

Energy Diagrams and Spectra

I. Classical Model of the Hydrogen Atom

1. Consider the classical model of a Hydrogen atom - an electron in circular motion around a proton at a radius r with velocity v . What is the frequency of the electron's orbit? Explain.

2. We can model the electron orbiting around the proton as a dipole rotating. (A dipole has a positive charge at one end and a negative charge at the other end.)

How does the frequency of the dipole's rotation compare to the frequency of the electron's orbit? Make a sketch to justify your reasoning.

An oscillating dipole radiates light. What frequency of light will the dipole radiate? (Hint: think of this backwards – what frequency of light do you need to shine on the dipole to get it to oscillate with the correct frequency?) Explain.

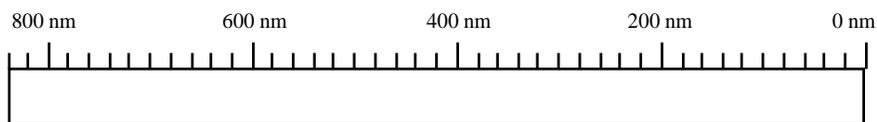
When the electron radiates light will the total energy of the electron *increase, decrease, or stay the same*? Explain.

Will the radius of the electron's circular motion *increase, decrease, or stay the same*? What will happen to the electron? Explain.

3. If a typical atom initially has a radius of 0.5×10^{-10} m and the speed of the electron in a circular orbit at that radius is 2.3×10^6 m/s what frequency of light does the electron emit as it orbits around the atom?

Spectroscopy

A large collection of non-interacting hydrogen atoms emits light that can be measured and described by a spectrum. Based on your calculations and the model of an oscillating dipole, sketch the spectrum of the hydrogen atom in the space below. Explain how you arrived at your answer.



Is the result of this model consistent with what we observe in nature? Give specific examples of any consistencies or inconsistencies.

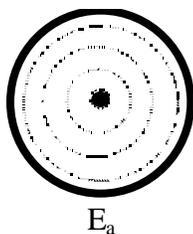
Summarize two reasons why the classical model cannot describe the atom.

II. Quantum Model for Energy Levels in an Atom

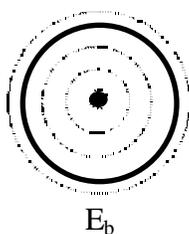
Since the classical model of the electron's trajectory leads to predictions contradictory to experimental observations, we will consider the energy of the electron-proton system instead.

Analyzing a simple model of energy states

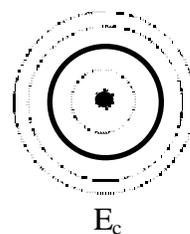
Let us model the various energy states of the emitter using the pictures shown below, where $E_a > E_b > E_c$. We will call this an “energy diagram” model.



E_a



E_b



E_c

1. In what ways could the energy diagram model be misleading? Explain, using the results from section I.

Spectroscopy

In what ways is the energy diagram model useful? Explain.

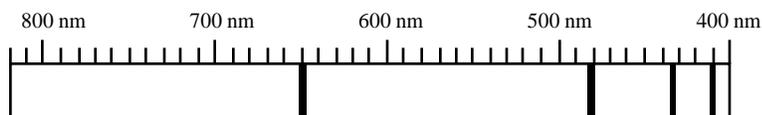
- Experiments have shown that when white light is shown onto hydrogen gas, photons with a wavelength of 656 nm are absorbed. What happens to atoms in the process? Explain.

Using the diagrams on the previous page, fill in the 'reaction' that occurs when a photon is emitted. Explain how you arrived at your answer.



Using multiple representations to describe the emission of photons

- Consider a gas of many non-interacting hydrogen atoms. A current flows through the gas, so that it emits a spectrum, part of which is shown below.

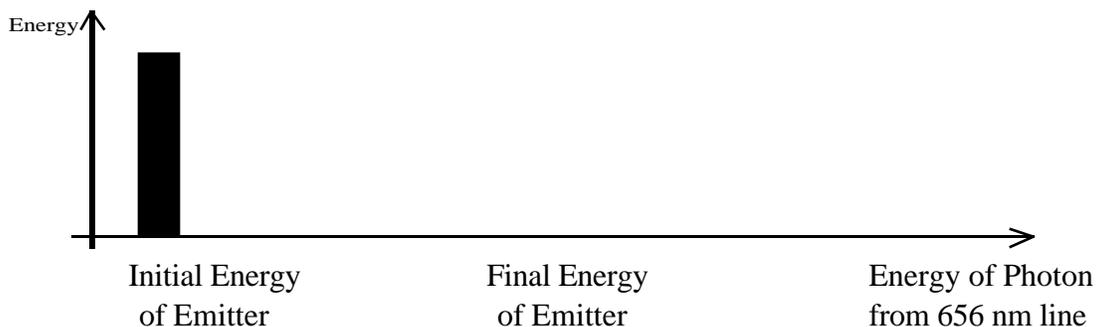


What is the energy of a photon that contributes to the 656 nm line?

How can you account for the creation of a photon with this energy? Explain.

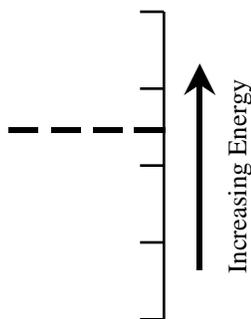
Spectroscopy

2. Below is a histogram representing the initial energy of the emitter. Draw the energy of the emitter after the photon is emitted and the energy of the photon. Explain your reasoning.



Using typical mathematical symbols (+, -, =, etc.) show the relationships between the above pictures. Explain.

3. Instead of a histogram, we can represent the energy of the emitter as a level, as shown below. To the right, draw its energy after the photon is emitted.



Initial



Final

Which of these energy states is associated with the 656 nm spectral line? If neither, state so explicitly. Explain.

Combine the initial and final diagrams into one showing the energy level before, after, and an arrow specifying the transition from before to after.

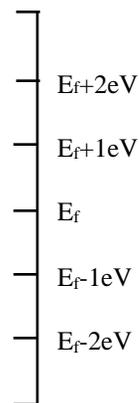


Spectroscopy

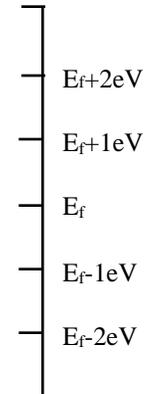
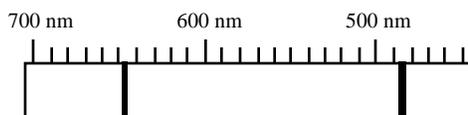
4. How, if at all, do laboratory observations indicate the initial energy of the emitter? How, if at all, is the initial energy equal to the energy of the photon that is emitted?

Comparing photon spectra and atomic energy levels

1. Consider the 486 nm photon emission line.
 Assume the emitter has an energy of E_f after the photon contributing to this line is emitted.
 Draw the energy level diagram which is associated with this spectral line. Explain.



Suppose the laboratory experiment was set up so that the observed spectrum was as shown below.
 Draw the energy level diagram that would produce such a spectrum, assuming E_f is the same for both spectral lines (assume this has been shown by other experiments). Explain.



2. The range of measured photon wavelengths is changed, so that wavelengths from 0 nm to 2000 nm can be seen. Do you expect to see any more spectral lines? If so, what will their wavelengths be? Explain.