POWER SOURCES CHALLENGE

FUSION PHYSICS! A CLEAN ENERGY

Summary: What if we could harness the power of the Sun for energy here on Earth? What would it take to accomplish this feat? Is it possible?

Many researchers including our Department of Energy scientists and engineers are taking on this challenge! In fact, there is one DOE Laboratory devoted to fusion physics and is committed to being at the forefront of the science of magnetic fusion energy.

In order to understand a little more about fusion energy, you will learn about the atom and how reactions at the atomic level produce energy.

Background: It all starts with plasma! If you need to learn more about plasma physics, visit the Power Sources Challenge plasma activities.

The Fusion Reaction that happens in the SUN looks like this:

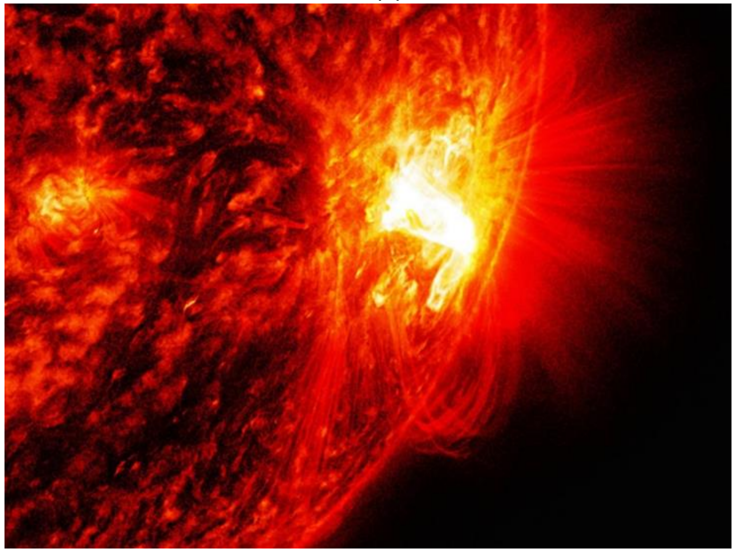


Photo by Department of Energy

Fusion reactions occur when two nuclei come together to form one atom. The reaction that happens in the sun fuses two Hydrogen atoms together to produce Helium. It looks like this in a very simplified way: H + H → He + ENERGY. This energy can be calculated by the famous Einstein equation, $E = mc^2$.

Each of the colliding hydrogen atoms is a different isotope of hydrogen, one deuterium and one tritium. The difference in these isotopes is simply one neutron. Deuterium has one proton and one neutron, tritium has one proton and two neutrons. Look at the illustration—do you see how the mass of the products is less than the mass of the reactants? That is called a mass deficit and that difference in mass is converted into energy. A really important note is that for a very small change in mass, an enormous amount of energy is produced. How can scientists and researchers simulate this reaction that happens in the sun here on earth to produce energy?

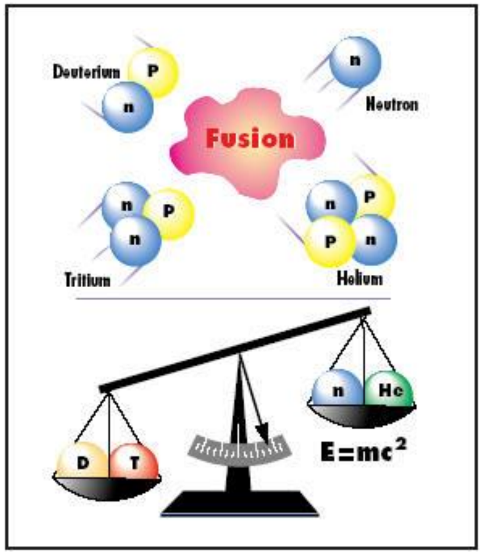


Illustration by U.S. Department of Energy

From a small change in mass, an enormous amount of energy is produced, and has the potential to be an inexhaustible source of energy.

Learning Objectives - After this activity, students should be able to:

- Describe atomic structure including sub-atomic particles and their charges
- Define fusion reactions
- Understand the differences in the isotopes of hydrogen
- Model a fusion reaction to understand how nuclei come together and how that affects energy
- Using the mass deficit to understand nuclear energy
- Design a project to explain fusion using art and/or media

Introduction: Fusion is the process that powers the sun and the stars. In one example of this type of reaction, two atoms of hydrogen combine together to form an atom of helium. In the process, some of the mass of the hydrogen is converted into energy. The easiest fusion reaction to make happen combines deuterium with tritium to make an atom of helium. Nuclear fusion depends on three things; high density of particles, close proximity of the particles to one another and a high rate of speed. Since we cannot duplicate the high gravitational field of the sun (which causes the high density—specifically atoms being very close together), we can increase the nuclei's rate of speed by heating to more than 4 times the temperature of the sun.

The chemical formula for water is H_2O, so there are 2 hydrogen atoms in every water molecule. One out of every 6500 atoms of hydrogen in ordinary water is deuterium, giving a gallon of water the energy potential of 300 gallons of gasoline. In addition, fusion is environmentally friendly because it produces no combustion products or greenhouse gases.

While fusion is a nuclear process, the products of the fusion reaction (helium and a neutron) are not intrinsically radioactive. Short-lived radioactivity may result from interactions of the fusion products with the reactor walls, but with proper design a fusion power plant would be passively safe, and would produce no long-lived radioactive waste. Design studies show that electricity from fusion should eventually be about the same cost as present day sources.

We're getting close! While fusion sounds simple, the details are difficult and exacting. Heating, compressing and confining hydrogen plasmas at 100 million degrees is a significant challenge. A lot of science and engineering had to be learned to get fusion to where we are today.

Magnetic fusion programs expect to build their next experiments, which will produce more energy than they consume within the next 15 years. If all goes well, commercial application should be possible by the middle of the 21st century, providing humankind a safe, clean, inexhaustible energy source for the future.

Magnetic Fusion: Magnetic fields affect the flow of electricity, simply by directing how electrons move. Magnetic fusion uses magnets to fuse hydrogen particles together to form plasma. The energy released from 1 gram of fused Deuterium equals the energy from about 2400 gallons of oil. That is a LOT of clean energy to help us answer our energy challenges!

Activities:

Materials:

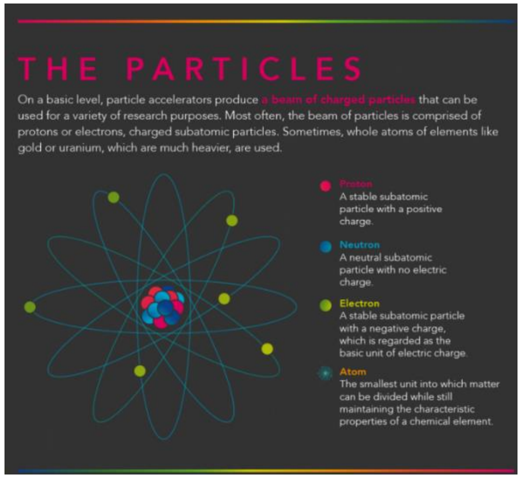
- Copies of Mini-Modeling template
- Mini-candies
- 2 long magnets and iron filings
- Copies of A STAR FOR US illustrated science booklet
- Props for multimedia presentation
- Recording device (a smartphone will suffice)

In the following activities, you will learn about the structure of sub-atomic particles, specifically the difference in the isotopes of hydrogen. You will use your knowledge of the atomic structure of hydrogen and its isotopes to design a multimedia presentation describing what happens in a fusion reaction. The Power-Up activities that support this lesson will help you understand the particles that contribute to a fusion reaction as well as having a basic understanding of the transfer of a loss in mass, to energy.

Mini-Modeling the Atom: Have you ever wondered what constitutes the atoms that make up everything we know? This activity will help you visualize these particles, where they are located in the atom, and the difference in their charges.

As we talk about sub-atomic particles, what do they look like in an atom and how are they arranged? Can you model the difference in the three isotopes of hydrogen?

You will need the attached Mini-Modeling Map and mini-candies. You can choose one color of the candy for protons, a different color for neutrons, and a third color for electrons. Can you model the three different isotopes of hydrogen on your modeling map? Can you model an atom of helium that was formed by fusion?



Infographic by Department of Energy

Examine your models and compare to the illustration. Refer to the power-up activity for a more detailed explanation for this activity.

Feel the Force: Students will use magnets and magnetic iron filings to model fusion. This will help students understand the force of a magnetic field and how that contributes to fusion reactions.

What is magnetic fusion? How does a magnetic field work to help particles come together?

Take two magnets and examine them separately. As you start to bring the magnets together, what do you observe? When two particles fuse together, they make a new substance. Using your sense of touch, what differences do you feel? Rotate the magnets and repeat observations.

Now that you have felt the force of a magnetic field, you can actually "see" that force using iron filings. Take one of your magnets and place it under a white sheet of paper. Use a small amount of iron filings and sprinkle them on top of the paper just above the magnet. What do you see?

Collect your iron filings from the paper. Now place your two magnets parallel to each other. In the same way as the first map, place your white sheet of paper over the magnets and sprinkle the iron filings on the paper. What do you observe this time? How is it different from the first map?

You might want to sketch what you see with each map or take a picture if you have a camera, that way you can compare the difference in the two pictures.

YOU be the STAR (like the Sun)! Now that you have learned about magnetic fusion and how it might help solve our future energy challenges, you will have the opportunity to shine (just like the sun!). For this activity, you will use your creativity and imagination, just like the designers of the science booklet "A Star for Us".

You will be on a team with three other students or friends and brainstorm your ideas. Your mission will be to use any media (visual, song, video, skit, etc) to help others your age understand magnetic fusion as a clean energy. You will capture your explanation in a recording no longer than 5 minutes.

Make sure you have the following: Title, Authors, Definition of Fusion and Wrap-up. Ideally, you will post to an online secure video channel. Have fun!

Next Generation Science Standards (4,5 and MS):
Students who demonstrate understanding can:

- 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- 4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.
- 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- 5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.
- 5-PS1-3. Make observations and measurements to identify materials based on their properties.
- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
- MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
- MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
- MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Science and Engineering Practices:

- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships. (4-PS3-3)
- Make observations to produce data to serve as the basis for evidence for an explanation of a
- phenomenon or test a design solution. (4-PS3-2)
- Use evidence (e.g., measurements, observations, patterns) to construct an explanation. (4-PS3-1)
- Develop a model to predict and/or describe phenomena. (MS-PS1-1),(MS-PS1-4)
- Develop a model to describe unobservable mechanisms. (MS-PS1-5)
- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)
- Apply scientific ideas or principles to design an object, tool, process or system. (MS-PS2-1)

Disciplinary Core Ideas:

- Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (4-PS3-2),(4-PS3-3)
- Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2),(4-PS3-4)
- Energy and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not. (4-ESS3-1)
- The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish. (5-PS1-2) Measurements of a variety of properties can be used to identify materials. (Boundary: At this grade level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation.) (5-PS1-3)

- No matter what reaction or change in properties occurs, the total weight of the substances does not change. (Boundary: Mass and weight are not distinguished at this grade level.) (5-PS1-2)
- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. (MS-PS1-1)
- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. (MS-PS1-3)
- Some chemical reactions release energy, others store it. (MS-PS1-6)
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. (MS-PS2-3)
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively). (MS-PS2-5)

Crosscutting Concepts:

- Energy can be transferred in various ways and between objects. (4-PS3-1), (4-PS3-2),(4-PS3-3),(4-PS3-4)
- Over time, people's needs and wants change, as do their demands for new and improved technologies. (4-ESS3-1)
- Natural objects exist from the very small to immensely large. (5-PS1-1)
- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. (MS-PS1-1)
- Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. (MS-PS1-3)
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-PS1-3)
- Macroscopic patterns are related to the nature of microscopic and atomic-level structure. (MS-PS1-2)

Sources:

- A Star for Us: http://www.pppl.gov/sites/pppl/files/basic_pages_files/PPPL_AStarForUs_fusioncomic_download.pdf
- Next Generation Science Standards: www.nextgenscience.org

POWER SOURCES CHALLENGE

POWER UP ACTIVITIES – FUSION PHYSICS

ACTIVITY ONE:

MINI-MODELING THE ATOM

Have you ever wondered what makes up the atoms that make up everything we know? This activity will help you visualize these particles, their location in the atom, and their differences in charge.

Question:

As we learn about sub-atomic particles, what do they look like in an atom and how are they arranged? Can you model the difference in the three isotopes of hydrogen?

Explore:

You will need the attached Mini-Modeling Map (please provide a link for downloadable mini-modeling template that I sent you here) and mini-candies. You can choose one color of the candy for protons, a different color for neutrons, and a third color for electrons. Can you model the three different isotopes of hydrogen on your modeling map? Can you model an atom of helium that was formed by fusion?

Explain:

Isotopes of an atom have the same number of protons but vary in the number of neutrons. Protons and neutrons reside in the nucleus (the center of the atom) and electrons move quickly through clouds of specific levels surrounding the nucleus. Hydrogen's most abundant isotope (99.98%) contains 1 proton, 0 neutrons and 1 electron. Deuterium (or heavy hydrogen) has 1 proton, 1 neutron and 1 electron. Tritium is present is minute amounts and has 1 proton, 2 neutrons and 1 electron. (this is already in the next column)

Check your pictures with the ones below. What color was used for proton, neutron and electron? Can you deduce which isotope is which from looking at each image?

ACTIVITY TWO:

FEEL THE FORCE

Students will demonstrate modeling fusion using magnets and magnetic iron filings to understand the force of a magnetic field and how that contributes to fusion reactions.

Question:

What is magnetic fusion? How does a magnetic field work to help particles come together?

Explore:

Take two magnets and examine them separately. As you start to bring the magnets together, what do you observe? When two particles fuse together, they make a new substance. Using your sense of touch, what differences do you feel? Rotate the magnets and repeat observations.

Now that you have felt the force of a magnetic field, you can actually see that force using iron filings. Take one of your magnets and place it under a white sheet of paper. Use a small amount of iron filings and sprinkle them on top of the paper just above the magnet. What do you see?

Collect your iron filings from the paper. Now place your two magnets parallel to each other. In the same way as the first map, place your white sheet of paper over the magnets and sprinkle the iron filings on the paper. What do you observe this time? How is it different from the first map?

You might want to sketch what you see with each map or take a picture if you have a camera, that way you can compare the difference in the two pictures.

Explain:

You have just mapped a magnetic field! You can trace the force that you felt by looking at the pattern of the iron filings. Magnetic fields affect the flow of electricity, simply by directing how electrons move. Magnetic fusion uses magnets to fuse hydrogen particles together to form plasma. These reactions produce energy. Scientists and engineers can direct the flow of charged particles by varying the number and the strength of the magnets. Compare your pictures to the one below, how are they alike or different?

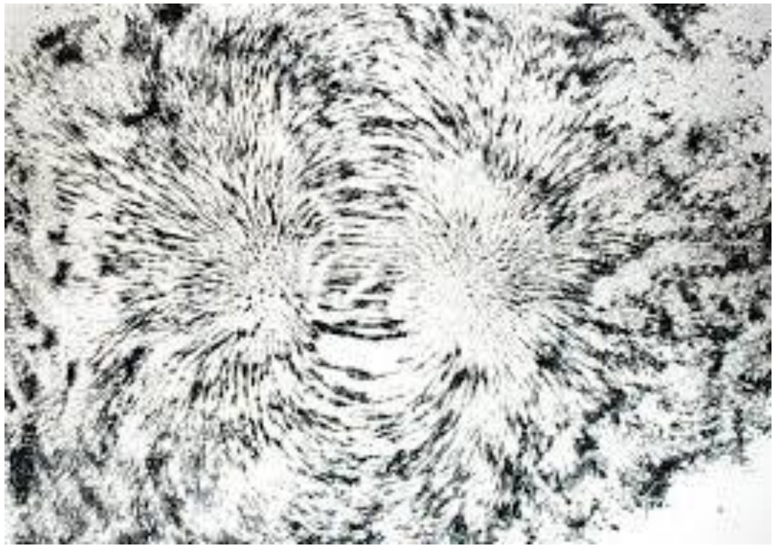


Photo from Wikimedia.org

ACTIVITY THREE:

A SWEET MODEL FOR FUSION

Students will use cookie dough to model fusion and the energy emitted through the mass deficit.

Question:

How can you model fusion and mass deficit?

Explore:

You will use two pieces of cookie dough, a balance and a microwave oven to perform this activity. You can also use an add-in such as a chocolate chip, raisin, cranberry or nut to place in the dough to represent protons and neutrons.

Take your raw dough and place the correct number of “add-ins” to represent protons and neutrons in the center. Roll into a sphere and place very close together (but not touching) on a paper plate. If you can, take the mass or weigh the dough before you cook it. Then place the dough in a microwave oven following directions on package for cook time. What happened to the two spheres? How do they look now? If you can mass or weigh the product, did you note a difference?

After making your observations and capturing “before” and “after” images, you may eat your new element!

Explain:

Fusion reactions occur when two atoms come together or fuse to form a new atom. You used two small separate pieces of dough, and after you added energy (by heating in a microwave), they became one piece. If you used add-ins to represent protons and neutrons, you made a new element because of the different amounts of protons and neutrons.

Mass deficit occurs differently in your model and in nuclear fusion reactions such as the one in the sun. If you massed your cookie dough before and after you cooked it, you should have seen a difference. Do you know why there was a difference? When baking cookies, you turn some of the water in the dough into a vapor that escapes when you open the microwave door!

But nuclear fusion is much different. The Law of Conservation of Mass states that the mass of the reactants in a chemical reaction should be equal to the mass of the products. If there is a difference, then that mass has been converted to energy according to the equation E=mc2. For very small changes in mass, there is a tremendous amount of energy produced.

Photo by commons.wikimedia.org

ACTIVITY FOUR:

STEM + A (Art)=STEAM

This power-up activity introduces students to a creative and imaginative way to learn about nuclear fusion.

Question:

How can artists use their talents in STEM?

Explore:

Read the PPPL (Princeton Plasma Physics Laboratory) beautifully illustrated attached science booklet and think about ways to involve your unique talents to intersect with STEM disciplines.

Explain:

STEM disciplines are a wonderful place to use ALL of your talents. Science and engineering involve creative thinking to discover innovative ideas and methods. Engineering requires innovative design and original ideas to iterate and improve prototypes. This science booklet can help you think about the different ways we can think about science topics such as magnetic fusion energy and illustrate those topics for all to understand.