Paragraph No.

How does a LASER work?

This is a fascinating question to answer but we shall start with the most essential ingredient of all – the amplifying medium. 1

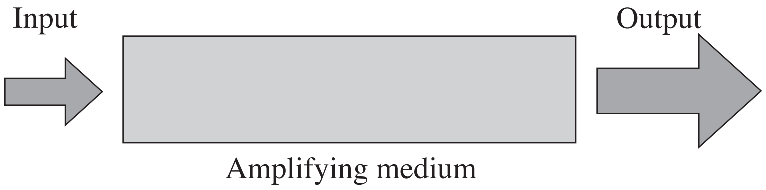

Fig. 1

All lasers contain an energized substance that can increase the intensity of light passing through it. This substance is called the amplifying medium and it can be a solid, a liquid or a gas. Whatever its physical form, the amplifying medium must contain atoms, molecules or ions which can store energy that is subsequently released as light. How the amplifying medium increases the intensity of light passing through it will be explained later. 2

When the intensity of the light is increased by the amplifying medium, we refer to this as gain and the gain coefficient (α) is defined by the equation 3

$$I = I_0 \exp(\alpha x) \qquad \textbf{equation 1}$$

where I is the intensity of the laser beam, I_0 is the initial intensity and x is the distance travelled by the beam in the amplifying medium.

Increasing the intensity of a light beam that passes through an amplifying medium amounts to putting additional energy into the beam. This energy comes from the amplifying medium which must in turn have energy fed into it in some way. In laser terminology, the process of energizing the amplifying medium is called "pumping". 4

A laser consists of a pumped amplifying medium positioned between two mirrors as indicated below. The purpose of the mirrors is to provide what is described as 'positive feedback'. This means simply that some of the light that emerges from the amplifying medium is reflected back into it for further amplification. 5

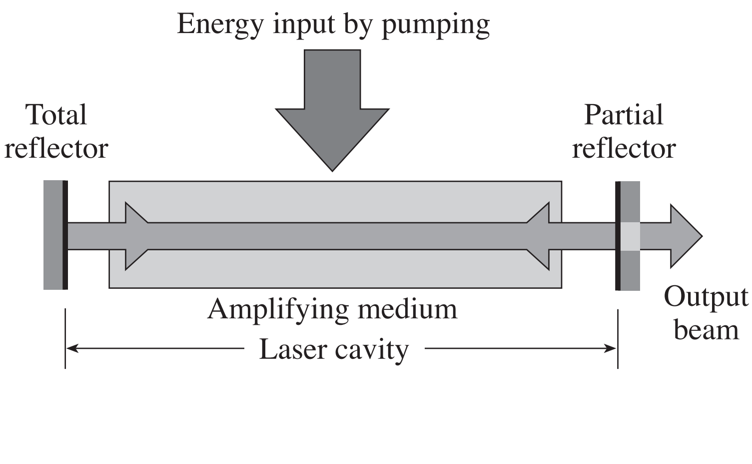

Fig. 2

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The beam within the laser cavity undergoes multiple reflections between the mirrors and is amplified each time it passes through the amplifying medium. One of the mirrors reflects all of the light that falls upon it. The other mirror reflects most of the incident light but the light that is not reflected is transmitted through the mirror. This transmitted portion is the output beam of the laser. 6

The cavity ensures that the beam is well directed. Only light that travels in a direction closely parallel to the axis of the cavity can undergo multiple reflections at the mirrors and make multiple passes through the amplifying medium. Other rays execute a zig-zag path within the cavity and wander out of it. 7

The laser cavity also improves the spectral purity of the laser beam. Only light of particular wavelengths can undergo repeated reflection up and down the cavity. This behaviour is similar to that of a vibrating guitar string in that a particular string will only vibrate at certain frequencies. In a similar way, an optical cavity will only sustain repeated reflections for particular well-defined wavelengths of light. 8

So far, nothing has been written about how an amplifying medium amplifies light. We must begin with an account of how light can interact with individual atoms within an amplifying medium ("atoms" will be used to include molecules and ions). There are many energy levels that an electron within an atom can occupy, but here we will consider only two. Also, we will consider only the electrons in the outer orbits of the atom as these can most easily be raised to higher unfilled energy states. 9

Absorption

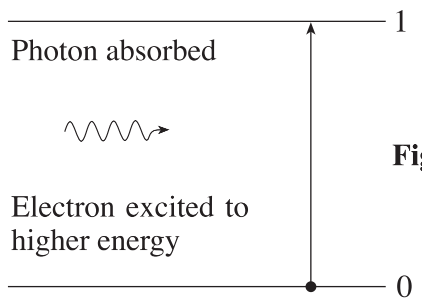

Fig. 3

Spontaneous Emission

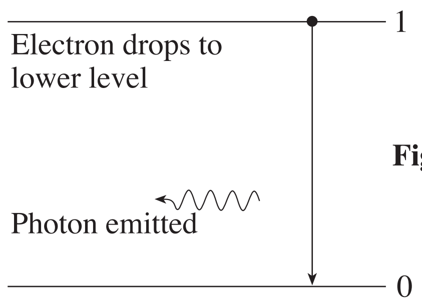

Fig. 4

These common processes of absorption and spontaneous emission should be familiar to A-level students. These processes cannot give rise to the amplification of light. The best that can be achieved is that, for every photon absorbed, another is emitted. 10

However, there is another process called ***stimulated emission***. This is a very uncommon process in nature but it is central to the operation of lasers. 11

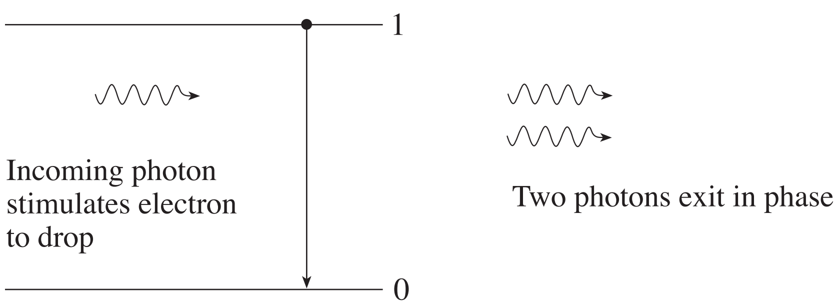

Fig. 5

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If a photon of light interacts with an excited atom, it can ***stimulate*** a return to the lower state. One photon interacting with an excited atom results in two photons emerging. Furthermore, the two photons are said to be in phase. Stimulated emission is the process that can give rise to the amplification of light. If we consider a photon of light interacting with a single atom, stimulated emission is just as likely as absorption; which process occurs depends upon whether the atom is initially in the lower or the upper energy level. The bad news is that, under most conditions, stimulated emission does not occur to a significant extent. The reason is that, normally, there will be far more atoms in the lower energy level, 0, than in the upper level, 1, so that absorption will be much more common than stimulated emission. If stimulated emission is to predominate, we must have more atoms in the higher energy state than in the lower one. This unusual condition is referred to as a population inversion and it is a necessary condition for laser action to occur. 12

Finding substances in which a population inversion can be set up is central to the development of a laser. The first material used was synthetic ruby. 13

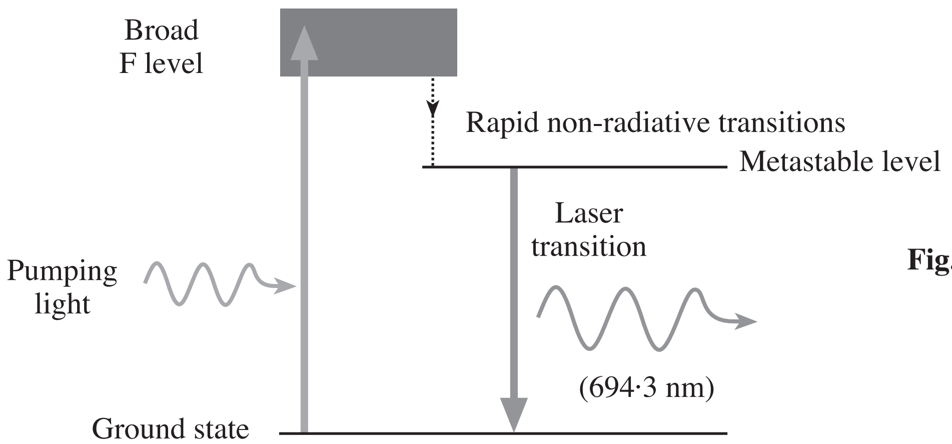

Fig. 6

Energy levels of chromium ions in ruby

In a ruby laser, a rod of ruby is irradiated with the intense flash of light from flashtubes. Light in the green and blue regions of the spectrum is absorbed by chromium ions in the ruby, raising the energy of electrons of the ions from the ground state level to the broad F level. Electrons in the F level rapidly undergo transitions to the metastable level. The metastable level is unusual in that it has a relatively long lifetime of about 4 ms, the major decay process being a transition to the ground state. This long lifetime allows a high proportion (more than a half) of the chromium ions to build up in the metastable level so that a population inversion is set up between this level and the ground state level. This population inversion is the condition required for stimulated emission to overcome absorption and so give rise to the amplification of light. Now, if one electron drops spontaneously to the ground state, it will emit red light of wavelength 694·3 nm. This light can then interact with other chromium ions that are in the metastable level causing them to emit light of the same wavelength by stimulated emission. As each stimulating photon leads to the emission of two photons, the intensity of the light emitted will build up quickly. 14

Adapted from Laser Tutorials written by John Gormally. The original article can be found at members.aol.com/WSRNet/tut/ut1.htm.