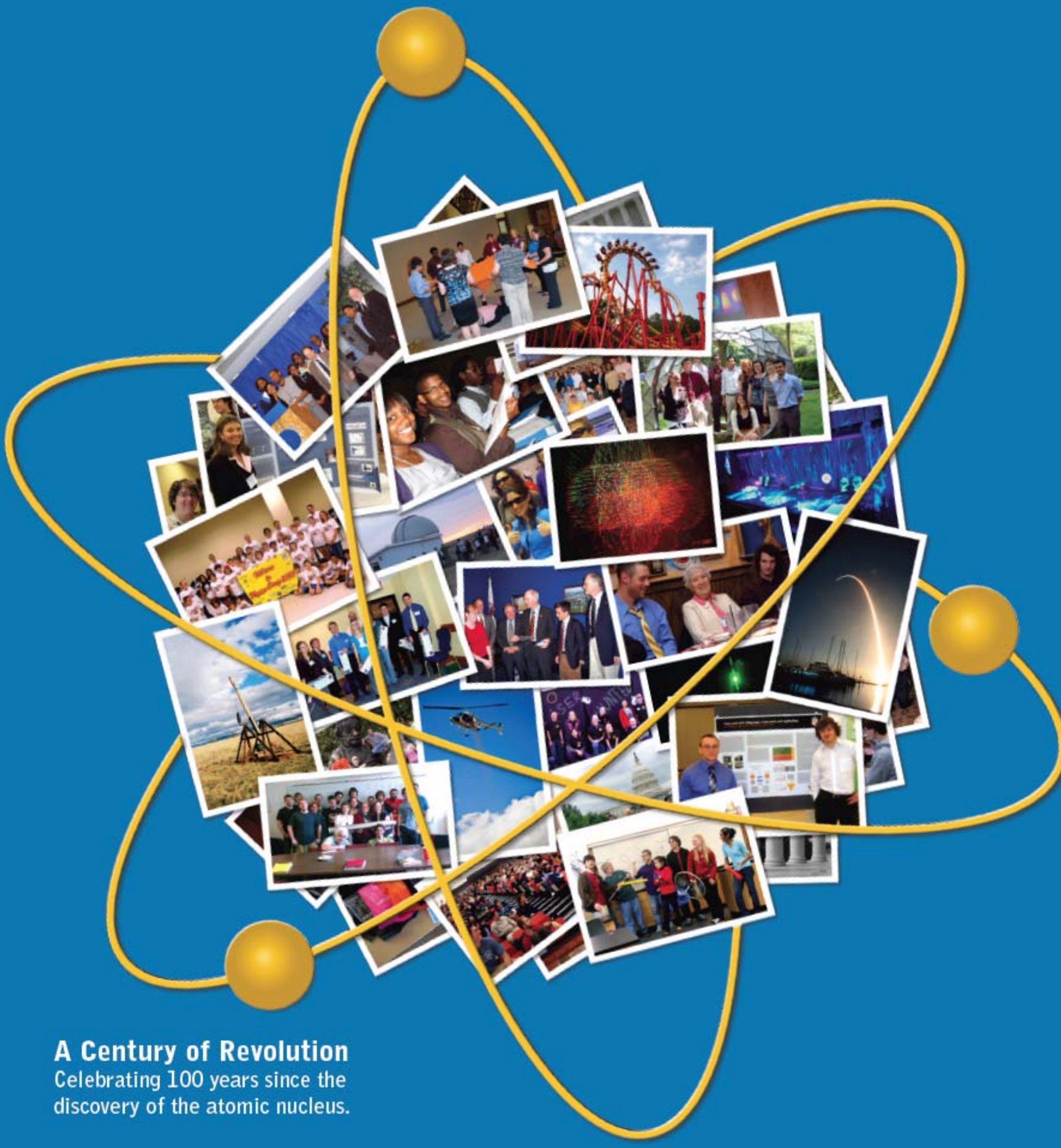
A Century of Revolution

The 2011 Science Outreach Catalyst Kit (SOCK)



A Century of Revolution
Celebrating 100 years since the discovery of the atomic nucleus.

Dear SOCK Recipient,

Congratulations on taking a first step in building a successful outreach program—receiving the Science Outreach Catalyst Kit (SOCK)! The next step involves sitting down with your chapter and going through this kit to see how the enclosed materials can help you with your outreach events.

To get you started we have enclosed materials for 3 lessons, built around the science of Rutherford's discovery of the atomic nucleus. These items and lessons are a starting point. We encourage you to try out the activities in the kit and then come up with your own additions and modifications. We just ask that you turn in your report and complete a SOCK Survey after your event so that we can make the next SOCK even better.

An electronic copy of this manual is included on the CD provided if you want to physically change any of the lessons or the worksheets. The CD also includes videos that are an integral part of the lesson.

SPS National and the 2011 Summer SPS SOCK interns thank you for taking part in this year's project. Have fun exploring and modifying the lessons to suit your outreach programs. If you have any questions or comments please feel free to contact us at sps@aip.org.

Good luck on all of your outreach events!

Sincerely,

The SPS SOCK Monkeys (2011 Interns)

Erin Grace, University of Delaware
Amanda Palchak, University of Southern Mississippi

Kit Contents

Collisions and the Great Gold Robbery Mystery

2 Bags of Balls:

- Golf Ball
- Ping Pong Ball
- Large Plastic Ball
- Wooden Ball
- Bouncy Ball
- Foam Ball

Other Collision Activity Items:

- 2 Hot Wheels Gravity Clamp packs
- Copy of Collision Activity Worksheet (also on CD)
- Video clip of the aftermath of a “robbery” on CD or downloaded from the web

Mystery Box Activity/Gold Foil Experiment

- Bag of Marbles
- Ramp with 5 Tracks
- Gold Mystery Box
- Heavy Ball (Mystery Item)
- 5 Sheets of nontoxic Fly Paper (Mystery Item)
- 2 Posters (Rolled Up)
- Mystery Box Items Worksheet (also on CD)

Fission Activity

- 35 Mouse Traps
- 36 Ping Pong Balls
- Balloon bag: U-235 balloon with 2 marbles, 4 empty U-235 balloons, Kr-92 balloon, Ba-141 balloon, marble with thumbtack
- Video of Operation Mousetrap (CD)
- Fission PowerPoint (CD)

Other

- DVD with Lesson Videos and Copy of Manual
- 2 Bags of Pins: Standard Model and Nucleons

Lesson 1: Collisions and the Great Gold Robbery Mystery

Present a gold robbery mystery to the students that you need their help to solve. Students try out different collisions with a variety of balls to help solve the mystery.

Note: This lesson ties into Activity 2: The Rutherford Experiment. Rutherford used an understanding of collisions to interpret the results of the Gold Foil Experiment. Therefore, this activity is designed to be used as part of a larger lesson on the nucleus.

Objectives

- Students will be able to explain when a ball will bounce back after a collision and when it will continue forward
- Students will be able to predict the directions balls will go after a collision if they are able to examine the balls beforehand
- Students will able to use experimental evidence to support their solution to the mystery

Materials Included

- CD with Mystery Video
- 2 Hot Wheels Gravity Clamp Packs
- 2 Bags of balls: bouncy ball, golf ball, wooden ball, ping pong ball, large plastic ball, ping pong ball
- Collisions Worksheet

Materials Needed

- Desk or chair about 1.5 feet high to attach clamp to.
- Laptop, projector and speakers

Advanced Preparation

- Attach the clamp to a suitable surface and attach the 4 track pieces.
  *If the top of the track is too high, the balls will bounce out of the track for most collisions. We found that about 1.5 feet worked well.

In the Classroom:

First one of the SPS members as "Head Investigator" will present the mystery to the students, who are the "team of detectives." Take the role seriously to draw the students in. Feel free to make the dialogue your own but here's a sample dialogue for elementary students:

"Today we want you to be our detectives to help us solve a mystery. Our case is a bank robbery. This morning at 9am the burglar alarms at National Bank in [insert city] went off. When the police arrived at the bank, they did a search and found 100 million dollars of gold was stolen. One of our clues is a video.

A man across the street from the bank had a video camera. He noticed something weird was going on and so he started videotaping. He caught some suspicious activity on camera and we need to watch it to get clues to find the gold."

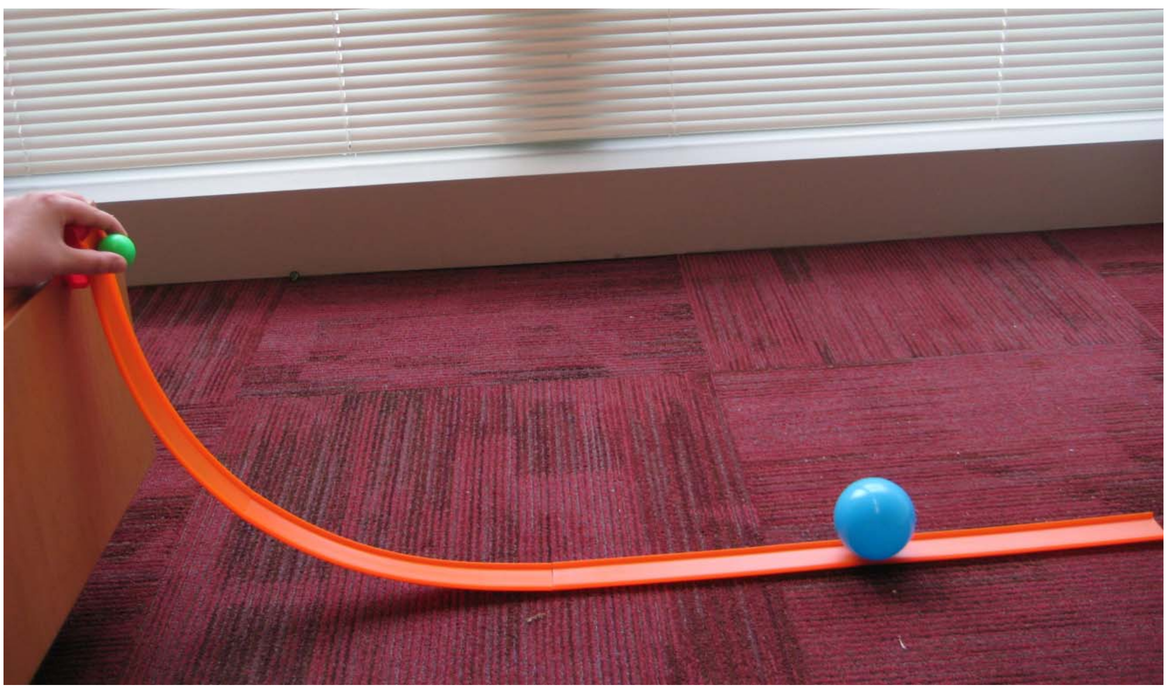
*For younger students, they may become focused on whether or not the video is "real" and if the robbery "really happened." You can tell them that the mystery is "pretend" or "for practice."

Show video. Pause then show video again to allow students to notice more details.

Tell the students that the video looks suspicious and that we want to investigate collisions to find more clues.

Explain the collision Activity to Students.

1. Place one ball in the middle of the flat portion of the track.
2. Hold the second ball at the top of the ramp.
3. Predict the directions that the balls will go after the collision.
4. Release the ball and observe the collision.
5. Record the balls' directions on a worksheet.



Divide students into groups (groups of 2 to 4 are recommended). When walking among the groups, make sure students are making predictions and **ask them why** they choose the direction that they did. At the end of the collisions, the students should be able to state the rule that when a lighter (less massive) object collides with a heavier object, it bounces backward and when a heavier (more massive) object hits a lighter object, it continues forward.

If groups finish the collisions early, they should work on the challenge activity. Students try to recreate the car collision using any two of the balls provided.

Bring the class back together for a full class discussion. Ask groups to report their findings about the collision activity. Discuss.

Reshow Mystery video. Ask class if anyone has solved the mystery of where the gold has gone. Call on students to share. Make sure to ask them why they came to their conclusions.

(The yellow Smart car has the stolen gold inside. Without the gold, the Smart car has much less mass than the SUV and both cars would move forward after the collision. However, the SUV bounced back after the collision. Therefore the Smart Car must have something inside it-gold- that makes it more massive than the SUV)

Congratulate students on solving the mystery!

Modifications for Older Students

1. We found that it was effective to present the mystery in a slightly different way to junior high students. We jumped right into the details of the robbery without a transition. This caught the attention of the older students.

"Good morning detectives. It looks like today we've got another robbery. Here are the details from the report. This morning at 9:05 am the burglar alarms at National Bank at [insert address] in [insert city] went off. The police arrived at the bank at 9:15. They did a routine search of the premises and found 100 million dollars of gold was stolen. After reviewing the security cameras, the police found that they had been wiped blank since 8am. The police interviewed some of the witnesses on the scene. One man across the street from the bank had a video camera. He claims he noticed something strange was going on and started videotaping. He caught some suspicious activity on camera. I will share the video with you now."

Feel free to make the dialogue your own and be creative with it. You could even get into costume with a trench coat or a clipboard.

2. You can modify the activity to provide greater number of variables. For example you can use 2 gravity clamp packs to make a U formation. There should be a long flat section on the floor so that the collisions occur on a level surface. Students release two different balls from either side of the U so that they collide on the flat part at the bottom while they are both moving. Students should observe what directions the balls go after the collision.

3. For high school students, you can introduce the topics of elastic and inelastic collisions and conservation of momentum.

Numbers behind the Bank Mystery (based on summer 2011 prices and weights):

Weight of a Smart Car: 2,150lbs [1]

Weight of an SUV: ~5,000 lbs[2]

Weight of 100 Million Dollars of Gold: 4,564 lbs

Weight of Smart Car with the Gold: 6,464 lbs

Value of Gold: $21,910 / lb [3]

Volume of 100 Million Dollars of Gold: 3.744 ft^3

…so there's plenty of room in a Smart Car for this much gold!

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[1] http://www.caranddriver.com/reviews/car/10q2/2011_smart_fortwo_electric_drive-first_drive_review
[2] http://articles.latimes.com/2007/apr/18/autos/hy-wheels18
[3] http://www.wolframalpha.com/

The Physics of Collisions

A collision occurs when two or more objects exert forces on each other for a short period of time. Most collisions are two body collisions because the probability of three bodies colliding simultaneously is very small. While the velocities of the objects may change, the net momentum of the objects remains constant for any collision (assuming that the objects are a closed system, a.k.a. there are no outside forces acting on the objects). Another way to state this principle is to say that the center of mass velocity remains constant. So the sum of the initial momentums must be equal to the final momentums: $\Sigma p_i = \Sigma p_f$

Unlike momentum, kinetic energy is rarely conserved in real-world collisions, even in closed systems. In real collisions, some the object's kinetic energy is converted to internal energy. An inelastic collision is a collision in which kinetic energy is not conserved. In theory, when two objects collide and all of the kinetic energy can be conserved it is called an elastic collision. Some real collisions approximate elastic collisions, like the collisions of pool balls or other hard objects. Collisions between particles in ideal gases and between subatomic particles come much closer to approaching elastic collisions than do macroscopic collisions, generally. For collisions that approximate the elastic case, one can find the final velocities of the objects using the combination of conservation of kinetic energy and conservation of momentum.

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

where u_1 and $u_2$are the velocities before collision, and v_1 and v_2 are the velocities after collision.

Assuming we know the initial velocities, we can solve this system of equations for the final velocities:

$$v_1 = \frac{m_1-m_2}{m_1+m_2}\,u_1 + \frac{2m_2}{m_1+m_2}\,u_2 \qquad\qquad v_2 = \frac{m_2-m_1}{m_1+m_2}\,u_2 + \frac{2m_1}{m_1+m_2}\,u_1$$

We can also consider the special cases of $m_1 \gg m_2$ and $m_1 = m_2$

For $m_1 \gg m_2$, the equations simplify to:

$$v_1 = u_1 \qquad\qquad v_2 = 2\,u_1 - u_2$$

So if one of the masses is much larger than the other, it maintains its velocity after the collision. If the massive object was at rest before the collision, it would remain at rest. This makes sense if we picture a ping pong ball hitting a bowling ball, the bowling ball would remain still.

The less massive object gets a velocity of twice the massive object's initial velocity minus its initial velocity. Thus if the massive object is initially at rest, the final velocity of the light object will be the opposite of its initial velocity. So the ping pong ball hitting the bowling ball would bounce back with a speed equal to its initial speed.

For $m_1 = m_2$, the equations simplify to:

$$v_1 = u_2 \qquad\qquad v_2 = u_1$$

Thus the velocities of the two objects exchange. If one of the objects is at rest, then the object hitting it will stay at rest after the collision and the other will continue with the initial velocity of the other. We see this case approximately when one pool ball directly strikes another. (We have not tried to include the effects of rolling on the collisions, which does complicate the analysis. The most obvious rolling effect is that the striking ball in this equal mass case continues to rotate about its center of mass and so when contact with the floor is re-established, friction will cause the striking ball to start forward again, contrary to the above equations. In developing these lessons we opted to steer clear of nearly equal mass objects for this reason, so that this effect and similar effects do not cloud the results and conclusions that are relevant for either the nuclear case or the gold mystery case)

Even for collisions that are not elastic, one can solve the system

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + KE_{Lost}$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

for the final velocities v_1 and v_2. Writing KE_{Lost} as some fraction *f* times the initial kinetic energy, or $f*\frac{1}{2}m_1u_1^2$, and assuming that the initial speed of the second ball u_2 is zero, we find, upon solving this system of two equations and two unknowns:

$$v_1 = \frac{m_1 - m_2\sqrt{1-f*(m_1+m_2)/m_2}}{m_1+m_2}\,u_1 \qquad\qquad v_2 = \frac{m_1 + m_1\sqrt{1-f*(m_1+m_2)/m_2}}{m_1+m_2}\,u_1$$

When *f* = 0, these equations reproduce the elastic case results above for $u_2 = 0$.

For $0 < f < (1-(m_1/m_2)^2)*m_2/(m_1 + m_2)$, we find that the smaller mass ball m_1 does change directions when incident on the more massive stationary ball. For larger values of *f*, namely,

$(1-(m_1/m_2)^2)*m_2/(m_1 + m_2) < f < m_2/(m_1 + m_2)$,

the incident ball doesn't change directions when it has smaller mass, but if the difference in mass is readily noticeable , then these correspond to rather inelastic collisions. The conclusion is that for any reasonably bouncy collisions in which the incident ball has considerably less mass than the stationary ball, the incident ball will change directions upon impact.

Links

http://phet.colorado.edu/en/simulation/collision-lab

This is one of the PhET simulations from the University of Colorado. Students can test collisions of balls in one or two dimensions and with up to 5 balls at a time. The applet can show the center of mass, velocity and momentum vectors, etc.

Lesson 2: Mystery Box/Rutherford's Gold Foil Experiment

In this activity, students will roll marbles into a mystery box and to determine what is inside by analyzing the direction the marbles roll out of the box, in analogy with Rutherford's experiment (the marbles play the role of the alpha particles, the box is like the gold foil, etc.). The students will then learn about Rutherford's results of the Gold Foil Experiment and connect his results with theirs.

Objectives

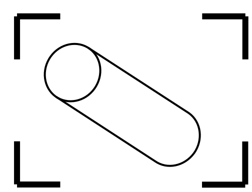
- Students will be able to use knowledge from collisions to analyze what is inside of a mystery box
- Students will be able to explain the evidence they used to hypothesize what is in the box
- Students will be able to relate their results of this activity to Rutherford's results from the Gold Foil Experiment

Materials Provided

- Gold box
- Marbles
- Mystery items: bocci ball and fly paper.
- Ramp with 5 tracks
- Copy of Mystery Box Item Worksheet (also on CD)

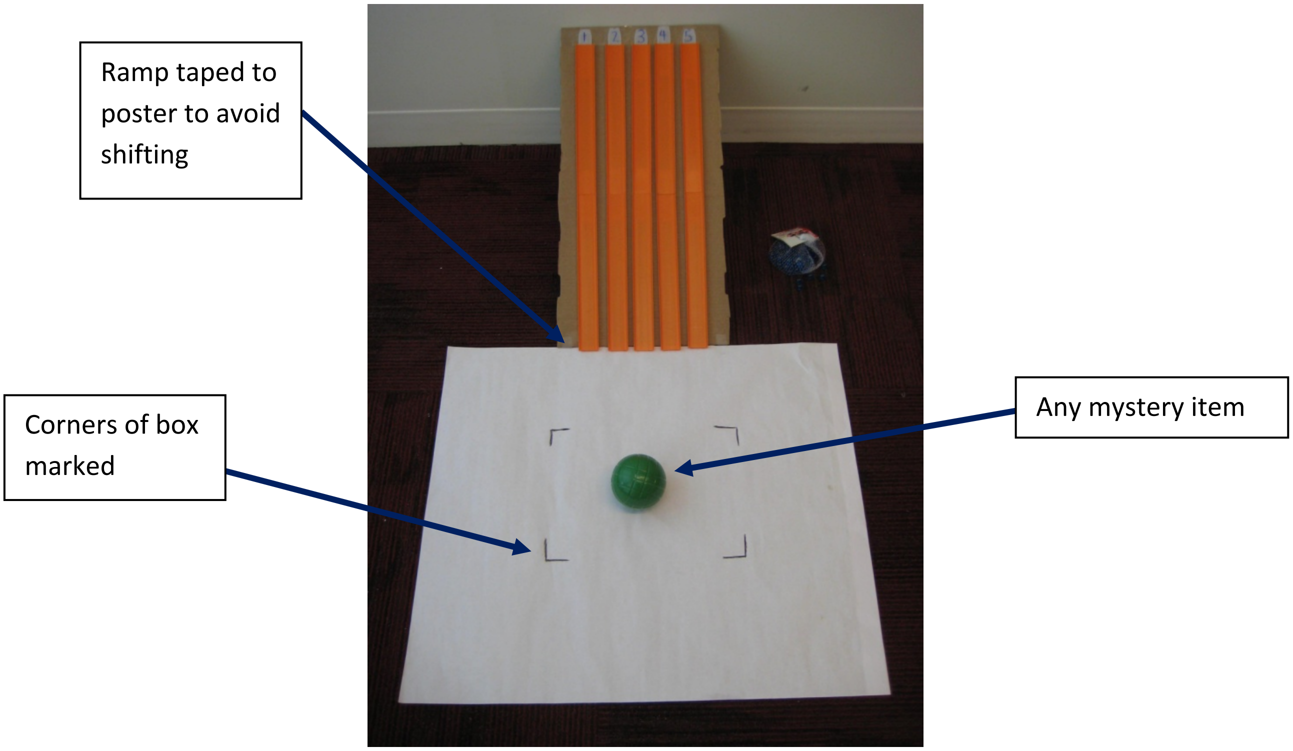
Materials Needed

- Wall to prop up ramps
- Pen/Marker
- Piece of paper
- Tape
- Additional mystery items. Be creative and let us know if your chapter finds an interesting item!
    - For example a can of spray paint can be placed diagonally in box



Advanced Preparation

- Edit Mystery Box Items Worksheet depending on items used
- Find appropriate place to lean ramps
- Tape edges of ramp to edge of poster to secure the two together
- Place boxes on poster board making sure to center the box with respect to the ramp. Mark where the corners of the box are located on the paper (see picture)
- Put mystery item in the box area (see picture)
    - For Fly Paper: Tape the non-sticky side of the fly paper to the poster in the middle of the box. Then peal of the cover of the sticky side. You can use 1 sheet of fly paper per box or put two side-by-side to go the full length of the box
- Put box back on paper
- Tape a sheet of paper to the top of the box. (Students will mark on the paper where in the box the mystery item is)



In the Classroom

- **Students describe the smallest things they know about**

  Students should name small things in nature that they know of, leading to the atom.
  Ask the students in the class to name small things they know about. If they tend to name objects on a macro scale, ask them if they know of anything smaller, particularly things they cannot see.

- **Discuss the atom with students**
  Tell students that one small thing you know about is the atom. (It makes up everything in the universe, even you and me!) Ask students how they can learn about things they cannot see. Possibly answers might include: microscope, magnifying glass, etc. Discuss how atoms are too small to be readily seen with these devices, but that they can explore things that cannot be seen by using their knowledge of collisions.

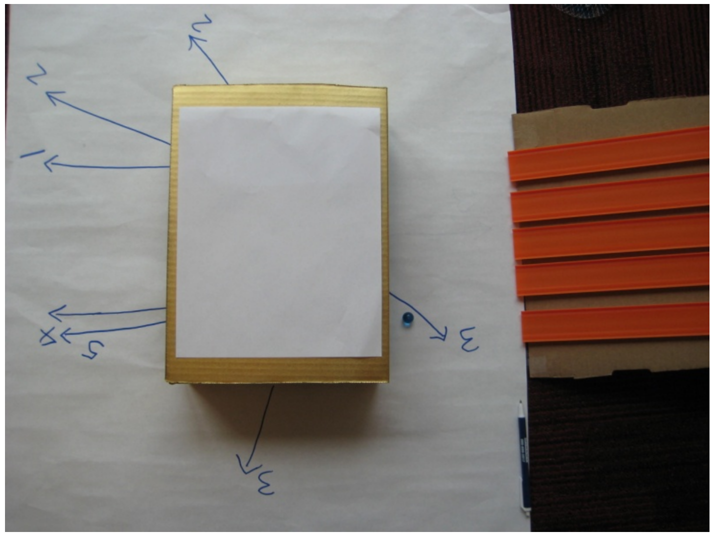
- **Explain activity**
  Students work in groups to figure out what is inside their mystery box.

  1. Release a marble from the top of track 1 so that it rolls into the box

  2. Observe the direction the marble goes out of the box

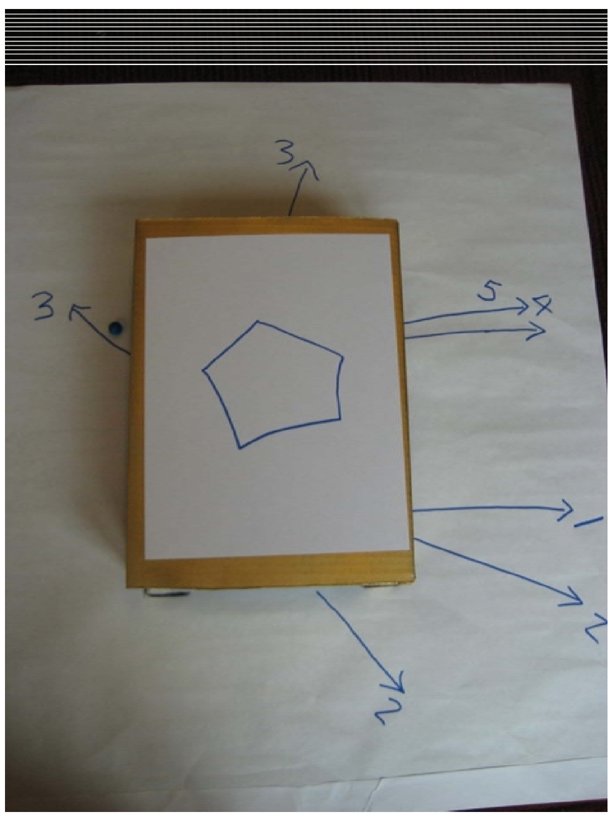
  3. Draw an arrow on the poster underneath the box to show the marble direction and write a "1" by the arrow to show that the marble came from track 1

  4. Do the same for all tracks and feel free to repeat any track.



During the first 4 steps, groups should discuss their theories of what is in the box, how big it is and where specifically in the box it is. Encourage students to use evidence like noises and the speed of the marbles exiting the box.

5. Students circle the item they think is in the box on the mystery box item worksheet. They draw their item(s) on the paper on the top of the box.



Ask them why they choose that object, why they choose that size and why they choose that location in the box. Emphasize that their theories are based on evidence.

6. Reveal what's inside!

*Encourage students to sit around the box—getting them at the same vertical level as the experiment increases involvement.

*Students want to peek!! Ask students to stop themselves from peeking because real scientists don't get to "peek"

We recommend groups of 3 to 5 students at each box. This activity can be done several ways.

1. Small groups of students rotate between mystery boxes, with each box having a different item.

   a. If the boxes are spread out enough, then the SPS member at each box reveals the item and then groups rotate to another box.

   b. Groups make their guesses and then rotate to another station. Students save their papers with their drawings and you reveal the items at the end of all the rotations.

2. The groups stay at one box. After the students guess, the SPS member reveals the item and then has the students close their eyes while they switch out the item.

- **Discuss Rutherford's Results**

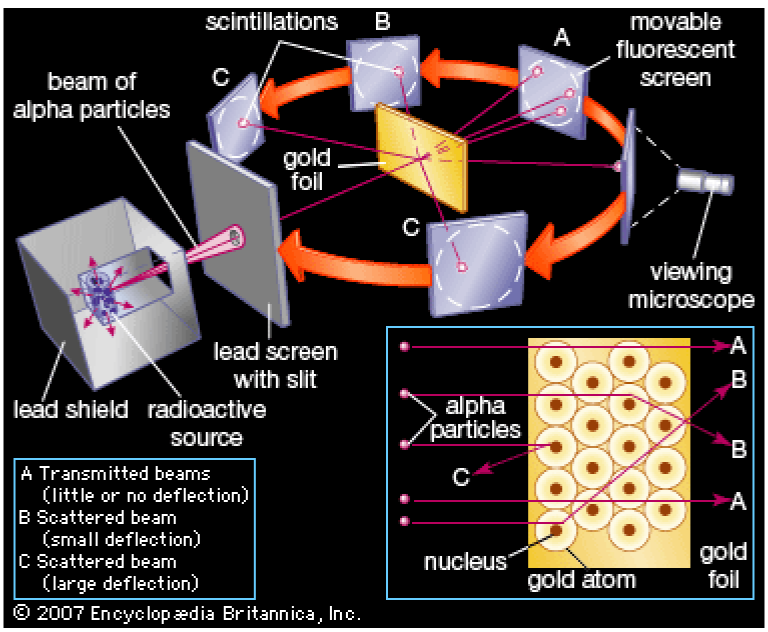
Discuss this year's theme: A Century of Revolution. Continue to talk about how Rutherford did an experiment to figure out what was inside of an atom by doing collisions. Before explaining that Rutherford discovered the nucleus, describe the results of his experiment (alpha particles being deflected and bouncing back as a result of a collision). For upper level students, have them choose which mystery box gave the most similar results to Rutherford's. For elementary students/smaller classes, have students make connection between Rutherford's results and their results. After this connection is made, reveal what Rutherford discovered during his Gold Foil Experiment: there is a small, mass dense center to an atom called the nucleus.

The Physics (and History) of the Gold Foil Experiment

The physicist Ernest Rutherford was born in New Zealand in 1871. By the turn of the century, Rutherford was working on classifying and measuring radiation. In 1909, his students Hans Geiger and Ernest Marsden (an undergraduate!) carried out the Gold Foil Experiment under his guidance. First Rutherford and Geiger created a zinc sulfide screen that lit up when hit by alpha particles. This detector of alpha particles was encircled around a very thin gold foil—only 0.00004 cm. There was a slit in the detector so that alpha particles could be shot at the foil. Radon provided the source of alpha particles.

At the beginning of the 20th Century, the current atomic model was J.J. Thompson's plum pudding model. He stated his model in a paper published in 1905. In the paper, he theorized: "atoms of the elements consist of a number of negatively electrified corpuscles enclosed in a sphere of uniform positive electrification." His corpuscles (or electrons) were like raisins in a pudding or sea of positive charge.

According to the plum pudding model, the alpha particles should have experienced only small angle deflections from the corpuscles. However, the experimental results were that a small percentage (only 1 in 20,000!) of the alpha particles were deflected at large angles, some even greater than 90°.



[4]

Rutherford commented on the results:

> It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration, I realized that this scattering backward must be the result of a single collision,

[4] Encyclopædia Britannica, Inc.

> and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive center, carrying a charge.

Thus Rutherford was able to definitively reject the plum pudding model in his 1911 paper on his results. Instead he hypothesized the existence of a 'central charge' where almost all of the atom's mass was concentrated, which later became known as the nucleus. He estimated that the central charge took up only 1/4000 the volume of the atom, and outside it the atom was mostly empty space. He also argued that the central charge was likely positive, rather than negative. His conclusions were based on his calculations using purely classical mechanics to analyze collisions. He knew that only an object more massive than the alpha particle could cause the alpha particles to bounce back. If the mass had been spread out through the atom as in the plum pudding model, then there wouldn't be enough mass at a single point to reflect the alpha particles.

Links

http://phet.colorado.edu/en/simulation/rutherford-scattering

This PhET simulation allows you to see the Gold Foil experiment from the view of one Gold atom. You can watch the paths of alpha particles as they are deflected by the nucleus. You can control the energy of the alpha particles and the size of the nucleus. The simulation also has a plum pudding model animation so you can see what the results would have been if that model was correct.

http://www.ffn.ub.es/luisnavarro/nuevo_maletin/Rutherford%20(1911),%20Structure%20atom%20.pdf

This is a copy of Rutherford's 1911 paper about the Gold Foil experiment.

http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/ruther14.swf

This is a flash animation with audio explaining the gold foil experiment.

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

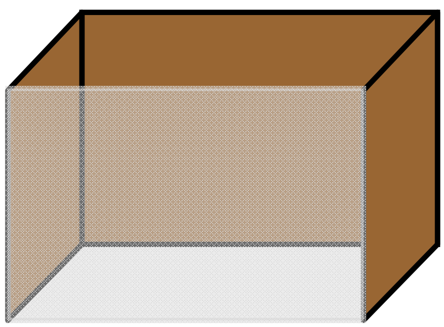
• Ping pong balls start new reactions • Both can produce a chain reaction but only in certain conditions • In both cases you need a way to keep the ping pong balls/neutrons in the reaction (either by walls in the mousetrap demo or by moderators in a nuclear reactor)	are certain probabilities of getting 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:

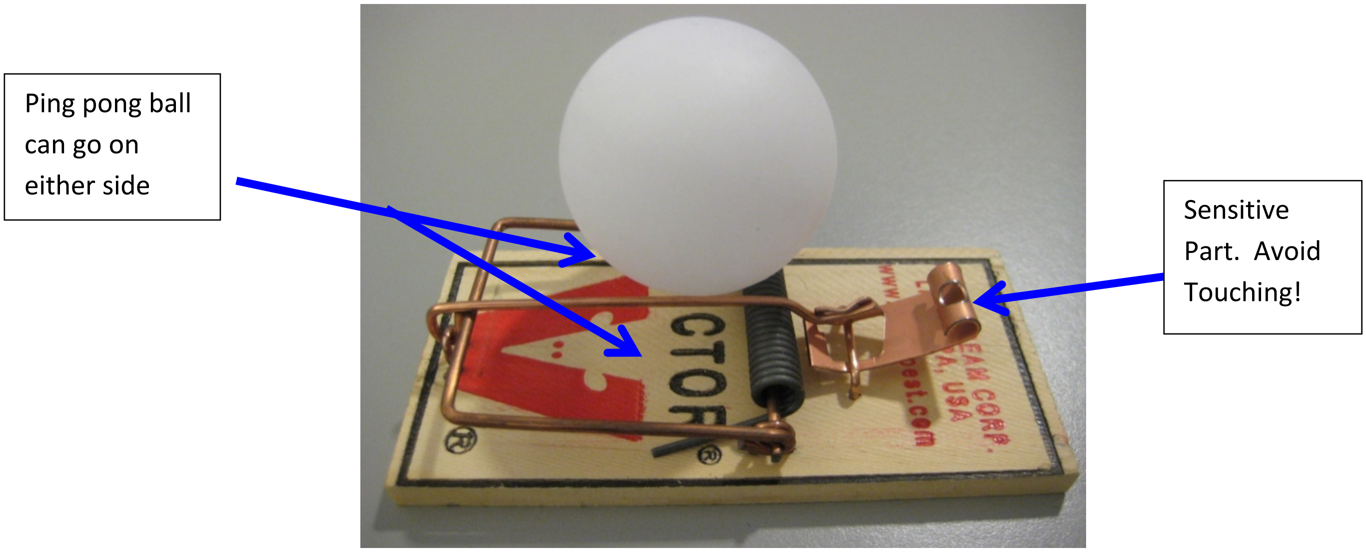
CAUTION: Mousetraps can be dangerous! Use caution when setting them and handling them. They can snap on your fingers which is painful! On the SOCK CD is a video of how to safely set a mousetrap. Watch the video before setting mousetraps!

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.

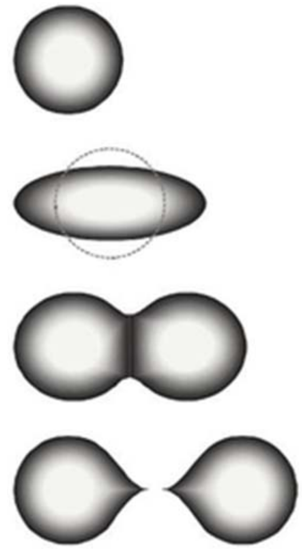
Things to experiment with:

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!

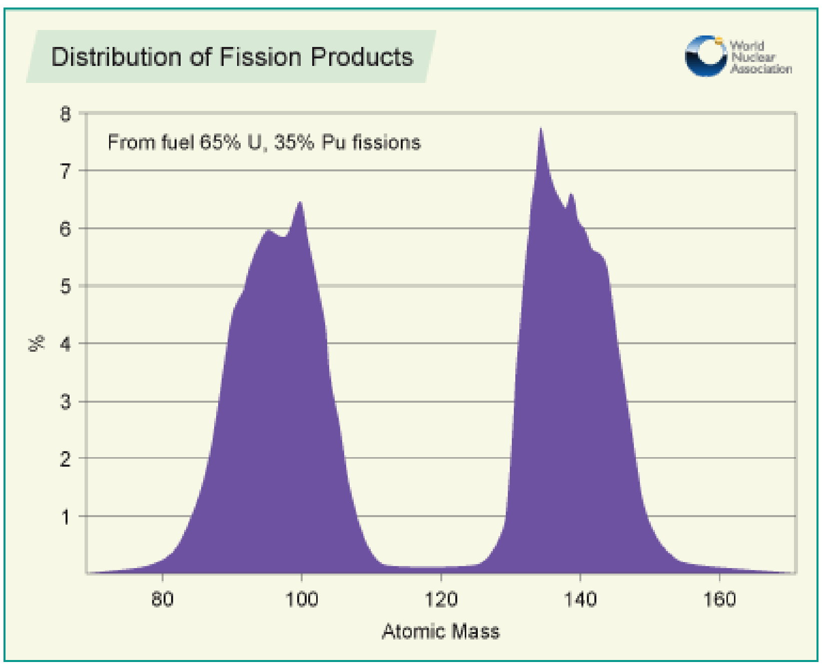
3. In nuclear reactors, the neutron products from fission reactions are in most cases moving so fast that they won't be absorbed by another Uranium 235 (the neutron absorption cross-section is very small for fast neutrons) or they leave the uranium rod quickly. Therefore we use collisions to slow the 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
```

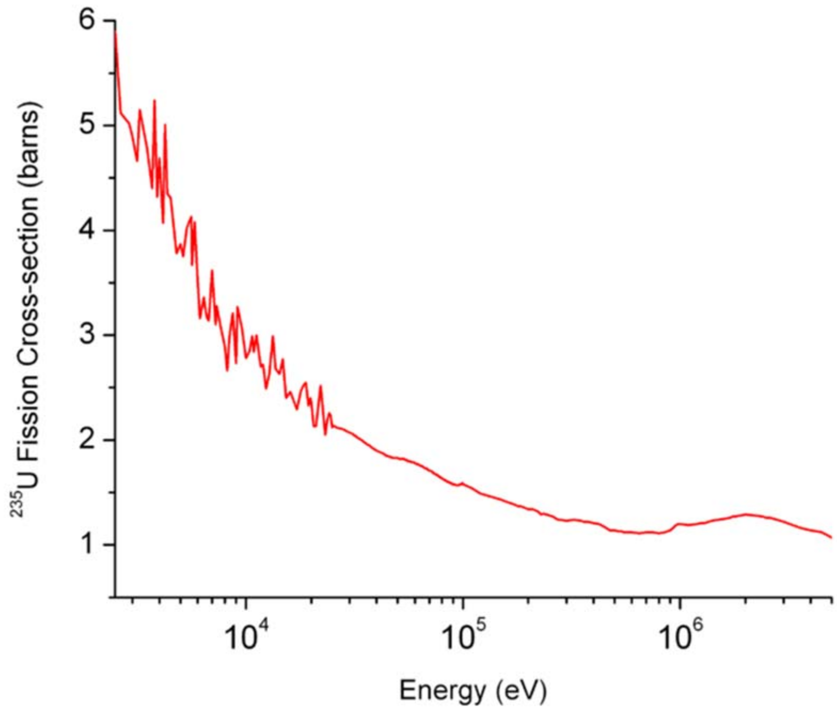
This energy comes from the fact that the mass of the products of fission are only 99.9% of the mass of the reactants. That 0.1% of the mass has changed form from mass to energy according to Einstein's mass-energy equivalence equation: $E=mc^2$.

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

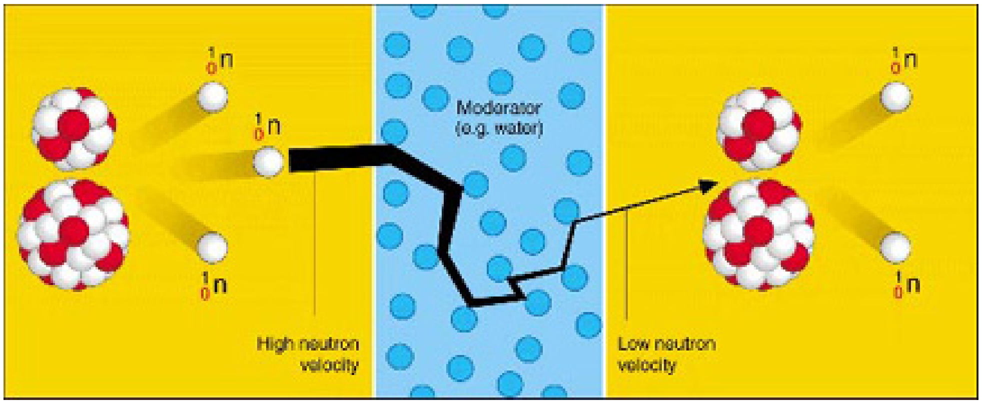
[9] http://en.wikipedia.org/wiki/File:U235_Fission_cross_section.png



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.

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

The Story of the SOCK

www.spsnational.org/programs/socks

The SPS Outreach Catalyst Kit (SOCK) began in 2001 as part of an outreach effort by the National Office of the Society of Physics Students (SPS). This kit was designed for SPS chapters starting outreach programs to students from kindergarten through college, to help them stimulate interest in physics at any age level. For younger students there are qualitative lessons to introduce critical thinking and brainstorming skills. More advanced students can be challenged with quantitative aspects of the lessons, reinforcing critical thinking skills and learning to apply mathematics to real situations. The demonstrations are hands-on to encourage active participation, and the lessons can be adjusted to fit any situation.

2001 *Rainbow Suite e*xplored different properties of rainbows. Created by Mark Lentz.

2002 *Dimensions in Physics* explored geometry in a variety of settings. Created by Lauren Glas and Jason Tabeling.

2003 *Spanning Space* brought in the first experimental component with a nation-wide cylinder dropping experiment. Created by Stacey Sude and Ashley Smith.

2005 *The World Year of Physics 2005* celebrated Einstein's accomplishments and included an experiment to measure the speed of light. Created by Heather Lunn and Matthew Shanks (2004) and Morgan Halfhill and Rebecca Keith (2005).

2006 *Absolute Zero* centered on the effects of temperature and it coincided with the *Absolute Zero and the Conquest of Cold* campaign. Created by by Katherine Zaunbrecher and Jackie Michalek.

2007 *Motion and Collisions* had many experiments, including the ever popular Diet Coke and Mentos reactions. Created by Justin Reeder and Ryan Field.

2008 *Makin' Waves* included a giant slinky and lessons on polarization, sound, and reflection/refraction. Created by Mary Mills and Jenna Smith.

2010 *Rolling with LaserFest* is in honor of the 50^{th} anniversary of the laser with a new lesson on the difference between LEDs and lasers. It also included a rolling activity. Created by Mary Mills, Scott Stacy and Erica Watkins (2009), Jasdeep Maggo and Patrick Haddox (2010).

2011 *A Century of Revolution* celebrates 100 years since Ernest Rutherford discovered the atomic nucleus based off the results of the Gold Foil Experiment. It includes a gold robbery mystery, a collision activity, a recreation of the Gold Foil Experiment and a dramatic demonstration of a chain reaction using mousetraps and ping pong balls. Created by Erin Grace and Amanda Palchak (2011)

The SOCK project is supported by the Society of Physics Students and its associated honor society, Sigma Pi Sigma. SPS is the professional society for physics students and their mentors. It operates within the American Institute of Physics (AIP), an umbrella organization for ten other professional societies.

Planning an Outreach Event

There are many different levels and types of science outreach that can be done in your community and school. Outreach activities might include performing science shows and demonstrations for local schools, performing workshops and demonstrations for campus clubs and organizations, homework tutoring, and high school mentoring programs.

After establishing a willingness within your chapter to do outreach, there are a few steps you should take before you actually perform an outreach event.

Suggested Procedure for Planning Outreach Events

- Determine what topic(s) you would like to cover with the students, and the amount of time you and your chapter are willing to invest.

- Identify an audience
    a. Talk to your chapter advisor, physics faculty, and education faculty to see if there is an existing outreach program you can join.
    b. Contact the science teachers in your local school district to let them know you are interested in putting on science events for their students.
    c. Contact local youth organizations such as the Boy and Girl Scouts of America, 4H, and YMCA to see if they have any interest.

- Schedule an event and get all the details—contact person, phone number, parking restrictions, setting, number of students, grade level, available equipment, time constraints, and any other special considerations.

- Create an outline for your time, include time for volunteers to introduce themselves and talk about their physics interest.

- Test the experiment and demonstrations.

- Verify the logistics the day before your event and pack. Make sure everything is ready to go, including replacement parts (like extra batteries).

- Do a post evaluation of your outreach event to discuss how things went and what you can do better next time.

- Complete the SOCK survey!

SPS's primary goal with the SOCK program is to encourage others to explore the universe around them. As the name suggests, the SOCK is meant to serve as a catalyst, prodding your chapter to plan an outreach activity with local schools and community members. You may need to supplement the materials in this SOCK in order to engage students effectively. Therefore we have provided contact information for all the vendors we used to compile this kit. Have fun and enjoy your outreach programs!

National Science Education Standards

One important topic to take into account when visiting a classroom is how your lessons fit in with what the students are supposed to be learning, as given by national, state, and local curriculum standards. While each state defines its own standards, most are based on the National Science Education Standards (NSES), published in 1996 by the National Academy of Science. These standards cover K-12 and describe what students should understand and be able to do in science at each level. The NSES are available on the National Academies Press (NAP) website, http://www.nap.edu/catalog/4962.html#toc.

Below we highlight some of the standards that the lessons and demonstrations in the SOCK address. There are two Content Standards addressed – Scientific Inquiry (Content Standard A) and Physical Science (Content Standard B). Detailed descriptions for each topic can be found on the NAS website.

Scientific Inquiry

Content Standard A:

As a result of the activities in grades K-12, all students should develop an understanding of:

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science

Content Standard B:

As a result of the activities in grades K-4, all students should develop an understanding of:

- Properties of objects and materials
- Position and motion of objects
- Light, heat, electricity, and magnetism

As a result of the activities in grades 5-8, all students should develop an understanding of:

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

As a result of the activities in grades 9-12, all students should develop an understanding of:

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Vendor List

This list is meant to be a starting point for people who want to expend or create their own SOCK. It is not an exhaustive list and SPS does not endorse any of the vendors. For the balls for the collision activity or the mystery box items, feel free to buy whatever is easily available since many different things would work.

Activity	Item	Source	Price
Collisions	Hot Wheels gravity clamp packs	Toys R Us (in store only)	$4.29
	Wooden balls	Local Craft Store	$0.40
	Golf balls	Various	$1
	Ping pong balls	Various (for bulk see chain reaction)	$6 for 6
	Large plastic (ball pit) balls	Various	$16 for 100
	Rubber bouncy balls	Local Party Store (party souvenirs)	$3 for 12
	Foam balls	Craft Store	$0.50
Mystery Box	Mystery boxes	Various – ask stores for extra boxes	
	cardboard ramp	Various – can cut from boxes	
	Marbles	Local Craft Store	$2.50 for 100
	Straight hot wheels tracks	Toys R Us	$1 each
	Fly paper	Fly Web Glue Board 10 Pack by Gardner Manufacturing*	$9.95 for 10
	Bocci balls	Halex Classic Series Bocce Set (90mm Composite Molded Balls)*	$19.40 for 8
	Posters	Pacon Peacock Railroad Board, 22x28 Inches*	$15.29 for 15
Chain Reaction	Mousetraps	Woodstream Corp Victor Mtl Mouse Trap*	$38.49 for 72
	Ping pong balls	Bulk Table Tennis Balls (Pack of 144) by S&S Worldwide*	$29.95 for 144
Fission Balloon	17” Balloons	Local Party Store (party souvenirs)	various
	12” Balloons	Local Party Store (party souvenirs)	~$1.50 for 12
	Marbles	Local Craft store	$2.50 for 100
Other	Particle Zoo Pins	http://www.particlezoo.net/individual_pages/shop_button-badges.html	Various

* These items can be found on amazon.com