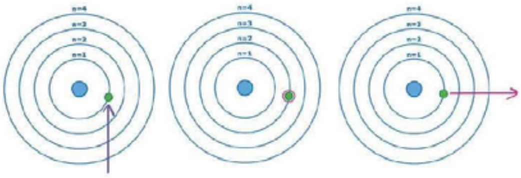
Student 2: High Merit

NZQA Intended for teacher use only

The Bohr Model of the hydrogen atom and electron transitions

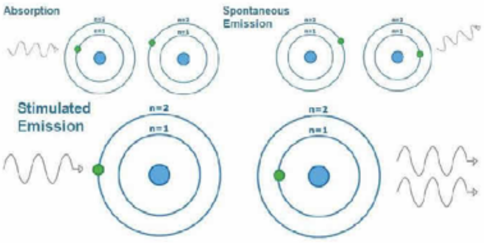


Bohr said that the electron that orbits the hydrogen nucleus can sit at one of multiple 'levels', of certain radii, in which it can orbit the nucleus. However, to sit at a given orbital level, the electron must have the necessary discrete energy value corresponding to that orbital level. The idea of multiple orbital levels contrasts what was previously proposed by Rutherford. This diagram illustrates the process of electron transition between energy levels due to photon emission and absorption.

The left-hand diagram illustrates a photon (purple arrow) being absorbed by an electron (green ball). The central diagram illustrates an electron (green ball with pink circle) which has been excited to a higher energy level (from n=1 to n=2). The right-hand diagram shows the electron emitting a photon (pink arrow). This photon (pink arrow) has energy equal to the difference between energy levels n=1 and n=2. Therefore, the electron has the correct quantised energy value to decay from its excited state (n=2) to its ground state (n=1).

To be specific, the photon required to be emitted/absorbed to cause an electron to transition between n=1 and n=2 of a hydrogen atom is part of the Lyman series and has a wavelength of 122nm. In the diagram above, if the wavelength of the photon (purple arrow) was anything other than 122nm, then the excitation from n=1 to n=2 would never have occurred. A photon must have the exact wavelength, and thus discrete energy value for absorption or emission to occur. An electron cannot remain between two energy levels. This explanation refers specifically to a hydrogen atom. The same principles apply when other elements are used as a lasing medium, although the mathematics is more complex due to greater number of electrons. ①

Spontaneous Emission Versus Stimulated Emission



Generally, an electron in an excited energy state must eventually decay to a lower energy level. As per the principles of electron transition, a photon will be emitted as it decays to that lower level. "This event is called 'spontaneous emission' and the photon [will be] emitted in a random direction and a random phase". Another type of photon emission is called stimulated emission. Consider an electron is orbiting a hydrogen nucleus at energy level n=2 and it is going to decay to energy level n=1. Before the electron undergoes spontaneous emission, it coincidently encounters a photon that has a wavelength of exactly 122 nm. What is likely to occur is a 'stimulated emission'; where a "photon will be emitted at the same wavelength, in exactly the same direction, and with exactly the same phase as the passing photon".

The diagram of a hydrogen atom at top left represents a photon, that must have a 122nm wavelength as per proof 1.2, exciting an electron to a higher state. The diagram at top right represents the spontaneous decay of an electron, causing emission of a photon with a wavelength of 122nm in a random direction and random phase. The bottom diagram represents a 122nm photon coming into contact with an electron, already at n=2, and thus stimulating the emission of a coherent (in-phase), collimated (parallel) light wave with exactly the same wavelength (122nm, as per proof 1.2) as the electron decays to its ground state.

Amplification by Stimulated Emission of Radiation

This diagram represents a group of atoms all in the same excited state. The energy required to initially excite these atoms was provided by an external 'pump' source. A photon interacts with the first atom (the grey ball furthest left) and causes stimulated emission of a coherent photon. "The two coherent photons then interact with the next two atoms in line, and the result is four coherent photons ... At the end of the process, we will have eleven coherent photons, all with identical phase and travelling in the same direction ... In other words, the initial photon has been 'amplified' by a factor of eleven". The 'initiating' photon of stimulated emission is a result of spontaneous emission.

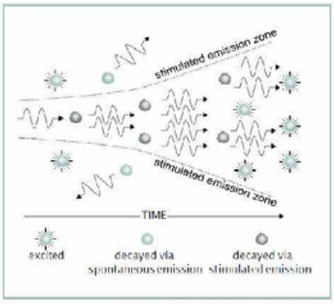
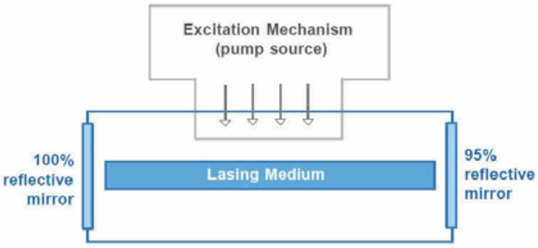


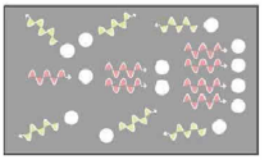
Diagram by Melles Griot, 2009.

②

Population Inversion

When an excited atom spontaneously emits the 'initiating' photon for a chain of stimulated emission then that photon could either be absorbed by an atom in its ground state or it could cause stimulated emission of an already-excited atom. For stimulated emission to be sustained, there has to be a greater probability of the initiating photon causing stimulated emission than it being absorbed. For this to occur, a greater proportion of the atoms must already be in the excited state. An external energy source (pump source) is used to sustain this critical proportion of excited atoms compared to ground-state atoms. This is called population inversion.





A look inside the lasing medium.

The diagram represents a model for a LASER. The excitation mechanism provides the energy to ensure that the population of atoms is inverted (i.e. higher proportion are in excited state). The 'initiating' photon is spontaneously emitted in a path perpendicular to the mirrors. This photon causes stimulated emission of photons from the atoms that are continuously being excited by the excitation mechanism. The initial photon has now been 'amplified' and has created a chain of coherent, collimated photons all of the same wavelength.

The mirrors at each end reflect the chain of photons to cause further amplification through creating a standing wave. It is critical that these two mirrors are positioned at a distance that is an exact multiple of half the wavelength of the photons of laser-light. If the length between the mirrors is not a multiple of half the photon wavelength, then a standing wave would cease to occur and the effects of deconstructive interference from out-of-phase photons would gradually weaken the laser-beam. The distance between mirrors being a multiple of half the wavelength is crucial for amplification of laser-light. However, one of the two mirrors is only 95% reflective. This mirror allows a small proportion of the laser-light to pass, while reflecting enough photons to sustain **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The laser-light that is allowed to pass can then be used for medical, commercial, scientific or recreational purposes.