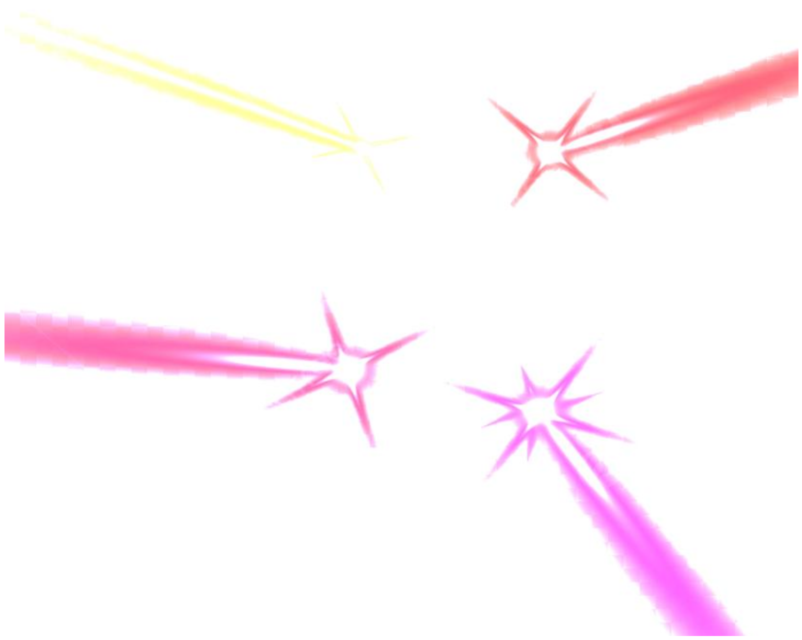
Lecture 4 / Part 2
Types of Lasers



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Lasers are commonly categorized according to their gain medium—the material responsible for amplifying light through stimulated emission. Depending on the radiating species involved, lasers can operate using atoms or molecules in a dilute gas, organic dyes dissolved in liquid solutions, semiconductor materials, or dielectric solids and glasses doped with specific ions. Based on these media, lasers are broadly classified into four main types: gas lasers, liquid (or dye) lasers, semiconductor lasers, and solid-state lasers.

Second: Gas Lasers

Gas lasers are an important class of lasers that use a gas or a mixture of gases as the active medium for light amplification. These lasers operate by exciting the gas atoms, molecules, or ions to higher energy levels, and when they return to their ground states, they emit coherent light. Depending on the type of gas and excitation method, gas lasers can produce different wavelengths and power outputs, making them suitable for various scientific, industrial, and medical applications.

There are several types of gas lasers, each with unique characteristics and operating principles.

- Helium-neon laser
- Nitrogen laser
- Carbon dioxide laser
- Ion laser
- Gas dynamic laser

1- Helium-Neon Laser He-Ne Laser

A helium-neon laser (He-Ne laser) is a type of small gas laser that uses a mixture of helium and neon gases as its active medium. It is one of the most common and widely used gas lasers due to its simplicity, stability, and ability to produce a highly coherent and visible red beam. The typical operating wavelength of a He-Ne laser is 632.8 nm, which lies in the red region of the visible spectrum, although other wavelengths, such as 1.15μm and 3.39μm in the infrared region can also be produced under different conditions.

The He-Ne laser operates through electrical excitation, where electrons collide with helium atoms, transferring energy to neon atoms through a process called resonant energy transfer. This creates a population inversion in neon atoms, enabling laser emission.

The He-Ne laser was the first gas laser ever invented, developed in 1960 by Ali Javan, William R. Bennett Jr., and Donald Herriott at Bell Telephone Laboratories. They successfully achieved continuous-wave (CW) laser operation.

Construction of He-Ne laser:

1. The gain medium of a Helium-Neon (He-Ne) laser, is a mixture of helium and neon gases in a ratio typically ranging from 5:1 to 20:1. This gas mixture is contained at low pressure—about 50 pascals per centimeter of cavity length—within a sealed glass tube.

2. The laser is powered by an electrical discharge of approximately 500 to 1000 volts applied between an anode and a cathode located at opposite ends of the tube. During continuous-wave (CW) operation, the discharge current typically ranges from 5 to 100 milliamperes.
3. The optical resonator, or cavity, usually consists of a highly reflective flat mirror at one end and a concave output coupler mirror with about 1% transmission at the other end. He-Ne lasers are generally compact devices, with cavity lengths ranging from about 15 centimeters up to 0.5 meters, and they produce optical output powers between 1 milliwatt and 100 milliwatts.

The characteristic red emission wavelength of a He-Ne laser is often stated as 632 nm. However, the actual wavelength in air is 632.816 nm.

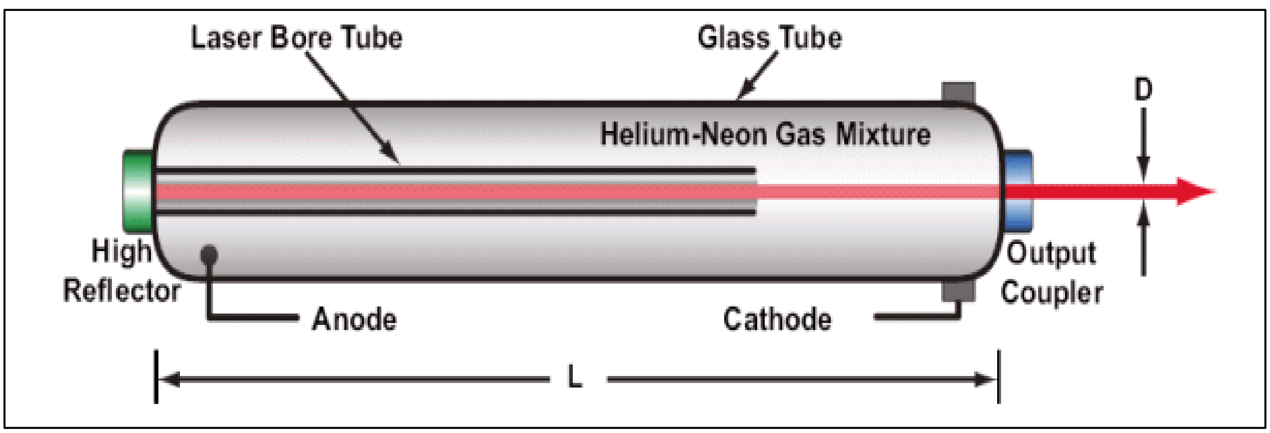

Fig. (1) Construction of He-Ne laser.

Laser Process in a He-Ne Laser:

To achieve population inversion in a He-Ne laser, energy must be supplied to the gain medium. This is done using a high-voltage DC electrical discharge as the pump source. When a voltage of about 10 kV is applied between the anode and cathode, energetic electrons are generated and move through the gas mixture inside the glass tube.

- ☒ The gas mixture mainly consists of helium atoms with a smaller amount of neon atoms. As the energetic electrons pass through the gas, they collide primarily with helium atoms and transfer part of their energy to them. These collisions excite the helium atoms from their ground state to long-lived metastable excited states.

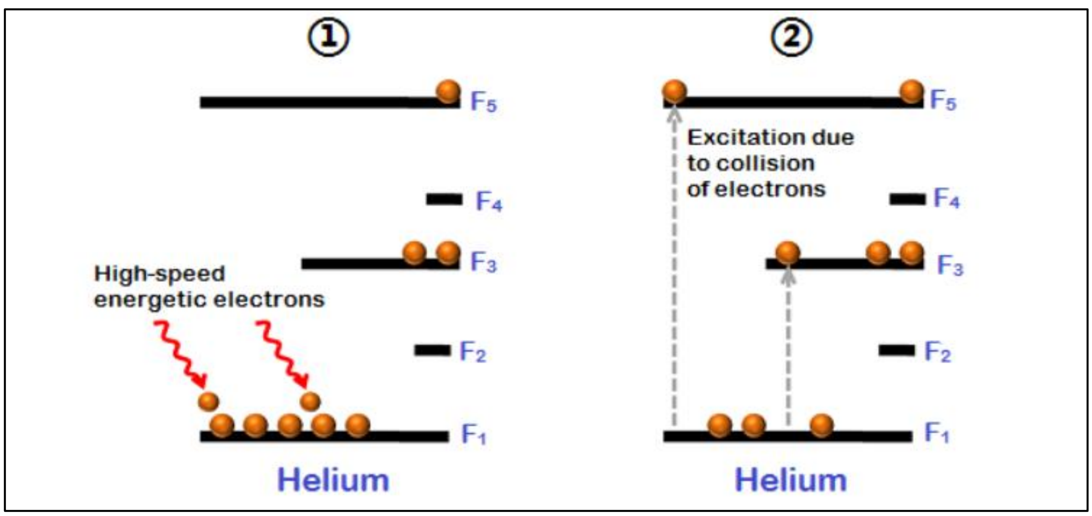

Fig. (2) The first step of the process in a He-Ne Laser.

- ☒ The excited helium atoms cannot easily return to their ground state by spontaneous emission. However, when these excited helium atoms collide with ground-state neon atoms, they can transfer their energy to the neon atoms. This happens because some of the excited energy levels of neon are nearly equal to the metastable energy levels of helium, allowing efficient energy transfer.

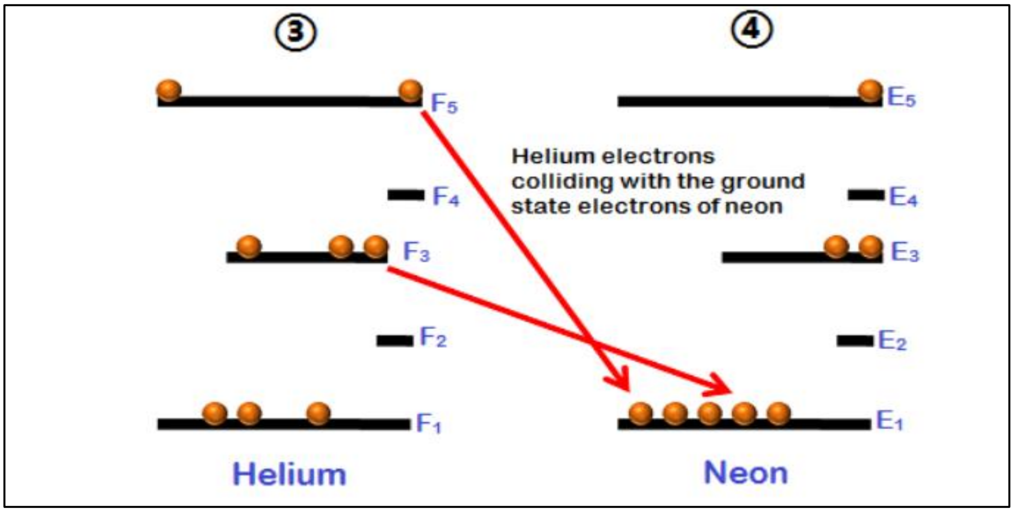

Fig. (3) The second step of the process in a He-Ne Laser.

- As a result, the electrons in the neon atoms are raised to higher excited states, while the helium atoms return to their ground state. In this way, helium atoms help excite the neon atoms and create a population inversion in the neon gas.

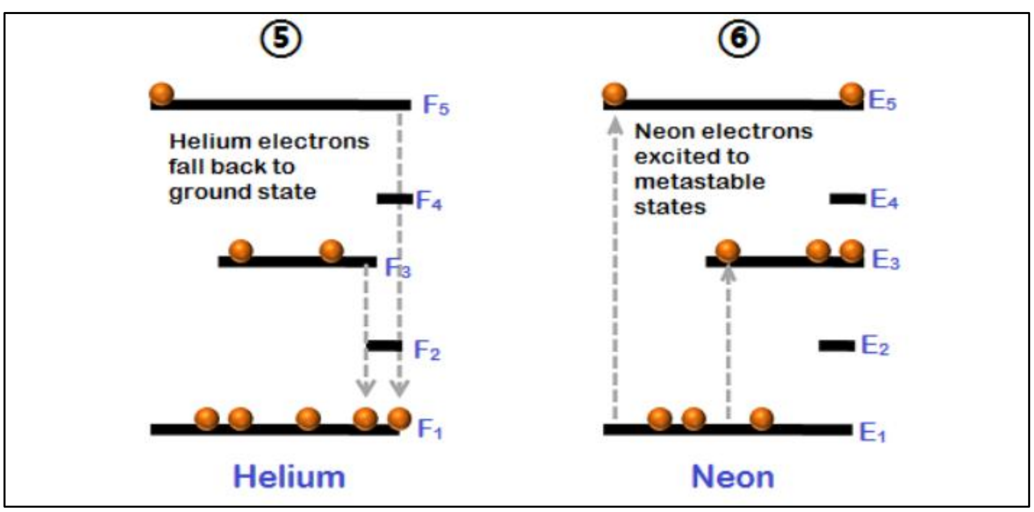

Fig. (4) The third step of the process in a He-Ne Laser.

- Since these excited states of neon have relatively long lifetimes, a large number of neon atoms accumulate there, forming a stable population inversion. After some time, the excited electrons in neon atoms fall to lower energy levels, emitting photons of red light with a wavelength of about **632.8 nm**.

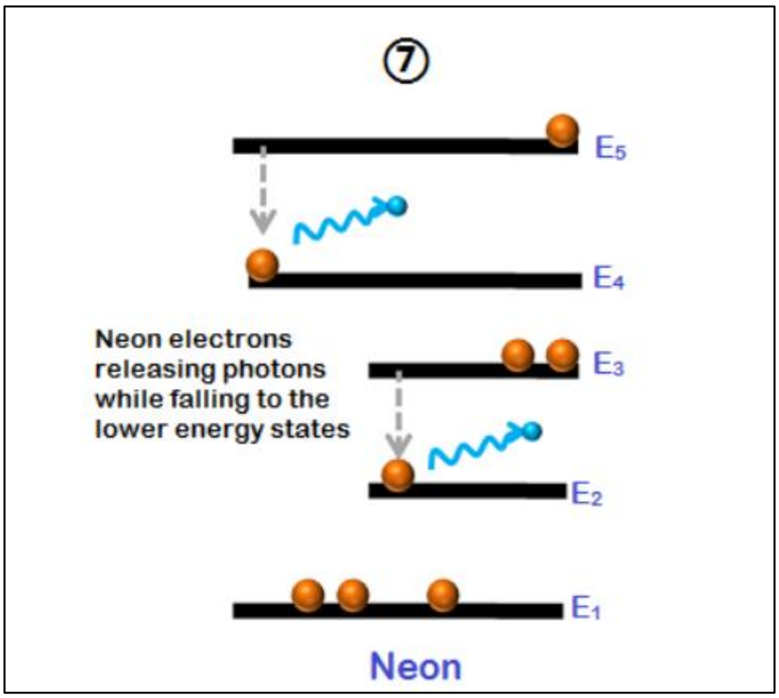

Fig. (5) The fourth step of the process in a He-Ne Laser.

These photons reflect back and forth between two mirrors placed at the ends of the laser tube. As they bounce between the mirrors, they stimulate other excited neon atoms to emit more photons in the same phase and direction — this process is called **stimulated emission**. Eventually, a portion of this coherent light passes through the partially reflecting mirror (the output coupler) to produce the visible red laser beam of the He-Ne laser.

Applications of the He-Ne Laser

- **Scientific and Educational:** Used in laboratories for demonstrations of interference, diffraction, and optical alignment due to its stable and coherent beam.
- **Industrial:** Applied in alignment systems, surface inspection, and precision measurements.
- **Electronics and Instrumentation:** Used in barcode scanners, optical projectors, and position-sensing devices.
- **Medical:** Employed for low-power biomedical measurements and therapeutic research applications.

2- Ion lasers/Argon ion laser

Ion lasers are a type of gas laser in which light is produced by stimulated emission between two energy levels of an ion rather than a neutral atom. To operate, the laser must first supply enough energy to remove one or more electrons from the atom, forming ions. Then, additional energy is required to excite these ions to higher energy states where stimulated emission can occur. Because of the high energy required for ionization and excitation, ion lasers usually have low efficiency.

When an atom loses one electron, it becomes singly ionized, and its lowest energy state is called the "singly-ionized ground state." If the ion receives more energy and loses another electron, it becomes doubly ionized, and so on. The energy-level structures of ions are similar to those of neutral atoms, but their energy values are shifted due to the missing electrons.

Excitation in Argon Ion Lasers

In an argon ion laser, excitation of the atom from its ground state to the upper lasing level requires about 36 eV of energy. This energy is delivered by collisions with energetic electrons inside the discharge tube. Each electron collision transfers about 2 to 4 eV to the atom, so many collisions are needed to reach the required energy. Because the excited states have very short lifetimes, the atom must collide again quickly before it can return to the ground state. For this reason, a high current density is necessary to provide frequent collisions and maintain excitation. Increasing current density in the laser tube increases the output power.

1. **Ionization (Creating Ar^+ ions):** Electrons accelerated by a high voltage collide with neutral argon atoms, removing one electron and forming singly ionized argon (Ar^+).
2. **Excitation (Pumping):** Additional collisions between energetic electrons and Ar^+ ions excite the ions from the ground level of Ar^+ to higher energy states around **35 eV**.
3. **Population of Upper Lasing Levels:** Some of these excited ions accumulate in the upper laser levels. These levels are the starting points for the laser transitions.
4. **Laser Transitions (Stimulated Emission):** The excited ions transition from the upper laser levels down to lower levels, emitting photons of specific wavelengths: **514.5 nm (green light)**, **488 nm (blue light).** These two transitions are the most powerful and common in argon ion lasers.

5. **Radiative Decay (~72 nm):** After lasing, ions in the lower laser levels lose energy by emitting ultraviolet radiation (around 72 nm) and return to the ground state of the Ar^+ ion.
6. **Recombination:** Eventually, Ar^+ ions can capture free electrons and return to the **neutral argon atom (Ar)** ground level, completing the cycle.

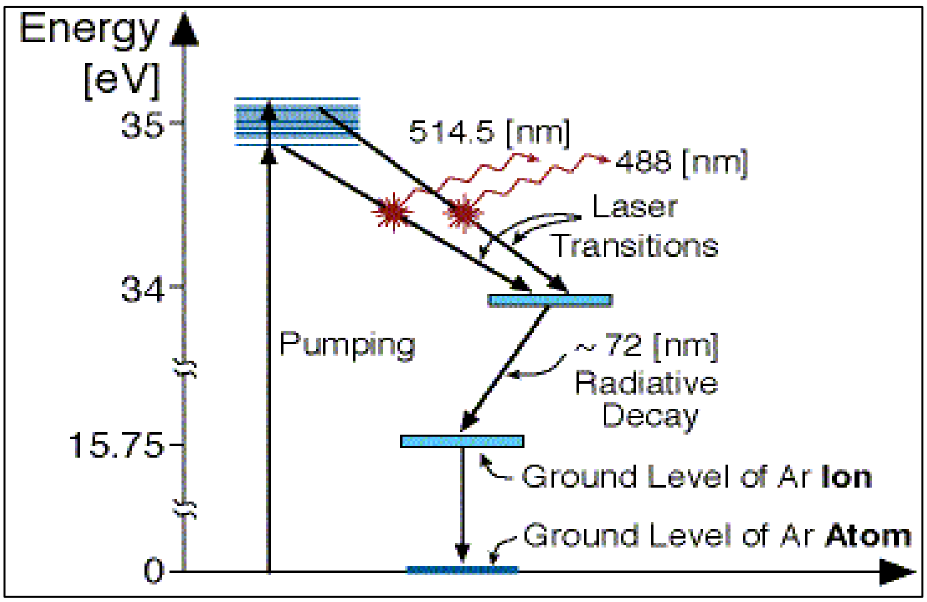

Fig. (6) Argon Ion Lasers.

Applications of Argon Ion Lasers

1. **Scientific Research:** Used in spectroscopy and interferometry for precise optical measurements.
2. **Medical and Biomedical Fields:** Applied in ophthalmology (retinal surgery, photocoagulation) and fluorescence microscopy.
3. **Laser Displays and Light Shows:** Produces bright blue and green beams used in entertainment and projection systems.
4. **Semiconductor and Materials Processing:** Used for photolithography and thin-film patterning due to its high beam quality.

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