**Introduction**

This demonstration explores cavity-modes and mode-locked lasers. The simulation is of a mode-locked laser where the cavity length, the gain medium, and the number of modes centered around the central mode frequency are specified.

**Mode Locking**

What is mode locking

**Lasers, an overview:**

Lasers are highly tunable devices capable of either delivering a very narrow (near single) frequency of light or a broadband of frequencies much like a comb. In general applications such as laser pointers, lasers are most noted for their spatial coherence. That is, their ability to maintain their near uniform intensity and shape across far distances. Thomas Young’s double-slit experiment was first to conceive of this notion of coherence where a wave propagating through space can be described by the statistical similarity of the wave’s attributes between two points in space. Coherence in lasers arises from the principle of stimulated emission, which serves as the required amplification inside lasers to create an intense beam of emitted of photons. This concept of stimulated emissions inside a laser device is what led to its own namesake since LASER was initially just the acronym for “**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation”.

**Stimulated Emissions**

Quantum mechanics describes several possible interactions between photons and atoms; the simplest being the absorption of a photon in transit near an atom. Typically, atoms exist in a ground state, which is the lowest-energy state possible for an atom to exist in. However, an electron contained within an orbital of an atom has the chance to absorb the quanta of energy carried by a photon passing nearby. This causes the electron to transition into a higher energy state and thus effectively raising its atom to an energetic state above its own ground state. The “lifetime” for an atom to exist in this excited state is finite and may only last on the order of nanoseconds.

Max Planck determined the frequency of the photon, or the radiant energy absorbed or emitted, was directly proportional to the frequency of the radiation by the scalar constant, Planck’s constant. Consequently, the energy of a system will change by units of (electron-volts), such that:

Furthermore, Bohr established a frequency condition which proposed that the energy absorbed or emitted by an atom must

When the electron reoccupies its original orbital energy state after occupying a higher energy level, the atom falls back to its ground state but not before also emitting a photon. This photon carries the quanta of energy lost by the atom and originally carried by the first photon. This form of photon generation is referred to as spontaneous emission and occurs naturally.

We don’t normally perceive spontaneous emissions because it’s rare to find an atom above its ground level. When one does, though, the frequency of occurrence is random enough that we cannot entirely perceive any quantized amount of photon emission above our eye’s perceivable threshold. Photons are spontaneously emitting all around us though.

An important caveat to note is some materials have a greater proclivity for spontaneous photon emission. Some radioactive isotopes, for instance, have an exponential decay of harmful photons referred to as ionizing gamma radiative emission. Radioactive emission can be classified as being alpha, that is, helium nuclei emission, beta, which is electron or positron emission, and gamma radiation, which is characterized as photon emission. Gamma photon emission is the most dangerous due to its devastation on organic living matter and requires significant shielding of either lead or concrete.

While the lifetime of an atom occupying an energetic state above its ground state is short, there are instances where an atom lives just long enough to interact with a transit photon. Back in 1917, Albert Einstein postulated a third emission event where an atom could spontaneously generate a photon from interacting with a photon. In this scenario, the transit photon causes the atom to spontaneously drop back down to a lower energy level and generate a second new photon carrying the released quanta of energy. This process is the contra to photon absorption where the *energy* involved in the level transition is identical, but the atomic transition *direction* in a stimulated emission is opposite to absorption.

The diagram below summarizes the various forms of photon interaction so far discussed:

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| Three forms of photon interaction are illustrated for an atom described with a 3-level energy diagram.   |  |  | | --- | --- | | **(A) Absorption** | occurs when a photon carrying quanta of energy is absorbed by an atom causing an atom’s electron to transition to a higher energy level for a short period of time. | | **(B) Spontaneous Emission** | occurs when the electron can no longer hold its higher energy state and releases the original quanta of energy in the form of a photon causing the atom to drop back down to a lower energy level. | | **(C) Stimulated Emission** | occurs when an atom can exist in a higher energy state long enough to interact with a photon causing a second photon to be generated. | |

Population inversion is the situation where there are a greater number of atoms in their excited state than in their ground state. This principle is necessary to produce a laser because excess photon generation is desired, and this only occurs if photons are absorbed by atoms within their excited state. Conversely, if more atoms are in their ground state, photons are absorbed without emission.

When atoms are excited into a highly excited energy state level, their lifetime within that state is on the order of nanoseconds, which is not long enough for stimulated absorption occurring in the order of microseconds or even milliseconds. Consequently, spontaneous emission or decay occurs. To work around this, metastable states within the energy band of an atom must be available to allow for longer lifetimes.

Examples of common pump sources are electrical discharges, flashlamps, arc lamps, light from another laser, chemical reactions, and even explosive devices. The type of pump source used principally depends on the *gain medium*, and this also determines how the energy is transmitted to the medium.

Cavity Resonators

Longitudinal Modes

Transverse Modes

<https://micro.magnet.fsu.edu/primer/java/lasers/electroncycle/index.html>

<https://en.wikipedia.org/wiki/Stimulated_emission>

<https://en.wikipedia.org/wiki/Theodore_Maiman>

<https://flex.phys.tohoku.ac.jp/~rsaito/saito20-GaussianBeam.pdf>

<https://laser.physics.sunysb.edu/_alex/tmodes/webreport.html>

<https://www.slideshare.net/dlorenser/part-i-laser-basics-lorenser-2009>

<https://www.rp-photonics.com/stimulated_emission.html>