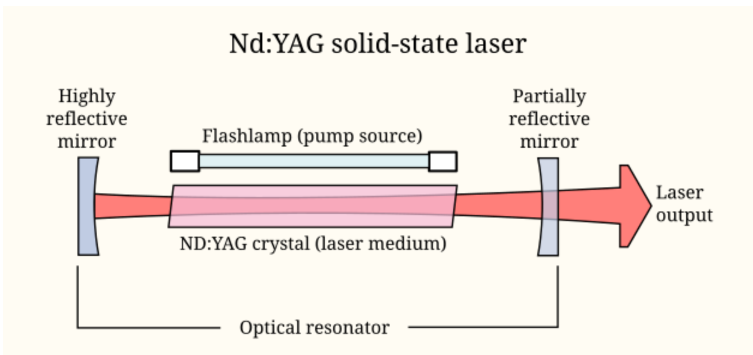
15.6.2: Lasers

One of the more transformative technologies to come from the photon model of light and the Bohr model of the quantized atom is the laser. Lasers are used in an enormous number of ways upon which our technological society has come to depend, such as:

- Communications: Fiber optic cables use lasers to transfer data at extreme speeds.
- Medicine: Lasers are used in many medical procedures including eye surgery, dermatology and precision surgery.
- Manufacturing: To cut, weld, drill and mark materials.
- Research: For spectroscopy, microscopy and in particle accelerators.
- Military: For range finding, laser guidance of munitions, remote sensing and surveillance.
- Entertainment: Light shows, stage lighting and projection systems.
- Electronics: Barcode scanners. laser printers, optical mice, CD, DVD and Blu-Ray drives.
- Instrumentation: Atomic clocks, interferometers, holographic displays.
- Environment: Lidar weather systems, pollutant and gas detection.
- Art Conservation: Cleaning artifacts, sculptures and buildings without damage.

The word is an acronym of the process that creates laser light: Light Amplification (by) Stimulated Emission (of) Radiation. The process creates an 'avalanche' of photons, each with the same wavelength and therefore the same energy. Thanks to our study of the atomic model, we can understand the principles that make it work.



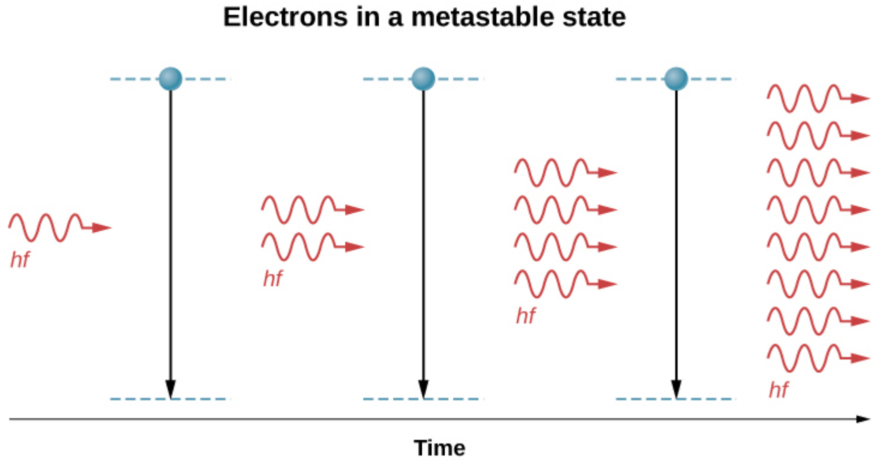
Laser Schematic taken from Wikipedia and is licensed under CC-BY-SA 3.0

A laser has three fundamental components. A *gain medium*, a power supply, and a mechanism to create optical feedback. The gain medium is a material which can absorb electromagnetic energy. You've probably heard of Helium-Neon lasers, or Carbon Dioxide lasers, both of which describe the gain medium. The gain medium can also be crystals, glasses, semiconductors and liquids for more exotic types of lasers.

Recall that under normal conditions, atomic electrons like to be in the lowest possible energy state. When the gain medium absorbs energy, electrons are promoted from low energy states to higher energy states. The characteristics of a gain medium are such that these excited electrons do not return to the lower energy states immediately, as they normally would. Instead they remain in a *metastable state* called a *population inversion*, where the lower energy states remain empty and the high energy states remain filled.

Obtaining the population inversion requires that energy be transferred to the gain medium by the power supply. This process is known as *laser pumping*. Pumping can be achieved by electrical currents, discharge lamps (essentially a turbo-charged camera flash), chemical reactions, nuclear fission or beams of high energy electrons. Once complete, the gain medium has stored a significant amount of power supply energy in the metastable states of the gain medium's orbital electrons.

When one of the excited electrons returns to the low energy state it came from, a photon is emitted. The photon has a frequency which describes its energy. When this photon disturbs one of the other excited electrons, it causes that electron to drop to the lower energy state and emit a second photon identical to the first. Now there are two identical photons, each of which triggers a drop in energy of other electrons. One becomes two, two becomes four, four become eight and so on. There is a similar process involved in the production of nuclear power, which will be described in a later chapter.



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To maximize the chances for these photons to stimulate the emission of additional photons, it is useful to 'trap' them in the gain medium. This is often accomplished by a pair of mirrors, called the *optical resonator*. One is perfectly reflective and the other one is partially reflective, meaning that some photons escape but many are returned to the gain medium to promote the production of more photons. If enough time passes, all the electrons will have returned to the lower energy states and the process would stop. A poor analogy would be pushing someone on a swing. If you only push once, the person will stop swinging after some time has passed. To maintain their motion, you must periodically push on them and add energy. To maintain laser operation, the power supply must pump the gain medium repeatedly.