Name: _____   Date: _____

Student Exploration: Nuclear Reactions

[Note to teachers and students: This Gizmo was designed as a follow-up to the Nuclear Decay *Gizmo. We recommend doing that activity before trying this one.]*

Vocabulary: chain reaction, CNO cycle, catalyst, deuterium, electron volt, fission, fusion, isotope, nuclear reaction, positron, positron emission, proton-proton chain

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

The chart to the right gives the **isotope** name, element name, number of protons, and number of neutrons of three isotopes.

Isotope	Protons	Neutrons
Hydrogen-1	1	0
Carbon-12	6	6
Uranium-235	92	143

1. What do you notice about the isotope number and the sum of protons and neutrons?

   _____

2. The element symbol for uranium-238 is $^{238}_{92}U$. This means U-238 has a total mass of 238 and contains 92 protons. Write the element symbols for the isotopes in the table:

   Hydrogen-1 _____   Carbon-12 _____   Uranium-235 _____

Gizmo Warm-up

The *Nuclear Reactions* Gizmo simulates a particle accelerator. Particle accelerators speed up atoms to very high velocities, then crash the atoms together with enough energy to cause changes called **nuclear reactions**. There are three particle beams available in this Gizmo, protons, neutrons, and helium-3 nuclei.
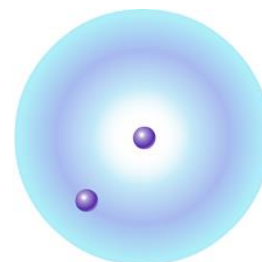
1. Click **Fire Proton** to engage the first particle beam.

   What happens? _____

2. Colliding particles don't always react. Click **Reset**, and then click **Fire neutron**.

   A. Does a reaction occur? _____

   B. Explain: _____

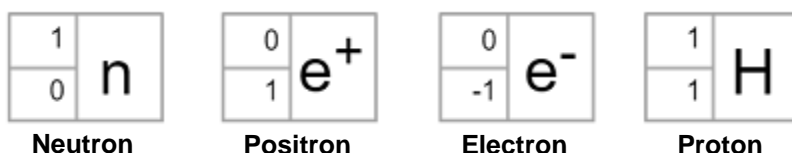| Activity A: Proton-proton chain	Get the Gizmo ready: • Click **Reset**. • Be sure **Proton-proton** is selected in the **Reaction** menu.	● Proton ○ Neutron

Introduction: All stars turn hydrogen into helium in a process called nuclear **fusion**. Stars perform this process in different ways. In stars like our sun, the **proton-proton chain** is used. This reaction requires temperatures greater than 4,000,000 K to occur.

Question: How does the process of fusion turn hydrogen into helium in stars?

1. Observe: Click **Fire proton** and observe. What happens after the proton merges into the

   nucleus? _____

   _____

   This is a form of nuclear decay called **positron emission**. During positron emission, a proton decays into a neutron. In this process, it emits a **positron**, which is a nearly massless antimatter particle with a positive charge.

2. Observe: Click **Reset** and click **Fire proton**. Observe what happens. Many subatomic particles appear frequently in nuclear reactions. Their element symbols are given below:

   $${}_{0}^{1}\text{n} \qquad {}_{1}^{0}\text{e}^{+} \qquad {}_{-1}^{0}\text{e}^{-} \qquad {}_{1}^{1}\text{H}$$

   Neutron   **Positron**   **Electron**   **Proton**

   (Neutrinos ${}_{0}^{0}v$ are also produced but are beyond the scope of this Gizmo.)

   Click **Reset** and click **Fire proton**. Turn on the **Write equation** checkbox. Based on what you have observed, write in the equation for this reaction in the Gizmo and below.

   $${}_{1}^{1}\text{H} \ + \ \boxed{} \ \rightarrow \ \boxed{} \ + \ \boxed{}$$

   A. Turn on **Show equation**. Was your predicted equation correct? _____

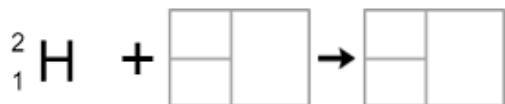   Correct your equation if necessary. The resulting H-2 isotope is called **deuterium**.

   B. Emitted energy is reported in megaelectron volts (MeV), where one MeV is equal to

      one million **electron volts**. How much energy is emitted in this reaction? _____

(Activity A continued on next page)

Activity A (continued from previous page)

3. Hypothesize: Click **Next**. In the next step, another proton will be fired at the hydrogen-2 atom. Make a prediction about what will happen by filling in the equation in the Gizmo and below, and then click **Fire proton**.

$$_1^2 H \ + \ \boxed{} \ \rightarrow \ \boxed{}$$

    A. Turn on **Show equation**. Was your predicted equation correct? _____

    B. Correct your equation if necessary. How much energy was emitted? _____

4. Apply: Click **Next**. The last step in this cycle involves two helium-3 atoms reacting. Click **Fire He-3**. Observe what happens, and then write an equation to describe this process.
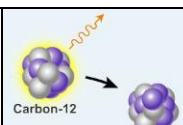
$$_2^3 He \ + \ \boxed{} \ \rightarrow \ \boxed{} \ + \ \boxed{} \ + \ \boxed{}$$

    A. Turn on **Show equation**. Was your predicted equation correct? _____

    B. Correct your equation if necessary. How much energy was emitted? _____

5. Calculate: To find the total energy emitted in the proton-proton chain, you have to consider the fact that *two* He-3 atoms must be created to form the final He-4 atom. Write the energy produced in each step, and then find the sum of all of these energies using the table below.

	First step (H-2 created)	Second step (He-3 created)	Last step (He-4 created)	Total energy
First He-3 atom				
Second He-3 atom				

6. Extend your thinking: To determine the net equation for the conversion of hydrogen-1 to helium-4, list the equations for each step of the proton-proton chain in the space at right. (Write two equations for the first step and the second step, because these are repeated.)

Next, cross out any elements that appear on both sides of the equation. Anything that remains makes up the net equation.

| Activity B:

CNO Cycle | Get the Gizmo ready:

• In the **Reaction** menu, select **CNO cycle**.
• Select the **Write equation** checkbox. |
Carbon-12 |

Introduction: In stars larger than the Sun, the CNO cycle is the main pathway for fusion. In this reaction cycle, a heavy atom like carbon or oxygen participates in each step. At the end of one cycle, the original heavy atom has been recreated and hydrogen has been transformed into helium. This reaction begins when temperatures reach 15,000,000 K or more.

Question: How do large stars form helium from hydrogen through fusion?

1. Observe: The Gizmo starts with an atom of carbon that reacts with the first hydrogen atom, and produces only one product. Click **Fire proton** to see what happens.

    A. What did you see? _____

    B. Turn on **Write equation**. In the space below and in the Gizmo, write a balanced equation for this reaction. Then, turn on **Show equation** to check your work.

    $^{12}_{6}C$ + ☐☐ → ☐☐

2. Predict: Click **Reset**. Go through the steps of the CNO cycle. Before each step, make a prediction about what the reaction will be, and type it into the Gizmo. You can use the information in the Gizmo to help you. As you check your answers in the Gizmo, write down the correct reaction below. Record the energy emitted in each step as well.

Step	Equation	Energy emitted
1	$^{12}_{6}C$ + ☐☐ → ☐☐	
2	$^{13}_{7}N$ → ☐☐ + ☐☐	
3	$^{13}_{6}C$ + ☐☐ → ☐☐	
4	$^{14}_{7}N$ + ☐☐ → ☐☐	
5	$^{15}_{8}O$ → ☐☐ + ☐☐	
6	$^{15}_{7}N$ + ☐☐☐ → ☐☐☐ + ☐☐	

(Activity B continued on next page)

Activity B (continued from previous page)

3. <u>Calculate</u>: What is the total energy emitted by the CNO cycle? _____

   How does this value compare to the energy released in the proton-proton chain? _____

   _____

4. <u>Analyze</u>: As you did with the proton-proton chain, determine the net equation for the CNO cycle. In the space at right, write the equations of the CNO cycle in a column. Then, cross out any substances that appear on both sides. Write the remaining substances at the bottom. This is the net equation for the CNO cycle.

   A. What is the net equation for the CNO cycle?

      _____

   B. How does the net equation for the CNO cycle compare to the net equation for the proton-proton chain?

      _____

      _____

   C. How does this help explain what you observed in question 4 above? _____

      _____

      _____

5. <u>Interpret</u>: A **catalyst** is a substance that takes part in a reaction without being consumed. In what ways is the carbon in the first step in the CNO cycle similar to a catalyst?
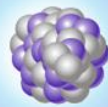
   _____

   _____

6. <u>Make a connection</u>: Many scientists feel that fusion would be a great way to generate electricity the future. What is the biggest obstacle to harnessing the energy of fusion?

   _____

   _____

| Activity C:

Fission | <u>Get the Gizmo ready</u>:

• Select **Fission** from the **Reaction** menu.
• Be sure **Write equation** is turned on. | |

Introduction: Fission is the splitting of an atom. In a fission reaction, large atoms like uranium-235 become two smaller atoms. The resulting isotopes are often radioactive, and undergo additional nuclear reactions to form a variety of products.

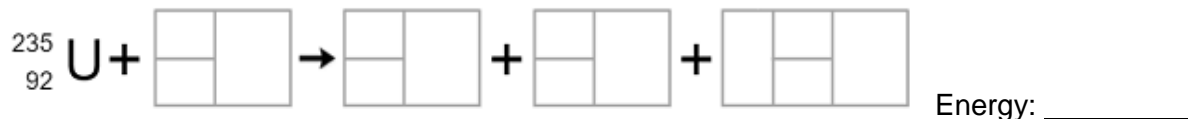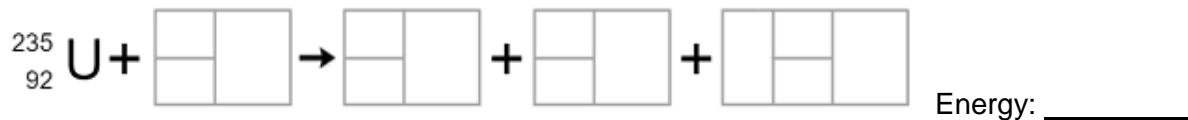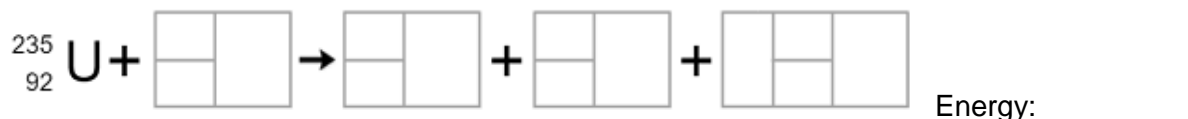**Question: How does a nuclear reactor produce power?**

1. <u>Observe</u>: Click **Fire neutron**. Describe your observations. _____

   _____

   How much energy was released? _____

2. <u>Predict</u>: Based on what you observed, write a balanced nuclear equation. Check the **Show equation** checkbox to check your work. Correct your equation if needed.

$$^{235}_{92}U + \boxed{} \rightarrow \boxed{} + \boxed{} + \boxed{}$$

3. <u>Explore</u>: Nuclear fission does not always result in the same products. Click **Reset**, and then launch another neutron. Record your observations and repeat this process. What are the three fission reactions modeled in this Gizmo, and how much energy does each produce?

$$^{235}_{92}U + \boxed{} \rightarrow \boxed{} + \boxed{} + \boxed{}$$ Energy: _____

$$^{235}_{92}U + \boxed{} \rightarrow \boxed{} + \boxed{} + \boxed{}$$ Energy: _____

$$^{235}_{92}U + \boxed{} \rightarrow \boxed{} + \boxed{} + \boxed{}$$ Energy: _____

4. <u>Analyze</u>: Are all of these nuclear equations balanced? In other words, do they all have the same number of positive charges and same mass on both sides of the equation? Explain.

   _____

   _____

(Activity C continued on next page)

Activity C (continued from previous page)

5. <u>Draw connections</u>: The uranium fission reactions are triggered by a neutron, and each reaction produces two or three more neutrons. What do you think will happen next?

    _____

    _____

    When the product of one reaction causes another reaction to start, it is called a **chain reaction**. In the case of nuclear fission, the number of atoms undergoing fission can multiply exponentially with the potential to release an enormous amount of energy. In a nuclear power plant, many safeguards are in place to keep the reaction under control.

6. <u>Compare</u>: In the spaces below, list the amounts of energy released by the proton-proton chain, the CNO cycle, and nuclear fission. (For fission, list the average emitted energy.)

    Proton-proton chain: _____   CNO cycle: _____   Fission: _____

    Based on these numbers, which reaction yields the most energy? _____

7. <u>Analyze</u>: Fission produces a lot of energy, but it involves very heavy atoms. A uranium atom has 235 times the mass of a hydrogen atom. A better way to compare the energy released in each reaction is to consider how much energy is release per atomic mass unit (amu). To find this value, divide the emitted energy by the mass of the reactants in the table below.

Reaction	Energy released	Mass of reactants	Energy/amu
Proton-proton		4 amu (4 H-1 atoms)	
CNO cycle		4 amu (4 H-1 atoms)	
Fission		235 amu (U-235)	

    Based on this table, does fission or fusion release the most energy per amu? _____

8. <u>Infer</u>: Suppose the same mass of fuel was used in a fusion reaction and a fission reaction. About how many times more energy would be released by the fusion reaction?

    _____   Show your work:

    Today, nuclear power plants rely on fission. While fusion reactions have been used in nuclear bombs, many scientists and engineers hope that in the future we can use fusion to produce energy. What are some possible advantages of fusion energy over fission energy?

    _____

    _____

    _____