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# Dr. M.G.R

## EDUCATIONAL AND RESEARCH INSTITUTE

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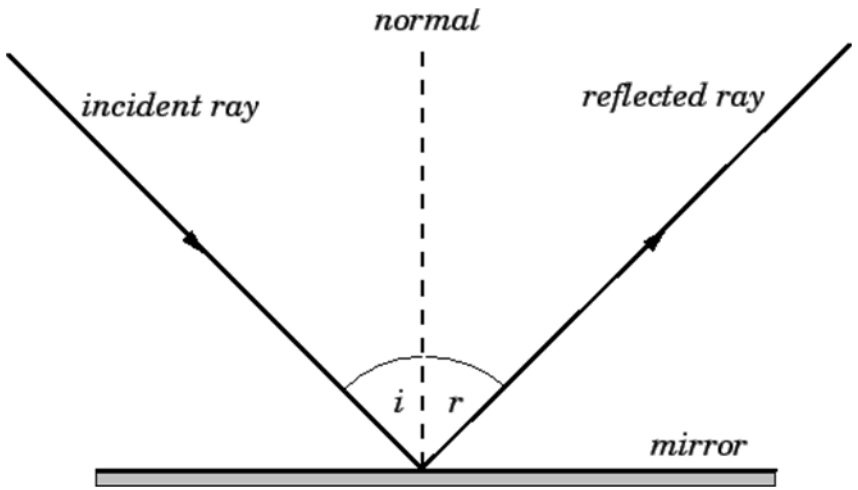
Maduravoyal, Chennai - 600 095, Tamilnadu, INDIA

# Laser

# Law of reflection

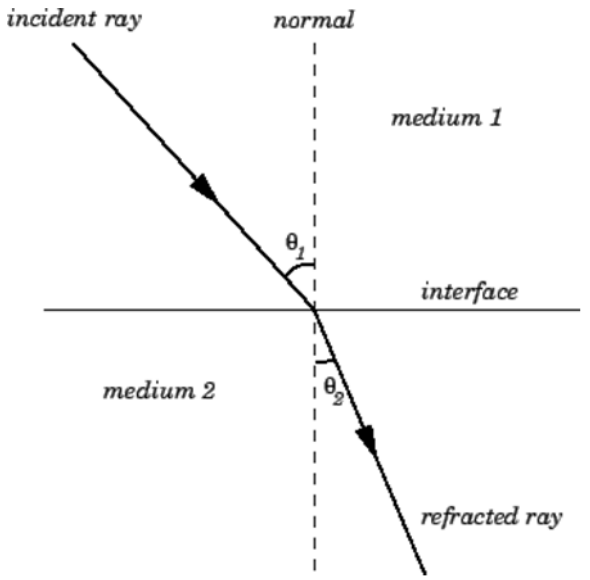
- Law of reflection states that the incident ray, the reflected ray, and the normal to the surface of the mirror all lie in the same plane
- The angle of reflection *r* is equal to the angle of incidence *I*
- So this law states that any ray of light that strikes an object will reflect off the object such that the striking or incident angle is

$$\boldsymbol{\theta_i = \theta_r}$$



# Law of refraction

- Incident ray, reflected ray, refracted ray and the normal of the system lie in the same plane
- Incident ray, coming from one medium to the boundary of another medium, is refracted with a rule derived from a physicist Willebrord Snellius
- He found that there is a constant relation between the angle of incident ray and angle of refracted ray
- This constant is the refractive index of second medium relative to the first medium.

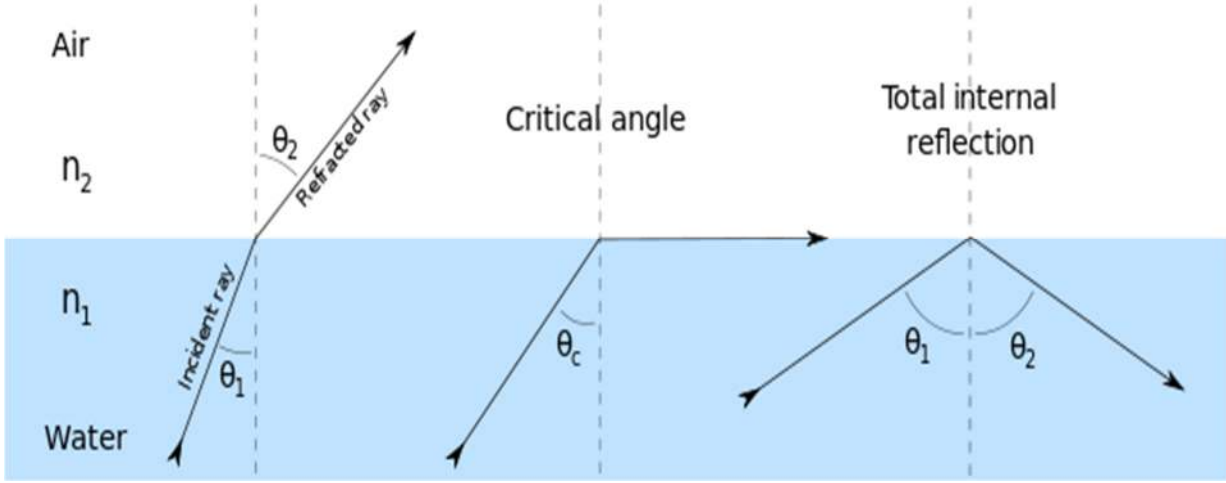



$$n_1 \sin\theta_1 = n_2 \sin\theta_2,$$

# Total Internal Reflection (TIR)

- An interesting effect known as total internal reflection can occur when light attempts to move from a medium having a given refractive index to a medium having a lower refractive index
- Suppose that light crosses an interface from medium 1 to medium 2, where $n_2 < n_1$
- According to Snell's law,

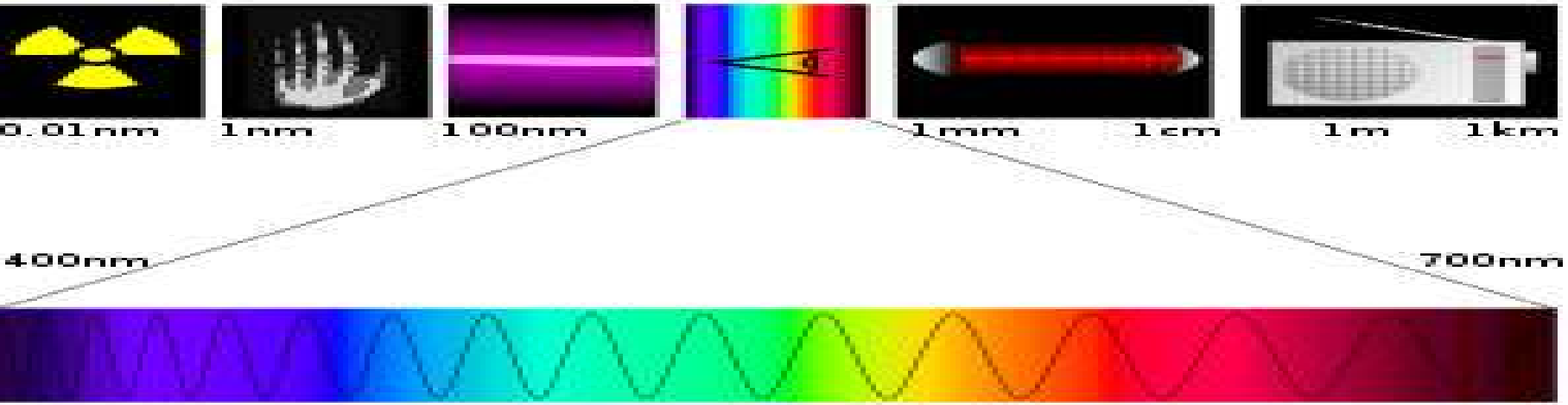
$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1.$$



# LASERS

LASER stands for **Light amplification by stimulated emission of radiation**

- Laser is a device which emits a **powerful monochromatic**, collimated beam of light.
- The emitted light waves are **coherent in nature**.



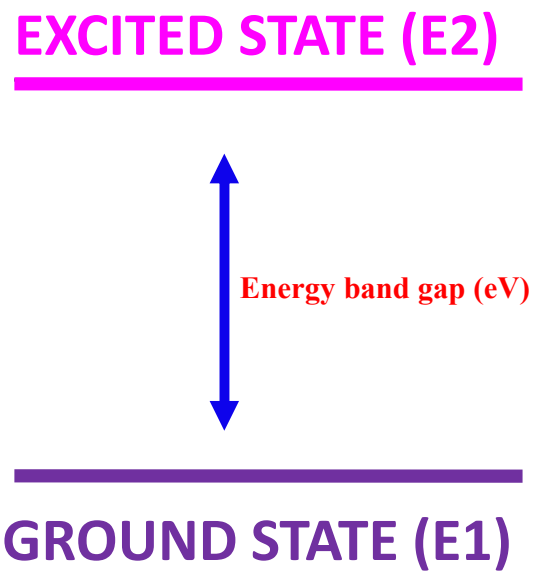
# Basic terms

**GROUND STATE**

The lowest energy state of an atom or the minimum energy possessed by the atom is called ground state energy E1.

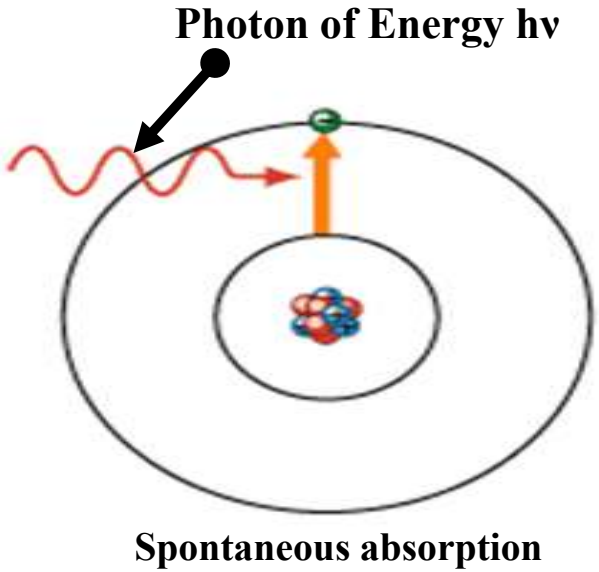
**EXCITED ENERGY STATE**

The atoms in the ground state will absorb external energy and goes to the energy state higher than the ground state. This state is called excited energy state or higher energy state E2.



# Absorption

- An atom in the **GROUND STATE** with energy **E1** absorbs an incident photon of energy hν.
- It goes to an higher energy state with energy **E2** (**EXCITED STATE**).
- This process is known as stimulated absorption.



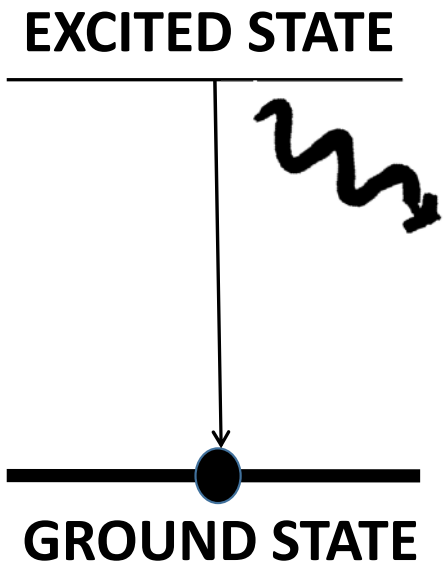

$$E1 - E2 = h\nu$$

Where, h is the Planck's constant ($6.625 \times 10^{-34}$ Joule second)

- ν is the frequency of photon
- hν is the energy of the photon

# Emission

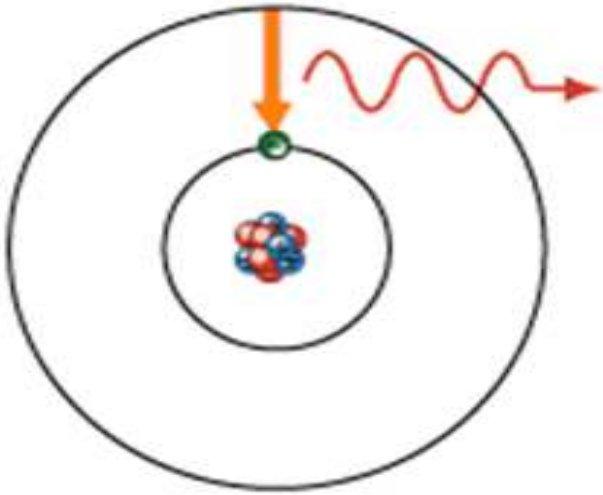
- The atoms in the excited state will not stay much longer, since the life time of an atom in the excited state is **$10^{-8}$ second**
- So the atoms **quickly return to the ground state** by emitting a photon of frequency ν and energy hν
- This process is known as **emission**
- The emission process may take place in two forms.
    1. **Spontaneous emission**
    2. **Stimulated emission**



# Spontaneous emission

Spontaneous emission

- The atoms in the excited state **E2 (EXCITED STATE)** will not stay much longer, and returns to the ground state **E1 (GROUND STATE)** by emitting a photon of energy hν **(equal to E2-E1)** without the action of any external agency
- This process is known as **spontaneous emission**



**Spontaneous emission**

**The spontaneous emission is a random process and is uncontrollable**

# Stimulated Emission

- Einstein pointed out that if a photon can stimulate an atom to move from a **lower energy E1 to a higher energy level E2** by means of absorption transition, then a photon should also be able to stimulate an atom from the same upper level to the lower energy level E1
- The photon is said to stimulate or induce the excited atom to emit a photon of energy

$$E2 - E1 = h\nu$$

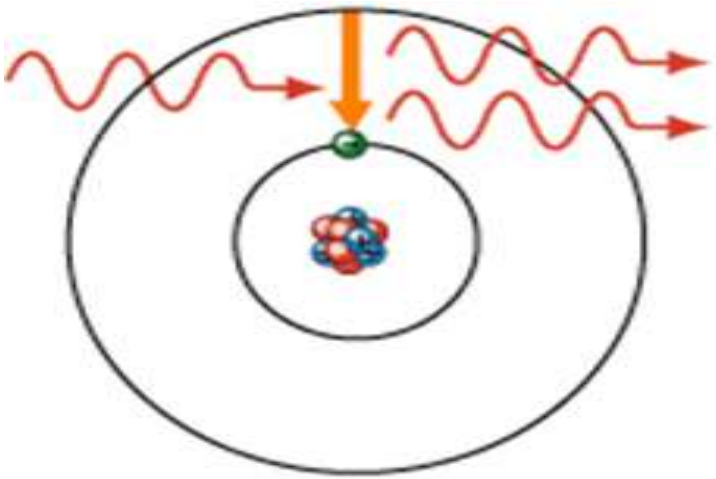
- The passing photon does not disappear and in addition to it there is a second photon which is emitted by the excited atom

# Contd..

- The phenomenon of forced emission of photons due to the action of an external agency is called stimulated or induced emission

Stimulated or Induced Emission is the Principle of Lasers

- The emitted photons propagates in the same direction
- The induced photon posses same frequency, phase as that of the stimulating photon



**Stimulated emission**

# Difference between spontaneous and stimulated emission

| Sr. No. | Spontaneous Emission | Stimulated Emission |
|---|---|---|
| 1. | An atom in the excited state returns to ground state thereby emitting a photon, **without any external inducement** is called Spontaneous Emission. | The phenomenon of forced **emission of photons due to the action of an external agency** is called Stimulated or induced emission. |
| 2. | Emission of light is not triggered by external agent. | Forced emission of radiations by incident photons. |
| 3. | Emitted photons travel in **all directions and random**. | Emitted photons travel in the **same direction**. |
| 4. | The spontaneous emission is **uncontrollable**. | The process of stimulated **radiation is controllable**. |

| Sr. No. | Spontaneous Emission | Stimulated Emission |
|---|---|---|
| 5. | The light resulting through this process is **not monochromatic** | The light emitted through this is **highly monochromatic** |
| 6. | The radiation is less intense and **incoherent** | The radiation is highly intense and **coherent** |
| 7. | The emitted photons are **in phase** | The emitted photons are **not in phase** |
| 8. | It is **independent of incident radiation intensity** | It **depends on incident radiation intensity** |
| 9. | This process is the **key factor for ordinary light** | This process is a **key factor for laser operation** |

# Population inversion

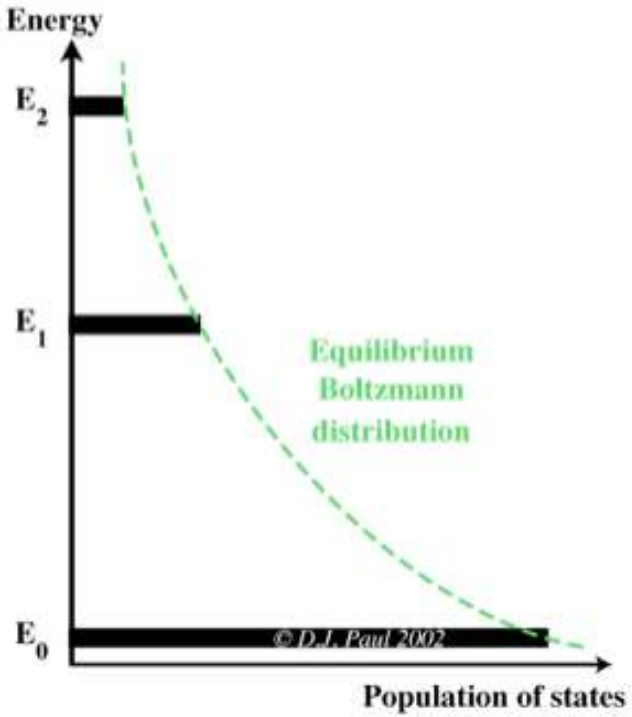
# Population inversion

- A state in which a substance has been energized, or excited to specific energy levels
- More atoms or molecules are in a higher excited state
- The process of producing a population inversion is called **pumping**
- Examples

  → by lamps of appropriate intensity

  → by electrical discharge

# Cont..


Energy
E2
E1
E0
Equilibrium
Boltzmann
distribution
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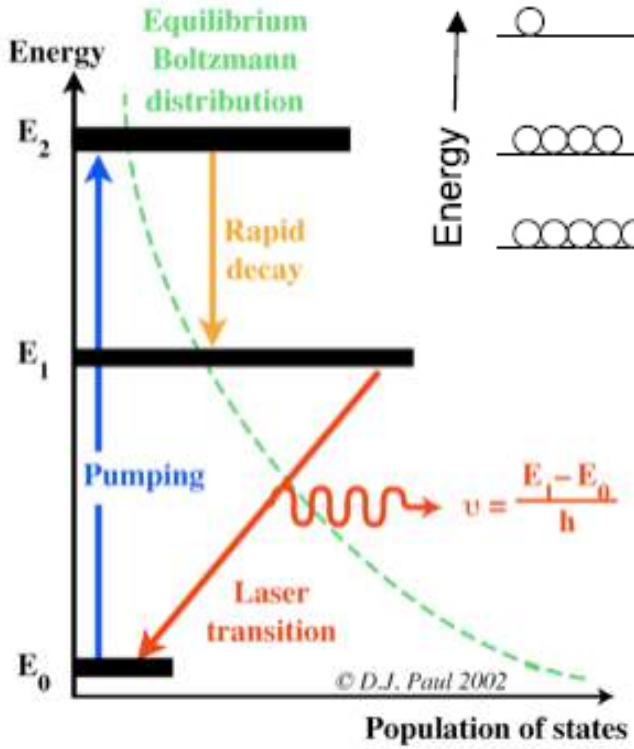
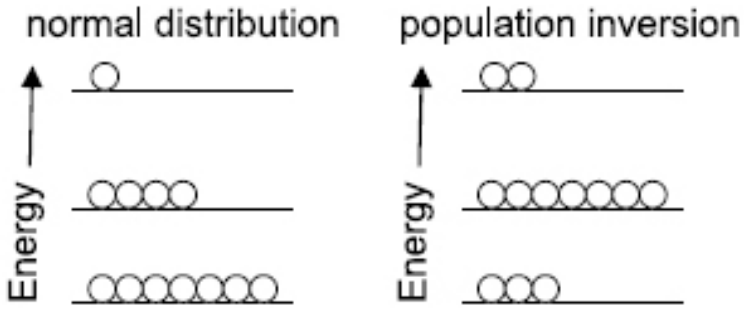
Population of states


Energy
Equilibrium
Boltzmann
distribution
E2
Rapid
decay
E1
Pumping
υ = (E1 − E0) / h
Laser
transition
E0
© D.J. Paul 2002
Population of states


normal distribution
population inversion
Energy
Energy

# Cont..

N2< N1 absorption dominates

N2>N1 stimulated emission dominat es

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/K_B T}$$

If T is +Ve $N1 = N2\, e^{+ve}$

if N2=5 and if $(E2-E1)/K_BT \sim 2$

$N1 = 5.\ e^{+2}$

N1 = 36.9

If T is -Ve $N1 = N2\, e^{-ve}$

if N2=5 and if $(E2-E1)/K_BT \sim 2$

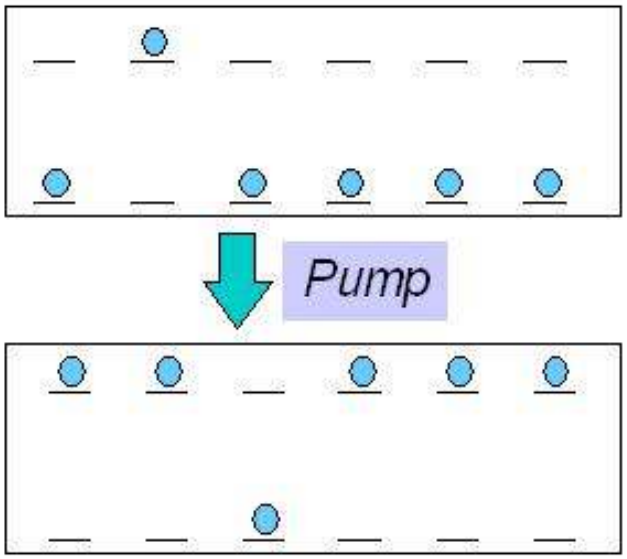
$N1 = 5.\ e^{-2}$

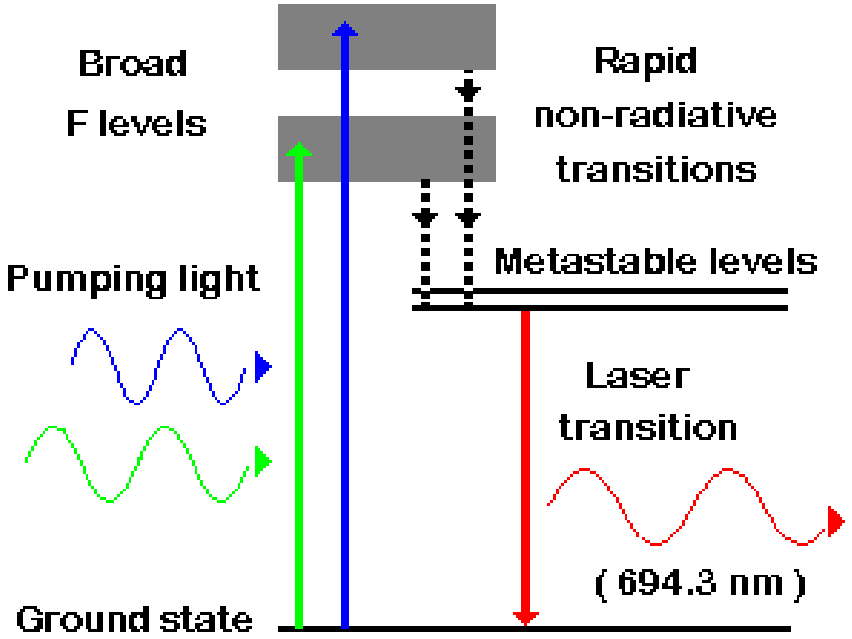
N1 = 0.6766

Practically negative temperature is not possible

Population inversion - artificial process - pumping process

# Cont..

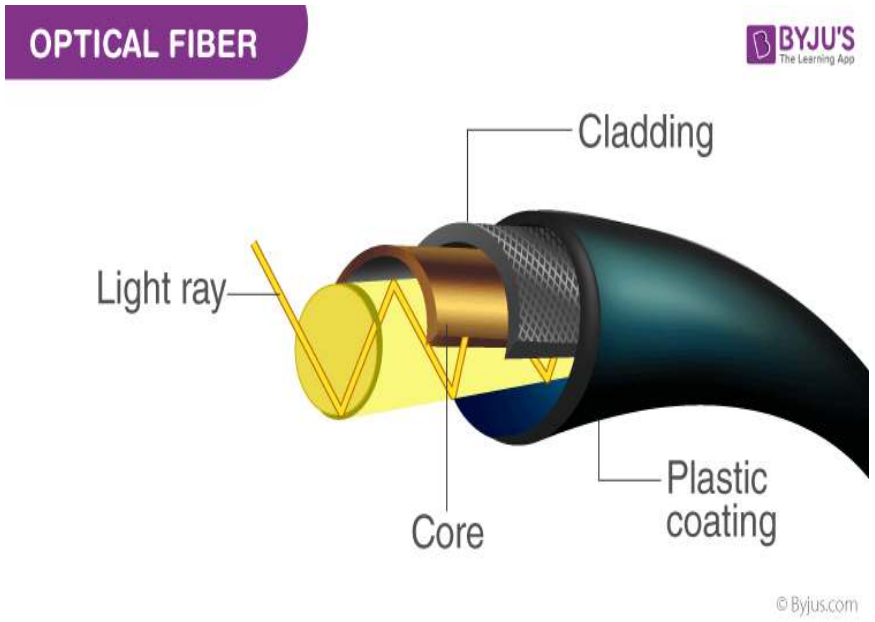


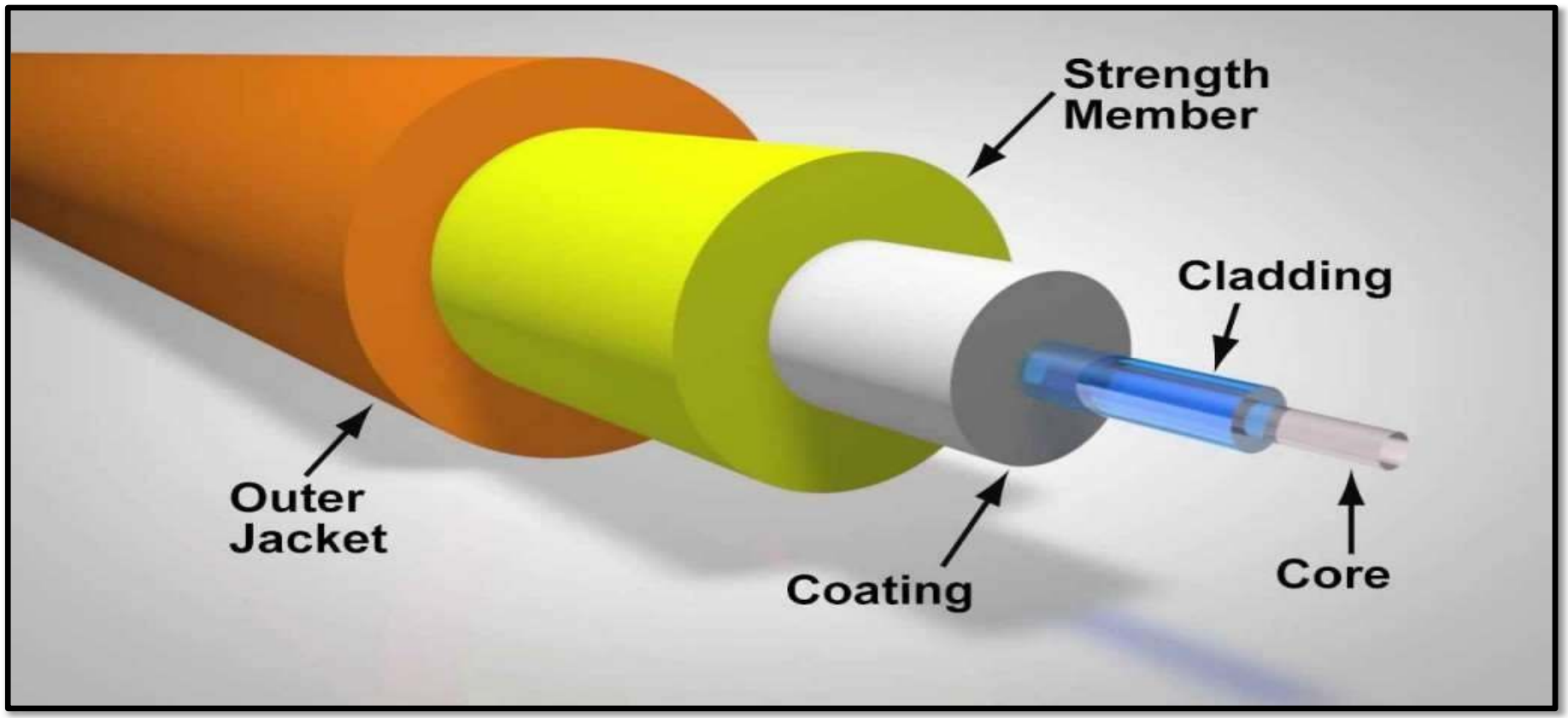

Energy levels of chromium ions in ruby

# Optical fibre

- Optical fiber is the technology associated with data transmission using light pulses traveling along with a long fiber which is usually made of plastic or glass.
- Metal wires are preferred for transmission in optical fiber communication as signals travel with fewer damages.
- Optical fibers are also unaffected by electromagnetic interference. The fiber optical cable uses the application of total internal reflection of light.



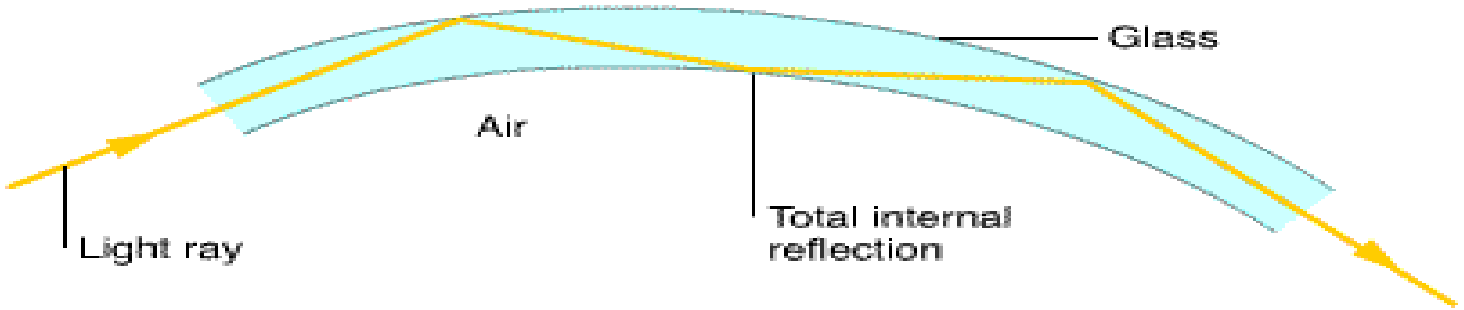
# Structure of optical fiber



# Conti…

- Core- central tube of very thin size made up of optically transparent dielectric medium and carries the light form transmitter to receiver. The core diameter can vary from about 5um-100um.
- Cladding- outer optical material surrounding the core having reflecting index lower than core. It helps to keep the light within the core throughout the phenomena of total internal reflection.
- Buffer Coating- plastic coating that protects the fiber made of silicon rubber. The typical diameter of fiber after coating is 250-300um

# Working principle




- When an ray of light travels from a denser to a rarer medium such that the angle of incidence is greater than the critical angle, the ray reflects back into the same medium this phenomena is called TIR.

- In the optical fiber the rays undergo repeated total number of reflections until it emerges out of the other end of the fiber, even if fiber is bend.

# Types of optical fiber

- Optical fiber is classified into two categories based on:-

1)The number of modes-

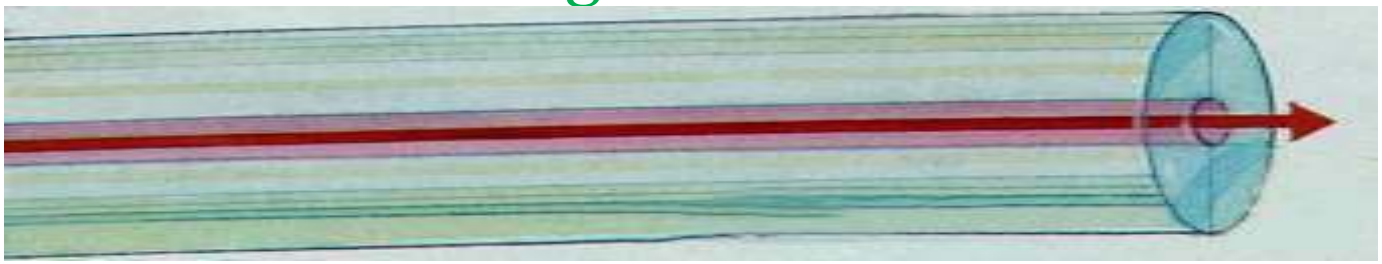
- Single mode fiber(SMF) and
- Multi-mode fiber(MMF

2) The reflective index-

- Step index optical fiber
- Graded- index optical fiber

# On basis of number of modes:-

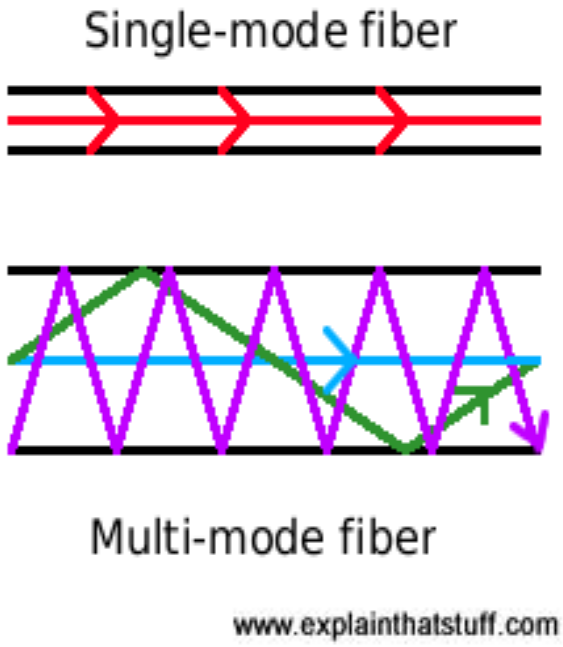
## Single mode fiber-



- In single mode fiber only one mode can propagate through the fiber.
- It has small core diameter (5um) and high cladding diameter (70um).
- Difference between the refractive index of core and cladding is very small.
- There is neither dispersion nor degradation therefore it is suitable for long distance communication.
- The light is passed through the single mode fiber through laser diode.

# Multi- mode fiber

- It allows a large number of modes for light ray travelling through it.
- The core diameter is 40um and that of cladding is 70um.
- The relative refractive index difference is also large than single mode fiber.
- There is signal degradation due to multimode dispersion.
- It is not suitable for long distance communication due to large dispersion and attenuation of signal



# On the basis of refractive index

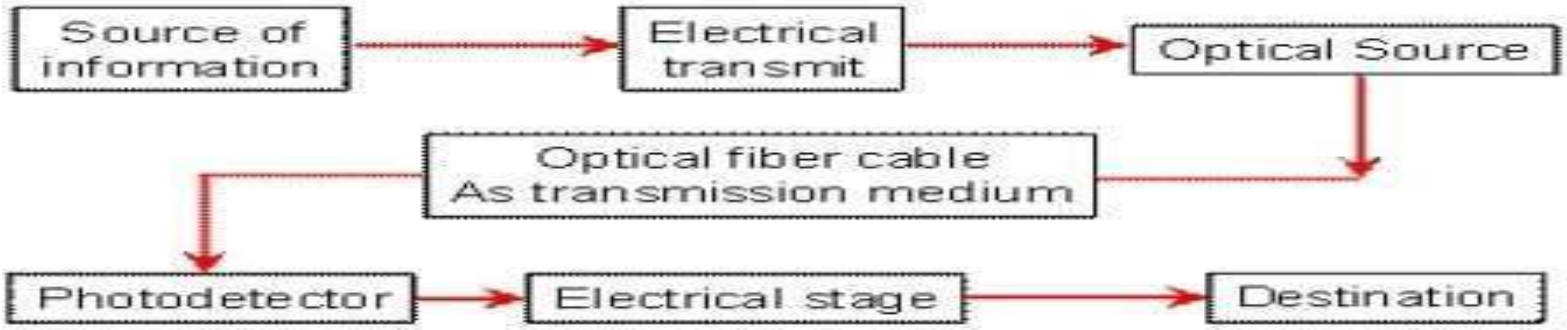
Single Index fiber

- Single-index optical fiber-the refractive index of core and cladding are constant.
- The light ray propagate through it in the form of meridiognal rays which cross the fiber axis during every reflection at the core cladding boundary.

Graded Index Fiber:-

- In this type of fiber core has a non uniform refractive index that gradually decrease from the center towards the core cladding interface.
- The cladding has a uniform refractive index.
- The light rays propagate through it in the form of helical rays. They never cross the fiber axis.

# Optical Fiber Communication System




- Information source- it provide an electrical signal to atransmitter comprising an electrical stage.
- Electrical transmitter- It drives an optical source to give an modulation of the light wave carrier.
- Optical source- It provides the electrical-optical conversion. It may be a semiconductor laser or an LED.

# Applications

- Optical fiber have wider range of application in almost all field, some are specified below:-
- In telecommunication field
- Civil, consumer and industrial application
- In military applications
- Broadband applications
- In decorations, etc.

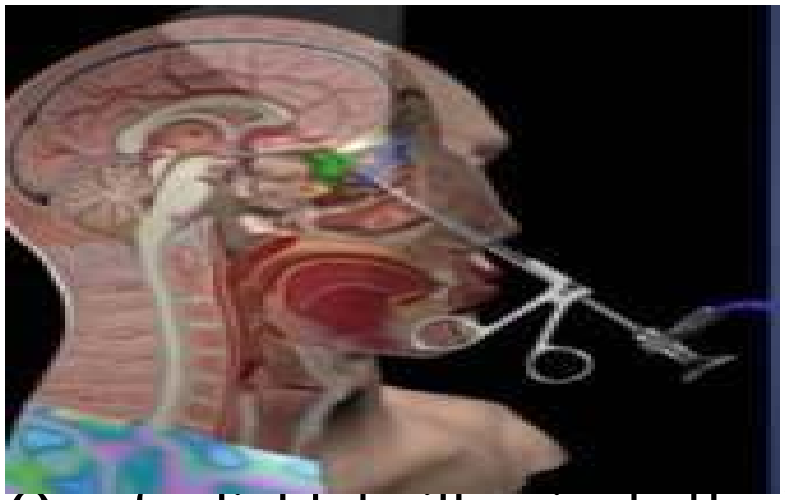
# Application in medical field

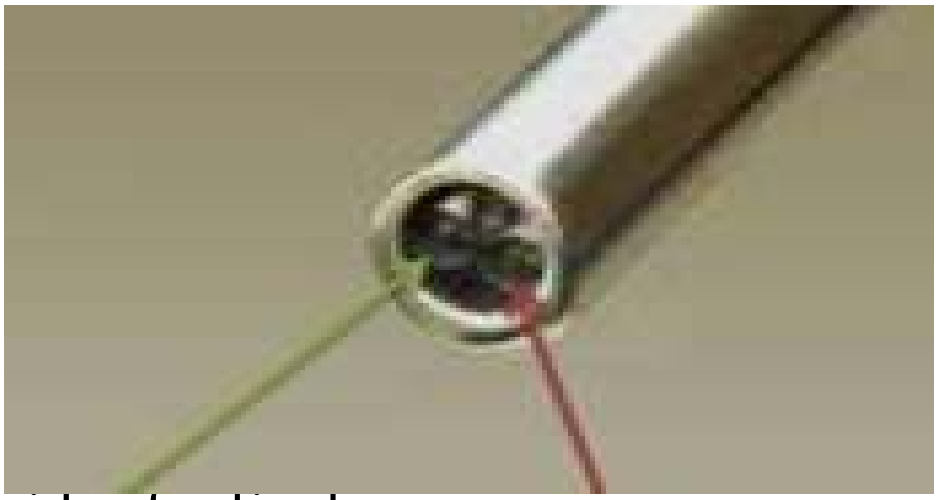
- Optical fibre medical instruments may contain bundles of optical fibres. An optical fibre instrument used to see the internal parts of human body is endoscope. The endoscope facilitates the physicians to see the internal parts of body without performing surgery. The main part in endoscope is fibrescope. Based on application, the endoscopes are classified into:
- **Gastroscope** is used to examine the stomach. A gastroscope can be fitted with various parts to photograph tumours and ulcers. Laser-used gastroscope is used to remove objects that have been swallowed. Gastroscope can also guide a laser, used to destroy tumours.
- **Bronchoscope** is used to see upper passages of lungs.

- The integration of optical fibers into the medical community has enabled safer procedures, more efficient surgeries, faster recovery time, and better diagnostic examinations. The ideal characteristics of optical fibers, such as their amendability to sterilization and small dimension size, provide many opportunities for the development of medical instrumentation Light theraphy
- Ophthalmic laser
- Lab and clinical diagnostics
- Endoscopy
- Surgical microscopy
- Dental hand pieces

# The Endoscope(In medical field)

There are two optical fibers in endoscope:





1) One for light, to illuminate the inside of patient.
2) Another for a camera to send the images back to doctor.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