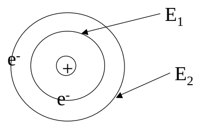
PHY2208 Lecture 20

The origin laser light: stimulated emission
Basic laser operation

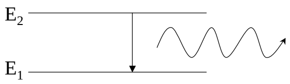
Y&F sec 40-7 & 37-2
Pedrotti & Pedrotti sec. 21-2 to 21-5

Both the directionality and the temporal coherence/monochromaticity of laser light originate from the unique emission mechanism by which laser photons are generated:

Consider an atom with orbiting electrons occupying discrete energy levels:



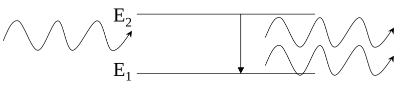
In the QM description of light/matter interactions a photon is emitted when an electron jumps from a higher to a lower energy level:



$$\nu = \frac{E_2 - E_1}{h}$$

In a thermal light source, such electron 'jumps' occur spontaneously. This is **spontaneous emission (**SPE**)**. The photons emitted by an ensemble of atoms emitting in this way are uncorrelated in direction, energy and phase.

Einstein (1916) predicted that atoms could be stimulated to emit radiation. An electron can be stimulated to jump from energy level E_2 to energy level E_1 by another photon of energy $E_2 - E_1$:



Crucially, the emitted photon is **identical** (in phase, polarization, direction and energy) to the stimulating photon. A laser beam comprises a vast number of 'cloned' photons and thus possesses great directionality and monochromaticity/temporal coherence and is highly polarized.

The process is known as **stimulated emission** (STE).

Basic laser operation

To fabricate a laser we need to meet the following conditions

An ensemble of atoms is required which are capable of emitting photons of the desired wavelength

These atoms must be placed into an excited state i.e. electrons must be excited to an upper energy level in preparation for being stimulated into emitting quanta of energy by another photon.

An initial 'seed' photon must be produced to get the whole process running.

The **gain medium** is a piece of material containing the emitting atoms. Many hundreds of suitable gain media exist including solids (e.g. ruby), liquids (e.g. organic dyes), and gases (e.g. helium/neon and carbon-dioxide).

The **pump mechanism** is the means of supplying energy to the atoms in the gain medium, to place their electrons into excited energy levels prior to STE. Many pump mechanisms exist including optical flashlamps, electrical discharges, and chemical reations.

The **cavity mirrors** fold the generated beam of photons onto itself and effectively increases the length of the gain medium. One mirror is 100% reflective, whilst the other is less than 100% to allow the beam to escape from the device. The mirrors and the region between them are collectively known as the **laser cavity**.

A typical sequence of events leading to the generation of the beam is:

The pump mechanism ‘fires’ and excites the atoms in the gain medium from a lower energy level into a higher one via absorption.

⇓

SPE causes some atoms to emit photons in random directions (‘seed’ photons).

⇓

These seed photons rapidly begin to replicate via STE.

⇓

Photons propagating away from the optic axis leave the gain medium and stop replicating. Photons propagating along the optic axis continue to replicate and form a wave of photons which oscillates between the cavity mirrors

The process is continual and the STE photons travelling along the optic axis rapidly come to dominate the whole photon population and so use all the available pump power.

It is important to appreciate that the origin of the extreme monochromaticity of the laser is not just determined by the existence of discrete energy levels; the cavity mirrors have an important role too.

SPE and STE can occur over a relatively broad range of energies e.g. by thermal or pressure broadening. For example the gain medium in a HeNe laser can emit and absorb over about 10^{-3} nm about the centre wavelength, which is many orders of magnitude greater than the output linewidth (~10^{-8} nm).

The line narrowing is produced by the cavity mirrors, which effectively comprise a Fabry-Perot etalon surrounding the gain medium. The FP at normal incidence is resonant to wavelengths satisfying:

$$m\frac{\lambda}{2} = L$$

High transmission occurs in a band around these values where:

$$\frac{\lambda}{\Delta\lambda_{\text{cavity}}} = \frac{\pi}{2}\sqrt{F}m$$

where F is the coefficient of finesse, which is determined by the mirror reflectivity. Typically

$$\Delta\lambda_{\text{cavity}} << \Delta\lambda_{\text{medium}}$$

Fin

Have a go at the problems on Problem Sheet 4