

Laboratory Exercise: The Electronic Structure of the Hydrogen Atom

In this laboratory exercise, we will probe the behavior of electrons within atoms using Emission Spectroscopy. In particular, we will focus on the behavior of the electron in the simplest atom, Hydrogen, and this atom's emission spectrum. For comparison, we will look at the emission spectrum of the next more complex atom, Helium.

Probing the behavior of electrons within atoms is problematic; atoms themselves are far too small to be seen and their presence must be inferred, and the electron itself is a quantum mechanical object whose behavior defies our common expectations. However, understanding the behavior of these electrons is important because this behavior determines an atom's chemistry. Thus, we must find an indirect probe of the electronic behavior of an atom.

It is found that an electronically excited atom of a given element can relax and emit a photon whose energy matches the energy of the atom's electronic transition. The collection of photons emitted by a collection of variably excited atoms of a given element can be separated by a prism into the emission spectrum for that element. These photons are directly observable as spectral lines; therefore they provide us with a window into the behavior of electrons within an atom.

Photons are quantum mechanical objects that exhibit a Wave-Particle Duality. The wavelength (λ) of a photon is related to its speed (c) via:

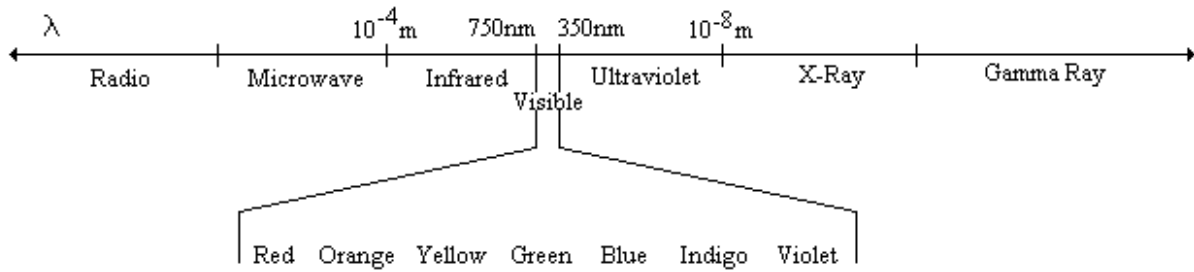
$$c = \lambda \nu \quad (\text{Eq. 1})$$

where ν is its frequency. In a vacuum the speed of a photon is $c = 2.99792 \times 10^8$ m/sec. Its energy (E) is then related to its frequency via:

$$E = h \nu \quad (\text{Eq. 2})$$

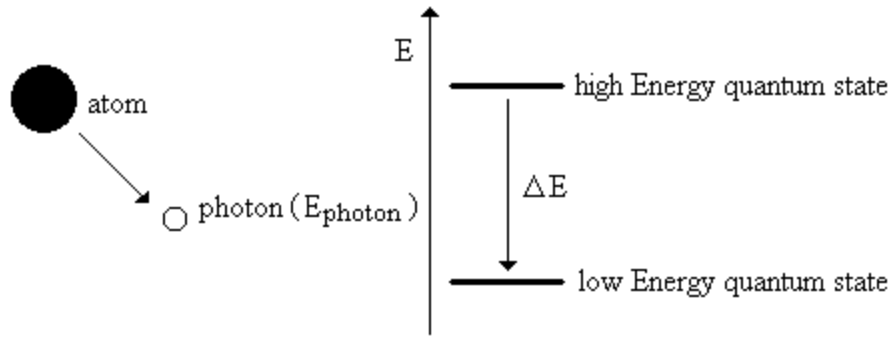
where h represents Planck's constant; $h = 6.62608 \times 10^{-34}$ Jsec. Photons can cover a wide range of energies, from very low energy Radio Waves to high energy Gamma Radiation. This Electromagnetic Spectrum of photon wavelengths is represented below:

Electromagnetic Spectrum



Typical electronic transitions within atoms are such that the corresponding photons have energies in the Visible and Ultraviolet regions of the spectrum.

As an atom that has been electronically excited into a higher energy state relaxes, a photon whose Energy matches the difference in state energies can be emitted by the atom when the atom transitions back into its lower energy state. These energy states, because they are separated by a discrete energy difference (ΔE), are referred to as the atom's allowed quantum states.



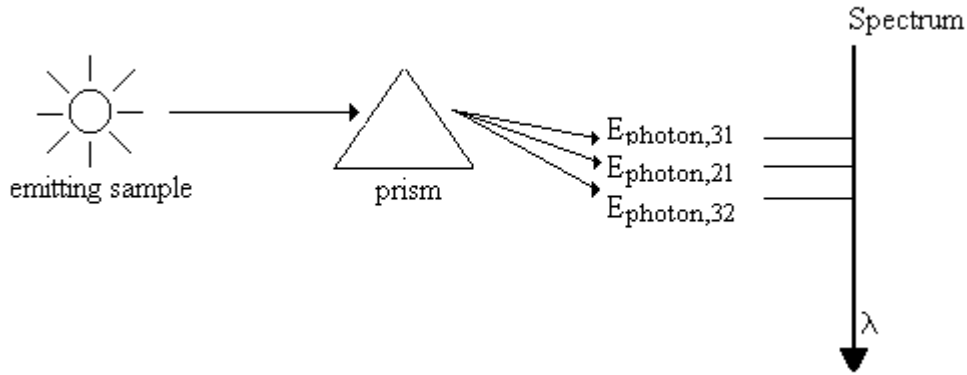
This will appear as distinctly colored light emitted from the excited sample. In these cases, the Energy difference between the participating quantum states is related to the Energy of the photons via:

$$\Delta E = E_{\text{photon}} = hc / \lambda \quad (\text{Eq. 3})$$

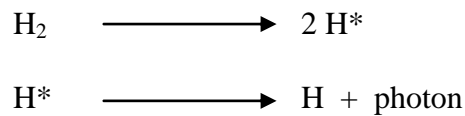
Thus, the photons emitted by a sample of the atom in question are a direct probe of the energy difference between quantum states of that atom.

Visually we see these photons as a characteristic color emitted by the sample. For instance, excited Sodium (Na) atoms emit yellow photons and the sample will appear to glow with a yellow color. The photons emitted by a collection of excited atoms of a given element can be separated by passing the emitted light through a dispersing element, such as a prism or

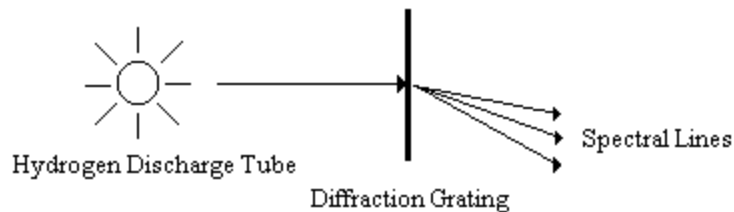
diffraction grating, to produce a series of spectral lines; each line corresponding to photons of a given wavelength.



In this lab we will observe the photons emitted by excited Hydrogen atoms. In this case we will excite the atoms by placing gaseous Hydrogen (H_2) into a discharge tube and applying a high voltage to the sample. In the resulting electric field, the H_2 molecules dissociate and leave the resulting H atoms in an excited state (H^*).



These excited atoms will subsequently relax, giving off photons corresponding to the energy differences between associated quantum states. We will examine the resulting glow by passing this light through a prism to disperse the photons according to their wavelength.



We will view the resulting spectral lines thru a spectroscope that includes a slit for focusing the light from the discharge tube, a prism and a rotatable viewer to find the spectral lines.



Then we will determine the energies of the photons associated with each spectral line produced.

Procedure

1. Go to the darkened room where your instructor has set-up the Hydrogen Discharge Tube.
2. Turn on the power supply and observe the emitted light through a spectroscope. You should see a series of sharp, bright spectral lines. Consult with your instructor to confirm you are indeed seeing the correct lines.
3. Record your observations.
4. View the Helium spectrum through a spectroscope. Record your observations.

Data Analysis

1. Examine the complete emission spectrum for Hydrogen provided in the Appendix. Determine the wavelengths of the emission lines you observed. These visible spectral lines were characterized by Johann Balmer in 1885 and are referred to as Balmer Lines. Calculate the photon energies for each spectral line you observed.

<u>Color</u>	<u>Wavelength [nm]</u>	<u>Energy [J]</u>
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

2. Do the same calculation for the first three spectral lines which occur in the Ultraviolet region of the Hydrogen emission spectrum; the so-called Lyman Lines.

<u>Line</u>	<u>Wavelength [nm]</u>	<u>Energy [J]</u>
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Post Lab Questions

1. An FM station broadcasts at 93.5 MHz.

a) What is the frequency of this electromagnetic wave in sec^{-1} ?

Answer: _____

b) What is the wavelength of the radiation in meters?

Answer: _____

c) What is the energy of one photon of this radiation?

Answer: _____

2. Ozone molecules in the upper atmosphere can absorb radiation of wavelength of $\sim 210 \text{ nm}$.

a) What is the wavelength of this radiation in meters?

Answer: _____

b) To what spectral region does this radiation belong?

Answer: _____

c) What is the energy of a photon of this radiation?

Answer: _____

Appendix - Complete Emission Spectrum of Hydrogen

