Helium-Neon Laser

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Back and History of Helium-Neon Laser:

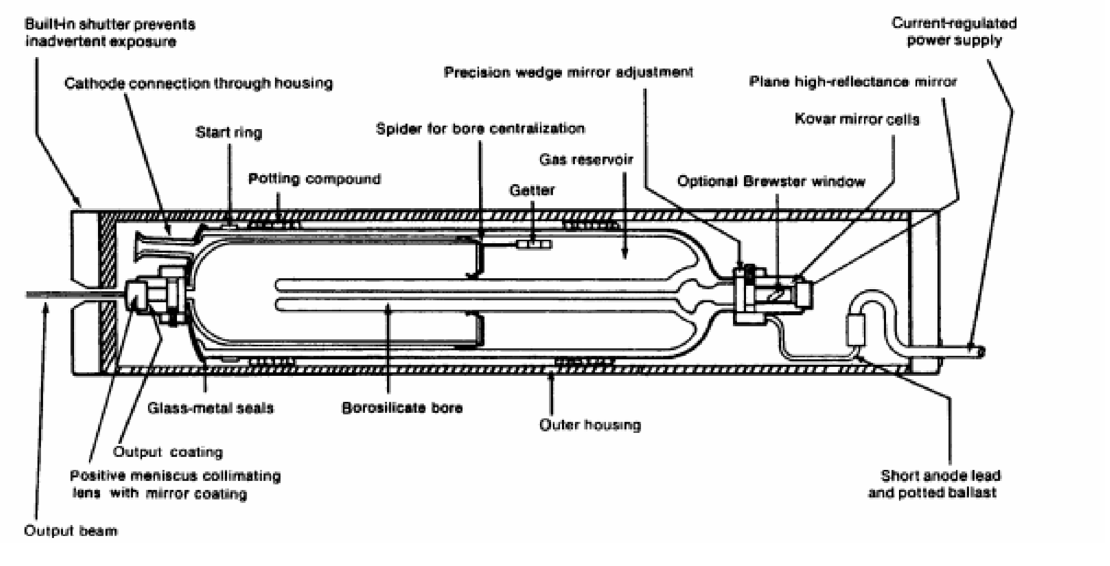
The helium-neon laser is probably the most commonly used laser. It is least-expensive gas laser, and has long been the standard choice to demonstrate laser physics in colloges and museums.

The helium-neon laser was the first gas laser (Javan et al., 1961) and was among the first lasers demonstrated. Initial versions emitted infrared light at 1153 nm,but other researchers soon found that the same gas mixture could laser in the red light (White and Rigden, 1962). Many other lines were produced in the laboratory, but the strong 632.8-nm red line has long been the most important because it made up to about 50 mW available at a visible wavelength.

General configuration of helium-neon laser:

The typical helium-neon laser consists of three components: the laser tube, a high-voltage power supply, and structural packaging. The laser tube consists of a sealed glass tube which contains the laser gas, electrodes, and mirrors. Depending on the power output of the laser, the size of tube may vary from one to several centimeters in diameter, and length could vary from five centimeters to several meters. The laser gas is a mixture of helium and neon in proportions of between 5:1 and 14:1, respectively. Electrodes, which situated near each end of the tube, discharge electricity through the gas. Mirrors located at each end of the tube define the laser cavity. The power supply provides the high voltages needed (10kV to start laser emission and 1-2kV to maintain it.) The structural packaging consists of mounts for the laser tube and power supply. The laser may also include safety shutters to prevent random exposure and external optics to fine-tune the beam.

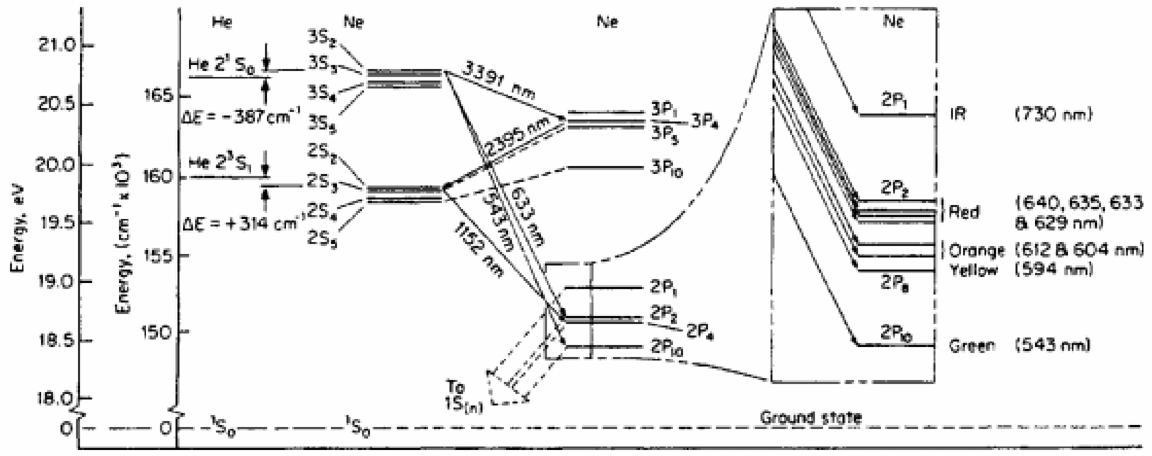
The following figure shows the internal structure of a typical modern helium-neon laser.



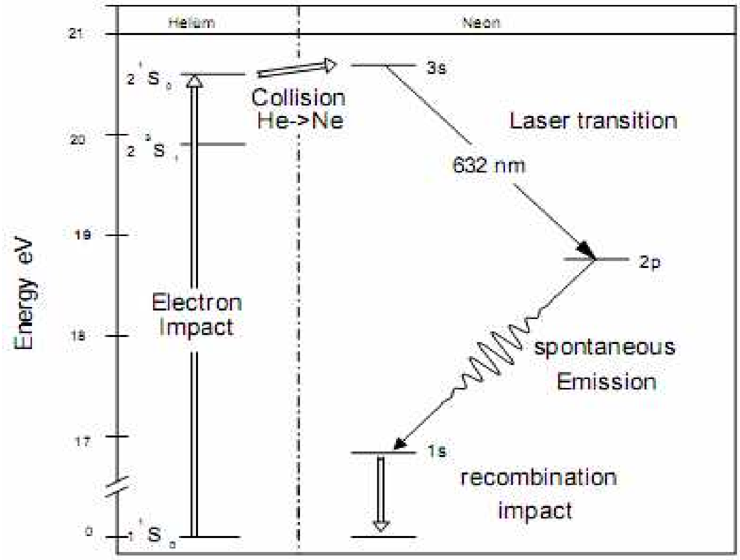
The discharge passes from the cathode at one end of the tube to the anode at the other. When discharge goes through the capillary structure, it is concentrated, thus overall efficiency can be improved. The small diameter of the discharge bore also helps control laser beam diameter, mode, and beam divergence. Much effort goes into selecting electrode shapes to make the discharge uniform.

In today’s He-Ne lasers, cavity mirrors are typically bonded directly to the tube, through the metal end plate. This approach exposes the mirror coating directly to the discharge inside the laser tube, but fortunately hard coatings can withstand such conditions.

He-Ne energy level diagram:



There are many sub-energy level in He-Ne laser. Consequently, there are many possible laser transitions. In the following analysis, we simplifier the above graph by focusing on those important levels that involves laser processes at wavelength of 632nm.



In helium-neon lasers, the neon atoms are the source of laser light. Because stimulated emission only takes place when there are excited neon atoms available, the process will quickly come to an end unless the neon atoms are replenished with energy.

In order to achieve laser action, it is necessary to have a large number of atoms in excited states and to establish population inversion. Now, let us consider the processes, in the simplified energy diagram, that lead to excitation of He and Ne atoms in the discharge.

1. A He atom is excited to the state of 2^1S_0 by an energetic electron collision.

2. The excited He atom collides with an unexcited Ne atom at 3S energy level. As a result, the atoms exchange internal energy, producing an unexcited He atom and excited Ne atom. The reason that this energy exchange process occurs with high probability is because of the coincidental near equality of the two excitation energies of the two levels in these atoms.

3. The $3S_2$ level of Ne is a metastable atomic state which means that the Ne atom de-excites to the $2P_4$ level by emitting a photon of wavelength 632.8 nm, after a relatively long period of time. The wavelength of the emitted photon is determined by the energy difference between the two states. (Δ E). Specifically, $\lambda = hc/\Delta E$. In the presence of a suitable optical configuration, it is this emission of 632.8 nm light by Ne atoms that leads to lasing action.

4. The Ne atom at energy level $2P_4$ rapidly de-excites to its ground state by emitting additional photons or by collisions with the tube walls. Because of the extreme quickness of the de-excitation process, at any moment in the He-Ne plasma, there are more Ne atoms in the $3S_2$ state than in the $2P_4$ state. So, a population inversion is established between these two levels.

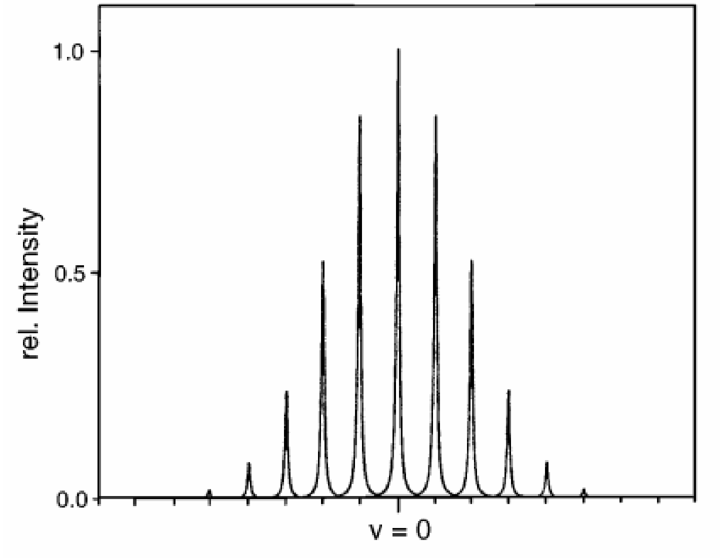
Output Profile:

The gain bandwidth of He:Ne laser is dominated by Doppler broadening. For laser emission, we might expect the emission profile to be a sharp peak, but due to Doppler broadening it is actually Gaussian. The Doppler width (full-width at half maximum) is at around 1.5 GHz.

Although the gas emits radiation that has a Gaussian lineshape, the laser cavity does not permit a continuous spread of frequencies to resonate. Only those frequencies that achieve constructive interference in the resonator will reach the threshold gain level. When constructive interference occurs, the difference between adjacent permitted frequencies follows the equation:

$$\Delta\nu = \frac{C}{2L}$$

Where L is the length of the laser cavity, C is speed of light. Since the gas emits light with a Gaussian line shape and the cavity permits only discrete number of frequency, the output intensity is like a combination of the two:

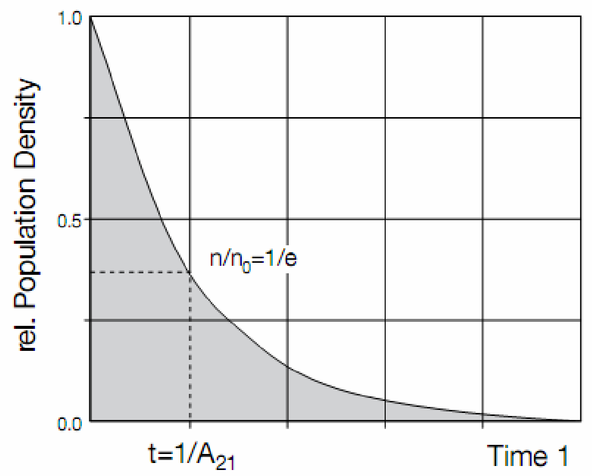


Decay Rate:

The population n2 of state 2 decays into state 1 with lower energy with a time constant t_s following the equation:

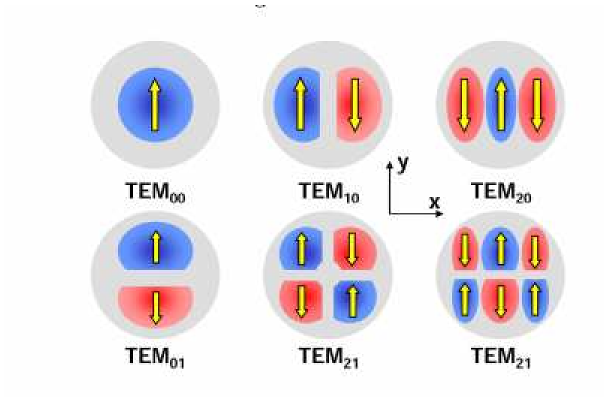
$$n_2(t) = n_2(0)e^{-A_{21}t}$$

Where A_{21}= 1/ ts is Einstein coefficient for the spontaneous emission



Operation Modes:

Most helium-neon lasers produce a good-quality TEM00 beam with a classic Gaussian intensity distribution. However, due to diffraction and other effects in imperfect cavities, transveral modes can occur, which have slightly different frequencies and amplitude distributions given by Hermite functions.



Coherence Length, Beam Diameter and Divergence:

Mass-produced He-Ne lasers have coherence lengths around 20 to 30 cm, which is adequate for holography of small objects. Single-frequency He-Ne lasers have much narrower spectral bandwidths and thus much longer coherence lengths, but are usually much more expensive.

Beam diameters of helium-neon lasers with TEM$_{00}$ output in the milliwatt range are usually around a millimeter. Also it tends to increase with output power. For longer, high-power models, beam diameters can reach a couple of millimeters, with divergence about 0.5 mrad. Divergence of mass-produced He-Ne laser is on the order of 1 milliradian. Divergence drops when beam diameter increases, because these lasers normally operate near the diffraction limit.

Output power and efficiency:

Commercial models of He-Ne laser emit continuous beams from a few tenths of a millwatt to 75mW, with most in the 0.5mW to 7mW range. Overall efficiency of a helium-neon laser is low, typically in the range of 0.01% to 0.1%.

Conclusion:

Although helium-neon laser is not the most powerful or efficient laser, it has many advantages over other types of lasers. Most lasers have an efficiency of about 1 percent, which is about ten times the efficiency of typical helium-neon laser. Moreover, other types of lasers are capable of delivering power far beyond helium-neon laser's limitation of 75 milliwatt. The advantages of helium-neon lasers are that they can emit visible light, are affordable and have good beam quality. While most lasers cannot efficiently emit visible light, helium-neon lasers usually emit red light at 632.8nm. Furthermore, Helium-neon lasers do not require any consumables (sapphire rods for example), nor do they generate too much heat to require special cooling devices. They also have good beam quality, that is, their beams stay tightly focused even over long distances.

Reference:

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