TITLE: A Fact of Matter
Subtitle: Exploring trends across the periodic table

Authors: Vikram Baliga, PhD Candidate, University of California Santa Cruz, CA
Burnne Yew, Teacher, Watsonville High School, Watsonville, CA
Ruth Herradora, Teacher, Watsonville High School, Watsonville, CA
Bill Callahan, Teacher, Watsonville High School, Watsonville, CA

Field tested with: several classes of 10^{th}-11^{th} grade Chemistry students, Watsonville High School, Watsonville, CA

Module Type: Lab Activity

Duration: ~75 minutes

Key materials (for each pair of students):
- 1 paper plate
- 3 markers (red, blue, black)
- 1 rulers (metric only)
- 1 compass

Concepts: periodic table, atomic structure, atomic radius, first ionization energy, atomic trends, modeling

Skills: creating scaled models of atoms; identifying trends in atomic radius and first ionization energy across the periodic table

Science Education Standards:
NGSS - HS-PS1-1: 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.

Cross-cutting concepts: patterns; systems & system models; scale, proportion & quantity

Overview:
This project is an opportunity for students to learn:

- About the relative sizes of elements in the periodic table
- Definitions of atomic radius, and first ionization energy
- How trends in atomic structure relate to trends in first ionization energy and atomic radius

Navigate: Background Materials &Time Starting Point Procedures Standards Supplemental

Background for Teachers

Why this matters: The periodic table is oddly-shaped, yet is designed to reflect the key properties of all of the elements. This module gives an overview of the trends we see in atomic radius and first ionization energy within each period and within each group of the periodic table. This module directly addresses NGSS Performance Expectation HS-PS1-1 by having students analyze trends in the periodic table in relation to atomic radius and first ionization energy.

Assumed background: We assume the students already know some basics of atomic structure:

1) Atoms are composed of protons, neutrons, and electrons
2) The atom is composed of a nucleus (protons and neutrons) and that electrons orbit the nucleus
3) Electrons are often modeled as occupying distinct orbital regions, called “shells”

We also assume students are competent using the metric system, know how to convert between different dimensional units, and are familiar with scientific notation.

Special context: The properties of atoms (i.e. first ionization energy) are emergent properties of atomic structure.

Scaffolding supplements: A PowerPoint presentation complements this activity

Module Description

Materials (for each pair of students):

- 1 paper plate
- 3 markers (red, blue, black)
- 1 rulers (metric only)
- 1 compass

Preparation:

The instructor must make a paper plate model of the atomic structure of carbon before the lesson begins. This will be a template for each of the students' models. Ideally, the model will look like the one shown in **Figure 1**. In the nucleus, each **red** dot represents a proton and each **black** dot represents a neutron. In the shells, each **blue** dot is an electron. The **distance** from the outermost shell to the center of the nucleus is the atomic radius. We will use the scale "2 picometers to 1 millimeter". Since the actual atomic radius of carbon is 77 pm, the paper plate model will have an outer shell radius of 38.5 mm.

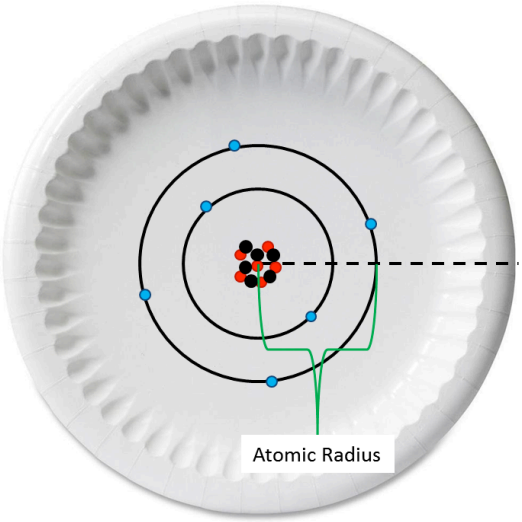

Figure 1: Model of Carbon. Do not assign carbon to students. Instead, you will make the model before the lesson begins.

Timeline:

1. Part 1: Atoms are Tiny! 10 min.
2. Part 2: Model the Elements 40 min.
3. Part 3: Ionization Energy 10 min.
4. Cleanup and Wrap-Up 15 min.

Starting Point For Inquiry:

The periodic table is oddly-shaped, yet is designed to reflect key properties of all of the elements. This module gives an overview of the trends we see in atomic radius, and first ionization energy within each period and each group of the periodic table.

Detailed Procedure:

1. Part 1: Atoms are Tiny! 10 min.

   This activity helps students understand the size of atoms. The students are given the atomic radius measurements (in picometers) for two atoms: helium and carbon. They convert these picometer measurements to meter and millimeter measurements (which may be challenging for some). We recommend students use dimensional analysis to keep track of units. If they are not already familiar with dimensional analysis, have them set up the conversion as follows (values given are for helium):

$$37 \text{ ~~picometers~~} \times \frac{1 \text{ meter}}{10^{12} \text{ ~~picometers~~}} = 3.7\times10^{-11} \text{ meters}$$

2. Part 2: Model the Elements 40 min.
Students get into pairs. Assign each pair an element, starting with hydrogen (atomic number 1) and ending with calcium (atomic number 20). **Remember to skip carbon (atomic number 6), because you (the instructor) will have already made that model (see: Preparation).**

Give each pair of students: 1 paper plate, 1 metric ruler, 3 markers (red, blue, black) and 1 compass. They will use these to construct paper plate models that mimic the carbon model you already created. Some things to keep in mind:

a) The scale is "2 picometers to 1 millimeter". The range of atomic radius for the first 20 elements is 31 – 227 pm. This means their models will range 15.5 – 113.5 mm in radius. **It might be wise to have the students verify their radius calculations with you before creating the model.**
b) We assume that students are familiar with electron orbital levels and can assign the correct number of electrons to each level.
c) The radii of each inner level corresponds to the atomic radius of the noble gas element for that energy level.

When the students have completed their models, they will bring them to you. Hang up the models at the front of the classroom as they are arranged on the periodic table. Discuss with the students the trends they see and have them answer the questions on the worksheet.

3. Part 3: Ionization Energy 10 min.
The first ionization energy of an atom is the amount of energy required to remove one electron from the atom. In this process, atoms become *ions* as they lose an electron. First ionization energy for atoms is typically given in kJ/mol. This is the amount of energy (kiloJoules, kJ) per mole of atoms needed to remove an electron from the outer shell of a particular atom. We provide a periodic table with first ionization energies for each element color-coded into the graphic. On this image, elements with higher ionization energies appear deeper red. Use this graphic to assess whether students make the connection between the magnitude of the ionization energy and the atomic radius of the element.

4. Cleanup and Wrap-Up 15 min.
Review the concepts covered (if you think the students need further reinforcement), and then clean up materials.

Assessment Methods:

Students can be assessed on the accuracy of their paper plate models (i.e. is the radius drawn on the plate reasonably close to that which the model should have?). They can also be assessed on the accuracy of their answers to the worksheet questions.

Possible pitfalls:

Students might make errors in their calculations or may be inconsistent in their use of colors. A good strategy is to encourage them to outline the design of their models in pencil first and then use markers once their measurements are verified (by them, or by the instructor).

Glossary:

First Ionization Energy: the amount of energy (kJ/mol) required to remove one electron from the atom

Picometer (pm): equal to 10^{-12} meters. In other words, within 1 meter, there are 1,000,000,000,000 (that's one trillion) picometers.

Science Education Standards Addressed

Next Generation Science Standards (NGSS):

HS-PS1 Matter and its Interactions

NGSS HS-PS1-1: 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.

Cross-cutting concepts: patterns; systems & system models; scale, proportion & quantity

Guide to supplemental materials

Student worksheet – entitled "Baliga et al FactofMatter Student Handout"
-provides an outline of the procedure and a few questions

PowerPoint Presentation – entitled "Baliga et al FactofMatter Powerpoint"
-provides the atomic radii for the elements of interest
-provides a periodic table with color-coded ionization energy (made by VB)