Lesson 3: Nuclear Fission

Why does Rutherford's discovery matter? In this activity, students will learn how nuclear fission works. They will see an example of fission using balloons and marbles. They will define chain reaction in their own words after watching a demonstration using mousetraps and ping pong balls.

Objectives

- Students will be able to describe fission and list technologies that use fission
- Students will be able to explain what a chain reaction is
- Students will be able to compare the mousetrap demonstration to nuclear fission

Materials Provided

- 2 Balloons with marbles inside
- 1 empty balloon
- 35 mousetraps
- 36 ping pong balls
- CD with Mousetrap video and fission PowerPoint

Materials Needed

- Laptop, projector and speakers
- Enclosure for mousetraps – made of cardboard, posterboard, etc.

If desired:

- More ping pong balls and mousetraps for a larger reaction

Advanced Preparation

- Edit PowerPoint for your needs. It is currently geared toward a high school class but can be simplified.
- Practice your own mousetrap demonstration
- Set up the mousetrap demonstration
- Prepare the balloon demonstration: Put the Ba-141 and Kr-92 balloons inside of the U-235 balloon with the 2 marbles in it. Then either 1. Blow the balloon up a medium amount and tie it off or 2. Just tie it off as is. See the In the Classroom section for more details.

In the Classroom

1. Explain to students that Rutherford's discovery had many important results (for older students ask them to explain why the discovery was important).

2. Go through fission PowerPoint with the class. Or for younger students, you can just explain what fission is in simple terms without the PowerPoint. After the first slide (Fission: splitting the nucleus), do the balloon fission demonstration.

3. Balloon Fission Demonstration: There are two suggested ways to do the balloon fission demonstration. Both have their pluses and minuses.

Version 1: Blow air into the Uranium-235 balloon and tie it off. Then hang it from a hook or using tape from the wall. Throw a marble with a thumb tack taped to it at the balloon like you're throwing a dart. The balloon pops releasing 2 additional marbles and 2 daughter products. The pluses of this one are that you use the marble (neutron) to start the fission and the balloon popping makes it exciting. The minuses are that blowing the air in the balloon does not represent the structure of real nuclei and you can't see the bumps of the marbles in the balloon as well.

Version 2: Tie the Uranium-235 balloon off without blowing it up. Then to start the fission you rip open the balloon with your hands/with a sharp point. The plus of this version is that you can see the bumps of the marbles (protons and neutrons) in the balloon. The minuses of this version are that ripping the balloon doesn't use a marble (neutron) to start the fission and it is not as exciting.

Things to explain during the demo: The balloon represents the nucleus of the Uranium-235 atom. The 235 means that there are 235 total protons and neutrons in the nucleus. Marbles represent protons and neutrons. In a uranium atom, the diameter of the uranium nucleus is 23,000 times smaller than the diameter of the uranium atom itself. Therefore, since the balloon nucleus is about 6 inches long, the edges of the uranium atom---meaning its outermost electrons--- would be 1.1 miles away. Have students guess how far away the edges of the atom would be. Make sure to stress the scale of the atom, as it is hard to wrap your mind around the scale of the nucleus and atom. After doing the fission, discuss what comes out of the balloon: daughter products Barium-141 and Krypton-92 and two additional neutrons, making a net 3 neutrons from the reaction. Explain that these neutrons travel "several miles" to other uranium atoms which then release more neutrons and so on, creating a chain reaction.

4. Finish the PowerPoint on fission.

5. Do the mousetrap chain reaction demonstration. See next page for mousetrap demonstration advice. (Note: if you don't have enough set-up time for an event, you can just show the mousetrap video.) After you do the demonstration, show the mousetrap video so that students can see the reaction in slow motion. (You can show the video that we made OR make your own video)

7. Discussion: Have the students to define chain reaction based on the video they just saw. Talk about how the mousetraps work as a model for nuclear fission – where does the model work and where does it break down?

Works	Breaks Down
• Mousetraps are unstable like Uranium atoms • When a ping pong ball hits a mousetrap, 2 ping pong balls leave the reaction and in a fission, sometimes the reaction produces 2 neutrons (though sometimes it makes 3).	• The mousetrap reaction only produces 1 mousetrap and 1 net ping pong ball instead of two daughter products and 1 net ping pong ball • The mousetrap reaction always produces the same result whereas in fission there

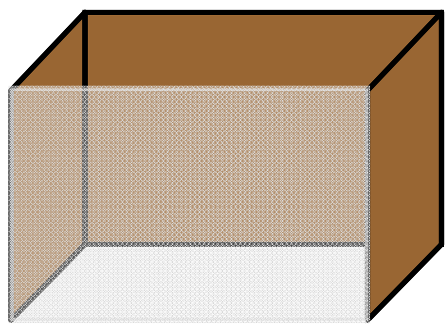
• Ping pong balls start new reactions • Both can produce a chain reaction but only in certain conditions • In both cases you need a way to keep the ping pong balls/neutrons in the reaction (either by walls in the mousetrap demo or by moderators in a nuclear reactor)	are certain probabilities of getting different products • Assuming the mousetrap/pin pong ball combination represents the nucleus of a Uranium-235, the nuclei are much too close together • Mousetraps can set off other mousetraps whereas in fission only the neutrons and not the daughter nuclei set off further reactions

Doing Your Own Mousetrap Demo

We've enclosed 35 mousetraps and 36 ping pong balls for your chapter to do your own mousetrap demo. This will make a small demonstration. If your chapter wants to do a larger scale demonstration, see the vendor list for how to buy mousetraps and ping pong balls in bulk. Here's some advice:

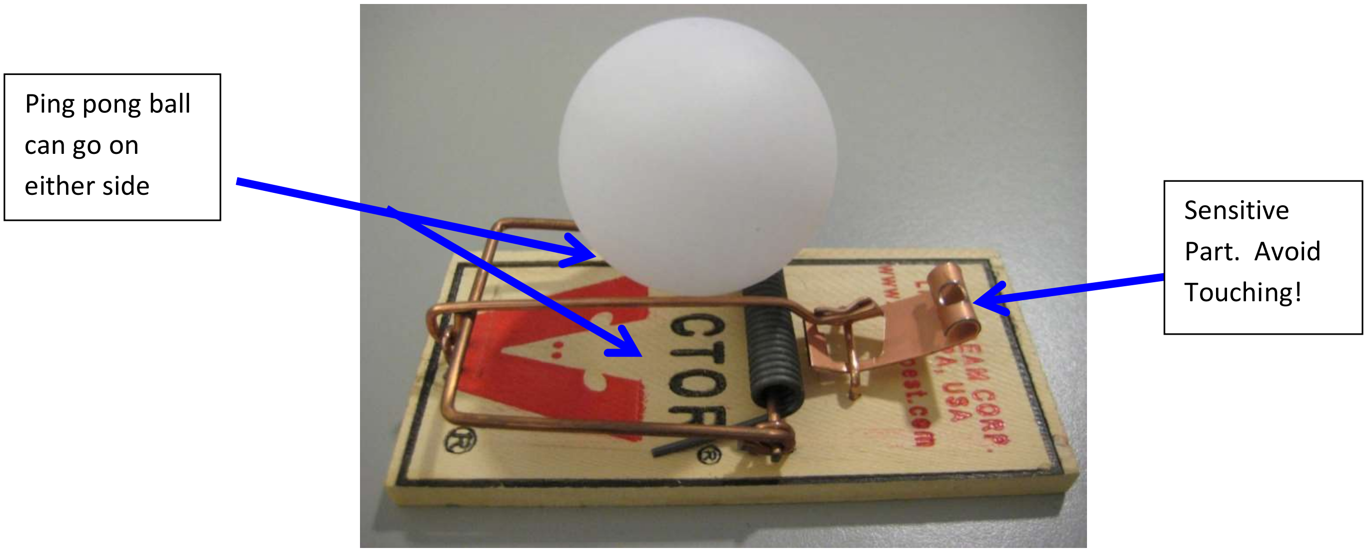
CAUTION: Mousetraps can be dangerous! Use caution when setting them and handling them. They can snap on your fingers which is painful! On the SOCK CD is a video of how to safely set a mousetrap. Watch the video before setting mousetraps!

1. Make an enclosure to put around your mousetraps. The walls keep the ping pong balls in the reaction. We used three sheets of corrugated poster board spray painted black and one sheet of plexiglass for the front. Darker walls provide a contrast with the white ping pong balls. At least one wall should be transparent so that students can see into the enclosure. (It is not recommended that students look down into an enclosure from above because they can be hit by ping pong balls). Try using cardboard walls or a plexiglass ceiling for your enclosure also.



2. For large demonstrations, it helps to set up groups of mousetraps separately. This way, if one section of mousetraps gets set off, then you don't set off all of them. We used 3 poster boards on the floor and set up 90 mousetraps on each. Then we pushed the boards together (Pushing them together is a delicate process! Try to do it as gradually and smoothly as possible. It helps if there isn't much friction between the board and the floor)

3. To set up the mousetrap/ping pong balls, we recommend setting all the mousetraps first and then setting the ping pong balls on top. Start in the middle of the board and work your way to the edges to avoid reaching over set mousetraps. For those who haven't had the pleasure of setting a mousetrap, there is an instructional video of how to set a mousetrap on the DVD.



4. In order to do a mousetrap demonstration in an outreach event, you will need to set up the mousetraps beforehand. You could set up in a separate room, outside, in the hallway or on a large cart.

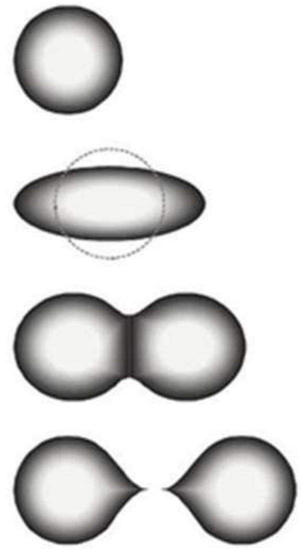
Things to experiment with:

1. Make a video! We recommend using multiple cameras to film the demonstration so you can do a side and top view of the mousetraps. Also a camera with higher fps (frames per second) will allow you to slow the speed of the video even more while the ping pong balls remain unblurred.

2. For chain reactions, the density of reactants is vital. If the density is at or above the critical density a chain reaction occurs. However if you are just under this threshold, a chain reaction is highly unlikely. We challenge you to find the critical density of mousetraps for a chain reaction to occur. This critical density will be different depending on whether you have an enclosure, whether the enclosure has a roof, etc. Send us your findings!

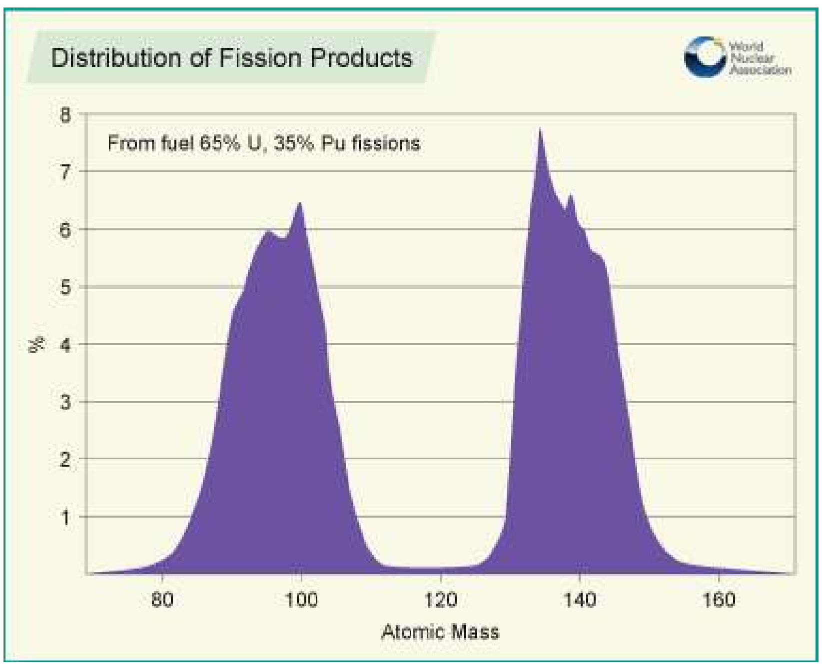
3. In nuclear reactors, the neutron products from fission reactions are in most cases moving so fast that they won't be absorbed by another Uranium 235 (the neutron absorption cross-section is very small for fast neutrons) or they leave the uranium rod quickly. Therefore we use collisions to slow the neutrons down. The particles used for the collisions are called moderators and common moderators are water and heavy water because they slow the neutrons down the most. We challenge you to include a moderator in your mousetrap demo. Perhaps don't include walls (which act as a moderator) and hang ping pong balls or streamers over the mousetraps to slow down the ping pong balls? However, ping pong balls may not need moderating…

The Physics of Fission



Fission is the process of splitting an atomic nucleus. Fission can occur spontaneously in rare cases but it is generally caused by a neutron being absorbed by a nucleus. Absorbing the neutron causes the nucleus to become unstable and it splits. In most cases, the nucleus splits into two main smaller nuclei and several additional neutrons. This is called binary fission. In 0.3% of cases, ternary fission occurs and the nucleus splits into three nuclei and the additional neutrons. To the left you can see the water droplet model of fission.[5] The neutron input energy deforms the nucleus until the two budding spheres are far enough away to escape the strong force holding the nucleus together.

The mass of the products of a fission reaction, or the daughters, have a probability distribution. Below is one example:[6]



As you can see the distribution for Uranium and Plutonium fission products is bimodal with peaks around 95 amu and 135 amu. The most likely mass ratio of the products is 3:2 because it is the most energetically favorable. Here are two example reactions: [7]

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[5] http://en.wikipedia.org/wiki/File:Stdef2.png

[6] http://world-nuclear.org/education/phys.htm

^{235}U + 1 neutron → ^{92}Kr + ^{141}Ba + 3 neutrons + 200MeV

^{235}U + 1 neutron → ^{94}Sr + ^{140}Xe + 2 neutrons + 200MeV

Notice that the daughter nuclei are very close to that mass ratio (1.533 and 1.489 respectively). The daughter products are not the final products of the reaction however. The products of fission tend to beta decay to change their excess neutrons into protons. Another very important feature of the reaction is that it produces energy around 200 MeV per reaction. This is around 10 million times the energy per reaction of a chemical reaction such as burning coal. This energy takes several forms:[8]

165 MeV	~ kinetic energy of fission products
7 MeV	~ gamma rays
6 MeV	~ kinetic energy of the neutrons
7 MeV	~ energy from fission products
6 MeV	~ gamma rays from fission products
9 MeV	~ anti-neutrinos from fission products
200 MeV	~ total energy

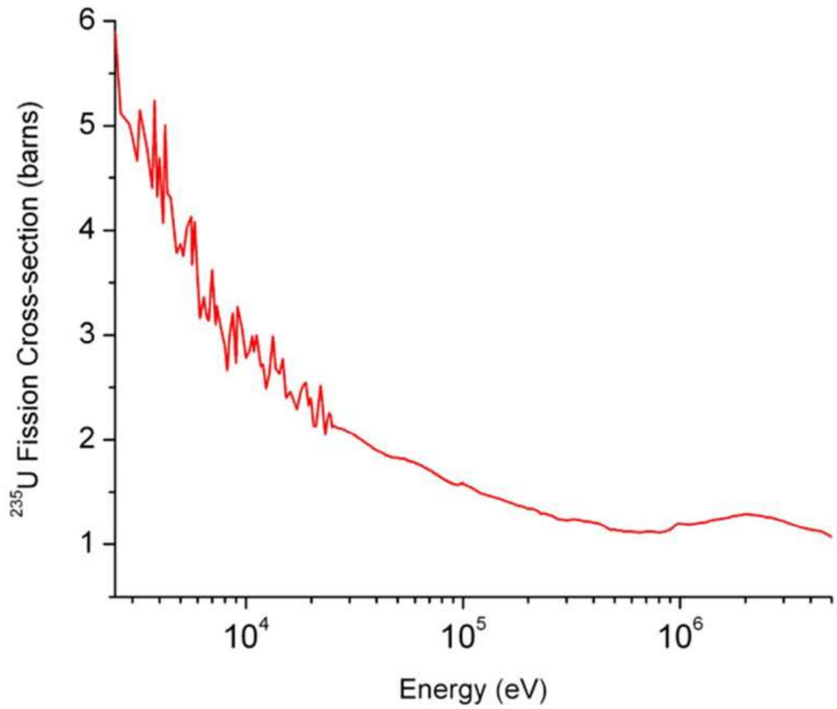
This energy comes from the fact that the mass of the products of fission are only 99.9% of the mass of the reactants. That 0.1% of the mass has changed form from mass to energy according to Einstein's mass-energy equivalence equation: $E=mc^2$.

Only certain elements are fissionable – able to undergo fission. Even fewer elements are what is called fissile. A fissile atom produces neutrons that are capable of starting another fission reaction. These neutrons are moving relatively slower and are called thermal neutrons because they are moving close to the speed given by their temperature. The most commonly used fissile atoms are U-235 and Pu-239. A non-fissile atom such as U-238 produces fast neutrons which are moving too fast to be absorbed by another U-238 since the absorption cross section is too small – see the graph below for the relationship between neutron speed and absorption cross section.[9]

[7] http://library.thinkquest.org/17940/texts/fission/fission.html

[8] http://www.atomicarchive.com/Fission/Fission2.shtml

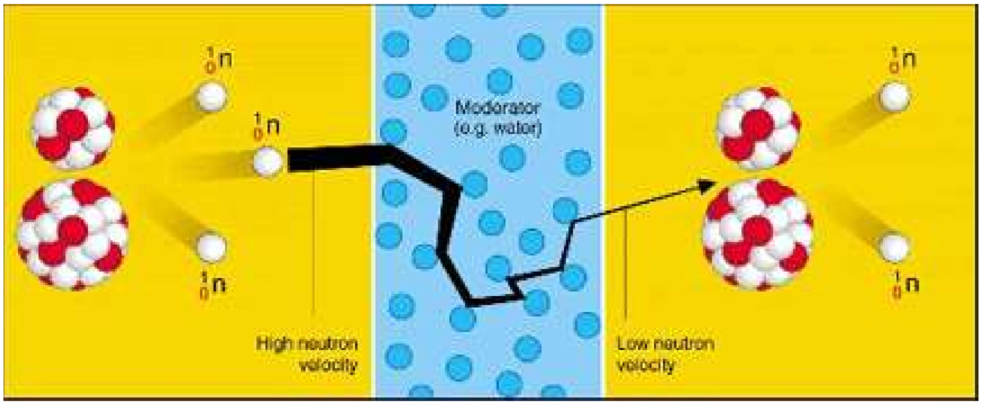
[9] http://en.wikipedia.org/wiki/File:U235_Fission_cross_section.png



Since fissile elements produce neutrons that have the ability to start another reaction, the reaction has the potential to become a chain reaction. In a chain reaction, positive feedback causes a reaction rate to exponentially increase. Two applications of fission make use of the chain reaction: nuclear power plants and nuclear bombs. However there is a key difference in these chain reactions: in a power plant the reaction is controlled so it is impossible for it to go out of control and in a nuclear bomb, it is impossible to stop a reaction.

In a nuclear reactor, moderators and neutron poisons act to control the amount of neutrons available for reactions. The neutron poisons come in rods called control rods which can be lowered into a reactor to slow or stop a reaction. They are called neutron poisons because they are very good at absorbing neutrons. Many different elements, such as boron, halfnium, silver, indium and cadmium, are used depending on the energy of the neutrons from the reaction.

Moderators are used to slow down fast neutrons to make them thermal neutrons that have a better chance of initializing a fission reaction. Common moderators are water and heavy water. They work to slow down neutrons using collisions. If a neutron collides with a H^+ ion in the water (or Deuterium in heavy water), it is a near-equal mass collision and the neutron is slowed. In many reactors the water is used as both a coolant and a moderator. This way if there is a loss of coolant, the reaction will come to a stop because the reaction cannot continue without a moderator.



[10]

Links

http://phet.colorado.edu/en/simulation/nuclear-fission

This PhET simulation has three parts. First you can shoot a neutron at a U-235 nucleus and see the potential energy curve inside and outside the nucleus. Then you can control the amount of U-235 and U-238 in trying to create a nuclear chain reaction or nuclear bomb. Lastly you can move control rods into and out of a reactor to try to produce the most energy.

http://www.atomicarchive.com/Fission/Fission1.shtml

This website gives a summary of fission and nuclear reactors.

[10] http://www.daviddarling.info/encyclopedia/M/moderator.html