UNIT II

LASERS AND MASERS

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Applied Physics-II

B.Sc.(Home Science)Semester IV

LASERS

- The word LASER is an acronym that stands for **“Light Amplification by Stimulated Emission of Radiation”.**
- Perhaps the most important optical device to be developed in the past 50 years. Essentially an optical amplifier.
- Albert Einstein, as early as 1917, first predicted the existence of a new irradiative process called **“Stimulated Emission”.**
- In 1954, C .T. Townes and coworkers developed a microwave amplifier based on stimulated emission of radiation. It was called a MASER.

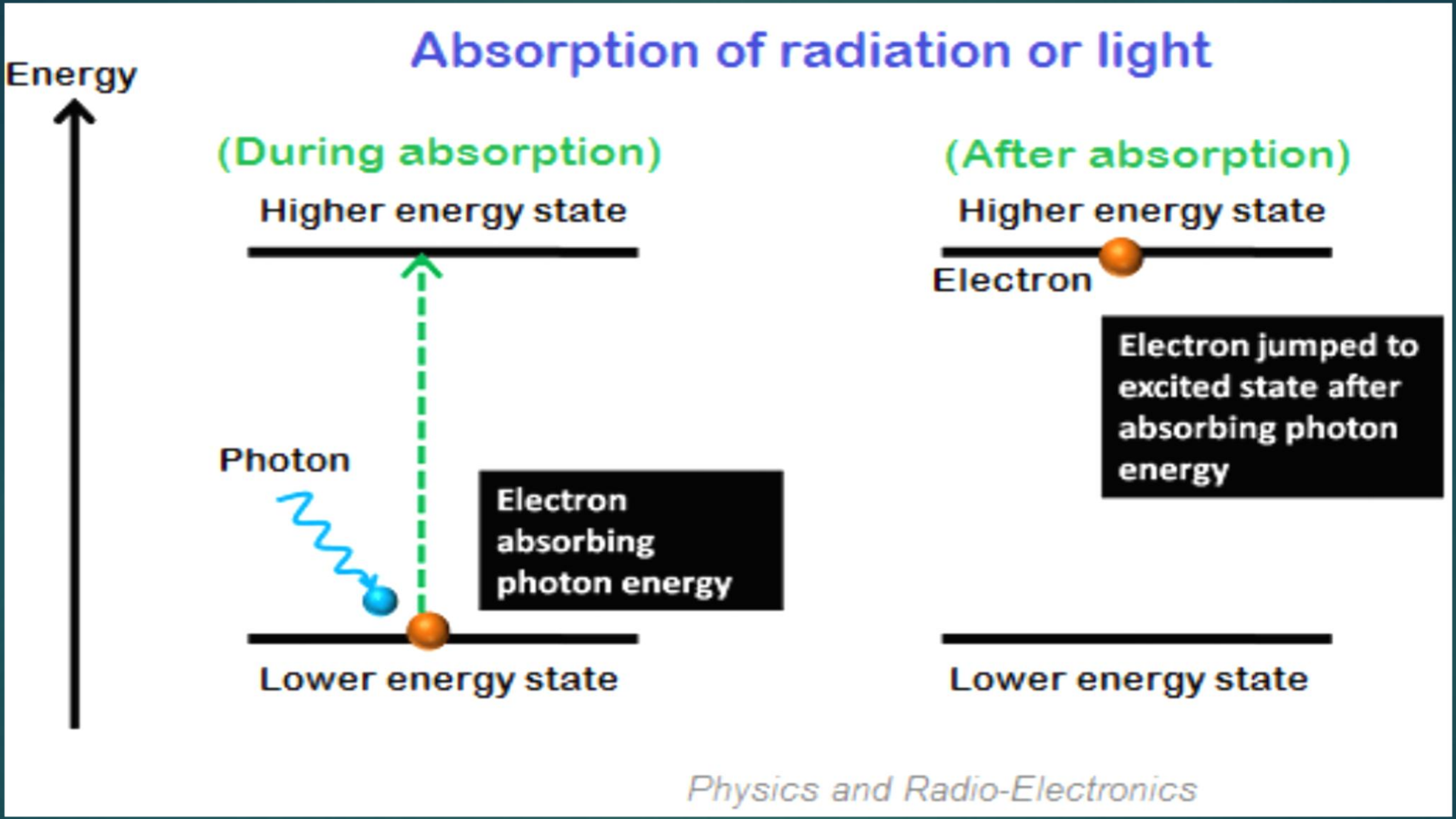
Einstein's Quantum Theory of Radiation:

In 1916, according to Einstein, the interaction of radiation with matter could be explained in terms of three basic processes:-

1. Stimulated Absorption/ Absorption of Radiation
2. Spontaneous Emission
3. Stimulated Emission

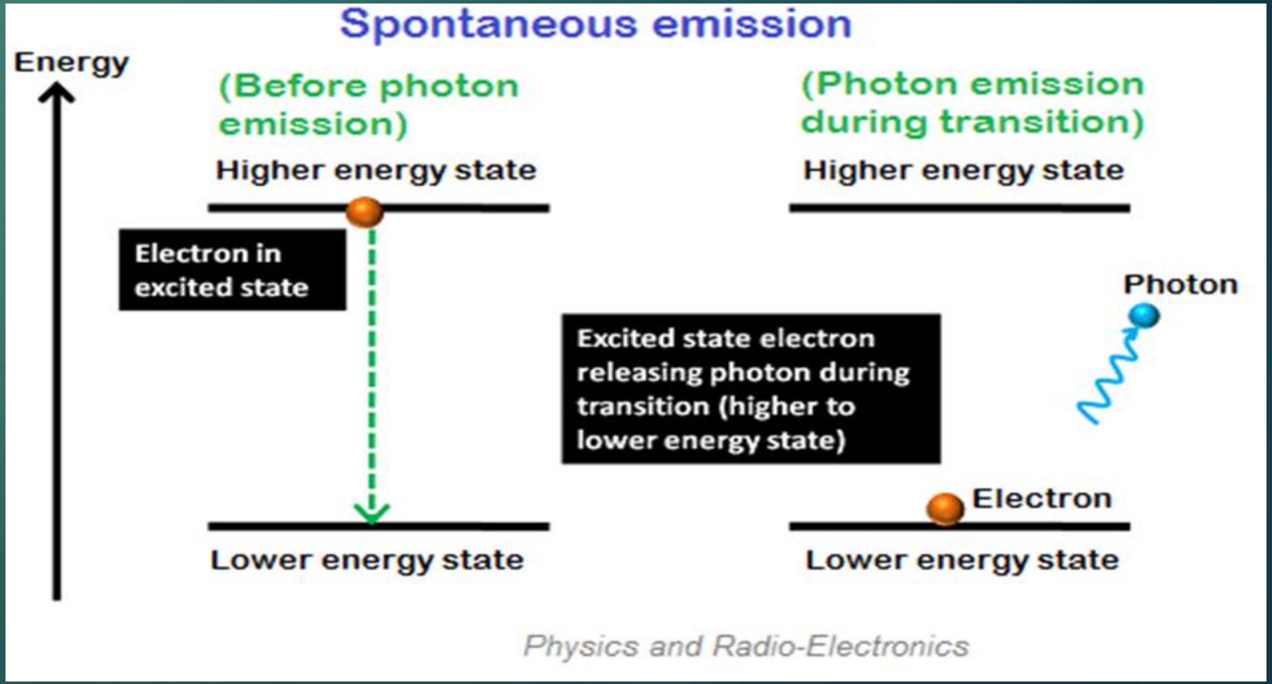
1. Stimulated Absorption:

- Atoms and molecules can exist in certain energy states.
- The state of lowest energy is called the ground state.
- All other states have more energy than the ground state and are called excited states.
- Under ordinary conditions, almost all atoms and molecules are in their ground states.
- Whenever a photon is incident on an atom or molecule, it excites the atomic system from a lower energy state into a higher energy state. This is called absorption or sometimes **Stimulated Absorption**.
- Stimulated absorption occurs when a photon strikes an atom with just exactly the proper energy to induce an electronic transition between two energy states.


Absorption of radiation or light
Energy
(During absorption)
Higher energy state
Photon
Electron absorbing photon energy
Lower energy state
(After absorption)
Higher energy state
Electron
Electron jumped to excited state after absorbing photon energy
Lower energy state
Physics and Radio-Electronics

2.Spontaneous Emission:

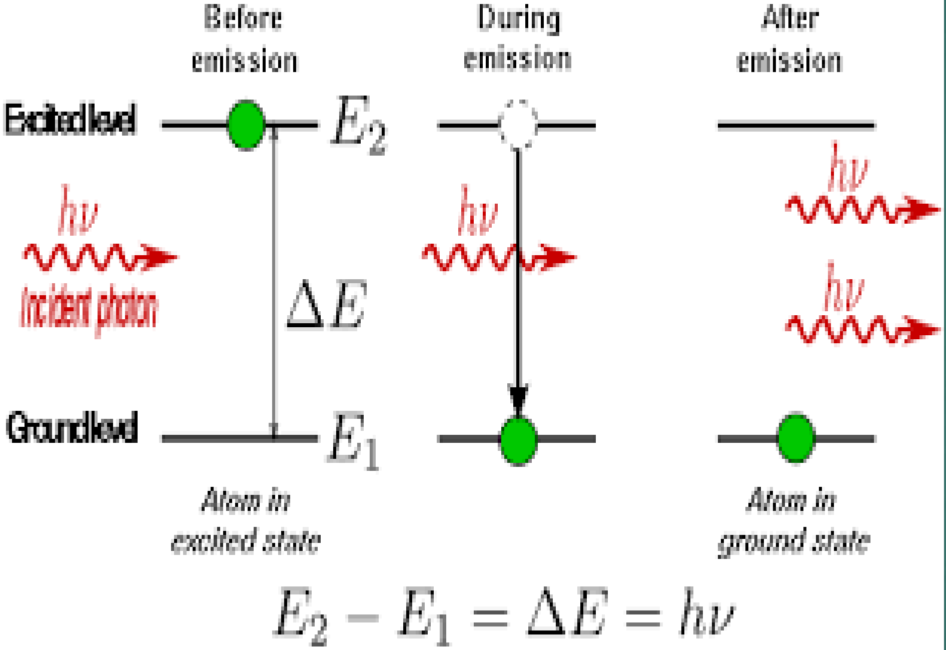
- Consider an atom (or molecule) of the material exists initially in an excited state E_2.
- No external radiation is required to initiate the emission. Since $E_2 > E_1$, the atom will tend to spontaneously decay to the ground state E_1 .
- Therefore , a photon of energy $h\upsilon = E_2 - E_1$ is released in a random direction. This process is called spontaneous emission.
- When the energy released ($E_2 - E_1$) is delivered in the form of an electromagnetic wave, the process is called Radiatiative Emission.

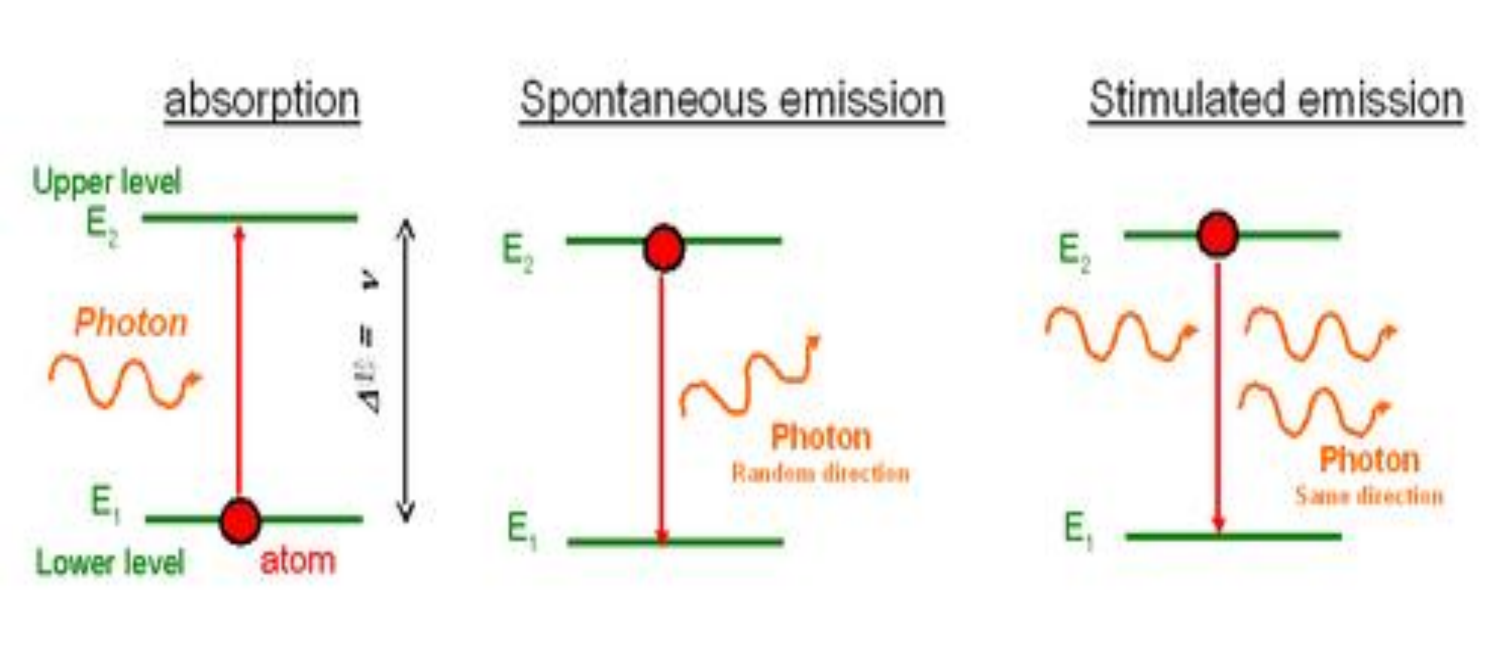


3.Stimulated Emission:

- Requires the presence of external radiation.
- When an incident photon of energy hʋ = E_2-E_1 passes by an atom in an excited state E_2, it stimulates the atom to drop or decay to the lower state E_1.
- The atom releases a photon of the same energy, direction, phase, and polarization as that of the photon passing by.
- The net effect is two identical photons (2hʋ) in the place of one, or an increase in the intensity of incident beam.

It is precisely this process of stimulated emission that makes possible the amplification of light in LASERS.





In stimulated emission, the light energy is supplied directly to the excited electron instead of supplying energy to the ground state electrons.

Common Components of all LASERS:

1. **Active medium:**

- The active medium may be solid crystals such as ruby or Nd: YAG (neodymium-yttrium aluminum garnet), liquid dyes, gases like CO_2 or Helium/ Neon or semiconductors such as GaAs (Gallium Arsenide). Active medium contains atoms whose electrons may be excited to a metastable energy level by an energy source.

2. **Excitation Mechanism:**

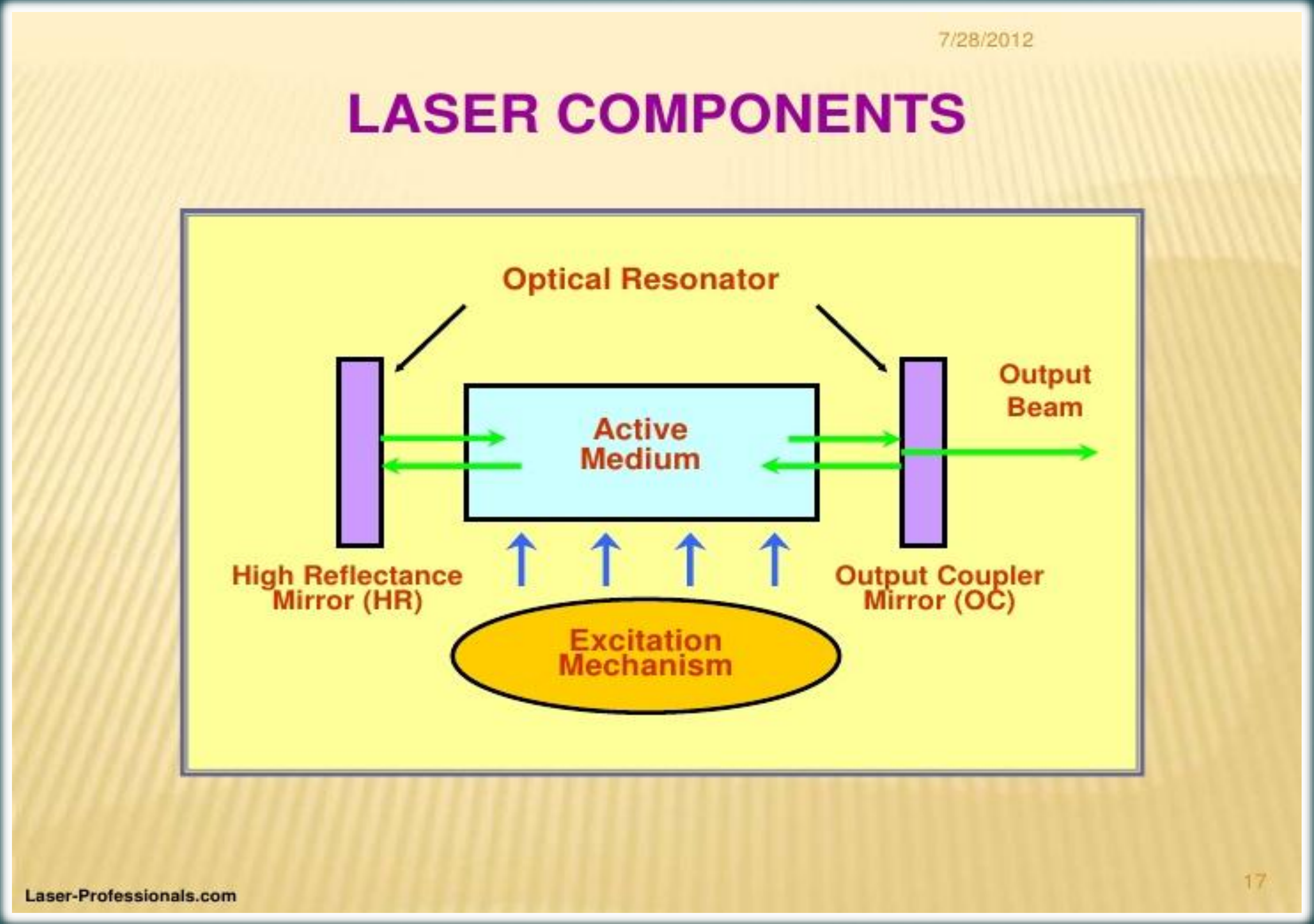
- These pump energy into the active medium by one or more of three basic methods: - Optical, Electrical or Chemical.

3. **High Reflectance mirror:**

- A mirror which reflects essentially 100% of laser light.

4. **Partially Transmissive mirror:**

- A mirror which reflects less than 100% of the laser light and transmits the remainder.



Gas lasers consist of a gas filled tube placed in the laser cavity. A voltage (external pump source) is applied to the tube to excite the atoms in the gas to a population inversion. The light emitted from this type of laser is normally continuous wave.

Lasing Action:

1) Energy is applied to a medium , raising electrons to an unstable energy level.

2) These atoms spontaneously decay to a relatively long- lived, lower energy, metastable state.

3) A population inversion is achieved when the majority of atoms have reached this metastable state. **The number of electrons per unit of volume in an energy state is the population of that energy state.**

4) When a sizable population of electrons resides in upper levels, this condition is called **population inversion**.

Contd…….

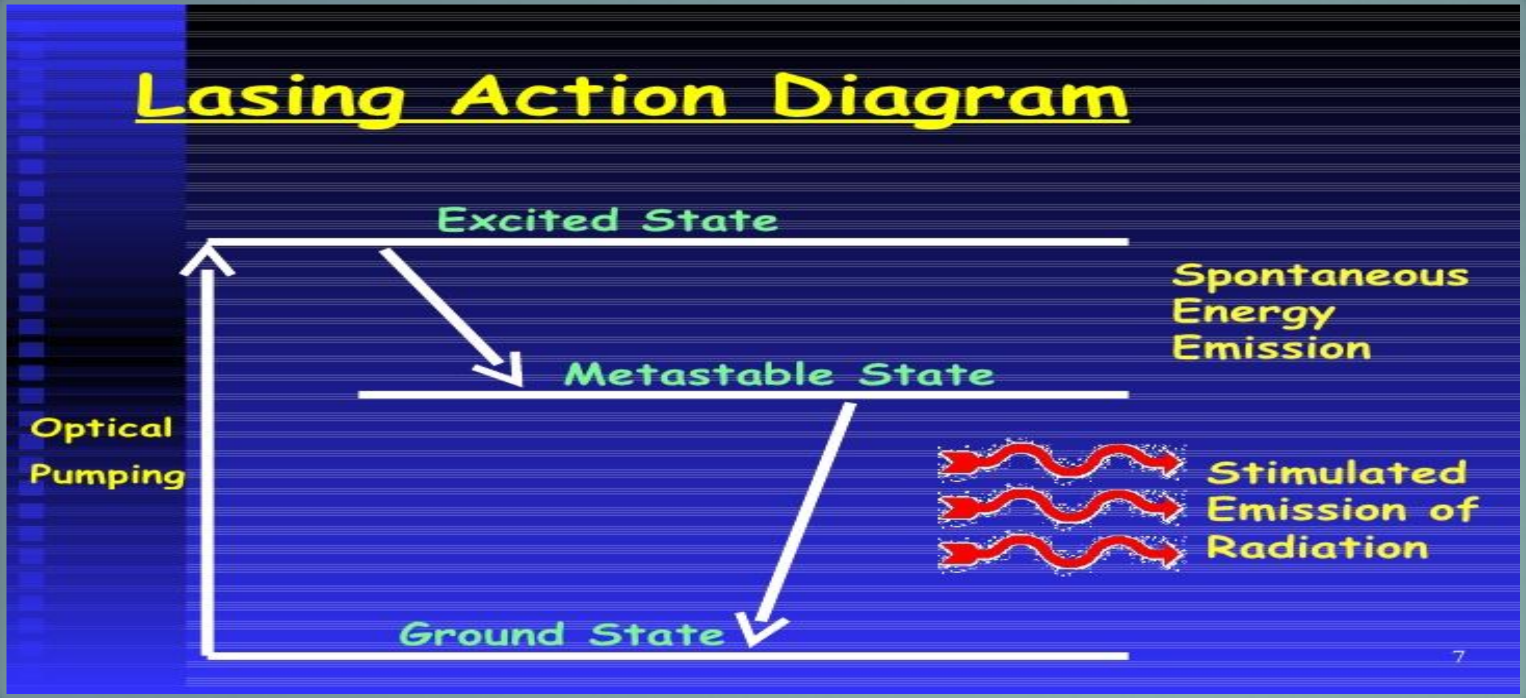
5) Lasing action occurs when an electron spontaneously returns to its ground state and produces a photon.

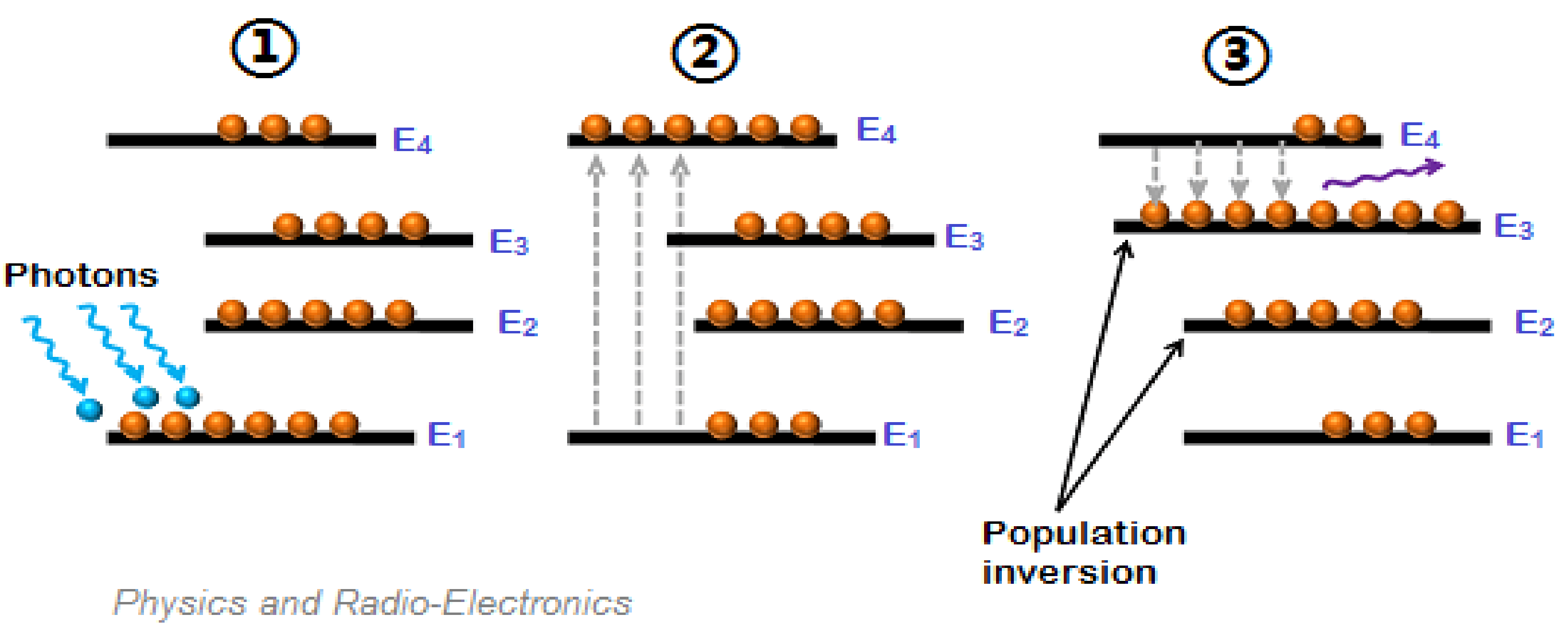
6) If the energy from this photon is of the precise wavelength, it will stimulate the production of another photon of the same wavelength , resulting in a **cascading effect**.

7) The highly reflective mirror and partially reflective mirror continue the reaction by directing photons back through the medium along the long axis of the laser.

8) The partially reflective mirror allows the transmission of a small amount of coherent radiation that we observe as the **beam**.

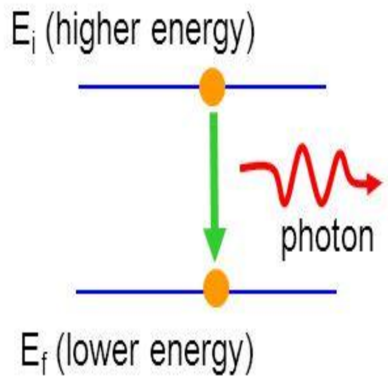
9) Laser radiation will continue as long as energy is applied to the lasing medium.


Lasing Action Diagram
Excited State
Spontaneous
Energy
Emission
Metastable State
Optical
Pumping
Stimulated
Emission of
Radiation
Ground State
7

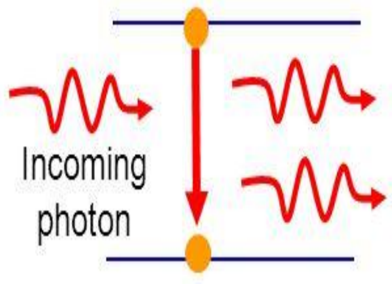

①
②
③
E4
E3
E2
E1
Photons
Population
inversion
Physics and Radio-Electronics

Spontaneous *vs.* Stimulated Emission

- Coherent radiation is produced when an atom undergoes stimulated emission.
- Spontaneous emission occurs when an electron makes an unprovoked transition to a lower energy level
- Stimulated emission occurs when an incoming photon induces the electron to change energy levels → **amplification**

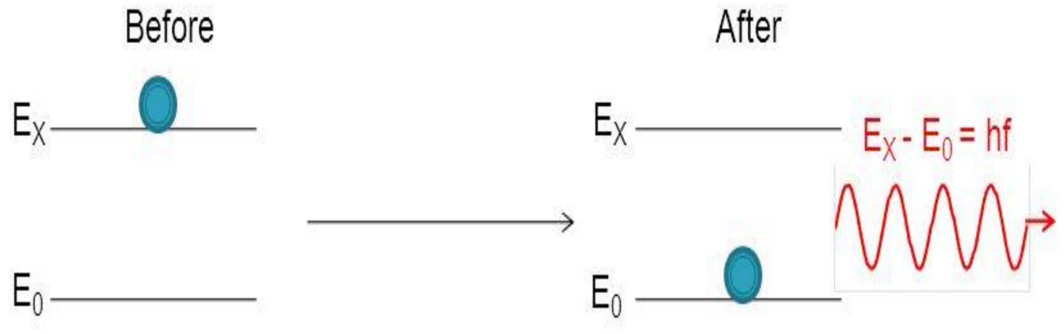


Spontaneous emission

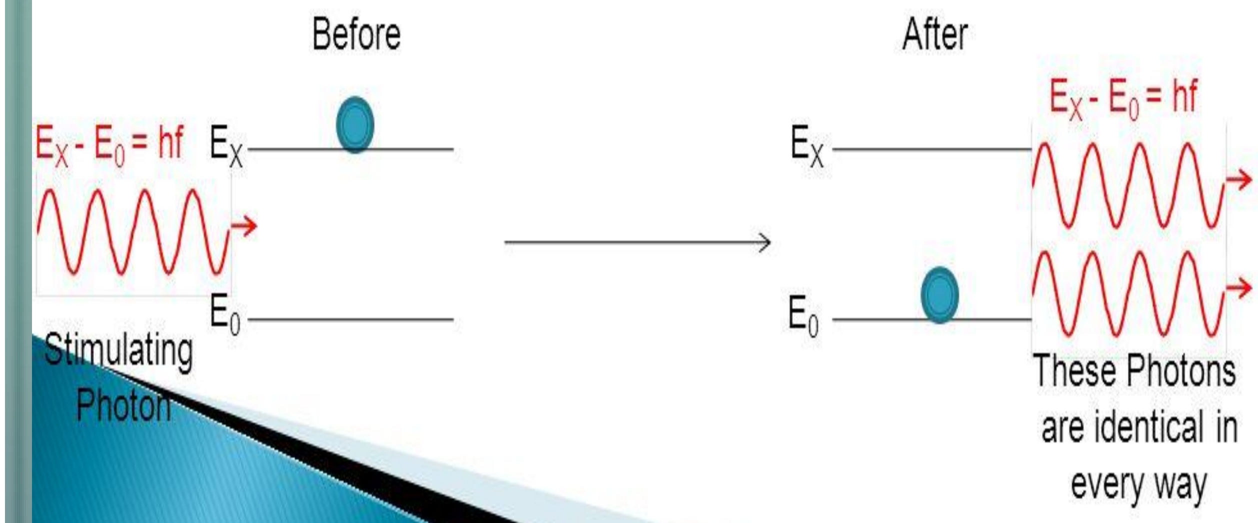


Stimulated emission

Spontaneous Emission

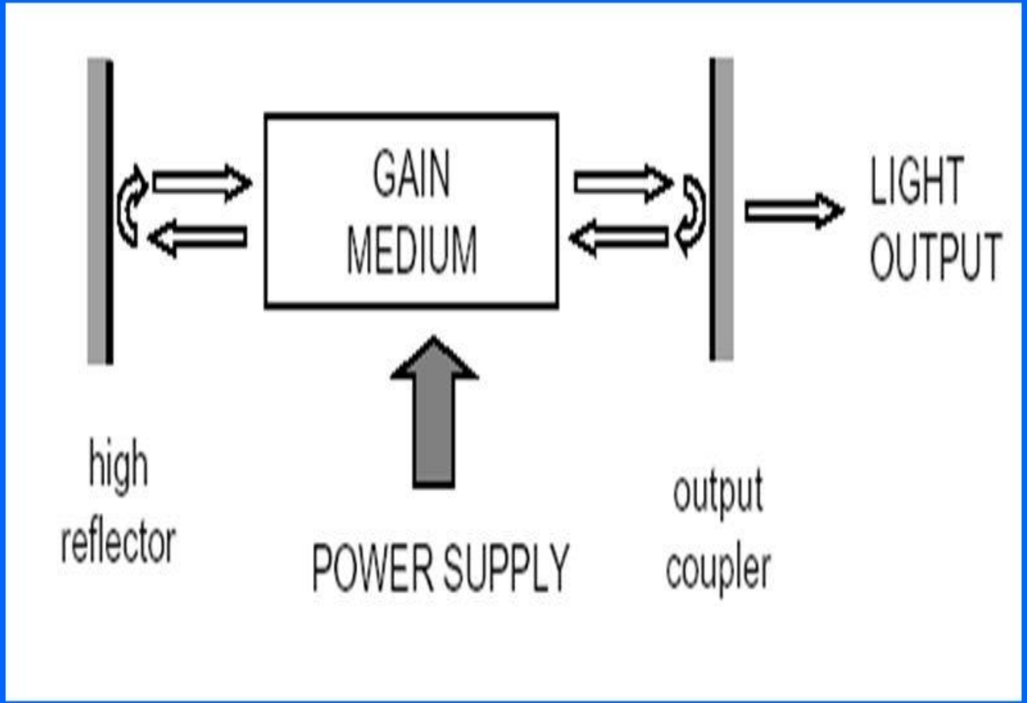


Stimulated Emission

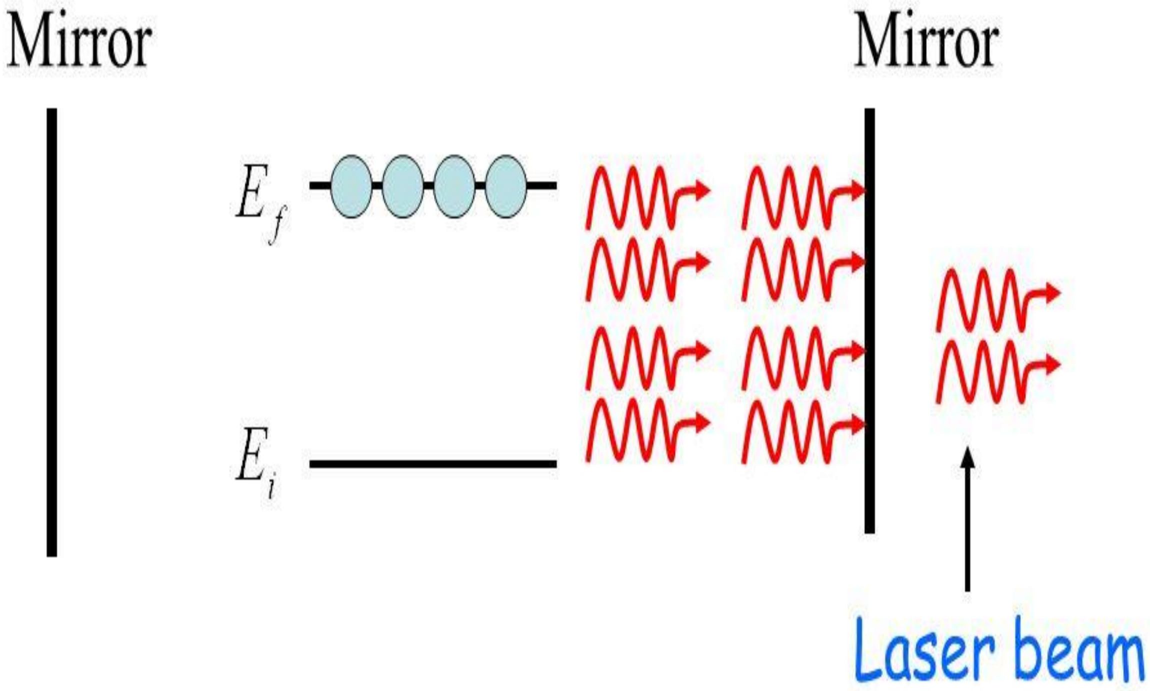


Positive Optical Feedback

Positive optical feedback is achieved by inserting the amplifying medium inside a resonant cavity. Light in the cavity passes through the gain medium and is amplified. It then bounces off the end mirrors and passes through the gain medium again getting amplified further.



After several round trips...



Photons with:

- same energy : Monochromatic
- same direction of propagation : Spatial coherence
- all in synchrony: Temporal coherence

Types of Lasers:-

Depending on the wavelengths and their applications, there are different types/categories of lasers. Few of them are -

1. **SOLID STATE LASER**

   In these kind of LASERs solid state materials are used as active medium. The solid state materials can be ruby, neodymium-YAG (yttrium aluminum garnet) etc.

2. **GAS LASER**

   These LASERs contain a mixture of Helium and Neon. This mixture is packed up into a glass tube. It acts as active medium. We can use Argon or Krypton or Xenon as the medium. CO_2 and Nitrogen LASER can also be made.

3. **DYE OR LIQUID LASER**

   In these kind of LASERs organic dyes like Rhodamine 6G in liquid solution or suspension used as active medium inside the glass tube.

Contd….

4. **EXCIMER LASER**

   Excimer LASERs (the name came from excited and dimers) use reactive gases like Chlorine and fluorine mixed with inert gases like Argon or Krypton or Xenon. These LASERs produce light in the ultraviolet range.

5. **CHEMICAL LASER**

   A chemical laser is a LASER that obtains its energy from a chemical reaction. Examples of chemical lasers are the chemical oxygen iodine laser (COIL), all gas-phase iodine laser (AGIL), and the hydrogen fluoride laser, deuterium fluoride laser etc.

6. **SEMICONDUCTOR LASER**

   In these LASERs, junction diodes are used. The semiconductor is doped by both the acceptors and donors. These are known as injection laser diodes. Whenever the current is passed, light can be seen at the output.

LASER	EXAMPLES
GAS LASERS	He-Ne Laser, Argon Laser, Krypton Laser, CO_2 Laser, CO Laser etc.
CHEMICAL LASERS	Hydrogen Fluoride Laser, Deuterium Fluoride Laser, All Gas Phase Laser etc.
SOLID STATE LASERS	Ruby Laser, Nd: YAG Laser (neodymium-yttrium aluminum garnet), Ti-Sapphire Laser etc.
SEMICONDUCTOR LASERS	GaN, InGaN, Semiconductor Laser Diode etc.

APPLICATIONS/ USES OF LASERS:

Many scientific, military, medical and commercial laser applications have been developed since the invention of the laser in 1958. The coherency, high monochromaticity and ability to reach extremely high powers are all properties which allow for these specialized applications.

MEDICAL:

1. Eye surgery and refractive surgery.
2. Soft tissue surgery.
3. Bloodless surgery.
4. To destroy kidney stones.
5. ‘No touch’ removal of tumors, especially of the brain and spinal cord.
6. Cosmetic surgery: - removing tattoos, scars, stretch marks, wrinkles, birth marks and hair.
7. In dentistry for carries removal, endodontic/ periodontic procedures, tooth whitening, oral surgery.   And many more ..

INDUSTRIAL AND COMMERCIAL :

- Laser Cutting
- Laser Welding
- Laser Drilling
- Laser marking
- Laser printers
- Optical communications over optical fiber or in free space.
- Guidance systems
- Barcode scanners / Readers
- Laser Pointers
- Laser engraving of plates
- Holography
- Laser Switches
- Plastic welding
- Laser Lighting Displays
- To store and retrieve data in optical discs. etc.

SCIENTIFIC :

- A wide variety of interferometric techniques
- Raman Spectroscopy
- Atmospheric Remote Sensing
- Light Detection and Ranging technology
- Holographic techniques
- Lasers have been used aboard spacecrafts
- Laser based LIDAR(light RADAR) etc.

MILITARY :

- For target designation and ranging.
- Defensive counter measures.
- Communications
- Directed Energy weapons
- Laser dazzler
- Laser sight
- Firearms etc.

LASER HAZARDS:-

1. **Eye: -** Acute exposure of the eye to lasers of certain wavelengths and power can cause corneal or retinal burns or both. Cataracts or retinal injury can also occur due to chronic exposure to excessive levels.
2. **Skin: -** Acute exposure to high levels of optical radiation may cause skin burns while Carcinogenesis may occur for U.V. wavelength.
3. **Chemical:-** Some lasers require hazardous or toxic substances to operate i.e. Chemical dye, Excimer lasers
4. **Electrical:-** Most lasers utilize high voltages that can be lethal
5. **Fire: -** The solvents used in dye lasers are flammable. High voltage pulse or flash lamps may cause ignition. Flammable materials may be ignited by direct beams or specular reflections from high power continuous wave infrared lasers. etc.

LASERS FUNDAMENTALS:

- The light emitted from a laser is **monochromatic** i.e., it is of one colour/ wavelength. Whereas, ordinary white light is a combination of many colours or wavelengths of light.

- Lasers emit light that is highly **directional**, i.e., laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.

- The light from a laser is said to be **coherent**, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.

These three properties of laser light make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.

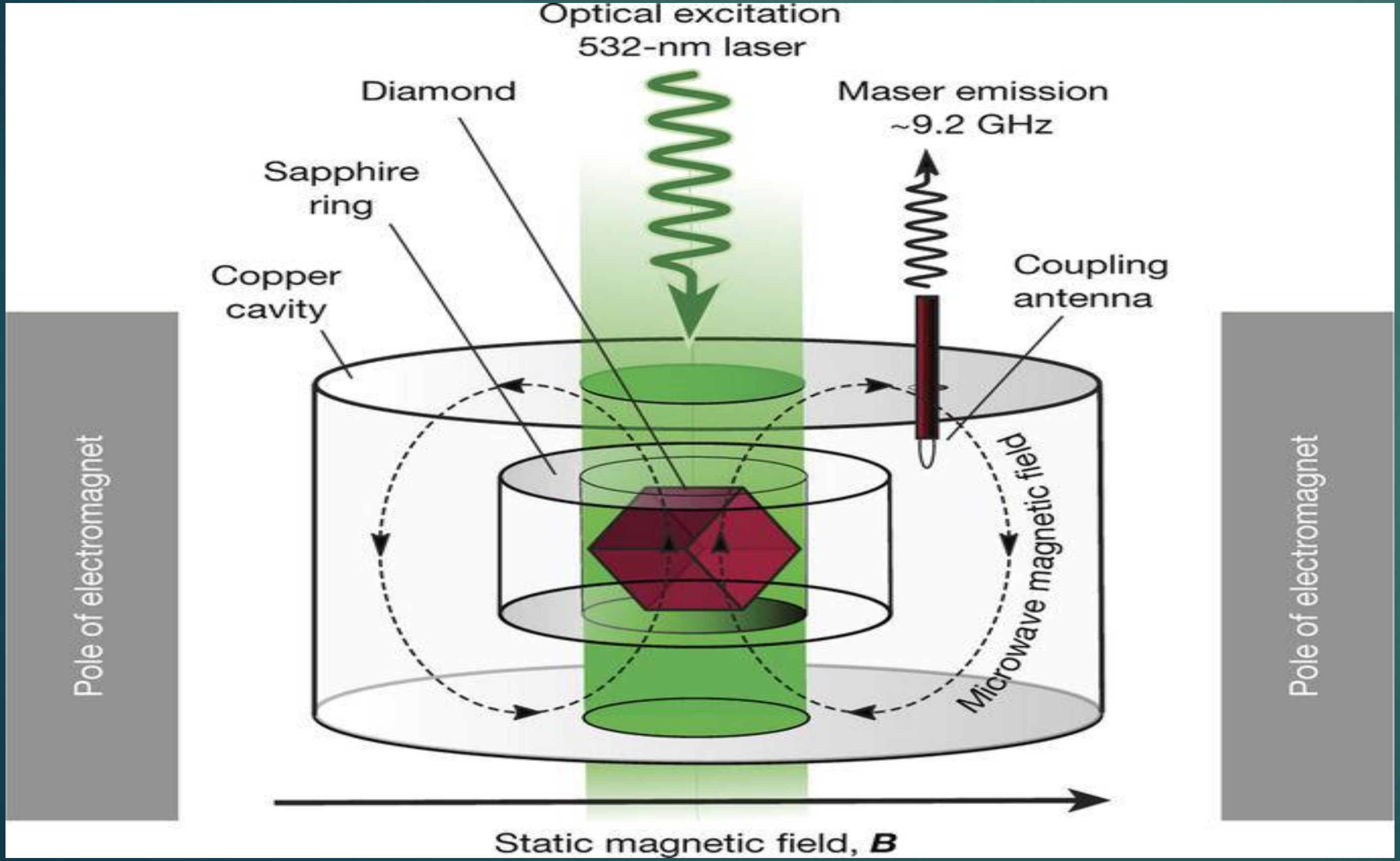
MASERS:

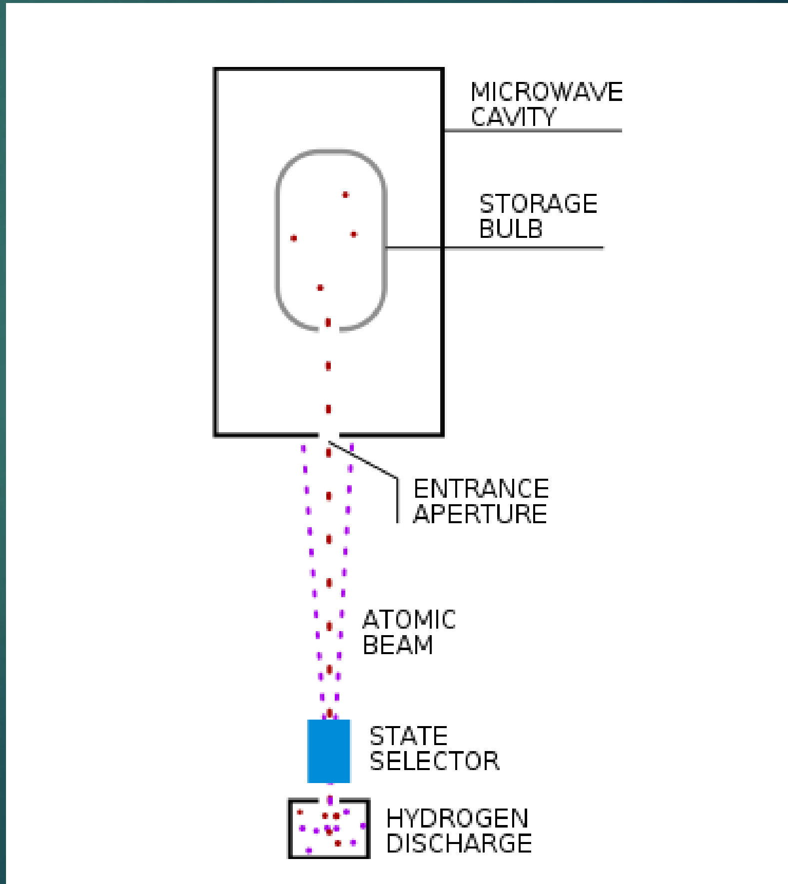
Microwave Amplification by Stimulated Emission of Radiation

- Masers are basically Nature's bases - Caused by stimulated emission from molecular clouds.
- Masers are just like lasers except that the radiations they emit is in the microwave part of the electromagnetic spectrum.
- This light has a longer wavelength and less energy than the usual light emitted by lasers.
- Masers were created in the laboratory in the 1950s, before the invention of laser.
- Due to nature of stimulated emission, maser light is highly beamed and coherent and quite bright. The amplified light can be seen from billions of light years away.
- Masers are found in and out of galaxies, around young stars, on comets, in supernova remnants and possibly in planetary atmospheres. Usually they are associated with star forming regions.

- Charles Townes and his colleagues built the first maser in 1954.
- The first natural maser was discovered in the Orion Nebula in 1965.

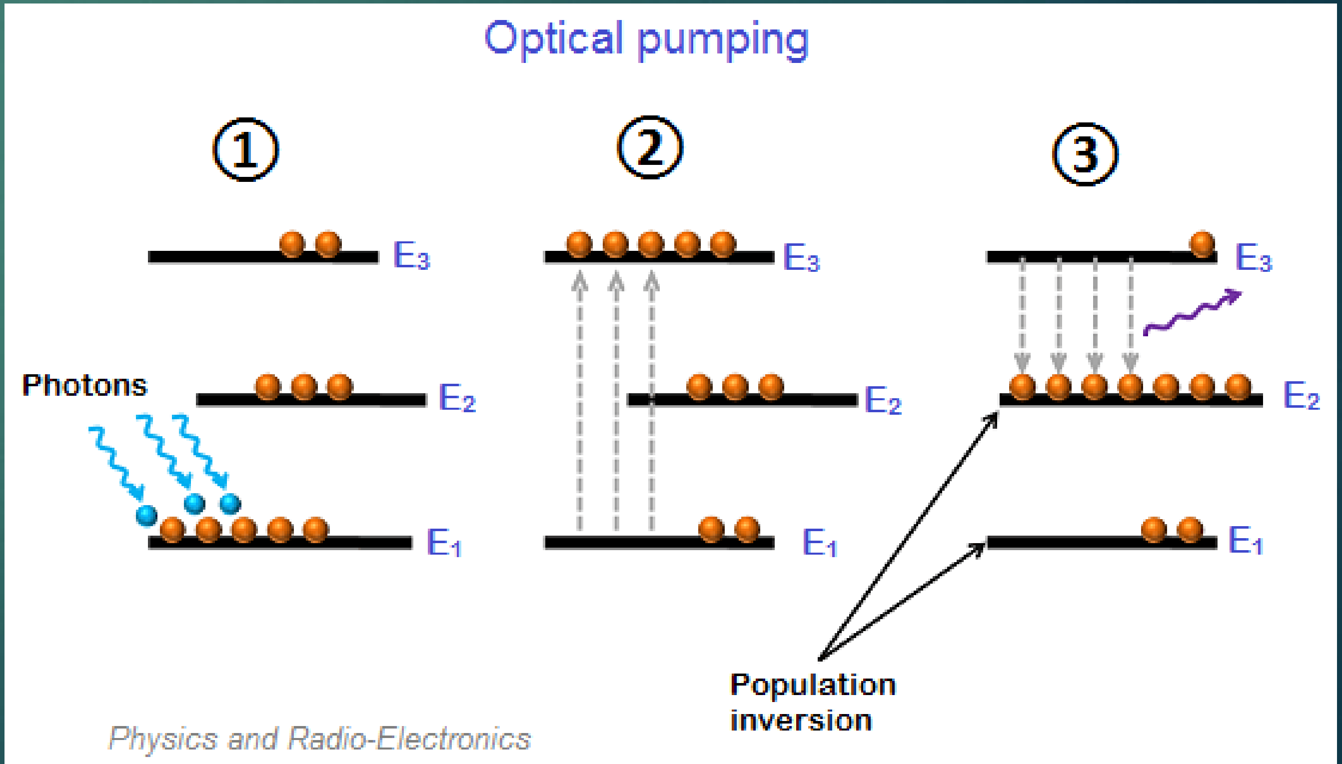
Radiation from maser (or laser) is much more intense than radiation from other light sources. The amplified light from masers can be strong enough to the seen from billions of light years away. To radio telescopes, masers look like very small, very bright dots.

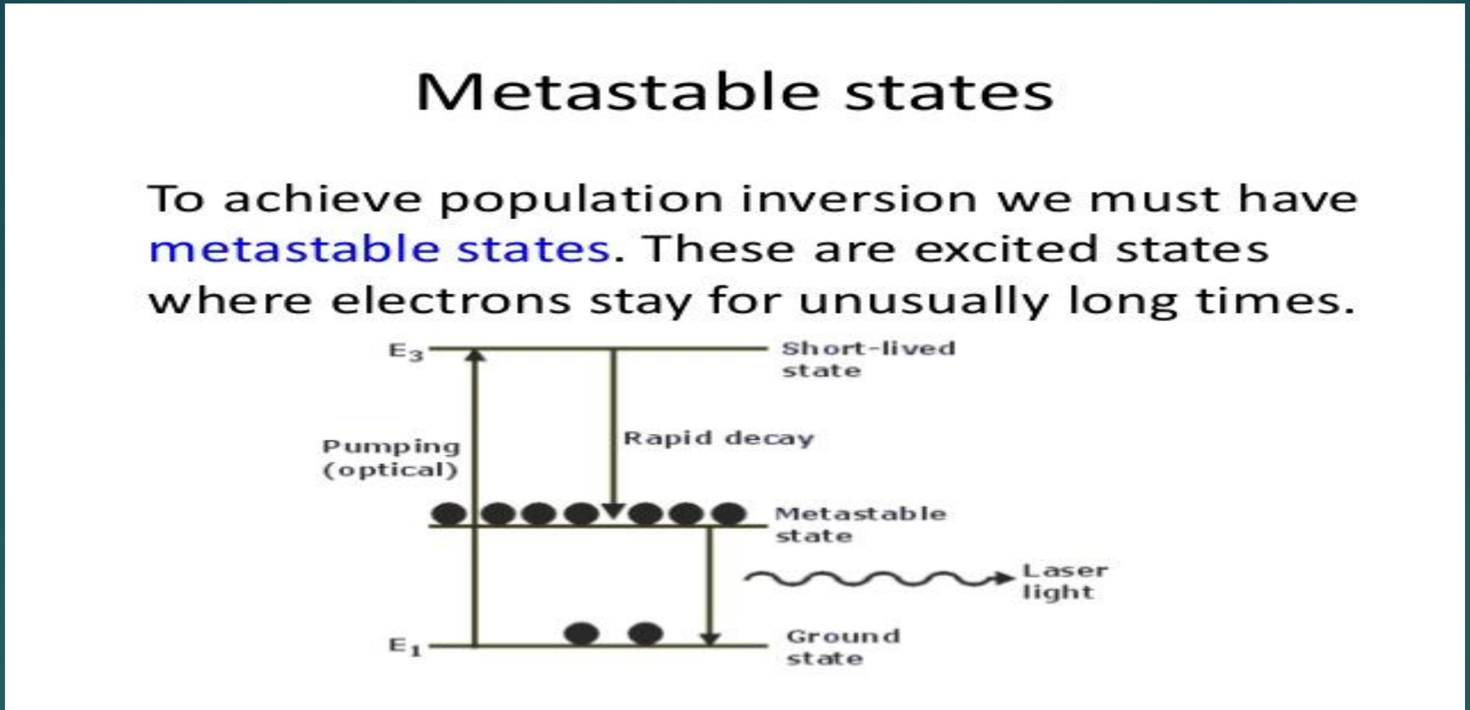




I

- Masers are so powerful because they emit from regions with a population inversion.
- Every electron in a system has a certain amount of energy.
- In most systems, the number of low energy electrons outnumber those with high energy.
- Population inversion occurs when most of the electrons are in the higher energy state.



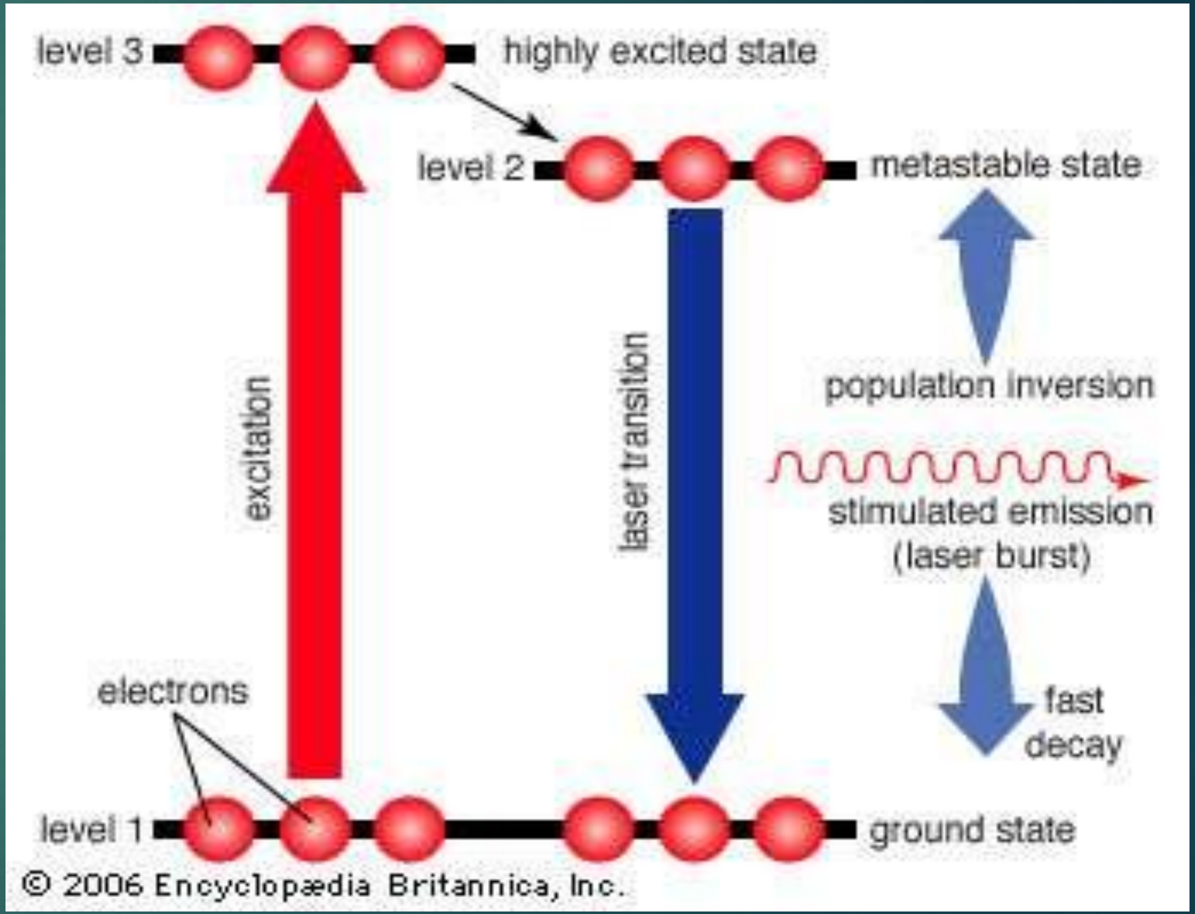


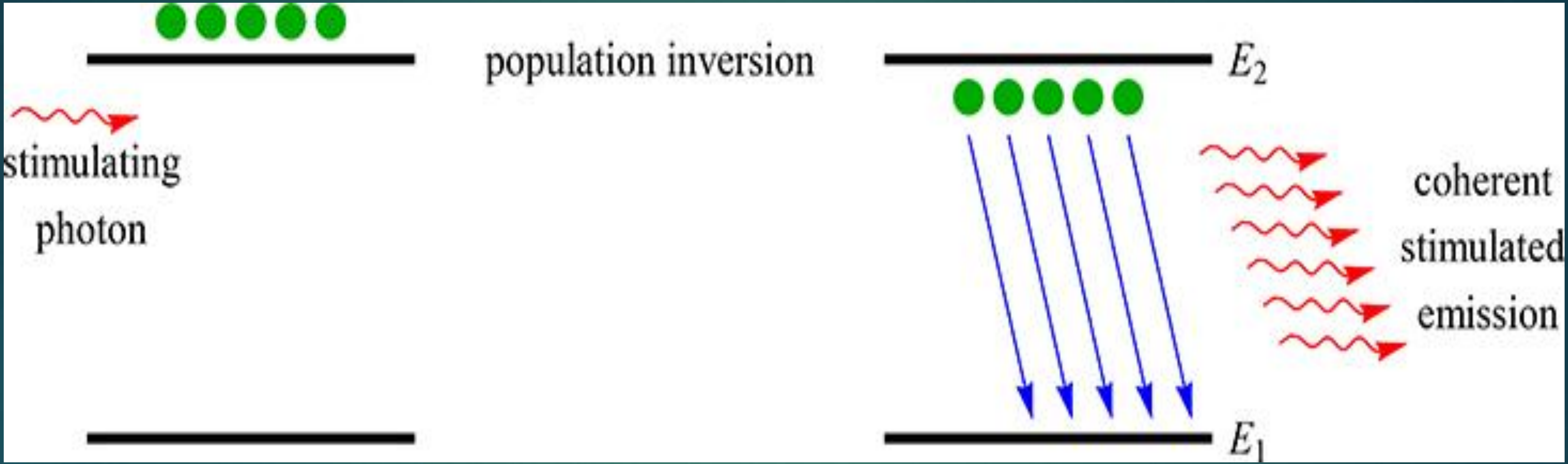
There are several ways in which a system can be pumped into this higher energy state including:-

- Collisions with other particles
- Absorbing light
- Being placed in an electric field

II

- In the inverted population, one of the electrons randomly jumps to the lower energy level.
- When it does, it emits a photon with an energy equal to the energy differences between the two levels.
- As this photon passes another electron,
- its mere presence stimulates the
- release of another photon. As their
- release was stimulated, the group of
- photons has unique properties.





Light bulls emit electromagnetic radiation in a most disorganized way. Masers emit radiation much more orderly. Because they are produced by stimulated emission all the photons are monochromatic (single color/wavelength), in phase, similarly polarized and travel in the same direction.

TYPES OF MASERS

- **Atomic beam masers**
  - Ammonia Maser
  - Free electron Maser
  - Hydrogen Maser
- **Gas Masers**
  - Rubidium Maser
- **Solid state Masers**
  - Ruby Maser
  - Iron-Sapphire Maser
- **Dual Noble Gas Maser**

USES OF MASERS:

- Masers are used in Satellite Communication
- Also used in air to air communication
- Masers are used in Radio Telescope
- They are also used in radar technology
- Maser is used as an amplifier and oscillator in microwave in those components or equipment where low noise factor is of the utmost importance.
- Masers serve as high precision frequency references. These " **atomic frequency standards** " are one of the many forms of atomic clocks . and many more

The most important type of maser is the **Hydrogen Maser,** which is currently used as an atomic frequency standard. Together with other kinds of atomic clocks, these help make the **International Atomic Time**. This is the international time scale, which is coordinated by the international bureau of weights & measures.

End of Unit II