EO Experiment 1: Laser Experiment

Tutor: Chen Ho Cho
Professor: Dr. H.Y.Lin

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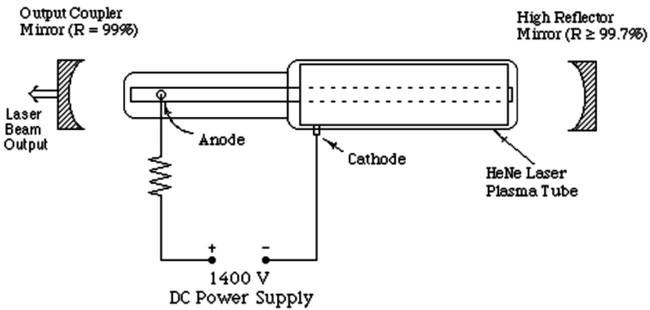


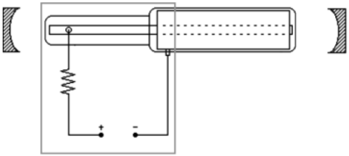
One of the most common lasers used in labs is the HeNe laser.

The He-Ne laser is essentially an optical cavity, consisting of:

- A capillary tube with (around 1mm inner diameter), pumped to a high vacuum with small amounts of the named gases (He, Ne, and sometimes CO_2) added at precise pressures.
- Two mirrors, one at each end, confining the photons generated. One of the mirrors reflects almost 100% of the light. The other reflects about 99% and transmits 1% of the light out of the cavity,

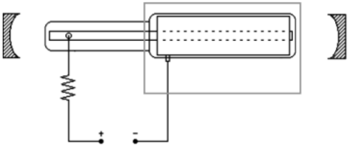
Laser Functional Blocks 1-3

A laser have three functional groups



Pumping Source: Provides energy to the laser.
This can be optical (e.g. incandescent lightbulb, flash lamp, helium lamp, or even light from another laser), or electric (e.g. electron bombardment). Generally, this involves hitting/exciting the active atoms (gain medium) with something, like photons, electrons, or heat etc.

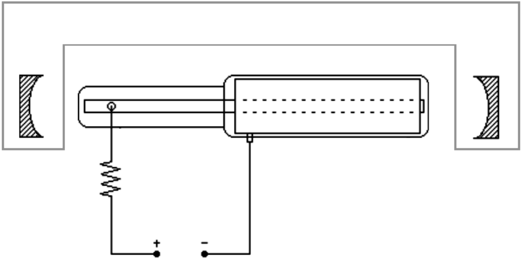
Laser Functional Blocks 2-3



Gain Medium: Provides a system for pumping and lasing to happen.

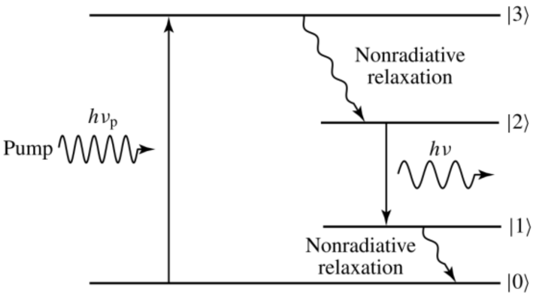
The gain medium generally categorizes the laser. This can be many things, gas (gas laser), liquid (dye laser), crystal (solidstate laser), and semiconductor (semiconductor laser). The active atom have discrete energy levels (or bandgap in the case of semiconductor) to absorb and emit specific wavelengths of light.

Laser Functional Blocks 3-3



Optical Cavity: Confines the optical energy within the cavity. Can be formed by two mirrors, even more mirrors, a waveguide, or an optical fiber. Simply put, any methods or setups to make the light travel through the gain medium multiple times.

Working Principle 1-2

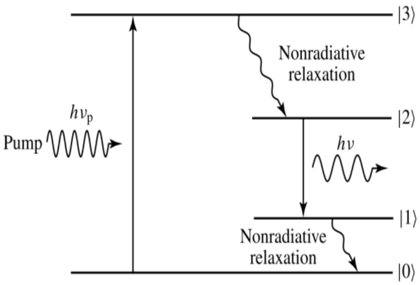


Inside the gain medium, the atoms (or molecules) have distinct energy levels. For the sake of explaination, this is a 4-level laser system.
At first, the atoms are resting in the **ground state** $|0\rangle$.

Working Principle 2-2

- With the pump source turns on, atoms at the grounds state jumps up to the **excited state** $|3\rangle$.
- Atoms at $|3\rangle$ are extremely unstable, and very quickly decays to a **metastable higher state** $|2\rangle$.
- A photon of the desired laser wavelength is released, when a $|2\rangle$ atom decays to the **lower state** $|1\rangle$.
- The remaining energy of atoms in $|1\rangle$ dissipates, and the atom drops back down to $|0\rangle$.
- Then the cycle repeats.

Laser Threshold 1-3



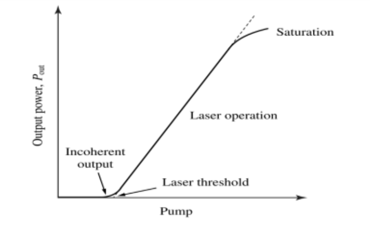
When a photon of the same wavelength comes near a $|2\rangle$ atom, the atom can be induced to decay down to $|1\rangle$ immediately, releasing a photon. This is called **stimulated emission**. Lasers rely on this produce light.

Laser Threshold 2-3

In fact, in the beginning, the name "laser" comes from
- Light
- Amplification by
- Stimulated
- Emission of
- Radiation.

The idea is, after an atom in |2⟩ spontaneously decays naturally and release a photon, that photon will then induce another atom in |2⟩ to decay and release another photon, the two photons would then induce another two atoms to become 4, then 4 become 8, 8 to 16... etc.

Laser Threshold 3-3



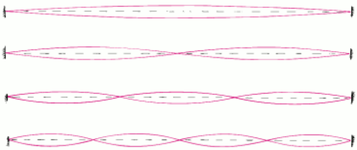
Problem is, when the pumping is low, after a |2⟩ photon decays spontaneously, that photon can't see another |2⟩ atom to induce. Only, when the pumping is high enough, the laser then starts "lasing".

The intercept, between the steep linear part and the pump power/current/intensity axis, is called **threshold pump power/current/intensity**.

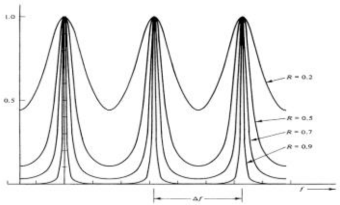
Longitudinal Modes 1-3

The **longitudinal modes** of a laser, are **ways that the laser can exist in the longitudinal direction** due to the gain medium and the optical cavity.

- **Optical Cavity**
  Light undergoes hundreds of reflections within the cavity, therefore light surviving inside the cavity must form standing waves between the mirrors. All other lights will interfere destructively.



Longitudinal Modes 2-3



The frequency that can exist is given by $f_m = \frac{mc}{2nL}$

and the wavelengths by $\lambda_m = \frac{2nL}{m}$

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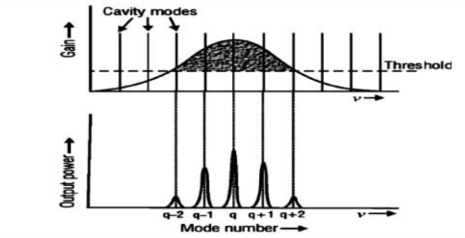
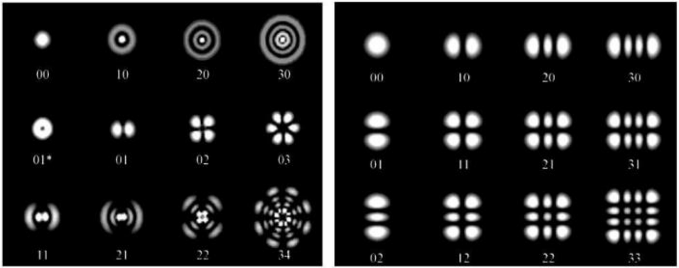
Longitudinal Modes 3-3

- **Gain Medium**
  The gain medium can only provide gain over a frequency range, centered on a specific frequency of light.



Transverse Modes



The **transverse modes** of a laser are **ways that the laser can exist in the transverse direction.**
Different solutions can be solved depending on the boundary condition. The Laguerre-Gaussian modes (left) is solved with a circular boundary, and the Hermite-Gaussian modes (right) are solved with a square boundary.

Second Harmonic Generation

So to produce green light, the majority uses a technique known as **second harmonic generation.**

- Passes the light through a non-linear crystal.
- Crystal responds with light of twice the frequency.

Green light can be obtained by passing an infrared (IR) laser through a SHG crystal.

Pre-Experiment Questions 1-3

- A **cavity** made of **two flat mirrors** (of 5 cm diameter spaced 10 cm apart) have been **misaligned**. One of the mirrors have a **1° tilt**. What is the **maximum** number of reflections within the cavity before the light escapes the cavity completely? (State the assumptions you made with your answer, and show your reasons.)

Pre-Experiment Questions 2-3

- Draw the transverse mode (Hermite-Gaussian) intensity pattern of TEM_{01}, TEM_{10}, and $TEM_{01}+TEM_{10}$.

Pre-Experiment Questions 3-3

- A cavity is made up of two mirrors, spaced 100 mm apart. Calculate the wavelength and frequency of the (longitudinal) fundamental mode and 2 other modes of the cavity.

- A crystal with refractive index n=1.6 is placed inside the cavity between the two mirrors. How will this affect the wavelength and frequency of the caavity modes?