LASER
UNIT-1

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1. WHAT IS A LASER?

A laser is a device that generates a focused beam of light with unique properties, such as coherence and high intensity, through a process called **stimulated emission**. Here's a quick breakdown of the main terms:

- **Light Amplification**: The word "laser" stands for "Light Amplification by Stimulated Emission of Radiation." It means the laser can produce light that's much stronger than natural light sources.

- **Stimulated Emission**: This is the core process of laser function. When an electron in a higher energy level is "stimulated" by incoming energy, it drops to a lower level, emitting a photon (a particle of light) with the same energy and direction as the incoming light. This creates a focused, coherent light beam.

Why are Lasers Different from Other Light Sources?

- **Coherence**: All light waves from a laser move in sync (same phase and frequency), unlike a flashlight or regular light bulb.
- **Monochromaticity**: Lasers emit light of a single color or wavelength, which helps in focusing energy precisely.
- **Directionality**: Laser beams are highly focused and can travel long distances without spreading out.

Coherence

- **Explanation**: Laser light waves are in phase (have the same phase difference) and frequency, making them highly predictable.

- **Why It's Important**: This coherence allows lasers to maintain a focused beam over long distances, reducing signal loss in fiber optic communications.

1. Temporal Coherence Example

- Laser Pointer vs. Flashlight:
  - **Laser Pointer**: The light emitted is temporally coherent, meaning the waves are synchronized over time, leading to a steady, predictable beam.
  - **Flashlight**: The light emitted is not temporally coherent. The phases of the waves vary randomly, making the light less focused and less predictable.

Real-World Application:

- **Optical Interferometry**: Temporal coherence is important in techniques like interferometry (used in sensors, holography, and measuring distances), where the phase of light needs to remain constant over time for precise measurements.

2. Spatial Coherence

•**Definition**: Spatial coherence describes how well different points on the wavefront of the laser light are in phase across a particular distance.

•**Meaning**: Imagine holding a piece of paper in the laser beam — spatial coherence means that any two points on the wavefront are “in sync” with each other across the whole beam.

•**Example**: This property gives laser light its focused, narrow beam. In contrast, a light bulb emits light in all directions, so it lacks spatial coherence.

•**Measurement**: Spatial coherence is measured by the **transverse coherence length**, which is the maximum width over which the light waves remain in phase.

Key Point: Spatial coherence allows lasers to have a narrow, focused beam that doesn’t spread out, which is why lasers can transmit data over long distances without losing intensity.

3. Longitudinal Coherence Length

•**Definition**: This is a measure of how far along the direction of travel (or the "longitudinal axis") the light remains coherent.
•**Meaning**: It’s related to the wavelength purity of the laser. The longer the coherence length, the purer the wavelength.
•**Measurement**: This length indicates how far the light travels before its phases start to vary.
Key Point: Longitudinal coherence length helps ensure that laser beams remain pure and in sync over long distances, making them ideal for precise applications like telecommunications.

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1. Emission of Light

Emission occurs when an atom or molecule releases energy in the form of light. This happens when an electron in an atom or molecule moves from a higher energy state to a lower energy state, releasing the excess energy in the form of photons (light).

There are two main types of emission:

a. Spontaneous Emission

•**Definition**: Spontaneous emission occurs when an atom or molecule in an excited state randomly drops to a lower energy state and releases a photon.

•**Characteristics**:

- **Random process**: The emission happens without any external stimulation.
- **Photon emitted randomly**: The emitted light has no defined phase, direction, or frequency.
- **Example**: Fluorescence in materials after being excited by UV light.

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b. Stimulated Emission

•**Definition**: Stimulated emission occurs when an electron in an excited state is stimulated by an incoming photon, causing the electron to drop to a lower energy state and release a photon that has the same energy, phase, and direction as the incoming photon.

•**Characteristics**:

- **Coherent process**: The emitted photon has the same frequency, phase, and direction as the incoming photon.
- **Critical for lasers**: This is the principle behind the functioning of lasers.
- **Energy conservation**: The photon emitted has the same energy as the stimulating photon.
- **Example**: Laser light production.

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•**Formula**: The energy difference between the levels is the same as the photon's energy:
Ephoton=Ehigher state−Elower stateE_{\text{photon}} = E_{\text{higher state}} - E_{\text{lower state}}Ephoton=Ehigher state−Elower state

2. Absorption of Light

Absorption occurs when an atom or molecule absorbs a photon of light, causing an electron to move from a lower energy state to a higher energy state.

Characteristics of Absorption:

•**Electron excitation**: When a photon's energy matches the energy difference between two energy levels, it can excite an electron from a lower state to a higher one.

•**Energy Matching**: The energy of the absorbed photon must match the energy gap between the two states for absorption to occur.

•**Absorption Spectrum**: The set of wavelengths of light absorbed by an atom or molecule. This spectrum typically appears as dark lines (or bands) in a continuous spectrum of light.

•**No photon emission**: When absorption happens, the energy is temporarily stored in the electron as it transitions to a higher state, and the photon is "lost" to the atom or molecule.

Types of Absorption:

•**Linear Absorption**: The absorption of light happens uniformly with respect to the material's properties (most common).

•**Nonlinear Absorption**: Happens when the intensity of the light is so high that the absorption rate is not linear. This is more common with lasers and intense light sources.

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Characteristics of Light in Emission and Absorption

•**Energy**: In both emission and absorption, the energy of the photon involved is related to the difference in energy between the atomic or molecular states. The equation for this is:

•E=hν=hcλE = h \nu = \frac{h c}{\lambda}E=hν=λhcwhere:

- EEE is the energy of the photon,
- hhh is Planck's constant,
- ν\nuν is the frequency of the light,
- ccc is the speed of light,
- λ\lambdaλ is the wavelength of the light.

•**Wavelength**: The wavelength of the emitted or absorbed light depends on the energy difference between the two states involved. For absorption, the light's wavelength corresponds to the energy gap, and for emission, the emitted light has a wavelength that corresponds to the difference in energy levels.

Einstein Coefficients:

In the context of light absorption, emission, and interaction with atoms or molecules, **Einstein's coefficients** describe the rates of spontaneous and stimulated processes involved. These coefficients are critical in understanding the interactions of light with matter and are used to explain the behavior of lasers, spectral lines, and other related phenomena.

There are three important coefficients introduced by Einstein:

1. A_{21}: **Spontaneous Emission Coefficient**
   - **Definition:** This coefficient corresponds to the rate at which an atom or molecule in an excited state (level 2) spontaneously decays to a lower energy state (level 1), emitting a photon.
   - **Units:** s^{-1} (per second).
   - **Characteristic:** It's a measure of how likely spontaneous emission occurs from the upper level to the lower level.
2. B_{12}: **Stimulated Absorption Coefficient**
   - **Definition:** This coefficient describes the rate at which an atom or molecule in a lower energy state (level 1) absorbs a photon of light and jumps to a higher energy state (level 2).
   - **Units:** $\mathrm{m}^3\mathrm{s}^{-1}$ (per cubic meter per second).
   - **Characteristic:** It's a measure of the probability that an atom will absorb a photon and transition to a higher energy state.

3. B_{21}: **Stimulated Emission Coefficient**

- **Definition:** This coefficient represents the rate at which an atom or molecule in an excited state (level 2) emits a photon and transitions to a lower energy state (level 1) when stimulated by an incoming photon of the same energy.
- **Units:** $\mathrm{m^3 s^{-1}}$ (per cubic meter per second).
- **Characteristic:** It's a measure of how likely stimulated emission will occur from the upper level to the lower level in the presence of light.

Relation Between the Einstein Coefficients

The Einstein coefficients are related to each other and are linked by the **Bose-Einstein distribution** and the principles of detailed balance. The relation between them is as follows:

$$\frac{B_{12}}{B_{21}} = \frac{\nu^3}{c^3}$$

Where:

- ν is the frequency of the radiation (photon).
- c is the speed of light in a vacuum.

This shows the relationship between the **stimulated absorption** (B_{12}) and **stimulated emission** (B_{21}) coefficients.

The Fundamental Relation Between All Three Coefficients:

The relationship between all three Einstein coefficients A_{21}, B_{12}, and B_{21} can be derived from the **Planck's law of black body radiation**. The fundamental relation is:

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

Where:

- h is Planck's constant,
- ν is the frequency of the radiation,
- c is the speed of light.

This equation expresses how the **spontaneous emission coefficient** A_{21} is related to the **stimulated emission coefficient** B_{21}.