The Quantum Atom

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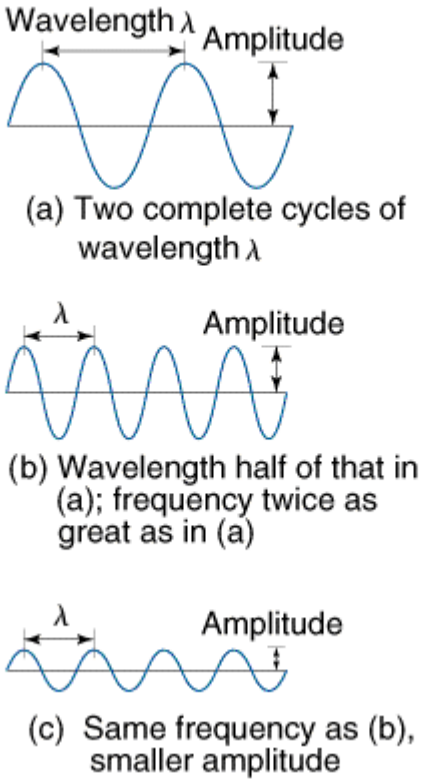
Remember that the behavior of waves is much different than the behavior of particles. Wave phenomena has many common examples, but all waves share some common features. Waves have a frequency, a wavelength, a wave velocity, and an amplitude:

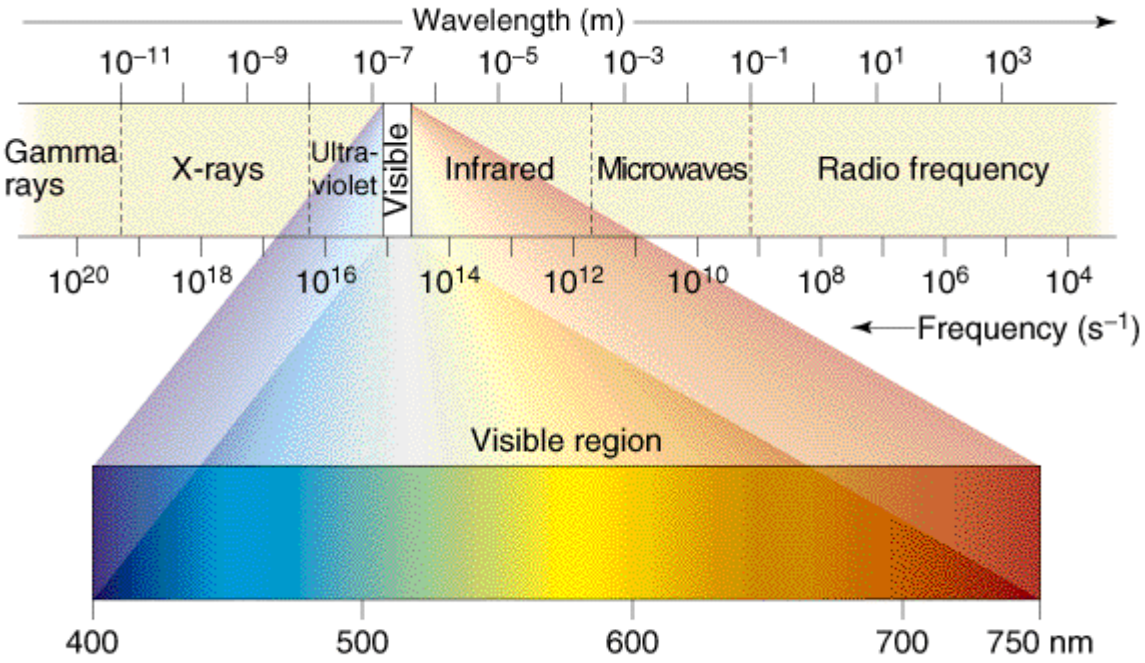


For a given type of wave in a given medium, the wavelength λ and the frequency ν can be related to the speed of propagation of the wave.

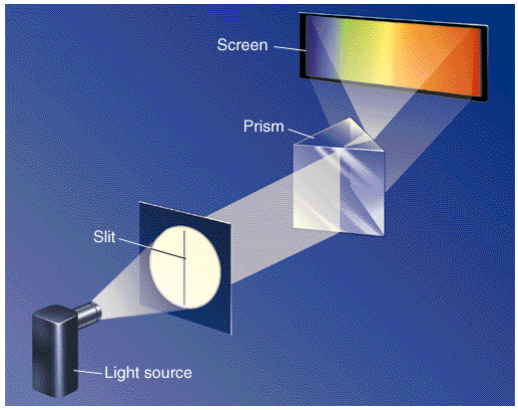
$$\lambda \nu = c$$

For Light (electromagnetic waves) the speed of propagation is the speed of light: 3×10^8 m/s.

Light is just one portion (one range of frequencies) of the EM spectrum



A device that separates light by its frequency is said to 'disperse' the light. Prisms and raindrops disperse light by refraction, gratings and holograms by refraction.



Newton and Einstein both thought that light, although a wave, can also have some properties of a particle. In fact, they were right, and light actually is a stream of particles called photons. The amplitude of the light can be related to the number of photons in a given volume, and the energy of each photon is related to the frequency of the light:

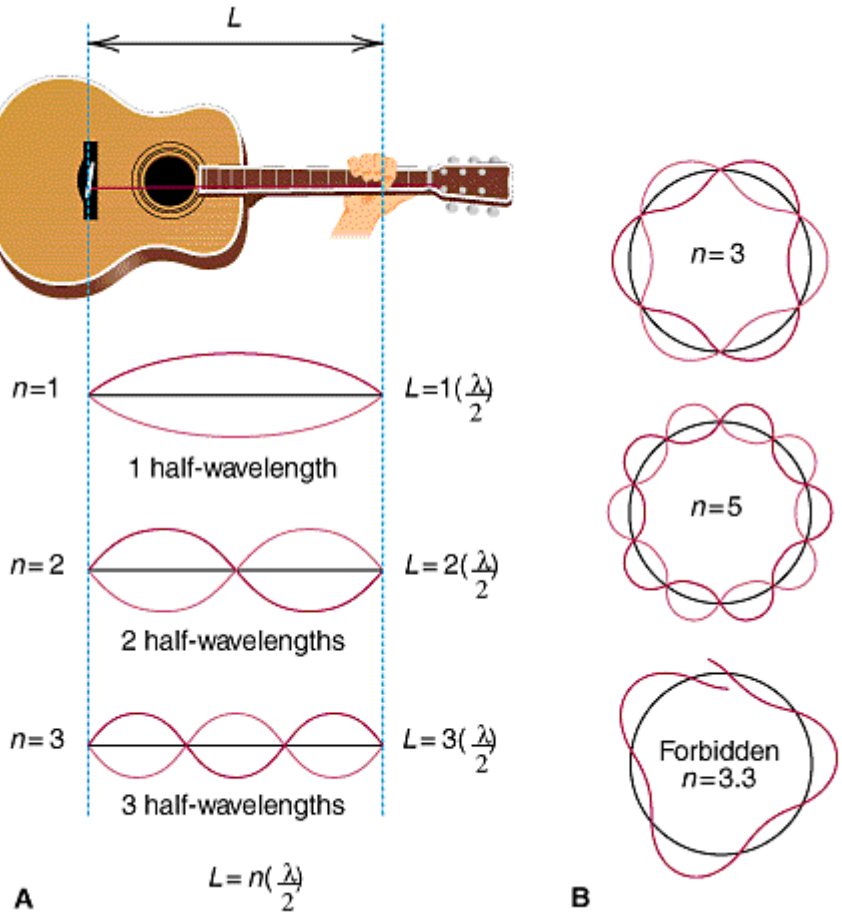
$$E = h \nu$$

When light strikes matter, and in particular a molecule, the entire energy of the photon must be absorbed or emitted. Thus the color of the light that interacts with a particular piece of matter tells you about the change in energy that is possible in that matter,

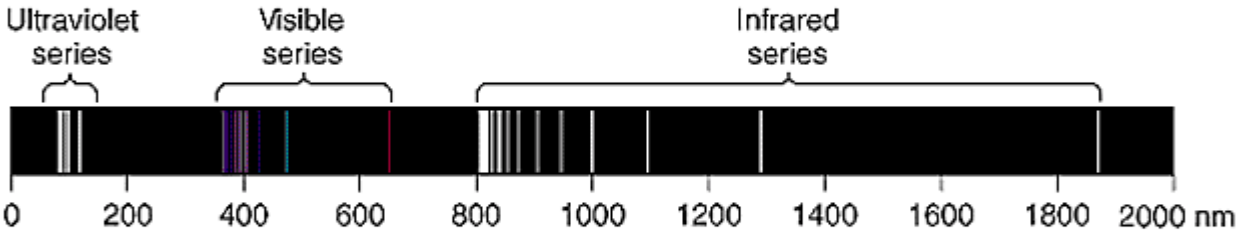
If Light has properties of a particle, surely particles have properties of a wave. DeBroglie showed that this was in fact the case, in the first equation that has both wave and particle like properties related:

$$p = h / \lambda$$

When one confines a wave to a particular region of space, the edges of the containment place a constraint on the wavelength due to 'boundary conditions'. This is how you play different notes on the same guitar string by moving the position in which you make the wave amplitude zero, i.e. where your finger touches the fret.



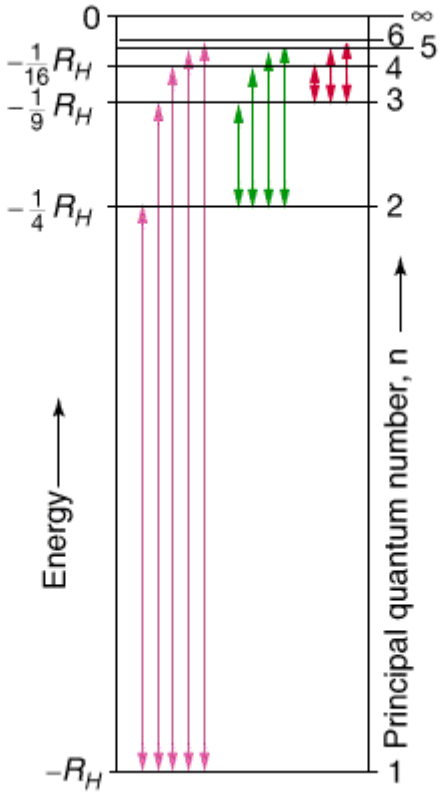
If electrons are waves, then the wavelength of the electron must 'fit' into any orbit that it makes around the nucleus in an atom. All orbits that do not have the electrons wavelength 'fit' are not possible, because wave interference will rapidly destroy the wave amplitude and the electron wouldn't exist anymore. This 'interference' effect leads to discrete (quantum) energy levels and the discrete 'line' spectrum of the hydrogen atom:



This pattern is described by discrete energy levels of the atom that have energy inversely proportional to the square of the number of waves in the orbit, or more precisely the number of nodes in the wave plus one.

$$E_n = -Z^2 R_H / n^2$$

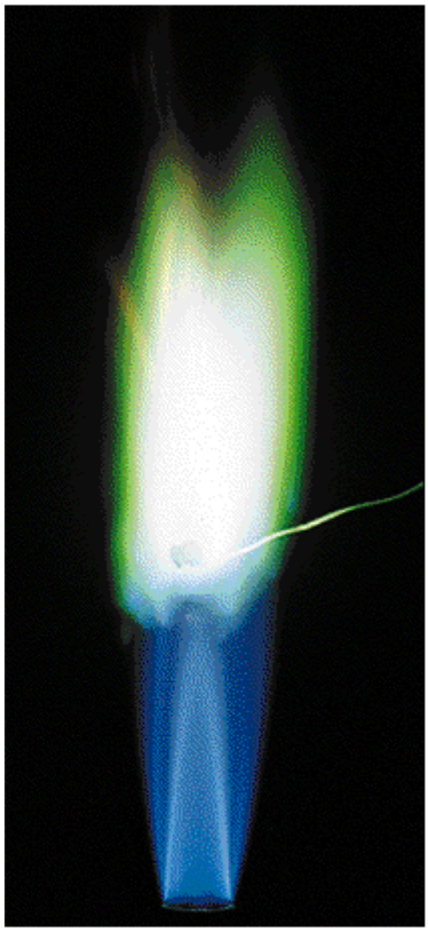
This is the pattern of energy levels that exist in the Hydrogen atom. Transitions between these levels give the pattern in the absorption or emission spectrum of the atom.



The frequency of the transitions between the energy levels should be given by

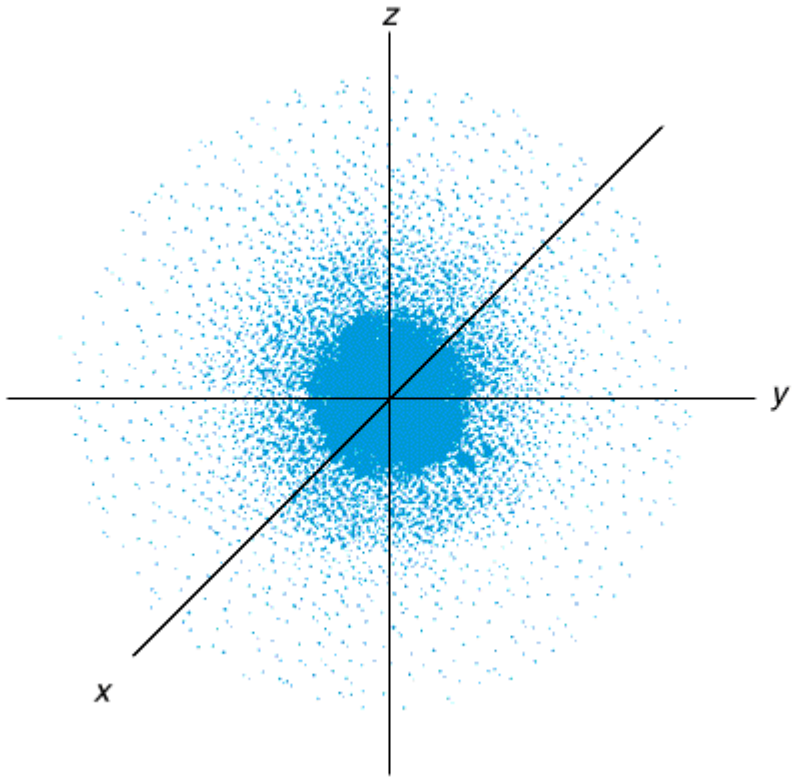
$$h\nu = \Delta E = E_{n2} - E_{n1} = -Z^2 R_H (1/n_2^2 - 1/n_1^2)$$

The energy patterns of atoms give the elements their characteristic 'flame' colors

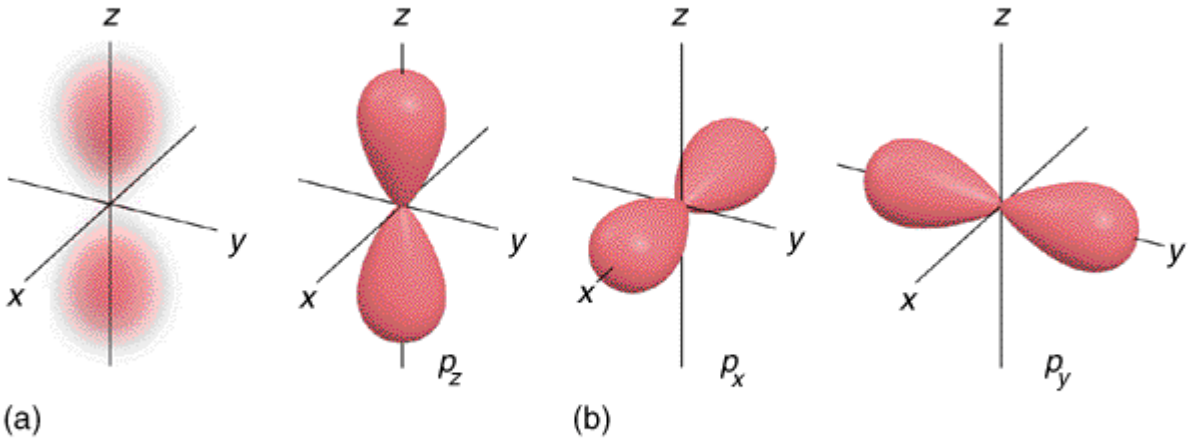


We know, too, that Sodium is yellow (Streetlights) and Neon is red (Fluorescent Signs)...

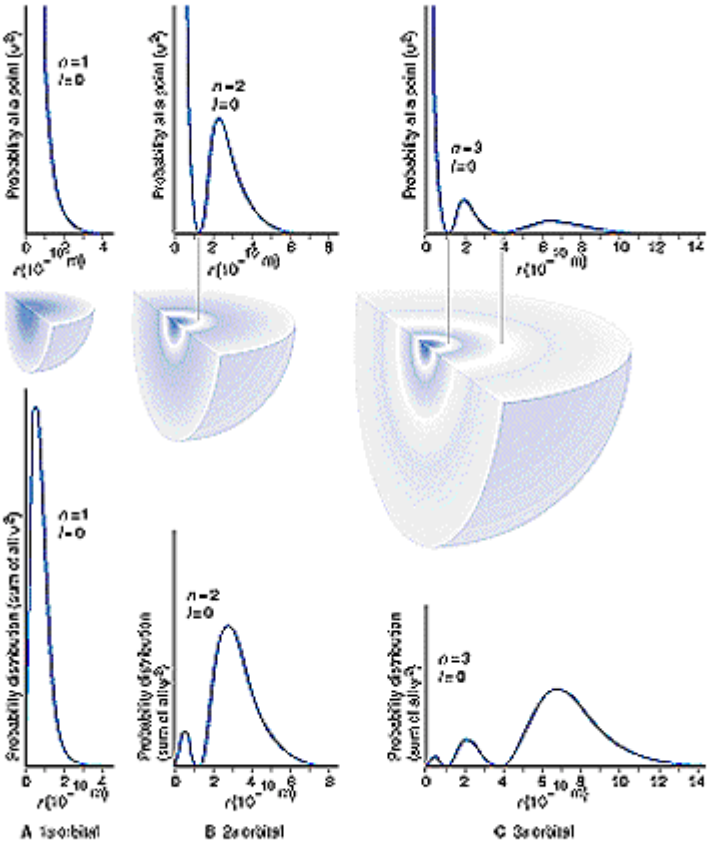
The wave nature of the electron is what makes atoms have the properties that they do. It explains the colors of the atoms and also their size. It also means that we cannot think about the electron in an atom as a little ball whirling about the nucleus, but a cloud of probability that is smeared out over the orbit.



This cloud is only spherical for the lowest energy level of the atom. As the energy of the electron in the atom increases, its wavelength decreases, and the number of times the wave amplitude crosses zero per orbit increases. These zero crossings are called **nodes**. The number of nodes is related to the frequency of the wave and therefore its energy.
The greater number of nodes, the greater the energy.
The lowest level of the H atom has no (zero) nodes, the next higher level has 1 node, but that node can either be an angular node or a radial node. If it is an angular node, then you have a 2p orbital

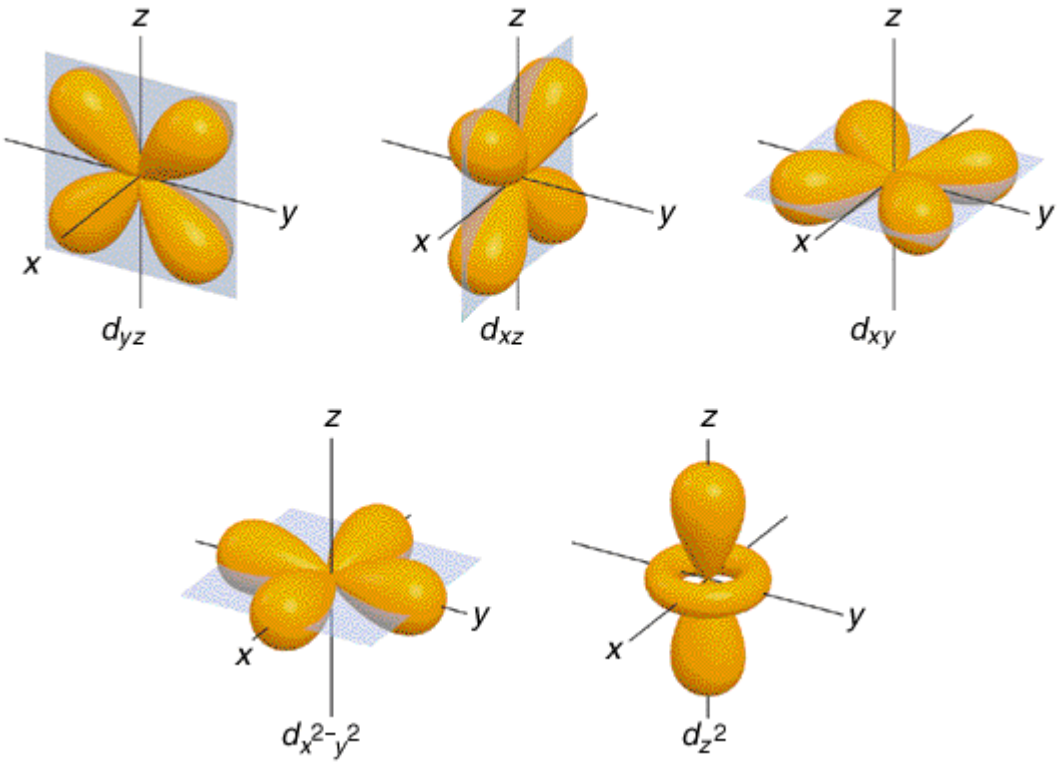


If you have a radial node, then you have a 2s orbital (3s shown also)



The number of nodes determines the energy. The Principle quantum number **n** is equal to the number of nodes plus 1, i.e. nodes= n-1. For a hydrogen atom, the energy it takes to make a radial node is equal to the energy it takes to make an angular node.

For higher **n**, you can have a greater numbers of nodes. For **n**>=3, you can have 2 angular nodes, and these are called **d orbitals**



In short, the energy of the atom is determined by the number of nodes (n-1).
The number of angular nodes is labelled by a letter

s: no angular nodes
p: one angular node
d: two angular nodes
f: three angular nodes
The number of radial nodes is the total number of nodes minus the number of angular nodes.

This document provides a brief description of the modern quantum atom – you do not need to know this for the course. However it is good to have a bit of an idea of the modern concept of the structure of the atom even though this will not be in your exam.

The Bohr model describe in the course is adequately describes the electrical nature of the atom.

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