw**: To fix position during measurement

Working: Object is placed between jaws, movable jaw is adjusted to hold object firmly. Reading is taken by noting main scale reading and adding vernier coincidence value.
Least Count: Smallest measurement possible with vernier caliper.

$$\text{LC} = \frac{\text{1 division on main scale}}{\text{Number of divisions on vernier scale}}$$

Zero Error: Error when caliper shows non-zero reading with jaws closed.
- **Positive error**: Subtract from reading
- **Negative error**: Add to reading

Mnemonic

“”Very Careful Measurements Leave Count Errors Zero””

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

Distinguish between accuracy and precision.

Solution

Table 2. Accuracy vs Precision

Accuracy	**Precision**
Closeness of measurement to true value	Repeatability of measurement
Affected by systematic errors	Affected by random errors
Represented by mean of measurements	Represented by standard deviation
Improved by calibration	Improved by using better instruments
Example: If true value is 10 cm, measurements of 9.9, 10.1, and 10.0 cm are accurate	Example: Measurements of 9.8, 9.8, 9.8 cm are precise but not accurate if true value is 10 cm

Mnemonic

“”Accurate measurements Are Always At true value, Precise measurements Produce Perfect repeatability””

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

Pitch of a micrometer screw gauge is 0.5 mm and there are 50 divisions on its circular scale. Find its least count.

Solution

Formula:

$$\text{Least Count} = \frac{\text{Pitch}}{\text{Number of divisions on circular scale}}$$

Calculation:

$$\text{LC} = \frac{0.5 \text{ mm}}{50} = 0.01 \text{ mm}$$

Least Count of micrometer screw gauge = 0.01 mm

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

What is SI unit of heat?

Solution

SI unit of heat is **Joule (J)**

OR

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

How are absolute and relative errors calculated?

Solution

Absolute Error (Δa): Difference between measured value and true value. For multiple measurements, it's difference between measured value and mean value.

Calculation of Absolute Error:

- **Single measurement**: $\Delta a = |\text{Measured value} - \text{True value}|$
- **Multiple measurements**:
  1. Calculate mean (a_m)
  2. For each measurement: $\Delta a_i = |a_i - a_m|$
  3. Mean absolute error: $\Delta a = (\Delta a_1 + \Delta a_2 + ... + \Delta a_n) \div n$

Relative Error (ϵ_r): Ratio of absolute error to true value.

$$\epsilon_r = \frac{\text{Absolute error}}{\text{True value}} = \frac{\Delta a}{\text{True value}}$$

Percentage Error (ϵ_p): Relative error expressed as percentage.

$$\epsilon_p = \text{Relative error} \times 100 = \left(\frac{\Delta a}{\text{True value}}\right) \times 100\%$$

Mnemonic

“”Absolute Always measures Actual deviation; Relative References the total value””

OR

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

Main scale of a vernier caliper is calibrated in mm and there are 50 divisions on its vernier scale. Find its least count.

Solution

Formula:

$$\text{Least Count} = \frac{\text{1 division on main scale}}{\text{Number of divisions on vernier scale}}$$

Calculation: 1 division on main scale = 1 mm

$$\text{LC} = \frac{1 \text{ mm}}{50} = 0.02 \text{ mm}$$

Least Count of vernier caliper = 0.02 mm

OR

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

In which of the mode of heat transfer, medium is not required?

Solution

Radiation does not require a medium for heat transfer.

Question 2(a) [3 marks]

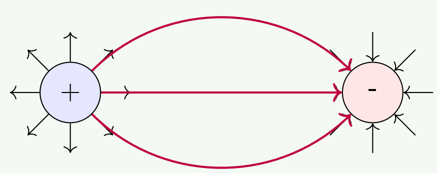
Write characteristics of electric field lines.

Solution

Characteristics of Electric Field Lines:

1. Electric field lines start from positive charge and end on negative charge
2. Field lines never cross each other
3. Field lines are always perpendicular to the surface of conductor
4. Number of field lines is proportional to magnitude of charge
5. Closer field lines indicate stronger electric field
6. Field lines are continuous curves
7. Field lines contract longitudinally and expand laterally

Figure 2. Electric Field Lines Geometry



Lines start at + and end at -

Mnemonic

“”Electric Field Lines: Start Positive, End Negative, Cross Never””

Question 2(b) [4 marks]

Explain Coulomb’s inverse square law for electrostatic forces.

Solution

Coulomb's Inverse Square Law: The electrostatic force between two point charges is directly proportional to the product of magnitudes of charges and inversely proportional to the square of distance between them.
Mathematical Form:

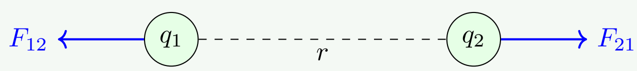
$$F = k\frac{q_1 q_2}{r^2}$$

Where:
- F = electrostatic force (in Newtons)
- k = electrostatic constant (9×10^9 N $\cdot$ m^2/C^2)
- q_1, q_2 = magnitudes of charges (in Coulombs)
- r = distance between charges (in meters)

Properties:
- **Vector Quantity**: Force acts along the line joining the two charges
- **Attractive/Repulsive**: Like charges repel, unlike charges attract
- **Central Force**: Follows Newton's third law
- **Medium Dependence**: Depends on the medium between charges (k changes)

Figure 3. Coulomb's Law Interation

Repulsive Force (Like Charges)



Mnemonic

“”Charges Attract/Repel Leveraging Distance Squared””

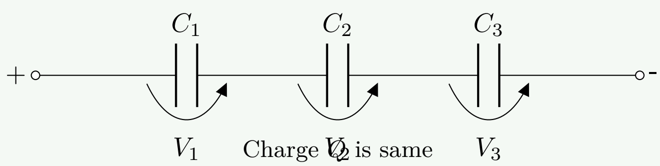
Question 2(c)(i) [4 marks]

Derive formula for equivalent capacitance of capacitors connected in series and parallel combination.

Solution

For Series Combination:

Figure 4. Capacitors in Series



When capacitors are connected in series:
- Same charge Q appears on each capacitor
- Potential difference distributes across capacitors
- $V = V_1 + V_2 + V_3$

For each capacitor: $V_1 = Q/C_1$, $V_2 = Q/C_2$, $V_3 = Q/C_3$
Total voltage:

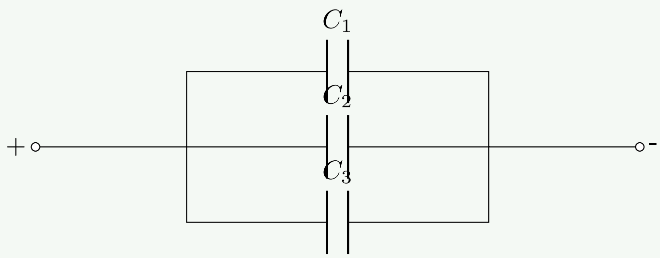
$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

For equivalent capacitance: $V = Q/C_{eq}$
Therefore:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

For Parallel Combination:

Figure 5. Capacitors in Parallel



Voltage V is same

When capacitors are connected in parallel:
- Same potential difference V across each capacitor
- Total charge distributes among capacitors
- $Q = Q_1 + Q_2 + Q_3$

For each capacitor: $Q_1 = C_1V$, $Q_2 = C_2V$, $Q_3 = C_3V$
Total charge:

$$Q = C_1V + C_2V + C_3V = (C_1 + C_2 + C_3)V$$

For equivalent capacitance: $Q = C_{eq}V$
Therefore:

$$C_{eq} = C_1 + C_2 + C_3$$

Mnemonic

“”Series Sums Reciprocals, Parallel Puts Capacitance Together””

Question 2(c)(ii) [2 marks]

Two capacitors of capacitances 8 μF and 9 μF are connected in parallel combination. Find equivalent capacitance.

Solution

Formula for parallel combination: $C_{eq} = C_1 + C_2$
Given:
- $C_1 = 8\mu\text{F}$
- $C_2 = 9\mu\text{F}$

Calculation:

$$C_{eq} = 8\mu\text{F} + 9\mu\text{F} = 17\mu\text{F}$$

Therefore, equivalent capacitance = 17 μF

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

Write full name of ”LASER”.

Solution

LASER: Light Amplification by Stimulated Emission of Radiation

OR

Question 2(a) [3 marks]

What is a capacitor? Define capacitance and write its unit.

Solution

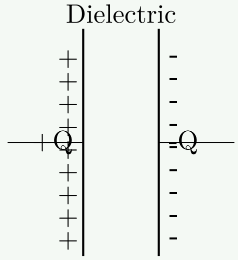
Capacitor: A device that stores electric charge and electrical energy in the form of electric field.
Capacitance: The ability of a capacitor to store electric charge. It is defined as the ratio of charge stored to the potential difference applied.
Mathematical Form:

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

Where:
- C = capacitance
- Q = charge stored on capacitor
- V = potential difference across capacitor

Unit of Capacitance: Farad (F)

Figure 6. Parallel Plate Capacitor



Mnemonic

“”Capacitors Collect Charge, Volts Vary Fastidiously””

OR

Question 2(b) [4 marks]

Explain intensity of electric field and electric potential.

Solution

Electric Field Intensity:
- **Definition**: Force experienced by unit positive charge placed at that point
- **Formula**: $E = F/q$
- **Unit**: Newton/Coulomb (N/C) or Volt/meter (V/m)
- **Vector Quantity**: Has both magnitude and direction
- **Direction**: Same as force on positive charge

Electric Potential:
- **Definition**: Work done to bring unit positive charge from infinity to that point
- **Formula**: $V = W/q$
- **Unit**: Volt (V) or Joule/Coulomb (J/C)
- **Scalar Quantity**: Has only magnitude
- **Relation with field**: $E = -dV/dr$ (field is negative gradient of potential)

Table 3. Field vs Potential

Property	Electric Field	Electric Potential
Definition	Force per unit charge	Work done per unit charge
Nature	Vector	Scalar
Unit	N/C or V/m	V or J/C
Dependence	Varies as $1/r^2$	Varies as $1/r$
Direction	Away from +ve charge	No direction

Mnemonic

“”Electric Field Forces charges; Potential Provides energy””

OR

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

Using formula of capacitance of a parallel plate capacitor, explain effect of plate area, separation between plates and presence of dielectric material between the plates on its capacitance.

Solution

Formula for capacitance of parallel plate capacitor:

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

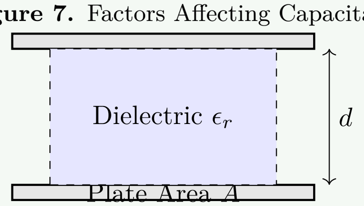
Where:
- C = capacitance
- ϵ_0 = permittivity of free space (8.85×10^{-12} F/m)
- ϵ_r = relative permittivity of dielectric
- A = area of overlap between plates
- d = distance between plates

Effect of Plate Area (A):
- Capacitance is directly proportional to area of plates
- Increasing area → Increases capacitance
- Doubling area → Doubles capacitance

Effect of Separation (d):
- Capacitance is inversely proportional to distance between plates
- Increasing separation → Decreases capacitance
- Doubling separation → Halves capacitance

Effect of Dielectric Material (ϵ_r):
- Capacitance is directly proportional to relative permittivity of dielectric
- Inserting dielectric → Increases capacitance
- Dielectric constant measures this increase: $C_{\text{dielectric}} = \epsilon_r \times C_{\text{air}}$

Figure 7. Factors Affecting Capacitance



Parallel Plate Structure

Mnemonic

""Area Amplifies, Distance Diminishes, Dielectrics Double""

OR

Question 2(c)(ii) [2 marks]

Voltage between plates of a capacitor of capacitance 0.5 μF is 150 V. Find magnitude of electric charge on plates.

Solution

Formula: $Q = CV$
Given:

- Capacitance $(C) = 0.5\ \mu\text{F} = 0.5 \times 10^{-6}$ F
- Voltage $(V) = 150$ V

Calculation:

$$Q = CV = 0.5 \times 10^{-6} \times 150 = 75 \times 10^{-6} \text{ C} = 75\mu\text{C}$$

Therefore, charge on plates = 75 μC

OR

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

Of the two parts of an optical fiber, the core and the cladding, which one has larger refractive index?

Solution

The **core** has a larger refractive index than the cladding.

Question 3(a) [3 marks]

Define conduction and convection of heat.

Solution

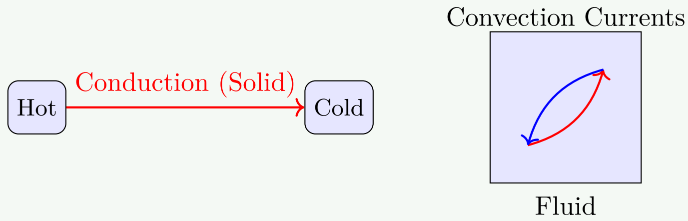
Heat Conduction:

- Transfer of heat through matter without actual movement of particles
- Occurs due to direct molecular collisions
- Heat flows from higher to lower temperature region
- Metals are good conductors of heat
- Examples: Heat transfer through metal rod, cooking pot

Heat Convection:

- Transfer of heat through actual movement of matter
- Occurs in fluids (liquids and gases)
- Involves formation of convection currents
- Examples: Room heater, sea breeze, boiling water

Figure 8. Modes of Heat Transfer



Mnemonic

“”Conduction Connects molecules; Convection Carries material””

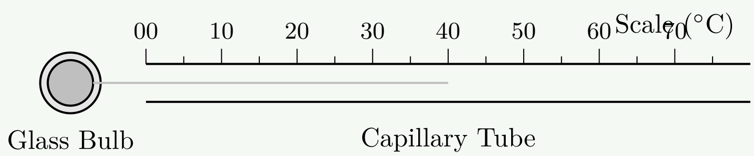
Question 3(b) [4 marks]

Explain construction and working of mercury thermometer.

Solution

Construction of Mercury Thermometer:

Figure 9. Mercury Thermometer



- **Glass bulb**: Contains mercury, acts as reservoir
- **Capillary tube**: Thin glass tube connected to bulb
- **Scale**: Calibrated with temperature markings
- **Protective glass cover**: Protects capillary tube and scale

Working Principle:

1. Based on thermal expansion of mercury
2. When temperature increases, mercury expands and rises in capillary
3. When temperature decreases, mercury contracts and level falls
4. Temperature is read from scale at mercury level

Temperature Range: -38.83°C to 356.73°C.

Advantages: High accuracy, Linear expansion, Visible. **Limitations**: Toxic mercury, Cannot measure very low temps.

Mnemonic

“”Mercury Moves Through Capillary, Showing Temperature””

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

State laws of thermal conductivity and derive formula of coefficient of thermal conductivity.

Solution

Laws of Thermal Conductivity:

1. Heat flow is directly proportional to temperature difference (ΔT)
2. Heat flow is directly proportional to cross-sectional area (A)

3. Heat flow is inversely proportional to length (L)
4. Heat flow is directly proportional to time (t)

Derivation of Coefficient of Thermal Conductivity:
According to Fourier's law:

$$Q \propto A \times t \times \frac{\Delta T}{L}$$

Converting to equation with proportionality constant K:

$$Q = K \times A \times t \times \frac{\Delta T}{L}$$

Rearranging:

$$K = \frac{Q \times L}{A \times t \times \Delta T}$$

Where:
- Q = Heat conducted (in Joules)
- L = Length of conductor (in meters)
- A = Cross-sectional area (in m^2)
- t = Time (in seconds)
- ΔT = Temperature difference (in Kelvin)
- K = Coefficient of thermal conductivity (in W/m · K)

Figure 10. Thermal Conduction Model

Hot T_1 → Conductor (Length L, Area A) → Cold T_2 Heat Q

Mnemonic

"”Heat Transfers Faster when Area Larger, Temperature higher, Length shorter””

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

The total area of glass window pane is 0.5 m^2. Calculate amount of heat conducted per hour through the pane if thickness of glass is 0.6 cm, the inside temperature is 30°C and outside temperature is 20°C. Coefficient of thermal conductivity of glass is 1.0 Wm^{-1}K^{-1}.

Solution

Formula: $Q = \frac{K \times A \times t \times \Delta T}{L}$

Given:
- Area (A) = 0.5 m^2
- Thickness (L) = 0.6 cm = 0.006 m
- Inside temperature (T_1) = 30°C
- Outside temperature (T_2) = 20°C
- Temperature difference (ΔT) = 10°C = 10 K
- Coefficient of thermal conductivity (K) = 1.0 W/m · K
- Time (t) = 1 hour = 3600 seconds

Calculation:

$$Q = \frac{1.0 \times 0.5 \times 3600 \times 10}{0.006}$$

$$Q = \frac{18000}{0.006}$$

$$Q = 3,000,000 \text{ J} = 3000 \text{ kJ}$$

Therefore, heat conducted = 3000 kJ per hour

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

Which property of light is responsible for transmission of light through optical fibre?

Solution

Total Internal Reflection (TIR) is responsible for transmission of light through optical fiber.

OR

Question 3(a) [3 marks]

Define heat capacity and specific heat.

Solution

Heat Capacity:
- Amount of heat energy required to raise temperature of an object by 1°C or 1K
- Depends on mass and material of object
- Formula: $C = Q/\Delta T$
- Unit: Joule/Kelvin (J/K)

Specific Heat:
- Amount of heat energy required to raise temperature of 1 kg of substance by 1°C or 1K
- Property of material, independent of mass
- Formula: $c = Q/(m \times \Delta T)$
- Unit: Joule/kg · K (J/kg · K)

Relation: Heat capacity (C) = mass (m) × specific heat (c)

Table 4. Heat Capacity vs Specific Heat

Property	**Heat Capacity**	**Specific Heat**
Definition	Heat per degree for object	Heat per degree per unit mass
Symbol	C	c
Unit	J/K	J/kg · K
Depends on	Mass and material	Only material
Formula	$Q/\Delta T$	$Q/(m \times \Delta T)$

Mnemonic

“”Heat Capacity for Complete object, Specific heat for Single kilogram””

OR

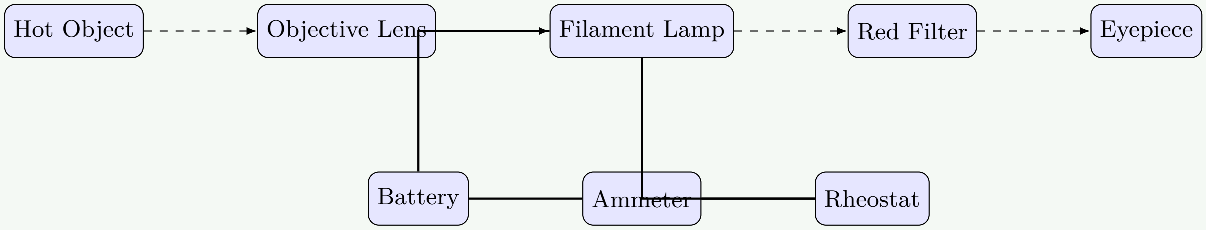
Question 3(b) [4 marks]

Explain construction and working of optical pyrometer.

Solution

Construction of Optical Pyrometer:

Figure 11. Optical Pyrometer Block Diagram



- **Telescope**: To view hot object
- **Filament lamp**: Calibrated tungsten filament
- **Rheostat**: To adjust current through filament
- **Ammeter**: To measure current
- **Red filter**: To match wavelengths
- **Eyepiece**: For viewing

Working Principle:

1. Based on comparing brightness of hot object with standard lamp filament
2. Object is viewed through telescope
3. Current adjusted until filament brightness matches object brightness
4. At match point, filament "disappears" against object background
5. Temperature determined from calibrated scale or ammeter reading

Temperature Range: 700°C to 3000°C

Mnemonic

“”Pyrometer Produces Perfect Temperature by Brightness Comparison””

OR

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

Define linear thermal expansion of solids and derive formula of coefficient linear thermal expansion.

Solution

Linear Thermal Expansion: Increase in length of a solid material when its temperature increases.
Coefficient of Linear Thermal Expansion (α): Fractional change in length per unit change in temperature.
Derivation: For small temperature changes:

- Change in length (ΔL) is directly proportional to original length (L_0)
- ΔL is directly proportional to change in temperature (ΔT)

Therefore: $\Delta L \propto L_0 \times \Delta T$
Converting to equation with proportionality constant α:

$$\Delta L = \alpha \times L_0 \times \Delta T$$

Rearranging:

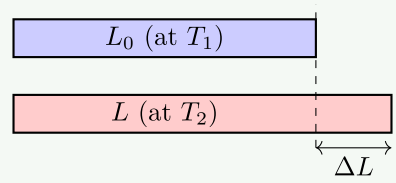
$$\alpha = \frac{\Delta L}{L_0 \times \Delta T}$$

Where:

- ΔL = Change in length (in meters)
- L_0 = Original length (in meters)
- ΔT = Change in temperature (in Kelvin or Celsius)
- α = Coefficient of linear thermal expansion (per °C or per K)

Final length: $L = L_0(1 + \alpha\Delta T)$

Figure 12. Linear Expansion



Mnemonic

""Linear Expansion Numerically Gives Total Length Increase""

OR

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

Length of a steel rod at 0°C is 150 cm. What will be its length at 200°C, if its coefficient of linear thermal expansion is 12×10^{-6} per °C.

Solution

Formula: $L = L_0(1 + \alpha\Delta T)$
Given:
- Original length (L_0) = 150 cm
- Temperature change (ΔT) = 200°C
- Coefficient of linear expansion (α) = 12×10^{-6} per °C

Calculation:

$$L = 150(1 + 12 \times 10^{-6} \times 200)$$

$$L = 150(1 + 24 \times 10^{-4})$$

$$L = 150(1 + 0.0024) = 150 \times 1.0024 = 150.36 \text{ cm}$$

Therefore, final length of steel rod = 150.36 cm

OR

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

Which type of emission of radiation is responsible for emission of ordinary light?

Solution

Spontaneous emission is responsible for emission of ordinary light.

Question 4(a) [3 marks]

Define amplitude, frequency and time period of a wave.

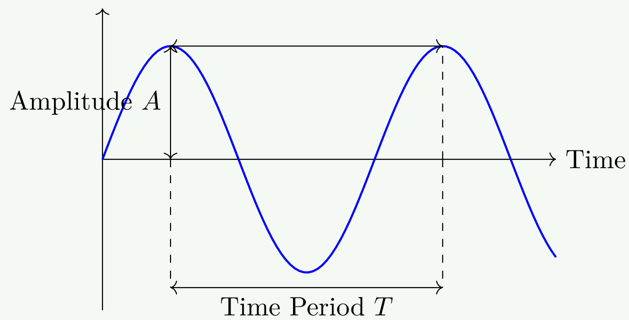
Solution

Amplitude:
- Maximum displacement of medium particles from equilibrium position
- Represents energy of wave
- Denoted by 'A', measured in meters (m)

Frequency:
- Number of complete oscillations per unit time
- Denoted by 'f' or 'ν', measured in Hertz (Hz)
- $f = v/\lambda$

Time Period:
- Time taken to complete one oscillation
- Denoted by 'T', measured in seconds (s)
- $T = 1/f$

Figure 13. Wave Parameters



Mnemonic

"”Amplitude Adjusts energy, Frequency Finds cycles, Time-period Tracks one cycle””

Question 4(b) [4 marks]

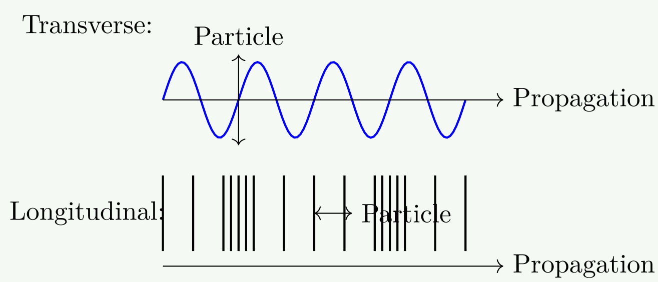
Write difference between transverse and longitudinal waves.

Solution

Table 5. Transverse vs Longitudinal Waves

Property	Transverse Waves	Longitudinal Waves
Direction of motion	Perpendicular to propagation	Parallel to propagation
Formation of	Crests and troughs	Compressions and rarefactions
Examples	Light, water, EM waves	Sound, seismic P-waves
Medium	Can travel through vacuum	Requires material medium
Polarization	Can be polarized	Cannot be polarized
Equation	$y = A\sin(kx - \omega t)$	$s = A\sin(kx - \omega t)$

Figure 14. Wave Types



Mnemonic

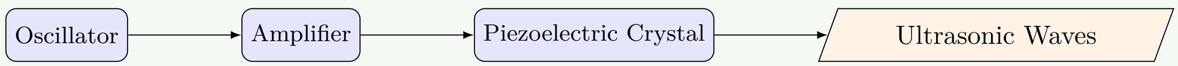
“”Transverse Travels perpendicular, Longitudinal Lies along length””

Question 4(c)(i) [5 marks]

How is ultrasonic wave produced using piezoelectric method?

Solution

Figure 15. Piezoelectric Method



Working Principle:
1. Based on piezoelectric effect.
2. High-frequency AC voltage applied across piezoelectric crystal (quartz, tourmaline).
3. Crystal vibrates at frequency of applied voltage.
4. At resonance (applied frequency = natural frequency), maximum amplitude vibrations occur.
5. Ultrasonic waves are generated.

Frequency Range: 20 kHz to several MHz. **Advantages**: High efficiency, Precise control, Compact.

Mnemonic

“”Piezo Produces waves when Properly Pulsed with electricity””

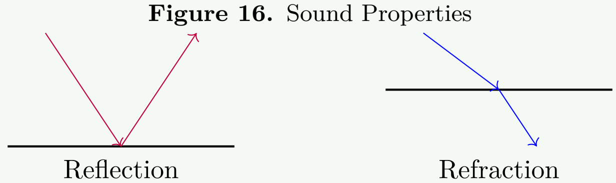
Question 4(c)(ii) [2 marks]

Explain any two properties of sound wave.

Solution

1. **Reflection of Sound**:
   - Bounces back from obstacles
   - Follows law: angle of incidence = angle of reflection
   - Creates echoes
2. **Refraction of Sound**:
   - Bending when passing between media with different speeds
   - Explains sound focusing and night-time audibility

Figure 16. Sound Properties



Mnemonic

“”Sound Shows Remarkable Refractions During travel””

OR

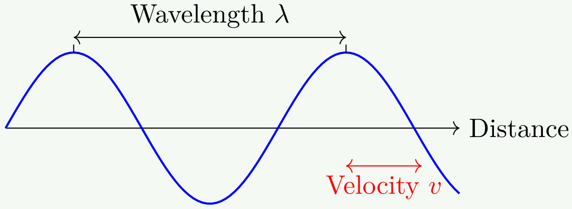
Question 4(a) [3 marks]

Define wavelength, phase and velocity of a wave.

Solution

Wavelength (λ): Distance between two consecutive points in phase. Distance traveled during one complete oscillation. $v = \lambda f$.
Phase: State of oscillation at a specific point and time. Points differing by 2π are in phase; by π are in opposite phase.
Velocity (v): Rate at which wave propagates. $v = \lambda f$. Depends on medium.

Figure 17. Wave Properties



Mnemonic

“”Wavelength Wraps one cycle, Phase Portrays position, Velocity Values propagation speed””

OR

Question 4(b) [4 marks]

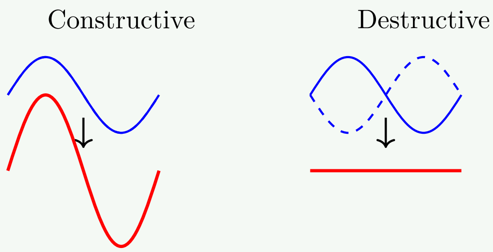
Explain constructive and destructive interference of waves.

Solution

Constructive Interference:
- Waves meet in phase (crest meets crest)
- Phase diff = $2n\pi$, Path diff = $n\lambda$
- **Result**: Larger amplitude (sum of individuals)

Destructive Interference:
- Waves meet in opposite phase (crest meets trough)
- Phase diff = $(2n + 1)\pi$, Path diff = $(n + 1/2)\lambda$
- **Result**: Smaller amplitude (difference of individuals)

Figure 18. Interference Types



Mnemonic

“”Constructive Creates Larger waves; Destructive Diminishes wave height””

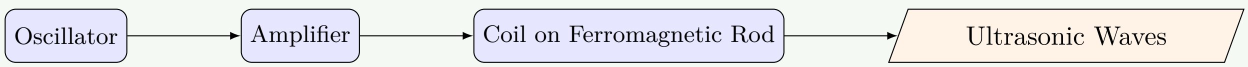
OR

Question 4(c)(i) [5 marks]

How is ultrasonic wave produced using magnetostriction method?

Solution

Figure 19. Magnetostriction Oscillator



Working Principle:
1. Based on magnetostriction effect (dimensional change in magnetic field).
2. Alternating magnetic field applied to ferromagnetic rod (Ni, Fe).
3. Rod expands/contracts at frequency of applied field.
4. Vibrations generate ultrasonic waves.

Frequency Range: 20 kHz to 100 kHz. **Advantages**: High power, Rugged. **Limitations**: Low frequency only, Heating issues.

Mnemonic

“”Magnetic Materials Move Minutely Making ultrasonic waves””

OR

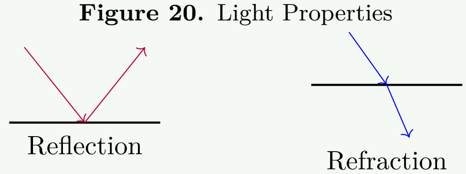
Question 4(c)(ii) [2 marks]

Explain any two properties of light wave.

Solution

1. **Reflection**: Bouncing back from surface. Angle i = Angle r. Used in mirrors.
2. **Refraction**: Bending when changing medium. Snell’s law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$. Used in lenses.

Figure 20. Light Properties



Mnemonic

“”Light Likes to Reflect from mirrors and Refract through media””

Question 5(a) [3 marks]

Write characteristics of LASER.

Solution

Table 6. LASER Characteristics

Characteristic	Description
Monochromatic	Single wavelength (pure color)
Coherent	Waves in same phase (high interference)
Directional	Minimal divergence over long distance
High Intensity	Concentrated energy

Figure 21. Laser vs Ordinary Light

Mnemonic

“”LASER Light: Monochromatic, Coherent, Directional, Intense””

Question 5(b) [4 marks]

Discuss importance of LASER in engineering and medical field.

Solution

Engineering:
1. **Manufacturing**: Cutting, welding, 3D printing.
2. **Measurement**: LIDAR, alignment.
3. **Communications**: Fiber optics, free-space.

Medical:
1. **Surgery**: Bloodless cutting, LASIK.
2. **Diagnostics**: Imaging, spectroscopy.
3. **Therapy**: Cancer treatment, pain management.
4. **Dentistry**: Teeth whitening.

Mnemonic

“”LASER Enhances Manufacturing, Measures precisely, Communicates data, Heals patients””

Question 5(c)(i) [5 marks]

What is importance of population inversion and metastable state for production of LASER?

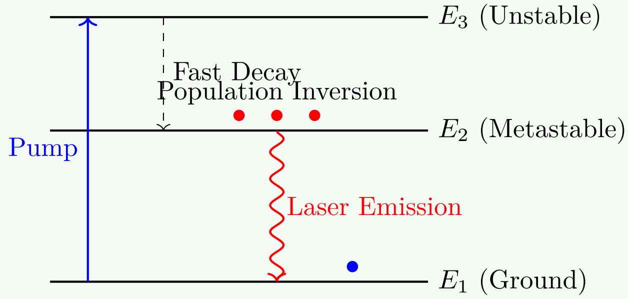
Solution

Population Inversion:
- State where more atoms are in excited state than ground state.
- Essential for stimulated emission to dominate absorption.
- Enables light amplification.

Metastable State:

- Excited state with long lifetime (10^{-3}s vs 10^{-8}s).
- Allows accumulation of excited atoms.
- Necessary to establish population inversion.

Figure 22. Energy Levels



Mnemonic

“”Population Inversion Makes Electrons Stay high; Metastable maintains this Situation Longer””

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

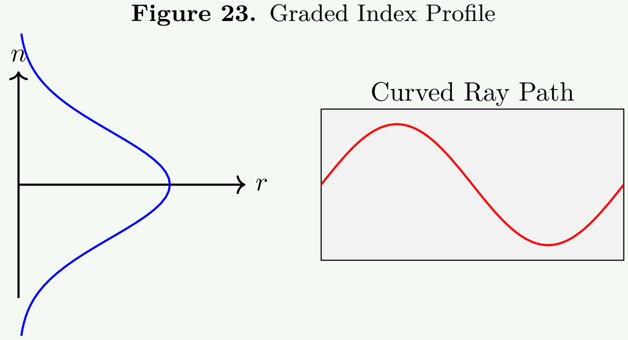
Explain graded index optical fibre.

Solution

Graded Index (GRIN) Fiber:

- Core refractive index decreases parabolicly from center to periphery ($n(r) = n_1(1 - \alpha r^2)$).
- Light travels in curved paths.
- Reduces modal dispersion and increases bandwidth.

Figure 23. Graded Index Profile



Mnemonic

“”Graded Index Gradually Improves transmission by Smoothing dispersion””

OR

Question 5(a) [3 marks]

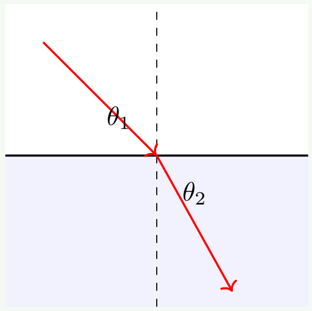
Define refraction of light and write Snell’s law.

Solution

Refraction: Bending of light passing between media due to speed change. **Snell's Law**: Ratio of sines of angles equals ratio of refractive indices.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Figure 24. Refraction



Mnemonic

“”Sine ratios Equal Index ratios””

OR

Question 5(b) [4 marks]

Discuss importance of optical fibre in engineering and medical field.

Solution

Engineering:

- Comms: High speed internet, secure data.
- Sensors: Strain, temp monitoring.
- Industrial: Remote inspection.

Medical:

- Diagnostics: Endoscopy.
- Surgery: Laser delivery, microsurgery.
- Imaging: OCT.

Mnemonic

“”Optical Fibers Connect, Sense, Visualize, and Treat””

OR

Question 5(c)(i) [5 marks]

Derive formula for numerical aperture and angle of acceptance of optical fibre.

Solution

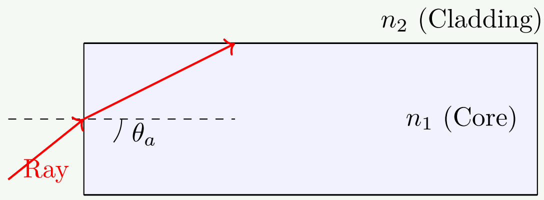
Numerical Aperture (NA):

1. At core-cladding interface, critical angle θ_c: $\sin \theta_c = n_2/n_1$.
2. Max angle in core: $90° - \theta_c$.
3. Apply Snell's law at entrance (Air $n_0 = 1$): $\sin \theta_a = n_1 \sin(90° - \theta_c) = n_1 \cos \theta_c$.

4. Substitute $\cos\theta_c = \sqrt{1-\sin^2\theta_c} = \sqrt{1-(n_2/n_1)^2}$.
5. $\sin\theta_a = n_1\sqrt{1-(n_2/n_1)^2} = \sqrt{n_1^2 - n_2^2}$.

Formula: $\text{NA} = \sin\theta_a = \sqrt{n_1^2 - n_2^2}$

Figure 25. Numerical Aperture



Mnemonic

“”NA Notes Acceptance angle; Square root of n-squared difference Shows maximum sine””

OR

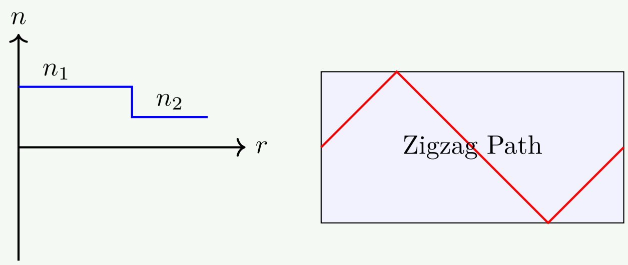
Question 5(c)(ii) [2 marks]

Explain step index optical fibre.

Solution

Step Index Fiber:
- Uniform core index n_1 surrounded by lower uniform cladding index n_2.
- Sharp ”step” transition.
- Types: Single-mode (small core), Multi-mode (large core).
- Limitation: Modal dispersion.

Figure 26. Step Index Profile



Mnemonic

“”Step Index Shows Two distinct Indices with Perfect boundary””