Activity: Building a Nuclide

FOR THE TEACHER

Summary
In this activity, students will construct a model of a nuclide and use this model to investigate why the mass of the nuclide is less than the summative mass of the individual nucleons (protons and neutrons). Additionally, the constructed nuclide will be used to help students conceptualize and differentiate between key lesson terminology (mass defect, strong nuclear force, and nuclear binding energy).

Grade Level
High School

NGSS Alignment
This activity will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-8**: Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion and radioactive decay.
- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Developing and Using Models

Objectives
By the end of this activity, students should be able to:

- Calculate mass defect to verify that the mass of a nuclide is less than the combined mass of its individual nucleons.
- Explain in terms of mass and energy why the nucleus of an atom has less mass than the summation of its individual nucleons.
- Differentiate between mass defect, strong nuclear force, and nuclear binding energy.

Chemistry Topics
This activity supports students’ understanding of:

- Atomic Structure
- Subatomic Particles
- Atomic Mass
- Mass Defect
- Nuclear Chemistry
- Law of Conservation of Mass and Energy

Time
**Teacher Preparation**: 10 minutes
**Lesson**: 40-50 minutes

Materials
- **Magnetic balls** of different colors sized 5mm or larger
  - Magnetic feature is highly recommended for conceptual understanding of terminology (see Teacher Notes).
- Set of element cards
  - Example: The Photographic Deck of the Elements
  - A periodic table (if cards are not available)
- Pencil or pen
- Calculator
- Markers (colors should closely match the colors of the magnetic balls)

**Safety**
- No safety considerations necessary for this activity.

**Teacher Notes**
- The Khan Academy provides some helpful science background for teachers or students that may need it.
- Each student or group will need a different number of magnetic balls depending on their chosen (or assigned) nuclide.
- Students will need 2 different colors of magnetic balls (1 color for protons and 1 color for neutrons). For example, if constructing the nuclide potassium student would need 19 blue magnetic balls (protons) and 20 purple magnetic balls (neutrons) to total 39 nucleons.
- I find that the visual appeal of elements using the element cards enhances this activity and student connection. If the card deck is not available, use a periodic table for students to make their element selection.

Recommended sequence and execution of the lesson:
- **Part 1:** Building a Nuclide worksheet: Students build a nuclide using the outlined materials and student worksheet. If needed, review/introduce the nucleon term, what a nuclide is and how to represent a nuclide in the $\frac{Z}{A}$ format where Z is the nuclide, A is the mass number and X is the atomic number.
  - Building a Nuclide worksheet:
    - The worksheet has numbered boxes 1-4.
    - Boxes 1-2 are the planning phase. Have students complete these prior to obtaining materials.
    - Box 3 begins material gathering (markers, magnetic balls, calculator) and modeling phase.
    - Box 4 requires students to compare calculations in box 3 (the atomic mass of the element and the summation of the individual masses of the nucleons) and report and comment on their observation.

- **Part 2:** Teacher should reconvene the class as a group. Ask students to share their observations and conclusions from the Building a Nuclide worksheet. Teacher can ask, “Do our observations violate the concept that matter can neither be created nor destroyed?” Allow student input.
- At this point, a student may suggest the mass was converted into energy, if so, ask the class if there is an equation that relates mass and energy. If not, simply write the $E=mc^2$ equation in big writing on the board and discuss with students the interchange between mass and energy to work towards awareness that mass can be converted to energy. Then, relate this to nuclides (when a nuclide is formed from its individual parts/nucleons energy is released)
  - Hand out the worksheet, **Part 2:** $E=mc^2$ and complete in a collaborative nature helping groups stay at similar paces for boxes 1-4, eventually introducing the formal term for the change in mass between the mass of the nuclide and the individual nucleons, the mass defect (box 4). Time permitting, teacher can have students’ complete box 5 or skip and come back at the end of the lesson.

- **Part 3:** Terminology: Explanation of key terminology using constructed nuclides. The magnetic feature of the constructed nuclides provides an excellent tool for conceptual understanding during discussion of strong nuclear force and nuclear binding energy:
  - **Strong nuclear force:** First, have students hold the nuclide in their hands and instruct them to gently try and pull the nucleons apart. This makes use of the magnetic feature of
the balls to help students recognize that the protons and neutrons are held together by “something.” Ask them what this “something” is and/or what the magnetic force of attraction might represent in terms of the nuclide, ultimately introducing the strong force.

- **Nuclear binding energy:** After introducing the strong force, ask students how easy it would be to dissemble/separate all the nucleons of their nuclide (students should suggest/recognize this endeavor would require energy); this provides a natural segue into the introduction of nuclear binding energy as the energy required to split an atomic nucleus into individual protons and neutrons.

- **Nuclear binding energy increases as nucleons increase/mass number increases:** Select a student with the smallest number of nucleons in their nuclide and a student with the greatest number of nucleons in their nuclide and have them (starting at the same time) deconstruct their nuclide into its individual nucleons. Have the class observe who finishes first. To this end, ask students what they might conclude about the relationship between nuclear binding energy and the number of nucleons (or mass number) per nuclide and (or atom) helping students recognize that as the number of nucleons increase so does the nuclear binding energy.

- **Optional:** This is a good time to show and have students interpret the traditional nuclear binding energy per nucleon chart.

- If students finish early, have them consider why the mass of electrons were not considered when subtracting the mass of the nuclide from the atomic weight. Ask them to design an investigation to determine if the electron mass should or should not be accounted for in this activity (they should explain their reasoning using evidence gathered). For this provide students with mass of electron = 0.0005486 amu

- **Pair groups together to compare and discuss results of each worksheet.**
  - Teacher may pair students according to strengths and weaknesses and assign individual roles that correlate to specific box numbers for *Building a Nuclide* and *E=mc²* worksheets (example one student takes group notes, one constructs the nuclide, another calculates).
  - The terminology worksheet differentiates instruction by allowing students to define terms with words, diagrams and/or labels, whichever best helps the individual learner.

- **Lesson extension:** An extension option for this lesson is to connect it to the study of nuclear fusion. For example, students should use their results and discussion from the activity to conclude how it is possible that nuclear fusion results in large releases of energy.

- **Student worksheets, and answer keys are provided.**