UNIT 3

Atoms and Light

Exploring Atomic and Electronic Structure

Unit Overview

This unit covers the progression of the model of the atom from the discovery of the first subatomic particle to the development of quantum mechanics. After completing this unit, students will understand the major experiments that changed our understanding of the chemical world over the past few centuries. The major model of the atom was transformed from a simple billiard ball to a complex nuclear model with electrons existing as both particles and waves. Students will gain an understanding of how scientists modify existing theories based on newly available evidence.

Learning Objectives and Applicable Standards

Participants will be able to:

1. Compare and contrast the different models of the atom.
2. Describe the experiments of the major atomic theorists and the progression of the models of the atom over time.
3. Evaluate the evidence that allowed scientists to infer the internal structure of the atom.

Key Concepts and People

1. **J. J. Thomson and Robert Millikan:** Thomson discovered the electron with his cathode ray tube experiment. Later, Millikan determined the charge of the electron based on the results of his oil drop experiment.
2. **Ernest Rutherford:** Rutherford shot positively charged alpha particles at a piece of gold foil. He was able to infer the existence of the nucleus because some of the alpha particles were deflected by areas of dense positive charges within the foil. He then confirmed the existence of the proton, the particle that gives nuclei a positive charge. Later, one of Rutherford's students, James Chadwick conducted experiments in which he discovered the neutron.
3. **The Electromagnetic Spectrum:** The whole range of light, or electromagnetic radiation, is called the electromagnetic spectrum. The spectrum ranges from gamma rays

to radio waves with visible light being in the middle of the spectrum.

4. **Light From Elements:** Scientists burned elements in flames and used spectroscopes to study the emission spectra of various elements. Each element has its own "spectral signature" and they were able to discover new elements using spectroscopes.

5. **Niels Bohr:** Bohr explained the emission spectra for hydrogen. This data had existed for centuries, but no one was able to explain why hydrogen only emits certain wavelengths when excited. Bohr surmised that electrons exist at specific, quantized energy levels. His model is called the planetary model because it shows electrons orbiting the nucleus in set paths.

6. **Max Planck:** Max Planck proposed that light is emitted in discrete packets of energy called "photons." This idea revolutionized chemistry and physics and launched the field of quantum mechanics.

7. **Quantum Model:** Bohr's model of the atom only worked for hydrogen, but other elements also have unique spectra. The quantum theorists, including Werner Heisenberg, Louis de Broglie, and Erwin Schrödinger, amended Bohr's model based on the fact that an electron can exist as both a particle and a wave. We use the quantum model today, which describes the energy and location of electrons as electron clouds, or orbitals.

Video

In the early 20th century, identification of the internal parts of the atom (electrons, protons, and neutrons) led to a modern subatomic theory. Meanwhile, the study of atomic spectra – the light given off by atoms at definite wavelengths – led to the Bohr model of the atom, where electrons exist at distinct energy levels and move between these levels by absorbing and emitting discrete quanta of energy. The measurement of atomic spectra has applications in astrophysics as well as forensic chemistry.

VIDEO CONTENT

Host Science Explanation
"Making Light with Electrons"

Host Dr. Michael C. McCarthy, an astrochemist at the Harvard-Smithsonian Center for Astrophysics, studies the chemical composition of the universe. Here, he introduces the electromagnetic spectrum and explains that we can study matter by seeing how matter absorbs or emits light under different conditions.

Real World Application

Dr. Wayne Strattman is an artist who manipulates the properties of gases to make stunning visual effects. Each element has a unique color, and mixtures of different elements are used to create different color effects.

History of Chemistry
"Atomic Models"

This segment includes animations and demonstrations of key experiments and findings of atomic theorists. Harvard University Manager of Lecture Demonstration Services Dr. Wolfgang Rueckner demonstrates JJ Thomson's cathode ray tube experiment, his plum pudding model, and Rutherford's gold foil experiment. Niels Bohr's model of the atom, and the quantum mechanical model of the atom are also represented. Dr. Michael C. McCarthy also demonstrates that the nucleus of an atom would be the size of a golf ball if an atom were the size of a stadium.

Laboratory Demonstration
"The Flame Test"

Harvard University Lecture Demonstrator Daniel Rosenberg demonstrates that each element emits a distinct color of light when burned. The flame excites electrons up to a higher energy level, and photons of light are emitted when the electron falls back down to its original energy level. For example, lithium burns bright red and copper burns green.

Current Chemistry Research
"Observing Sunlight"

Dr. Kelly Korreck of the Harvard-Smithsonian Center for Astrophysics uses spectroscopy to study the chemical composition of the sun. She studies high-energy emissions from the sun and also builds instruments to take images of the sun from satellites. Her images can be analyzed for individual wavelengths in order to better understand solar events.

Laboratory Demonstration
"Emission Spectra"

Harvard University Lecture Demonstrator, Daniel Rosenberg uses a diffraction grating to visualize the different colors emitted by various metal salts when the salts are held in a flame. For example, the calcium flame appears orange, but the diffraction grating shows it is also emitting some green.

Real World Application
"Forensic Spectroscopy"

Dr. Megan Roppolo, an Application Scientist at Olympus NDT, demonstrates the use of a handheld X-ray Fluorescence Analyzer. She uses it to discover the chemical composition of a historical cannon at the U.S.S. Constitution Museum.

Unit Text

Content Overview

This text provides a roadmap for the changes in the models of the atom over time. Unit 2 ended with John Dalton's theory describing an atom as a billiard ball, and Unit 3 progresses through the subsequent models of the atom and the evidence used in their development. The text is organized by subatomic particle or structure rather than chronologically in order to emphasize the transition between the major models.

Sidebar Content

1. **Robert Millikan's Oil Drop Experiment:** Robert Millikan and his student, Harvey Fletcher, perfected the technique for measuring the mass of an electron by using tiny drops of oil in an electric field.

2. **Discovery of the Neutron Made the Atomic Bomb Possible:** This sidebar briefly discusses the role of the neutron in the development of the atomic bomb. An atomic bomb would not have been possible if scientists were not curious about the inner structure of the atom.

3. **Microwaves:** Every student has seen or used a microwave oven, and the sidebar explains how they work. The scientists covered in Unit 3 used different types of waves to elucidate the internal structure of the atom.

4. **Fraunhofer Lines:** Joseph von Fraunhofer used a spectroscope to study the spectrum of light emitted by stars.

5. **Werner Heisenberg and Niels Bohr**: Heisenberg and Bohr had a complex relationship during World War II. Being on opposite sides of the conflict ruined their previously close relationship.

Interactives

Historical Timeline of Chemistry

This interactive illustrates how different discoveries build upon, disprove, or reinforce previous theories. This not only reinforces basic chemistry concepts, but also emphasizes the nature of science. Scientists mentioned in this unit are listed on the timeline. Many of the scientists that contributed to the understanding of the atom are contemporaries so students should note how quickly the model of the atom changed in the late 19th and early 20th centuries.

During the Session

Before Facilitating this Unit

The main lessons in this unit include the progression of the model of the atom over time and how each scientist was able to draw conclusions from his data. Students should also understand that a model is based on data, but is not an exact representation. Models are edited or replaced as new technologies and data become available.

Tips and Suggestions

1. **The iconic picture of the atom with orbiting electrons is actually incorrect. Many students assume this representation is the most accurate.** After completing this unit, students should be able to clearly explain the correct internal structure of the atom.

2. **Chemistry is a progressive discipline that can change based on available technology.** Some of chemistry dates back to ancient times, but it remains a dynamic endeavor.

3. **Models are useful, but often are over-simplifications.**

Starting the Session: Checking Prior Thinking

You might assign students a short writing assignment based on the following questions, and then spend some time discussing prior thinking. This will help elicit prior thinking and misconceptions.

1. What is an atom?

2. Draw a picture of the atom.

3. Atomic theorists performed experiments and *inferred* the structure of the atom from their data. What does it mean to infer?

Before Watching the Video

Students should be given the following questions to consider while watching:

1. What is a scientific model?

2. Explain a few different models of the atom.

3. What types of evidence were used to show that the atom is divisible?

4. What are some ways scientists use the electromagnetic spectrum in their work?

Watch the Video

After Watching the Video
Use these additional questions as follow-up, either as a group discussion or as short writing assignments.

1. If you wanted to create a firework display of a green star, what element would you use? Why?

2. If an atom was the size of your classroom, about how big do you think the nucleus would be?

3. Why does Dr. Korreck use telescopes on satellites to take pictures of the sun?

4. What is a diffraction grating? What is it used for?

Group Learning Activities

Making an Atomic Theorist Manipulative

Objective
Students will make a foldable study guide and distill the most important information about the theorists and their experiments. This activity provides a teachable moment to help students focus on the most important information. For example, do you want students to memorize years or just focus on the general chronology? What are the major models of the atom and what do they look like?

List of Materials
- Paper
- Scissors
- Rulers
- Writing utensils
- Textbook or lecture notes on theorists

Set Up
Give each student a piece of paper, scissors, and a ruler. They need access to a textbook or notes on the theorists.

Procedure

1. Fold the paper in half lengthwise.

2. Using the ruler, draw lines to divide the folded flaps into strips. Make sure to have enough strips for all of the theorists.

3. Write the name of a theorist on top of the first strip. Write the important information about that theorist underneath the strip. Draw pictures where appropriate.

4. Repeat for each of the required theorists.

Discussion

These questions can help guide students thinking during and after the activity:

1. Why were the atomic theorists limited to gathering indirect evidence? Does this mean their conclusions are weak? Why or why not?

2. What are the major changes in the model of the atom over time?

3. Why did the model of the atom change over time?

4. Whose discovery do you think was the most important? Why?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

Creative Writing Assignment

Objective

Students will research the lives of the atomic theorists and will write a creative assignment from the point of view of a theorist. This lesson provides opportunities for the more creative types in your class. Possible formats include a letter, journal entry, comic strip, poem, page from the scientist's lab notebook, etc. The written product should show research into the theorist's life and discussion of how his model differed from the previous model. When introducing this assignment, you can use the play *Copenhagen* by Michael Frayn as an example. http://www.pbs.org/hollywoodpresents/copenhagen/index.html It is a fictionalization of a meeting between Heisenberg and Bohr that occurred during World War II. In 2002, PBS produced a film version of the play, starring Daniel Craig as Heisenberg. The introduction to the play in the PBS video is a great summary of the lives and times of the two scientists.

Models of the Hydrogen Atom Simulation

Objective

Using a PhET simulation, students will investigate the spectral evidence used to determine the current model of the atom. PhET, a project at the University of Colorado at Boulder, uses education research to design online STEM interactives. The programs are free to use.

List of Materials

- Computers with internet access
- Questions sheet (please see discussion section for a list of suggested questions)

Set Up

Hand out the question sheet to each group of students.

Procedure

1. Log on to the computer and go to the following website:
   http://phet.colorado.edu/en/simulation/hydrogen-atom

2. Use the simulation to answer the provided questions.

Discussion

Suggested questions to include on handout:

1. Why do the photons of white light have different colors?

2. What wavelengths of light are emitted by the atom?

3. After switching to the prediction mode, which models correctly predict the emission spectra of hydrogen? What do they all have in common? What are the differences?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

In-Class Chemical Demonstrations

Rutherford Scattering Simulation

Objective

Students will learn how to infer the shape of an object based on indirect evidence, and understand how Rutherford concluded that an atom has a nucleus. This activity involves rolling marbles at a mystery shape and using the path of the marbles to infer the shape.

List of Materials

- 10-12 marbles
- A piece of cardboard
- A 3-D shape (packing Styrofoam or wooden shapes work well)
- Analysis sheet

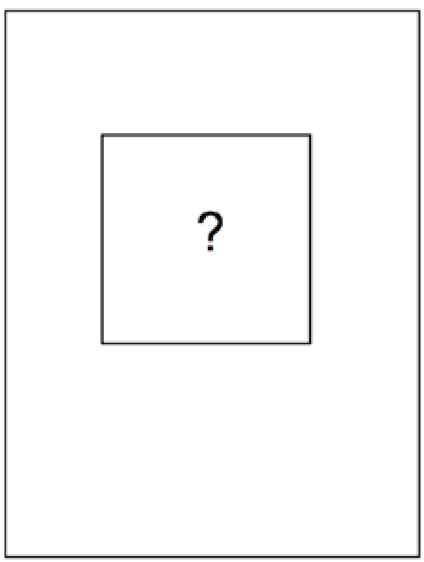
Set Up

1. Without students seeing the shape of the Styrofoam or piece of wood, place that object on the floor with a piece of cardboard on top to hide the shape.
2. Hand out data sheets to each student.

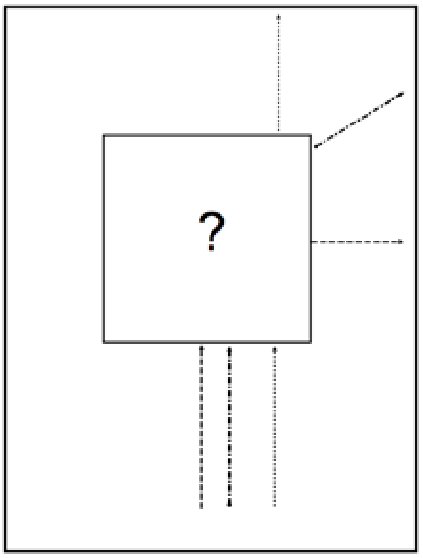
Procedure

1. Have students take turns rolling marbles toward the shape one at a time and record the approximate path of the marbles on their data sheet.
2. Once there have been enough rolls (usually about 30), have students work in small groups to determine the shape.
3. Reveal the actual shape to the class and discuss the results

The blank data sheet:



The data sheet with the first few rolls:



Discussion

These questions can help guide a student's thinking during this demonstration:

1. What do the marbles represent in this activity?
2. What does the mystery shape represent?
3. How close was your drawing to the actual mystery shape? Explain.
4. What evidence did you use in your drawing? Explain.
5. How does this activity mimic the experience of Rutherford during his gold foil experiment?
6. Explain the significance of the marbles that went straight through. What did this observation reveal to Rutherford in the actual experiment?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

Flame Test

Objective

The flame test is an easy demonstration to perform in order to visualize the differences between elements and the behavior of electrons. There is also a flame test in the video.

Materials

- 25 mL of 1 M sodium chloride solution
- 25 mL of 1 M barium chloride solution
- 25 mL of 1 M calcium chloride solution
- 25 mL of 1 M copper(I) or copper(II) chloride solution
- Wooden coffee stirrers
- Bunsen burner

Procedure

1. Soak the wooden coffee stirrers in the salt solutions for at least 10-15 minutes.

2. Place the soaked stirrers into the flame one at a time, and have students observe the results.

Discussion

Many students are exposed to the flame test during middle school, but have not discussed energy levels of electrons before chemistry class. While the splints are burning, explain to the students that they are actually seeing a combination of different wavelengths, and these wavelengths are the products of electrons changing energy levels within the atom.

Hazards

Barium chloride is toxic when ingested. Be careful with the flames.

Disposal

Check local regulations for proper disposal procedures for any leftover barium or copper salts.

Going Deeper (In-class Discussion or Reflection)

Instructors should allow up to 30 minutes for discussion at the end of the session, or students can use the time to reflect on one or more of these questions in journals.

1. What does it mean to "infer"? Why did atomic scientists have to use indirect data to draw conclusions about the structure of the atom?

2. How does the flame test relate to pigments used in clothing or art?

3. In science, what does "model" mean? Can you think of common models used in science?

Before the Next Unit

Learners should read the Unit 3 text if they haven't already done so. They may wish to read one or more of the reading assignments from the list below, or, if you choose to have them use the course materials outside of class, they can watch the Unit 4 video and/or read the Unit 4 text as an assignment before the next session.

References and Additional Resources

Frayn, Michael. *Copenhagen*. London: Methuen, 1998.

Garfield, Simon. *Mauve: How One Man Invented a Color and Changed the World* (London: Norton, 2002).

Godbole, Rohini. "An Experiment that Shaped the Physics of the Century." *Resonance*. 16:11 (2011): 1019-1028.

Nagendrappa, Gopalpur. "Ernest Rutherford: The Man Who Found Nucleus in the Atom." *Resonance*. (2011): 1007 – 1018. Accessed August 27, 2013. http://111.93.135.171/ResonanceNew/Volumes/16/11/1007-1018.pdf

Phet Interactive Simulations. "Rutherford Scattering," University of Colorado at Boulder. Accessed March 29, 2013. http://phet.colorado.edu/en/simulation/rutherford-scattering

Phet Interactive Simulations. "Models of the Hydrogen Atom," University of Colorado at Boulder. Accessed March 29, 2013. http://phet.colorado.edu/en/simulation/hydrogen-atom

Rhodes, Richard. *The Making of the Atomic Bomb*. New York: Simon and Schuster, 1986.

For Professional Development

In addition to watching the videos, reading the text, and going through the activities listed in the course guide, participants taking this course for professional development should read the following papers and answer the corresponding reflection questions. Participants should then complete the accompanying professional development assignments.

Further Reading & Reflection Questions

Viana, Helio Elael Bonini and Paulo Alves Porto. "The Development of Dalton's Atomic Theory as a Case Study in the History of Science: Reflections for Educators in Chemistry." *Science & Education*, 19 (2010): 75–90. Accessed July 7, 2013. http://www.iq.usp.br/palporto/VianaPortoSci%26Educ2010.pdf

1. Page 76 discusses the reasons for the shift to include the history of science in science education in Denmark. Do you agree with any of these reasons? If, so, which ones and

why? If not, why not?

2. Did you find the case study of the development of Dalton's theory helpful for your own understanding of chemistry, and science in general? If so, how? If not, why not?

3. Do you include the history of science in your curriculum? Why or why not?

4. Does this paper influence how you will approach teaching chemistry? If so, how? If not, why not? Has this paper convinced you that understanding the history of science is important to understanding scientific principles themselves? Why or why not?

Gilbert, John K., "The role of visual representations in the learning and teaching of science: An introduction." *AsiaPacific Forum on Science Learning and Teaching*, Volume 11, Issue 1, Forward, p.1. (Jun., 2010). Accessed October 24, 2014. http://www.ied.edu.hk/apfslt/download/v11_issue1_files/foreword.pdf

1. How do you currently use models to teach certain chemistry concepts? What are some of the challenges you face in using models to teach chemistry concepts? What are some of the challenges your students have had in learning about models?

2. Did this paper help clarify for you how models can be used to teach scientific concepts? If so, how? If not, why not? Was there anything in this paper that stood out for you? Explain.

3. Does this paper influence how you will use models in teaching chemistry? If so, how? If not, why not?

Professional Development Assignments

1. After reading the papers above and reflecting on the questions presented, develop a lesson plan designed to teach material presented in this unit.

2. Using a group activity or classroom demonstration presented in this course guide, show how you would implement it in your classroom. Where would it fit into your curriculum or standards? Would you change the demonstration or activity in any way? How would you assess student learning?