AKTU

B. Tech I-Year

Gateway Classes

GATEWAY CLASSES

Semester -I & II | **Common to All Branches**

BAS101 / BAS201: ENGINEERING PHYSICS

Unit-4 : Fiber Optics & Laser

Gateway Series for Engineering

- Topic Wise Entire Syllabus
- Long - Short Questions Covered
- AKTU PYQs Covered
- DPP
- Result Oriented Content

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For Full Courses including Video Lectures

AKTU

B. Tech I-Year

Gateway Classes

GATEWAY CLASSES

BAS101 / BAS201: ENGINEERING PHYSICS

Unit-4

Introduction to : Fiber Optics & Laser

Syallbus

Fibre Optics: Principle and construction of optical fiber, Acceptance angle, Numerical aperture, Acceptance cone, Step index and graded index fibers, Fiber optic communication principle, Attenuation, Dispersion, Application of fiber.

Laser: Absorption of radiation, Spontaneous and stimulated emission of radiation, Population inversion, Einstein's Coefficients, Principles of laser action, Solid state Laser (Ruby laser) and Gas Laser (He-Ne laser), Laser applications.

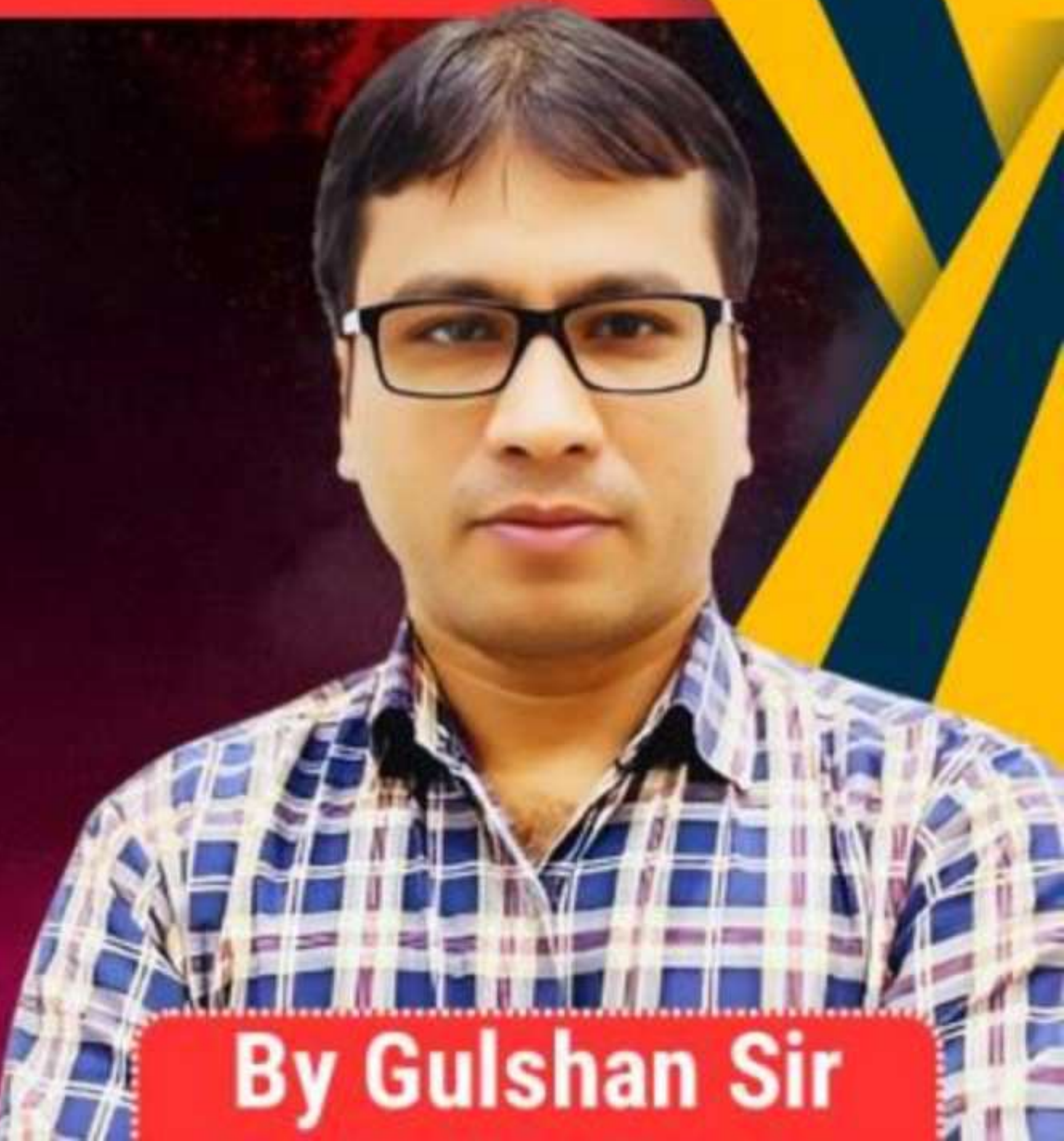
B. Tech : Engg. Physics

Unit : Fibre Optics and Laser

Lecture - 1

Today's Target

- Fibre Optics
- DPP
- PYQs



By Gulshan Sir

Fiber Optics

- Fiber optics is the technology for data communication or data transfer.
- Optical Fiber serves the same purpose as the copper wire by moving information from one place to another.
- In fiber optics, the transmission medium is light and that light is carried with in a hair – thin optical fiber via the process of total internal reflection.

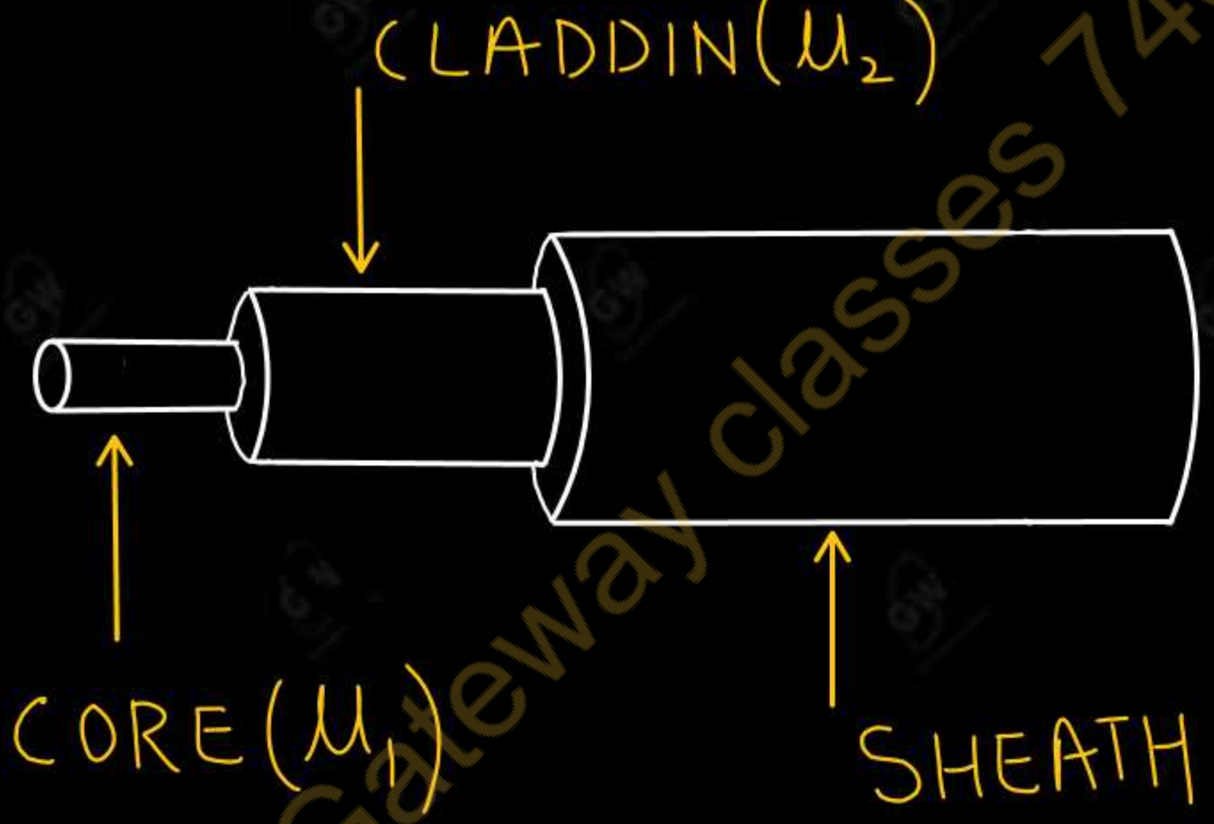
Advantages of fiber optics

- High data transmission rate
- Higher Bandwidth
- Low transmission loss
- Small size cable and weight
- Safety due to absence of electric spark
- Data security
- Abundant raw materials

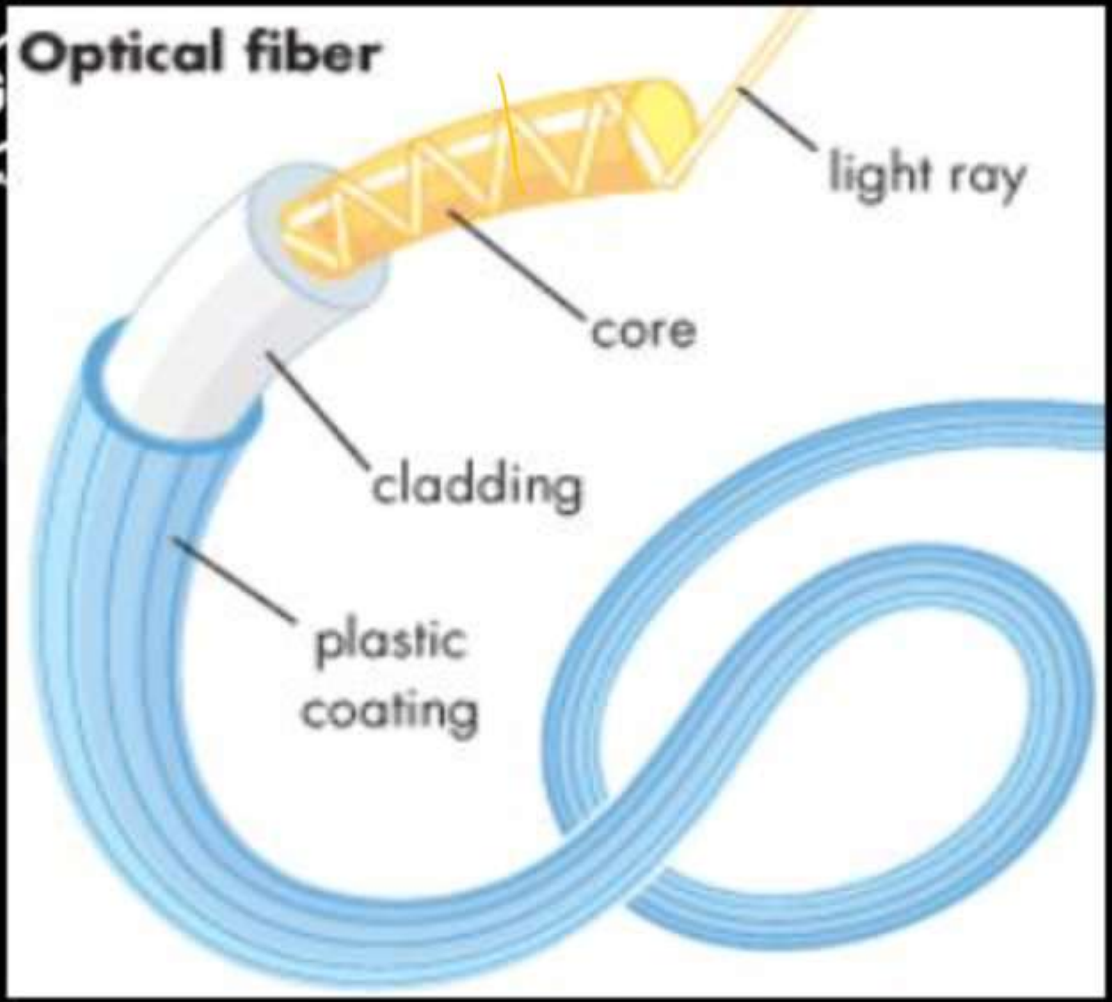
Optical Fiber

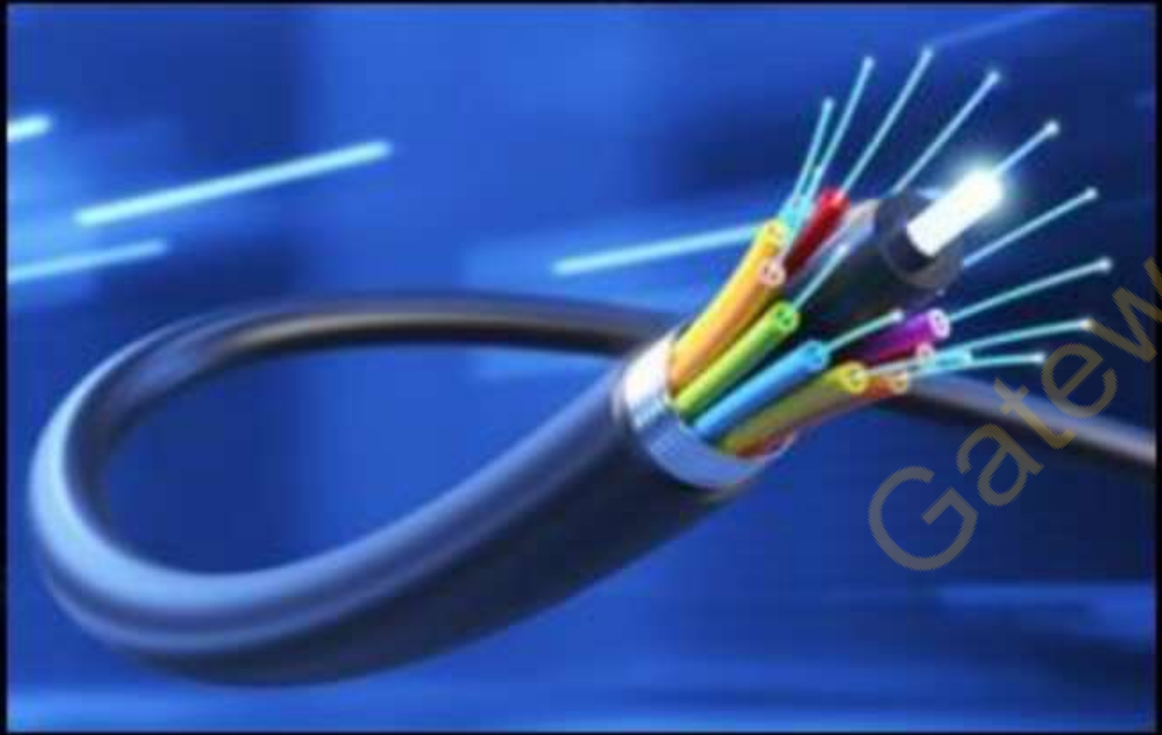
- An optical fiber is a hair – thin long strand of glass surrounded by a glass coating of slightly lower refractive index.
- It is used as a guided medium for transmitting an optical signal from one place to another

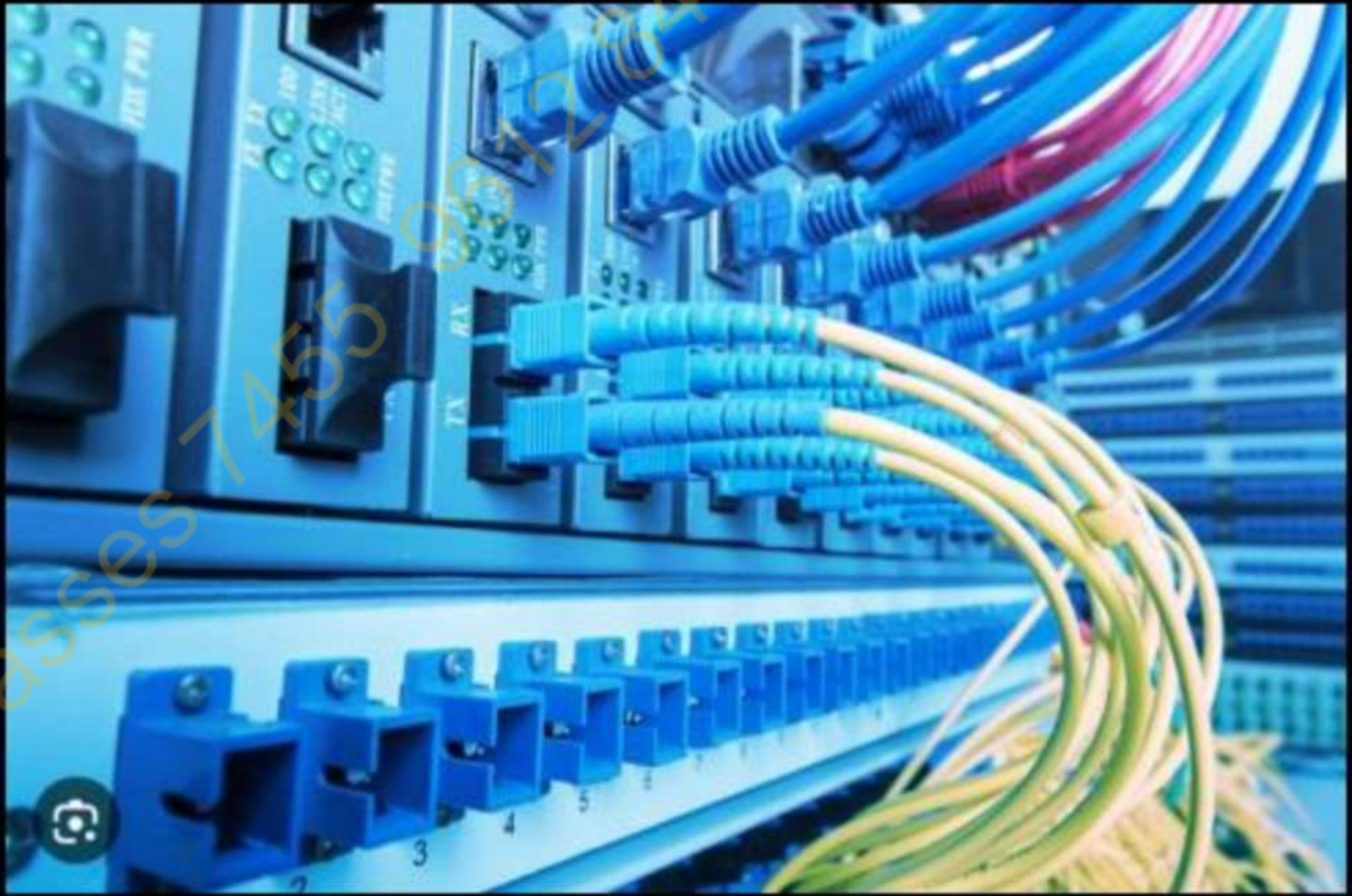
Construction: An optical fiber consist of three main parts



$$\boxed{\mu_1 > \mu_2}$$


Optical fiber
light ray
core
cladding
plastic
coating





(i) Core

- The central cylindrical core is made of high quality glass / silica / plastic of refractive index μ_1
- The diameter of core is 10 to 100 μm

(ii) Cladding

- The core is surrounded by a glass / plastic jacket of refractive index μ_2

$$\mu_2 < \mu_1$$

- Diameter of cladding is 100 to 250 μm

(iii) Sheath (or Buffer coating)

- For providing safety and strength, the core cladding of optical fibers is enclosed in a plastic jacket

Principle of optical fiber

- The working of optical fiber is based on the principle of total internal reflection.

Total internal Reflection

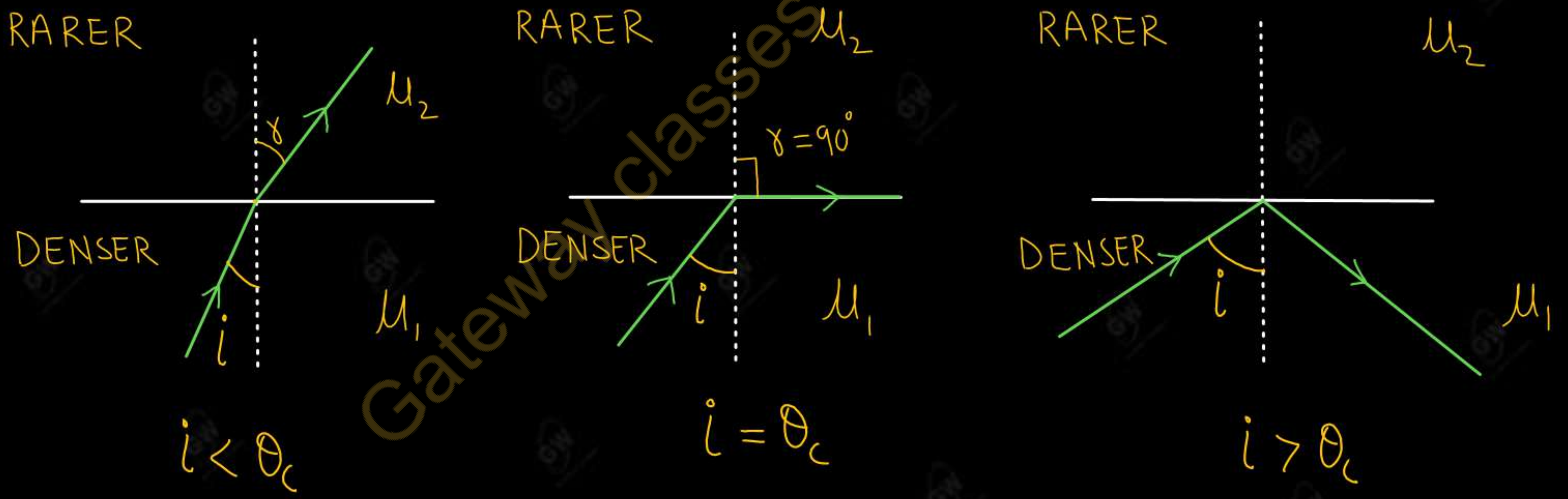
The phenomenon in which a ray of light travelling from denser medium (core) to a rarer medium (cladding) at an angle of incidence greater than the critical is totally reflected back in to the denser medium (core) is called total internal reflection.

Necessary condition for total internal reflection

θ_c = critical Angle

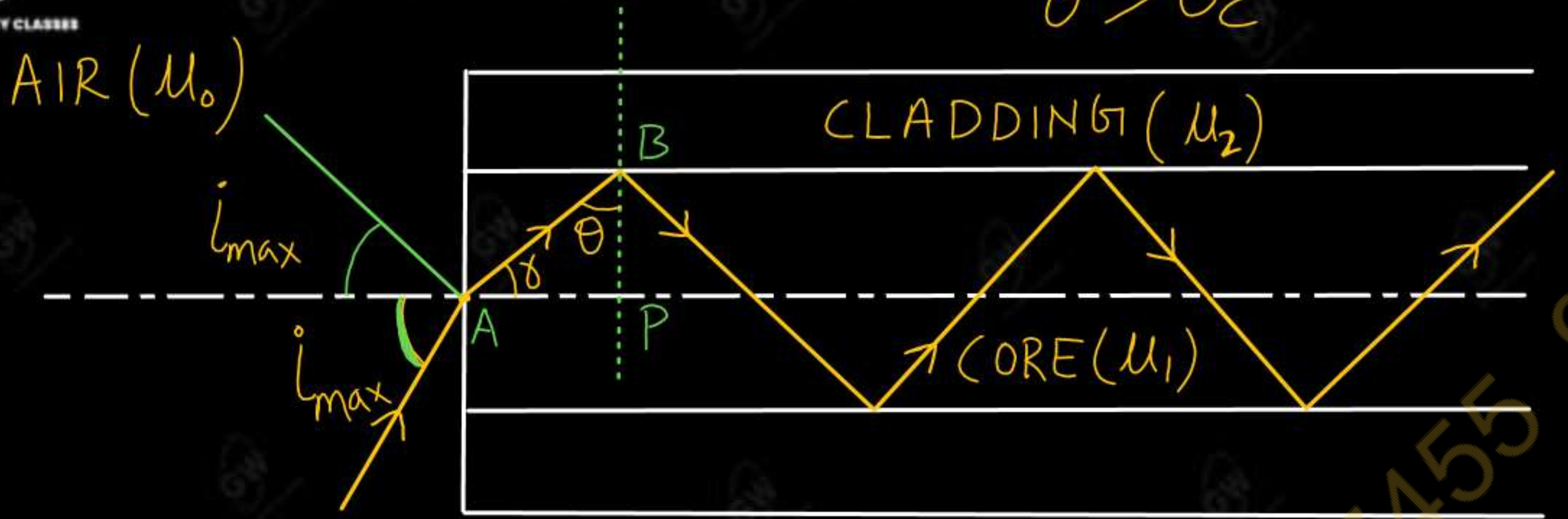
(i) Light must travel from an optically denser medium (core) to an optically rarer medium (cladding).

(ii) The Angle of incidence in the denser medium (core) must be greater than the critical angle.



Important terminology of optical fiber

$\theta > \theta_c$



$\gamma + \theta = 90$

(i) Critical Angle

- The Angle of incidence in the denser medium (core) for which the angle of refraction in the rarer medium (Cladding) is 90° is called critical angle of the denser medium.

(ii) Acceptance angle

- The maximum angle at which the light enters the core for which the total internal reflection just occur at the core-cladding interface is called Acceptance angle .

(iii) Acceptance cone

- All the light rays contained in the cone having vertex angle $2\,i_{max}$ are accepted and transmitted along the fiber. This cone is called as Acceptance cone.

(iv) Numerical Aperture

- The numerical aperture is measure of the amount of light accepted by the fiber.
- The numerical aperture is also defined as the sine of acceptance angle

V. imp

$$\boxed{NA = \sin i_{max}}$$

(v) Fractional refractive index change

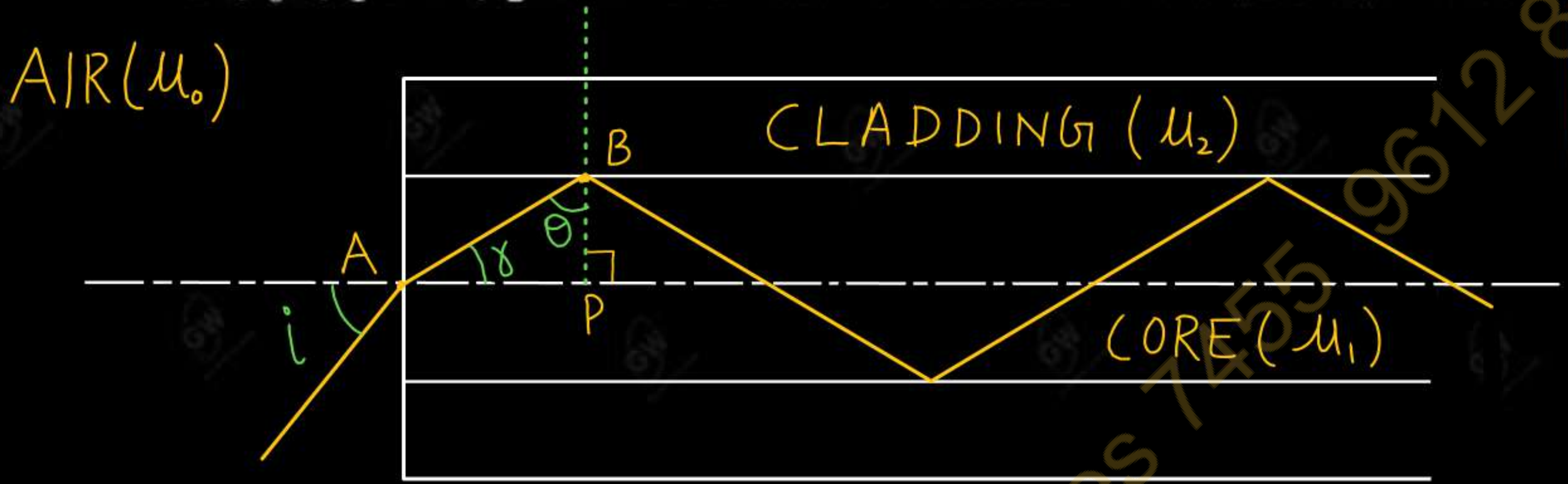
- It is defined as the ratio of the difference between refractive indices of the core and the cladding to the refractive index of core in an optical fiber
- It is denoted by Δ

V. Imp

$$\boxed{\Delta = \frac{\mu_1 - \mu_2}{\mu_1}}$$

Expression for Acceptance angle and Numerical Aperture

- Let μ_0 , μ_1 and μ_2 are the refractive indices of the air, core, and cladding respectively



Using Snell's Law at A (Air core interface

$$\frac{\sin i}{\sin \gamma} = \frac{\mu_1}{\mu_0}$$

$$\sin i = \frac{\mu_1}{\mu_0} \sin \gamma \quad \text{—— (1)}$$

In $\triangle ABP$

$$\gamma = 90 - \theta$$

Put γ in (1)

$$\sin i = \frac{\mu_1}{\mu_0} \sin(90-\theta)$$

$$\because \sin(90-\theta) = \cos\theta$$

$$\sin i = \frac{\mu_1}{\mu_0}\cos\theta$$

$$\because \cos\theta = \sqrt{1-\sin^2\theta}$$

$$\sin i = \frac{\mu_1}{\mu_0}\sqrt{1-\sin^2\theta}$$

Acceptance Angle is maximum (i_{max})

When $\theta = \theta_c$

$$\sin i_{max} = \frac{\mu_1}{\mu_0}\sqrt{1-\sin^2\theta_c} \quad \text{——— } (2)$$

Using Snell's law at B

$$\frac{\sin\theta_c}{\sin 90} = \frac{\mu_2}{\mu_1}$$

v. imp

$$\boxed{\sin\theta_c = \frac{\mu_2}{\mu_1}} \quad \text{OR} \quad \boxed{\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)}$$

Put $\sin\theta_c$ in (2)

$$\sin i_{max} = \frac{\mu_1}{\mu_0}\sqrt{1-\frac{\mu_2^2}{\mu_1^2}}$$

$$\sin i_{max} = \frac{\cancel{\mu_1}}{\mu_0}\frac{\sqrt{\mu_1^2-\mu_2^2}}{\cancel{\mu_1}}$$

$\because \mu_0 = 1$

$$\boxed{\sin i_{max} = \sqrt{\mu_1^2 - \mu_2^2}}$$

Numerical Aperture (NA)

$$NA = \sin i_{max}$$

$$\boxed{NA = \sqrt{\mu_1^2 - \mu_2^2}}$$ V.imp

Acceptance Angle (i_{max})

$$i_{max} = \sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$$

$$\boxed{i_{max} = \sin^{-1}(NA)}$$ V.imp

Relation between Numerical Aperture and Fractional refractive index change

We Know that

Numerical Aperture

$$NA = \sqrt{\mu_1^2 - \mu_2^2} \quad \text{--- (1)}$$

Fractional index change

$$\Delta = \frac{\mu_1 - \mu_2}{\mu_1} \quad \text{--- (2)}$$

From (1)

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$NA = \sqrt{(\mu_1 - \mu_2)(\mu_1 + \mu_2)}$$

$$NA = \sqrt{\frac{(\mu_1 - \mu_2)(\mu_1 + \mu_2)\, 2\mu_1}{2\mu_1}}$$

$$NA = \sqrt{\left(\frac{\mu_1 - \mu_2}{\mu_1}\right)\left(\frac{\mu_1 + \mu_2}{2}\right) 2\mu_1}$$

$$\because \frac{\mu_1 + \mu_2}{2} \approx \mu_1$$

$$NA = \sqrt{\left(\frac{\mu_1 - \mu_2}{\mu_1}\right) 2\mu_1^2}$$

v.imp

$$\boxed{NA = \mu_1 \sqrt{\frac{2(\mu_1 - \mu_2)}{\mu_1}}}$$

$$\boxed{NA = \mu_1 \sqrt{2\Delta}}$$

GW **Q.1** A silica glass optical fibre has a core refractive index of 1.50 and cladding refractive index of 1.45 Calculate the numerical aperture of the optical fibre.

Given

$\mu_1 = 1.50$

$\mu_2 = 1.45$

Numerical Aperture

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$NA = \sqrt{(1.50)^2 - (1.45)^2}$$

$$\boxed{NA = 0.384}$$

2nd Method

$$NA = \mu_1 \sqrt{\frac{2(\mu_1 - \mu_2)}{\mu_1}}$$

$$NA = 1.50 \sqrt{\frac{2(1.50 - 1.45)}{1.50}}$$

$$\boxed{NA = 0.387}$$

Q. 2 Calculate the numerical aperture, the acceptance angle and the critical angle of the fibre from the following data. $\mu_{core} = 1.48$ and $\mu_{cladding} = 1.46$. (AKTU : 2016-17, 2018-19)

Given

$\mu_1 = 1.48$

$\mu_2 = 1.46$

Numerical Aperture

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$NA = \sqrt{(1.48)^2 - (1.46)^2}$$

$$\boxed{NA = 0.2425}$$

Acceptance angle

$$i_{max} = \sin^{-1}(NA)$$

$$i_{max} = \sin^{-1}(0.2425)$$

$$\boxed{i_{max} = 14.03^\circ}$$

Critical Angle

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

$$\theta_c = \sin^{-1}\left(\frac{1.46}{1.48}\right)$$

$$\boxed{\theta_c = 80.57^\circ}$$

Q.3 A silicon optical fibre with a core diameter large enough has a core refractive index of 1.50 and a cladding refractive index 1.47. Determine

(i) the critical angle at the core cladding interface

(ii) the numerical aperture for the fibre

(iii) the acceptance angle in the air for the fibre

(AKTU : 2021-22)

Given

$\mu_1 = 1.50$

$\mu_2 = 1.47$

(i) Critical Angle

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

$$\theta_c = \sin^{-1}\left(\frac{1.47}{1.50}\right)$$

$$\boxed{\theta_c = 81.87^\circ}$$

(ii) Numerical Aperture

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$NA = \sqrt{(1.50)^2 - (1.47)^2}$$

$$\boxed{NA = 0.2985}$$

Acceptance Angle

$$i_{max} = \sin^{-1}(NA) = \sin^{-1}(0.2985)$$

$$\boxed{i_{max} = 17.37^\circ}$$

V – Number

OR

Normalised Frequency

OR

CUT – OFF Parameter in optical fibre

- V – Number in optical fibre is a dimensionless parameter which is used to determine the maximum possible number of modes in a fibre
- V – Number gives the relation between radius (r) of the core, refractive indices μ_1 and μ_2 of the materials of the core and cladding and wavelength (λ) of the light propagating through the optical fibre and is given as

$$\boxed{V = \frac{2\pi r}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}}$$ V. imp ——— (1)

OR

$$V = \frac{\pi D}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$$

NOTE

(i) For single Mode Fibre

$V \leq 2.405$

(ii) For Multimode Fibre

$V > 2.405$

We know that

$$NA = \sqrt{\mu_1^2 - \mu_2^2} \quad \text{——— (2)}$$

Also

$$NA = \mu_1 \sqrt{2\Delta} \quad \text{——— (3)}$$

From (2) and (3)

$$\sqrt{\mu_1^2 - \mu_2^2} = \mu_1 \sqrt{2\Delta} \quad \text{——— (4)}$$

From (3) and (4)

$$\boxed{V = \frac{2\pi r}{\lambda} \mu_1 \sqrt{2\Delta}} \quad \text{OR} \quad \boxed{V = \frac{2\pi r}{\lambda} (NA)}$$

Number of mode in multimode fibre

- If N represents the number of modes in multimode fibre

  (i) For step index multimode fibre

$$\boxed{N \approx \frac{V^2}{2}}$$

  (ii) for graded index multimode fibre

$$\boxed{N \approx \frac{V^2}{4}}$$

Note : V – Number increases with numerical aperture and diameter of the core

Q.4 A step index fibre has $\mu_1 = 1.466$ and $\mu_2 = 1.46$ where μ_1 and μ_2 are refractive indices of core and cladding respectively. If the operating wavelength of the rays is 0.85μm and the diameter of the core = 50 μm, calculate the cut-off parameter and the number of modes which the fibre will support.

(AKTU : 2021-22)

$\boxed{1\,\mu m = 10^{-6}\,m}$

Given

$\mu_1 = 1.466$

$\mu_2 = 1.46$

$\lambda = 0.85\,\mu m$

$r = \frac{50}{2}$

$r = 25\,\mu m$

CUT-OFF Parameter

$$V = \frac{2\pi r}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$$

$$V = \frac{2 \times \pi \times 25}{0.85}\sqrt{(1.466)^2 - (1.46)^2}$$

$$\boxed{V = 24.4858}$$ ✓

No of modes

$$N = \frac{V^2}{2}$$

$$N = \frac{(24.4858)^2}{2}$$

$$\boxed{N \simeq 299}$$

Q.5 Calculate the V-number for a fibre of core diameter 40 μm and RI of 1.55 and 1.50 respectively for its core and cladding when a light of wavelength 1400 nm is propagating. Also calculate the number of modes that the fibre can support for propagation. (AKTU : 2023-24)

Given

$$r = \frac{40}{2} = 20\,\mu m$$

$$\mu_1 = 1.55$$

$$\mu_2 = 1.50$$

$$\lambda = 1400\,nm$$

V-Number

$$V = \frac{2\pi r}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$$

$$V = \frac{2\pi \times 20\times10^{-6}}{1400\times10^{-9}}\sqrt{(1.55)^2 - (1.50)^2}$$

$$\boxed{V = 35.05}$$

No. of modes

$$N = \frac{V^2}{2}$$

$$N = \frac{(35.05)^2}{2}$$

$$\boxed{N \approx 614}$$

Q.6 A step index fibre has core refractive index 1.468, cladding refractive index 1.462. Compute the maximum radius allowed for a fibre, if it supported only one mode at wavelength 1300 nm

(AKTU : 2015-16)

Given

$\mu_1 = 1.468$

$\mu_2 = 1.462$

$\lambda = 1300\,nm$

For single mode Fibre

$V = 2.405$

V-Number

$$V = \frac{2\pi r}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$$

$$2.405 = \frac{2\pi r}{1300}\sqrt{(1.468)^2 - (1.462)^2}$$

$$r = \frac{2.405 \times 1300}{2\pi\sqrt{(1.468)^2 - (1.462)^2}}$$

$$r = 3752.918\,nm$$

$$\boxed{r = 3.75\,\mu m}$$

Q.7 If the fractional difference between the core and cladding refractive indices of a fibre is 0.0135 and numerical aperture NA is 0.2425, Calculate the refractive indices of the core and cladding materials.

Given

$\Delta = 0.0135$

$NA = 0.2425$

We know that

$$\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$$

$$0.0135 = \frac{\mu_1 - \mu_2}{\mu_1}$$

$$\frac{\mu_1 - \mu_2}{\mu_1} = 0.0135 \quad \text{—— (1)}$$

Also

$$NA = \mu_1 \sqrt{2\Delta}$$

$$\mu_1 = \frac{NA}{\sqrt{2\Delta}}$$

$$\mu_1 = \frac{0.2425}{\sqrt{2 \times 0.0135}}$$

$$\boxed{\mu_1 = 1.476}$$

Put μ_1 in (1)

$$\frac{1.476 - \mu_2}{1.476} = 0.0135$$

$$1.476 - \mu_2 = 0.0135 \times 1.476$$

$$\boxed{\mu_2 = 1.456}$$

Types of optical fibre

Optical Fibres

- Based on Materials
  - Glass Fibre
  - Plastic Fibre
- Based on Number of Modes
  - Single mode Fibre
  - Multimode Fibre
- Based on Refractive index
  - Step index Fibre
    - Step index Single mode fibre
    - Step index Multimode fibre
  - Graded index Fibre
    - Graded index Multimode fibre

Single Mode Fibre

- The single mode fibre can support only one mode of propagation
- Diameter is (5-10μm) while that of cladding is (50 to 125 μm)
- Condition for single mode propagation in fibre is $V \leq 2.405$
- The difference in refractive index of core and cladding is very small.

Advantages

(i) Attenuation is low

(ii) Dispersion is low

(iii) Higher bandwidth

(iv) Suitable for long distance communication

Disadvantages

(i) Fabrication is difficult and costly

(ii) Transmission equipment is expensive (Laser diode)

(iii) Handling is difficult due to small core diameter

Multimode Fibre

- The multimode fibre can support large number of mode of propagation
- It has a larger core diameter (20-100 μm)
- Condition for multimode propagation in fibre is $V > 2.405$
- The difference in refractive index of core and cladding is larger than single mode fibre

Advantages

(i) Attenuation is high

(ii) Dispersion is high

(iii) Low and limited bandwidth

(iv) Suitable for short distance communication

Disadvantages

(i) Fabrication is less difficult and not costly

(ii) Transmission equipment is simple and low cost (LED)

(iii) Handling is easy due to large core diameter

Step Index Fibre

- In step index optical fibre, the refractive index of the core is uniform throughout and undergoes an abrupt step change at core cladding interface
- Both single mode and multimode step index fibre can be made
- Intermodal dispersion is more in step index multimode fibre.

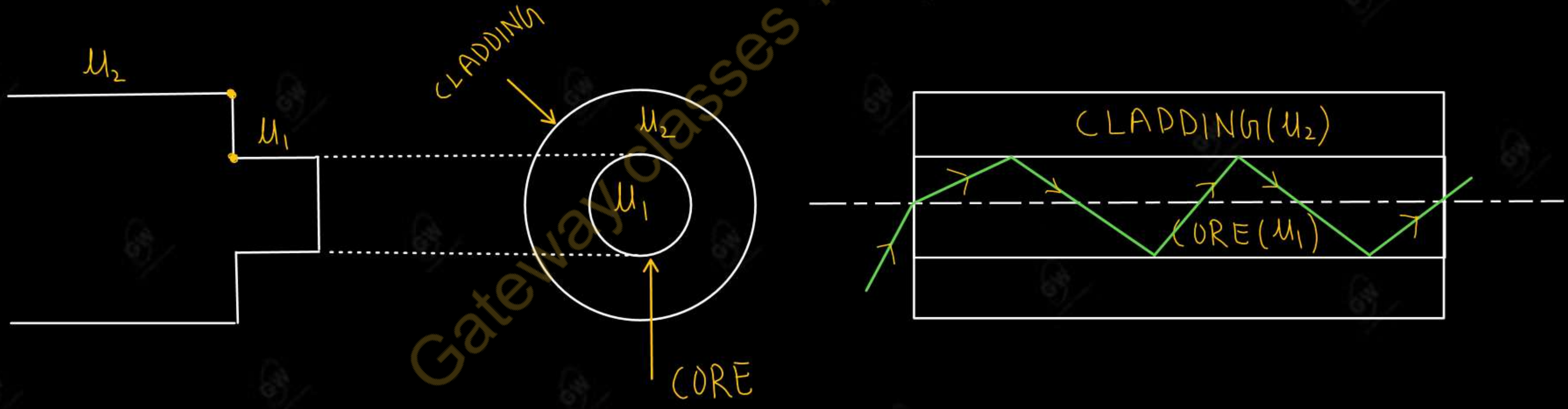
Graded index fibre

- In graded index fibre, the refractive index in the core of the optical fibre is not uniform and it decreases gradually from maximum value at the axis of the core to minimum value at the core-cladding surface.
- Graded index fibre can be multimode only.
- Intermodal dispersion is less in graded index multimode fibre.

Note : Refractive index of cladding is always uniform

Step index Single Mode Fibre

- In step index single mode fibre, the refractive index of the core is uniform throughout and undergoes an abrupt step change at core cladding interface
- Step index single mode fibre can support only one mode of propagation
- Diameter is (5-10μm) while that of cladding is (50 to 125 μm)
- Condition for single mode propagation in fibre is $V \leq 2.405$
- The difference in refractive index of core and cladding is very small.



Advantages and Disadvantages of step index single mode fibre

Advantages

(i) Attenuation is low

(ii) Dispersion is low

(iii) Higher bandwidth

(iv) Suitable for long distance communication

Disadvantages

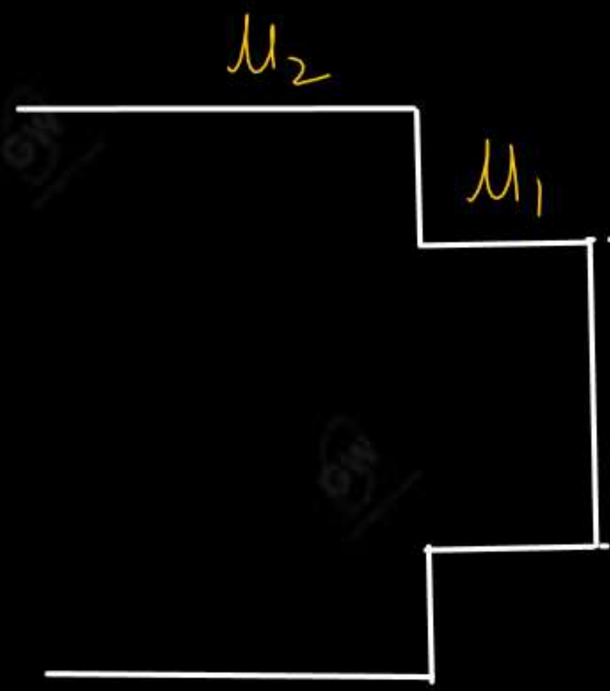
(i) Fabrication is difficult and costly

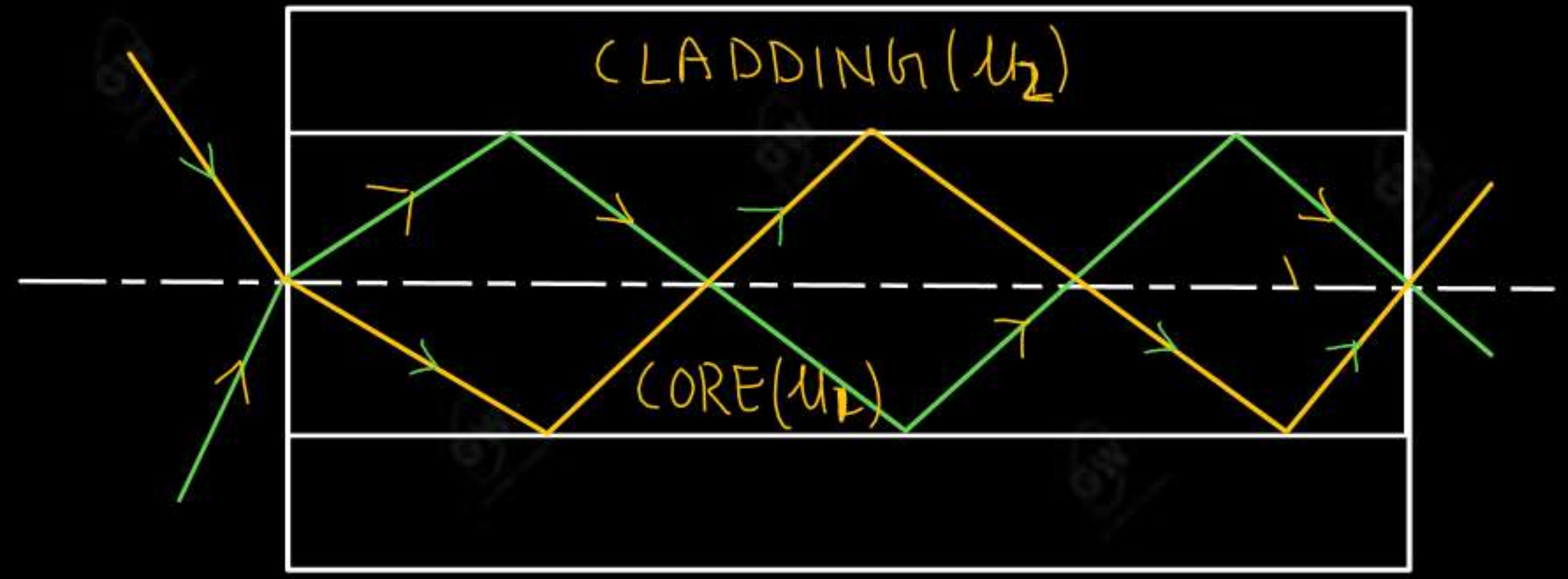
(ii) Transmission equipment is expensive (Laser diode)

(iii) Handling is difficult due to small core diameter

Step Index Multimode Fibre

- In step index multimode fibre, the refractive index of the core is uniform throughout and undergoes an abrupt step change at core cladding interface
- The multimode fibre can support large number of mode of propagation
- It has a larger core diameter (20-100 μm)
- Condition for multimode propagation in fibre is $V > 2.405$
- The difference in refractive index of core and cladding is larger than single mode fibre





Advantages and Disadvantages of step index multimode fibre

Advantages

(i) Attenuation is high

(ii) Dispersion is high

(iii) Low and limited bandwidth

(iv) Suitable for short distance communication

Disadvantages

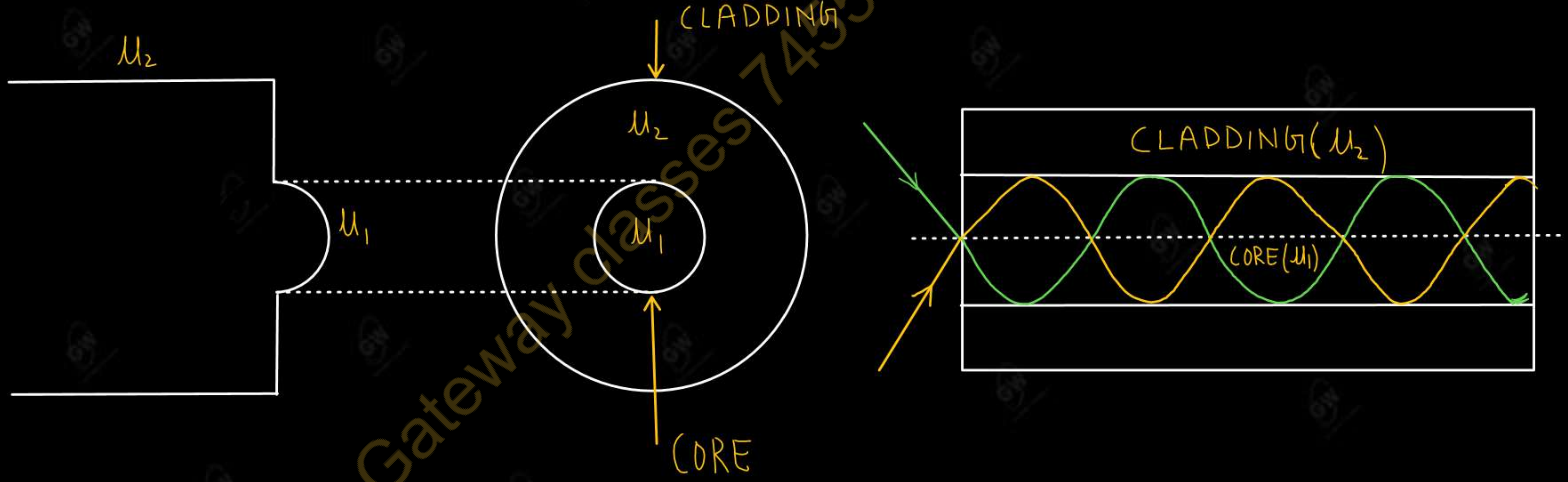
(i) Fabrication is less difficult and not costly

(ii) Transmission equipment is simple and low cost (LED)

(iii) Handling is easy due to large core diameter

Graded index multimode fibre

- In graded index multimode fibre, the refractive index in the core of the optical fibre is not uniform and it decreases gradually from maximum value at the axis of the core to minimum value at the core-cladding surface.
- Graded index fibre can be multimode only.



Advantages and Disadvantages of Graded index multimode fibre

Advantages

(i) Intermodal dispersion is less in graded index multimode fibre.

(ii) Bandwidth is greater than step index multimode fibre

(iii) Easy to couple with optical source

Disadvantages

(i) Very difficult to manufacture

(ii) Expensive

Losses in optical fiber

(i) Attenuation : Optical Power loss or Intensity loss)

(ii) Dispersion : Spreading of light or broadening of light

Attenuation

- The reduction in amplitude and intensity of a light signal as it is guided through an optical fiber is called attenuation.
- Attenuation is the loss of optical power or intensity as it propagate along a fiber.

- If P_i and P_o are the power of optical signal at input and putput end of fiber cabel having length (L), Then, Attenuation loss per unit length ($\propto$) is given by.

$$\boxed{\propto = \frac{-10}{L} \log_{10} \left(\frac{P_o}{P_i}\right)}$$

OR

$$\propto = \frac{10}{L} \log_{10} \left(\frac{P_i}{P_o}\right)$$

Unit ofAttenuation : It is measured in Decible per kilometer (dB/km)

Q.8 Calculate the fibre loss through the optical fibre when the mean optical power launched into a 5 km length of fibre is 120×10^{-6} W and the mean optical power at receiver is 4×10^{-6} W.

(AKTU : 2022-23)

α

Given

$L = 5\,km$

$P_i = 120 \times 10^{-6}\,W$

$P_o = 4 \times 10^{-6}\,W$

Fibre loss in dB/Km

$$\alpha = -\frac{10}{L}\log_{10}\left(\frac{P_o}{P_i}\right)$$

$$= -\frac{10}{5}\log_{10}\left(\frac{\cancel{4} \times \cancel{10^{-6}}}{\underset{30}{\cancel{120}} \times \cancel{10^{-6}}}\right)$$

$$= -2\log_{10}\left(\frac{1}{30}\right)$$

$$\boxed{\alpha = 2.954\ dB/km}$$

GW Q. 9 A communication system uses a 10 km fibre having loss of 2.5 dB/km. Compute the output power if the input power is 500 μW. (AKTU : 2021-22)

Given

$L = 10\,km$

$\alpha = 2.5\,dB/Km$

$P_i = 500\,\mu W$

OUTPUT POWER

$$\alpha = -\frac{10}{L}\log_{10}\left(\frac{P_o}{P_i}\right)$$

$$2.5 = -\frac{\cancel{10}}{\cancel{10}}\log_{10}\left(\frac{P_o}{500}\right)$$

$$\log_{10}\left(\frac{P_o}{500}\right) = -2.5$$

$$\frac{P_o}{500} = 10^{-2.5}$$

$$P_o = 500 \times 10^{-2.5}$$

$$\boxed{P_o = 1.58\,\mu W}$$

Q.10 An optical fibre loses 15% of its power after travelling 0.5 km through the fibre, Determine the attenuation of power in dB/km.

Given

$L = 0.5\,\text{km}$

$P_i = P$

$P_o = 0.85P$

Attenuation

$$\alpha = -\frac{10}{L}\log_{10}\left(\frac{P_o}{P_i}\right)$$

$$\alpha = -\frac{10}{0.5}\log_{10}\left(\frac{0.85\cancel{P}}{\cancel{P}}\right)$$

$$\alpha = -20\log_{10}(0.85)$$

$$\boxed{\alpha = 1.41\ \text{dB/km}}$$

Causes of Attenuation

There are three main Causes which are responsible for attenuation.

(i) Absorption loss

(ii) Scattering loss

(iii) Bending loss

Absorption loss

- The absorption of light by the core materials and impurities present in core materials of a fiber during wave propagation is the main source of attenuation.
- This type of optical attenuation arises due to conversion of optical power in to heat.
- The absorption in optical fiber is due to the following reasons.

(i) Intrinsic Absorption

(ii) Extrinsic Absorption

(iii) Imperfection in the atomic structure of the fiber material

(i) Intrinsic Absorption

- If an optical fibre were absolutely pure, with no imperfections or impuritics, then all absorptions would be intrinsic.
- Intrinsic absorption occured when pure galss core materials absorb light during propagation.

(ii) Extrinsic Absorption

- The absorption of light by the impurities present in the fibre materials.
- Mainly two types of impurities causes absorption of light propagating through fibre.

(i) Transistion metal impuritics like cobalt, manganese chromium etc.

(*ii*) Hydroxyl radical ions (OH^-).

The largest absorption loss is caused by OH^- ions.

(iii) Imperfection in the atomic structure of the fiber material

- Absorption losses are also occurred due to atomic defects in glass composition like missing molecules.
- Absorption losses due to the defects are very small as compared to impurity losses

Scattering Loss

- This is second main reason of signal attenuation in fibre.
- During the manufacturing of fibre, regions of higher and lower molecular densities are created and sometimes impurities are frozen in the glass. This become a sources of scattering of light passing through the galss.
- This results in the loss of optical power.
- It has been observed that rayleigh scattering loss is inversely proportional to the fourth power of the wavelength of incident light.

$$\boxed{\text{Scattering Loss} \propto \frac{1}{\lambda^4}}$$

- It is obious that an optical signal of shorter wavelength suffer more scattering loss than light of longer wavelength.
- Hence communication is avoided in shorter wavelength regions such as UV and visible range.

Bending Losses

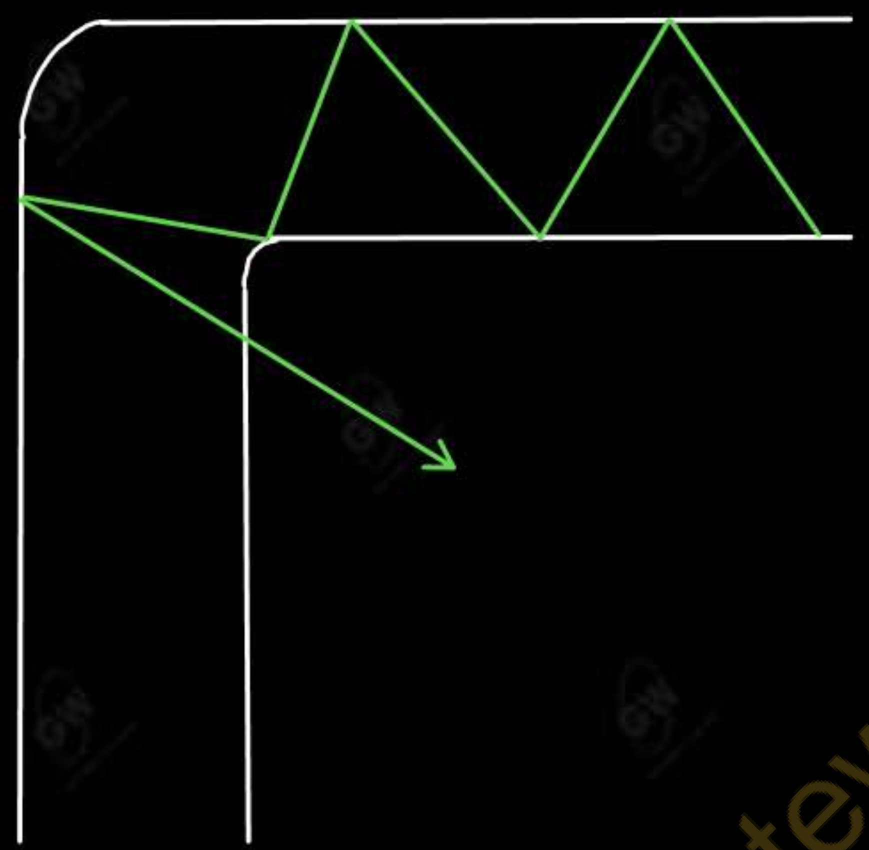
- These losses occur due to imperfections and deformation present in the fibre structure
- Bending of fibre causes attenuation, there are two types of Bending losses.

(i) Microbending Loss

- It is a loss due to small bending of fibre
- In Microbending either the core or cladding undergoes slight bends at its surface.
- These type of bends occur during manufactoring the fibre.
- It is also occur due to manufactoring defects in the fibre.

(ii) Macro – bending Loss

- It is a loss due to excessive beding of the fibre
- Macro – bending loss occur when the radius of curvature of bend is greater then fibre diameter.



Dispersion

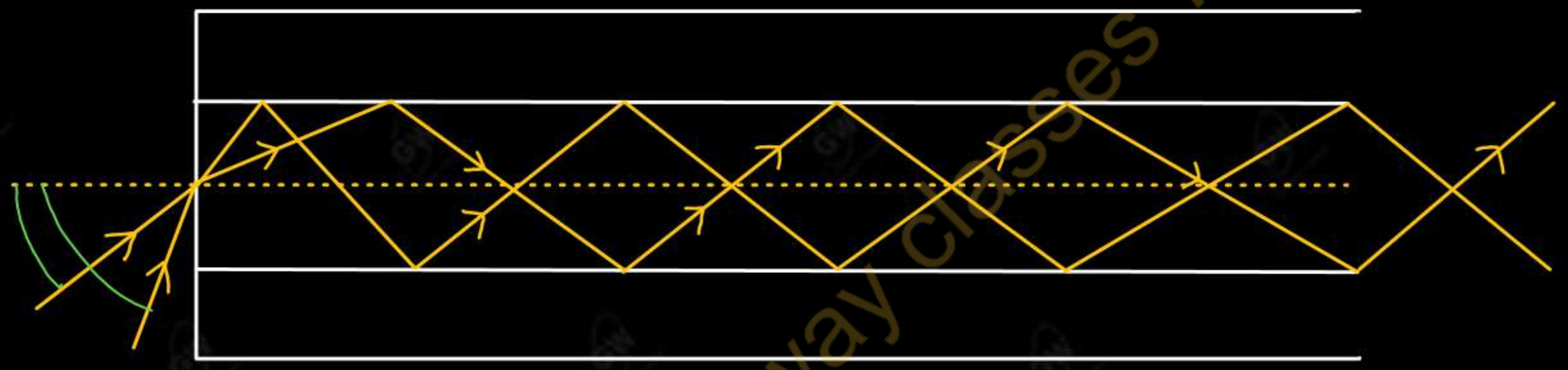
- Dispersion is defined as the signal broadening or Spreading while it propagates inside the fibre.
- Dispersion occur because of the fact that the different rays excited at the input end at one time after traversing through the fibre, exit the fibre at different time
- The spreading of the optical pulse limits the information carrying capacity of the fibre.
- There are two kinds of dispersion mechanisms in the optical fibre

Dispersion

- Intermodal Dispersion OR Modal Dispersion
- Intramodal Dispersion
  - Material Dispersion
  - Waveguide Dispersion

Intermodal Dispersion or Modal Dispersion

- Intermodal dispersion occures only in multimode fibre.
- When more than one mode is transmitting through the fibre, they will have different wavelengths and will take different time to propagate through the fibre.
- Hence, they reach the end of the fibre at different time. This results in the pulse broadining or spreading and known as intermodal dispersion.



- Rays making larger angle with the axis of the fibre take more time to traverse the length of the fibre.
- Smaller the pulse dispersion, the greater will be the information carrying capacity.

Intramodal Dispersion Or Chromatic Dispersion

Intramodal dispersion occures in all types of fibre . Ther are two types of intramodal dispersion

(i) Material Dispersion

(ii) Waveguide Dispersion

Material Dispersion

- Material Dispersion take place due to the variation of the refractive index of the core material as a function of wavelength.
- It means same fibre material offer different refractive index to light waves of different wavelengths.
- Hence, light of different wavelength travel with different velocities.

Materal Dispersion can be reduced either

(i) By reducing the spectral width

(ii) By using longer wavelength

Waveguide Dispersion

- Waveguide Dispersion is caused by the difference in the refractivbe index between the core and cladding.
- The amount of waveguide dispersion depends on the fibre design.
- Waveguide dispersion is negligible in multimode fibre but significant in single mode fibre.

Application of optical fibre

(i) In communication

- The optical fibre can be used as a medium for telecommunication and networking because it is flexible and can be bundled as cables.
- Although fibres can be made out of transparent plastic, glass, or a combination of the two, the fibres used in long-distance telecommunications applications are always glass, because of the lower optical attenuation.
- Both multimode and single-mode fibres are used in communications; multimode fibres are used mostly for short distances (up to 500m), and single-mode fibre are for longer distance links.

(ii) In optical sensors

- Optical fibres can be used as sensors to measure strain, temperature, pressure and other parameters.
- The small size and the fact that no electrical power is needed at the remote location, give the fibre optic sensor advantages over the conventional electrical sensor in certain applications.

- Optical fibres are used as hydrophones for seismic or SONAR applications.

In illumination applications

- Optical fibres are widely used in illumination applications.
- They are used as light guides in medical and other applications where bright light needs to be focused on a target without a clear line-of-sight path.

DPP-1

UNIT : Fiber Optics

Q. 1 What is an optical fibre? How does a light signal propagate through it ?

Q. 2 What is the principle of operation of an optical fibre?

Q.3 Define the relative refractive index difference of an optical fiber. Show how it is related to numerical aperture.

Q. 4 What is the condition for number of modes in single and multimode optical fibre?

Q. 5 Why model dispersion is negligible in single mode fiber?

Q. 6 What do you mean by critical angle, acceptance angle, acceptance cone and numerical aperture? Derive the expression for them.

Q. 7 What do you understand by an optical fibre and discuss its classifications. Explain their advantages and disadvantages.

Q. 8 Explain briefly the attenuation in optical fiber

Q. 9 What do you mean by scattering loss in optical fiber ?

Q.10 What do you understand by dispersion in an optical fibre?

Q.11 Describe briefly any three applications of optical fiber.

B. Tech : Engg. Physics

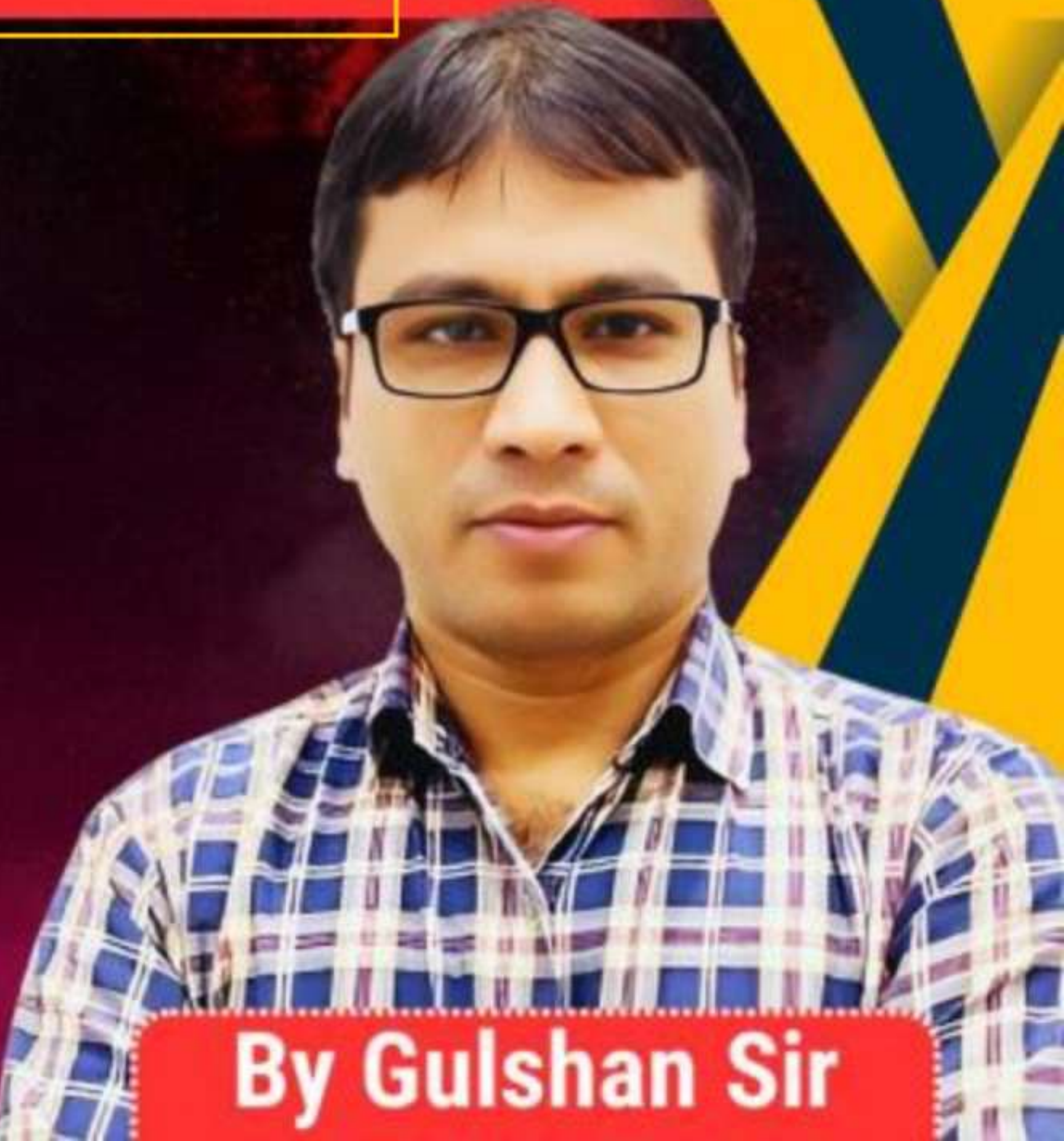
GATEWAY CLASSES

Unit : Fibre Optics and Laser

Lecture - 2

Today's Target

- LASER
- DPP
- PYQs



By Gulshan Sir

LASER

- The word "LASER" is an acronym for LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION
- Laser depends on the phenomenon of "Stimulated Emission".
- In 1917, Einstein gave the concept of "Stimulated Emission".
- Laser are invented and developed between 1959 and 1962.
- In 1960, Dr. T.H. Maiman invented first working LASER known as "RUBY LASER".

Properties of LASER

(i) Highly Monochromatic

- A LASER emits light beam of single frequency and single wavelength (single color).

(ii) Highly Intense

- All the power or energy is concentrated with in a small area

(iii) Highly Coherent

- The constituent waves are exactly in the same phase.

(iv) Unidirectional

- A laser emits light beam in one particular direction.

(v) Collimated

- All rays are parallel to each other and do not diverge significantly even over long distances.

Thus, Laser is device which emits a highly monochromatic, highly intense, highly coherent, unidirectional and collimated beam of light

Explan the following mechanism

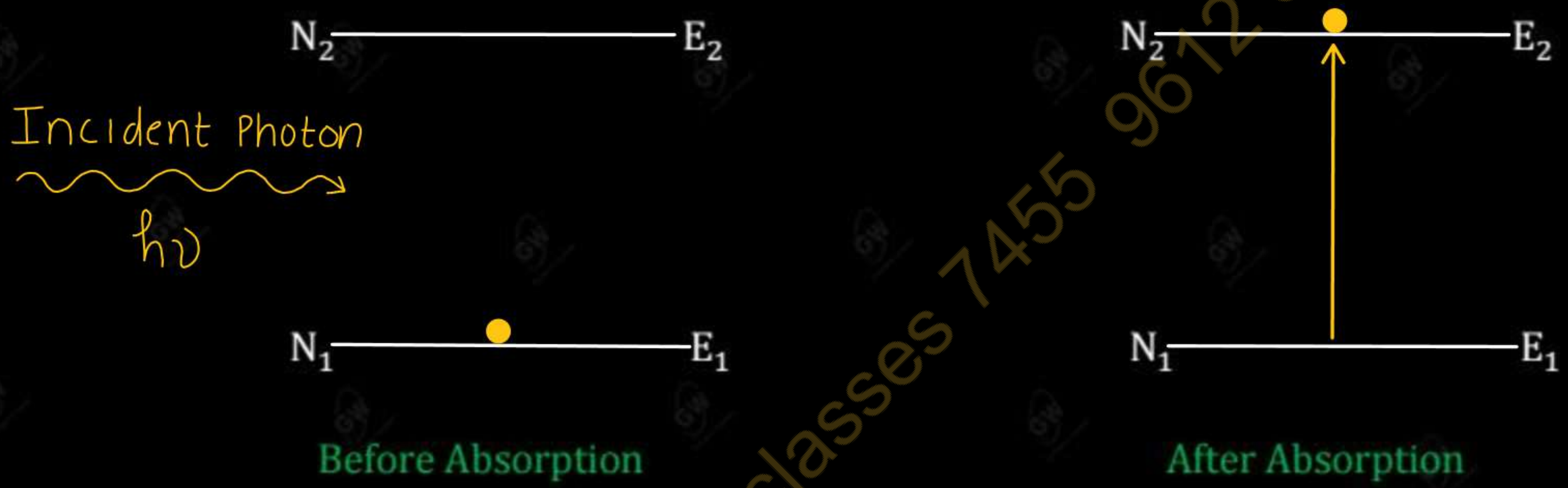
(i) Stimulated Absorption

(ii) Spontaneous Emission

(iii) Stimulated Emission

Stimulated Absorption

- Let us consider two energy level 1 and 2 of an atom with energies E_1 and E_2 as shown below



- An atom residing in the lower energy state E_1 may absorb the incident photon and jump to the higher energy state or excited state E_2, provided

$$E_2 - E_1 = h\upsilon$$

- This process is called stimulated absorption or induced absorption or absorption of radiation

The rate of absorption is directly proportional to the (i) number of atoms in lower energy state 1 (N_1) and (ii) energy density $E(\upsilon)$

$$P_{12} \propto N_1$$

$$P_{12} \propto E(\upsilon)$$

$$P_{12} \propto N_1 E(\upsilon)$$

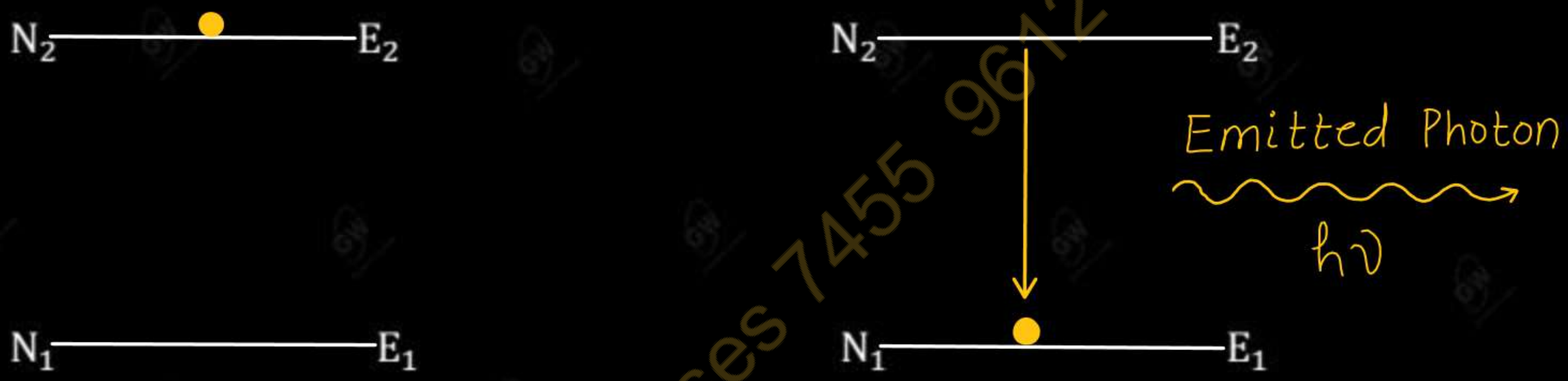
$$\boxed{P_{12} = N_1 B_{12} E(\upsilon)}$$

Where

B_{12} = Einstein's coefficient of absorption

Spontaneous Emission

- Let us suppose that the atom is in higher energy state or excited state E_2



Before spontaneous Emission

After spontaneous Emission

- The excited atom in the state E_2 returns to lower state E_1 to attain stability
- The mean life of atom in excited state is 10^{-8} seconds.
- During this transition atom will release a photon of energy hυ such that

$$E_2 - E_1 = h\upsilon$$

- This type of process in which photon emission occurs without any interaction with external radiation is called spontaneous emission.
- The rate of spontaneous emission is directly proportional to the number of atoms in excited state (N_2)

$$P'_{21} \propto N_2$$

$$\boxed{P'_{21} = N_2 A_{21}}$$

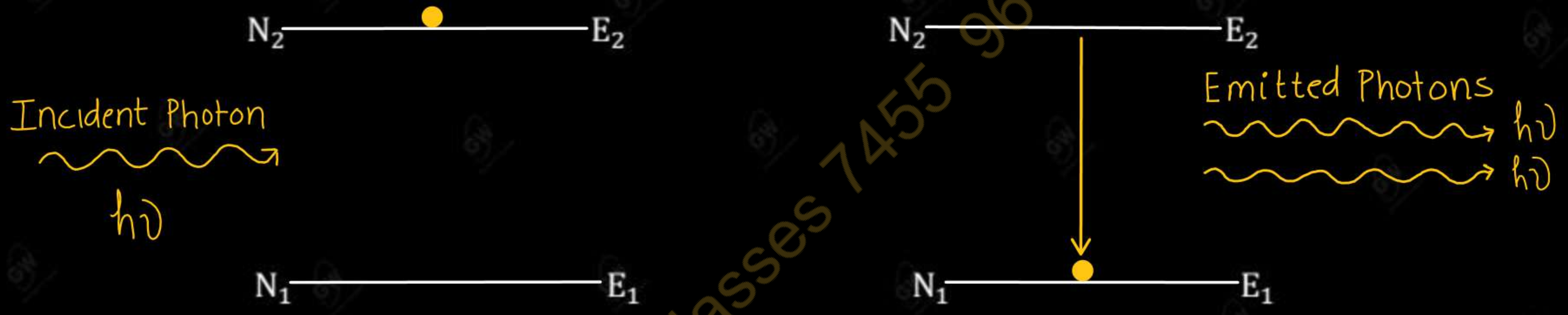
Where

A_{21} = Einstein's coefficient of spontaneous emission

- Ordinary light is obtained from spontaneous emission

Stimulated Emission

- As suggested by Einstein's in 1917, an atom in excited state E_2 can also make transition to lower energy state E_1 when triggered by photon of energy $h\upsilon$.



Before Stimulated Emission

After Stimulated Emission

- This transition produces a second photon which is identical to incident photon with respect to frequency, phase and propagation direction. This process is called stimulated emission

➢ The rate of stimulated emission is directly proportional to the (i) number of atoms in excited state (N_2) and (ii) energy density $E(\upsilon)$

$$P''_{21} \propto N_2$$

$$P''_{21} \propto E(\upsilon)$$

$$P''_{21} \propto N_2 \quad E(\upsilon)$$

$$\boxed{P''_{21} = N_2 B_{21} E(\upsilon)}$$

Where

B_{21} = Einstein's coefficient of stimulated emission

➢ LASER light is obtained from stimulated emission

Difference between Spontaneous Emission and Stimulated Emission

Spontaneous Emission	Stimulated Emission
1. Emitted photons can move in any directions.	1. Emitted photons move in same directions.
2. Emitted radiations are not coherent.	2. Emitted radiations are coherent
3. Emitted photons from various atoms have no phase relationship between them	3. Emitted photons have same frequency and are in phase with incident photons. .
4. The rate of spontaneous emission is directly proportional to the number of atom in excited state (N_2)	4. The rate of stimulated emission is directly proportional to the number of atoms in excited state (N_2) and energy density $E(\upsilon)$
5. Ordinary light is obtained from spontaneous emission	5. LASER light is obtained from stimulated emission

Relation between Einstein's Coefficients

- Let N_1 and N_2 be the number of atoms at any instant in the lower energy State 1 and Higher energy State 2

- The rate of absorption is directly Proportional to the

  (i) The number of atom in State 1 (N_1)

  (ii) Energy Density $E(\nu)$

$$P_{12} \propto N_1$$

$$P_{12} \propto E(\nu)$$

$$P_{12} \propto N_1 E(\nu)$$

$$P_{12} = N_1 B_{12} E(\nu) \quad \text{——— (1)}$$

- The rate of spontaneous emission is directly proportional to the number of atoms in excited State (N_2)

$$P'_{21} \propto N_2$$

$$P'_{21} = N_2 A_{21} \quad \text{——— (2)}$$

- The rate of Stimulated emission is directly proportional to the

(i) Number of atoms in Excited State(N_2)

(ii) Energy Density $E(\nu)$

$$P''_{21} \propto N_2$$

$$P''_{21} \propto E(\nu)$$

$$P''_{21} \propto N_2 E(\nu)$$

$$P''_{21} = N_2 B_{21} E(\nu) \quad \text{—— (3)}$$

Under thermal Equilibrium

$$P_{12} = P'_{21} + P''_{21}$$

$$N_1 B_{12} E(\nu) = N_2 A_{21} + N_2 B_{21} E(\nu)$$

$$N_1 B_{12} E(\nu) - N_2 B_{21} E(\nu) = N_2 A_{21}$$

$$(N_1 B_{12} - N_2 B_{21}) E(\nu) = N_2 A_{21}$$

$$E(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$E(\nu) = \frac{\cancel{N_2} A_{21}}{\cancel{N_2} B_{21}\left(\frac{B_{12}}{B_{21}} \times \frac{N_1}{N_2} - 1\right)}$$

$$E(\nu) = \frac{A_{21}}{B_{21}\left(\frac{B_{12}}{B_{21}} \times \frac{N_1}{N_2} - 1\right)} \quad \text{—— (4)}$$

According to Botlzmann's Distribution Law

$$\frac{N_1}{N_2} = e^{\frac{E_2 - E_1}{KT}}$$

$$\boxed{\frac{N_1}{N_2} = e^{\frac{h\nu}{KT}}} \quad \text{—— (5)}$$

V. imp

Using (5) in (4)

$$E(\nu) = \frac{A_{21}}{B_{21}\left(\frac{B_{12}}{B_{21}} \times e^{\frac{h\nu}{KT}} - 1\right)} \quad \text{—— (6)}$$

According to Planck's Radiation Law

$$E(\nu) = \frac{8\pi h\nu^3}{c^3} \times \frac{1}{\left(e^{\frac{h\nu}{KT}} - 1\right)} \quad \text{—— (7)}$$

Comparing (6) and (7)

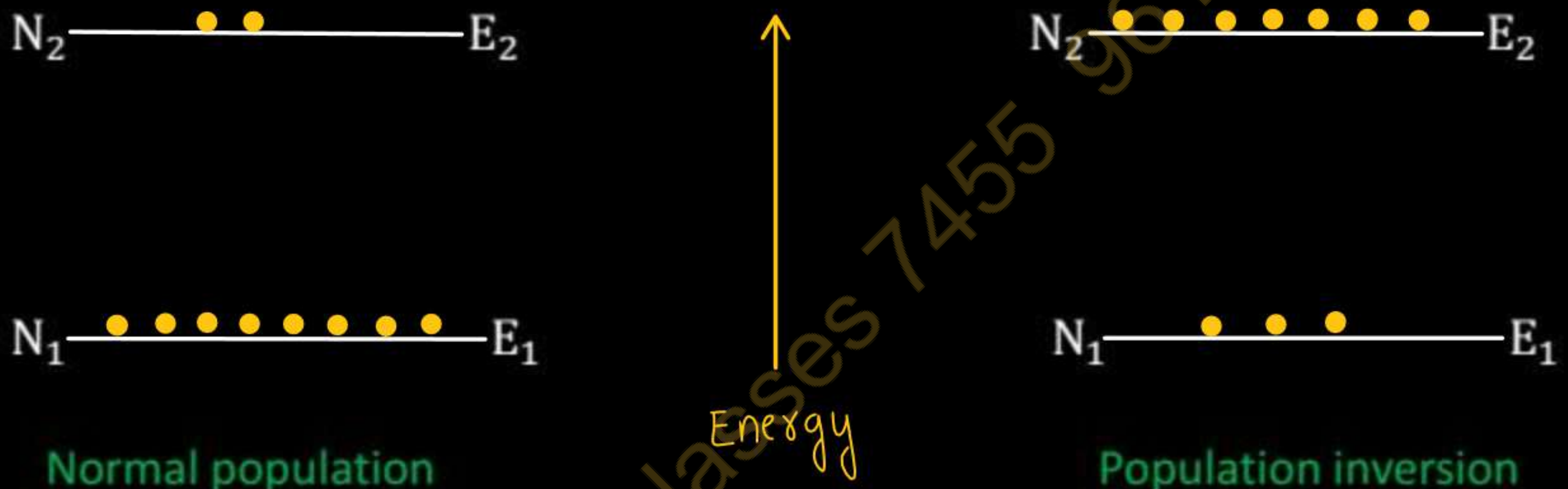
$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}}$$

$$\frac{B_{12}}{B_{21}} = 1$$

$$\boxed{B_{12} = B_{21}}$$

Population Inversion

- The situation in which the number of atoms in the higher energy state becomes comparatively greater than the number of atoms in the lower energy state is known as population inversion



Normal population

$N_1 > N_2$

Population inversion

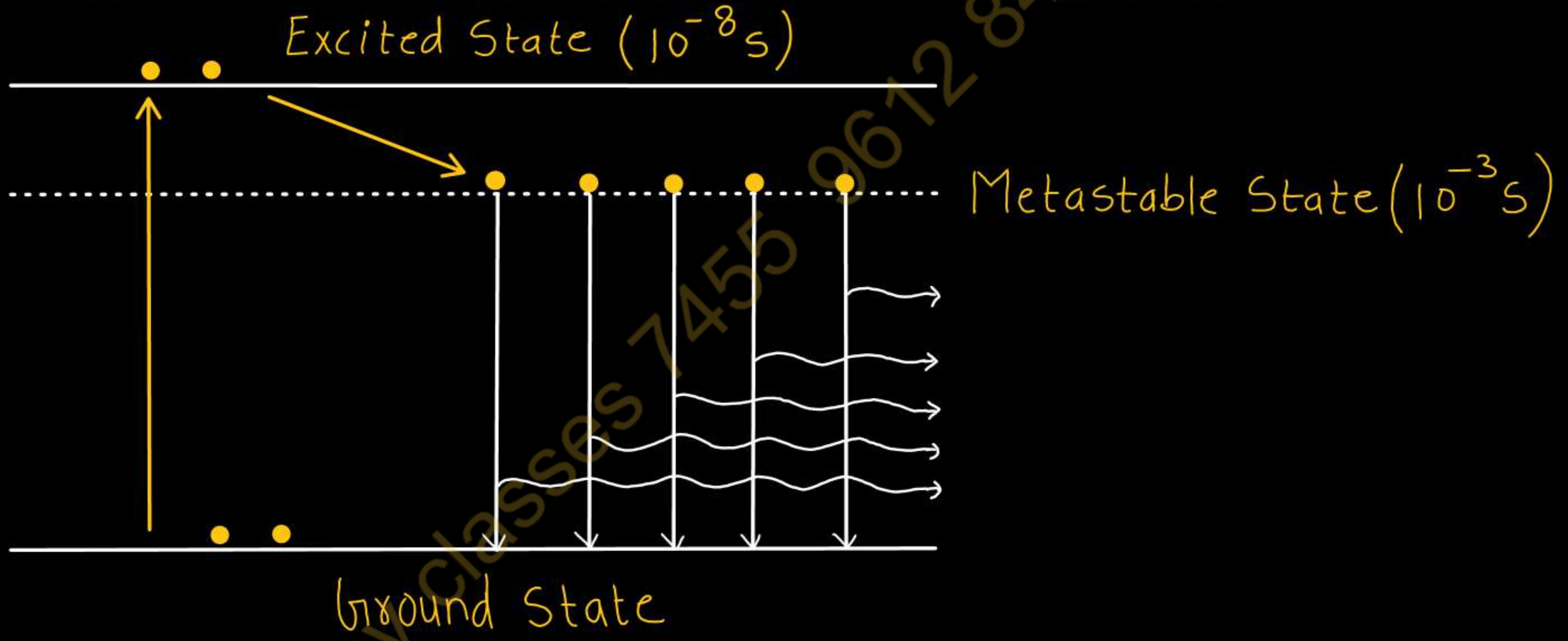
$N_1 < N_2$

- For laser action to take place, the higher energy level should be more populated than the lower energy level. i.e

$$N_2 > N_1$$

Metastable State

- Metastable State can be defined as a state where excited atom can remain for longer time than the normal excited state.



- It is also the excited state but having life time of 10^{-3} seconds.
- The population inversion occurs only in between the metable state and lower state.
- If metastable state do not exist, there could be no population inversion, no stimulated emission and hence no laser operation.

Necessary condition to achieve laser action

(i) The rate of emission must be greater than the rate of absorption

- Under normal condition, the number of atoms in the upper energy level is always smaller than that in lower energy level. If by some means, the number of atoms in higher energy state is made greater than that in lower energy state, the emission rate will become greater than the absorption rate.

(ii) The probability of spontaneous emission must be negligible in comparison to the probability of stimulated emission

- The condition can be achieved by taking working substance (active medium) such that its atoms have metastable states which have a lifetime 10^{-3} sec or more instead of the usual 10^{-8} sec. If certain atoms are excited to metastable state the probability of spontaneous emission will be quite negligible.

(ii) The coherent beam of light must be sufficiently amplified

- For this, active medium must be placed between two reflecting mirrors. The one of the mirror is fully reflecting while the other is partially transmitting.

Pumping

- The process by which we can raise the number of atoms from lower energy state to Higher state is known as pumping.

Two important method of pumping

(i) Optical Pumping

- In optical pumping the energy is supplied in the form of short flashes of light .
- The ground state atoms absorb this light energy and excite to higher energy state.
- This type of pumping is used in Ruby Laser

(ii) Electrical Pumping

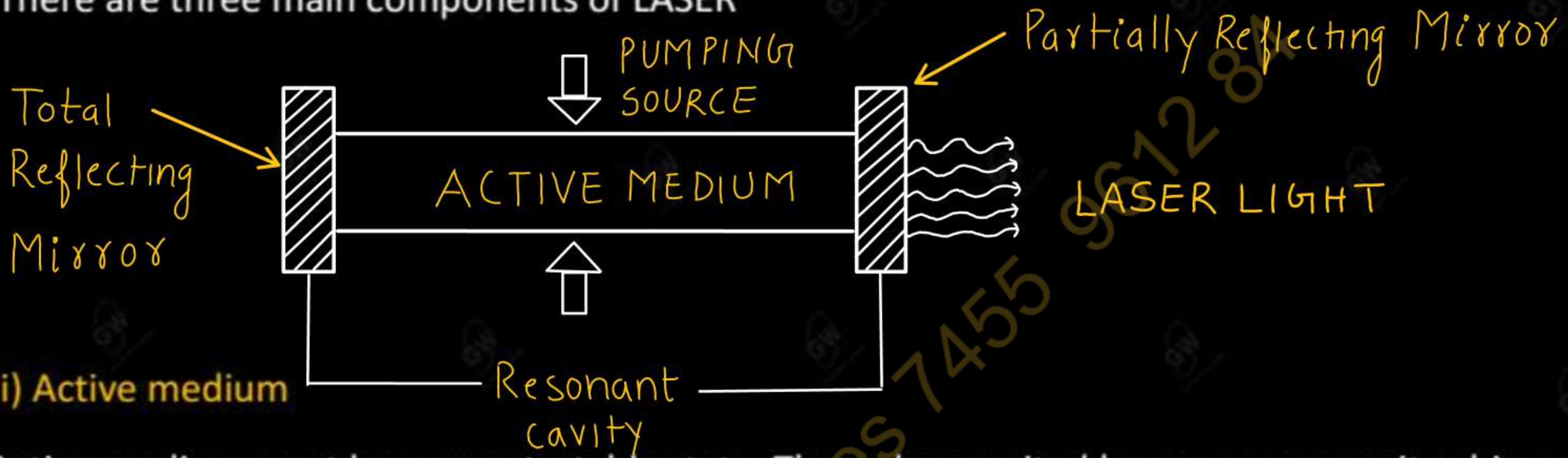
- In this method gas is ionized by means of suitable potential difference.
- Strong electric is applied to accelerate electrons emitted by cathode of the tube.
- During the motion towards the anode the accelerated electrons collide with the atoms of the medium and give up their energy to excite them to upper energy level.
- This type of pumping is used in Helium – Neon Laser

Principle of LASER

- All lasers work on the principle of "STIMULATED EMISSION" OF RADIATION with LIGHT AMPLIFICATION
- The ground state atom absorbs energy from external source and raise to higher state
- Due to short life (10^{-8} sec) of excited state, it spontaneously comes down to metastable state of long life (10^{-3} sec).
- Thus population inversion is achieved.
- A spontaneously emitted photon trigger other atoms of metastable state and initiating stimulated emission.
- The light beam is then amplified by the cavity resonator by multiple reflections between a pair of mirrors. This way, amplified laser beam is achieved.

Components of LASER

There are three main components of LASER



(i) Active medium

- Active medium must have a metastable state. Thus when excited by energy source it achieves population inversion.
- Active medium decide the types of laser:

(i) Solid laser

(ii) Liquid laser

(iii) Gas laser

(ii) Pumping source (or Energy source)

- With the help of energy source the system can be raised to an excited state.
- With the help of this source the number of atoms in higher energy state may be increased and hence the population inversion is achieved.

(iii) Resonant Cavity or Optical Resonator

- The optical resonator consists of two reflecting mirrors R_1 and R_2
- The mirror R_1 is fully reflecting while the other mirror R_2 is partially reflecting
- Active medium is placed between R_1 and R_2
- These mirror act as an optical resonator or resonant cavity

EINSTEIN'S COEFFICIENTS

- The Einstein's coefficients are mathematical quantities describing the probability of absorption and emission of a photon by an atom or molecule

  There are three Einstein's Coefficients

(i) B_{12} : Einstein's coefficient for Stimulated Absorption

(ii) A_{21}: Einstein's coefficient for Spontaneous Emission

(iii) B_{21}: Einstein's coefficient for Stimulated Emission

Three Level Lasers

In this laser system

E_1 : Ground State (Known as lower lasing level)

E_2 : Metastable State (Known as upper lasing level)

E_3 : Excited State (Known as pumping level)

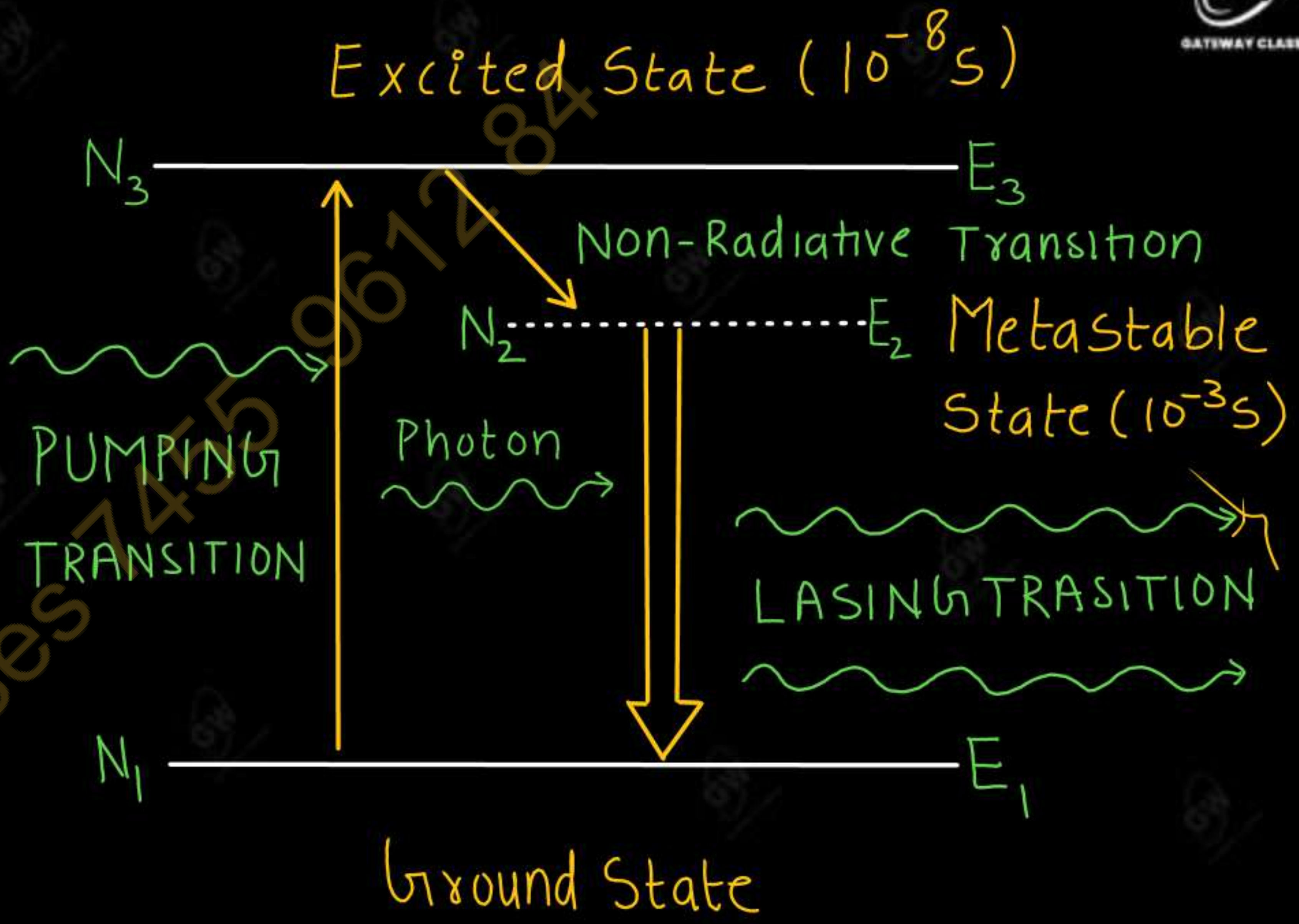
TRANSITIONS

1 - 3 : Pumping Transitions

3 - 2 : Non Radiative Transitions

2 - 1 : Spontaneous Emission

2 - 1 : Stimulated Emission



- The source of pumping excites some of the atoms from the ground level E_1 to a short lived (10^{-8}s) upper most pumping level E_3.

- Some of these atoms make spontaneous transition to the lowest energy level E_1 but most of them decay rapidly into an intermediate metastable state $\mathrm{E_2}$. This transition from E_3 to E_2 is radiation less or non-radiative.
- As the energy level E_2 is long lived, the atomic population of metastable state $\mathrm{E_2}$ goes on increasing gradually, while the atomic population of ground level $\mathrm{E_1}$ goes on decreasing. Because of continuous pumping the population inversion is achieved between $\mathrm{E_2}$ and $\mathrm{E_1}$ levels.
- Now photon of energy $\mathrm{h}\nu = (E_2 - E_1)$ can initiate stimulated or laser transition.

Example : Ruby Laser

Disadvantage of three level laser : Difficult to produce population inversion because it requires very high pumping power

Four Level Lasers

In this laser system

E_1 : Ground State

E_2 : Lower Lasing level (Lower Metastable State)

E_3 : Metastable State (or known as upper lasing level)

E_4 : Excited State (or known as pumping lasing level)

TRANSITIONS

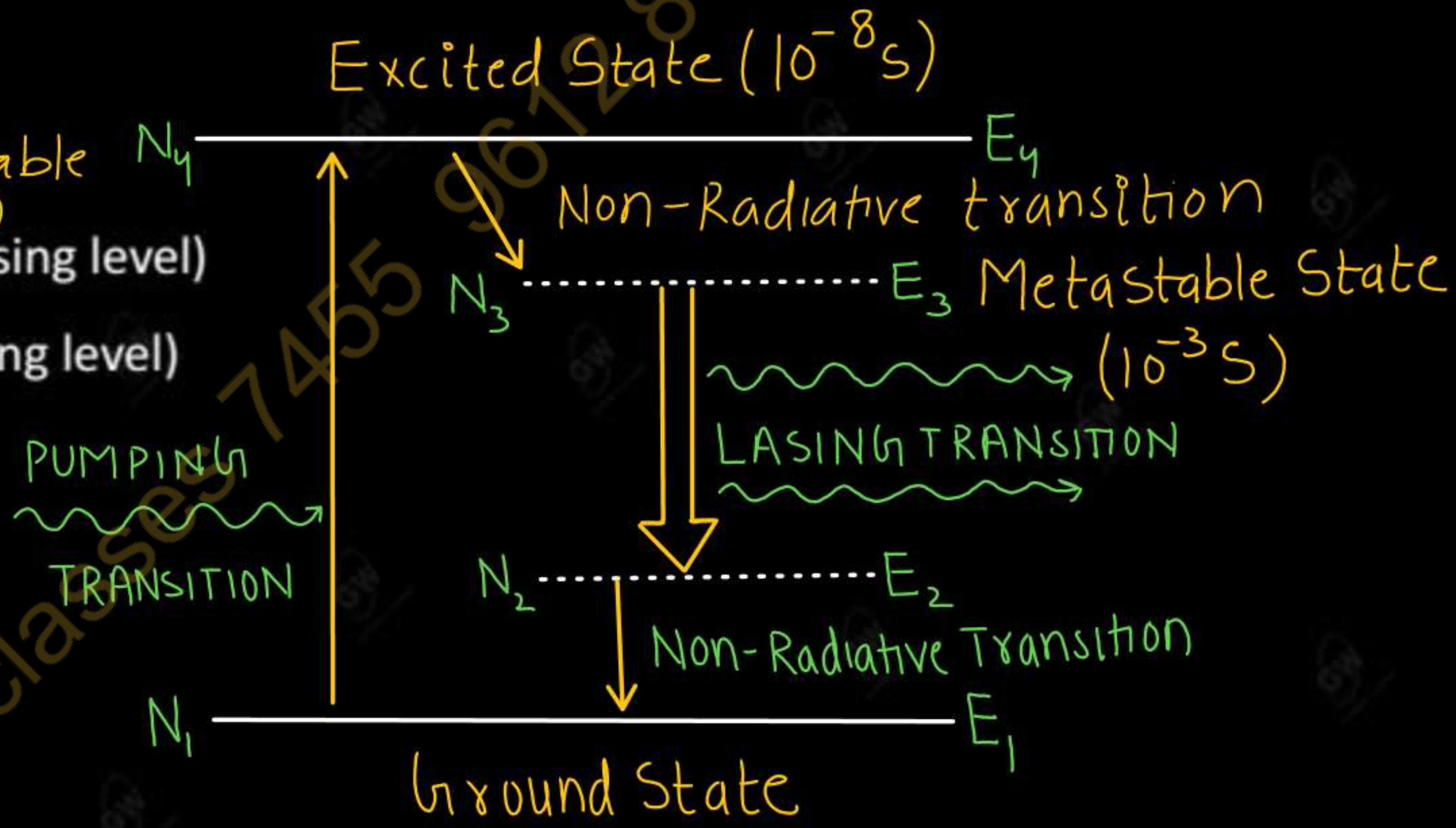
1 - 4 : Pumping Transitions

4 - 3 : Non Radiative Transitions

3 - 2 : Spontaneous Emission

3 - 2 : Stimulated Emission

2 - 1 : Fast Transitions



- The source of pumping excites some of the atoms from the ground level E_1 to a short lived upper most pumping level E_4.
- The transitions E_4 to E_3 as well as E_2 to E_1 are radiation less transition and much faster as compared to E_3 to E_2
- As the lower lasing level E_2 is not the ground state, but very much above the ground level E_1, it is virtually vacant or free from any atoms. Due to continuous pumping, population inversion is achieved between the levels E_3 and E_2. A spontaneous photon of energy $h\nu = E_3 - E_2$ can initiate a chain of stimulated emission.

Advantage of four level Laser over three level Laser

- The pumping power needed for the excitation of atoms is much lower than is a three level laser.
- The efficiency of four level laser is much better than that of a three level laser.
- Continuous operation is possible

Ruby Laser

- This is the first laser developed by T.H Maiman in 1960.
- The main characteristics of Ruby Laser are

(i) It is a solid state laser.

(ii) It is a three level laser.

(iii) Population inversion is achieved by using optical pumping.

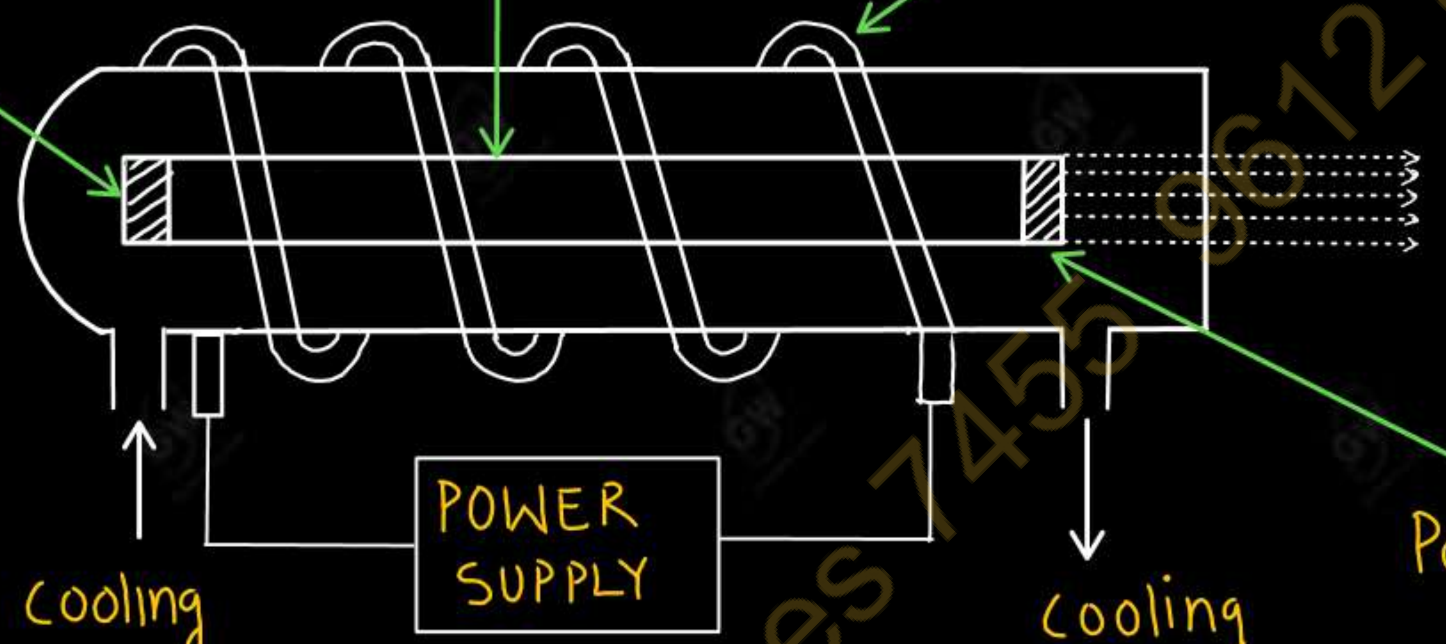
(iv) Output is in pulse form.

(v) External cooling is required

Construction

(i) Active Medium

- Ruby Rod is used as an active medium.
- Ruby rod is a crystal of aluminium oxide (Al_2O_3) doped with 0.05% of chromium oxide (Cr_2O_3).
- Some Al^{3+} ions are replaced by Cr^{3+} ions and these Cr^{3+} ions give pink colour to the ruby rod.
- Cr^{3+} ions act as active centres and responsible for laser action.



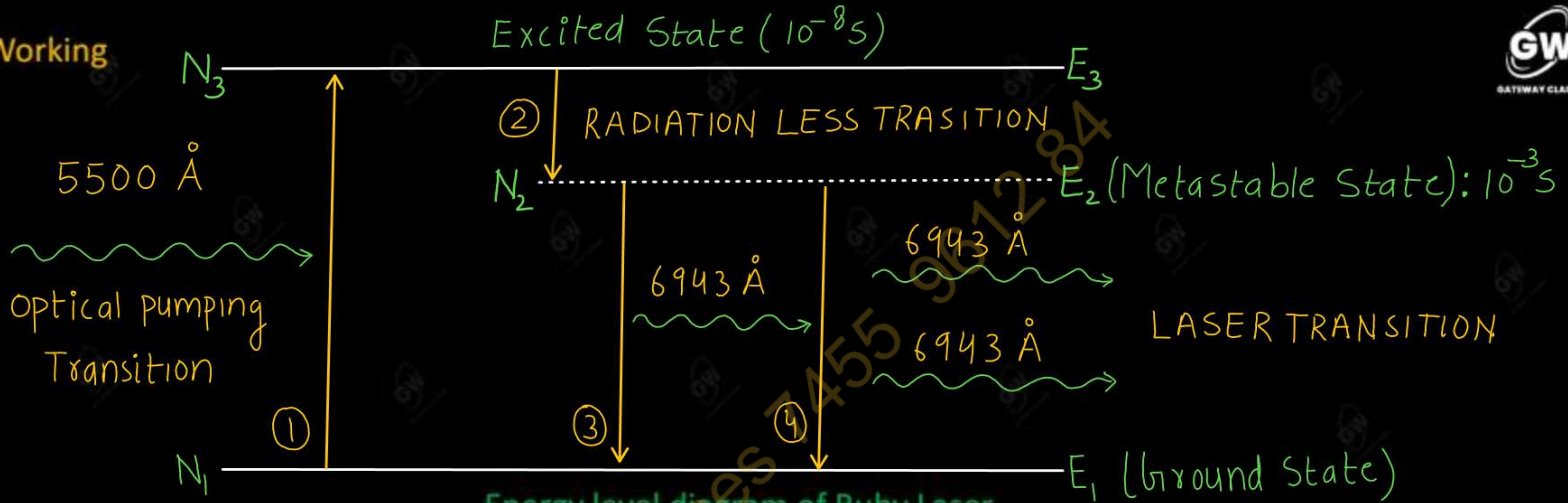
(ii) Pumping Source

- The Ruby rod is placed inside a helical shaped xenon flash lamp to excite the Cr^{3+} ions. Thus in ruby laser population inversion is achieved by using optical pumping.

(iii) Resonant Cavity

- The Ruby crystal is taken in the form of cylindrical rod and its ends are optically flat and parallel.
- One end of the ruby rod is coated with silver completely while the other one is partially silvered.
- These two silver coated ends of the ruby rod act as a Resonant Cavity.

Working



Energy level diagram of Ruby Laser

- Ruby Laser is a three level laser system and its energy level diagram consist of

  E_1 : Ground state

  E_2 : Metastable state

  E_3 : Excited state

- The energy difference $E_3 - E_1$ corresponds to a wave length of 5500 Å.

- Most of the Chromium ions are in the ground state E_1. After absorbing light (Photons) of wavelength 5500 Å from xenon flash lamp, some of the Cr^{3+} ions at ground energy level E_1 jump to higher energy level E_3. This is known as Pumping transition
- At Higher energy level (E_3), Cr^{3+} ions are unstable and by loosing a part of their energy to the crystal lattice, they fall metastable state E_2. This is known as Non-radiative transition.
- Since E_2 has a much longer life time (about 10^{-3} s), the number of Cr^{3+} ions goes on increasing in E_2 state while the number of these ions in ground state E_1 goes on decreasing due to pumping by the flash lamp. Thus population inversion is established between the metastable state E_2 and ground state E_1.
- Now, some of the Cr^{3+} ions will fall spontaneously to the ground state E_1 by emitting photons of wavelength 6943 Å. This is known as Spontaneous Emission
- The photons that are moving parallel to the axis of the rod will reflect back and forth by the silvered ends of the rod and stimulate other excited Cr^{3+} ions to radiate another photons with the same phase. This is known as Stimulated Emission

- Thus, due to successive reflection of these photons at the ends of the rod, the number of photons multiply. After a few microseconds, a monochromatic, intense, coherent, unidirectional and collimated beam of red light of wavelength 6943 Å emerges through the partially silvered end of the rod. Output is in pulse form.

Drawbacks

(i) The output of LASER is not continuous and occurs in the form of pulse.

(ii) It requires greater excitation in order to achieve population inversion.

(iii) Low efficiency.

(IV) External cooling is required

Helium-Neon Laser

- Ali Javan invented He-Ne gas laser in 1960. It is the first gas laser which was operated successfully.
- Main characteristics of He-Ne Laser

(i) It is a gas laser

(ii) It is a four level laser

(iii) Population inversion is achieved by using electrical pumping.

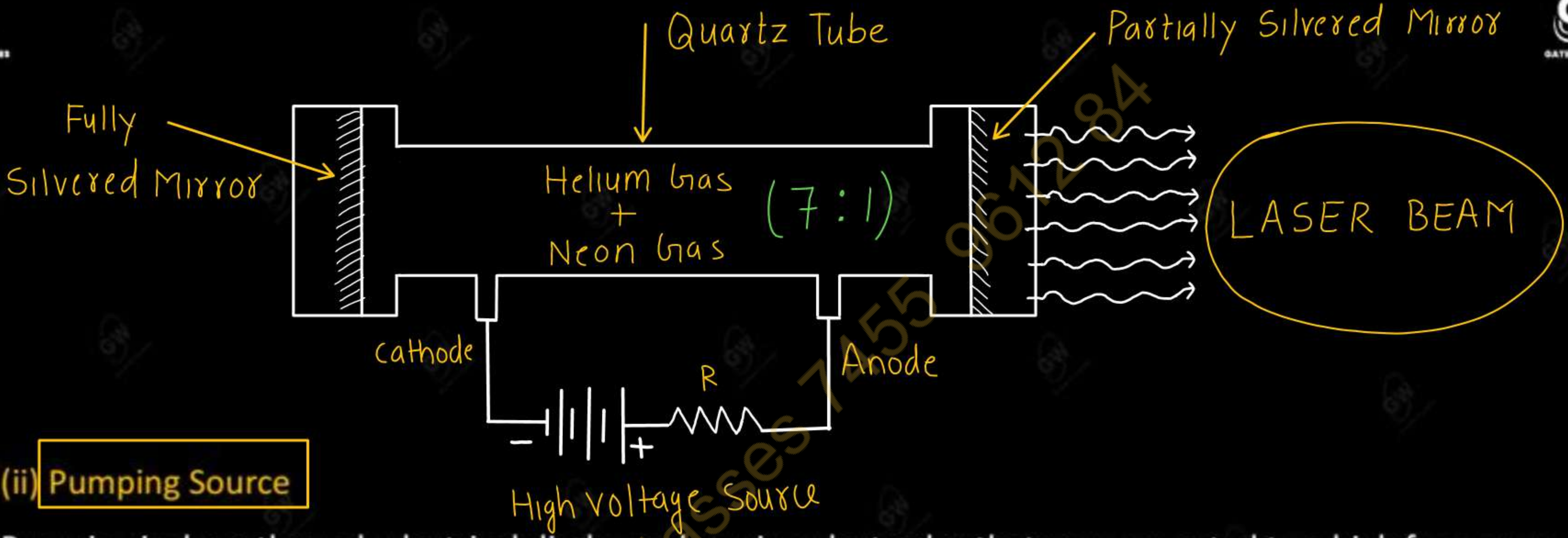
(iv) Output is in continuous form.

(v) External cooling is not required

Construction

(i) Active Medium

- He-Ne gas laser consist of a narrow quartz tube filled with a mixture of Helium and Neon in the ratio of 7:1 respectively at low pressure.
- Ne atoms act as active centres and responsible for the laser action while He atoms are used to help in the excitation process.



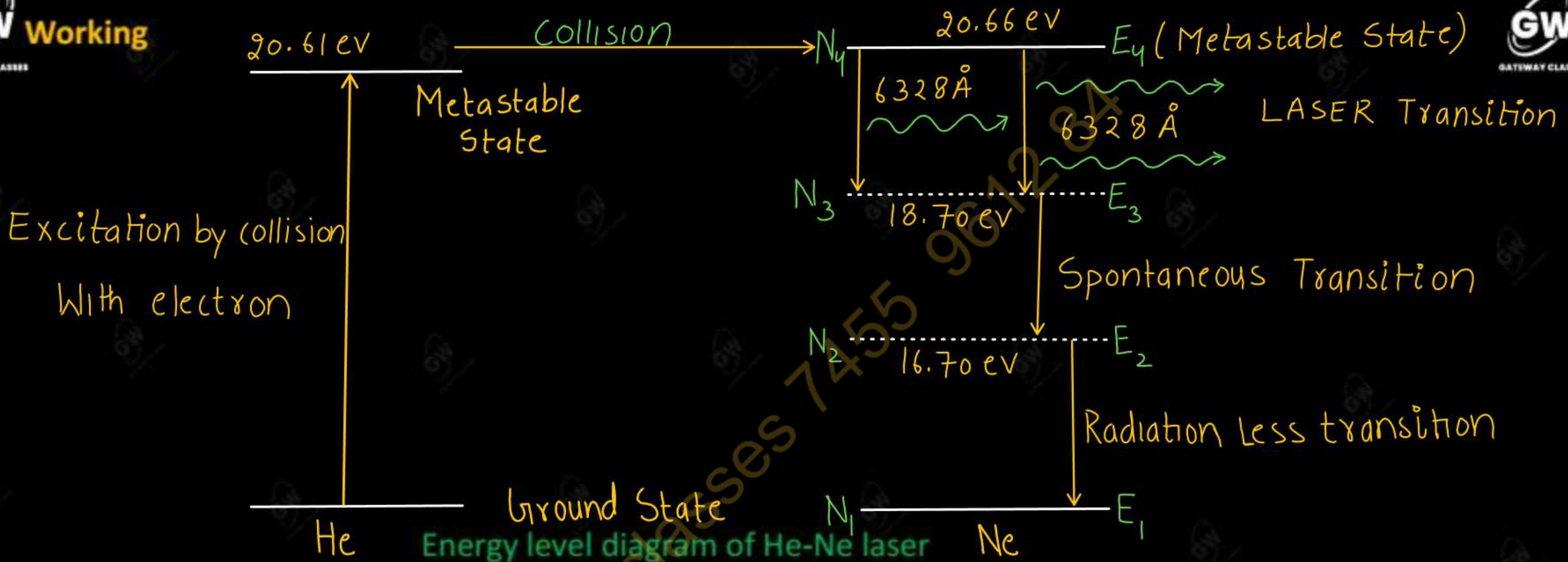
(ii) Pumping Source

➢ Pumping is done through electrical discharge by using electrodes that are connected to a high frequency alternating source.

(iii) Resonant Cavity

➢ To construct Resonant Cavity, two parallel mirrors are placed at the ends of the quartz tube one of them is partially reflecting while the other is fully reflecting.

Working



Energy level diagram of He-Ne laser

- He – Ne Laser is a four energy level laser system. The electrons produced from electric discharge collide with He and Ne atom and Excite or pump them to higher energy level (Metastable state) at 20.61 ev and 20.66 ev respectively.

As He atoms are lighter than the Ne atoms, they are easily excite to metastable state at 20.61 ev.

Some of the excited He atoms transfer their energy to the ground state Ne atoms by collision, with 0.5 ev of additional energy being provided by the K.E. of atoms.

$$He + e \rightarrow He^*$$

$$He^* + Ne \rightarrow Ne^* + He$$

Thus He atoms help in achieving a population inversion in Ne atoms.

- When an exited Ne-atoms drop down spontaneously from metastable state at 20.66 ev to lower energy state at 18.70 ev, it emits a 6328 Å photon in visible region.
- This photon travels through the mixture of gas and if it is moving parallel to the axis of tube is reflected back and forth motion by reflector ends until it stimulates an excited Ne-atom and causes it to emit a fresh 6328 Å photon in phase with stimulating photon. The stimulated transition from 20.66 ev level to 18.70 ev level is the laser transition.

- Thus, due to successive reflections of these photons at the ends of the tube the number of photon multiplies. After a few microseconds a monochromatic, intense, coherent, unidirectional and collimated beam of red light of wavelength 6328 Å emerges through the partially silvered mirror.
- The Ne-atoms drop down from 18.70 ev to lower metastable state through spontaneous emission by emitting in coherent light.
- From level E_2 Ne atoms come to ground state by losing their remaining energy through collision with the tube walls. Hence, final transition is radiation less.

Applications of Laser

- In medicine laser beam is used in treatment of kidney stone, cancer, eye – surgery, cornea etc.
- The laser beam is used for drilling, welding and melting of hard materials like diamonds, iron, steel, etc.
- It is used in heat treatments for hardening or annealing in metallurgy.
- Laser is used in holography and fiber optics
- Laser is very useful in science and research areas.
- Laser is used for communications and measuring large distances.
- Semiconductor lasers is used for recording and erasing of data on compact disks.
- Semiconductor laser and helium-neon lasers are used to scan the universal barcodes to identify products in supermarket scanners.
- During war-time, lasers are used to detect and destroy enemy missiles. Now, laser-pistols, laser-rifles and laser bombs are also being made, which can be aimed at the enemy in the night.

Q. 1 In a Ruby laser, total number of Cr^{3+} ions is 2.8×10^{19}. If the laser emits radiation of wavelength 7000Å, then calculate the energy of the laser pulse.

$$\boxed{\nu = \frac{c}{\lambda}}$$

Given

Number of Cr^{3+} ions (n)

$n = 2.8 \times 10^{19}$

$\lambda = 7000\,\text{Å} = 7000 \times 10^{-10}\,m$

$h = 6.62 \times 10^{-34}\,J\text{-}s$

$c = 3 \times 10^{8}\,m/s$

We know that

Energy of Laser Pulse (E) = Number of ions × Energy of one photon

$$E = nh\nu$$

$$E = \frac{nhc}{\lambda}$$

$$E = \frac{2.8 \times \cancel{10^{19}} \times 6.62 \times \cancel{10^{-34}} \times 3 \times \cancel{10^{8}}}{7 \times \cancel{10^{-7}}}$$

$$\boxed{E = 7.94\,J}$$

Q.2 Calculate the population ratio of two states in He – Ne laser that producers light of wavelength 6000Å at 300K.

Given

$\lambda = 6000\text{Å} = 6000 \times 10^{-10} m$

$T = 300 K$

K = Boltzmann's constant

$K = 8.6 \times 10^{-5} eV/K$

$K = 8.6 \times 10^{-5} \times 1.6 \times 10^{-19} J/K$

We know that

$$\frac{N_2}{N_1} = e^{\frac{-(E_2-E_1)}{KT}} = e^{\frac{-h\nu}{KT}}$$

$$\frac{N_2}{N_1} = e^{\frac{-hc}{\lambda KT}}$$

$$\frac{N_2}{N_1} = e^{\frac{-6.62 \times \cancel{10^{-34}} \times 3 \times \cancel{10^{8}}^{\,3}}{60\cancel{00} \times \cancel{10^{-10}} \times 8.6 \times \cancel{10^{-5}} \times 1.6 \times \cancel{10^{-19}} \times 3\cancel{00}}}$$

$$\boxed{\frac{N_2}{N_1} = e^{-80}}$$

Q.3 Calculate the energy and momentum of a photon of a laser beam of wavelength 6328 Å

Given

$\lambda = 6328\,\text{Å}$

$h = 6.62 \times 10^{-34}\ J\text{-}S$

$c = 3 \times 10^{8}\ m/s$

Energy of photon (E)

$E = h\nu$

$$E = \frac{hc}{\lambda}$$

$$E = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{6328 \times 10^{-10}}$$

$$\boxed{E = 3.14 \times 10^{-19}\ J}$$

$$E = \frac{3.14 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\boxed{E = 1.962\ eV}$$

Momentum of Photon (P)

$$P = \frac{h}{\lambda}$$

$$P = \frac{6.62 \times 10^{-34}}{6328 \times 10^{-10}}$$

$$\boxed{P = 1.05 \times 10^{-27}\ kgm/s}$$

Engineering Physics (By Gulshan Sir)

LASER (DPP-2)

GW GATEWAY CLASSES

Q.1 What is the principle of laser?

Q.2 Difine Population inversion in LASER

Q.3 Write the essential requirements for laser action.

Q.3 Define metastable state.

Q.2 Differentiate between spontaneous and stimulated emission of radiation. Which one is required for laser action?

Q.4 What are Einstein's coefficients? Obtain a relation between them.

Q.5 What do you understand by three and four level lasers? What is the advantage of three level laser over four level laser?

Q.6 What are solid state lasers? Explain the construction and working of Ruby laser with suitable diagram. Compare if with He – Ne laser?

Q.7 Draw a neat diagram of He – Ne laser and describe its method of working. How it is superior to Ruby Laser ?

Q.8 Discuss important applications of laser.

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Thank You