LASER

Light Amplification by Stimulated Emission of Radiation

- **Importance of LASER**
  Applications

- **Physics**
  Working principle and fabrication of LASER

- **Types of LASERs**

Important Characteristics of LASER

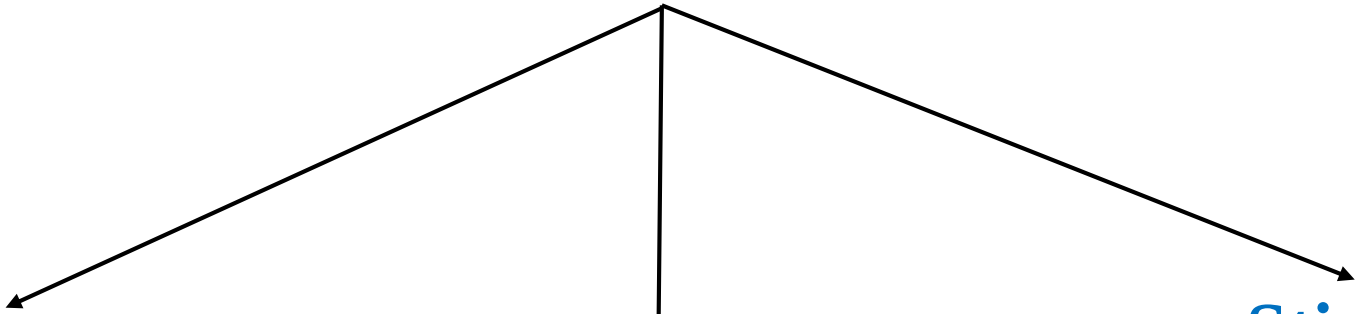
LASER Light	Ordinary Light
Monochromatic: Single wavelength	Polychromatic: Long range of wavelengths
Coherent: radiations are in phase, same frequency, constant amplitude	Incoherent: radiations are out of phase
Unidirectional	Divergent
High intense beam	Intensity decreases with distance
Stimulated emission	Spontaneous emission

Why to Study LASER? (Applications for Society)

- **Communication:** Fiber-optic communication
- **Research:** Spectroscopy, laser ablation, laser annealing, fluorescence microscopy, metrology (determine the distance of moon).
- **Medicine:** Bloodless surgery, laser healing, surgical treatment, kidney stone treatment, eye surgery, dentistry
- **Industry:** Cutting, welding, material heat treatment etc.
- **Law enforcement:** Fingerprint detection in the forensic identification field
- **Entertainment:** Laser lighting displays, Laser light shows
- **Military:** Marking targets, missile defence, alternative to radar

How LASER Works?

Working Principle
(Atomic interaction with matter)



Induced or Stimulated Absorption

$$A + h\nu \longrightarrow A^*$$

Spontaneous Emission

$$A^* \longrightarrow A + h\nu$$

Stimulated Emission

$$A^* + h\nu \longrightarrow A + 2\,h\nu$$

Induced or Stimulated Absorption:

Photons of suitable energy are supplied to the atoms in the ground state. These atoms absorb the supplied energy and go to the excited or higher state.

Spontaneous Emission:

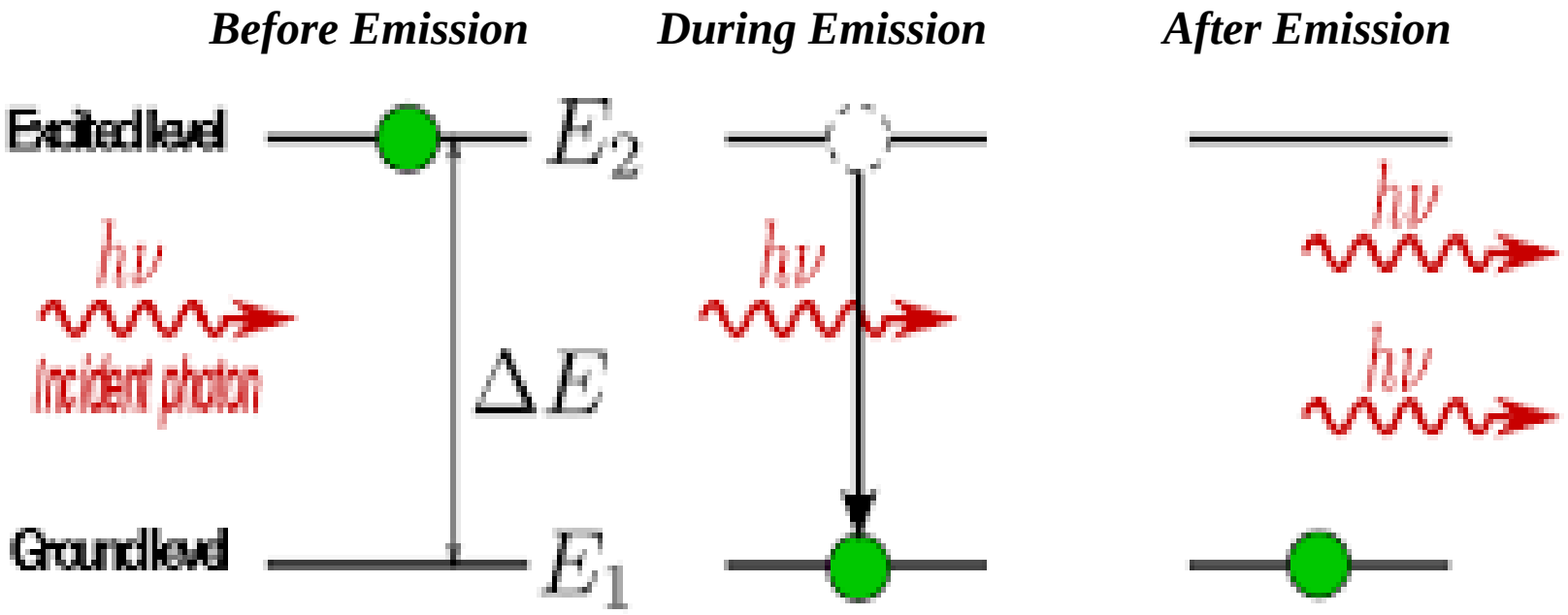
An excited atom can stay in higher state only for the time of 10^{-8} s. After this time it returns back to the lower or ground state by emitting a photon of energy $h\nu = E_2 - E_1$. This is called spontaneous emission.

1. Random direction
2. Not in phase
3. Natural process

Stimulated Emission:

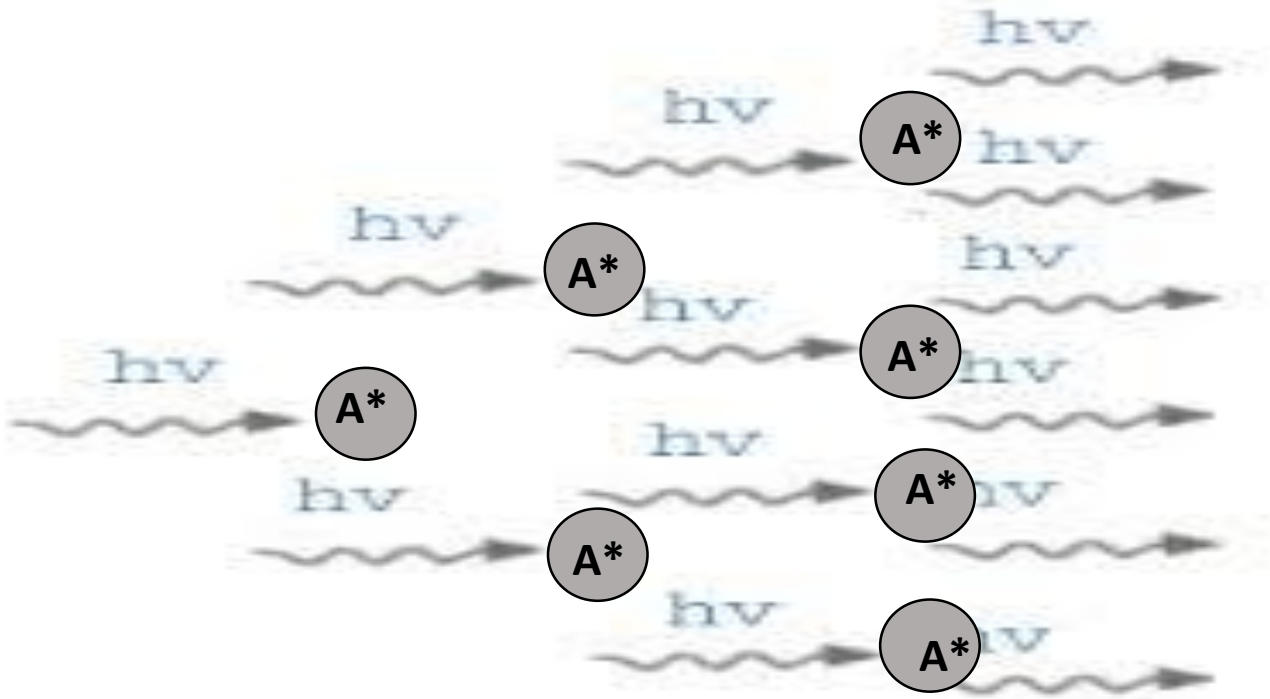
When photon of suitable energy is incident on an excited atom in the higher energy state, atom falls back to the ground state by emitting a photon of energy $h\nu = E_1 - E_2$ which in phase with the stimulating (incident) photon. Thus it results in the appearance of one additional photon. This process is called stimulated or induced emission.

Stimulated Emission (Lasing Action)

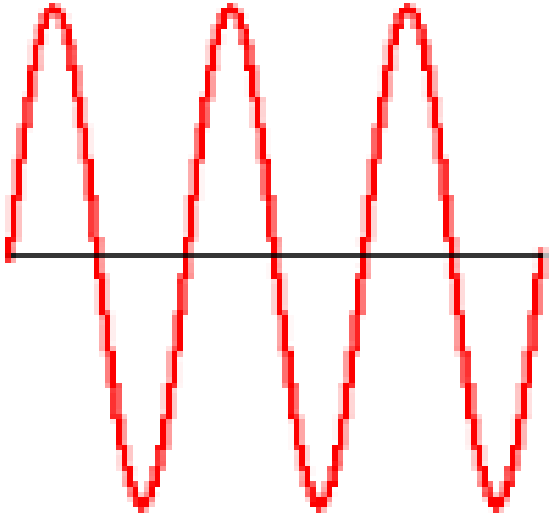


Atom in excited state

Atom in ground state



2^0 2^1 2^2 2^N



Stimulated Emission and Spontaneous Emission

- Emission with the help of external assistance
- One direction
- In phase (coherent)

- Natural Process
- Random direction
- Not in phase

Important Criteria for Lasing Action

1. Stimulated Emission

2. Population Inversion

Number of atoms in excited state are more than the number of atoms in ground state to achieve high percentage of stimulated emission (Negative temperature state or non equilibrium state).

3. Pumping

For realising and maintaining the population inversion, the atoms have to be raised continuously to excited state. It requires energy to be supplied to the system. The process of supplying energy to the atom to transfer it into the excited state is known as pumping.

- Optical Pumping
- Electric Discharge
- Direct Conversion

4. Metastable State

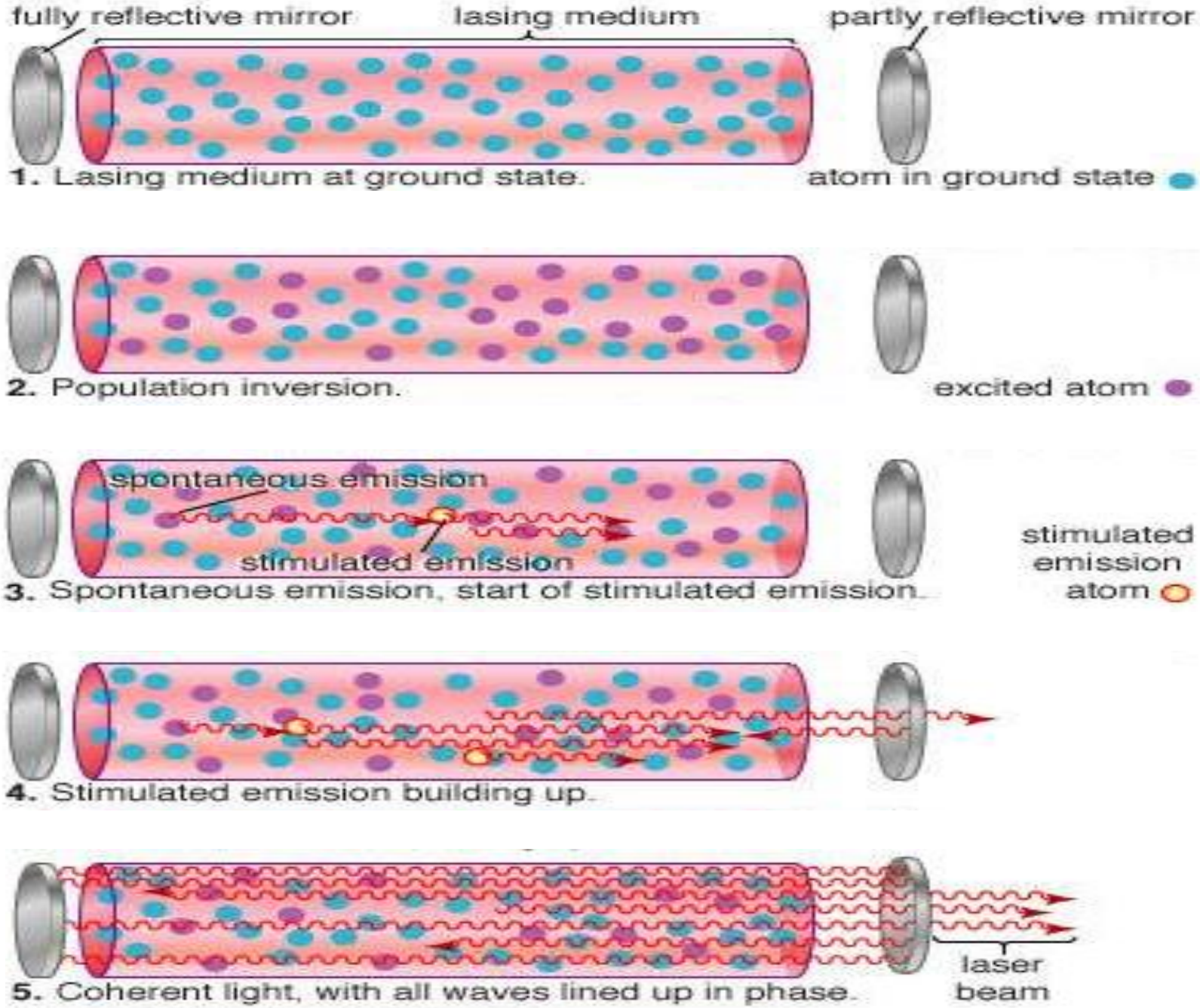
- The state in which electron can stay for a longer time than higher excited state.
- Lifetime = 10^{-6} to 10^{-3} s.
- Normally excited atoms have short lifetime = 10^{-10} to 10^{-8} s.
- Important state – population inversion for lasing medium
- Achieved – doping impurity atom
- Position- between the forbidden gap

5. Active Medium

- A medium in which light gets amplified is called active medium.
- It may be solid, liquid or gas.
- It contains atoms whose electrons may be excited to metastable energy level by an energy source.

6. Optical Cavity Resonator:

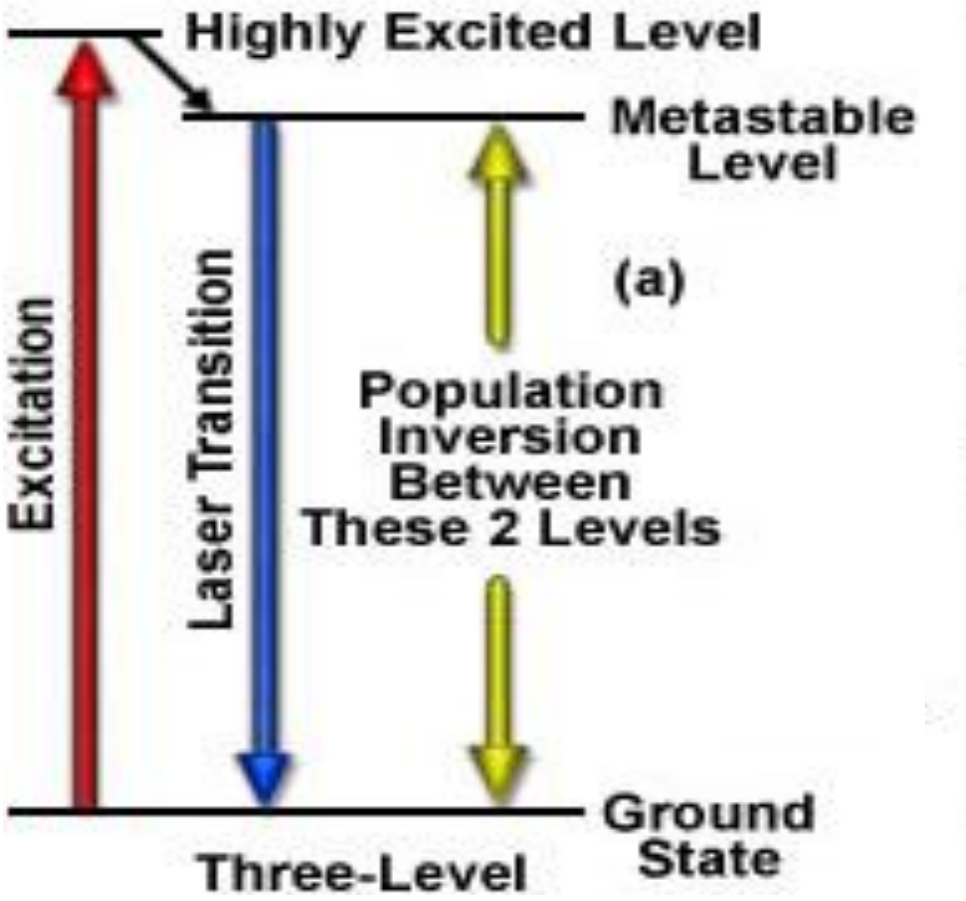
- Converts active medium into an oscillator and then into light generator
- Important and final criteria for getting unidirectional and highly intense light beam
- Used two mirrors; 100% reflected and partially reflected or semi-transparent
- Active material (solid, liquid or gas) inside cavity
- Spontaneously emitted photons acts as input light for stimulated photons


fully reflective mirror
lasing medium
partly reflective mirror
1. Lasing medium at ground state.
atom in ground state
2. Population inversion.
excited atom
spontaneous emission
stimulated emission
3. Spontaneous emission, start of stimulated emission.
stimulated emission atom
4. Stimulated emission building up.
5. Coherent light, with all waves lined up in phase.
laser beam

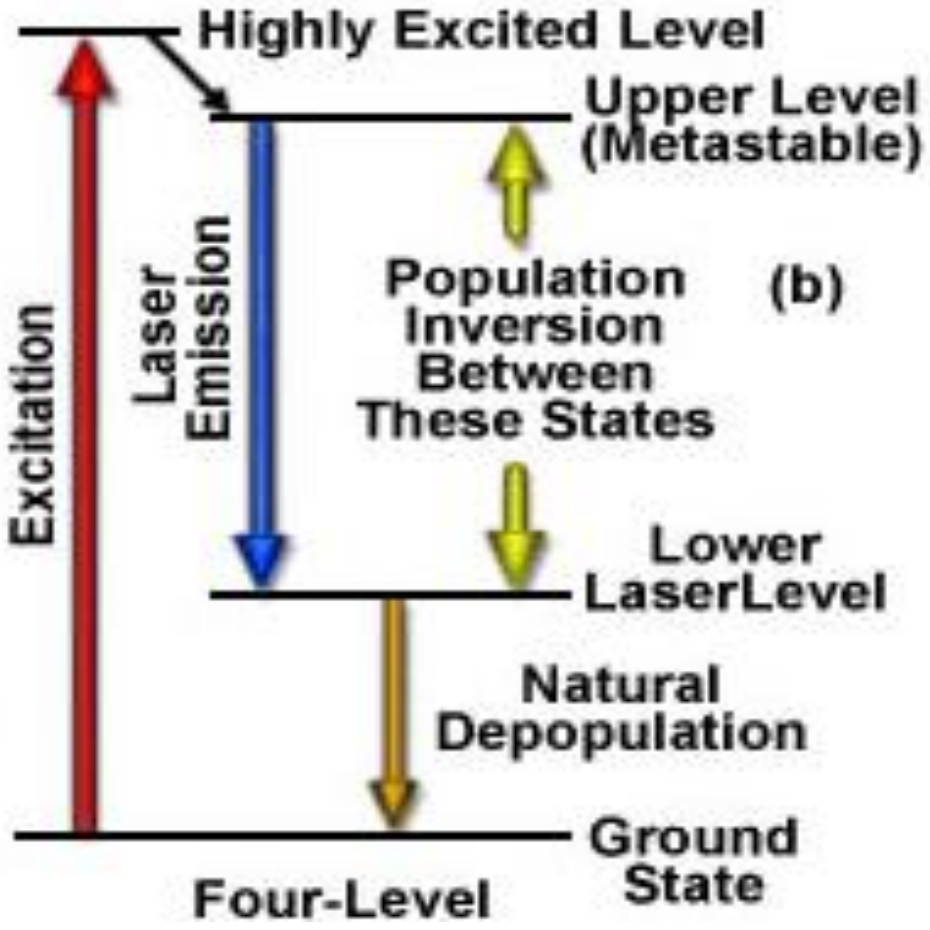
THE LASER

All the animations and explanations on
www.toutestquantique.fr

Three Level System



Four Level System



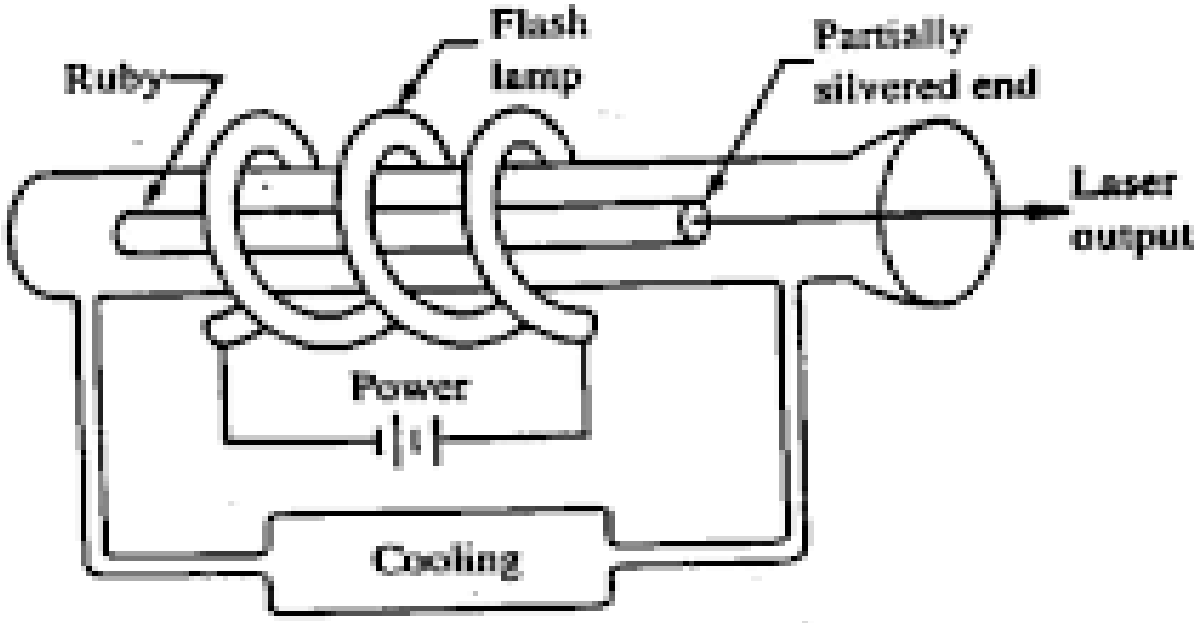
High pump power is required

Types of Laser

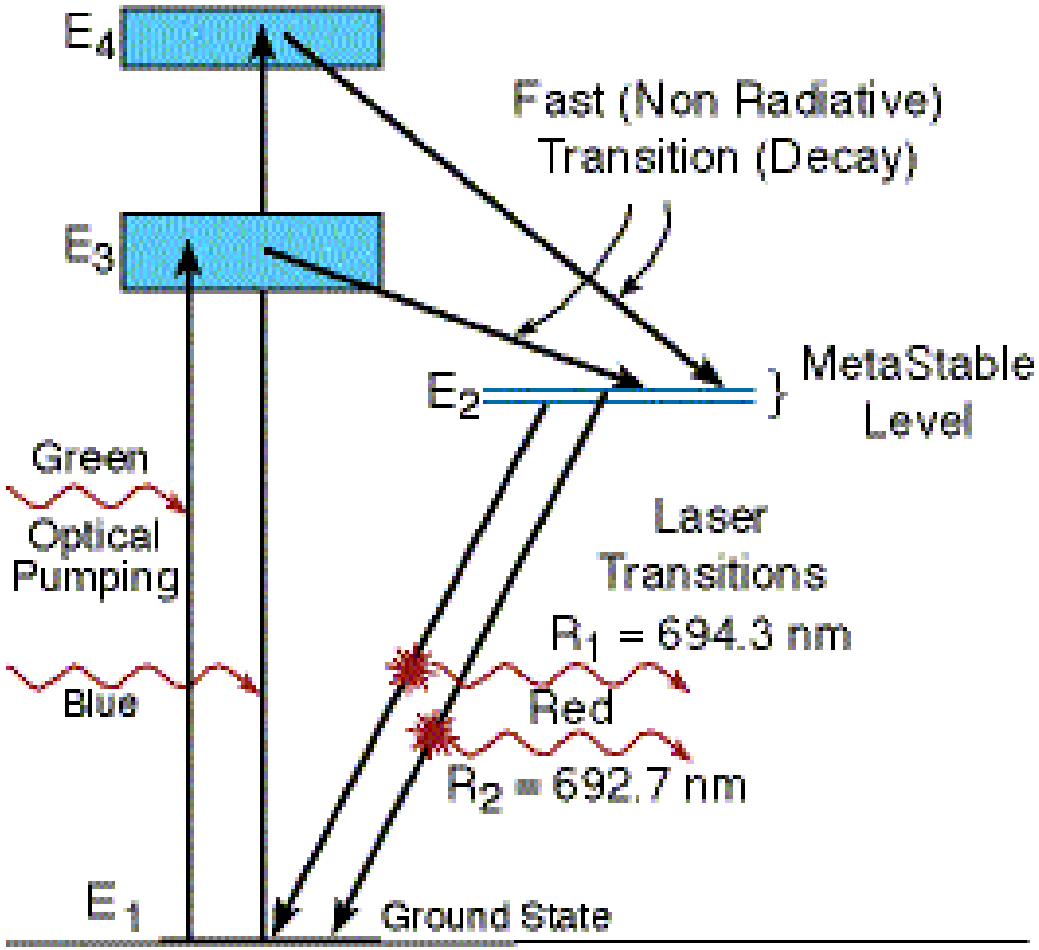
1. Solid State Lasers: Ruby Laser, Nd-YAG Laser
2. Gas Lasers: He-Ne Laser, CO_2 Laser, Argon Laser
3. Solid State Diode Lasers: Semiconductor diode
4. Liquid Dye Lasers: Organic dye

Ruby Laser (Solid State Laser)

- First laser (1960) by T. Maiman
- Ruby crystal (Al_2O_3 with 0.05% chromium)
- Optical pumping (Xenon flash lamp)
- Three level system
- Pulse Laser
- Industry (drilling holes), military (rangefinder), mostly used in tattoos and hair removal



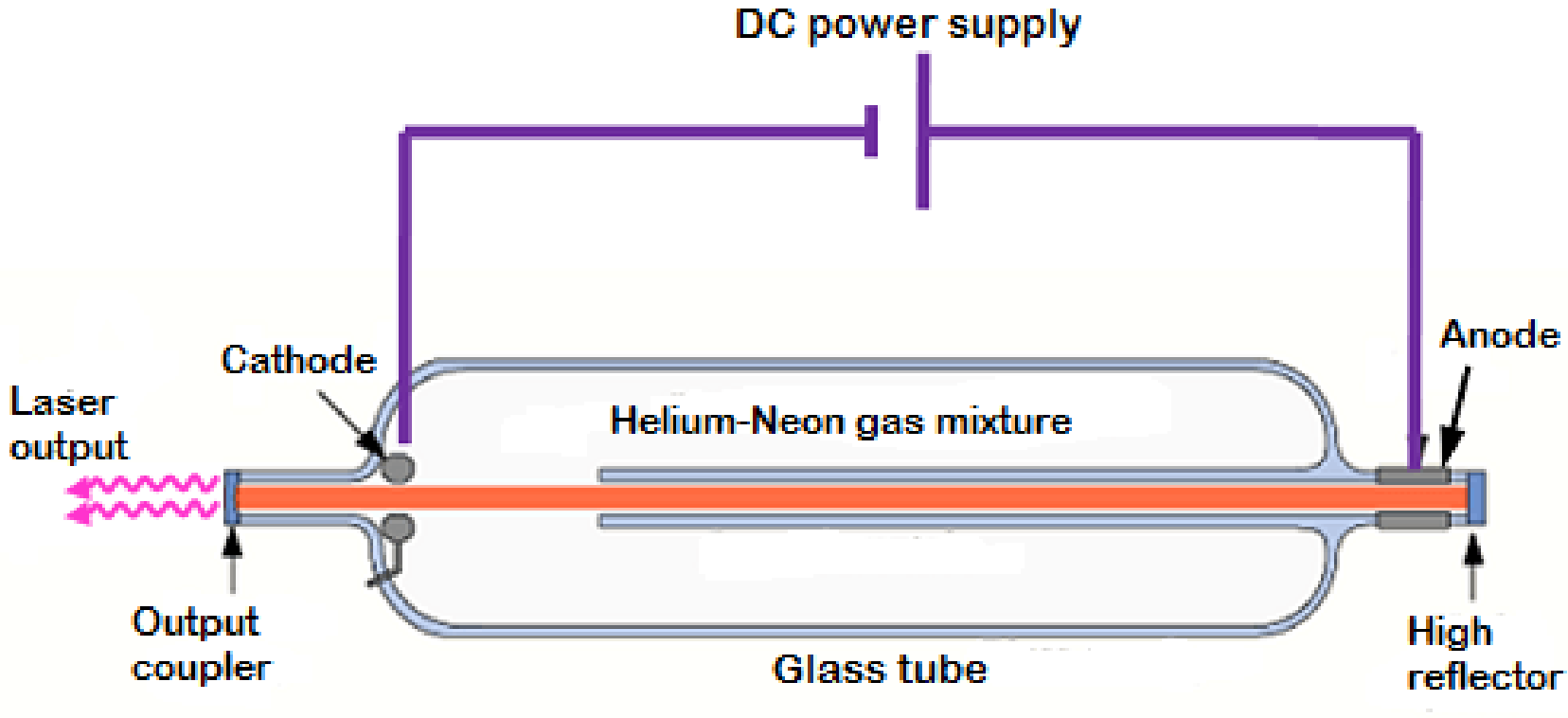
Energy Level Diagram of Ruby Laser

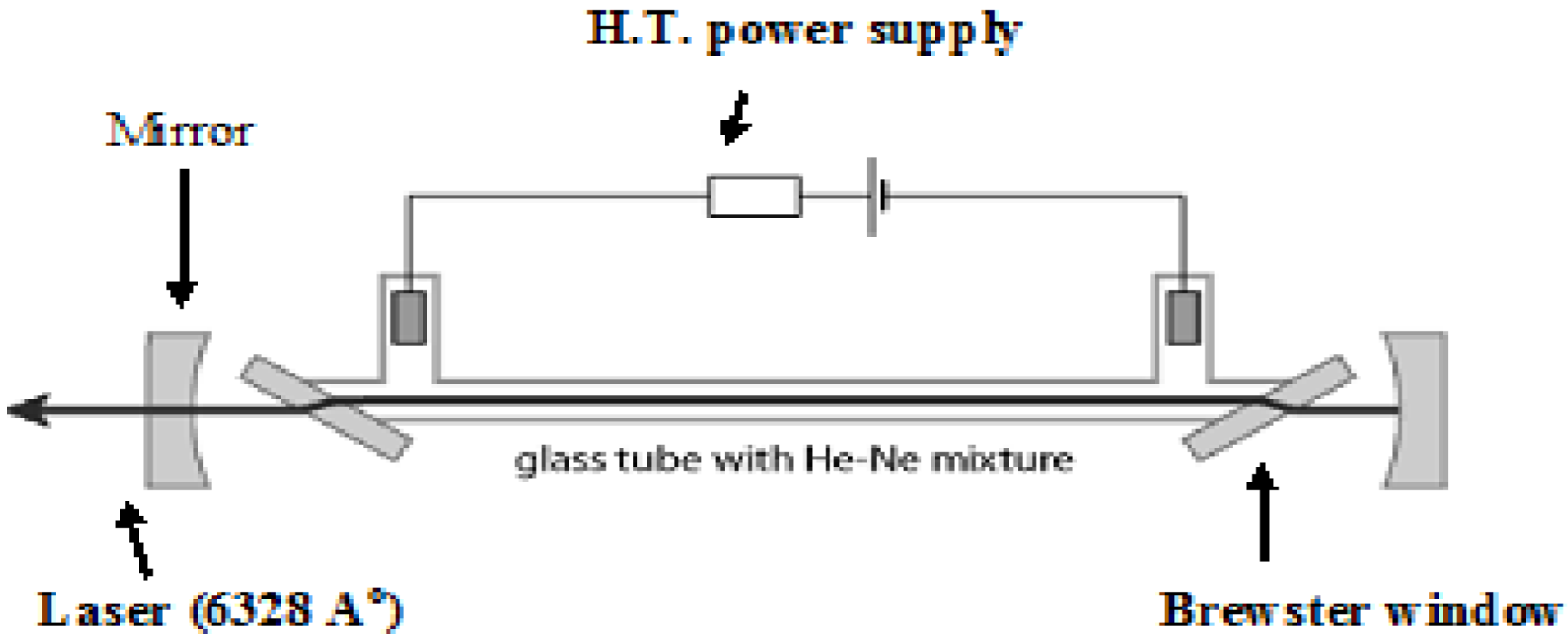


- Absorbs green (550 nm) and blue light (400 nm)
- Emits red light (694.3 nm) via spontaneous emission
- High fluorescence lifetime of metastable state (3 ms)
- Xenon flash lamp keep on for few ms.
- Metastable state gets depopulated and hence lasing action terminates
- Output: Pulse form; not continuous
- Efficiency: less
- Requires greater excitation energy (high power)

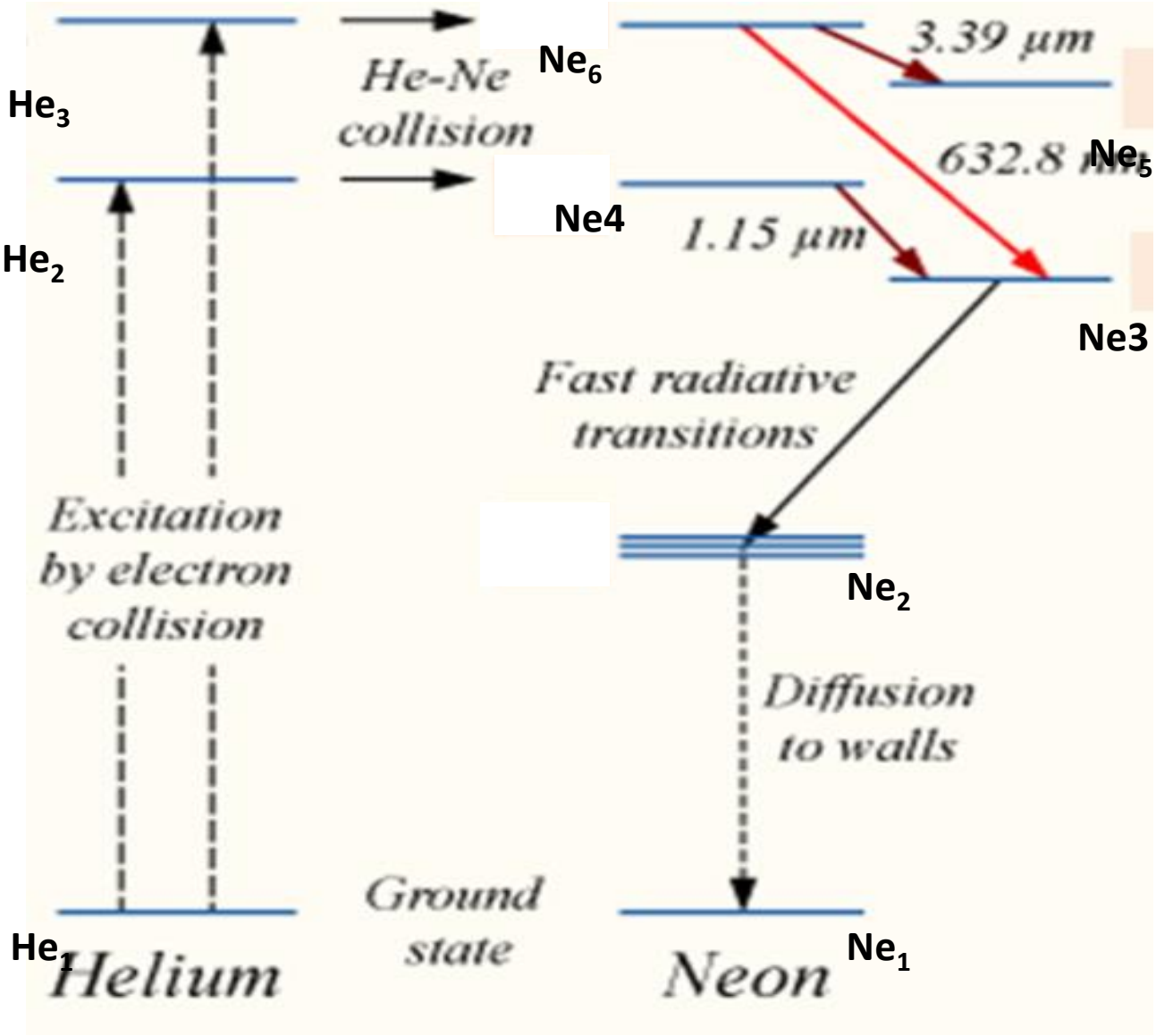
He-Ne Laser (Gas Laser)

- First gas laser (1961) by Javan, Bennett and Harroit
- Continuous laser, Four Level system
- Requires low power
- Wavelength: 632.8 nm
- Active medium: Helium (1 Torr) and Neon (0.1 Torr) mixture (10:1)
- Pumping: (Inelastic atom-atom collision) Electric discharge
- Lasing Action: Neon
- Resonator Cavity: two parallel mirror (reflecting and semi-transparent)
- Quartz tube: 10 to100 cm length and few mm diameter
- Checkout counters for scanning bar codes, Guns for targeting, Holography for 3D images


DC power supply
Cathode
Anode
Laser
output
Helium-Neon gas mixture
Output
coupler
Glass tube
High
reflector


H.T. power supply
Mirror
glass tube with He-Ne mixture
Laser (6328 A°)
Brewster window

Energy Level Diagram of He-Ne Laser



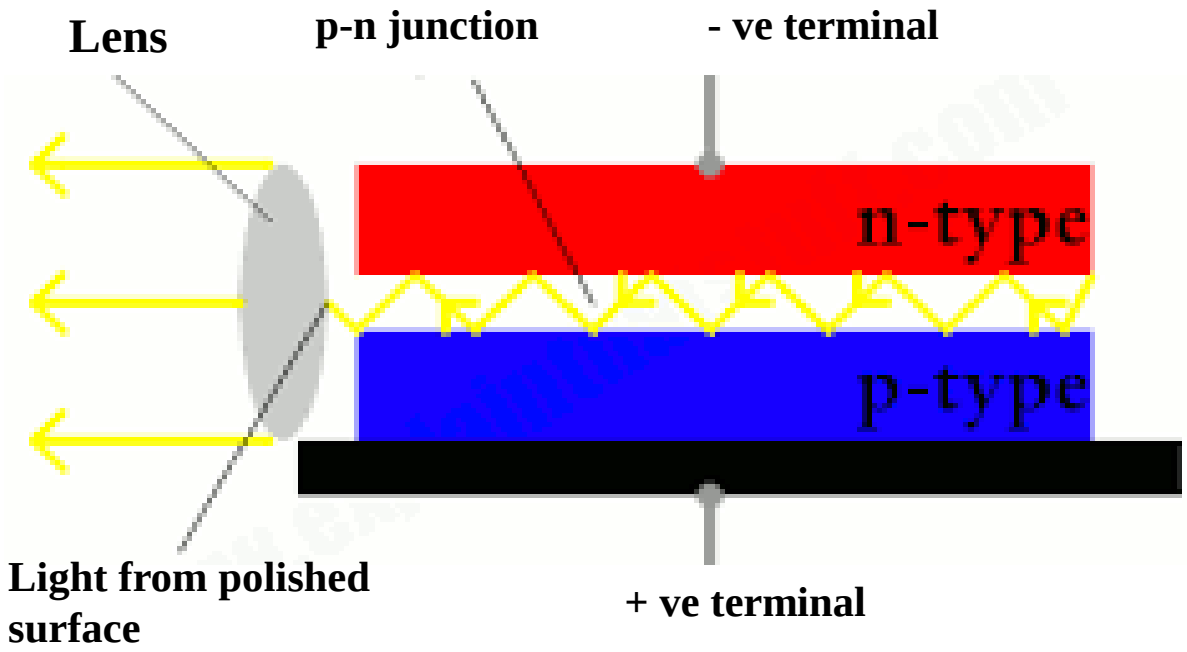
- Helium atom: to excite Neon atom and population inversion
- Neon atom: active centres (produce laser)
- Excited energy level: same for He and Ne
- Energy transfer through collision
- Ne_6 to Ne_3 transition: 632.8 nm (red)
- Ne_6 to Ne_5 transition: 3390 nm (far infrared)
- Ne_4 to Ne_3 transition: 1150 nm (infrared)

He-Ne Laser Vs Ruby Laser

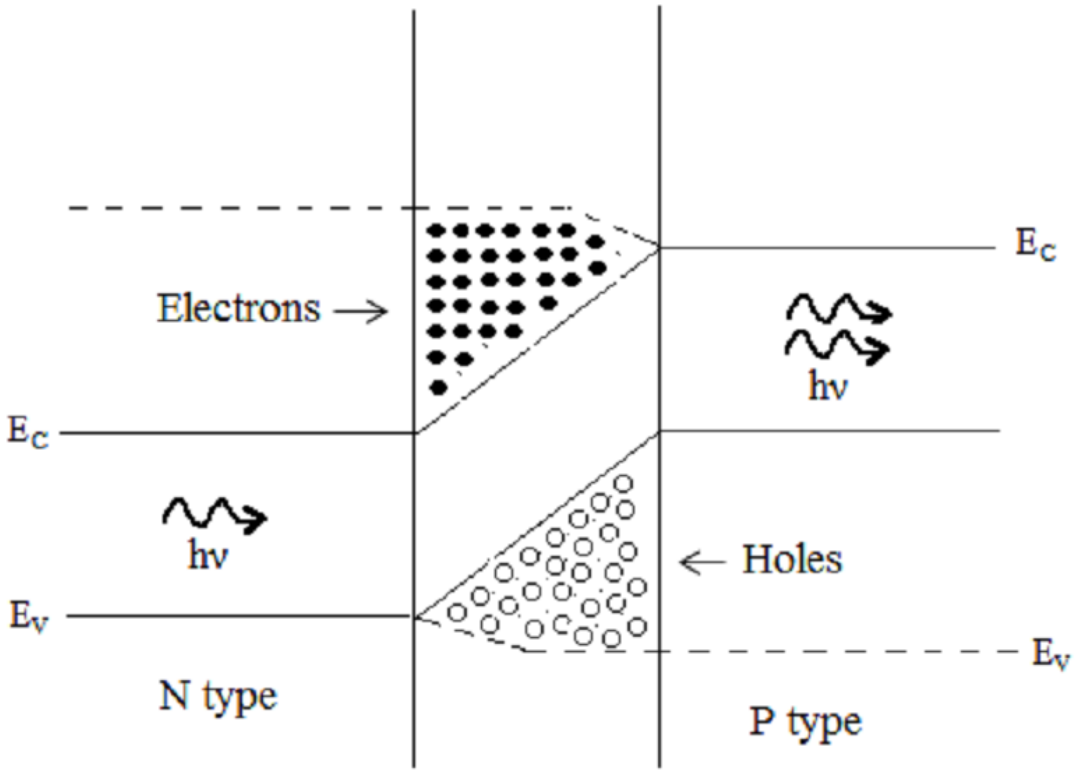
Ruby Laser	He-Ne Laser
Three level	Four level
Output: Pulse form	Continuous form
Pumping: High power source	Low power: electric discharge
Defects are present	No defects
Efficiency: less	More
Solid state	Gas
Expensive	Cheaper

Semiconductor Diode Laser (Two Level System)

- Two level system
- Pumping: Direct conversion
- Heavily doped p-n junction diode is used
- Less power
- More divergent, less monochromatic
- Compact, reliable and low cost
- Highly efficient
- Applications: read and write CDs, laser printers, Fiber optics communications



Energy Level Diagram of Semicond



n junction and

ıct as pumping

- GaAsP – 650 nm (visible)

Applications

- **Communication:** Fiber-optic communication
- **Research:** Spectroscopy, laser ablation, laser annealing, fluorescence microscopy, metrology (determine the distance of moon).
- **Medicine:** Bloodless surgery, laser healing, surgical treatment, kidney stone treatment, eye surgery, dentistry
- **Industry:** Cutting, welding, material heat treatment etc.
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- **Military:** Marking targets, missile defence, alternative to radar

Industrial and Engineering Applications

- **Welding:** CO_2 and Nd:YAG laser used
- **Cutting:** CO_2 and Nd:YAG laser used
- **Drilling:** Nd:YAG laser used
- **Measurement of atmospheric pollution levels:** LIDAR
- **Used in surveying and ranging**
- **Laser printers, CD read and write devices**
- **Optic fibre communication system**
- **Holography**

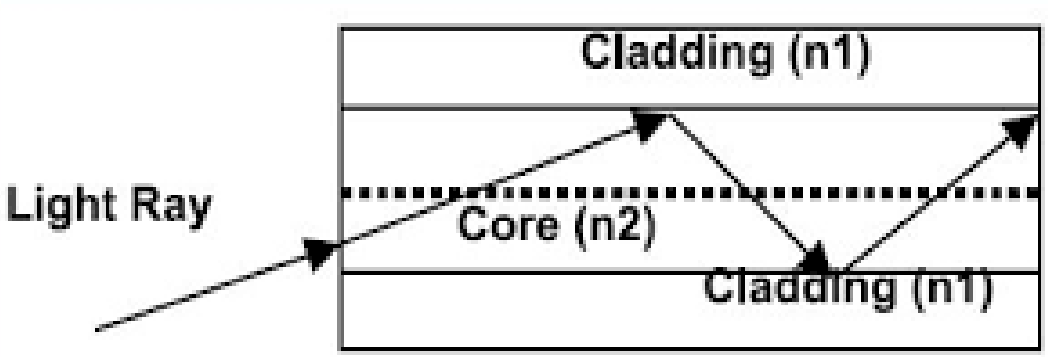
Applications

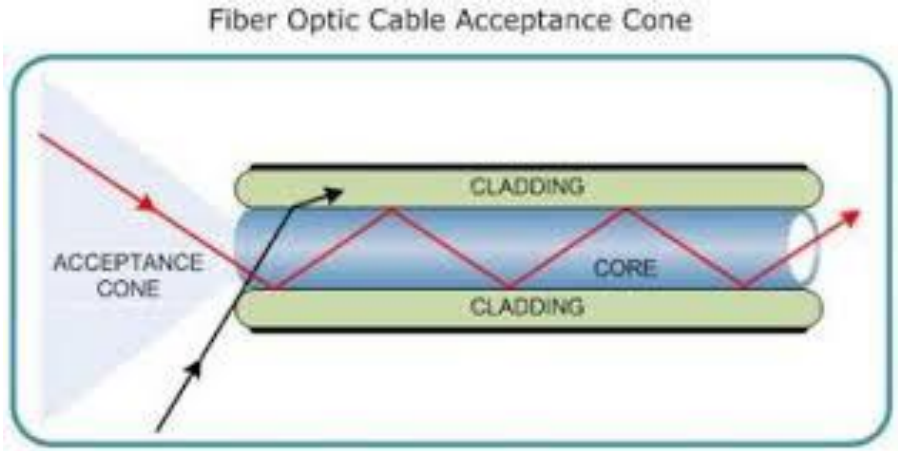
1. Optical Fibre Communication

- Optical frequency high $\approx 10^{14}$ Hz and large bandwidth
- It is thin, flexible and transparent fibre made up of glass (silica)
- Contains: transparent core and transparent cladding (dielectric material)
- Refractive index: **core > cladding**
- **Core:** doped silica (1.4475) and **Cladding:** pure silica (1.444)
- **Cladding:** to confine the light to the core by TIR at the boundary between core and cladding
- **Principle of light transmission :** Total Internal Reflection
- **Incidence angle > Critical angle** [$\theta_c = \sin^{-1} (\mu_2/ \mu_1)$]

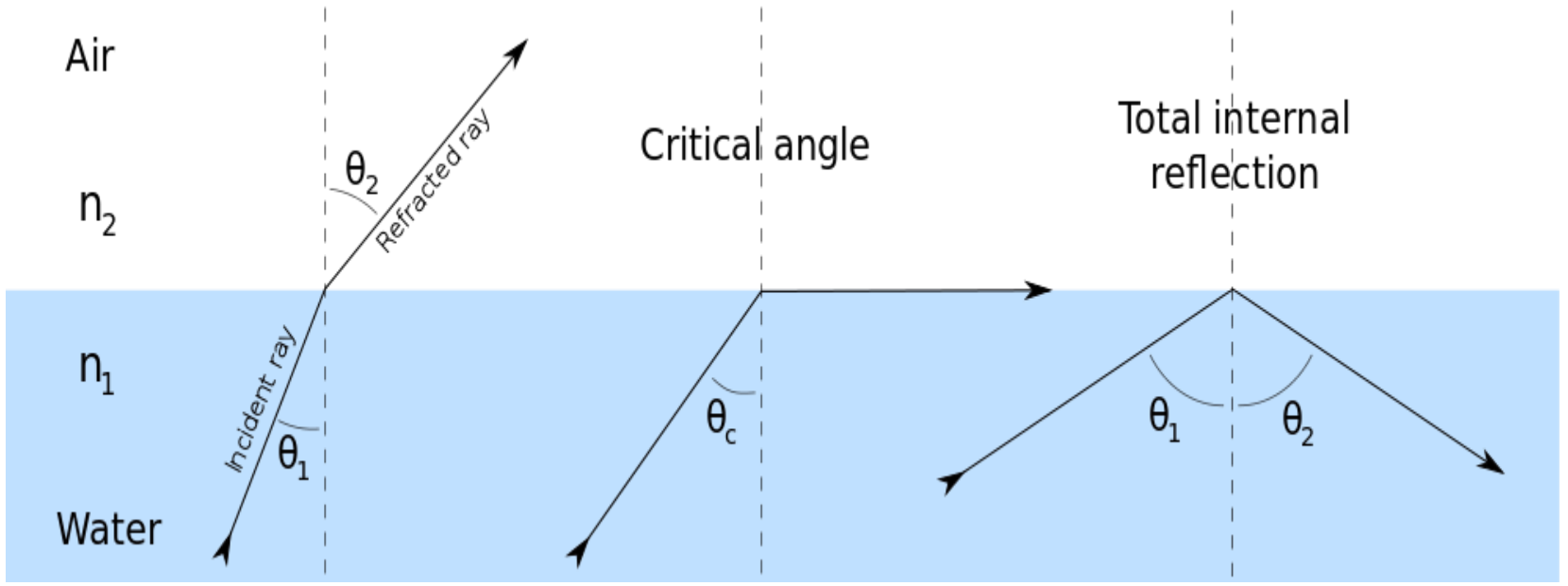
Total Internal Reflection (TIR)

It occurs when propagated wave strikes a medium boundary at an angle larger than a critical angle w.r.t the normal to the surface.

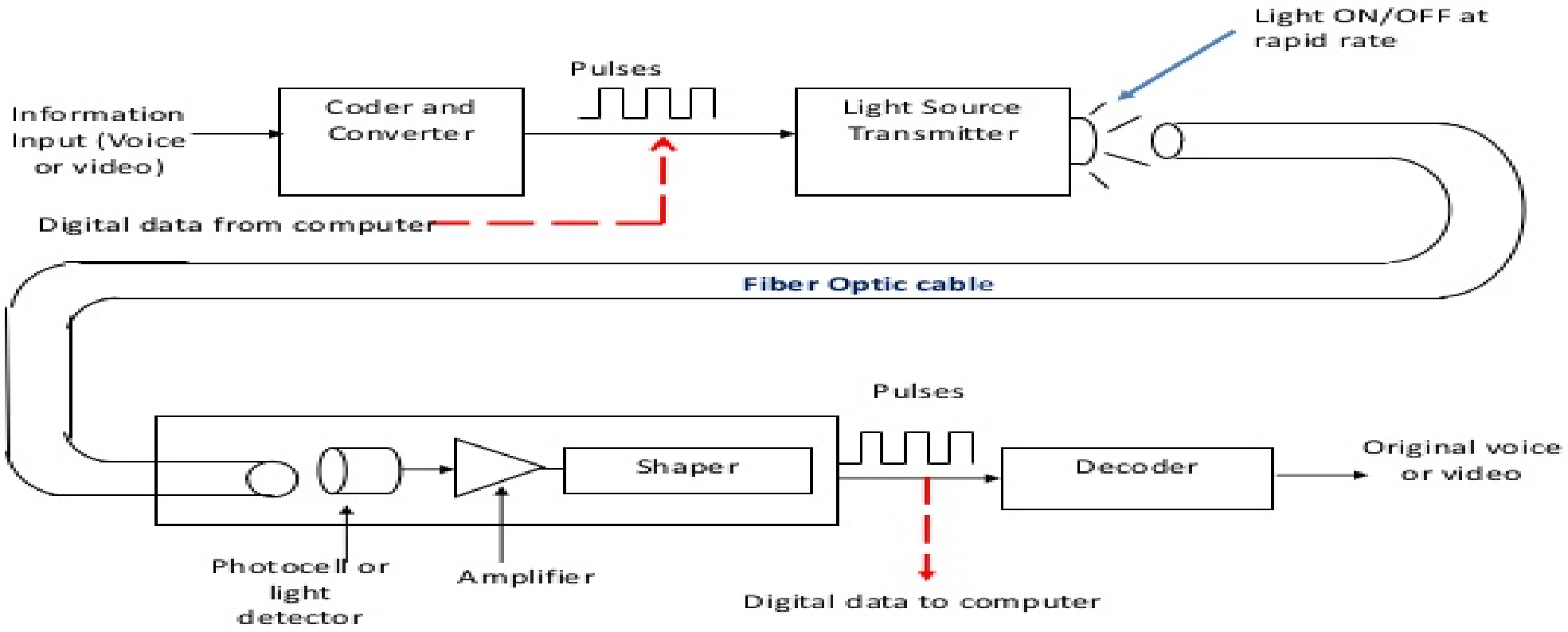




How total internal reflection takes place?



Fibre Optic Communications



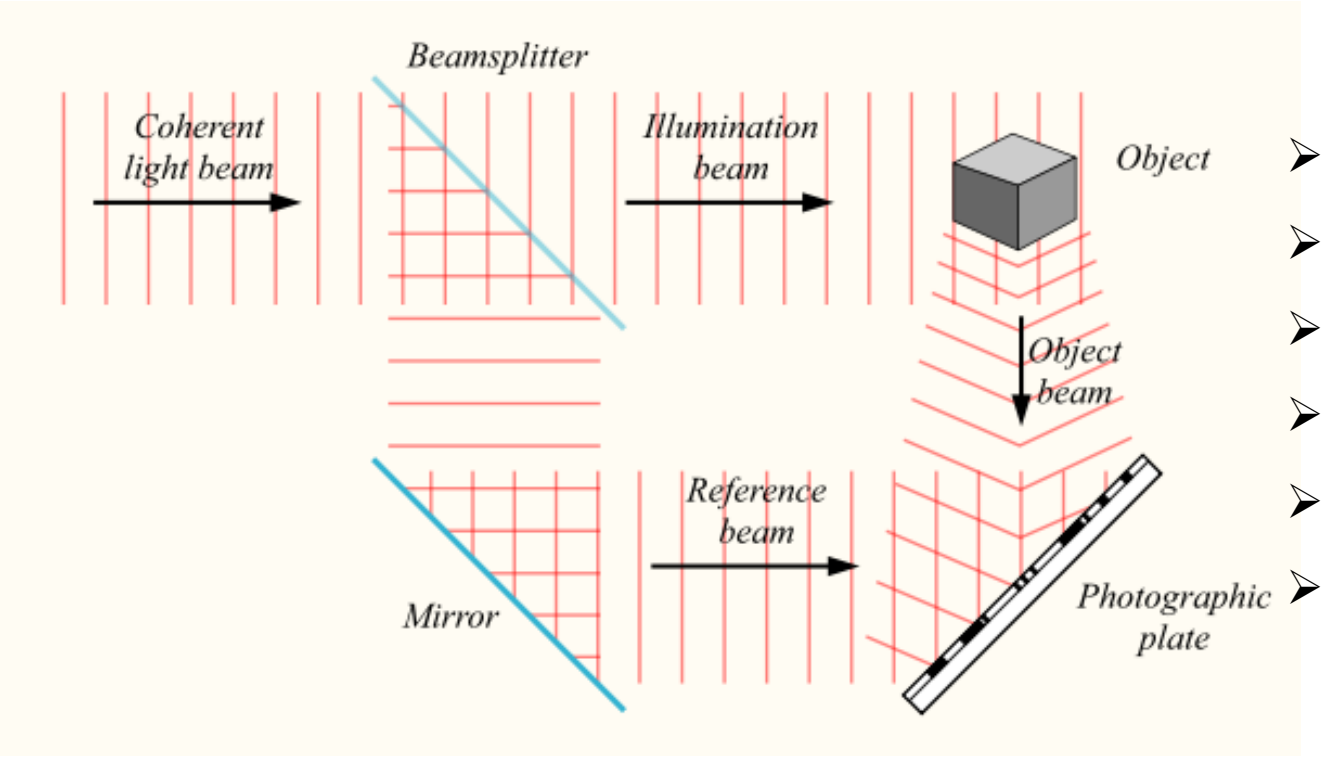
2. Holography (Dennis Gabour in 1948)

It is used to form hologram image (3-dimensional image)

Holo : Complete and Gramma: Writing

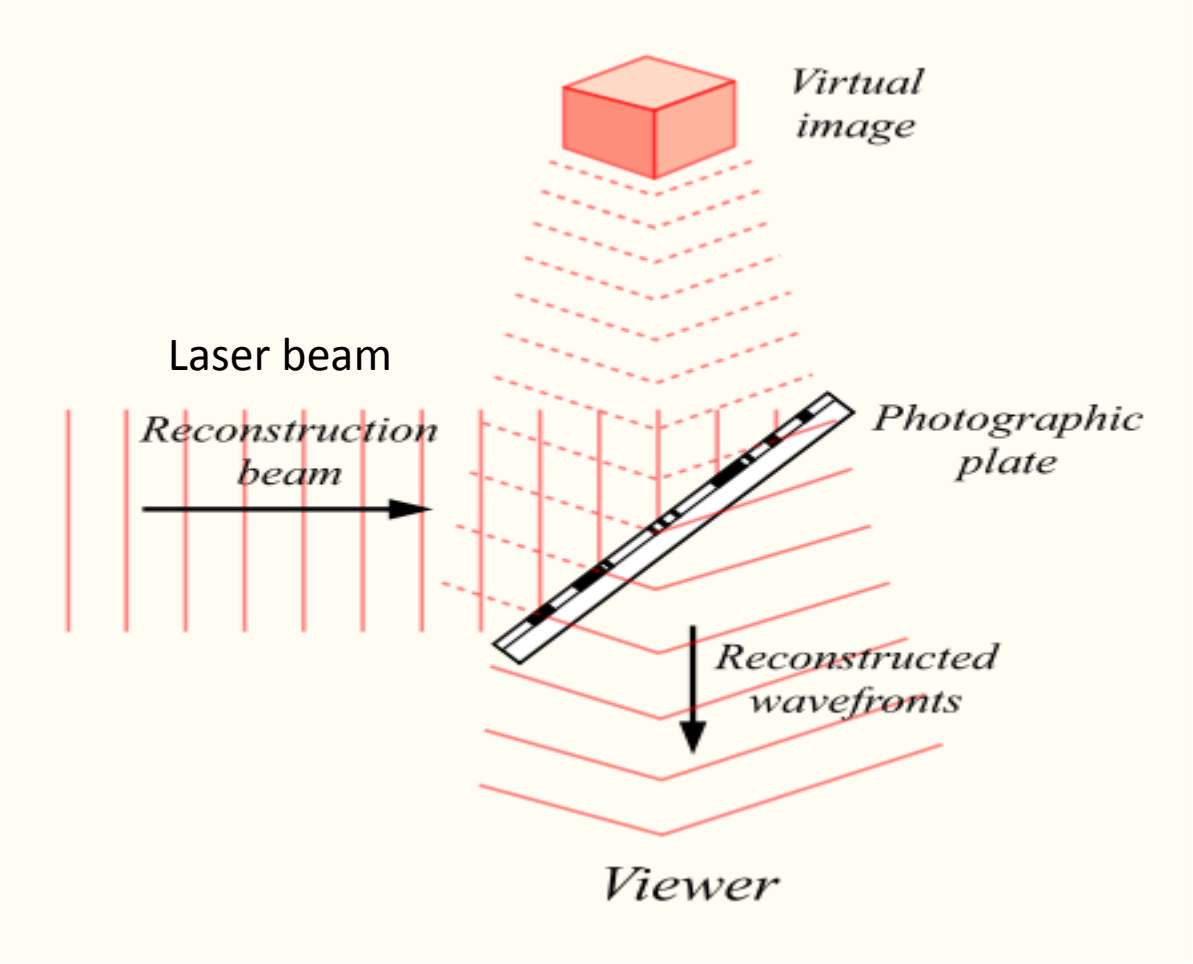
Conventional Photography	Holography
2-D image	3-D image
Only intensity is recorded No phase information	Intensity and phase (diffraction and interference of light)
Light recorded: one direction	Light from every direction
Required normal light	LASER light
Lens is used	Scattered light is directly recorded
Negative is required	Not required
Not repairable after broken	Can be reconstructed

Generation of Hologram



- Beam split: Reference beam and object beam
- Reference beam: directly reach to object
- Object beam: illuminates the object
- Interference: Scattered light from object and reference beam
- Photographic plate: Interference pattern
- It does not contain image; only dark and bright fringes

Reconstruction or Viewing of Hologram



- Object can be viewed by illuminating the hologram
- Laser beam same as reference beam used for illumination
- Hologram (photographic plate): transparent and opaque part: act as diffraction grating
- Light from hologram: constructively and destructively interference
- It will form real (front) and virtual (behind) image

➢ Hologram: two stage process

1. Recording of hologram in the form of interference pattern

2. Act as diffraction grating for reconstruction beam and to get image of object

- It is used to store large amount of data (ROM)
- Medical science (3D image of internal organs of human body)
- To check minute deformation in the object

Important Questions

LASER is a short form of			
Light amplification by spontaneous emission of radiation	b)	Light amplification by stimulated emission of radiation	
Light absorption by stimulated emission of radiation	d)	Light absorption by spontaneous emission of radiation	

The rate of spontaneous emission depends upon the number of atoms in the			
a)	Ground state	b)	Excited state
c)	Metastable state	d)	None of the above

The basic principle of holography is that ……			
a) to create the interference pattern of object wave and reference wave	b)	to create the interference pattern of object wave only	
c) to create the interference pattern of reference wave only	d)	none of the above	

Which laser was invented first?			
Semiconductor laser	b)	Ruby laser	
He-Ne laser	d)	CO_2 laser	

The light source used for optical pumping …….			
Neon	b)	Xenon	
Argon	d)	none of these.	