

Light Emission

When an electron is raised to a higher orbital (higher energy level), the atom is said to be excited. When the electron falls back to its original orbital, it releases energy in the form of light. Each element has its own characteristic set of energy levels. Since the frequency of the emitted light is determined by the energy differences of these energy levels, each element emits its own characteristic pattern of light frequencies called an emission spectrum.

The process by which light is absorbed by and emitted from an atom lies at the very foundations of Quantum Physics.

Generally, the quantum model states that light is absorbed and emitted by an atom in distinct packages of energy called "quanta". Such packaged quanta are often referred to as "photons".

When an atom absorbs a photon of sufficient energy, its *orbiting* electron "jumps" to a higher energy level--to an "electron shell" further from the nucleus. Then, after a brief period, the electron *jumps back down* (like a spring) to its previous energy level. During this "jump down" process, a photon is emitted from the atom.

"The energy of the emitted photon is equal to the *difference* in the two energy levels, obeying the quanta relationship: $E=h\nu$." (where ν is the frequency of the emitted light energy; and h is Planck's constant= 6.625×10^{-34} J-s)

So, the measured values of absorbed or emitted quanta are always restricted to some multiple of Planck's constant.

The basic quantum model also states that the energy emitted by the atom is equal to the energy that has been absorbed by the atom...adhering to energy conservation laws

Energy of the introduced quanta is absorbed by the electromagnetic field that serves as the binding energy between the electron and the nucleus. Sudden changes in density and pressure in this electromagnetic field, in conjunction with certain electron properties, govern the "jumps" towards the ionization threshold and back to ground state. Surplus EM field separates from the atomic system and is perceived as light emission.

Example of Basic Procedure:

The photon has *impacted* an atom (example with e1 and e2 shells <levels>)-'permeating' the electron shell. It imparts its inherent electromagnetic energy into the pre-existing EM field within the shell. The result is an increased EM field density within the. We will say that this EM field is now "saturated". With increased EM field density, comes increased EM pressure. This pressure exerts an *outward* force on the electron.

The increased *outward* EM pressure causes the electron to *jump* (away from the nucleus)--to a higher energy level (e-2 shell); in accordance with the quantum restrictions governed by Plank's constant. However...the EM field that once 'saturated' the smaller electron shell, e-1 suddenly occupies a much larger volume of space--(the volume enclosed by the larger e-2 electron shell.) Therefore the *density* of that EM field is greatly decreased; We will say that the once-saturated EM field is now "rarefied". With decreased EM field density, comes proportionally decreased EM pressure on the electron--outward (from the nucleus).

The decreased EM pressure of the 'rarefied' EM field is not great enough to sustain the *electron orbit* in the e-2 shell; (or "float" the electron--as it is sometimes described). [Speaking in terms of forces, we could say that the net force on the electron is dominated by its affinity for the nucleus; and that force overwhelms the (outward) force of the EM pressure within the e-2 shell.] So the electron races a world line towards the nucleus.(The electron misses the nucleus, due to certain effects of uncertainty principal (Heisseberg).

During the jump down, the electron and nucleus re-establish equilibrium and a *new* ground state electron shell begins to form. (e-1 shell). The density of the EM field within the new e-1 shell is *limited* to that which is necessary to bind the electron to the nucleus in the ground state energy level; (Hence, energy is conserved.) Consequently, there is an area of *excess* EM field that is virtually '*abandoned*' within the area of space of the (now empty) e-2 shell. The energy of this "abandoned" field is equal to the energy of the photon that was originally absorbed. This abandoned EM field autonomously *condenses* and becomes its own physical entity-- independent of the atomic system.

This now-independent, condensed EM field is, essentially, the *new* photon.

With our ideal atom, now restored to equilibrium (and its electron returned to ground state), the new photon is emitted.

Light is part of the electromagnetic spectrum, which ranges from radio waves to gamma rays. Electromagnetic radiation waves, as their names suggest are fluctuations of electric and magnetic fields, which can transport energy from one location to another. Visible light is not inherently different from the other parts of the electromagnetic spectrum with the exception that the human eye has evolved to detect visible waves.

Electromagnetic radiation can also be described in terms of a stream of photons which are massless particles each traveling with wavelike properties at the speed of light. A photon is the smallest quantity (quantum) of energy which can be transported and it was the realization that light travelled in discrete quanta that was the origins of Quantum Theory.

The atoms, ions or molecules have defined energy levels usually associated with energy levels that electrons in the matter can hold. Light can be generated by the matter or a photon of light can interact with the energy levels in a number of ways.

An atom or molecule in the lowest energy state possible known as the ground state can absorb a photon which will allow the atom or molecule to be raised to a higher energy level state or become excited.

The atom or molecule won't stay in an excited state so it relaxes back to the ground state by in a number of ways. In the simplest way the atom or molecule may re-emit a photon of light of the same energy and effectively the incident photon is scattered.

The photons emitted will be a characteristic energy appropriate for a particular atom or compound and so by studying the light emission the matter under investigation can be determined.

Light can be produced by matter which is in an excited state and as it will be shown excitation can come from a variety of sources. The atoms and molecules that make up matter typically emit light at characteristic energies. The light emission can be spontaneous or stimulated. In spontaneous emission matter at a sufficiently high energy level can relax by emitting photons of a characteristic energy, this is the process which occurs in flames, or discharge lamps. Stimulated emission occurs when matter in an excited state is perturbed by a photon of light and gives rise to a further photon of light, typically at the same energy and phase as the perturbing photon. This phenomenon is the process which gives rise to laser emission where you have many photons at the same wavelength and in phase with each other.

A body at a given temperature also emits a characteristic spectrum of light called black body radiation. Consider an electric filament as current is applied to it. As the electric current supplies energy to the filament and it heats up, it starts to glow red, and as it gets hotter it then turns orange and then white. The process underlying this is well understood for a theoretical body known as a 'black body'. Our filament will approximate a black body and as the filament gains energy from the electrical power it tries to equalize its energy with its surroundings by radiating its excess energy. It does this by emitting light starting first in the infrared and as the filament gets hotter or has more energy the radiation moves more into the visible spectrum. The spectral radiance emittance M in $\text{Wm}^{-2} \text{nm}^{-1} \text{sr}^{-1}$ of a black body of Temperature T in Kelvin is given by Planck's Law below:

$$M = \frac{2\pi c^2 h}{\lambda^5} \left(\exp \left(\frac{hc}{\lambda kT} \right) - 1 \right)$$

Where c is the speed of light, h = Planck's constant and K = Boltzmann constant.

The spectral irradiance for artificial sources in general deviate from a perfect black body radiation but the approximation is useful in many applications and by measuring the spectral output of a heated body its temperature can be remotely measured. For example Sunlight is due to the black body radiation characteristic of a body at approximately 5,800K

The source of the excitation to produce light emission can come from a variety of sources.

Light can also be produced by the acceleration of a free charged particle, such as an electron. The light emission is known as Bremsstrahlung or 'braking radiation'. The emission is characteristically seen in X-ray emission tubes which work by accelerating electrons with a high voltage and then by decelerating them very fast by directing them onto a metal target.

Electron absorbs some energy which causes it to "jump" to a higher energy level. This is called **excitation**.

The electron, preferring to be in the lower energy, immediately drops back down to the lower energy level (**de-excitation**).

In order to conserve energy, a photon (discrete bundle of energy) is emitted.

Because of the behavior of matter and energy at the atomic scale, which is governed by Quantum Mechanics, the energy of the photon is equal to the difference in the energies of the two energy levels and is also proportional to its frequency.

That is: $E_{\text{photon}} = hf$ where

- **h = Planck's constant.**
- **f = frequency of the photon.**

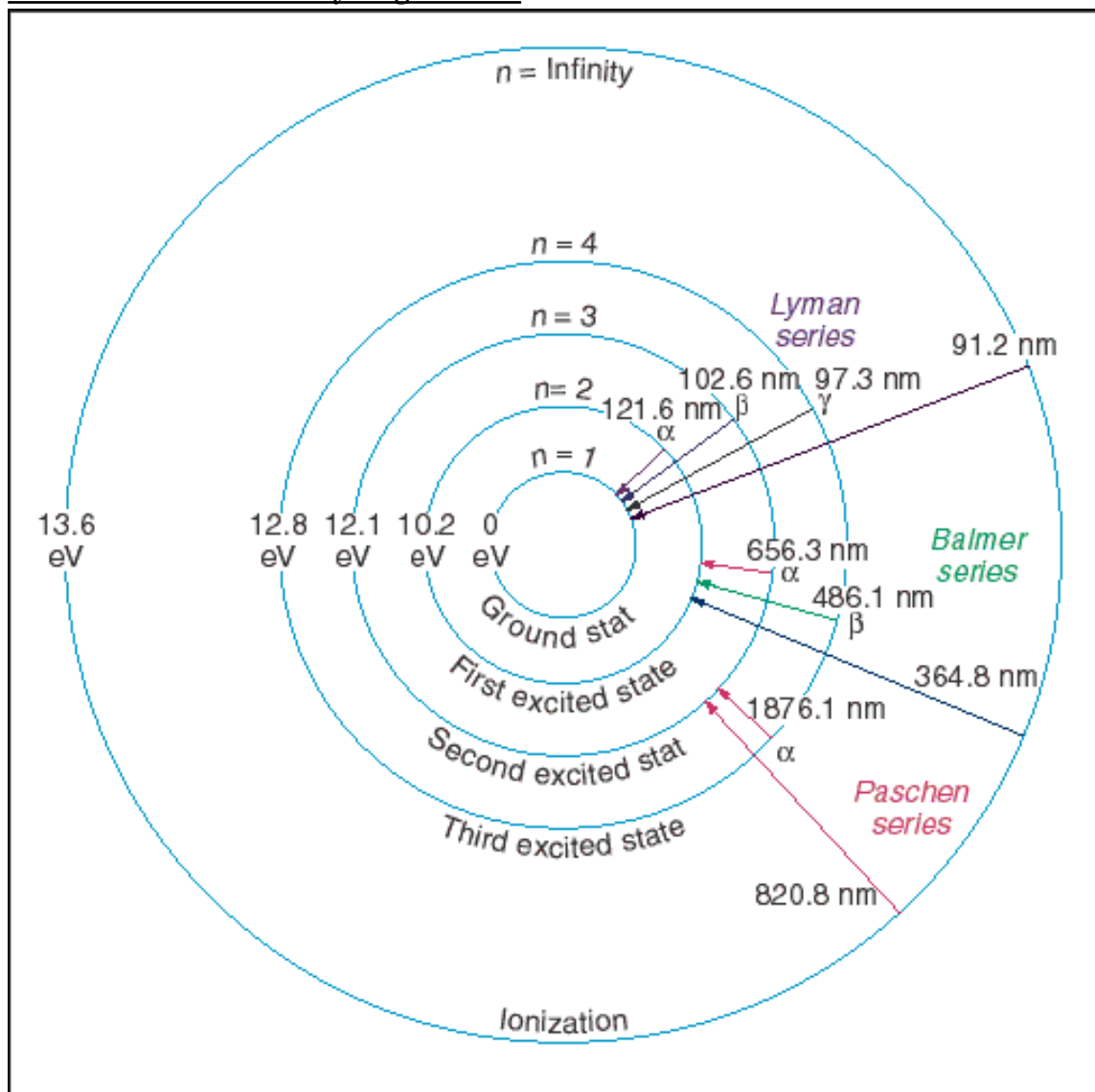
Depending on the element, only certain excitations and de-excitations (or transitions) are allowed for the electrons.

The cumulative result is that an atom of a particular element will only have light emissions of certain frequencies.

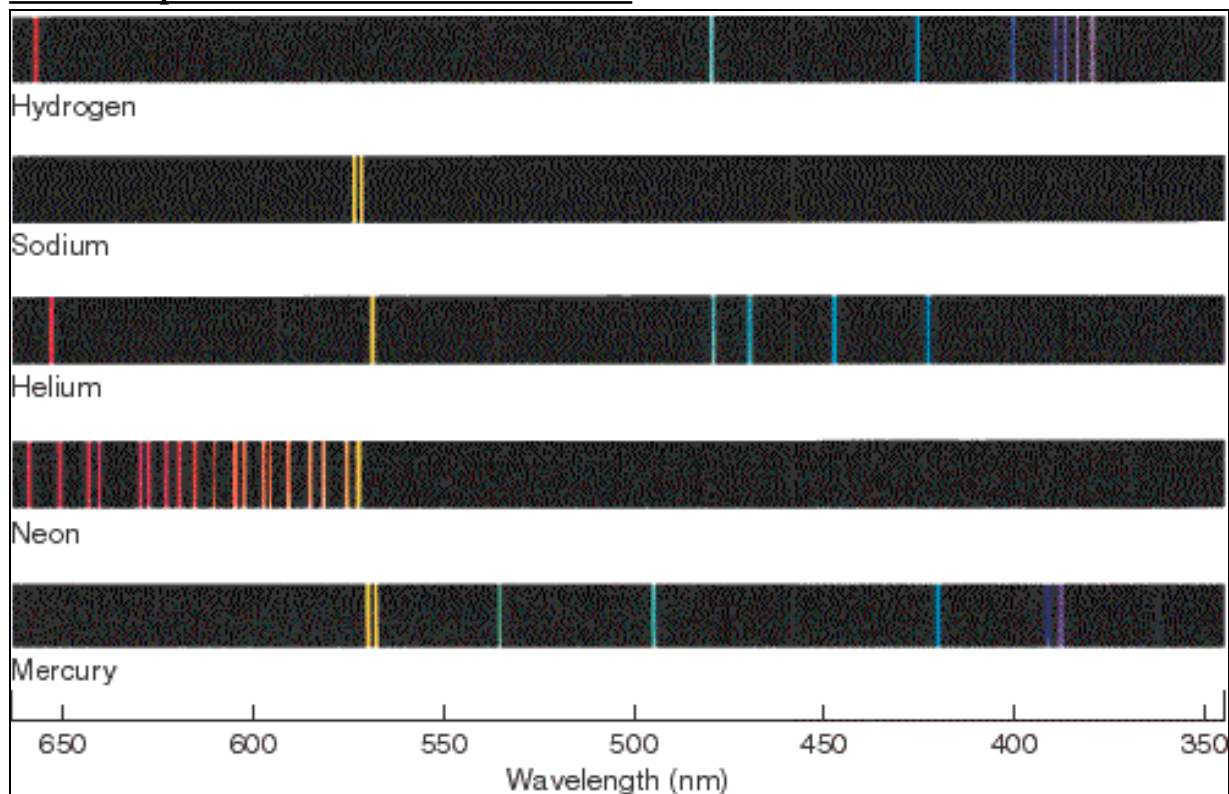
The combination of all the allowed transitions produces an emission spectrum for that particular element.

No two elements have the same emission spectrum, so the emission spectrum can be used to identify the element in question.

Emission Lines for the Hydrogen Atom



Emission Spectra of Some Common Elements



Emission spectra are emitted by atoms in a gaseous state where the atoms are so far apart that interactions between them are negligible (each atom behaves as an isolated system.).

Incoherent and Coherent light

White light from an incandescent light bulb is called incoherent light.

The light is composed of different colors and the waves are out of phase with each other.

If we pass the white light through a filter, we could get only one color (monochromatic) light which would still be out of phase (incoherent red light).

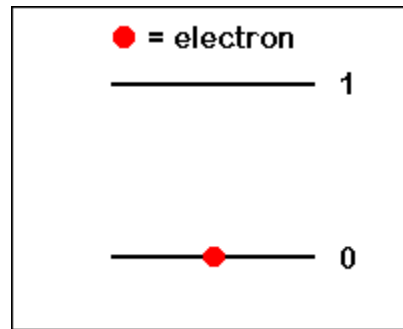
Monochromatic, Coherent light

By getting all the red light in phase, we would have monochromatic, coherent light.

This is the kind of light emitted by a **LASER**.

Absorption and Spontaneous Emission

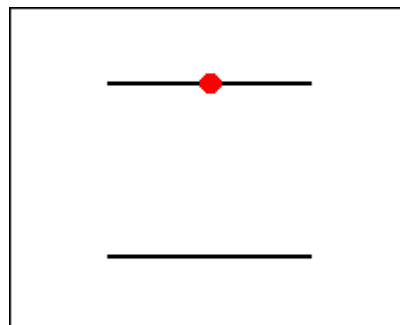
An example (with level 1):



A photon of light is absorbed by an atom in which one of the outer electrons is initially in a low energy state denoted by 0. The energy of the atom is raised to the upper energy level, 1, and remains in this excited state for a period of time that is typically less than 10^{-6} second. It then spontaneously returns to the lower state, 0, with the emission of a photon of light. Absorption is referred to as a resonant process because the energy of the absorbed photon must be equal to the difference in energy between the levels 0 and 1. This means that only photons of a particular frequency (or wavelength) will be absorbed. Similarly, the photon emitted will have energy equal to the difference in energy between the two energy levels. These common processes of absorption and spontaneous emission cannot give rise to the amplification of light. The best that can be achieved is that for every photon absorbed, another is emitted.

Stimulated Emission

Stimulated emission is a very uncommon process in nature but it is central to the operation of lasers.



Above it was stated that an atom in a high energy, or excited, state can return to the lower state spontaneously. However, if a photon of light interacts with the excited atom, it can stimulate a return to the lower state. One photon interacting with an excited atom results in two photons being emitted. Furthermore, the two emitted photons are said to be in phase, i.e. thinking of them as waves, the crest of the wave associated with one photon occurs at the same time as on the wave associated with the other. This feature ensures that there is a fixed phase relationship between light radiated from different atoms in the amplifying medium and results in the laser beam produced having the property of coherence. Stimulated emission is the process that can give rise to the

amplification of light. As with absorption, it is a resonant process; the energy of the incoming photon of light must match the difference in energy between the two energy levels. Furthermore, 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. However, under most conditions, stimulated emission does not occur to a significant extent. The reason is that, under most conditions, that is, under conditions of thermal equilibrium, 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 necessary to create a population inversion for laser action to occur.