QUANTUM (Q)-KIT

Quantum Chemistry:

Laboratory for Primary Level Students

Student Manual

WOMEN SUPPORTING
WOMEN IN THE SCIENCES

Meet a Scientist

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About me:

I started teaching while having a Bachelor's degree in Secondary Education and then I completed a Bachelor of Science in Physics and Mathematics. It still wasn't enough for me, so I decided to study for a Master's degree in Physics at the University of Dodoma. My Master's thesis project focused on first principles studies of electronic, optical, and elastic properties of corundum from different mining sites in Tanzania. I am interested in physics research, especially as it relates to quantum computing.

My advice for students interested in science:

- Don't worry if you don't understand everything at first.
- Don't be afraid to question things.
- Keep learning, stay patient, and enjoy the journey.

Mission Statement

The mission of this laboratory is to teach primary level students (ages ~5-11) about atoms with hands-on activities.

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1. Introduction to WS2 Laboratory Kits

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to primary and secondary school students, predominantly in eastern Africa. The lab kits utilized local resources and included topics that are especially relevant to young girls in order to spur their interest in STEM subjects. From 2020-2023, over 5100 students from eastern Africa at over 40 school sites engaged with our lab kits, with 62% being girls.

WS2 was awarded their second APS Innovation Fund in 2025 to support another Lab Kit Initiative, though this time with a focus on quantum topics. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, APS Forum on Education, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 is extremely grateful to the lab kit design volunteers for their hard work and external consultants (SciBridge and Projekt Inspire) for their advising. WS2 also thanks and acknowledges PhysicsQuest (https://www.aps.org/initiatives/physics-education/physicsquest) and Quantum Explorations Student Toolbox (QuEST) for example experiments that were used as foundation for the lab kit content.

1.2. Key Vocabulary

- Atom: the smallest unit of an element that is still that element
- Electron: negatively charged particle that forms “cloud” around atom’s nucleus
- Nucleus: dense center of atom consisting of neutrons and protons

1.3. Key Question

- What are the key features of the Rutherford model of the atom?

1.4. Purpose

The purpose of this lab kit manual is to enable students to understand atoms through theory and demonstration. The manual introduces the students to atomic models.

2. Background on Main Topics

2.1. The Atom

The atom is the basic building block of matter, making up everything around us. Atoms essentially are the smallest unit of an element (examples of elements are carbon, nickel, aluminum, and hydrogen) that still is that element. Atoms are incredibly small and cannot be seen with our naked eyes, but they are extremely important. Atoms determine the way things function, from metal chairs we sit on to the air we breathe. Beginning in the 1800s, scientists attempted to describe the atom. In 1808, John Dalton proposed that atoms were solid spheres that are small and indivisible. J. J. Thomson built on this model and in 1904 proposed the "plum pudding" model described the atom as a sphere of positive charge with negatively embedded electrons, like plums found inside pudding (similar to blueberries or other fruit pieces inside of a cake or muffin), and these opposing charges equal each other. Electrons, which are extremely light, play a key role in how chemical reactions occur and also are the carriers that flow in electricity.

The concept of the atomic nucleus came about in 1911, when Ernest Rutherford described atoms with a dense middle that contains positive charge, the so-called

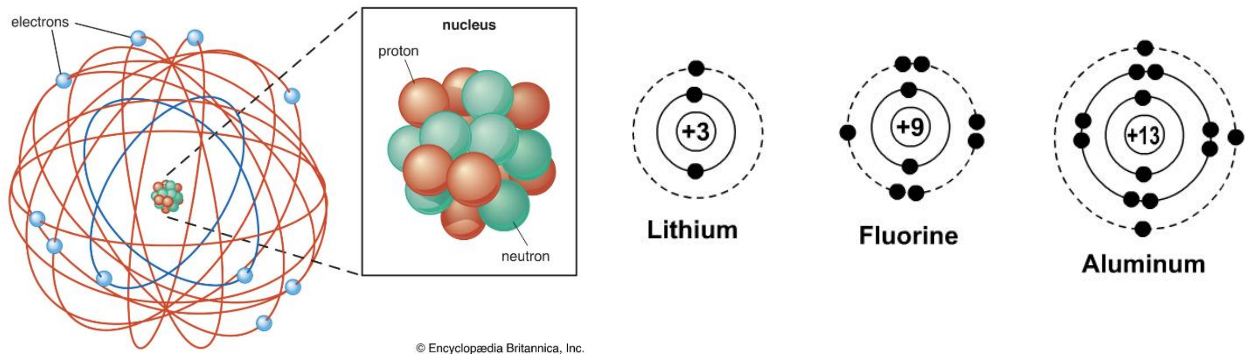


Figure 1. In the Rutherford model of the atom (left), the nucleus is a dense concentration of mass at the center of the atom and there is a lot of empty space. In Bohr model of the atom (right), the electrons orbit the nucleus with orbits that are well-defined sizes and energies. [This Photo](#) by Unknown Author is licensed under [CC BY-SA-NC](#).

nucleus. Electrons then move about the nucleus and the atom consists of a lot of empty space (Figure 1). Rutherford came up with this description after performing what became famously known as the "gold foil experiment" (see Figure 2). Rutherford and his team aimed particles at a thin gold sheet. Rutherford thought that these particles would pass directly through the sheet. Mostly these particles passed through the sheet, but occasionally, some bounced back. This was a remarkable finding, and led to Rutherford's famous quote, "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." This finding led Rutherford to conclude that atoms have a dense nucleus where most of their mass is concentrated. We now describe the nucleus as containing both protons, which are positively-charged particles that define the identity of an element, and neutrons, which are particles with no charge and have similar mass to protons. For comparison, protons and neutrons are about 2000 times heavier than electrons.

Improvements to the mode of the atom concerned electrons. In 1913, Niels Bohr said that electrons orbit the nucleus (like the way planets orbit the Sun), and the well-defined orbits have specific sizes and energies (see Figure 1), but this was later improved upon by Erwin Schrodinger in 1926 who said that electrons are really found in clouds, or orbitals, around the nucleus which contains protons and neutrons. The electron orbitals are areas that have a high probability of containing electrons. This model of the atom, known as the quantum mechanical model, is how we still describe atoms today.

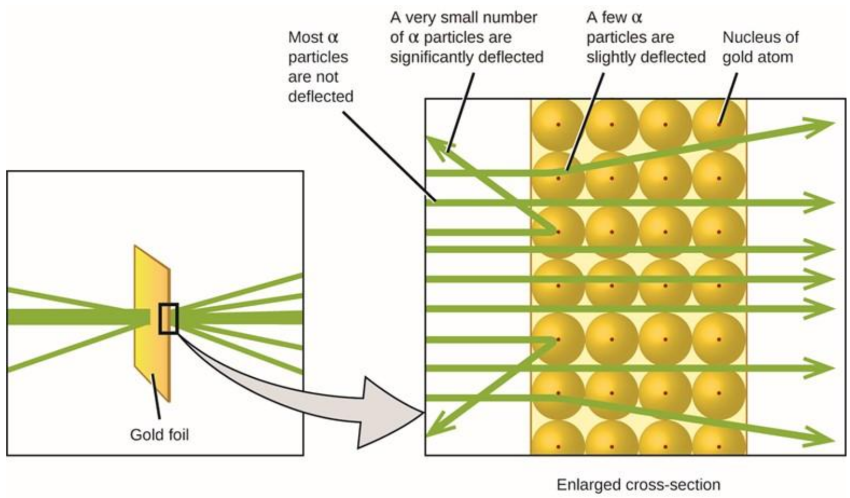


Figure 2. Gold foil experimental schematic. Most alpha particles passed through the gold foil, but a very small number are deflected when they hit the dense nucleus. [This Photo] by Unknown Author is licensed under [CC BY-SA-NC].

2.2. Supplies List

- Spherical-like candies of three colors (or compressed foil balls of three colors)
- Toothpicks
- Dark string (or pipe cleaners)
- Paper
- Marker

2.3. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should not eat or taste items during experiments.

3. Experiments

3.1. Part I. Candy Atomic Models

3.1.1. *Pre-Activity Questions*

1. What particles are found at the center of the atom (nucleus)?

2. What particles surround the nucleus?

3. What are the key features of the Rutherford model of the atom?

3.1.2. *Materials*

- Spherical-like candies of three colors (or compressed foil/paper balls of three colors) (at least 8 of each per group)
- Toothpicks
- Dark string (or pipe cleaners)
- Paper
- Marker

3.1.3. *Procedure & Analysis (work in groups of 2-4)*

1. Sort out candies of different colors (or create balls of paper/foil that are three different colors).
2. Select 8 candies each of two colors and use toothpicks to join them together in a densely packed nucleus. Set this nucleus on a piece of paper.

    a. What do these two types of candies represent? Label this on the paper.

3. Use two lengths of dark string (or pipe cleaners) and make concentric circles around the nucleus.
    a. What do these circles represent? Label this on the paper.

4. Select 8 candies of the remaining color and place them on the concentric circles.
    a. What do these candies represent? Label this on the paper.

5. Now, place 2 candies on the inner circle and 6 on the outer circle. This represents how electrons fill the outermost orbitals in this element (the first level contains 2 electrons and the second level contains 6 electrons, though it could contain up to 8 electrons total). See Figure 3 for an example of the candy atom model.

Figure 3. Example of the candy atom model with the densely packed nucleus and the electron orbits.

3.1.4. *Post-Activity Questions*

1. What element did you model in this activity? Hint: to figure this out, count the number of protons and then go to a periodic table (see Appendix) and find the element that has this number of protons (it will be labelled with an eight!)

2. Was this atom charged in this activity? Hint: to figure this out, count the number of protons in your atom and count the number of electrons in your atom. Are they the same? If so, the atom is neutral, which means it has no charge. If they are different, the atom is charged.

    a. <u>Extension question:</u> How could you imagine making this atom charged?

3. What are additional improvements that you could make to your model to more realistically represent an atom? Consider the other atomic models that followed Rutherford. Try these improvements out and record your observations.

4. Extension Challenge

The Challenge: Create another atom of a different element

We have seen in the previous demonstration that the number of protons dictates the element we have. Select another element on the periodic table in the first two rows and try to model it with your candies! Some important points to remember: for this model, the number of neutrons will equal the number of protons in your nucleus, a neutral atom contains the same number of electrons and protons, and the first electron orbital (circle) can contain 2 electrons and the second electron orbital (circle) can contain 8 electrons.

4.1 Extension Questions

1. What atom did you choose to model?

2. How many protons and neutrons do you need?

3. How many electrons do you need? Where will they go in your two orbitals?

4.2 Extension Sketch

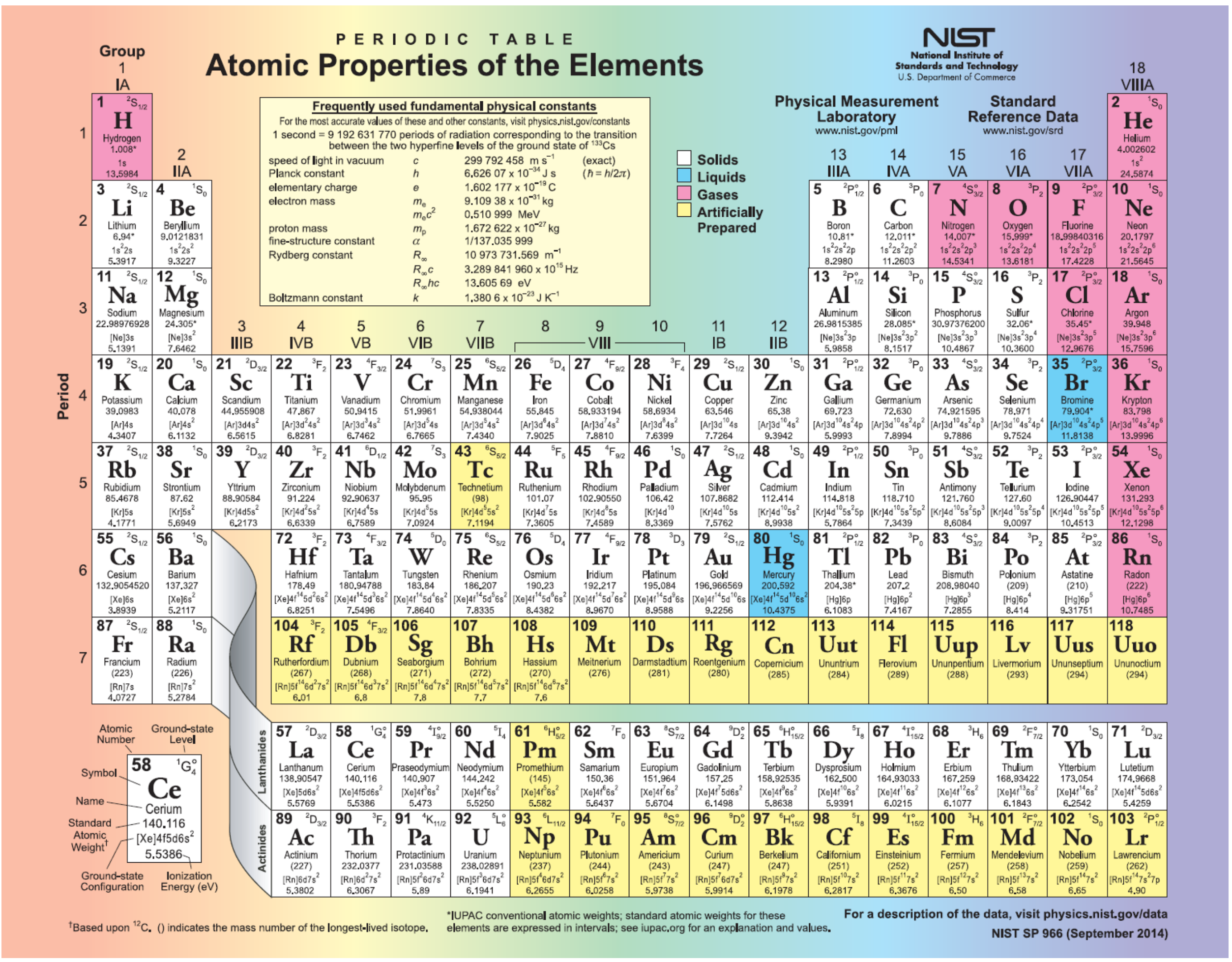
Sketch the model of your atom and then try to create it with your candies!

5. Sources

Atoms and atomic models:

https://medium.com/@Intlink.edu/a-timeline-of-atomic-models-cb2607b1da85

6. Appendix



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