
FOR THE TEACHER

Summary
This activity is designed for students to build a scientific argument about the relationship between energy and spectral lines by exploring how light interacts with atoms. In the process, students will examine proposed models of the hydrogen atom and use collected data to analyze the proposed models. They will then select one of the models and write a scientific argument to support their choice. Students will then review additional data to support and/or refute their selection. Based on their analysis, students will revise their selected model and construct a new argument to support their revisions.

Grade Level
High School

NGSS Alignment
This activity will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS4-4**: Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- **HS-PS4-5**: Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- **HS-ESS1-2**: Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.
- **Science & Engineering Practices**
  - Developing and using models
  - Analyzing and interpreting data
  - Constructing explanations (for science) and designing solutions (for engineering)
  - Engaging in argument from evidence
  - Obtaining, evaluating, and communicating information
- **Crosscutting Concepts**
  - Patterns
  - Cause and effect: Mechanism and explanation.

AP Chemistry Curriculum Framework
This lesson plan supports the following units, topic(s) and learning objectives:

- **Unit 1: Atomic Structure and Properties**
  - **Topic 1.5**: Atomic Structure and Electron Configuration
    - **SAP-1.A**: Represent the electron configuration of an element or ions of an element using the Aufbau principle.
- **Unit 3: Intermolecular Forces and Properties**
  - **Topic 3.11**: Spectroscopy and the Electromagnetic Spectrum
    - **SAP-8.A**: Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.
Topic 3.12: Photoelectric Effect

- SAP-8.B: Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

Common Core State Standards

- RST.11-12.7: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
- RST.11-12.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Objectives

By the end of this lesson, students should be able to

- Analyze data from the emission spectra of a hydrogen atom to refine their model of electrons within the atom.
- Analyze student models of electrons within the atom to create and revise a scientific argument of the location of electrons within the atom.

Chemistry Topics

This lesson supports students’ understanding of

- Energy
- Atomic Emission Spectrum
- Atomic Structure
- Spectroscopy
- Argumentation
- Model Based Reasoning
- Inferences

Time

Teacher Preparation: 20-30 minutes
Lesson: 100 minutes

Materials

- Hydrogen discharge tube
- Power source
- Diffraction gratings or spectroscopes
- Colored pencils

Safety

- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup and disposal of materials.

Teacher Notes

- Background Information for Teachers: Since Democritus described the first idea of “atoms” in Ancient Greece, scientists have been investigating the underlying structure of the atom. This task is particularly challenging due to the incredibly small size of atoms and subatomic particles. Since direct observations cannot be made, scientists must make inferences about the properties and structure of the atom based upon observations of energy. Thomson, for example, used his observations of his famous cathode ray experiments to make the connection that the negative charge of the cathode ray was caused by the negatively charged electrons within the atom. The next step of
the puzzle was found through Rutherford’s alpha radiation experiments. His results indicated the electrons were found on the outside of the atom, contradicting the previous “plum-pudding model.” At this point, Niels Bohr used his observations of atomic light emissions to further revise atomic models.

In his experiments, Bohr knew that light acts both as a wave and a particle. When observations are made of continuous light spectra, like natural sunlight or incandescent light bulbs, scientists can see every wavelength of visible light. Discontinuous spectra contain only spectral lines of specific wavelengths. Such spectra are produced by elements when sufficient energy is added. Each element releases a characteristic spectrum; these spectral lines observed from an elements emitting light is called an emission spectrum. Since these spectra are unique to each element, scientists can use the observed spectral lines to identify an unknown sample, even to identify the elemental composition of distant stars. Bohr applied his knowledge of spectral lines to establish his model of the atom. When Bohr analyzed the hydrogen atom, which contains only a single electron, he observed only four spectral lines of visible light. Since each color is determined by a specific wavelength of light, he calculated the exact energies being emitted by the hydrogen atom. Bohr then inferred that the electrons surrounding the nucleus within an atom can only be in specific energy levels. Since only four specific colors are visible with hydrogen, instead of random colors or the entire visible light spectrum, Bohr argued there must be some underlying structure which determines the colors emitted. In his model, the electrons were held at these energy levels due to the electrostatic attraction between the positively charged nucleus and the negatively charged electrons. If sufficient energy is added to the atom, the electrons can absorb the additional energy. This extra energy allows the electron to overcome the attractive electrostatic force of the nucleus and move further away to a higher energy level. At these higher energy levels, electrons are said to be “excited.” This arrangement is only temporary, however, and the electron eventually falls back to a lower energy level. Which level it falls to determines which type of electromagnetic radiation is released. When electrons release radiation of high levels of energy, it is considered ultraviolet radiation which is not visible by the human eye. Likewise small emissions of energy release infrared radiation which has too little energy to be seen by the human eye. Only when electrons fall between particular energy levels can visible light be released.

Bohr’s model was the first to place electrons in specific places outside the nucleus. Additional research has further revised his model. Instead of electrons moving around specific “orbits” around the nucleus, subsequent research implies the electrons are found within particular regions around the nucleus in which electrons have a high probability of being found.

**Student Prerequisite Information:**

- Parts of the atom (proton, electrons, neutrons) and their properties.
- Properties of a wave: wavelength, amplitude, crest, trough (students should already have an understanding of the inverse relationship between wavelength and frequency).
- Conservation of energy.
- Experimental design and control of variables.
- A basic understanding of direct and inverse relationships (although the terminology is not necessary).
- Light behaves like a particle and a wave.
- Historical models of the atom: billiard model, plum pudding model, and planetary model.
- Experience using and revising scientific models.
**FOR THE STUDENT**

Lesson

**Energy and the Electron: Atomic View and Argumentation**

**Part I: Warm Up**

1. Consider the following questions individually:
   a. What do you know about the structure of the atom?
   b. Draw what you think an atom looks like. Label the different parts of the atom.
   c. What do you think happens to matter (atoms) when you add energy?

**Part 2: Exploration**

**Step 1:** Look at the lights in the room or an incandescent light bulb through the spectrophotometer or diffraction grating.

1. What do you notice about the incandescent light bulb as seen with the “naked eye,” and observations using the spectroscope or diffraction grating?
   a. Observations – eyes only:
   b. Observations – spectrophotometer/diffraction grating:

2. Using colored pencils, draw what you see from the incandescent light bulb through the spectroscope or diffraction grating.

**Step 2:** Your instructor will show a gas tube filled with hydrogen gas (hydrogen spectral tube) in a power source. The power source runs an electrical current through the tube at a high voltage. Make observations of the hydrogen gas with your eyes only and then through the spectrophotometer or diffraction grating.

3. What do you notice about the tube of hydrogen gas as seen with the “naked eye,” and observations using the spectrophotometer or diffraction grating?
   a. Observations – eyes only:
   b. Observations – spectrophotometer/diffraction grating:

4. Using colored pencils, draw what you see from the hydrogen gas through the spectrophotometer or diffraction grating:

5. Compare and contrast your observations of the incandescent light with your observations of the hydrogen spectral tube.

6. Which subatomic particle do you think is affected when energy is added to the atom? Explain.
7. What do you think happens to this subatomic particle when it absorbs energy?

8. What do you think happens to this subatomic particle when it releases energy? Where does this energy go?

9. Two students are discussing the following questions: What does the observation of specific colored lines (spectral lines) tell us about how the electrons are organized outside the nucleus? Examine the responses of the two students below.

<table>
<thead>
<tr>
<th>Steve</th>
<th>Rebecca</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think electrons can be found anywhere outside the nucleus. They are not limited to specific places. When energy is added, these electrons just move around wherever.</td>
<td>I think electrons can only be found in specific energy levels. When energy is added, electrons can move to higher energy levels.</td>
</tr>
</tbody>
</table>

a. What is the main difference between the ideas of these students?

b. If Steve were correct, what would we see when energy is added to the spectral tube?

c. If Rebecca were correct, what would we see when energy is added to the spectral tube?

d. Which explanation is best supported by your observations of the hydrogen spectral tube? Explain.
Step 3: Four students are asked to propose a detailed model to represent the different energy levels the electron in a hydrogen atom could take. Their responses are shown below:

<table>
<thead>
<tr>
<th>Student A’s Model</th>
<th>Student B’s Model</th>
<th>Student C’s Model</th>
<th>Student D’s Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram of Student A’s Model" /></td>
<td><img src="image2" alt="Diagram of Student B’s Model" /></td>
<td><img src="image3" alt="Diagram of Student C’s Model" /></td>
<td><img src="image4" alt="Diagram of Student D’s Model" /></td>
</tr>
</tbody>
</table>

I think there are two possible energy levels. The electron can jump up to level 2 and then fall back to level 1.

I think there are three possible energy levels. The electron can jump up to level 2 or 3, and then fall with the following possibilities:

L3 → L2
L3 → L1
L2 → L1

These energy levels are all equally spaced, so the light released will be equally spaced.

I think there are three possible energy levels. The electron can jump up to level 2 or level 3 and then fall with the following possibilities:

L3 → L2
L3 → L1
L2 → L1

Energy levels 1 and 2 are a little closer together, and level 3 is a little further from level 2, so two of the colors of released light will be low energy and close together, while one will be high energy.

I think there are three possible energy levels. The electron can jump up to level 2 or level 3 and then fall with the following possibilities:

L3 → L2
L3 → L1
L2 → L1

Energy levels 2 and 3 are very close together, and level 1 is significantly further from level 2, so two of the colors of light will be high energy and close together, while one will be low energy.
10. For each student model, predict how many emission lines you would expect to see and their relative locations. Draw these on the spectrometers below.

<table>
<thead>
<tr>
<th>Model</th>
<th>Prediction of emission lines that would appear in the Spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td><img src="image" alt="Spectrometer: photons emitted / nm" /></td>
</tr>
<tr>
<td></td>
<td>High energy ← Low energy</td>
</tr>
<tr>
<td>Student B</td>
<td><img src="image" alt="Spectrometer: photons emitted / nm" /></td>
</tr>
<tr>
<td></td>
<td>High energy ← Low energy</td>
</tr>
<tr>
<td>Student C</td>
<td><img src="image" alt="Spectrometer: photons emitted / nm" /></td>
</tr>
<tr>
<td></td>
<td>High energy ← Low energy</td>
</tr>
<tr>
<td>Student D</td>
<td><img src="image" alt="Spectrometer: photons emitted / nm" /></td>
</tr>
<tr>
<td></td>
<td>High energy ← Low energy</td>
</tr>
</tbody>
</table>
**Step 4:** Previously we added electrical energy to the hydrogen tube. However, in this simulation, the energy going into the hydrogen gas is light. Recall that the light energy is related to the wavelength. We will represent the amount of energy going in and released (emitted) in terms of its wavelength ($\lambda$).

Using the simulation, students are able to expose a sample of hydrogen gas to light energy of specific wavelengths. Four experiments are carried out with four different wavelengths ($\lambda$). For each incoming wavelength, the students measure the wavelength of the light emitted, or given off. Their results are given below:

<table>
<thead>
<tr>
<th>Experiment 1: Incoming $\lambda$: 174 nm Emission $\lambda$: No emission detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 2: Incoming $\lambda$: 122 nm Emission $\lambda$: One emission line at 122 nm</td>
</tr>
<tr>
<td>Experiment 3: Incoming $\lambda$: 110 nm Emission $\lambda$: No emission detected</td>
</tr>
<tr>
<td>Experiment 4: Incoming $\lambda$: 103 nm Emission $\lambda$: Three emission lines detected at 103 nm, 122 nm, &amp; 656 nm</td>
</tr>
</tbody>
</table>

11. Does incoming light energy of every wavelength ($\lambda$) result in light emissions? Explain.

12. Which student model does the experimental data support? Explain your reasoning.

13. Build an argument to support your choice.
   a. Claim
b. Evidence

c. Reasoning

Part 4: Experimentation
You will now work with your group to further explore the model of the hydrogen atom. Additional experiments using the same tube of hydrogen exposed to various wavelengths of light have been conducted and the results are provided for you. With your group, examine and discuss the results of each experiment. Use the data and information you collect to answer questions that follow. Complete the data in the table below. Results of the previous four experiments are already recorded.

<table>
<thead>
<tr>
<th>Incoming Wavelength (λ)</th>
<th>Observed Emission Wavelength (λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>94 nm</td>
<td></td>
</tr>
<tr>
<td>103 nm</td>
<td>Three emissions: 103 nm, 122 nm, &amp; 656 nm (Experiment 4)</td>
</tr>
<tr>
<td>108 nm</td>
<td></td>
</tr>
<tr>
<td>110 nm</td>
<td>No emission detected (Experiment 3)</td>
</tr>
<tr>
<td>115 nm</td>
<td></td>
</tr>
<tr>
<td>122 nm</td>
<td>One emission at 122 nm (Experiment 2)</td>
</tr>
<tr>
<td>174 nm</td>
<td>No emission detected (Experiment 1)</td>
</tr>
<tr>
<td>326 nm</td>
<td></td>
</tr>
<tr>
<td>white light</td>
<td></td>
</tr>
</tbody>
</table>

14. Do the new data imply more, less, or the same number of energy levels as those presented in the student models? Explain.

15. Do the new data support your selected model? Explain.

16. How would you revise your model to account for the new data? Draw a diagram of your revised model.
17. Build an argument to answer the question: *What happens to electrons when energy is added to atoms?* Be prepared to share this with the whole group.
   
a. Claim

b. Evidence

c. Reasoning

d. Model Revisions