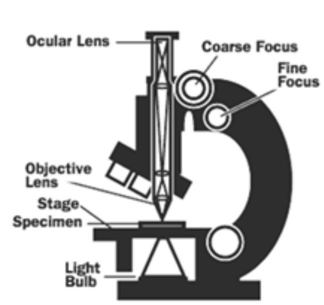
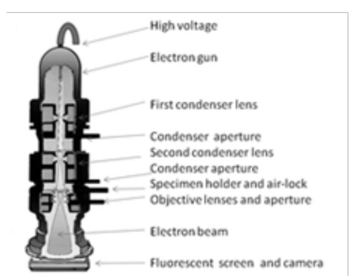
Application: Electron Microscopes

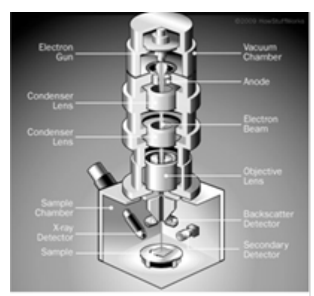
In order to resolve objects beyond the limits imposed by the wavelength of visible light, the wave properties of electrons are used in electron microscopes. The de Broglie wavelength of an electron can be 100,000 times smaller than the wavelength of a photon of visible light so a microscope using an electron beam can resolve objects that are much smaller than those of a light microscope.



Light Microscope



Transmission Electron Microscope



Scanning Electron Microscope (SEM)

Uses: visible light
Resolution: about 200 nm
Magnification: 2000x

Uses: electrons
Resolution: 50 pm
Magnification: 50,000,000x

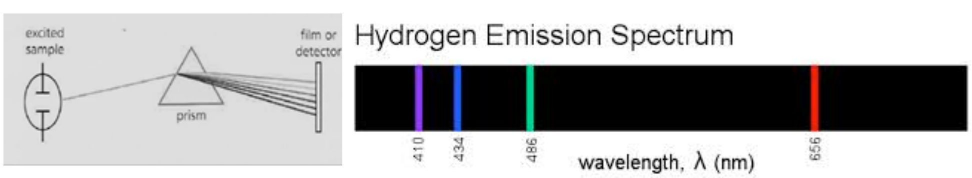
Uses: electrons
Resolution: 1 nm
Magnification: 50,000,000x

Why are electrons used instead of light? Smaller wavelengths mean greater resolving power, greater resolution

How can a particle be thought of as a wave?

A particle like an electron can be thought of as a superposition of many waves that cancel out everywhere except in a small region of space.

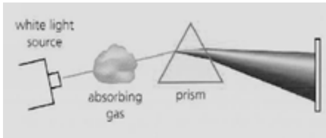
Production of **Emission Spectra**

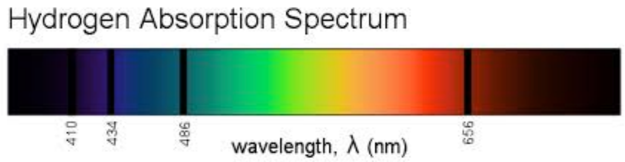


1. Low pressure gas (hydrogen,neon, mercury, argon, etc.) is energized by applying a potential difference across it causing it to heat up.

2. The hot gas emits light energy only at certain well-defined frequencies, as seen through a diffraction grating (spectroscope) or prism

Production of **Absorption Spectra**





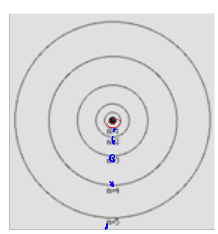
1. Light is shone through a cool low pressure gas.

2. A diffraction grating or prism is used to determine what frequencies pass through the gas and which are absorbed.

postulates of the **Bohr Model** of the Atom

I. Electrons in an atom can only exist in certain well-defined (discrete) stationary states called energy levels or energy states. (These can be visualized as orbits.)

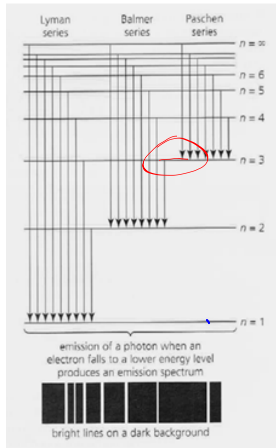
For the hydrogen atom, the amount of energy an electron has in these states can be calculated from:

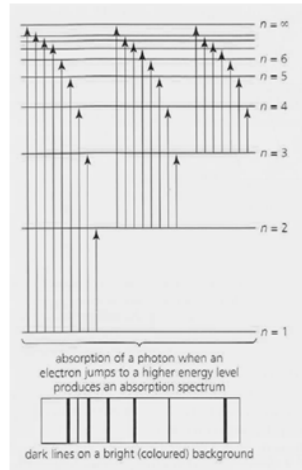


$$E_n = \frac{-13.6\,eV}{n^2}$$

II. Electrons may move from one stationary state to another by emitting or absorbing a quantum of radiation (photon) whose energy equals the difference in the two states.

The energy of a photon emitted or absorbed can be calculated from



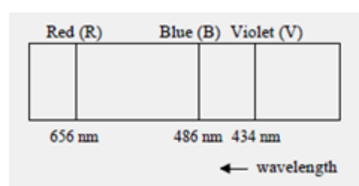


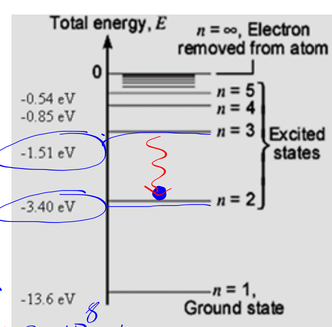
$$E_{photon} = \Delta E_n$$

$$|E_f - E_i| = hf$$

1. Calculate the wavelength of the spectral line associated with an energy level transition from n = 3 to n = 2 in the visible spectrum of hydrogen.

The Balmer Series: The Visible Emission Spectrum of Hydrogen





$$E_{photon} = |E_f - E_i|$$

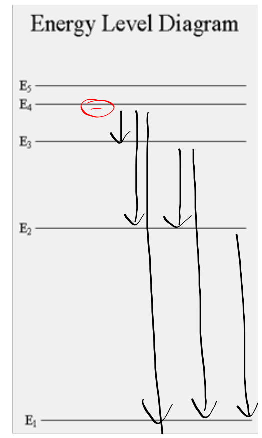
$$|-3.40\,eV - -1.51\,eV|$$

$$= 1.89\,eV = hf = h\,c/\lambda$$

$$\lambda = \frac{hc}{E_{photon}} = \frac{4.14\times10^{-15}\,\cancel{eV}\cdot\cancel{s}\cdot 3\times10^{8}\,m/\cancel{s}}{1.89\,\cancel{eV}} = 658\,nm$$

2. Electrons are excited from the ground state to the n = 4 state.

a) How many possible different photons may be emitted as the electrons relaxes back down to the ground state? Sketch them on the diagram.



b) Which transition produces a photon with the most energy?

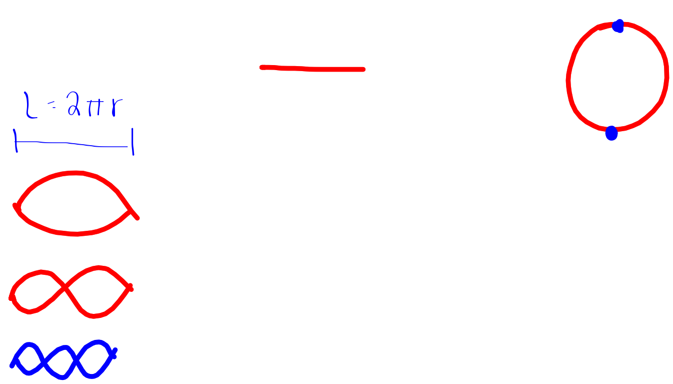
$4 \to 1$

c) Which transition produces a photon with the highest frequency?

$4 \to 1$

d) Which transition produces a photon with the longest wavelength?

$4 \to 3$



III. The angular momentum of an electron in a stationary state is quantized in integral values of h/(2π).

Math Model:

$p = h/\lambda = mv$

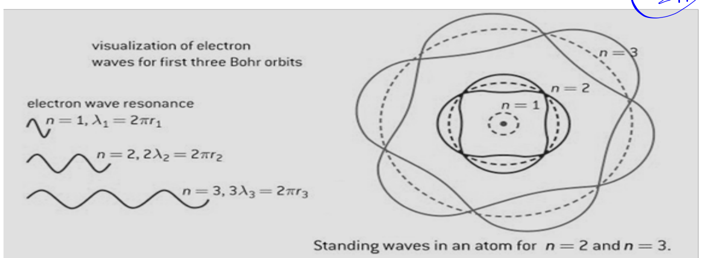
$\lambda = \frac{2\pi r}{n}$

Derivation:

$mv = \frac{h}{2\pi r/n}$

$mvr = n\frac{h}{2\pi}$ $\hbar$

$mvr = n\frac{h}{2\pi}$



Standing waves in an atom for $n = 2$ and $n = 3$.

NOTE: This postulate enabled Bohr to calculate which stable orbits are allowed.

The next step in understanding quantized energy levels is the Schrödinger model (or quantum mechanical) of the atom, using a wave equation developed by **Erwin Schrödinger** (Austrian physicist, 1887-1961). This model assumes that electrons in the atom may described by wave functions, not matter waves. A wave function is a mathematical equation that describes the behavior of the electron. Solving Schrödinger's wave equation using the electron's wave function gives a more accurate description of the hydrogen atom than the Bohr model and can be extended to all other atoms, unlike Bohr's model.