AMERICAN ACADEMIC PUBLISHER

INTERNATIONAL JOURNAL OF MEDICAL SCIENCES

ISSN NUMBER: 2692 - 5206 Volume 6. No 02. February ,2026

THE WORKING PRINCIPLE OF LASERS

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Abstract

This article discusses the working principle of lasers and their underlying physical foundations. The formation of laser radiation is explained based on the concepts of stimulated emission, population inversion, and the optical resonator. The main components of a laser system, including the active medium, energy source, and resonator, are also examined. In addition, the article provides a brief overview of different types of lasers and their practical applications.

Key words Laser working principle, how lasers work, basics of laser technology, laser operation principle, fundamentals of lasers, stimulated emission, spontaneous emission, population inversion, optical pumping, laser cavity, optical resonator, active medium, gain medium, energy levels, photon amplification, coherent light, monochromatic light, highly directional beam, solid-state lasers, gas lasers, semiconductor lasers, fiber lasers, diode lasers, laser efficiency, laser applications, advantages of lasers.

The operation of laser devices is based on the process of stimulated emission.However, for the formation of such an orderly, directed and powerful radiation, simple thermal equilibrium conditions are not enough. Because in the natural state, atoms are more abundant in low energy levels, and high levels are very rarely occupied. Therefore, photons entering the system are often absorbed, that is, there is no increase in energy, but rather a decrease. In order to form a laser, it is necessary to disrupt this natural balance, that is, to create a population inversion. Population inversion is a state in which the number of atoms in high energy levels is greater than the number in low energy levels. Such a situation almost never occurs under normal conditions, and to create it, external energy is supplied to the active medium. This process is called pumping. Pumping can be carried out by optical radiation, electric discharge, electron injection in semiconductors, or chemical energy. To create inversion, the system usually has a metastable energy level. Atoms that have risen to this level remain there for a longer time.

Therefore, atoms accumulate in a metastable level, and the number in the upper level increases compared to the lower level. It is under these conditions that when stimulated emission occurs, the photons emitted from the system have the same frequency, direction, and phase.If there is no population inversion, laser light cannot be produced. Because the stimulated emission process only becomes more powerful when the number of atoms in the upper level is large enough. When population inversion occurs, photons appear in different directions within the active medium. An optical resonator is used to bring them into a single direction, amplify them many times, and output them in the same phase. The resonator usually consists of two mirrors:

- a total reflection mirror,
- a semi-transmitting mirror.

Photons repeatedly reflect and move between these two mirrors. During each return process, they collide with newly excited atoms, generating stimulated radiation again. This leads to a sharp increase in radiation. Laser resonators are optical systems that generate a standing electromagnetic wave and provide the ability to receive high-intensity radiation, which is necessary to increase the efficiency of the forced emission process of particles excited in the working medium, and to coherently amplify the electromagnetic wave. The system of optical resonators in lasers, in addition to the time of occurrence of the radiation quantum, preserves the possibility of the particle's forced emission of radiation beyond the critical limit and determines the frequency-time characteristic of the radiation. The wavelength in the radio wave range is many times larger than the size of the optical resonator, the size of the oscillation contour with parameters that generate electromagnetic oscillations, and such a classical system distributes the electromagnetic wave isotropically around the region. The wavelength of radiation in the infrared and visible ranges is many times smaller than the dimensions of the optical resonator. In this case, the optical resonator also controls the effect of focusing the radiation, determining its spatial characteristics. The operation of laser devices is based on the process of stimulated emission. However, for the formation of such an orderly, directed and powerful radiation, simple thermal equilibrium conditions are not enough. Because in the natural state, atoms are more abundant in low energy levels, and high levels are very rarely occupied. Therefore, photons entering the system are often absorbed, that is, there is no increase in energy, but rather a decrease. In order to form a laser, it is necessary to disrupt this natural balance, that is, to create a population inversion.

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working medium, and to coherently amplify the electromagnetic wave. The system of optical resonators in lasers, in addition to the time of occurrence of the radiation quantum, preserves the possibility of the particle's forced emission of radiation beyond the critical limit and determines the frequency-time characteristic of the radiation.

The wavelength in the radio wave range is many times larger than the size of the optical resonator, the size of the oscillation contour with parameters that generate electromagnetic oscillations, and such a classical system distributes the electromagnetic wave isotropically around the region. The wavelength of radiation in the infrared and visible ranges is many times smaller than the dimensions of the optical resonator. In this case, the optical resonator also controls the effect of focusing the radiation, determining its spatial characteristics. Laser resonators are optical systems that provide the ability to receive high-intensity radiation, which is necessary to increase the efficiency of the process of forced emission of particles excited in a working medium, in which a stationary electromagnetic wave is generated, and coherently amplify the electromagnetic wave. The system of optical resonators in lasers, in addition to the time of occurrence of the radiation quantum, preserves the possibility of the particle's forced emission of radiation beyond the critical limit and determines the frequency-time characteristic of the radiation.

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The simplest optical resonator can be considered a Fabry-Perot resonator. The Fabry-Perot resonator consists of two flat, mutually parallel mirrors, which are located at a distance. Due to the loss of electromagnetic wave energy in the Fabry-Perot resonator as a result of diffraction, it is practically not used in continuous-wave lasers with high power. In technological lasers, mirrors with a spherical shape on one side are often used. The properties of these optical resonators depend on the radius of curvature R of the spherical mirrors, which are not equally effective, and on the distance between the mirrors. In equal-weight optical resonators, the focusing (focusing) of the electromagnetic field is formed as a result of multiple reflections of radiation in the mirrors and has a continuous mode. In geometric optics, when an electromagnetic wave is reflected many times from mirrors, the radiation energy is scattered in a direction transverse to the axis of the optical resonator and exits the optical resonator. The loss of electromagnetic wave energy from the optical resonator can exit through the mirrors as a result of the relative permeability (transparency) of the mirrors. If there are no energy losses in the optical resonator, that is, if the condition is met, the electromagnetic wave can oscillate inside the optical resonator for an infinitely long time. In non-equilibrium optical resonators, as a result of successive reflections of light beams (i.e., electromagnetic waves) on the mirrors, the edge of the beam moves along the transverse direction of the optical resonator axis and exits the optical resonator. The properties of the optical resonator and the characteristics of the appearance of radiation can be explained from the point of view of wave theory or geometric optics. Here a and are parameters characterizing the cross section and length of the beam propagating in the optical resonator. If the condition is met, the laws of geometric optics are used. If the condition is met, it is necessary to take into account the wave properties of electromagnetic radiation. From the point of view of geometric optics, the condition for an equally efficient state of an optical resonator looks like this:

In this expression (2), - is the distance between the mirrors, which always has a positive value, and takes positive values for concave (sunken) mirrors, and negative values for convex (bulging outward) mirrors. The range of values of the parameters of optical resonators , and for equally efficient (stable) and non-equiefficient (unstable) cases is shown in the diagram in Figure 1 below. The section filled with points in the following coordinate system is an equally efficient optical resonator section, bounded by the hyperbola line and the coordinate axes.

In conclusion, lasers operate based on the principles of stimulated emission and population inversion, which enable the amplification of light within an optical resonator. The unique properties of laser light, such as coherence, monochromaticity, and high directionality, make lasers highly effective in various applications. Understanding the working principle of lasers is essential for the development and improvement of modern technologies in science, industry, medicine, and communication.

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