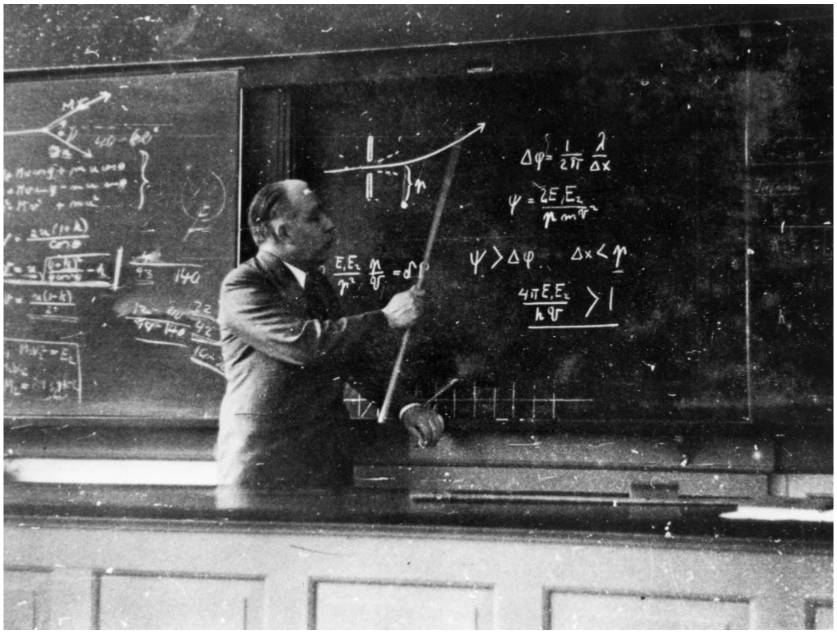
Lesson Plan

The Evolution of Atomic Theory



Niels Bohr, ca. 1947, lecturing on atomic energy levels. Courtesy AIP Emilio Segrè Visual Archives.

Grade Level(s): 9-12
Subjects: Chemistry, History, Physics
Supplements: Physics History, Atomic Theory, Quantum Theory
In-class Time: 45-55 minutes
Prep Time: 15-20 minutes

Materials

- Lesson Plan (this document)
- Whiteboard/blackboard and markers/chalk
- Supplemental Materials:

- Student Handouts (printed, one per student)
- Handout Answers document
- (Optional) Historical Research Activity instructional handout

Objective

This lesson plan covers major developments and changes in atomic theory, with a focus on the 1800s and 1900s. Students will make timelines, read real primary sources of the discoveries in atomic theory, and either learn how to model atoms or conduct research on underrepresented scientists who contributed to breakthrough discoveries in atomic theory.

Introduction

"It has often been demonstrated that we do not grasp how each thing is or is not."
– Democritus[1]

Pre-1850s:

Democritus (ca. 460 BC–ca. 390 BC)**:** one of the first atomists, a Greek philosopher who challenged the idea that objects are immutable, and are instead made up of smaller pieces: atoms.

John Dalton (1766–1844)**:** used meteorological knowledge to discern that different materials are made of different kinds of atoms with different weights and "complexities."

Michael Faraday (1791–1867): a physicist specializing in electricity, who postulated that atoms might have some involvement with electricity.

1850s–1900s:

Using equipment Faraday had developed, **J.J. Thomson** (1856–1940), made a big discovery. He used a cathode-ray tube, which is a nearly-empty vacuum tube with a radiation detector at one end and a beam emitter at the other that can be connected to electricity. The cathode ray shoots through the tube and impacts the radiation detector, showing where the ray ends up. It could be expected that the ray wouldn't experience any change in direction at all—after all, why should it? However, the ray is deflected by the particles within the tube and lights up the radiation detectors that are not directly across from the cathode ray emitter. The conclusion Thomson came to was that there were "cathode rays" in all atoms, and he was able to find the charge-to-mass ratio of an individual cathode ray. **George Stoney** (1826–1911) coined the term "electrons" (from the Greek *elektron* meaning amber) to replace the now-outdated term "cathode ray," because the experiment showed that individual electrons were particles, not a continuous beam. Thomson then developed the first model of the atom, which showed a solid spherical form with electrons scattered uniformly throughout. This model has come to be known as Thomson's plum pudding model.[2]

Robert Millikan (1868–1963) supposed that, because the electromagnetism is a force, and gravity is a force, he could set the two of them opposite to one another and find the charge of an electron based on Thomson's charge-to-mass ratio. He placed two oppositely-charged plates horizontal and parallel to one another, connected to a voltage source, and rigged a mister to spray individual droplets of oil in between the charged plates. Because like repels like, he knew that the negatively charged plate would repel the electrons in the oil droplet. From there, he

[1] "68: Dêmocritus of Abdêra." Translated by Kathleen Freeman, *Ancilla to the Pre-Socratic Philosophers*, p. 92.
[2] "Joseph John "J.J." Thomson." *Science History Institute*, 19 May 2023. https://sciencehistory.org/education/scientific-biographies/joseph-john-j-j-thomson/

would balance the electromagnetic force on the oil droplet by changing the voltage until the drop was perfectly balanced between the plates. From there, he measured the weight of the droplet, and he calculated the charge on the electron: 1.602e-19 C. With this knowledge, scientists were now able to calculate the charges on specific objects in terms of the number of electrons they were storing.

Next, **Ernest Rutherford** (1871–1937) expanded on atomic theory using the emission of charged particles by radioactive materials. At that time there were thought to be two kinds of emitted particles, each oppositely charged. Alpha particles are positively charged, and beta particles are negatively charged. The belief at the time was that an alpha particle launched at a thin sheet of atoms should pass straight through, undeflected. Using a thin sheet of pure gold, Rutherford tested the penetration of alpha particles and found something astounding. Following his expectations, the majority of alpha particles passed directly through, but a handful would deflect directly off to the sides, or even back towards the emitter. Based on this experiment, Rutherford modified the model of the atom to reflect his findings. He transformed Thomson's plum pudding model, instead giving the atom a dense, very positive center (now known as the nucleus) with a large, empty space around it where electrons floated. This model explained what he believed was happening; alpha particles passed through most of the atom completely unaffected, but the nucleus was simply too dense for them to penetrate, and they would be deflected. Rutherford later theorized the existence of the neutron, but never confirmed its existence.

Henry Moseley (1887–1915) used Rutherford's new nucleus model to further the categorization of atoms on the periodic table. Until Moseley, the periodic table was organized solely by atomic mass and the properties it had, which left some glaring idiosyncrasies that made physicists and chemists at the time profoundly uncomfortable. Moseley believed that the periodic table would be more logically organized by the number of protons in the nucleus of an atom, rather than by atomic weight. In fact, he was correct—the mass of the nucleus makes up so much of the mass of the atom that it was nearly correct to simply use the atomic mass. He developed technology to find that the charge on the nucleus increased by exactly the charge on one proton from an atom of one element to the next element. Any extra mass that was noted in the periodic table was made up of neutrons. As he shuffled around the periodic table based on his findings, the problem spots scientists had been puzzling over immediately disappeared. He then restructured Rutherford's atomic model to show that the nucleus, made of protons and neutrons, had a discrete charge on it that was balanced out by an equivalent number of electrons in a haze around the nucleus.

Quantum Theory and Beyond:

The next development came from a somewhat unexpected quarter: quantum theory. **Niels Bohr** (1885–1962) was a quantum theorist who proposed that the atom is both classical and quantum—classical when it's not radiating, and quantum when it is. It was known from Marie Curie and Rutherford that electron emission was a form of radiation, and Bohr expanded this to include atomic radiation, which was the ejection of electrons from the orbit of an atom. He found that electrons were only emitted with discrete, quantized energy levels depending on where in the atom they were ejected from. He made one final set of changes to Rutherford's atomic model; rather than a cloud of electrons floating wherever they liked around the nucleus, they instead traveled in distinct orbits, with each orbit representing a different energy level. This method worked well for small- to medium-sized atoms but became more complicated when the atom was subjected to a magnetic field. Nevertheless, the Bohr model remains to this day the standard method of atomic notation that most students are familiar with, and it remains the model that is most popular in media.

Despite most people's being most familiar with the Bohr-Rutherford orbit model of the atom, the evolution of atomic theory didn't stop there. **Erwin Schrödinger** (1887–1961), another quantum theorist, expanded the wave-particle model of light to include electrons, stating that they can either be continuous and probabilistic or particulate and discrete depending on circumstance. He believed that, because electrons could be continuous, rather than elliptical orbits as in the Bohr model, electrons instead occupied lobe-shaped orbitals extending around the atom, and the electron could be anywhere within the lobe at any given time. This further entrenched the atom in quantum theory, with the most accurate known representation being three-dimensional and continuous.

Instructions/Activities

Engage: 5-10 Minutes

Teachers will pass out Section 1 of the Student Handout and instruct students to try to fill out the atomic theory timeline based on prior knowledge.	
What is the teacher doing? Instructing students to try to fill out the timeline of atomic theory discoveries in Section 1 of the Student Handout.	**What are the students doing?** Filling out their best guesses at when atomic theory discoveries were made in the timeline in Section 1 of the Student Handout.

Explore: 20-25 Minutes

Teachers will pass out Sections 2 and 3 of the Student Handout. Students will then read excerpts from each of the major discoveries and learn when they really took place, and what the discoveries were. Students will fill out the timeline in Section 3 based on what they have just read.	
What is the teacher doing? Reviewing the Introduction materials in preparation for the Explain section. The teacher won't need to lecture to the class, but the introductory information gives an overview of the discoveries and dates from the excerpts the students are reading, as well as some connections between the works in order.	**What are the students doing?** Reading the scientific excerpts and noting the years of discovery, as well as what discoveries were made. The students will use the second timeline in Section 3 of the Student Handout to take notes and draft a new timeline on.

Explain: 5-10 Minutes

The teacher will lead students in a class-wide exchange, in which the class collaborates to modify their initial guess at the timeline based on the readings they did.	
What is the teacher doing? Lead the class in redoing the timeline with their new knowledge. Teachers can draw the timeline on the board and fill in information as the class agrees on it. Once the class has come to a consensus on the timeline, the teacher can use the Handout Answers document (found in Supplemental Materials) to correct any information that the students have still missed.	**What are the students doing?** Using the timeline notes they took while reading the publication excerpts, contributing to the class discussion on the correct timeline for atomic theory.

Elaborate: 5-10 Minutes

Teachers elaborate on the primary sources the students read (including drawing the relevant atomic models, if desired), using some of the information from the Introduction to draw connections. Techers can also introduce the individuals mentioned in the Historical Research Activity in Extensions.	
What is the teacher doing? Steering the discussion. Points should focus on: 1. Which discoveries do students believe were most impactful? 2. Who are other people/topics/ideas that were involved in atomic theory? 3. Introducing the marginalized individuals elaborated upon in the Historical Research Activity.	**What are the students doing?** 1. Asking questions and discussing what they learned from the primary sources. 2. Discussing how a marginalized identity can hinder (or help) with scientific discovery—what makes for good conditions for scientific advancements?

Evaluate:

The first opportunity for evaluation is tracking student participation. Another is the optional Historical Research Activity.

Required/Recommended Reading and Resources

Excerpts included in Section 2 of the Student Handout:

- Thomson, J.J. "Cathode Rays." Philosophical Magazine, vol. 44, 1897. pp. 302-303.
- Millikan, Robert. "On the Elementary Electrical Charge and the Avogadro Constant." Physics Review, vol. 11 no. 2, August 1913. p. 109.
- Rutherford, Ernest. "The Scattering of and Particles by Matter and the Structure of the Atom." Philosophical Magazine, vol. 21 no. 6, May 1911. p. 686.
- Moseley, Henry. "The High-Frequency Spectra of the Elements." Philosophical Magazine, vol. 27, 1914. pp. 712-713.
- Bohr, Niels. "On the Constitution of Atoms and Molecules." Philosophical Magazine, vol. 26, 1913. p. 24.
- Schrödinger, Erwin. "An Undulatory Theory of the Mechanics of Atoms and Molecules." Physical Review, vol. 28 no. 6, December 1926. pp. 1058-1059.

Recommended AIP Web Exhibits for Further Reading:

- The Discovery of the Electron https://history.aip.org/exhibits/electron/index.html
- Marie Curie and the Science of Radioactivity https://history.aip.org/exhibits/curie/index.html
- Rutherford's Nuclear World https://history.aip.org/exhibits/rutherford/index.html
- Heisenberg / Uncertainty https://history.aip.org/exhibits/heisenberg/index.html

Extensions

History Research Activity

Although this lesson plan has covered some of the most famous names in physics, many other lesser-known individuals have contributed to the development of atomic theory. The individuals below include gender minorities, racial minorities, and people from the global south who conducted important research in atomic theory and related fields.

Should teachers choose to assign this project, students will work either individually or in groups (one group per historical figure) to write a brief report about the biographical details and identity of their chosen person, their connection to physicists they learned about in this lesson plan, and interesting information about the work they conducted.

- Fakhr al-Dīn al-Rāzī (approx. 1149 – 1209), polymath
  - Early proponent of atomism and the existence of multiple universes
- Jane Dewey (1900-1976), quantum chemist
  - A member of Bohr's research group who lectured to them on wave mechanics
- James A. Harris (1932-2000), physical chemist
  - Researched elemental physics and confirmed theories about missing elements on the periodic table.
- Elmer Imes (1883-1941), physicist
  - Used infrared spectroscopy to determine first accurate measurement of the distance between atoms in molecules.
- Elizabeth Laird (1874-1969), physicist
  - Studied X-ray propagation and imprinting with Thomson and the cathode-ray tubes.
- Ali Moustafa Mosharafa (1898-1950), theoretical physicist
  - Contributed to the development of Schrödinger's quantum theory and Einstein's theory of relativity.
- Elizabeth Rona (1890-1981), chemist
  - Studied how atoms diffused based on their size, and developed the science behind radioactive tracers
- Ahmed Zewail (1946-2019), chemical physicist
  - Studied energy transitions in atoms undergoing chemical reactions using lasers.

Related AIP Teacher's Guides on the History of the Physical Sciences:

- African Americans and the Manhattan Project
- Dr. Elmer Imes and Spectroscopy
- Spectra and Margaret Huggins
- Women and the Manhattan Project

Common Core Standards

For more information on Common Core Standards, visit http://www.corestandards.org/.

Speaking & Listening	
CCSS.ELA-LITERACY.RI.9-10.4	Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings; analyze the cumulative impact of specific word choices on meaning and tone (e.g., how the language of a court opinion differs from that of a newspaper).
CCSS.ELA-LITERACY.RI.11-12.4	Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings; analyze how an author uses and refines the meaning of a key term or terms over the course of a text (e.g., how Madison defines faction in Federalist No. 10).
CCSS.ELA-LITERACY.RI.9-10.9	Analyze seminal U.S. documents of historical and literary significance (e.g., Washington's Farewell Address, the Gettysburg Address, Roosevelt's Four Freedoms speech, King's "Letter from Birmingham Jail"), including how they address related themes and concepts.
CCSS.ELA-LITERACY.RI.11-12.9	Analyze seventeenth-, eighteenth-, and nineteenth-century foundational U.S. documents of historical and literary significance (including The Declaration of Independence, the Preamble to the Constitution, the Bill of Rights, and Lincoln's Second Inaugural Address) for their themes, purposes, and rhetorical features.
CCSS.ELA-LITERACY.W.9-10.6	Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically. (If the Historical Research Activity is assigned.)
CCSS.ELA-LITERACY.W.11-12.6	Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information. (If the Historical Research Activity is assigned.)

Next Gen Science Standards

For more information on the Next Generation Science Standards, visit http://www.nextgenscience.org/.

Physical Sciences	
HS-PS1-1 Matter and its Interactions	Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
HS-PS4-4 Waves and their Applications in Technologies for Information Transfer	Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.