



LASER PRINCIPLES

Chapter One

Basic Concepts

- ✓ **Historical Vision**
- ✓ **Laser Definition**
- ✓ **Laser Components**
- ✓ **Laser Working Principle**
- ✓ **Laser Generation Conditions**
- ✓ **Laser Properties**

Assist.Prof. Dr. Sahar Naji Rashid

CHAPTER ONE: BASIC CONCEPTS

1-1) Historical Vision

Since ancient times, human has been contemplating the possibility of obtaining and controlling high-intensity light and heat radiation for various peaceful purposes, as well as harnessing them as an effective weapon in the military arena. In 1917, physicist Einstein established the theoretical foundations for the operation of the laser in his research on the photoelectric effect. In this phenomenon, scientists observed that when electromagnetic radiation is shone upon a metal surface, electrons are emitted from the surface if the light frequency exceeds a certain threshold value. However, if the light frequency is lower than this threshold, electrons are not emitted at all, regardless of the intensity of the illuminated light.

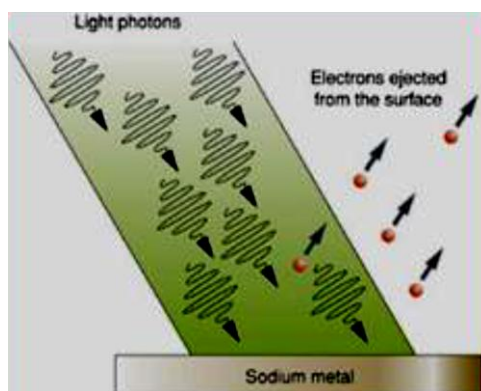


Figure (1-1): Emission of electrons from the surface of the material

Atoms consist of electrons orbiting the nucleus in specific orbits. Electrons can only move from a lower-energy orbit to a higher-energy one by shining electromagnetic radiation where the energy of the photon emitted is greater than the energy difference between the orbits. When an electron descends from a higher-energy orbit to a lower-energy orbit, the energy difference between them is emitted as radiation, with the photon's energy exactly equal to the energy difference between the orbits. Einstein studied the interactions between electromagnetic radiation and the atoms of matter and developed the equations governing these interactions. From these equations, he predicted the existence of the phenomenon known as stimulated emission, which is the basis for the operation of the laser. Scientists have struggled to achieve stimulated emission, but their efforts have been unsuccessful, and some have even denied the existence of such a light phenomenon. In 1947, the American physicist Lamb succeeded in demonstrating the existence of stimulated emission.

In 1954, American physicist Townes succeeded in achieving stimulated emission in the microwave range, and named this device "maser", an acronym for "Microwave Amplification by Stimulated Emission of Radiation". This achievement renewed scientists' hopes of achieving stimulated emission in the visible or non-visible light range and, subsequently, of developing lasers. In 1955, Russian physicists Prokhorov and Basov proposed using optical pumping to achieve the so-called inverted electron distribution, one of the conditions for laser operation. In 1960, American physicist Maiman succeeded in creating the first laser in the visible light range. It consisted of a cylindrical rod of pure ruby, the sides of which were finely polished. The ruby rod was wrapped around an electric lamp consisting of a glass tube filled with xenon gas. When an electric bulb is turned on, the light emitted excites the chromium atoms in the ruby, causing them to emit pure red light that pulses out from one side of the ruby rod. In 1960, Iranian physicist Ali Javan and American Bennett created a laser using helium and neon gases. This laser emitted continuous radiation, rather than pulses like the ruby laser. In 1962, American engineer Hall created a small semiconductor laser. In 1964, the carbon dioxide laser was created, which is characterized by its high radiation power. Since then, the laser has become one of the most important scientific discoveries utilizing photoelectric technology, and its use has spread across many fields. Interest in these rays has greatly increased, as they have become a source of curiosity for many scientists who want to learn about their history, properties, concept, classification, and the extent of their danger to living organisms.

1-2) Laser Definition

Laser is a source of visible and invisible light that has characteristics not found in light emitted by natural or artificial light sources. It produces a very thin and powerful light beam capable of cutting the hardest natural material (diamond). Some beams can be transmitted so far that they can reach the moon without losing their power. The word "laser" is an abbreviation for "Light Amplification by Stimulated Emission of Radiation". Lasers generate a distinctive type of light whose properties differ from the natural light emitted by the sun and stars and the artificial light emitted by various types of electric bulbs. Laser technology has expanded beyond the ultraviolet region toward the high-energy X-rays, and each wavelength in these regions provides the ability and assistance to humans in inventing diverse applications.

- ✓ **Laser Light:** A beam of light containing photons of the same frequency and identical wavelength, creating a relatively high-energy light pulse.
- ✓ **Photon:** The amount of light energy in an electromagnetic wave, with its own frequency and wavelength.
- ✓ **Phase:** The state of an electromagnetic wave at a specific point in space and time.
- ✓ **Interference:** The presence of two or more electromagnetic waves on a single optical path, with or without a phase difference between the two waves.
- ✓ **Constructive Interference:** Interference in which there is no phase difference between the two waves, and the resultant amplitude is the sum of the two amplitudes. This is a requirement for multilayer laser mirrors.
- ✓ **Destructive Interference:** is the interference in which there is a phase difference between the two waves, where one of the waves weakens the second wave or cancels it completely. This interference harms the laser.

1-3) Laser Components

Theoretically, it is possible to emit a laser beam from any element or its compounds. Practically speaking, this process requires the development of appropriate induction or stimulation methods. In recent years, laser beams have been created from a large number of atoms and molecules, whether in the form of gases, solids, or liquids. Some of these devices are commercially available, while others are currently under experimental research. These devices come in a variety of shapes, sizes, and energies, but their design fundamentals are the same: three main common elements: the material medium, the pumping source (energy), and the resonator.

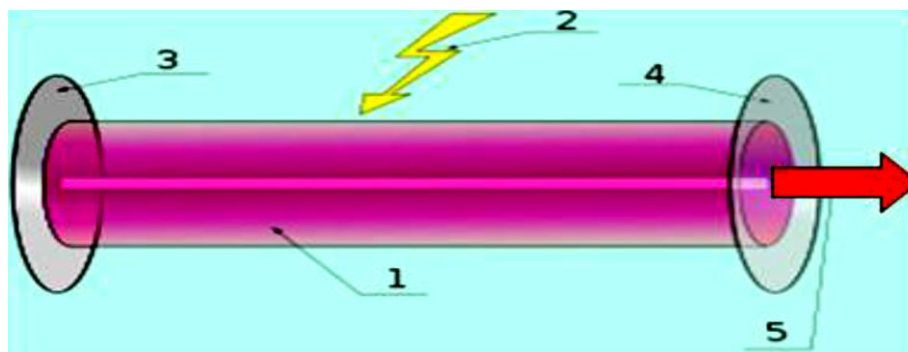


Figure (1-2): Parts of a laser: 1) Active medium, 2) Pumping source, 3) Perfect reflecting mirror, 4) Partial reflecting mirror, 5) Laser beam exit

1) Active Medium:

It is the medium from which radiation is generated. The medium may be a group of atoms, molecules, an element, a compound, or a mixture in a solid, liquid, or gaseous state, with a number of energy levels that are suitable for the three necessary transitions (**absorption**, **spontaneous emission**, and **stimulated emission**). Active media are classified based on the probability of transition between levels.

2) Pumping Source:

Pumping is done by a powerful flash light or by an electrical discharge. This pumping helps provide the largest possible amount of energy to electrons, enabling them to move to higher energy levels. The active medium in the laser consists of atoms with excited electrons. Exciting a large number of atoms is essential to produce a laser. This process is called inverse distribution or qualification, meaning that the number of excited atoms in the material exceeds the number of unexcited atoms. This distribution is what makes the light produced by the material a laser. Just as the electrons absorb significant energy through the pumping process, they release the absorbed energy in the form of photons with a specific wavelength that depends on the difference in energy levels between which the excited electrons have moved.

3) Resonator:

It consists of two opposite flat or spherical concave mirrors, between which the active material is placed, with the reflective side facing inwards, i.e., towards the active material. This arrangement amplifies, magnifies, and develops the stimulated radiation through feedback, resulting in a stable, monochromatic laser wave. Typically, one of the mirrors is 100% reflective, while the other has a lower reflectivity, resulting in a transmittance through which the laser beam emerges. The mirrors help reflect some photons back into the laser material several times. These photons stimulate other excited electrons to emit more photons of the same wavelength and phase. This is the process of light amplification. For the emitted radiation to have the correct oscillation (i.e., the optical path length is equal to an integer number of half-wavelengths), constructive interference occurs, resulting in a highly directive laser beam.

- **Beam Guide:** It is used in the case of laser radiation in the invisible light region such as ultraviolet and infrared rays.

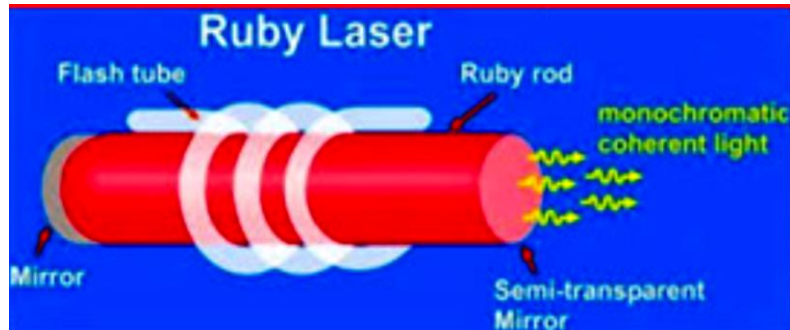


Figure (1-3): Laser beam generation

1-4) Laser Working Principle

The idea behind the laser's theory is that it works on a system with a large number of active atoms and molecules. These atoms are exposed to energy to move from the ground state to higher levels. This occurs when the atoms absorb energy, spend a period of time called the excitation time (the time the atoms remain in the higher levels before returning to the ground state), and then emit photons. This process is repeated several times to produce a large number of photons that travel between two mirrors, one semi-silvered and the other fully reflective. This results in concentrated light with several properties that distinguish it from any other light. This means that lasers occur as a result of several processes: absorption, spontaneous emission, stimulated emission, and inverse diffusion. In 1917, Einstein studied the interaction of electromagnetic waves, or radiation for short, with the atoms of matter and found that there are three types of interactions: absorption, spontaneous emission, and stimulated emission.

- 1) **Absorption:** Atoms of a material absorb incoming photons of radiation. The energy of the absorbed radiation raises electrons from low-energy orbits (E_1) to high-energy orbits (E_2), placing the atoms in an excited state. Photons are only absorbed by a material if their energy exceeds the energy difference between the electron orbits of the atoms of that material. Therefore, materials are transparent to all radiation with frequencies below specific values determined by the atomic structure of the material, such as glass. The probability of absorption from the E_1 to E_2 level is given by the following equation:

$$\frac{dN_1}{dt} = -B_{12}N_1\rho \dots\dots\dots (1-1)$$

dN_1/dt represents the absorption rate, B_{12} represents the Einstein absorption coefficient, N_1 represents the filling of the E_1 level with atoms, and ρ represents the energy density.

2) Spontaneous Emission: Emission is generally the process of transferring (losing) energy from matter to its surroundings. This reduces the energy of the atoms or molecules of matter and causes them to drop to lower energy levels than they were in. However, in spontaneous emission, excited atoms emit electromagnetic waves as a result of electrons descending from high-energy orbits to lower-energy orbits. This radiation is called incoherent radiation because the electrons descend by themselves and between different atomic orbits. This radiation is measured at a very large number of frequencies. Light sources normally rely on the phenomenon of spontaneous emission, which is known as spontaneous emission. The probability of spontaneous emission from the E_2 level to the E_1 level is given by the following equation:

$$\frac{dN_2}{dt} = -A_{21}N_2 \dots\dots\dots(1-2)$$

Where dN_2/dt represents the spontaneous emission rate, A_{21} is the Einstein coefficient of spontaneous emission, and N_2 represents the qualification of the E_2 level by atoms. A_{21} can be calculated from the following equation:

$$A_{21} = \frac{1}{t_{spont}} \dots\dots\dots(1-3)$$

Where t_{spont} represents the spontaneous emission lifetime, which is the period of time it takes for spontaneous emission to occur.

3) Stimulated Emission: It is the process of losing energy from a substance in the form of light under external influence, and it is the basis of laser operation. Excited atoms radiate electromagnetic waves as a result of electrons descending from high-energy orbitals to lower-energy orbitals, but not in a spontaneous and random manner as in spontaneous emission, but rather as a result of being stimulated (induced) by radiation of a specific frequency. The stimulated radiation emitted by an excited substance is called coherent radiation because the electromagnetic waves resulting from the descending electrons have a frequency and phase exactly equal to the frequency and phase of the waves that stimulated the electrons to radiate. Therefore, this radiation theoretically has a frequency of ν . The frequency of the radiation emitted by a substance can be calculated by dividing the energy difference between the two orbitals through which the electron moved by Planck's constant h .

$$E_2 - E_1 = \Delta E = h\nu \dots\dots\dots(1-4)$$

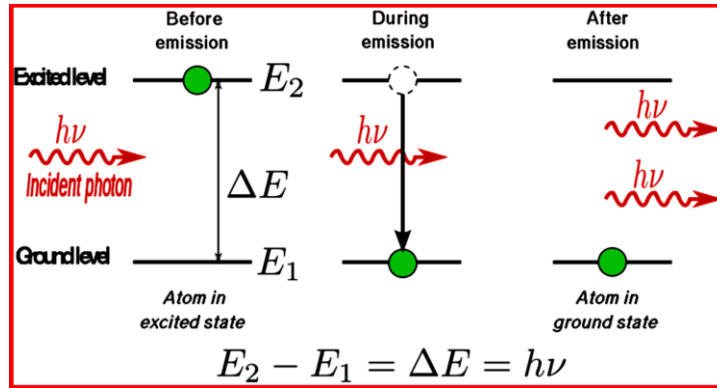


Figure (1-4): Stages of the stimulated emission process

The probability of stimulated emission from level E_2 to level E_1 is given by the equation:

$$\left(\frac{dN_2}{dt}\right)_{stim} = -B_{21}N_2\rho \dots\dots\dots(1-5)$$

Where $(dN_2/dt)_{stim}$ represents the stimulated emission rate, B_{21} is the Einstein coefficient for stimulated emission, and N_2 represents the qualification of the E_2 level by atoms, the ratio \hat{R} between the probability of spontaneous emission and the probability of stimulated emission can be calculated from the following equation:

$$\hat{R} = e^{h\nu/KT} - 1 \dots\dots\dots(1-6)$$

Where K represents the Boltzmann constant (1.38×10^{-23} J/K), T represents the temperature in Kelvin. The rate of stimulated emission increases as the wavelength of the radiation or electromagnetic wave increases. Therefore, lasing at long wavelengths (infrared) is easier than at short wavelengths (visible and ultraviolet). Stimulated emission cannot be achieved without spontaneous emission, as a photon with an energy equal to the energy difference between the upper and lower laser levels can be obtained from spontaneous emission itself.

When absorption, spontaneous emission, and stimulated emission occur together, they can be expressed as a group by the equation:

$$\frac{dN_2}{dt} = -B_{21}N_2\rho - A_{21}N_2 + B_{12}N_1\rho \dots\dots\dots(1-7)$$

❖ **Eg.:** Calculate the ratio between spontaneous emission and stimulated emission for a tungsten lamp operating at a temperature of (1727 °C) where the emitted light is visible.

Sol.: Since the emitted light is visible, this means that the wavelength lies between (400 - 700 nm) and we will take an intermediate value between the two values:

$$\lambda = \frac{400+700}{2} = 550 \text{ nm} = 55 \times 10^{-8} \text{ m}$$

$$v = \frac{c}{\lambda} = \frac{3 \times 10^8}{55 \times 10^{-8}} = 5.45 \times 10^{14} \text{ Hz}$$

$$\hat{R} = \exp\left(\frac{6.63 \times 10^{-34} \text{ (J.s)} \times 5.45 \times 10^{14} \text{ (Hz)}}{1.38 \times 10^{-23} \left(\frac{\text{J}}{\text{K}}\right) \times 2000 \text{ (K)}}\right) - 1 = 4.85 \times 10^5$$

This means that spontaneous emission is greater than stimulated emission, so stimulated emission in a tungsten lamp is negligible.

❖ **Eg.:** Find the wavelength at which the rate of spontaneous emission equals the rate of stimulated emission at room temperature under thermal equilibrium.

Sol.: Since ($\hat{R}=1$) and ($T=25$ °C) then:

$$e^{hv/KT} = 2 \quad , \quad \frac{hv}{KT} = \ln 2$$

$$\lambda = \frac{c}{v} = \frac{3 \times 10^8 \left(\frac{\text{m}}{\text{s}}\right) \times 6.63 \times 10^{-34} \text{ (J.s)}}{1.38 \times 10^{-23} \left(\frac{\text{J}}{\text{K}}\right) \times 298 \text{ (K)} \ln 2} = 66.9 \times 10^{-6} \text{ m}$$

1-5) Laser Generation Conditions

There are three basic conditions that must be met to generate a laser beam:

- 1) Population Inversion:** The inverse distribution of electrons in the atoms of the material that will generate light is required. This means that the number of electrons in the excited state must be greater than in the unexcited state. This condition is only met in certain materials called active mediums, which have three or more orbitals in their conduction band, and where there is a metastable orbital between the low-energy orbit and the high-energy orbit. There are certain conditions for stimulated emission to occur, which parallel what Einstein predicted. If we have N atoms with two energy levels (N_1 and E_1 in the ground state and N_2 and E_2 in the excited state), stimulated emission is proportional to the number of atoms in the upper level. To achieve significant stimulated emission, N_1 must be $> N_2$, meaning the electron distribution must be

inverted. If the stimulation is external, this is called pumping. The distribution of atoms and molecules between the levels is calculated from Boltzmann's law as follows:

$$\frac{N_2}{N_1} = \exp\left(-\frac{E_2 - E_1}{KT}\right) \dots\dots\dots(1-8)$$

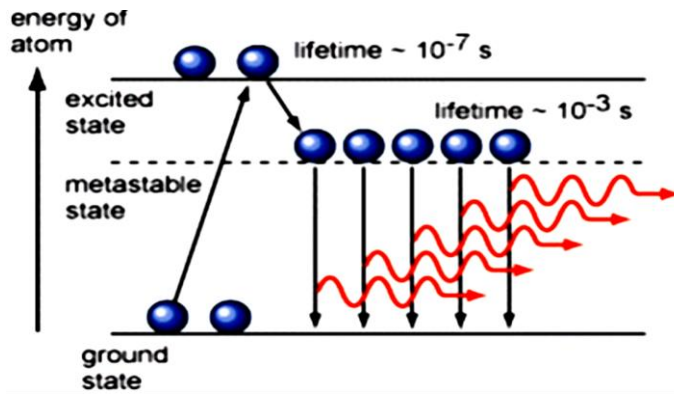


Figure (1-5): Inverse distribution

- 2) **Pumping:** The second condition is the availability of a source to pump electrons from low-energy (non-excited) orbitals to high-energy (excited) orbitals in order to obtain the inverted electron distribution.
- 3) **Amplification:** The third requirement is the availability of a positive feedback system for the laser to function as an oscillator, generating the desired light frequency and subsequently amplifying it. Mirrors are often used for this purpose. The resonator amplifies, magnifies, and develops the stimulated radiation using a feedback method. The amplification generated by the active material alone is insufficient to generate a laser beam, and the photons emitted by it are scattered in all directions. The resonator collects the photons emitted by repeated stimulated emission processes and causes the photon generated by this emission to be reflected back through the active material, which in turn stimulates the emission of another photon.

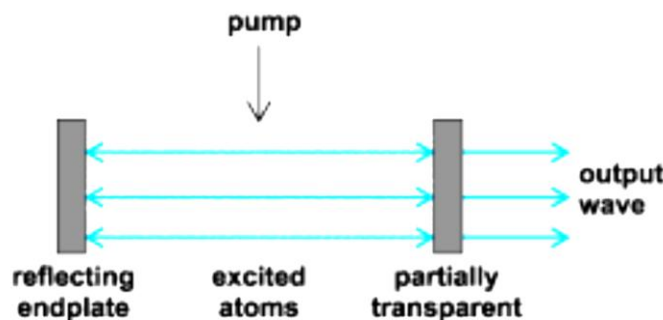


Figure (1-6): Positive feedback

Thus, the laser works by pumping electrons using an external pumping source such as light or electric current from a lower orbit to a higher orbit. The excited electrons then descend through spontaneous emission from the higher orbit to the metastable orbit, which lies between the lower and higher orbits. Electrons accumulate in this orbit, producing the desired inverted distribution. If a light photon with a specific frequency passes through the material while it is in the inverted distribution state, it will stimulate some of the electrons in the metastable orbit to descend to the lower orbit, producing a number of light photons with the same frequency, phase, and direction as the photon that stimulated them. Mirrors are used to reflect some of the generated photons so that they pass through the atoms of the active material, generating more photons with the same properties.

❖ **Eg.:** If the energy difference between levels E_1 and E_2 in a given medium is equal to KT , can a laser be generated?

Sol.:

$$\Delta E = E_2 - E_1 = KT$$

$$\frac{N_2}{N_1} = e^{-1}, \quad N_2 = 0.37N_1$$

That is, the inverse distribution condition will not be met, since $N_1 > N_2$, so the laser cannot be generated.

1-6) Laser Properties

Laser light has several important characteristics that make it suitable for use in many applications, compared to light emitted by natural sources such as the sun, traditional lamps, and artificial light such as electric lamps. The most important of these characteristics are the following:

1) Monochromaticity:

It means that the laser light has only one wavelength and one frequency.

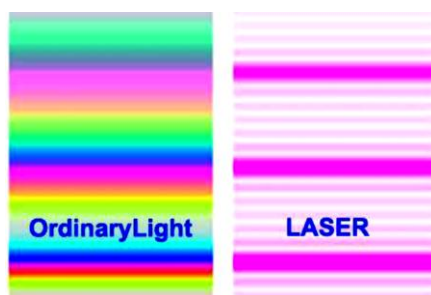


Figure (1-7): Monochromaticity of laser

Since laser light consists of a very strong band of optical frequencies, unlike other types of light, which consist of a very broad spectrum of frequencies, the human eye perceives it as white light containing all the colors of the visible spectrum, while laser light appears to be only one. This property is exploited by radio developers to use laser light as a fiber carrier, especially in fiber optic communications, which requires monochromatic sources, meaning their light frequency range is extremely small.

2) Spectral Purity:

Lasers have high spectral purity due to their single-wavelength nature. The physical quantity that expresses the degree of spectral purity is the emission line width (ΔV_o). This value depends on the light source and the highest energy level of the transition. The spectral emission line width is inversely proportional to power. It can span a wide range for some materials and can oscillate in a large number of modes within the resonator. In pulsed operation, the emission line width is determined by the reciprocal of the pulse duration (τ_p). For example, in a pulsed laser, it is:

$$\tau_p = 10^{-8} \text{ sec} \quad , \quad V_o = 100 \times 10^6 \text{ Hz}$$

3) Coherence:

This means that the difference between any two points on the laser beam's wavelength is constant as the beam moves in time and space. The frequencies that make up the laser beam have the same phase and the same polarization, and this property is exploited to produce interference patterns that cannot be achieved using other types of light. Optical interference in laser beams is used in countless applications, such as measuring distances, optical interference, velocities, studying material composition, and 3D imaging.

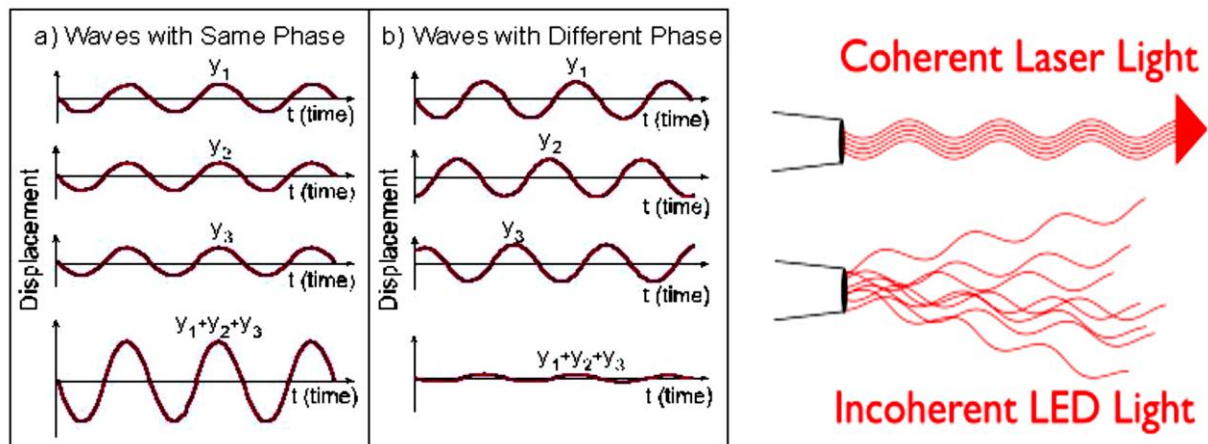


Figure (1-8): Laser light coherent

For light waves to have coherence, two conditions must be met:

- **The first condition:** It must have approximately a single frequency value. This means that the frequency spread around this value (the exposure of the spectral line to it) is very small. If this condition is met, the wave has time coherence.
- **The second condition:** The wavefront must maintain its shape over time. If this condition is met, the wave has spatial coherence.

For a light source to be perfectly coherent, it must be coherent in time and space.

- ✓ **Temporal Coherence:** An atom emits a photon in a limited time, which is called the average lifetime of the upper emission level (τ). For an atom far from external influences, this time is about (10^{-8} sec). Therefore, we can imagine that the wave is emitted during this time with an initial intensity equal to zero from the upper level and ends up at zero upon reaching the lower level. Due to the presence of a large number of atoms in the upper level (due to the continuous pumping to it), there are a large number of models of this wave. If we assume the possibility of monitoring the amplitude and phase of such waves, then this monitoring will be for a period not exceeding a time (τ_c), which is called the wave coherence time. Temporal coherence is directly related to the monochromatic property, where the exposure of the emission line of a wave with a coherence time (τ_c) is given by the following relationship:

$$\Delta V_0 = \frac{1}{\tau_c} \dots\dots\dots (1-9)$$

The longer the average lifetime, the longer the entanglement time. The entanglement distance ζ , which corresponds to this time, is given by the equation:

$$\zeta = c\tau_c \dots\dots\dots (1-10)$$

$$\zeta = \frac{c}{\Delta V_0} \dots\dots\dots (1-11)$$

Where c represents the speed of light. If the excited atom emits a photon in the presence of other atoms or molecules, the delocalization time will be shorter, and thus the delocalization distance may reach fractions of a millimeter. The delocalization distance can be a few hundred kilometers, but commercially available lasers produce delocalization distances ranging from a few centimeters to tens of meters.

- ✓ **Space coherence:** In this case, it is not important to monitor the amplitude and phase of the wave at a given location within a given time period, but rather to monitor the phase of the points on a single wavefront. If the phase difference between any two points on a single wavefront is constant over time, the wave has space coherence. The time of this type of coherence is indefinite, so the space coherence of the laser output is almost perfect. Therefore, the corresponding coherence distance is also unlimited, unlike in the case of temporal coherence, where the coherence distance is limited and may be very short.

The reason why conventional sources are non-coherent or weakly coherent is the photon emission process. In these sources, emission is spontaneous and random, and the waves representing these photons are not linked to each other by a specific phase relationship. Photons emitted as a result of stimulated emission processes are specifically correlated, so the waves they represent are in phase.

Finally, it is clear from the above regarding the two coherences that the time coherence is related to the phase of the electromagnetic wave at a certain point in time t , and after a subsequent period of time (t). If the phase difference remains constant for any time τ , then the wave is said to have time coherence for period τ , or that τ is the coherence time of the wave. The time coherence may be expressed by a distance representing the length of the coherence corresponding to the coherence time. On the other hand, the spatial coherence is related to the relative phase of two points located on the same wave side of the electromagnetic wave. If the phase difference between these two points remains constant with time, then the wave is said to have spatial coherence during this time or for the corresponding path.

4) Directionality:

The laser beam has a very small divergence angle, enabling it to travel long distances without its energy being dissipated. For example, the divergence angle of a helium-neon laser beam is two ten-thousandths of a degree. The diameter of this laser beam is two millimeters when it exits the laser, while its diameter will be only five millimeters after traveling a thousand kilometers. The divergence angle of a laser beam is determined by several factors, the most important of which are: (the width of the beam at the exit of the source and the wavelength of the radiation), as it is inversely proportional to the width of the initial beam and directly proportional to the

wavelength, meaning that the angle decreases with increasing beam width and decreasing wavelength. For an ideal light beam with diameter D , the divergence angle of its beam is Φ due to diffraction. It can be said that the directivity is expressed by the magnitude of the divergence angle (which is the angle between the edge of the beam and its axis). From Bragg's law, we find:

$$\Phi = \frac{\beta\lambda}{D} \dots\dots\dots(1-12)$$

Where λ represents the wavelength of the laser beam, β is a coefficient that depends on the amplitude distribution of the light used and its beam diameter, and its value lies within the range of number (1). The directivity property is exploited in many applications such as measuring both long and short distances and influencing targets with extreme precision.

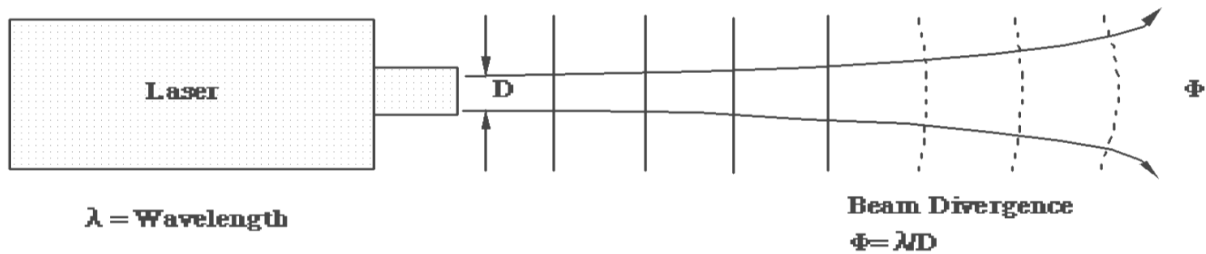


Figure (1-9): Laser beam divergence angle

Φ can be related to the laser spot size at the slit by an expression representing a diffraction pattern with an aperture of $(2\omega_0)$ instead of D :

$$\Phi = \frac{\lambda}{\pi\omega_0} = \frac{2\lambda}{2\pi\omega_0} = 0.64 \frac{\lambda}{2\omega_0} \dots\dots\dots(1-13)$$

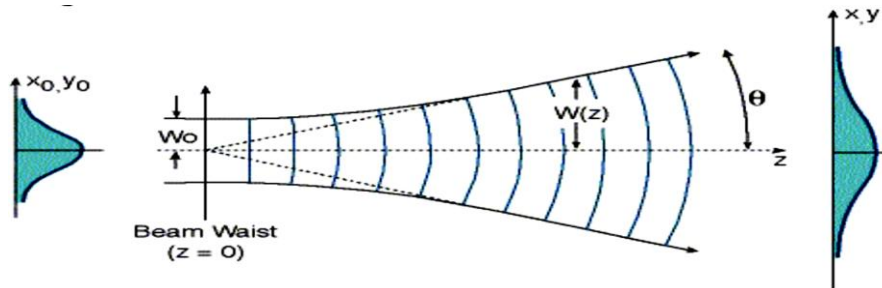


Figure (1-10): The beam intensity decreases with increasing distance from its axis.

The divergence of a laser beam tends to increase with increasing output power and beam oscillation modes. The divergence angle can be reduced to a smaller value by broadening the beam, which is accomplished by passing it in the opposite direction through a telescope. The beam will expand by (f_1/f_2) , so the divergence, which is inversely proportional to the beam diameter before and after using the telescope collimator, will be:

$$\frac{D_1}{D_2} = \frac{f_1}{f_2} = \frac{\Phi_1}{\Phi_2} \dots\dots\dots (1-14)$$

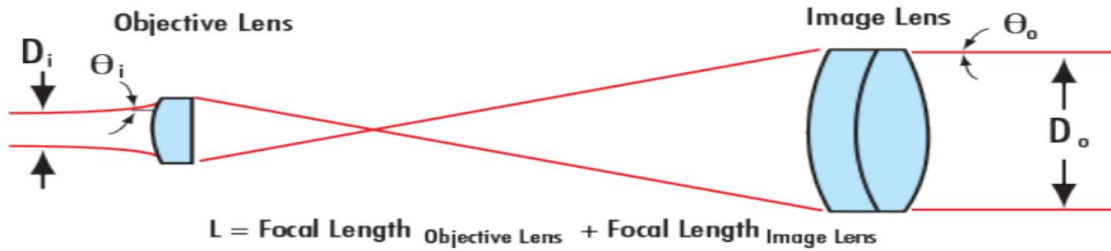


Figure (1-11): Schematic diagram showing how a laser beam is focused by a telescope with eyepiece diameter D_1 and focal length f_1 and objective lens diameter D_2 and focal length f_2

The directivity of the laser beam is important for its use in precision instruments for numerous applications related to alignment in engineering projects such as pipe laying, bridges and tunnels, and precision of aircraft and ship structures, as well as other projects that require alignment over long distances.

❖ **Eg.:** Find the divergence angle of a laser with a wavelength of $(1.06 \times 10^{-3} \text{ mm})$, a beam diameter of (3 mm) , and a diffusion coefficient of (1.1) .

Sol.:

$$\Phi_d = \frac{1.1 \times 1.06 \times 10^{-3}}{3} = 3.89 \times 10^{-4}$$

5) Brightness:

Brightness is a quantity that depends on both how the light emitted from a source is projected spatially, the source's output power, and the detector's response to light. To compare the brightness of materials for different sources, one takes into account how the light is propagated spatially from the light source. Conventional sources used for illumination emit energy in all directions within a solid angle of 4π , while laser light is emitted in a narrow beam with slight divergence. Brightness (B) is defined as the power emitted (P) per unit surface area (A) per unit solid angle (Ω):

$$B = \frac{P}{A\Omega} \dots\dots\dots(1-15)$$

The brightness of a laser beam with power P , its circular cross-sectional area $\pi D^2/4$ (where D is the diameter of its circular cross-section), and its emission angle $\pi\Phi^2$ (where Φ is the beam divergence angle, which is very small) can be calculated from the equation:

$$B = \frac{4P}{(\pi\beta\lambda)^2} \dots\dots\dots(1-16)$$

The power density of a laser beam per unit area is very high and is called intensity.

6) Luminescence:

A luminescence pattern can be observed when looking at light scattered off a rough surface, such as a wall. This scattered light pattern can be described as a random collection of bright spots and dark spots. A rough surface can be thought of as a large collection of point sources, and the waves emitted by these sources vary randomly in phase and amplitude (non-coherent). However, when this surface is illuminated by a laser, all of these point sources will emit coherent waves, thus generating a random interference pattern at all points between the surface and the observer. This property is important in holographic imaging, as holography is one application that relies on the scintillation property of the surface to be imaged.

7) High Intensity:

A laser beam has a very small cross-section, sometimes only a few square micrometers. Since all of the light energy emitted by the laser, despite its small size, is concentrated within this small cross-section, it is possible to achieve illumination intensity millions of times greater than that of sunlight or electric lights. This allows the laser beam to travel very long distances. This property is exploited for precision drilling, cutting, and welding of materials, in surgical operations, and in the treatment of many eye and skin diseases.

8) Collimation:

The dispersion of a laser beam is zero and it is naturally focused without the need for lenses. Its diameter can reach the diameter of a pin, and it can travel long distances with little energy loss, especially if there are no absorbing materials in its path.

9) Tuning:

The output of some types of lasers can be tuned to obtain different wavelengths that fall within the emission range of the laser's active medium. For example, in liquid lasers (dye lasers), their output can be tuned within a wide range that can extend to include the entire visible range of electromagnetic radiation.

10) Ultra-Short Pulses:

In addition to the constant-intensity continuous-wave (CW) laser, pulsed lasers can be achieved. These lasers operate with very short pulse durations and higher peak power using mode-locking technology. Ultrashort pulses, on the order of picoseconds, can be achieved. Laser pulses come in a variety of shapes and repetition rates, and the laser device can be controlled to emit the beam in pulses at specific rates. The pulse width can also be controlled. By reducing the pulse width, very high light intensity can be achieved, but for very short periods of time, regardless of the energy content of the pulse. This property is used in countless applications, such as melting or vaporizing metals, cutting and welding various materials, performing surgical procedures, and accelerating chemical and even nuclear reactions.

11) Close Beam:

This means that it maintains its thickness even after traveling a certain distance. The compactness and homogeneity of the laser beams result in a high energy density. Laser light can produce different tissue effects depending on the wavelength, energy density, exposure time, and absorption properties of the target tissue.

One of the characteristics of lasers in the medical field is **selectivity**, as each laser has one or more tissues that the laser specifically affects, without affecting others. This effect results in the production of high heat in the target tissue, and this heat is what gives the laser its therapeutic properties. The operation of the laser depends on the wavelength, color, and size of the target tissue.

Another characteristic of lasers is **safety** when used in the appropriate area of the body by a specialized, experienced physician who understands the specific effects of lasers on tissues and is able to protect themselves and their patients from the unwanted effects of the laser.

Since laser beams are concentrated light rays, they are subject to the laws of light in terms of reflection, refraction, and diffraction by mirrors, lenses, and glass prisms. Laser beams have been used to create amazing images using lenses, mirrors, and fiber optics.