History of Atomic Theory

Unit: Atomic Structure

MA Curriculum Frameworks (2016): HS-PS1-1

Mastery Objective(s): (Students will be able to…)

- Give a timeline for the development of atomic theory.
- Explain how each discovery changed our model of the atom.

Success Criteria:

- Discoveries are in the correct chronological order.
- Descriptions explain how each new discovery added to or changed the model of the atom.

Tier 2 Vocabulary: model,

Language Objectives:

- Correctly describe the parts of the atom and their locations within the atom.

Notes:

atomic theory: a theory that explains behavior of chemical elements based on the atoms that they are made of, and the composition of those atoms.

Modern Atomic Theory

The current model (theory) of the atom is the quantum mechanical model. It states that:

- The atom contains a nucleus at the center. The nucleus contains most of the mass of the atom. The nucleus consists of:
  - protons (positively charged)
  - neutrons (neutral)
- The atom contains electrons (negatively charged) outside the nucleus.
- Electrons can be added to or removed from atoms. An atom that has gained or lost electrons is called an ion.
- Each electron in an atom is confined to one of several specific regions around the nucleus (called orbitals), but each electron may move freely within its orbital. These orbitals are regions, but they do not have solid boundaries; each electron remains within its orbital because of a balance of forces, which are determined by how much energy the electron has.

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Historical Development of Atomic Theory

Democritus: ancient Greek philosopher. Credited with the first theory of atoms (~400 B.C.E.). The theory of Democritus held that everything is composed of "atoms", which are physically, but not geometrically, indivisible; that between atoms, there lies empty space; that atoms are indestructible, and have always been and always will be in motion; that there is an infinite number of atoms and of kinds of atoms, which differ in shape, size and mass.

John Dalton: English chemist, physicist and meteorologist. Credited with the first theory that described what atoms are and how they behave:

Dalton's Atomic Theory (1807-08):

- everything is made of atoms
- atoms of the same element are identical; atoms of different elements are different
- atoms are not created or destroyed in chemical reactions. Chemical reactions are simple rearrangements of the atoms into different compounds.
- every sample (molecule) of a compound contains the same atoms in the same proportions ("Law of Constant Composition")
- atoms in compounds occur in simple, whole-number ratios ("Law of Multiple Proportions")

J.J. Thomson: English physicist. Discovered the electron (1897). His experiment was to apply an electric current to a gas. This created cathode rays—rays of negatively-charged electric particles, which appeared to come from the cathode (positive electric terminal). Thomson determined that these particles (which he named "corpuscles") came from the atoms that the cathode was made of. This discovery was important because it was the first evidence that atoms were divisible. Thomson received the Nobel Prize for Physics in 1906 for this discovery.

"plum pudding" model: (1904) J.J. Thomson compared the atom with a bowl of plum pudding with raisins. (Plum pudding, which is a lot like oatmeal, is popular in England.) The "pudding" was the positively charged substance that most of the atom was made of, and the "raisins" were the negatively-charged electrons (which he called "corpuscles"). Thomson published this theory in 1907 in a book called *The Corpuscular Theory of Matter*.

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planetary model: (early 1900s) The atom was compared with a miniature solar system. In the 1906 physics textbook, *A First Course in Physics,* authors Robert Millikan and Henry Gale credited Thomson with this model (which at the time was called *electron theory*):

> "But since the atoms are probably electrically neutral, it is necessary to assume that they contain equal amounts of positive and negative electricity. Since, however, no evidence has yet appeared to show that positively charged electrons ever become detached from molecules, Thomson brings forward the hypothesis that perhaps the positive charges constitute the nucleus of the atom about the center of which the negative electrons are rapidly rotating.
>
> "According to this hypothesis, then, an atom is a sort of infinitesimal solar system whose members, the electrons, are no bigger with respect to the diameter of the atom than is the earth with respect to the diameter of the earth's orbit. Furthermore, according to this hypothesis, it is the vibrations of these electrons which give rise to light and heat waves; it is the streaming through conductors of electrons which have become detached from atoms which constitutes an electric current in a metal; it is an excess of electrons upon a body which constitutes a static negative charge, and a deficiency of electrons which constitutes a positive charge."

Robert Millikan: American physicist. Measured the electrical charge on an electron based on the rate that oil drops fall through an electric field (1909). The common factor in all of the measurements must be the basic particle of electric charge—the electron. Millikan received the Nobel Prize for Physics in 1923 for this discovery.

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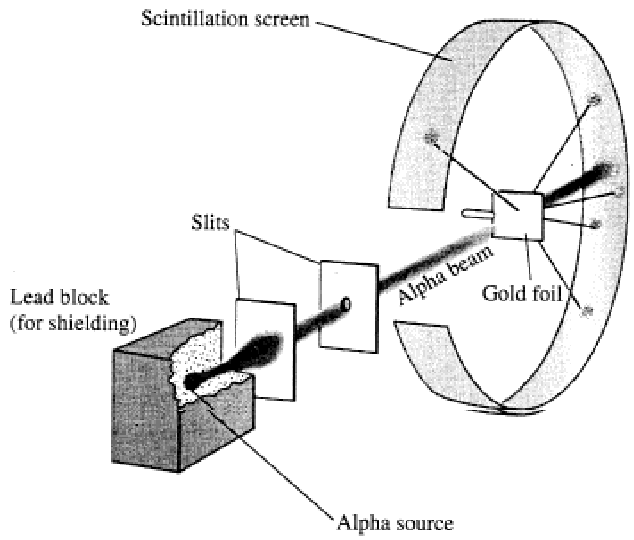
<u>Ernest Rutherford</u>: New Zealand-born British physicist. Supervised an experiment that corroborated electron theory and showed the existence of a dense, positively-charged nucleus (1909). In Rutherford's experiment, positively-charged alpha particles were allowed to pass through a thin sheet of gold foil.



Most of the particles passed through, as Rutherford had expected. However, a few were deflected sharply, as if they had interacted with a dense object with a strong positive charge. Rutherford described the result as follows:

> "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration, I realized that this scattering backward must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive centre, carrying a charge."

Conclusions from Rutherford's Experiment:

- Most of the atom is empty space.
- The atom has a dense, positively-charged nucleus in the center.
- Nearly all of the mass of the atom is in the nucleus.

Many people believe that the idea of a positively-charged nucleus originated with Rutherford. Electron theory actually predated Rutherford's gold foil experiment by several years (as stated above), but the experiment was the confirmation that enabled the theory to gain acceptance.

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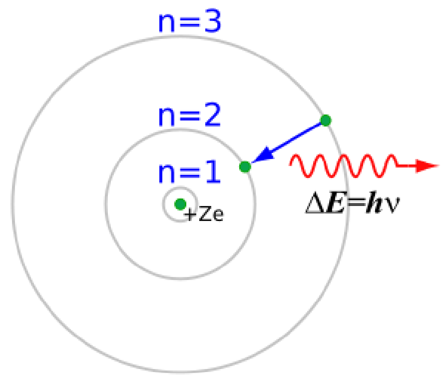

Bohr model: (1913) Danish physicist Niels Bohr hypothesized that electrons moved around the nucleus as in the planetary model, and the distance of each electron from the nucleus was determined by the amount of energy it had. The energy was quantized, so only specific orbits were allowed. These quantum values of energy could be described by a quantum number (*n*).

Bohr's model gained wide acceptance, because it combined three prominent theories of the time: electron theory, spectroscopy and quantum theory.

Even though the Bohr model of the atom has been superseded by the quantum mechanical model, the Bohr model is frequently taught today in elementary and middle school science classes because it is easier to visualize and because it relates the atom to the solar system, which is already familiar.

The Bohr model is described in more detail in the section "The Bohr Model of the Hydrogen Atom," which begins on page 199.

quantum mechanics: in 1900, German physicist Max Planck postulated that absorption and emission of energy that produces light occurs in discrete packets called "quanta".

photoelectric effect: In 1905, German physicist Albert Einstein discovered that energy from light could cause electrons to be emitted from a metal, that the energy from this light agreed with Planck's equation, that there was a certain minimum amount of energy specific to each metal that was required to drive off the electrons, and that this energy was quantized—the energy needed to release the electrons was all-or-nothing. Einstein received the Nobel Prize in Physics in 1921 for this discovery.

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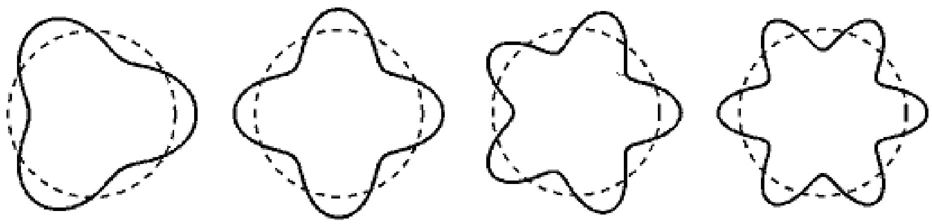
Louis de Broglie: In 1924, French physicist Louis de Broglie suggested that matter can act as both a particle and a wave. He theorized that the reason that only integer values for quantum numbers were possible was because as the electron orbits the nucleus, its path must be an integer multiple of the wavelength:



Erwin Schrödinger: Austrian physicist. Expressed de Broglie's hypothesis in mathematical form (the Schrödinger wave equation) and used it to predict the quantum energies of atoms (1926).

The solutions to Schrödinger's equation defined additional integer quantum numbers (ℓ and m) that specified the arrangements of electrons within the atom. These solutions supported the idea that an electron is either able to be detected (present), or unable to be detected (absent), as would be the case for a wave that is detectable at an antinode, but not at a node. Schrödinger's equations resulted in maps of regions around the nucleus of an atom (later named "orbitals," based on the probabilities of finding an electron in the different regions as a function of the energy of the electron.

Schrödinger received the Nobel Prize for Physics in 1933 for his work.

Sir James Chadwick: British physicist. Discovered the neutron (in 1932), which accounted for previously unexplained mass within an atom. His experiment was to collide alpha particles into beryllium, which caused neutral particles with the same mass as a proton to be ejected. Because these particles were neutrally charged, Chadwick named them neutrons. Chadwick received the Nobel Prize for Physics in 1935 for this discovery.

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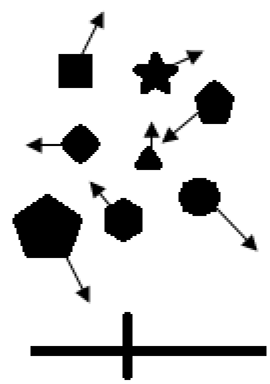
Homework

Make a timeline of how the theory of the atom developed, including the models of Democritus, Dalton, the "plum pudding" model, the planetary model, Bohr, de Broglie and Schrödinger. For each entry, your timeline should include:

- a sketch of what the atom might have looked like according to the model
- the year the model was proposed
- the name(s) of the scientist(s) credited with the model
- a 1–2 sentence description of the model

Here is an example of what the timeline entry for Democritus might look like:



~400 BCE

Democritus

Everything is made of indestructible atoms of different sizes, shapes and masses. These atoms are in constant motion.

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