Fusion is the Bomb!

Unit	Utah SEEd Standard / NGSS Performance Expectation	Estimated Lesson Time:
Chemistry 1.4 Structure and Property of Atoms: Nuclear Fusion	**Chem.1.4: Construct an explanation** about how fusion can form new elements with greater or lesser nuclear **stability**. Emphasize the nuclear binding energy, with the conceptual understanding that when fusion of elements results in a more stable nucleus, large quantities of energy are released, and when fusion results in a less stable nucleus, large quantities of energy are required. Examples could include the building up of elements in the universe, starting with hydrogen to form heavier elements, the composition of stars, or supernovae producing heavy elements. (PS1.C, ESS1.A)	90-140 min

Access to all material for this lesson: https://byu.box.com/s/8t7k3apua9tqkyu0sd3shp3s18k2yob8

Lesson Overview

Lesson Objective(s)

Students will be able to explain how nuclear binding energy relates to the change in energy from a fusion reaction.

DCI Focus: The nuclear binding energy, with the conceptual understanding that large quantities of energy are released when the fusion of elements results in a more stable nucleus.

Anchor Phenomenon

Hydrogen bomb

Driving Question(s)

Students come up with the driving questions. Some examples of what students should come up with include:

- Where does the energy come from?
- Why does the amount of energy released vary in different bombs?
- What affects the amount of energy that is released from an explosion?
- What reaction is taking place to cause the release of this much energy?
- What is happening to the nucleus of an atom that causes energy to be released?

Lesson Level Performance Expectations

- Students will track changes to energy and matter and construct an explanation about nuclear fusion within a hydrogen bomb.

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Lesson Snapshot

Lesson Summary:

DCI Focus: The nuclear binding energy, with the conceptual understanding that large quantities of energy are released when the fusion of elements results in a more stable nucleus.

	Estimated Time	Section Overview	How are students answering the driving question or meeting the learning objectives?
Experience the Phenomenon	**10-15 minutes**	Video of a hydrogen bomb	After watching the video, in groups of 3-4, students will individually write their observations on a sticky note. Next, the group will create 3-4 scientific questions from their observations. Lastly, the group will choose the question that will aid in explaining what is happening at the atomic level during the hydrogen bomb. Students will record their questions on the worksheet under #2.
Investigate the Phenomenon	**65-95 minutes**	Three activities with information on nuclear binding energy, mass, and nucleons	1st activity: Students will graph several atoms' mass numbers and binding energy. Students will use their completed graph to analyze, interpret, and make predictions. Next, students will refine their model to reflect the new information learned from analyzing the graph. 2nd activity: Read the Nuclear Fusion Infographic Afterward, students describe the key components that lead to changes in mass and energy in the system to fuse two nuclei successfully. Next, students will refine their model to reflect the new information learned from reading the article. 3rd activity: PHET simulation Students will interact with the simulation by building a nuclear model and noting the changes in energy and "binding" of nucleons as mass increases.
Model the Phenomenon	**15-30 minutes**	Explanation of hydrogen bomb.	Students will construct an explanation by compiling and evaluating evidence to create a claim regarding the driving question: **EXPLAIN HOW NUCLEAR BINDING ENERGY RELATES TO THE CHANGE IN ENERGY FROM A FUSION REACTION.** Finally, students will create a model to show their reasoning for their claim.

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Disciplinary Core Ideas

NGSS Appendix E

(PS1.C) Nuclear Processes

Nuclear fusion is a process in which a collision of two small nuclei eventually results in the formation of a single more massive nucleus with greater net binding energy and hence a release of energy. It only occurs under conditions of extremely high temperature and pressure. Nuclear fusion occurring in the cores of stars provides the energy released (as light) from those stars. The Big Bang produced matter in the form of hydrogen and smaller amounts of nelum and lithium. Over time, stars (including supernova explosions) have produced and dispersed all the more massive atoms, starting from primordial low-mass elements, chiefly hydrogen. The total number of neutrons plus protons does not change in any nuclear process.

(ESS1.A): The Universe and its Stars

The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.

Students know and apply the Disciplinary Core Idea (DCI) of PS1.C Nuclear Processes in their thinking and reasoning to communicate that:

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

Students know and apply the Disciplinary Core Idea (DCI) of ESS1.A: The Universe and its Stars in their thinking and reasoning to communicate that:

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage.

Science & Engineering Practices

NGSS Appendix F

Constructing Explanations: Students construct an explanation based on reliable evidence and scientific principles.

Students do and use this Science and Engineering Practice (SEP) by:

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena, taking into account possible unanticipated effects.
- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Crosscutting Concepts

NGSS Appendix G

Energy and matter: Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

Students think and connect this Crosscutting Concept (CCC) to reason that:

- The total amount of energy and matter in closed systems is conserved.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
- Energy drives the cycling of matter within and between systems.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

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This lesson could be one in a series of lessons building toward the following Performance Expectation(s): Students will construct an explanation to emphasize when fusion results in a less stable nucleus, large quantities of energy are required. A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy to take the molecule apart.		
Related knowledge and skills from prior grades		
Disciplinary Core Idea: [NGSS Appendix E] In grades 6-8, students should be familiar with the fact that matter is composed of atoms and molecules can be used to explain the properties of substances, diversity of materials, states of matter, phase changes, and conservation of matter. In grade 3-5, students learn that matter exists as particles that are too small to see, and so matter is always conserved even if it seems to disappear. Measurements of a variety of observable properties can be used to identify particular materials. In grades K-2, students Matter exists as different substances that have observable different properties. Different properties are suited to different purposes. Objects can be built up from smaller parts.	Science and Engineering Practices [NGSS Appendix F] Constructing explanations and designing solutions in 6–8 builds on K– 5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real world phenomena, examples, or events. • Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion. Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and retesting.	Crosscutting Concept: [NGSS Appendix G] In grades 6-8, students learn matter is conserved because atoms are conserved in physical and chemical processes. They also learn within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter. Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). The transfer of energy can be tracked as energy flows through a designed or natural system. in grades 3-5, students understand that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. They can also describe a system in terms of its components and their interactions. In grades K-2, students understand objects and organisms can be described in terms of their parts; and systems in the natural and designed world have parts that work together

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Materials		
Student Materials	**Teacher Materials**	**Lab Materials/Other Resources**
Student Worksheet – Follows the teacher's instructional slides Nuclear Fusion Article	Teacher Instruction Slides Phenomenon Video: US Nuclear Tests Assessment Scoring Rubric	Colored Pencils – 3 colors for each student

LESSON PREPARATION

Material Preparation:
Make copies of the **Student Worksheet** for each student. Make copies of the **Nuclear Fusion Article**, enough for each student. Have colored pencils available (3 different colors per student)
Hand out colored pencils and worksheets to students upon entering class. However, keep the Nuclear Fusion Article until noted in teacher instructional slides (beginning of activity 2)

Required Previous Knowledge:
This lesson builds on students' prior understanding of the atomic structure, isotopes, radioactive decay, nuclear stability, strong nuclear force, and nuclear fission. Students need to be familiar with atoms vs isotopes and sub-atomic particles. Students need to be familiar with atomic structure.

Supports students will need/adaptations:
Suggestion: Use the Brisk Learning tool to adapt reading material to appropriate Lexile for struggling readers.

Vocabulary Definitions:
Nuclear binding energy – The energy that holds the protons and neutrons together in the nucleus of an atom
Fusion – A process where two small atomic nuclei join together to make a bigger nucleus, releasing energy
Mass defect – The difference between the actual mass of a nucleus and the total mass of the protons and neutrons if they were separate
Energy-mass equivalence ($E = mc^2$) – Einstein's equation that shows mass can be converted into energy, where a small amount of mass can create a large amount of energy
Nucleons – The particles in the nucleus of an atom—protons and neutrons
Binding energy per nucleon – The average amount of energy that binds each proton and neutron in a nucleus

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Experience the Phenomenon/Problem	
What Students Are Doing	**Teacher Tips**
- Students will answer the question, "What do you know about a Hydrogen Bomb?" as a class discussion. (Prior knowledge) - Students watch the video showing the explosion of a hydrogen bomb. - After the video, groups of three students will write three observations. (Question #1) - Student groups will also write one question per observation. (Question #1) - Students will then pick one question to be their guiding question for the lesson. (question #2) - Each group will share their guiding question as part of a class discussion. - Using their observations and driving questions, students will individually make a hypothesis by drawing a model of what they think is happening to hydrogen at the nuclear level through the hydrogen bomb. (question #3) - Students will answer question #4 on the worksheet and think about other things they need to know to complete their model.	The Teacher can determine how to engage students in questioning during the phenomenon that works best for classroom management. When groups are sharing their question with the class, start with a strong group to share. If other groups are struggling, they may be able to pull ideas that are being shared. Encourage students to pair and share observations and build on those observations to form questions.
What Teachers Are Doing	**Teacher Tips**
- Teachers will project the presentation and introduce the title of the lesson. (**Slide 1**). - Teachers *clearly* share the 3D objective with students. (**Slide 2**) - Teacher will ask students, "What do you know about a Hydrogen bomb?" and record student answers on the board to connect phenomena to prior knowledge. (**Slide 3**) - Teachers are instructing groups to record observations while viewing the phenomenon. After the phenomenon, instruct *groups* to develop questions based on observations (**Slide 4** – instruction note). Teachers will walk around and listen to different groups' ideas/questions. - Teachers will instruct each group to share their driving questions with the class. (**Slide 5**) - Once the class share is finished, instruct students to *individually* construct a model of their current ideas of what is happening at the nuclear level. (slide 6)	Use "nuclear," not "atomic," to avoid confusion with other nuclear processes. Groups should be in 3-4 students. For individual work, use prompts like "pens without friends." Some slides have instructional notes to help lead class discussions.

Investigate the Phenomenon	
What Students Are Doing	**Teacher Tips**
- In **Activity #1**, students will construct a graph of the mass and nuclear binding energy and then analyze the graph for patterns in mass and nuclear binding energy. (Question #5-6) - Students will develop an explanation of the relationship between the fusion of smaller atoms and the quantity of energy released. (Questions #8-9)	

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- Students will share how they used this information to revise their model with their group and the class. (Teacher-directed group and class discussion) - For **Activity #2**, students will individually read the Nuclear Fusion Article. They will answer the questions in activity #2. (#10-13) - At the end of Activity #2, Nuclear Fusion Article, students will determine what new information would help with their explanation and add it to their original model in a separate color. (question #14) - Students will share with their group and the class how they used this information to revise their model. (Teacher-directed group and class discussion) - **Activity #3**, PHET Build a Nucleus Simulation: Students will go to https://tinyurl.com/stablenucleus and analyze the energy and nucleons on the screen. - Students will use the arrows on the PHET simulation to create a specific stable nucleus in Task A (questions #15-17) - After building a specific stable nucleus, students make the nucleus for hydrogen-3 in Task B. Students will analyze what occurs to energy and "binding" of nucleons as mass changes (questions #18-21)	
What Teachers Are Doing	**Teacher Tips**
- For **activity #1**, teachers should describe nuclear binding energy and how a formed nucleus has lower energy and higher stability (**slide 7**). - Teachers should describe nuclear binding energy and how a formed nucleus has lower energy and higher stability (slide 7). - Next, teachers will direct the students to use the data in the table on the left of their worksheet to make a line graph (connecting the dots) on the grid on the right (**slide 8**). - While students are doing the graph, teachers should rotate around the classroom, helping students fill out the graph appropriately. - As the students finish their graphs, the teachers will direct them to answer the following questions (questions 5-8) to analyze what they learned from the data in the graph. - Using the chart on **slide 7**, the teacher will describe the arrangement of nucleons before and after a typical fusion reaction. They will instruct students to share what they add to their model with their partners (**slide 9**). - For **Activity #2**, the teacher will instruct groups to read the article individually and answer questions 9-12 (**slide 10**) - As students work on the questions, the teacher will circle the room and check for student understanding by reading student responses and formally assessing them by asking open-ended questions.	Be sure that all students have someone with whom to share their unstable nucleus. During the PHET simulation, walk the classroom to help troubleshoot and ensure students understand and follow directions.

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- As students complete the revising of their model after activity #2, the teacher will have the students share the revisions they made. Instruct the students that they can add anything their partner had to improve their model (**slides 11-12**). - The teacher will remind students to use a different color while adding to their model (**slide 12**). - At the end of activity 2, the teacher will review the main concepts the students need to learn from the article on nuclear fusion. Focus on nuclear binding energy, mass defect, and conservation of energy. Check for understanding of the concepts and answer any students' questions. - Before students begin **activity #3—Phet**, teachers will demonstrate the tools on the platform and important views such as the "energy axis" and "nucleons" and to minimize the "partial nuclide chart" (**Slides 13-14**) - Teachers will instruct groups to work in pairs to complete the PHET activity and share their understandings with their group.	If there is not enough time for the lesson in one class period, it is a good idea for teachers to review with the students at the beginning of the second day. Remind students of the phenomenon, the lesson's driving question, and the main concepts learned in each activity.

MODEL THE PHENOMENON

What Students Are Doing	Teacher Tips
- Using a fusion model, students will explain that in the nuclear FUSION process, the nucleon's nuclear binding energy is released when two smaller nuclei combine to form a single nucleus. - Students will collect and record evidence from each activity - Students develop a claim based on their evidence to explain the result of energy in fusion. - Students develop a diagram to explain the connection between the evidence and their claim. Key parts of the diagram include correctly labeling energy changes, using arrows to illustrate the flow of energy change, and relating changes in nuclear binding energy in the system.	
What Teachers Are Doing	**Teacher Tips**
- Evidence: Direct students to summarize the key points or data from each activity (**Slide 15**) - Claim: Direct students to create an explanation based on their evidence for why the fusion reaction releases energy. (**Slide 16**) - Reasoning: Explain that students will illustrate the connections between their claim and evidence with a model. The model should include the information on the checklist. (**Slide 17**) - Have the students turn in their work as they complete the Evidence–Claim–Reasoning assessment on their student worksheets.	You may want to print the final assessment on the student worksheet on a separate piece of paper to differentiate the learning process from the actual assessment.

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Possible extensions/Alternative Adaptations

Possible extensions include:

- Expanding activity #1: Exploring Fusion to include nucleons larger than lead. These nucleons would undergo fission to reach stability. Students could analyze the graph with larger nucleons and make predictions on the type of reaction that would occur and why. Then, students could use this information and potentially additional self-directed research to compare and contrast fusion and fission.
- This lesson focused on nuclear binding energy; however, stability is also a component of fusion. Students could return to the third activity, explaining nuclear binding energy, and analyze the chart to understand what occurs to nucleons regarding stability throughout fusion reactions.
- Students can initiate guided research to hypothesize how fusion could benefit populations as an alternative energy means. Some guiding questions could include: "What types of waste are produced from fusion reactions, if any?" "How much energy is produced from a small amount of fusion, and what would this mean in terms of powering a large city (or 'our' city)?" and "What are barriers to developing fusion as a form of usable energy?"

Possible Adaptations:

- SEP: A possible option is to focus on developing and using models as the primary or secondary science and engineering practice. Models are used in this lesson to produce a connection/reasoning between the evidence and the claim. However, they could also be used as a method for students to apply their understanding through developing and revising a model.
- Phenomenon: For Multi-Language Learners, consider teaming up in a group of 3 and modifying the introductory strategy. Begin the dialog with each group writing 8 words they think of when they hear "energy." Have groups share their list. As each group shares, the following group includes only the 'novel' words that have not been said in an earlier list. This can allow MLLs to associate energy with other English words and expand their language knowledge and understanding early on in the lesson. This strategy change to the phenomenon may also address language deficits that sometimes occur in individuals with disabilities.

- Activity #1: Students with limited exposure to science in elementary/middle school may struggle with reading the graph and, therefore, be unable to analyze it. Consider adding questions that engage struggling learners to identify parts of the graph, such as the labels on the axis and the trend or pattern they see.
- Activity #2: The article in Activity #2 has been modified to be appropriate for any student reading at the 8^{th}-grade level or higher. Consider reading in teams, or a class read for struggling readers. Have students circle or highlight parts they feel are important and underline words they feel unsure about. Use their 'reading notes' to direct discussion so students can 'define' the unknown words. Have students compare what they thought was important (circled or highlighted parts) with a shoulder partner and discuss why they felt it was important.

- Assessment: Students may need the question rephrased to develop a claim. Having clear expectations or a 'checklist' for what to include in a 'claim-evidence-reasoning' statement is helpful to students. Frequent exposure to this type of response is necessary to help students build the skill.

This lesson was created by Anna Lewin, Kaitlyn Mecham, Rachel Trujillo, Sam Loepker

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