Unit-4. LASER and Fiber Optics - Short Solutions

Part A: Short Answers (1-2 marks)

(1) Snell's law

The ratio of sine of angle of incidence to sine of angle of refraction is constant.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \text{or} \quad \sin i / \sin r = n_2/n_1$$

(2) Full form of LASER

Light **A**mplification by **S**timulated **E**mission of **R**adiation

(3) Monochromatic and Polychromatic light

- **Monochromatic:** Single wavelength/color (e.g., laser, sodium lamp)
- **Polychromatic:** Multiple wavelengths/colors (e.g., white light, sunlight)

(4) Properties of laser light

1. Monochromatic (single wavelength)
2. Coherent (waves in phase)
3. Directional (highly focused beam)
4. High intensity
5. Polarized

(5) Definitions

Absolute Refractive Index: Ratio of speed of light in vacuum to speed in medium.

$$n = c/v$$

Critical Angle: Angle of incidence in denser medium for which angle of refraction becomes 90°.

$$\sin \theta c = n_2/n_1$$

Part B: Detailed Answers (2-3 marks)

(1) Refraction of light

Change in direction of light when passing from one medium to another due to change in velocity.

- Rarer to denser: bends towards normal
- Denser to rarer: bends away from normal

(2) Refractive index

Measure of how much light slows in a medium.

Absolute: n = c/v (always > 1)

Examples: Water (1.33), Glass (1.5), Diamond (2.42)

(3) Total Internal Reflection (TIR)

Complete reflection of light back into denser medium when traveling from denser to rarer medium.

Conditions:

1. Light travels from denser to rarer medium ($n_1 > n_2$)
2. Angle of incidence > critical angle ($i > \theta c$)

Applications: Optical fibers, prisms, diamonds, mirages

(4) Common light vs Laser light

Property	Common Light	Laser Light
Wavelength	Multiple	Single
Coherence	Non-coherent	Coherent
Direction	All directions	Unidirectional
Intensity	Low	Very high
Source	Spontaneous emission	Stimulated emission

(5) Applications of LASER (6 fields)

1. **Medical:** Surgery (LASIK), tumor removal, kidney stones
2. **Communication:** Optical fiber networks, data transmission
3. **Industrial:** Cutting, welding, drilling, 3D printing
4. **Military:** Range finders, guided missiles, LIDAR
5. **Scientific:** Spectroscopy, holography, measurements
6. **Commercial:** Barcode scanners, CD/DVD players, printers

(6) Types of optical fiber

By Mode:

- **Single Mode:** Core 8-10 μm, long distance, low dispersion

- **Multimode:** Core 50-200 μm, short distance, high dispersion

By Refractive Index:

- **Step Index:** Uniform core RI, zigzag path
- **Graded Index:** RI decreases from center, sinusoidal path

(7) Applications of optical fiber

1. **Telecommunications:** Internet, telephone, cable TV
2. **Medical:** Endoscopy, laser surgery, imaging
3. **Industrial:** Sensors, lighting, inspection
4. **Military:** Secure communication, navigation
5. **Networking:** LANs, data centers
6. **Automotive:** Safety systems, entertainment

(8) Construction of optical fiber

Three layers:

1. **Core:** Glass/plastic, high RI (n_1), carries light (8-200 μm)
2. **Cladding:** Lower RI (n_2), reflects light back (125 μm)
3. **Jacket:** Protective plastic coating (250-900 μm)

Light propagates through TIR at core-cladding interface.

(9) Advantages of optical fiber over coaxial cable

1. **Higher bandwidth:** Terabits vs Gigabits per second
2. **Lower loss:** 0.2-0.5 dB/km vs 10-30 dB/km
3. **EMI immunity:** Not affected by electromagnetic interference
4. **Higher security:** Difficult to tap
5. **Lighter and smaller:** Easy installation
6. **Non-conductive:** No spark hazard, lightning safe
7. **Longer distance:** 100+ km without repeaters
8. **Corrosion resistant:** Glass/plastic vs metal
9. **Future-proof:** Upgradeable without cable change
10. **Lower cost:** Cheaper raw materials (silica)

Part C: Numericals (3 marks)

(1) Refractive index of liquid

Given: c = 3×10^8 m/s, v = 1.8×10^8 m/s

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n = c/v = (3×10⁸)/(1.8×10⁸) = 1.67
```

Answer: 1.67

(2) Refractive index of glass

Given: c = 3×10^8 m/s, v = 2×10^8 m/s

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n = c/v = (3×10⁸)/(2×10⁸) = 1.5
```

Answer: 1.5

(3) Velocity of light in glass

Given: n = 1.56, c = 3×10^8 m/s

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v = c/n = (3×10⁸)/1.56 = 1.923×10⁸ m/s
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Answer: 1.92×10^8 m/s

(4) Acceptance angle

Given: n_1 = 1.563, n_2 = 1.498

```
NA = √(n₁² - n₂²) = √(2.443 - 2.244) = √0.199 = 0.446
θₐ = sin⁻¹(0.446) = 26.5°
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Answer: NA = 0.446, θ_a = 26.5°

(5) Acceptance angle and NA

Given: n_1 = 1.48, n_2 = 1.45

```
NA = √(n₁² - n₂²) = √(2.1904 - 2.1025) = √0.0879 = 0.297
θₐ = sin⁻¹(0.297) = 17.3°
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Answer: NA = 0.297, θ_a = 17.3°

Key Formulas

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Refraction: n = c/v = sin i/sin r
Critical Angle: sin θc = n₂/n₁
TIR Conditions: n₁ > n₂, i > θc
Optical Fiber: C = ε₀A/d
Numerical Aperture: NA = √(n₁² - n₂²)
Acceptance Angle: sin θₐ = NA
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Short Solutions - Unit 4