

# Emission of Light & Atomic Models<sup>1</sup>

## Objective

At the end of this activity you should be able to:

- Explain what photons are, and be able to calculate their energies given either their frequency or wavelength.
- Order the common kinds of radiation (UV, visible light, infrared) in the electromagnetic spectrum according to their wavelengths or energy.
- Calculate the wavelength of electromagnetic radiation given its frequency or its frequency given its wavelength.
- Be able to compare and contrast different models for the hydrogen atom.
- Distinguish between conceptual and physical models.
- Discuss how the emission spectrum of hydrogen gas was used to support (or refute) a given atomic model.
- Explain how electronic transitions between quantized energy-levels are responsible for the emission of photons of light with different energies.
- Collect emission data and apply atomic models to explain the electronic structure of elements like hydrogen and helium.

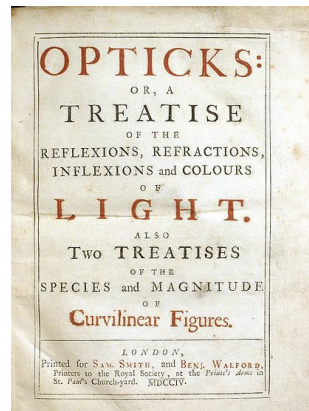
**These learning objectives are assessed in the post-lab Carmen quiz.  
There is no laboratory report.**

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## Introduction

When light from the Sun or white light is passed through a prism it produces a “rainbow” of different colors. This has been known for centuries, with Isaac Newton making significant advances in the area of “Opticks” in the 1700’s by investigating how light is reflected, refracted, dispersed, etc.

However, something very different occurs when light from a single element is emitted and passed through a prism. In this case only a small number of discrete lines are observed. Even more remarkably, the pattern of these lines is a defining characteristic of each element. What happens when light is emitted from an element like hydrogen? As you will see in this investigation, the answering of this question has led to profound insights into the electronic structure of the atom and, in turn, our modern understanding of chemistry.



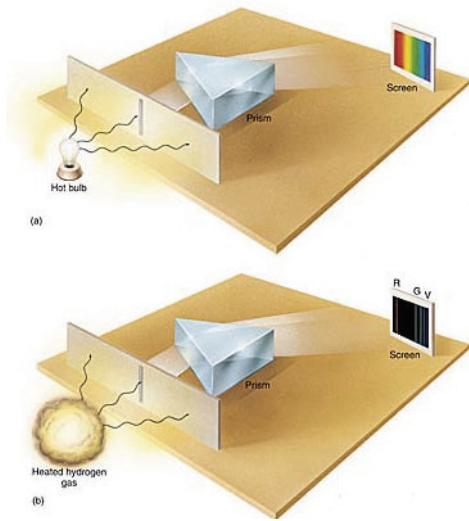
The emission of photons (particles of light) from atoms is thought to occur in the following way: First, the atom absorbs energy and an electron moves to a higher energy level, or “excited state”. When the electron eventually returns to a lower energy state energy is released. The specific amount of energy released corresponds to the difference between the energy levels. When this energy difference corresponds to visible light then our eyes can observe the photons. It is also possible the emitted photons will have energies we cannot see, such as in the infrared or ultraviolet regions of the electromagnetic spectrum.

Atoms can absorb energy in various forms (**heat, electrical, radiant**) and subsequently emit photons. Today, in this investigation, you will complete activities that involve radiant energy (photons of light). In another laboratory experiment, later this term, you will return to this topic and investigate the role of heat and electrical excitations. In each case the emission of photons is similar, although different energy levels and different elements may be investigated.

| <u>Activity</u>   | <u>Comment</u>    | <u>Estimated time</u>                                  |
|---|-------------------|--|
| 1) Computer Simulation: Models of the hydrogen atom.  | Worksheet.        | About 80 minutes.                                      |
| 2) Emission spectra of hydrogen and helium recorded with a discharge lamp and spectroscope. | Completed in lab. | Data collection 10 minutes. Data analysis ~30 minutes. |

**Total lab time~2 hours**

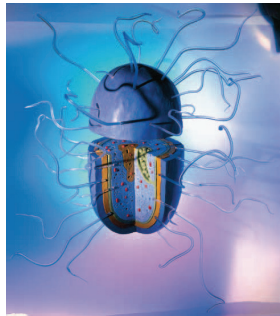
**All in-lab activities may be discussed with classmates and/or completed in a small group.** The teaching assistant will help manage your time.



## Laboratory Instrumentation

The instrument used to view line spectra is a **spectroscope**. Photons emitted from the atoms in their excited states strike the prism that separates them based on their particular wavelength. The resulting spectrum is superimposed on a scaled and is viewed through the eyepiece. Note, only the visible light portion of the spectrum is observed since the detector is the human eye.

## Scientific Models



**Physical model of a bacterium.**



**Conceptual model of the "weather".**

What is a **scientific model**? Sometimes scientists construct **physical models** that represent an object on a different scale. Models of an amoeba or bacterium (things very small made larger) or the solar system (something very large made smaller) are examples of physical models.

Scientists also devise **conceptual models**. A weather map is an example of a conceptual model. The weather map communicates some aspects of the weather, e.g. the temperature, areas of high and low pressure, precipitation, etc. It allows one to make predictions (will it rain in Columbus tomorrow?) and makes sense of a complex system. It is not, however, a physical representation.

**Atomic models are conceptual.** They aim to communicate different characteristics and make predictions for something that cannot be directly observed.

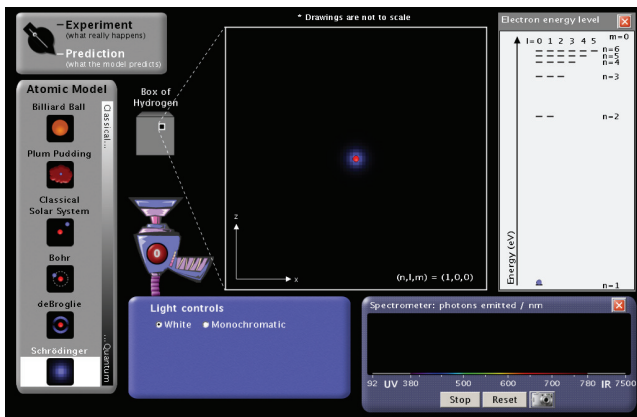
# Procedure

## Part 1) Computer Simulation – Models of the Hydrogen Atom

One of the most tantalizing puzzles at the beginning of the 1900s was how to describe the atom. In chapter 2 you learned about sub-atomic particles like protons, neutrons and electrons. With this activity you will continue your own exploration.

This begins by first observing a simulated light spectrum of hydrogen. You will then look at spectra predicted by different **models** of the atom. The models you will test include:

- John Dalton's *Billiard Ball* model
- J.J. Thomson's *Plum Pudding* model
- Ernest Rutherford's *Classical Solar System* model
- Niels Bohr's *Shell* model
- Louis deBroglie's *Electron Wave* model
- Erwin Schrodinger's *Quantum Mechanical* model



Models of the Hydrogen Atom Simulation

### Procedure and Questions

1. Start the **Models of the Hydrogen Atom** simulation.
2. Turn on the *White* light gun. **The white light is shining into a transparent box containing hydrogen gas. This is the ?-box. The gas molecules have been separated so hydrogen atoms are present, but the scientists cannot see these individual atoms (hence the "?"). It is possible, however, to send light into the box and record the light that is emitted from the box.**
3. To record the photons of light emitted from the transparent box check the **Show Spectrometer** box. Notice that the color of the photons being emitted from the box corresponds to a wavelength of UV, visible, or IR radiation.
4. In the **Light Controls**, click on *Monochromatic*. Notice that the incoming photons are now all the same color. A spectrum slider appears that allows you to change the energy of the incoming photons. Move the slider across the spectrum from ultraviolet (UV) down to the infrared (IR). Notice how the color of the lamp and the photons moving up the screen change.

Common calculations involve converting between energy, frequency, and wavelength. The following are useful expressions:

**E=hν** Planck's relationship for the energy of a photon where  $h = 6.63 \times 10^{-34}$  J s.

**c=λν** The speed of a wave is equal to the product of the wavelength x frequency,

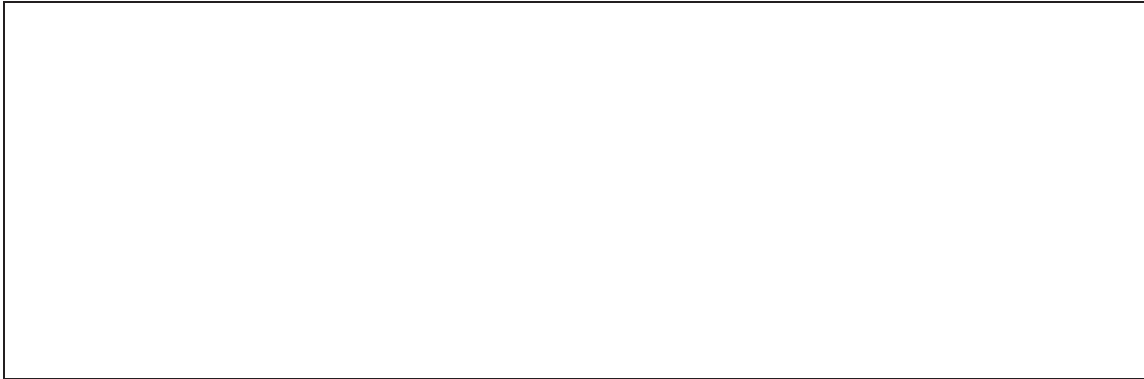
1 nm =  $1 \times 10^{-9}$  m

The speed of light  $c = 3.00 \times 10^8$  m/s in a vacuum.

|  |  |
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| If a photon of monochromatic light has a wavelength of 94 nm, what is its frequency (expressed in units of $s^{-1}$ )? |  |
| What is the energy of this photon (in joules)?   |  |
| What is the energy of 1 mol of these photons (in kJ/mol)?  |  |

5. Switch the **Light Controls** back to *White* light
6. Move the *Slow...Fast* slider all the way over to *Slow*
7. Watch the photons carefully. Most of the light gun photons pass through the box of hydrogen unaffected. Occasionally something happens in the ?-box and a photon is emitted. This emission is recorded by the spectrometer.
8. Move the *Slow...Fast* slider all the way over to *Fast*, **Reset** the **Spectrometer**, and let the simulation run until the red column is near the top (it will take a couple of minutes). Then, use the Spectrometer camera to take a snapshot of the **Experiment**. This is the experimental emission spectrum for atomic hydrogen. (If you are working with a partner, have one computer collect the spectrum and work ahead on the second computer).

9. Describe or sketch (in the box below) the experimental emission spectrum for atomic hydrogen. Include in your description the *colors (regions of the electromagnetic spectrum)*, estimated *wavelengths*, and *relative numbers* of stacked colored balls. These colored balls correspond to photons emitted by the ?-box.



The emission spectrum for hydrogen is a very important experimental observation used to support (or refute) different models of the hydrogen atom. Scientists **cannot** “look” inside the ?-box of hydrogen and actually see an atom. Instead, they construct theories and conceptual models to explain observations related to the atom. Models can be tested with experiments to learn if the model is useful for predicting how nature behaves.

**YOUR TASK in this simulation is to examine different models of the hydrogen atom. You will 1) examine the model, 2) see how the model produces an emission spectrum for hydrogen, and 3) decide which model agrees best with the experimental data.** It will be helpful to keep the experimental spectrum (the snapshot) available for comparisons.

## Dalton's Billiard Ball Model

10. In Chapter 2 you learned that John Dalton proposed that an atom was simply a very tiny hard ball. To see this simulated, in the top left corner, switch from **Experiment** to **Predict** and highlight the **Billiard Ball** model.

|  |  |
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| Use words or a drawing to describe this model of the hydrogen atom. What is the atom like? |  |
| What happens when photons interact with the atom in this model?                            | A) The photons are absorbed by the atom.<br>B) The photons are absorbed, and then other photons are emitted.<br>C) The photons divide into smaller photons.<br>D) The photons deflect off of the atom. |
| For this model is there an emission spectrum?  |  |

Why do you think the Dalton model does **not** include electrons?

(Circle all correct answers)

- A) Dalton thought electrons were unimportant.
- B) Dalton placed electrons in the nucleus.
- C) The smallest particle in Dalton's model is the atom, which is indivisible. It does not include sub-atomic particles like electrons.
- D) Electrons were discovered by J.J. Thomson 50 years after Dalton's death.



## Thomson's Plum Pudding Model

|   |   |
|---|---|
| Use words or a drawing to describe this model of the hydrogen atom. What is the atom like?  |   |
| What happens when photons interact with the atom in this model?   | (Circle all correct answers)<br>A. The photon bounces off of the atom.<br>B. The electron changes position when struck by the photon.<br>C. A photon is absorbed and a different photon is emitted.<br>D. The positive-charged proton "glue" interacts with the photon.<br>E. All emitted photons have the same energy. |
| Describe the resulting emission spectrum. Is it "right"?<br><br>(You should let the simulation run for ~1 minute with white light, then take a snapshot & save it). |   |

## Rutherford's Classical Solar System Model

11. Now click on and select next model, Rutherford's **Classical Solar System** model. This is the final atomic model you discussed in chapter 2.

|  |   |
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| Describe this model of the hydrogen atom. What is the atom like? | (Circle all correct answers)<br>A. There is a nucleus containing a proton.<br>B. There is an electron circling the nucleus, like a planet around the Sun.<br>C. The electron looks like a wave. |
|--|---|

The Classical Solar System Model has a **significant shortcoming**. You may need to run the simulation at a slow speed, or pause it, to find it. What is the shortcoming of the solar system model?

- A) Too many are photons emitted in the visible region of the emission spectrum.
- B) Too many photons are emitted in the UV region.
- C) The atom is not stable. The electron loses energy, spirals into the nucleus and the atom is destroyed. In this model atoms should not exist.



12. Switch to the **Bohr** model, click on **Show electron energy level** in the upper right hand corner, and set the speed to *Slow*.

*NOTE: The following questions are critical to you understanding the Bohr model. Take your time, discuss them with classmates, and ask questions!*

### Bohr's Model

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| Describe this model of the hydrogen atom. What is the atom like?   | (Circle all correct answers)<br>A) There is a nucleus where the proton resides.<br>B) There is an electron in motion in a circular orbit.<br>C) There are several possible orbits the electron may follow.<br>D) All of the above. |
| What happens when photons interact with the atom? Does the electron move?  |  |
| Describe the resulting emission spectrum. Is it "right"?<br><br><b>(You should let the simulation run for ~5 minutes on fast to compare with the experimental spectrum, then take a snapshot &amp; save it).</b> |  |

*In the **Bohr** model, electrons can exist only at certain energy levels (also called shells), not at any energy levels between them. Shells in this energy diagram go from 1 to 6. An increase in energy level (say from 1 → 6) can only occur if a photon of incoming light is absorbed. A decrease in energy level (say from 2 → 1) is accompanied by the emission of a photon as the excited electron releases its excess energy.*

13. In the **Help** menu, select **Transition**, then fill in the missing entries:

| Transition between n levels | Wavelength (nm) | UV, visible, or IR?<br>(Look at the spectrometer) |
|-----------------------------|-----------------|---|
| 1 $\leftrightarrow$ 2       | 122             | UV  |
|                             |                 |   |
| 1 $\leftrightarrow$ 4       | 97              | UV  |
|                             |                 |   |
| 2 $\leftrightarrow$ 3       | 655             | Visible   |
|                             |                 |   |
| 2 $\leftrightarrow$ 6       | 410             | Visible   |
| 3 $\leftrightarrow$ 4       | 1876            | IR  |
|                             |                 |   |
| 3 $\leftrightarrow$ 6       | 1094            |   |
|                             |                 |   |
| 4 $\leftrightarrow$ 6       |                 | IR  |
| 5 $\leftrightarrow$ 6       |                 | IR  |

14. Click on **Show electron energy level diagram**. Sketch the electron energy levels, paying attention to the spacing of the energy levels. Include the n-value for each energy level. The “n” is the **principal quantum number**.

15. Set the **Light Controls** to **Monochromatic**.

16. Set the monochromatic light source to 122 nm by clicking on the slider box and type in "122." This provides photons of just the right energy to raise (excite) the electron from  $n=1$  to  $n=2$  shell ( $1 \rightarrow 2$  transition).

What happens to the electron in the atom?

What happens to the energy level diagram?

What happens to the spectrometer? (You may need to reset the spectrometer).

17. Repeat this analysis with the light source set to 103 nm. This provides photons of just the right energy to raise (excite) the electron from  $n=1$  to  $n=3$  shell ( $1 \rightarrow 3$  transition). What do you observe?

18. Just to make sure you understand this model, set the light source to 97 nm. This provides photons of just the right energy to raise (excite) the electron from  $n=1$  to  $n=4$  shell ( $1 \rightarrow 4$  transition). Can you make sense of the atom diagram, the energy level diagram, and the spectrometer?

19. Set the light source to 656 nm. This corresponds to a transition from  $2 \rightarrow 3$ . What happens? Why?

*Louis de Broglie was the first atomic theorist to incorporate the ideas of Planck and Einstein that electrons can exhibit properties of both waves & particles. The de Broglie hypothesis is that any moving particle or object has an associated wave character. He created a new field in physics called wave mechanics, uniting the physics of light and matter. For this he won the Nobel Prize in Physics in 1929. Among the applications of this work has been the development of electron microscopes.*

20. Set the **Light Controls** back to **White**. Switch to the **de Broglie** Electron Wave model. Investigate the model. Be able to discuss what is the **same and different** for the de Broglie and Bohr models of the hydrogen atom.

### The de Broglie Model

|  |   |
|--|---|
| <p>Describe this model of the hydrogen atom. What is the atom like? How does it include waves?</p> <p><b>(NOTE: there is a pull-down menu to change from the radial view)</b></p>                                  | <p>(Circle all correct answers)</p> <ul style="list-style-type: none"> <li>A. The proton (in the nucleus) is in the center of the atom.</li> <li>B. The electron is a particle.</li> <li>C. The electron is a wave.</li> <li>D. The electron is in motion.</li> </ul> |
| <p>What happens when photons interact with the atom?</p> <p>Compare the energy-level diagram with that of the Bohr model.</p>  |   |
| <p>Describe the resulting emission spectrum. Is it "right"?</p> <p><b>(You should let the simulation run for a few minutes to compare with the experimental spectrum, then take a snapshot &amp; save it).</b></p> |   |

*Erwin Schrödinger began working on wave mechanics in 1925. His interest was sparked by a footnote in a paper by Albert Einstein. Like de Broglie, he began to think about explaining the movement of an electron in an atom as a wave. In 1926 he published his work, providing a theoretical basis for the atomic model that Bohr had proposed. The equation at the heart of his publication became known as Schrödinger's wave equation.*

### The Schrödinger Model

|  |  |
|--|--|
| Describe this model of the hydrogen atom. What is the atom like?   | (Circle all correct answers)<br>A. There is a nucleus.<br>B. The electron is a particle in a well-defined orbit.<br>C. The position of the electron is represented in an ambiguous manner. Different areas are shaded. |
| What happens when photons interact with the atom?  |  |
| Are the energy levels different when compared with the Bohr model?   | <p style="text-align: center;">Sketch the energy levels</p> <p style="text-align: center;"><b>Bohr model</b>                  <b>Schrödinger Model</b></p>   |
| Describe the resulting emission spectrum. Is it "right"?<br><br><b>(Let the simulation run for a few minutes to compare with the experimental spectrum, then take a snapshot).</b> |  |

**WHICH ATOMIC MODEL BEST AGREES WITH THE EXPERIMENTAL EMISSION SPECTRUM FOR ATOMIC HYDROGEN?**