BEAMenheimer

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Field(s) of Interest: Physics, Nuclear Energy, Nuclear Reactions

Brief Overview (1-3 sentences):
Mentees will be introduced to the concept of nuclear physics through a game- and craft-based lesson designed to mimic the processes that occur on the atomic level. Mentees will begin learning about the structure of the atom by crafting their own atom before then imitating nuclear reactions through a ping pong ball activity. Finally, the lesson will end with students learning about energy and shielding through an activity where they determine the effectiveness of shielding of specific materials, before playing a game where they are able to “shield” other mentees from a flashlight.

Agenda:
- Introduction (5 mins)
- Module 1: The Atom and Its Parts (15 mins)
- Module 2: Nuclear Reactions (20 mins)
- Module 3: Energy and Radiation (15 mins)
- Conclusion (5 mins)

Main Teaching Goals/Key Terms:	**Mentor Development Goals:**
➔ **Atom** ➔ **Nucleus** ➔ **Electron** ➔ **Nuclear Reaction** ➔ **Fission** ➔ **Fusion** ➔ **Chain Reaction** ➔ **Energy** ➔ **Radiation** ➔ **Shielding**	

Background for Mentors

Module 1

- **Atom**
- **Nucleus**
- **Electron**
- **Proton**
- **Neutron**
- **Periodic Table**

We can divide everything into smaller and smaller pieces, until we get to the smallest piece of matter, called the **atom**. The atom is composed generally of two parts, the **nucleus** and **electrons**. The nucleus is further composed of two types of subatomic particles: the positively-charged **proton** and the neutral **neutron**. These particles are bound together by a force called the strong force.

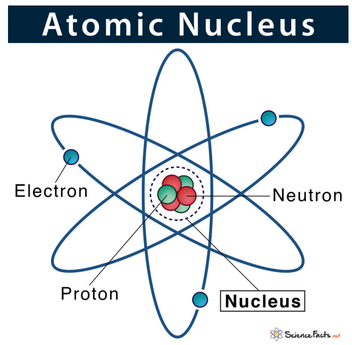

Figure 1. A diagram of the atom labeling all of its parts

The electron is a negatively charged particle that is orders of magnitude lighter than the nucleus. These particles orbit the nucleus in a range of distances, not exactly as displayed in **Figure 1**, but somewhat similarly. In order for a particle to be considered an atom, rather than an ion, the total charge must be neutral. This means that the number of protons in the nucleus has to be the same as the number of electrons orbiting the atom. An atom is assigned an identity based on the number of protons in its nucleus, with the number of neutrons being able to vary. We organize atoms based on their types with the **periodic table**, where types of atoms (elements) are listed from left to right, in order with their increasing number of protons.

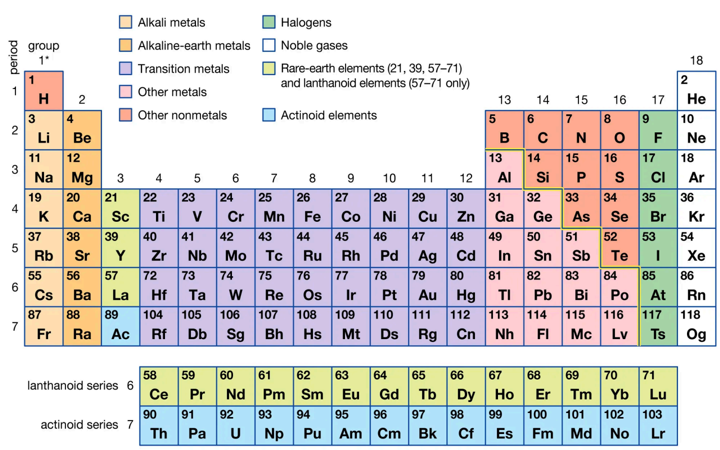

Figure 2. The Periodic Table of Elements

Module 2

- **Nuclear Reaction**
- **Fission**
- **Fusion**
- **Chain Reaction**
- **Laws of Conservation**

A **nuclear reaction** occurs when the nuclei of two atoms interact to release energy. There are two types of nuclear reactions, called **fusion** and **fission**. Fusion is the process by which two smaller nuclei, typically hydrogen or helium, collide and form a new, larger nucleus. Contrary to what you might initially think, this reaction actually generates energy, and is actually what powers our sun. This is due to the fact some of the mass of the two nuclei is actually converted into energy when they collide in accordance with Einstein's famous equation $E = mc^2$. This is in accordance with the **Laws of Conservation**, which state that mass and energy can never be destroyed, but can be converted from one to another. This type of reaction requires a huge amount of pressure and temperature to be applied, and as such we have yet to figure out an efficient way to generate electricity from it.

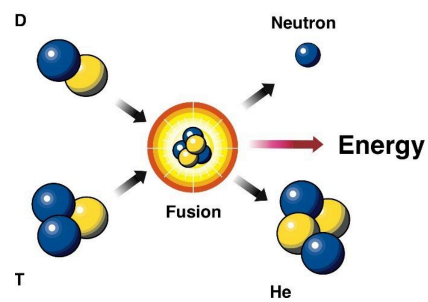

Figure 1. Fusion of two hydrogen isotopes to form a helium atom

A fission reaction differs from a fusion reaction in that the two are essentially opposites. While two atoms come together to form one in a fusion reaction, one atom breaks apart into two during a fission reaction. In order to initiate this breaking apart, neutrons are shot at a large, unstable nucleus in order to break it apart into two smaller nuclei. In breaking apart this big nucleus, energy is released.

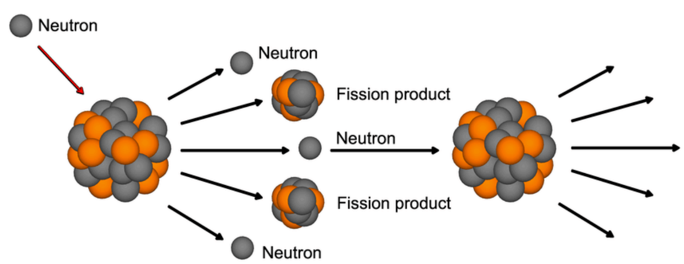

Figure 2. Fission of a large, unstable nuclei promoting fission of a second large, unstable nuclei

In breaking apart a large nuclei in a fission reaction, more neutrons are emitted which can then break apart further nuclei. We refer to this as a **chain reaction**, which allows the generation of a ton of energy from a very small sample. However, it can also make these reactions difficult to control.

Module 3

- **Energy**
- **Radiation**
- **Shielding**
- **Gamma Rays**
- **Beta Particles**
- **Alpha Particles**

Energy is simply defined as the ability of an object or system to do work. Energy comes in many shapes and forms, one of the most common of which is **radiation**. Radiation is a form of energy that travels in electromagnetic waves, and is the form of energy released from nuclear reactions. Radiation exists on a spectrum of energy, with lower frequency radiation such as visible light and radio waves being generally harmless to humans, but with higher frequency radiation such as x-rays or **gamma rays** being more damaging. Gamma rays specifically are the highest frequency form of electromagnetic radiation, and are thus very damaging to human tissues. These are also the form of radiation given off by nuclear reactions.

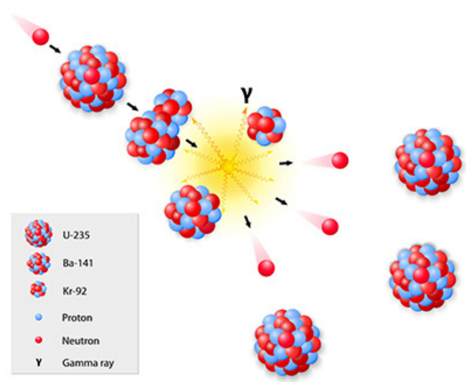

Figure 1. Fission reaction including gamma ray

Nuclear reactions also result in high-energy particles being emitted from the nucleus in the form of **alpha** and **beta particles**. However, even though nuclear reactions can generate all these nasty forms of energy, we have a way of protecting ourselves from them through **shielding**. Shielding is when we place a barrier between ourselves and a source of radiation that is able to block that radiation from reaching us, keeping us protected. Higher energy radiation requires much thicker shielding than lower energy radiation, meaning that while lead sheets may be required to protect us from gamma rays, the outer layers of our skin are enough to protect us from weaker emissions, such as alpha particles.

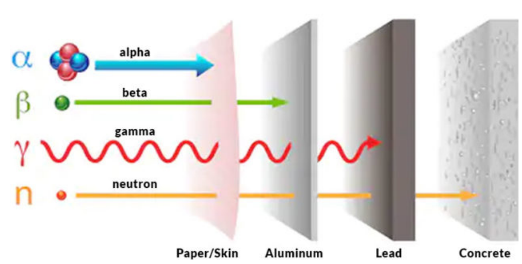

Figure 2. Effect of different types of shielding on different particles/radiation

Introduction

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Concepts to Introduce

- Subatomic Scale
  - While some mentees may have heard of atoms before, they might not have considered that the atom has even smaller parts
  - Compare the parts of an atom to the solar system; giving something they are more likely to have heard of helps
- Energy
  - Energy tends to be a little bit of a nebulous topic, so try and relate it to things they may have seen before
    - E.g. batteries, electricity, light bulbs, toaster, etc.

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Questions to Pique Interest

- What happens when we get down to the smallest possible piece of an object?
- What happens inside of a nuclear reactor?
- How can we use nuclear reactions to generate energy?
- How can we best protect ourselves from nuclear radiation?

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Scientists, Current and Past Events

- Albert Einstein's famous equation $E = mc^2$ models the conversion of mass to energy that we see in nuclear reactions
- In 2022, a fusion reaction was achieved for the first time where the amount of energy generated from the reaction was greater than the amount put in
  - link

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Careers and Applications

- Nuclear physicist - study atoms on the subatomic scale to understand their structure and interactions with other particles
- Nuclear engineers - design and test the tools and equipment required to operate and maintain nuclear reactors to generate electricity
- Nuclear medicine technologist - specializes in the preparation, administration, testing, and monitoring of radioactive substances to diagnose and treat illness

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Module 1: Protons are positively poggers

This is a craft-based module designed to introduce mentees to the atom and its parts. This activity can be made more complex through the construction of specific elements from the periodic table.

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Teaching Goals

Atom: The smallest bits of matter in our universe, they make up everything
Nucleus: The core of the atom, and the part that participates in nuclear reactions
Electron: Negatively charged particles that orbit the nucleus, they participate in most chemistry done with atoms, but not in nuclear reactions
Proton: A positively-charged subatomic particle that comprises part of the nucleus
Neutron: An uncharged subatomic particle that comprises part of the nucleus
Periodic Table: A table used to organize the elements in order of atomic number and electron configuration

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MD Goals

Understanding your mentees: Now that we are about halfway through the semester, mentors should have a better idea of their site's skill level. It can be useful to discuss beforehand (while site prepping, in the car ride, etc.) how many, if any, advanced teaching goals your site will cover with the mentees.

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Materials

Red, blue, and yellow pom poms
Craft wire
Glue
Scissors
Paper plate

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Different Methods for Teaching 1. **Atom:** Ask mentees to think of the smallest thing they can think of, then ask them if they can break it in half. Then ask them to imagine breaking that in half. Walk mentees through what would happen if they continuously broke that thing in half, until you inevitably get to the atom. 2. **Nucleus/Electron:** If your mentees are familiar with the solar system, a classic comparison of the atom is to that of the planets revolving around the sun. The planets do not collapse inwards, and keep moving around the sun in semi-set orbits. This is not really how electrons move, but it is a basic way of understanding that they center their

movement around the nucleus.

3. **Proton/Periodic Table:** IF your site is ready for this teaching goal, the periodic table and the proton can be discussed together, where the number of protons identify a type of atom, which can be found on the periodic table. This can be thought about as ordering an item from a fast food place - if you order a number 6, that can mean a burger + fries combo, just like how the number of protons, 6, can mean carbon on the periodic table.

Procedure

1. Give each mentee a few of each type of pom pom. It is important that the number of red pom poms are the same as the number of yellow pom poms. Give each mentee a paper plate as well.
2. Have mentees glue the red pom poms and black pom poms to the plate in a group. The resulting structure will be the nucleus of the craft atom.
3. Next, have mentees glue yellow pom poms around the nucleus in rings to represent the electrons orbiting the nucleus. Have mentees draw in lines to represent the orbits of the electrons.
4. (Optional) Cut down the plate using scissors to make the size of the diagram more proportional to the pom poms.
5. Poke a hole through the top of the diagram and loop some craft wire through. Twist the ends so that the wire makes a loop and the atom can be hung like a decoration!

Figure 1: *Gluing the nucleus to the plate*

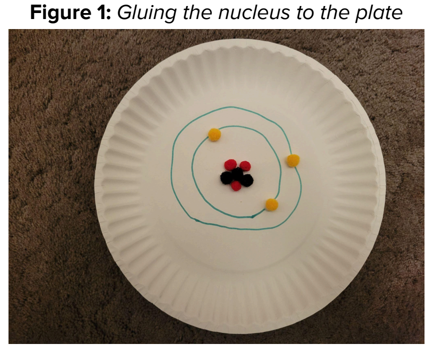

Figure 2: *Gluing on the electrons*

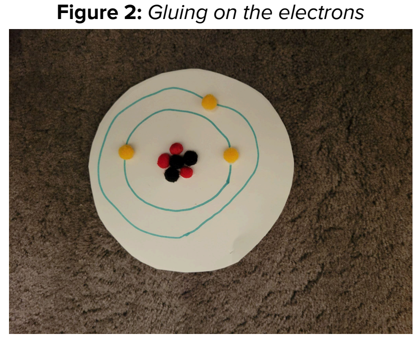

Figure 3: *Cutting it down to size*

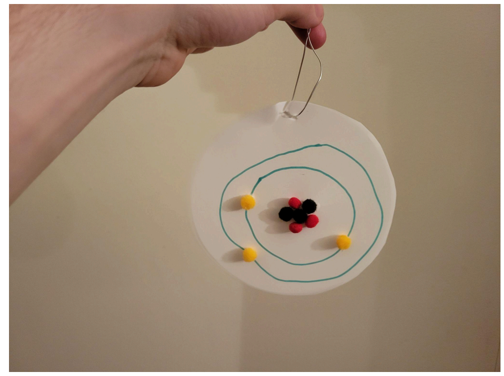

Figure 4: *The completed atom*

Classroom Notes

It may take a while for the glue to dry to get the pom poms to stick to the plate - make sure mentees do not disturb the craft while it is drying!

Module 2: Gone fission

This module will have mentees using ping pong balls to mimic nuclear reactions on a macroscopic scale.

Teaching Goals	Materials
Teaching Goals 1. **Nuclear Reaction:** A process in which the nucleus of an atom is changed via its interaction with another nucleus 2. **Fusion:** A nuclear reaction where two small nuclei collide and overcome their repulsive forces to combine 3. **Fission:** A nuclear reaction where a particle (neutron) collides with a nucleus, splitting it into smaller parts 4. **Chain Reaction:** The process by which the product of one nuclear reaction is able to start another nuclear reaction 5. **Laws of Conservation:** State that mass and energy can not be created nor destroyed, only converted from one form into another **MD Goals** 1. **Controlling the class:** With a high-energy activity such as this one, it can easily become very chaotic. Make sure to clearly explain what the ping pong balls represent before the activity begins, so that the	**Materials** • Ping pong balls

mentees are being more thoughtful with how they do the activity.	

Different Methods for Teaching

1. **Fusion:** Talk to mentees to hear where they might have heard the word “fuse” before. In this context, the word fusion is pretty much exactly as it sounds like - it is two smaller nuclei coming together to form a larger one! So if there are any Steven Universe or Dragonball fans in your crowd, they might have the right idea!
2. **Fission:** Once you’ve discussed what fusion is, you can introduce fission as the “evil twin” or something similar. The idea is that while these two processes may feel/sound similar, in reality they are basically opposites.
3. **Laws of Conservation:** Ask mentees if they have ever heard the word conserve before, and if they have what it means to them. Some mentees may have heard the term used in the context of conserving water or conserving the environment. In this case, we are saving energy/mass, just as when you conserve water you are saving it.

Procedure

1. Give each mentee a pair of ping pong balls. These balls will act as the mentee’s neutrons/nuclear fragments
2. Group the mentees together in a tight bunch. Each mentee will act as a fissile atom
3. Assign one mentor to be the “neutron/particle source.” This mentor will throw one ping pong ball into the group of mentees
4. Instruct mentees to throw their ping pong balls straight in the air if they are hit by *any* ping pong ball
5. The assigned neutron/particle source mentor will then throw their ping pong ball into the group of mentees. The ball will hit one mentee, who will throw their balls up into the air to hit at least one other mentee, who will throw theirs, causing a chain reaction

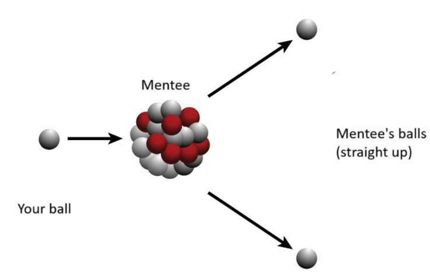

Figure 1. *The idea of the activity*

Classroom Notes
Make sure the mentees throw the balls straight up! We do not want mentees throwing balls directly at one another, as some mentees may get too excited and throw too hard.
Also! Before the activity begins, ask mentees to think about what will happen and make predictions - don't give away the chain reaction right away!

Module 3: Can you feel the Kenergy?

This module will focus on electromagnetic radiation and demonstrating how different forms of shielding better protect us from different forms of radiation.

Teaching Goals	Materials
1. **Energy:** The ability to do work 2. **Radiation:** A form of energy emitted during nuclear reactions as an electromagnetic wave; for the purposes of this lesson can be used interchangeably with **energy** 3. **Shielding:** A material that blocks electromagnetic radiation 4. **Alpha Particles:** A large particle given off during nuclear decay 5. **Gamma Rays:** A form of high-energy electromagnetic radiation that is very damaging to human DNA 6. **Beta Particles:** A small, high-energy particle emitted during radioactive decay that is damaging to human tissue	• Clear plastic bag • Paper sheets • Cardboard piece • Felt • Pie tin/Aluminum Tray • Brown paper bag • Flashlights

MD Goals

1. **Critical Thinking:** This activity requires mentees to think critically about how much shielding they need. Make sure to ask guiding questions that can help the mentees figure out these questions. When mentees weigh pros and cons of nuclear energy, remind the mentees of the teaching goals from all three modules.

Different Methods for Teaching

1. **Energy:** Talk to kids about things that make them feel energized - for example eating a lot of sweets. When they feel energized, they feel the need to move around, like running around the classroom, which is them doing work with the energy that they have in their system.
2. **Radiation:** This term can be used rather synonymously in this lesson with the concept of energy, as radiation is the form of energy released from nuclear reactions that we encounter most often on a daily basis. Radiation can be understood by mentees as behaving analogously to light - it can pass through certain things, but not others. Another example is infrared radiation, which can be experienced by us as heat. If you sit next to a heater and put a wall between you and it, you probably won't feel it, but a shirt won't have the same effect.
3. **Shielding:** You can compare types of shielding (lead, paper, skin) to the shield of a knight. A knight's shield may protect them from an arrow, but it won't help much against a cannon ball - in the same way different forms of radiation shielding are effective against some types of radiation but not others.

Procedure

Part 1:

1. First group mentees into groups of 3, 4, or 5 (depending on site size) and give each group a unique material for "shielding" and a flashlight to act as their "radiation" source
2. Ask mentees to determine how much of their shielding they need to use to hide their light.
3. Once each group has determined how much of their shielding they need to effectively "protect" them from the radiation, ask each

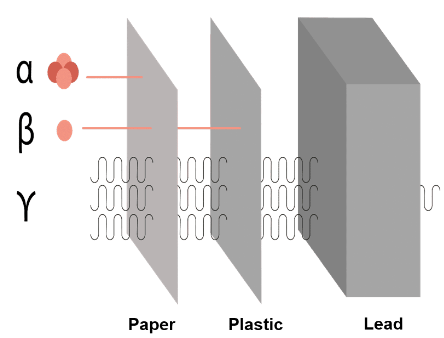

Figure 1. *Which material shields the best from gamma rays?* 🤔

group to share with the rest of the groups how much they needed, and why they think they needed more or less shielding compared to the other groups. Part 2: 1. Choose one of the groups at random to be the radiation “shielders” and the rest of the groups to be the radiation “detectors” 2. Have the “detectors” close their eyes/lower their heads while the “shielders” find a good place to hide their flashlight 3. The “shielders” will hide their flashlight somewhere in the room a. It is up to site discretion whether or not to leave the lights on for hiding/seeking in this activity 4. Once the flashlight is hidden, the “detectors” will then be allowed to look for and find the hidden source of radiation 5. Once the flashlight is found, the group who found it will be allowed to their flashlight next, unless they have already previously hidden it, in which case another group should be given a chance to hide their flashlight 6. Repeat this at least until each group has been given a chance to hide their flashlight	

Conclusion

With the discussion of energy and radiation finished, ask mentees to weigh the pros and cons of using nuclear reactions. Share with your mentees fields in which these reactions are used, and ask them what they think about those applications. Decide with your mentees as a group if you think that nuclear energy is an overall good or bad thing.

Summary Materials Table

Material	**Amount per Site**	**Expected $$**	**Vendor (or online link)**
Pom poms			

Craft wire			link
Glue			
Tape			
String			
Paper plates			
Magnet balls ?			link
Ping pong balls			
Felt			
Pie tin/aluminum tray			
Plastic bag			
Paper bag			
Paper sheets			
Flashlight	1		link

References

1. Atom construction craft: https://kidsactivitiesblog.com/7833/atom-for-kids/
2. Ping pong activity: https://www.ansto.gov.au/media/2830/download?inline
3. Shielding activity: https://hps.org/sciencesupport/documents/elementary_radiation.pdf