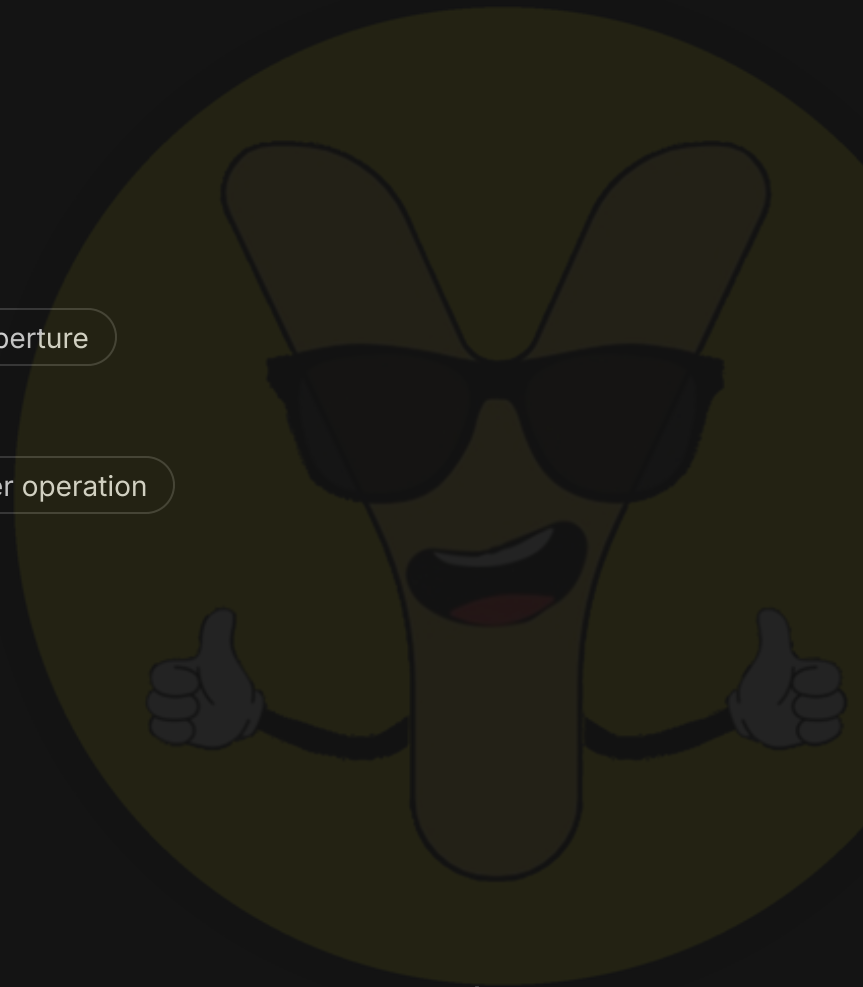
AKTU · 1ST YEAR · AAS101E / AAS201E

Quantum Physics and Applications

Unit 4 — Photonics

- Fiber optics: Fundamental idea about optical fiber
- Acceptance angle
- Acceptance cone
- Numerical aperture
- Principle of light propagation in optical fiber
- Attenuation and attenuation coefficient in fibre
- Laser: Interaction of radiation with matter (absorption, spontaneous and stimulated emission)
- Principle of laser operation
- Einstein's coefficients
- Ruby laser
- He-Ne laser
- Laser applications



DECODED BY

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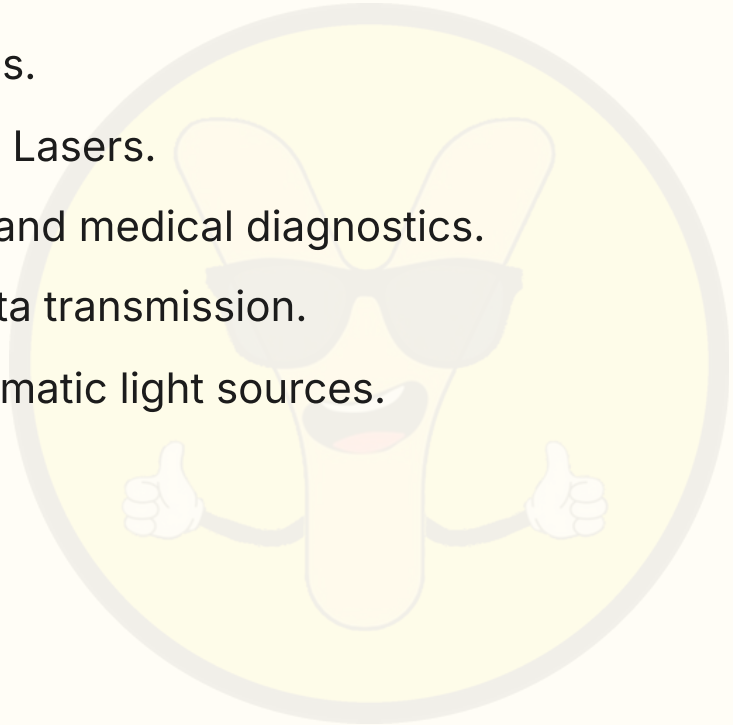
Introduction to Photonics

Photonics is the science and technology of generating, controlling, and detecting photons.

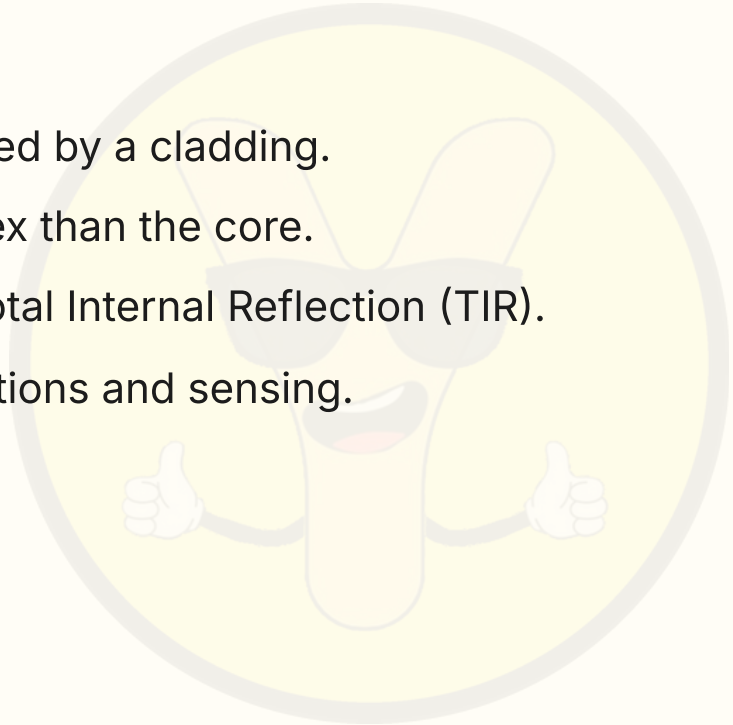
- Focuses on light-based technologies.
- Key components: Optical fibers and Lasers.
- Crucial for modern communication and medical diagnostics.
- Fiber optics enables high-speed data transmission.
- Lasers provide coherent, monochromatic light sources.



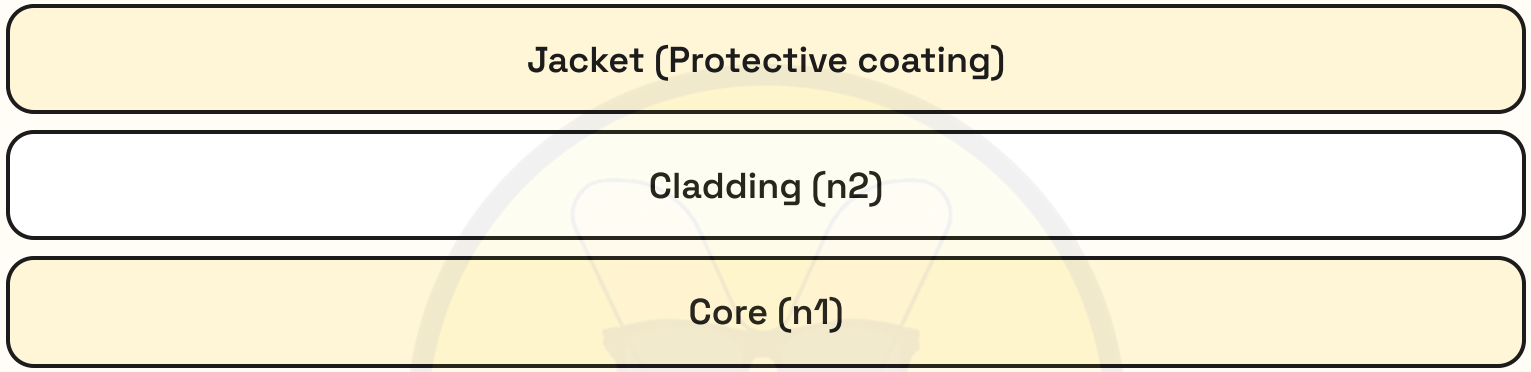
Optical Fiber: Fundamental Idea

An optical fiber is a flexible, transparent fiber made of glass or plastic.

- Functions as a waveguide for light.
- Consists of a central core surrounded by a cladding.
- Cladding has a lower refractive index than the core.
- Light travels through the core via Total Internal Reflection (TIR).
- Used extensively in telecommunications and sensing.



Structure of Optical Fiber



Cross-sectional view showing refractive indices where n1 > n2.

Acceptance Angle and Cone

These parameters define the light-gathering capacity of an optical fiber.

- Acceptance Angle: The maximum angle at which light can enter the fiber to be guided.
- Acceptance Cone: A cone formed by rotating the acceptance angle about the fiber axis.
- Light entering outside this cone will not undergo TIR.
- Formula: $\theta_a = \arcsin(\sqrt{n_1^2 - n_2^2})$
- Larger acceptance angles make coupling light easier.

Numerical Aperture (NA)

NUMERICAL APERTURE

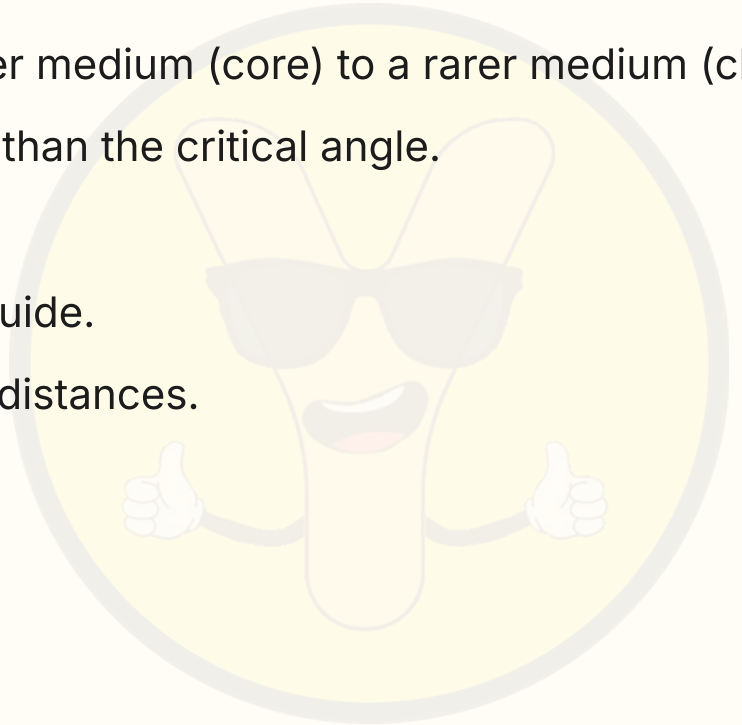
A dimensionless number that characterizes the range of angles over which the system can accept or emit light.

- NA = $\sin(\theta_a) = \sqrt{n_1^2 - n_2^2}$
- It represents the light-gathering efficiency of the fiber.
- Higher NA indicates better light collection but higher modal dispersion.

Principle of Light Propagation

Light propagates through an optical fiber primarily through Total Internal Reflection.

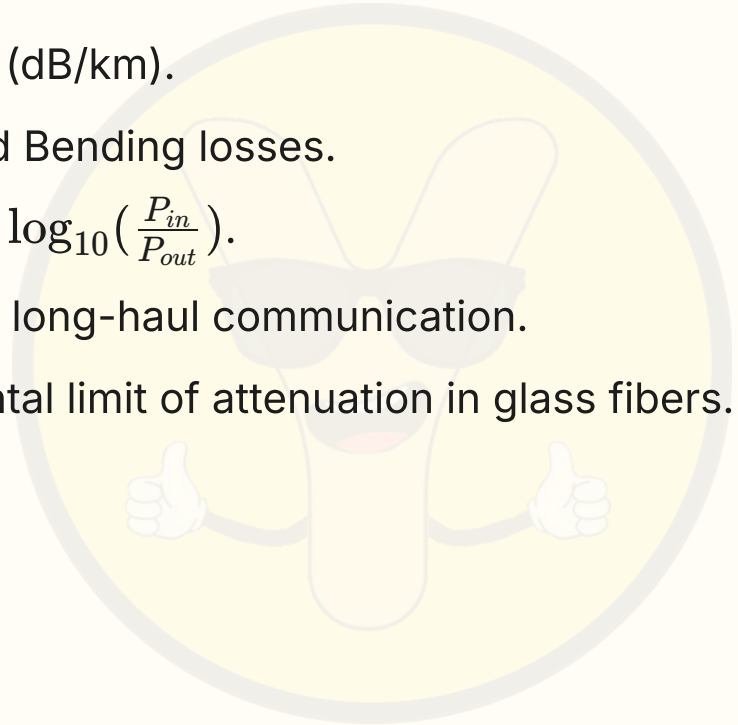
- Requires light to travel from a denser medium (core) to a rarer medium (cladding).
- Angle of incidence must be greater than the critical angle.
- Critical angle $\theta_c = \arcsin(n_2/n_1)$.
- The fiber acts as a dielectric waveguide.
- Maintains signal integrity over long distances.



Attenuation in Optical Fiber

Attenuation is the reduction in signal strength as light travels through the fiber.

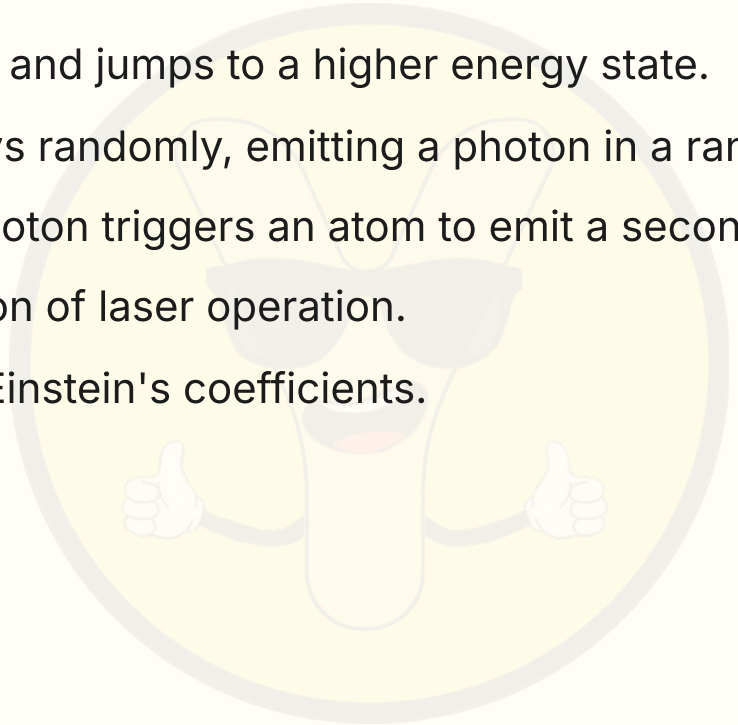
- Measured in decibels per kilometer (dB/km).
- Causes: Absorption, Scattering, and Bending losses.
- Attenuation Coefficient (α): $\alpha = \frac{10}{L} \log_{10}(\frac{P_{in}}{P_{out}})$.
- Minimizing attenuation is critical for long-haul communication.
- Rayleigh scattering is the fundamental limit of attenuation in glass fibers.



Interaction of Radiation with Matter

Light interacts with atoms through three primary processes.

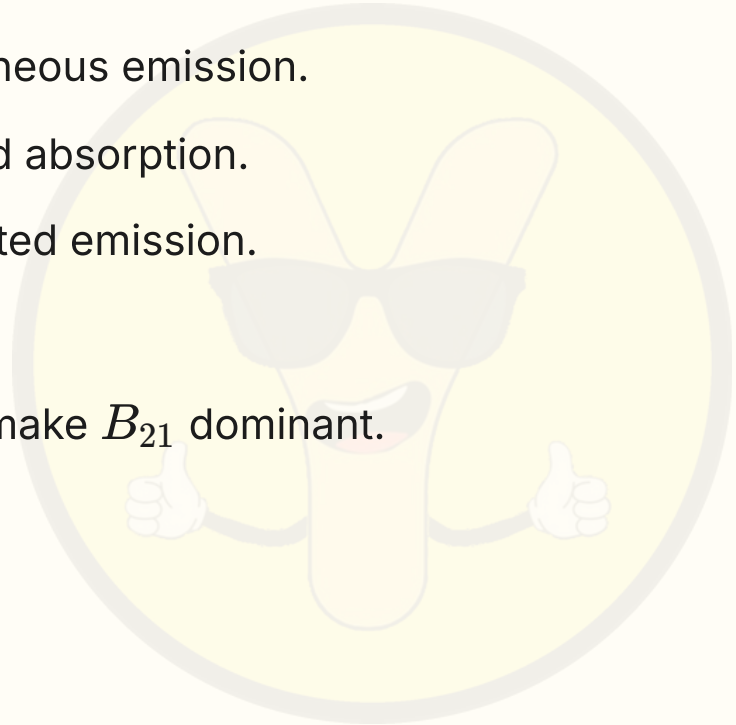
- Absorption: Atom absorbs a photon and jumps to a higher energy state.
- Spontaneous Emission: Atom decays randomly, emitting a photon in a random direction.
- Stimulated Emission: An incident photon triggers an atom to emit a second, identical photon.
- Stimulated emission is the foundation of laser operation.
- These processes are governed by Einstein's coefficients.



Einstein’s Coefficients

These coefficients describe the probabilities of atomic transitions.

- A_{21}: Einstein coefficient for spontaneous emission.
- B_{12}: Einstein coefficient for induced absorption.
- B_{21}: Einstein coefficient for stimulated emission.
- Relation: $\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$.
- Population inversion is required to make B_{21} dominant.



Principle of Laser Operation

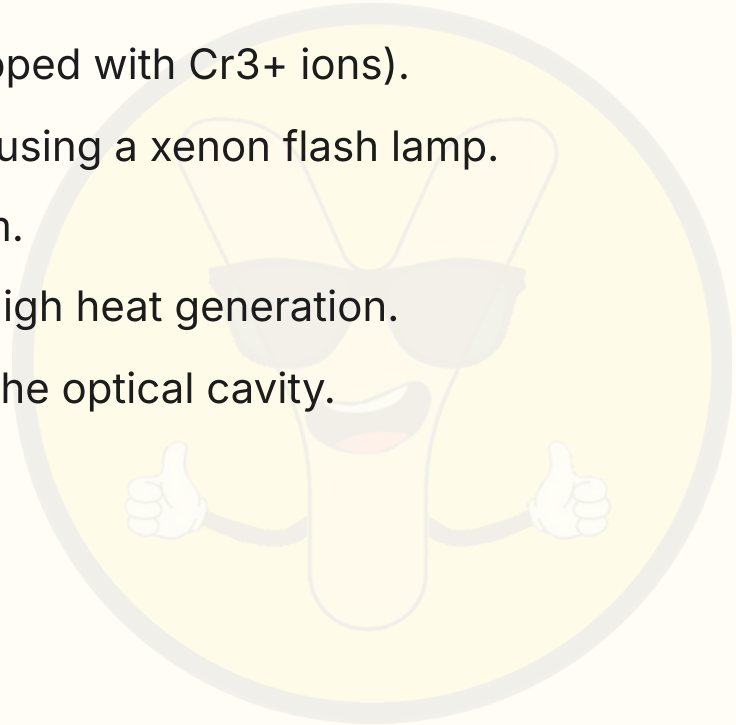
A laser requires specific conditions to produce coherent light.

- Population Inversion: More atoms in excited state than ground state.
- Optical Pumping: Energy source to achieve population inversion.
- Optical Resonator: Two mirrors (one partially reflecting) to provide feedback.
- Stimulated Emission: Amplification of the light wave.
- Result: Highly monochromatic, coherent, and directional beam.

Ruby Laser

The first working laser, a three-level solid-state laser.

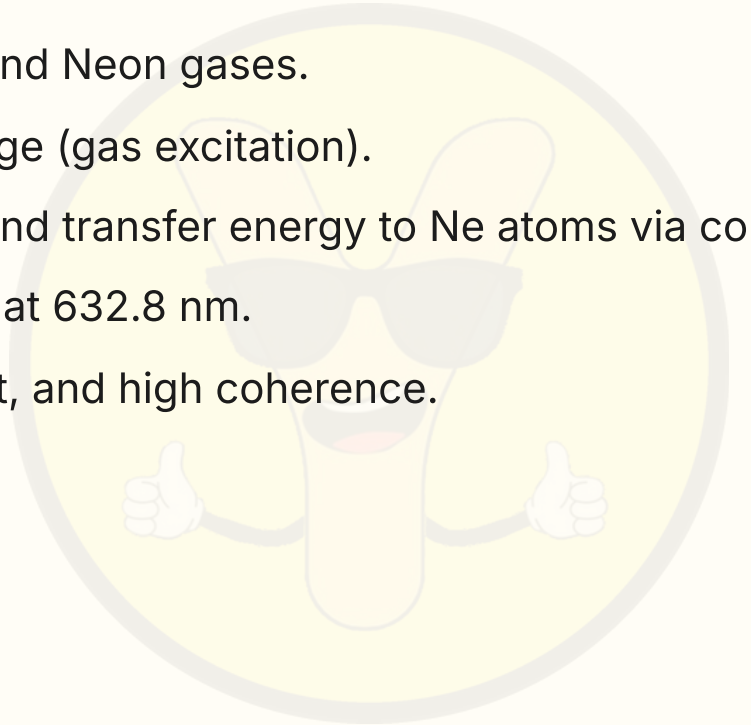
- Active medium: Ruby rod (Al2O3 doped with Cr3+ ions).
- Pumping method: Optical pumping using a xenon flash lamp.
- Output: Pulsed red light at 694.3 nm.
- Disadvantage: Low efficiency and high heat generation.
- Construction: Silvered ends act as the optical cavity.



He-Ne Laser

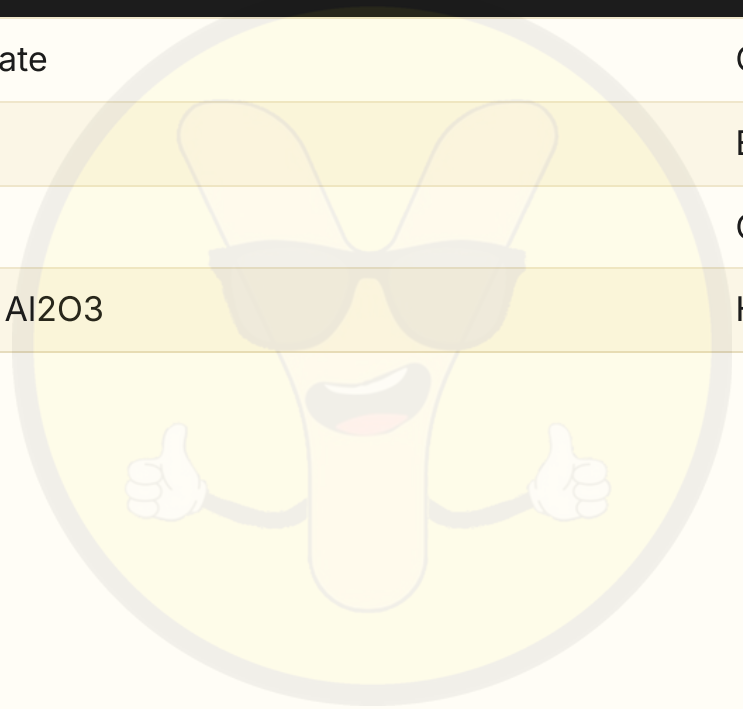
A continuous-wave gas laser widely used in laboratories.

- Active medium: Mixture of Helium and Neon gases.
- Pumping method: Electrical discharge (gas excitation).
- Mechanism: He atoms are excited and transfer energy to Ne atoms via collisions.
- Output: Continuous beam, typically at 632.8 nm.
- Advantages: Stable output, low cost, and high coherence.



Comparison: Ruby vs He-Ne Laser

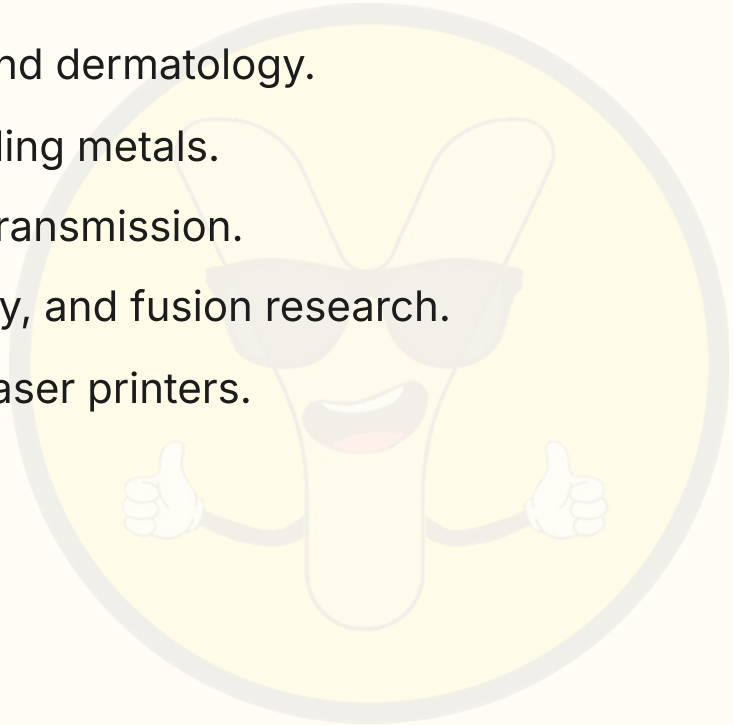
Feature	Ruby Laser	He-Ne Laser
Type	Solid State	Gas Laser
Pumping	Optical	Electrical
Output	Pulsed	Continuous
Medium	Cr3+ in Al2O3	He-Ne Gas



Laser Applications

Lasers have revolutionized various fields of science and industry.

- Medical: Surgery, ophthalmology, and dermatology.
- Industrial: Cutting, welding, and drilling metals.
- Communication: Fiber optic signal transmission.
- Scientific: Spectroscopy, holography, and fusion research.
- Consumer: Barcode scanners and laser printers.

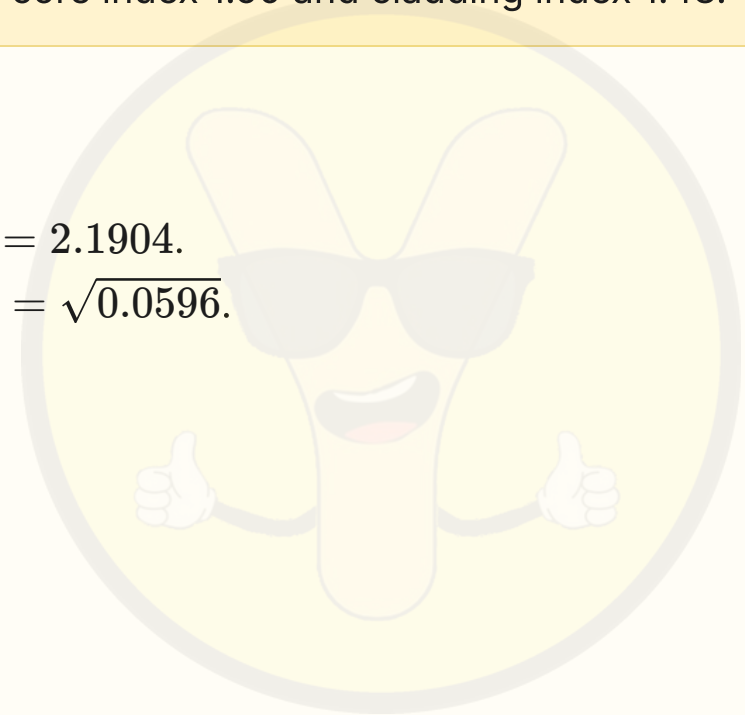


Numerical Aperture Calculation

Calculate the NA of an optical fiber with core index 1.50 and cladding index 1.48.

1. Identify indices: $n_1 = 1.50$, $n_2 = 1.48$.
2. Use formula: $NA = \sqrt{n_1^2 - n_2^2}$.
3. Calculate squares: $1.50^2 = 2.25$, $1.48^2 = 2.1904$.
4. Subtract and find root: $\sqrt{2.25 - 2.1904} = \sqrt{0.0596}$.

NA = 0.244



Exam corner

- **Q1** Define Numerical Aperture and derive its expression in terms of refractive indices.
- **Q2** Explain the principle of Total Internal Reflection in optical fibers.
- **Q3** What is attenuation? Explain the factors causing signal loss in fibers.
- **Q4** Distinguish between spontaneous and stimulated emission.
- **Q5** Explain the role of Einstein's coefficients in laser action.
- **Q6** Describe the construction and working of a Ruby laser with a neat diagram.
- **Q7** Compare He-Ne laser and Ruby laser based on their working principles.
- **Q8** List various applications of lasers in medicine and industry.

Unit 4 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 5 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

