

SOCIETY OF PHYSICS STUDENTS

Summer Intern Program

presents

SOCK 2012

(S c i e n c e O u t r e a c h C a t a l y s t K i t)

The Fabric of the Cosmos

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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 two main lessons, broken down into many smaller ones, centered on gravity and magnetism. 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 detailing your activities, any new lessons and complete a SOCK Survey after your event so that we can make the next SOCK even better. Your report should definitely include photos if at all possible.

An electronic copy of this manual is included on the DVD provided if you want to edit any of the lessons or the worksheets. We recommend saving the original and renaming any revisions that you make. The DVD also includes instructional videos for some of the lessons. These lessons will have a * by their title.

SPS National and the 2012 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,



Melissa Hoffman, Drew University

Meredith Woy, Bloomsburg University of Pennsylvania

SPS SOCK interns 2012

Kit Contents List

Be sure to check the packing list enclosed in your box for a more detailed list of kit contents.

Gravity

- Spandex
- 8 Tent Poles
- 12 Binder Clips
- 2 Hooks
- 100 Marbles
- 7 Bearing Balls
- 10 Shooter Marbles
- 7 Wooden Balls
- Instructional Video

Magnetism

- 2 Containers of Iron Filings
- 2 Magnetic Field Viewing Boxes
- 2 Pieces of shelf liner
- Assorted Magnets
 - Multipole(1), Disk(1), Horseshoe (1), Bar Magnets (16), Refrigerator Magnet
- Magnetic Field Viewing Film
- Faraday Flashlight
- Floating Magnet Set
- 8 Brass Washers
- Ruler
- Compass
- Ferrofluid 1oz. Bottle
- 3 plastic containers for Ferrofluid
- Gloves (latex free)
- 1 Screws
- 2 Neodymium Magnets
- Eyedropper
- Plate

Other Contents

- Fabric of the Cosmos DVD

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.

- 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 before you go! Make sure you are familiar with outcomes, and have some sense of what might go wrong.**
- Verify the logistics the day before your event and pack. Make sure everything is ready to go, including replacement parts.
- 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!

The Fabric of the Cosmos

SOCK2012

Part 1: Gravity

Notes: Spandex - The Fabric of Spacetime

Why Spandex?

Gravity is one of many invisible fields that truly do make up the “Fabric of the Cosmos” we know today. We’ve taken this concept very literally and are actually using a piece of fabric – Spandex – to model gravity. Spandex is the same material used to make biking shorts and other athletic clothing, and, as it turns out, it’s a very useful tool for mimicking and conceptualizing a simple model for warped spacetime!

What is the benefit of using a model?

By using a conceptual model to introduce and teach a topic, rather than just verbally conveying the idea, students are better able to visualize what you want them to understand. Developing and using models is outlined by the Committee on a Conceptual Framework for New K-12 Science Education Standards in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* as an essential practice for K-12 science education. The committee emphasizes that “building an understanding of models and their role in science helps students to construct and revise mental models of phenomena” (National Research Council 56). It is important for a student to develop mental models because “better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning” (National Research Council 56). In addition to helping to enhance mental modeling, conceptual models also are used by scientists “to represent their current understanding of a system under study, to aid in the development of questions and explanations, and to communicate ideas to others” (National Research Council 57).

What is contained in this packet?

This packet includes a series of short lessons on many topics related to gravitation in a solar system. We have used different combinations of these lessons to fit different time frames, room setups, and age groups, and found great success in customizing the lessons for each of our events. While we think every single lesson is worth doing with a group, you should pick and choose the lessons that best suit the type of outreach event you are planning and fit within time constraints. Each lesson includes a list of learning objectives; some overlap from lesson to lesson and all involve examining the effects of gravity in our solar system and universe! We recommend deciding what messages or lessons you would like to convey to your group, then checking which learning objectives fulfill your needs. Recommended age groups for each presentation are compiled in Table 1: *Suggested Age Levels for activities* Table 1.

Notes: “Assembling Spacetime”*

You can use the Spandex in one of two ways: assembled on a frame, so that it can be set down and requires no one to hold it or as a loose piece of Spandex that everyone grabs onto. The former is better for smaller groups. How you choose to set up the Spandex depends on the size of the group you are planning to work with, the nature of the event, the level of interaction required, etc. We have provided materials and instructions to make a frame for the Spandex. Among the items received in your SOCK are 1 sheet of Spandex, tent poles, and 12 binder clips. These are the only tools necessary to assemble your own personal patch of spacetime.

- Simply connect the tent poles by fitting the ends of each pole into the silver connecting pieces.
- **Carefully bend** the tent poles to make a circle by connecting the two ends (trust us, they will bend enough!). Spread the Spandex over the circle and use binder clips to clamp the edge of the Spandex to the poles. It may help to imagine the circle as a clock face and place the binder clips at the hours. Start with 12 and 6, move to 3 and 9, etc, working in opposite pairs on the imaginary clock face.
- To adjust tension in the Spandex, go around the circle and one-by-one take off a binder clip, pull the Spandex (or loosen it), and replace the binder clip.
- The Spandex frame must be supported at a minimum of three points around the edge to avoid warping the edges of the circle. This can be accomplished by having at least three people hold the Spandex frame or placing the Spandex on three desks. Using an external support system allows for as few as one person to play with the Spandex!



Figure 1- The Spandex Frame

(LEFT) The Spandex on frame, resting on three chairs for optimal support; (RIGHT) A binder clip holding the Spandex onto frame.

Notes: Other Tips for using the Spandex

These tips can be applied to all of the demos provided in our Spandex User Guide.

- Keeping the Spandex flat is extremely important. Holding the Spandex flat can be tough with smaller children, especially if you're not using the frame. Instruct them to hold the spandex at their waist with their knuckles up. Sometimes suggesting "look at your neighbor, and check if you're holding it at the same height as your neighbor," can help.
- Once you place the point mass, or two masses, at or near the center, students may be inclined to look underneath the Spandex to see what it looks like. Instruct everyone to look underneath at the beginning of the demo, so this does not cause a distraction throughout the lesson.
- Marbles will inevitably fly off the Spandex, we guarantee it! Tell students not to worry about marbles that fall off the Spandex, and simply clean them up afterwards or have a designated SPS volunteer pick them up throughout the lesson. This is particularly important during the "Formation of the Solar System" activity.
- In both the "Roche Limit" and "Tides" activity, it is useful to practice the demos beforehand to see how far away from the marbles the satellite should start. If you have trouble during the "Roche Limit" or "Tides" activity, try making deeper gravity wells with your hand, and keeping your orbit at a constant speed.
- During the "Two Masses" activity, younger students may not understand what the 'value of G' is, so it is worthwhile to explain it in a different light. For example, ask "How can we make the two balls come together faster? How can we make them not come together at all?" This way, they will understand the notion of changing a variable (how tightly the Spandex is stretched) to observe different outcomes.

Table 1: Suggested Age Levels for activities

Age	Single Point Mass	Two Heavy Masses	Rings	Tides	Two Masses	Formation of the Solar System	Density Gradient
Elementary School	X		X		X		X
Middle School	X	X	X	X	X	X	X
High School	X	X	X	X	X	X	X

Activity: Introduction to Spandex as a model for Spacetime

This activity helps students to establish properties of how the masses interact with Spandex that are fundamental to understanding all other activities. Students will establish that a mass causes a 'dent' in the Spandex and draw the parallel to masses denting spacetime, therein causing gravity. Students will establish that the larger the mass, the bigger the dent. Students will establish that two masses will distort each other's natural straight paths, causing their paths to curve around one another.

Objectives

- Students will be able to describe the effect that mass has on spacetime.
- Students will be able to discuss what happens to spacetime as more mass is added.

Materials

- Spandex
- Marbles
- 2 Steel Bearing Balls

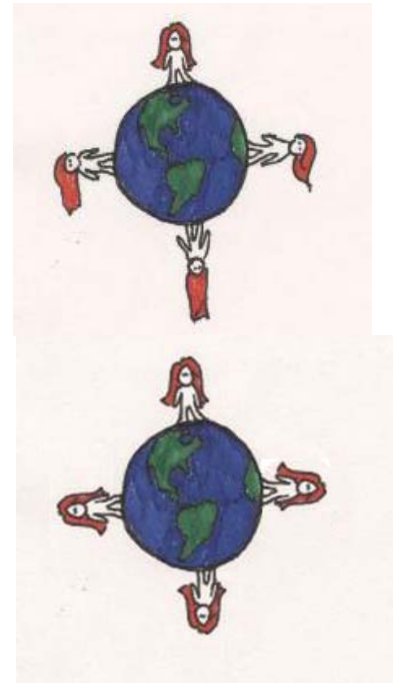
Using the Spandex in the Classroom

Introduction

We found that a useful way to introduce students to spacetime is to discuss Newton's gravity first, asking students about what happens when you let go of an object (it will be pulled toward the center of the Earth). To get students to understand that it is being pulled toward the center of Earth, instead of just falling down, draw the Earth on the board with four people, one at the top, one at the bottom, one on the left and one on the right. Ask students to draw hair on the people. The hair should all be pointing toward the center of the Earth. If gravity simply made objects fall down, wouldn't the hair on the person at the bottom be hanging in the same direction as the person standing on top of the Earth? Students should now make the connection that gravity pulls toward the center of the Earth. If not, lead them to this conclusion. Now question students about why gravity pulls things to the center of the Earth. Using Newton's gravity, there is no explanation for *why* gravity pulls towards the center of the Earth, just that it does. Einstein's concept of spacetime helps us understand the *why* that Newton was unable to explain.

Activity:

1. Decide how you will use the spandex, either supported by people or supported by the frame and get ready to use the slightly stretched spacetime fabric!
2. To begin the lesson, roll a single marble across Spandex. Have students discuss the shape of the path of the marble (straight) and the effect of the marble on the spandex (a small dent). Ask questions as necessary to get the students comfortable with speaking in the group.



*Figure 2: Gravity on Earth
Used to encourage thought about the nature of gravitational attraction*

3. Now roll one of the larger steel bearing ball across Spandex. Have students discuss the shape of the path, effect on Spandex, and difference from marble. (It still rolls in a straight line, but it makes a much deeper dent, deforming spacetime more.)
4. Roll two marbles towards each other without colliding. Encourage students to discuss with their neighbor what happens to their paths. Their paths should curve around one another, because the first mass distorts spacetime and therefore the path of the second marble. As they continue to roll on the Spandex they will be attracted to one another, and come together. This is one of the most important concepts for students to understand.
5. Keep adding marbles and masses and watch as the Spandex curves more as you add more mass. This in turn draws in more mass, which makes the Spandex curve more, etc. Ask students to discuss what's happening and predict what will happen as you continue to roll marbles.
6. Establish a large mass of marbles as the sun, or substitute the large mass of marbles with a bowling ball, cannon ball, or rock and place it in the center of Spandex. Roll the marbles and balls around the "sun" and help the students investigate orbits by posing the following questions for discussion:
 - a. Why does the marble/ball curve?
 - b. Why do they end up clumped with the "sun"? Explain how this is like gravity.
 - c. Predict: How can you get a marble to keep from crashing into the sun for as long as possible? (Answers might include keeping it far away, and hopefully tangential velocity.) Students should each try to create a stable orbit, and share what worked and why.
 - d. Why do our marble orbits decay quickly? Why doesn't this happen with our planets? (On the Spandex friction is the major issue, but many students will initiate poor orbits, and our early solar system was filled with these objects, which is why the sun is so very large and the space around it is nearly empty-- only a couple objects (like earth) haven't crashed into the sun yet.)

Activity: Single Point Mass*

The Single Point Mass demonstration represents a large mass, such as the sun or the earth, with satellites orbiting it. Students will roll marbles, which are the satellites, to make orbits and observe their shape. Discussion about Einstein's and Newton's gravity may be explained in greater detail with older students. Emphasis for younger students should be placed on shapes of orbits, what sorts of objects orbit the earth, sun and other planets, etc.

Objectives

- Students will be able to correctly list at least two different path shapes that objects can take when they orbit a point mass. For older students, they should be able to identify that these path shapes correspond to conic sections.
- Students will be able to distinguish between Einstein's and Newton's concepts of gravity giving at least one similarity and one difference.
- Students will be able to describe at least two distinguishing features of comet orbits.

Materials

- Spandex
- Hook
- Heavy mass
- Bag to hold mass
- Many marbles
- Washers

Creating your gravity well in the Spandex fabric

A bowling ball creates a great spacetime curve, but it is large and in the way. To create a substantial spacetime curve without taking up a lot of space, we have devised a method of suspending a mass under the spandex without damaging the spandex. Place marble on the center of the Spandex, where you want mass to hang from. Pinch the marble from beneath the spandex. Slide the spandex above the marble into the loop of the hook, allowing the circular top of the hook to hold the marble in place. Hang mass from hook. *This only needs to be a few pounds; we have used soup cans or big rocks placed inside a plastic shopping bag,*

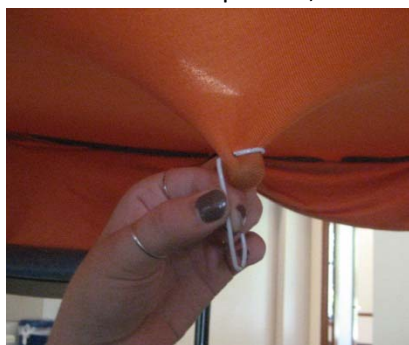


Figure 3 – Making a 'gravity well' in the Spandex

(LEFT) A hook placed around a marble from underneath spandex; (RIGHT) A bag with two soup cans suspended from hook.

Exploring with the gravity well in the classroom

1. Have students hold the Spandex as flat as possible if not using the frame. Try to emphasize strongly that the spandex represents a **2D model** of spacetime, and that the point mass can be thought of as the sun and the marbles as planets, or the point mass could be the Earth and the marbles the moon, asteroids, or other satellites.

2. Hand out marbles; have students predict the shape of the path that the marbles will take when they are rolled around the mass. Have students roll marbles on the spandex to create “orbits”--many different shapes of orbits should be observed.
 - a. Ask students to discuss these orbits.
 - b. Ask students to try to create certain orbital shapes, i.e. to create a circle or ellipse, try to roll the marble on a tangential path to a circle, to create parabolas or hyperbolas, roll the marble with a little vertical component.
 - c. Ask what bodies in the solar system make these different shapes. Some planets and moons are roughly circular, whereas others are more elliptical. Things with hyperbolic orbits and parabolic orbits fly past the object they are orbiting as they have a velocity greater than or equal to escape velocity.
3. Next, try rolling a washer (or coin) on its edge. This will form a slightly different orbit. You may have students guess what would make an orbit like this, or simply explain to them that this makes a comet-like orbit. Make sure students understand the difference between the shaped of planetary and comet orbits.

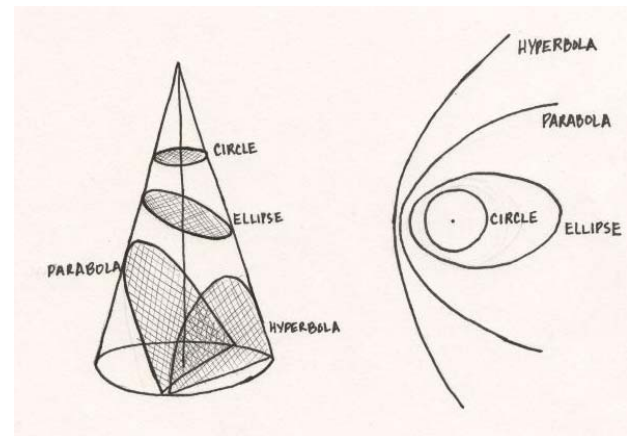


Figure 4: Using the Spandex to explore attraction of a single point mass (LEFT) Marbles orbiting a single point mass. (RIGHT) Diagram of conic sections.

Activity: Binary System*

This demonstration represents a binary star system. Orbits of binary systems are observed by rolling marbles on the spandex while two different heavy masses pull the spandex down.

Note: You will need two separate hanging masses. See “Creating your Gravity Well” in previous section.

Objectives

- Students will be able to correctly list at least two characteristics of a binary star system.
- Students will be able to identify orbits seen in a binary system.

Materials

- Spandex
- Two hooks
- Two bags to hold masses
- Two heavy masses
- Many marbles

Advanced Preparation

This demonstration is a variation of the previous demonstration. It is set up the same way, but instead of hanging one hook in the center of the spandex, there should be two hooks near the center of the spandex but spaced a few feet apart (two feet apart works well).

Exploring binary systems in the Classroom

1. Introduce students to binary star systems, and be sure students understand that this setup represents a binary star system. If possible, you may show them some telescope images, or pull up a website with images of binary star systems.
2. Distribute the marbles to students and ask them to predict the shape of the orbits when they roll the marbles this time. Allow students to roll marbles and observe the shapes of the orbits. Look for traditional conic sections, but also have them try to achieve ‘figure eight’ orbits and other variations from the Single Mass.
3. You may get the question “why don’t binary stars crash into each other?” If someone does not ask this question, raise it and encourage them to discuss. Explain that another property of binary star systems is that they are orbiting around each other and this makes them more stable. Explain to students that we cannot make the masses orbit each other since they are attached to the Spandex, but we can represent this by turning the whole spandex in a circle.
4. In order to demonstrate this redistribute the marbles, and have students hold the spandex in their right hands only. Tell students to begin walking clockwise while holding the spandex. Now have them roll the marbles again. This is a simplistic demonstration designed to get students thinking about complex systems.
5. To check for understanding, ask students to explain why the spandex was rotated, as well as what the point masses represent.

Fun fact to tell students: When you look in the sky, half of the stars you see are actually binary systems. It's more common than you might think!

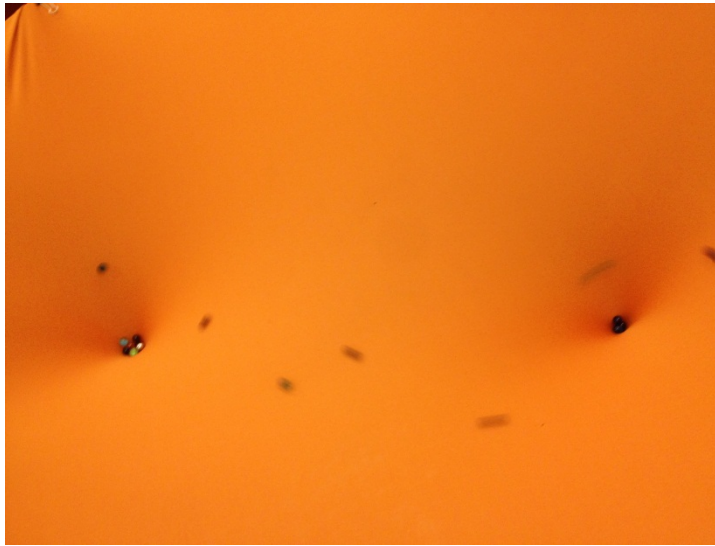


Figure 5: Marbles orbiting around two point masses

Activity: Density Gradient

The density gradient demonstration allows students to see how objects of different densities arrange themselves within a gravitational field. Students will see the objects of greater density move to the center and the objects of less density move to the outside of the pile.

Objectives

- Students will be able to describe the way objects of different densities arrange themselves in a gravitational field.
- Students will be able to describe where the densest part of Earth and the least dense part of Earth are located.

Materials

- Spandex
- 7 steel bearing balls
- 7 wooden balls
- 9-10 glass marbles



Figure 6- Demonstration of the formation of a density gradient

(LEFT) Marbles (spheres) in a cluster that depicts a random distribution of densities; (RIGHT) Here, the spheres have organized with most the dense at center, least dense around edges.

Exploring the density gradient concept in the Classroom

1. Arrange marbles, wooden balls, and bearing balls on the spandex so that they are all mixed together in a group. You will have to be intentional about have the balls randomly distributed, since the bearing balls will naturally move toward the center of the collection.
2. Ask students if objects of different densities are usually arranged randomly in a gravitational field, or if this representation is wrong. If they don't know, tell them to think of the layers of the Earth, what they are made out of, and where they are located.
3. Move your hand slowly in circles on the spandex around the group of balls so that your hand and the group orbit one another. This is a very similar motion to the tides and Roche limit demo, however, it requires a little more physical effort to get all of the objects in the group moving. You maybe have to push deeper into the Spandex or move your hand faster. The objects will arrange themselves so that the steel bearing balls are in the center with the marbles around them and the wooden balls on the outside.
4. Have students discuss whether this is consistent with their predictions.

Table 2 Densities of marbles used*	
Object	Density (± 0.001) g/cm ³
Steel Ball Bearing	7.692
Large Glass "shooter" marble	2.33
Wooden ball	0.699

*Measured by SPS SOCK Interns

Activity: Formation of the Solar System*

The formation of the solar system is modeled in this demonstration. Students each hold a few marbles and toss them up onto the spandex all at the same time. The marbles will conglomerate into a group and a few will orbit the larger collection near the center of the spandex briefly.

Objectives

- Students will be able to describe at least two conditions that existed for the formation of the solar system to occur.
- Students will be able to identify the reason the planets spin the same way around the sun.

Materials

- Spandex
- All available balls (marbles, steel bearing balls, shooter marbles, etc.)

In the Classroom

1. Have students hold the spandex or hold the frame with the spandex. If the frame is not used, make sure to emphasize that holding the spandex flat is imperative for this demonstration to work as a reliable model. This demonstration requires many spheres. If any of the spheres roll towards the edges. Instruct students not to catch them, since it will disturb the flat surface of the spandex when they move their support position.
2. Distribute marbles/bearing balls/shooter marbles/wooden balls to all the students. These represent the dust and debris particles that are in space. Each student should have about a handful.
3. Instruct students to gently toss the balls simultaneously onto the Spandex on a count of three. Before the countdown, instruct the students to carefully observe the motions of all the spheres. After the toss, allow the balls to settle.
4. Have students describe what they observed. You may have to repeat the experiment a few times because the settling happens fairly quickly. Students should report that all the spheres immediately begin to move together, with some of the spheres orbiting around the places where many spheres have collected. Try to get the students to express their ideas about what is happening, and what this represents. Use questioning to lead them to the idea that this illustrates a massive central point with other masses that orbit. This is like the sun near the center of our solar system, where most of the mass ends up, and the planets orbiting the sun. Have students point out interesting outcomes. After the discussion it is useful to try the experiment again.
5. Next, repeat the experiment, but instead of tossing the spheres directly out onto the spandex, this time include angular momentum. This is accomplished by instructing the students to toss spheres to the side slightly (either toward the left or right) as they throw them onto the spandex. This time, all of the orbiting bodies should be going in the same direction as they orbit around the places where larger masses have collected. This is a good model of our solar system, since evidence indicates that there was some initial angular momentum in the formation of our solar system.

Extension – for more advanced students

You might want to explore an increase or decrease in the strength of gravitation attraction using the spandex model of gravity and repeat the demonstration. To model an increase in the gravitational attraction, the spandex needs to be looser so the objects create a pronounced distortions in the spandex. This will result in more of the marbles staying on the spandex and being in the solar system, and perhaps even increased speed of formation, less 'rogue planets,' etc. To model a decrease in gravitational attraction, pull the spandex tighter, either by stretching it over the frame more tightly or having the people holding the spandex step back slightly. With a more tightly stretched fabric, the marbles will not produce as large a distortion in the spacetime. This also means that marbles will roll off of the spandex easier. If the spandex is too tightly stretch, modeling a situation where the gravitational attraction is too weak (the spandex will be really stretched) the solar system may not be able to form. Another thing to look for in this demonstration is the formation of binary systems, which we have seen happen once or twice with a small enough (but not too small) gravity!

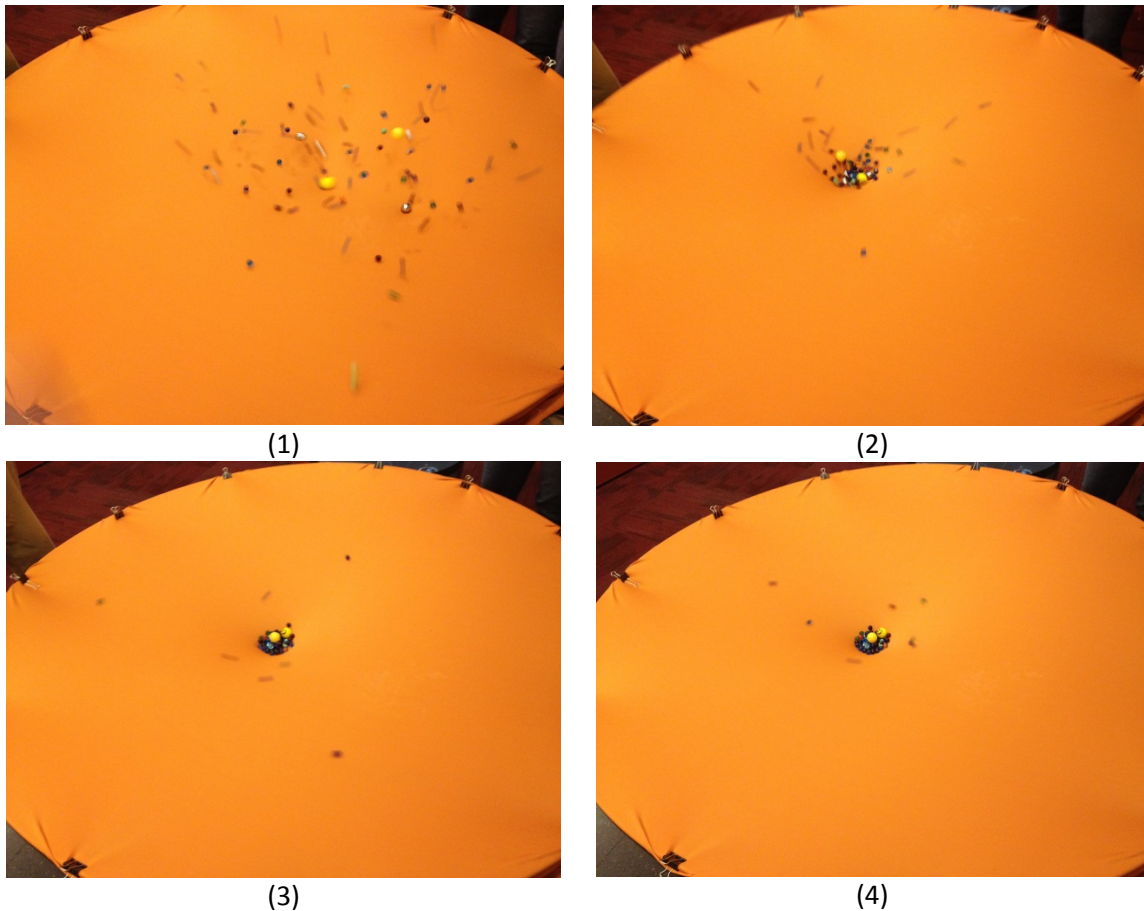


Figure 7 The Formation of the Solar System demonstration numbered chronologically.

(1) tossing marbles straight out onto the spandex; (2) marbles begin to collect into a single location on the spandex; (3) & (4) some marbles orbit around the collection near the center

Bonus Activity: Tides*

The Earth's tides are modeled using a group of marbles. When you use your hand as the moon and circle around the 'Earth', the marbles can be seen elongating in a line toward your hand, representing the tides.

Objectives

- Students will be able to identify the differential forces from the moon's gravity as the cause of tides.
- Students will be able to correctly state that there are two high tides and two low tides per day.

Materials

- Spandex
- Marbles
- Golf ball (if desired)

Exploring tides in the Classroom

1. Have students hold onto the spandex, forming a circle. It is recommended that the frame be used for this exercise.
2. Place a small group of marbles on the spandex, so that they are touching each other, forming a circular 'blob' in order to resemble a small, flat planet. Explain that this represents the Earth and that you will use your hand to represent the moon. Another alternative is to use a golf ball or other larger sphere to represent the Earth and surround that sphere by a collection of smaller marbles. The smaller marbles represent the water in the oceans that cover the majority of the Earth's surface.
3. Before doing any demonstrations, be sure to ask students what they know about tides. See if they know how many tides there are per day. And ask them to discuss their ideas about the cause of tides.
4. With your hand a small distance away from the "Earth," begin moving in circles around the "Earth" you have created out of marbles. This shows the moon (your hand) orbiting around the Earth (the marbles). Keep orbiting, and you will see the marbles move from their equal distribution around the golf ball, or circular shape and begin to elongate and form more of an oval shape. One "hump" of the oval of marbles will stretch towards your hand, and one will stretch away from your hand. Ask students what these two humps represent. These two "humps" that just formed on the Earth are the two high tides we pass through in a day. The parts that do not have the humps are the low tides.
5. Ask students what is causing the marbles to elongate. This is caused by the gravity of the moon.

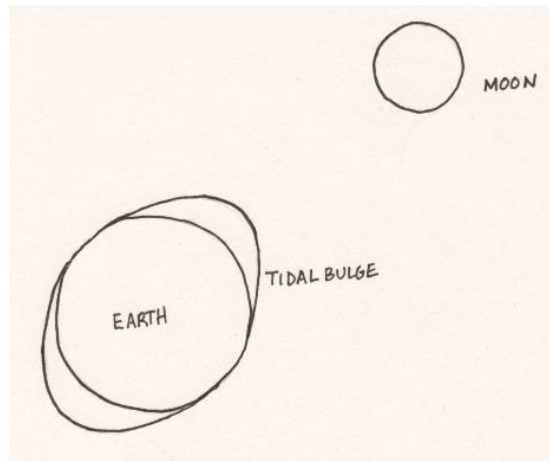
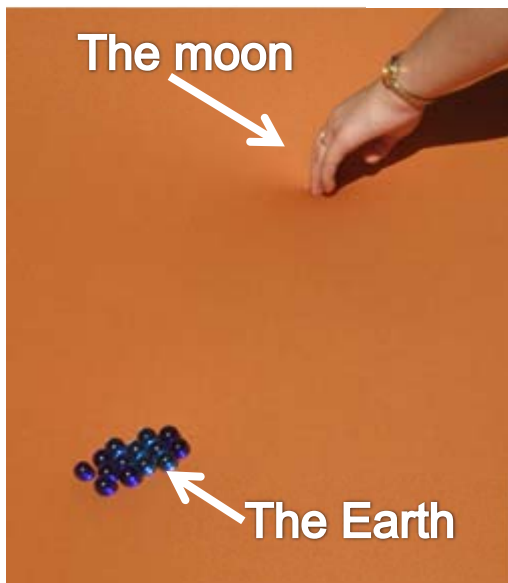


Figure 8: A demonstration of tidal phenomena (LEFT) A demonstration of the tides using hands and marbles. (RIGHT) A diagram of tidal bulges on the Earth.

Extension for older students:

Discuss the fact that these tidal actions vary depending on the relative locations of the Sun, Moon and Earth. These variations are called Spring and Neap tides

Spring tide - This is when the tides are higher than average, due to the alignment of the sun and moon.

Neap tide - The tides are lower than average, due to the sun and moon being perpendicular to each other.

For more discussion, see “Notes on the Physics of Tides” in Appendix 4.

Bonus Activity: Roche Limit*

This demonstration shows the formation of rings (for example, Saturn's rings). It starts with a group of marbles 'orbiting' your hand, with your hand representing the planet and the marbles representing a satellite. As you move your hand closer to the satellite, the satellite breaks up, resulting in rings around the planet. This demonstrates the Roche Limit, which is the closest a satellite can get to a planet before the difference in gravity causes the satellite to break apart.

Objectives

- Students will be able to describe the distance relationship of gravity as an inverse square law.
- Students will be able to describe a characteristic of the Roche limit.
- Students will be able to identify an effect of the Roche limit.

Materials

- Spandex fabric
- Marbles
- Hand

Advanced Preparation

Place a small group of marbles on the Spandex (10-20), the group of marbles should be slightly smaller than your fist. Practice beforehand to determine a good distance and depth of well.

Exploring the Roche limit in the Classroom

1. Have students stand in a circle holding the spandex. To achieve a dynamic system, move your hand (the planet) in a circular path in the spandex, depressing the spandex enough so the marbles (the moon) follow.
2. Ask students to predict what will happen if the moon and planet get closer together. This time, bring your hand in closer to the orbiting marbles and push down harder on the spandex. This will cause the group of marbles to break up but continue orbiting your hand. This represents how rings form around planets. When a moon comes within the Roche Limit, it will break into pieces. In space, these pieces will often form rings.
3. Explain that the strength of gravity is distance dependent, so as the moon and planet get closer together, gravity increases as an inverse square law ($1/r^2$). Gravity keeps increasing and eventually, when the moon gets within the Roche limit of the planet, the difference in the pull of gravity at different points within the moon is strong enough to pull it apart.
4. To make sure students understand this concept, ask them where the moons and the rings of Saturn are located. The moons are farther away from Saturn than the rings are, outside of the Roche limit, while the rings are inside of the Roche limit and therefore closer to Saturn. Make sure students understand that planetary rings are not solid, but they are formed by a lot of pieces all in a ring around the planet.



Figure 9: The Roche Limit Demonstration (Left) a satellite approaches and begins to orbit a “massive body” (the dent produced by pushing on the fabric with your hand and (Right) the satellites reaking apart as they cross the Roche limit.

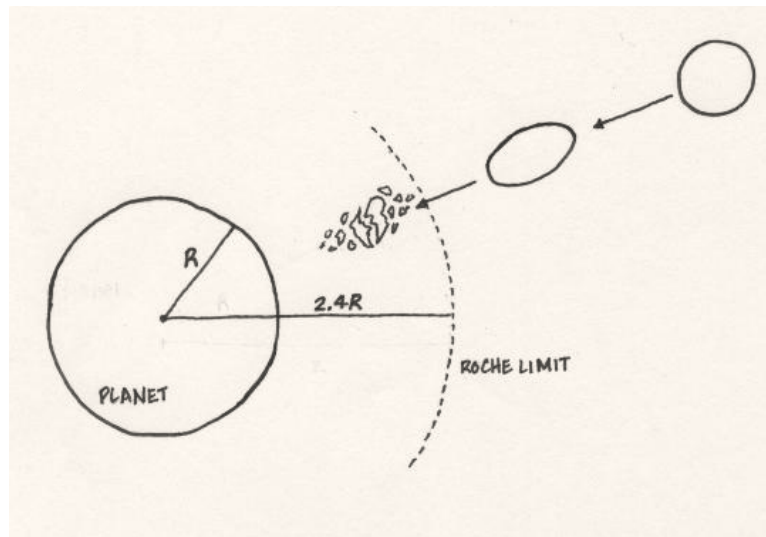


Figure 10: The Roche Limit

This diagram depicts the details of the location of the Roche Limit for a planet with radius 'R'.

Bonus Activity: “Big G” - The Gravitational Constant

This demonstration illustrates the effects of changing the gravitational constant, G . Two masses are dropped on the spandex and allowed to move freely. If G is strong enough (the spandex is loose), the masses will come together. If G is too weak (the spandex is stretched tight), The masses will not be able to come together.

Objectives

- Students will be able to describe the way spacetime causes two masses to move.
- Students will be able to describe one effect of a smaller gravitational constant and one effect of a larger gravitational constant.

Materials

- Spandex
- Two steel bearing balls

Exploring “Big G” in the Classroom

1. For this activity, it is best NOT to use the frame, but to have students hold onto the spandex. Have a student drop the two balls onto the spandex a foot or two apart from each other. The balls should move toward each other and end up touching. If not, try dropping them closer together.

2. Ask what this is modeling—try to get the discussion around to the point that this observation illustrates the way Einstein explained gravity. If we let the spandex represent the “fabric” of spacetime, then whenever mass is added to the fabric the spacetime becomes deformed, or warped. The bends in spacetime from the two masses is the cause for them to move towards each other.

3. After exploring with the two masses and getting in a good discussion, ask students how they think they could affect the “strength” of gravity in this model. Try to lead them toward the idea that in order to have an effect on the motion of the two masses, that is to change the effect of gravity on the masses, the spandex should be stretched or loosened. When the spandex is stretched to form a more taut surface, the strength of gravity is decreased. Students should observe that the balls do not move together as quickly as they did in the case where the fabric was stretched out less. In more technical terms, this models a decrease in the universal gravitational constant, “Big G”.

4. Once you have discussed the concepts, explore and observe this idea. Have the students all take a step back to stretch the spandex and ask what effect this will have if you drop the balls again now that the effect of gravity on the masses is decreased.

5. Try dropping the masses again and watch them come together. You will see that with this new decrease in the effect of gravity, the masses have a harder time responding to each other’s attractive forces. This change can be seen by looking at the dents the masses make in the spandex. The balls do not sink down as much, therefore they do not cause such drastic bends in spacetime.

6. Now, do the opposite and loosen the spandex, increasing gravity. Drop the masses again, and they will roll towards each other easier. They can now be dropped farther apart and still find each other because there is more gravity.

For more advanced students: This is a tricky correlation to make, since the idea of the universal constant of gravitation is a Newtonian concept, and the idea of curvature of spacetime is an idea developed in Einstein's explanations and understanding of gravity. However, you might discuss the implications of changes in the universal constant of gravitation, or "big G" to the way Newton observed gravitation in nature. We see this value in the equation Newton used to describe the force of attraction between any two particles with mass. The number "Big G" appears is directly proportional to the force of attraction. So, if the value of G is decreased, the force of attraction between any two masses is decreased. This corresponds to the spacetime fabric remaining flatter, with shallow indentations and decreased curvature. Likewise if the value of "Big G" increases, the force of attraction between any two masses is increased. This corresponds to the spacetime fabric having deep indentations, or increased curvature.

We should note that the value of the universal constant of gravitation, "Big G", was first measured in 1797 by Henry Cavendish, a remarkable experimental physicist. He was able to measure the very small force of gravitational attraction between two metal spheres. This force the he measured is about a billion times smaller than the force on the spheres due to the gravitation attraction from the Earth. This not only confirmed Isaac Newton's predictions but also allowed for the determination of mass values for the Earth, Moon and Sun!

The Fabric of the Cosmos
SOCK2012

Part 2: Magnetism

Activity: What is Magnetic and What is Not?

A common preconception that students have about magnets is that they “stick to metal”. This activity is designed to help students develop a better understanding of basic magnetic properties by exploring which type of materials cause magnets to be attracted. Exploring the actual physical interactions that explain why some materials (like iron, cobalt, nickel) cause an attraction, while other material (like copper, wood, plastic) do not, is likely beyond the scope of the audience. Instead, this activity is designed to be a student-centered investigation that puts equipment in their hands and allows them a chance to explore, record results, and report on their findings. The last portion is a simple numerical experiment that engages students by having them compete to pick up the most paperclips with their magnet. NOTE: This activity is geared toward younger elementary-aged students. You might want to skip this activity if working with older or more advanced students. The exception is the challenge to hold up paper clips. Even older students enjoy a challenge!

Objectives

- Given a list of materials, students will be able to develop an experiment to identify which ones are magnetic.
- Given two magnets and paper clips (or some other ferromagnetic material), students will be able to determine which magnet is stronger.

Materials

- Magnet (we recommend one of the small bar magnets in the kit)
- Materials to test
 - Magnetic materials: iron, nickel, cobalt, paper clips, wire clothes hangers, certain screws and nails, certain washers
 - Nonmagnetic materials: Use your imagination! We suggest that in addition to paper, plastic, glass, wood, and other obvious choices, include coins, jewelry, and other metallic objects that are not made of ferromagnetic materials. One common material is aluminum, either use foil or a soda can.
- Chalkboard/pieces of paper to make list of items. This can be a group list on a chalkboard or other large surface or can easily become a handout by printing out a table with two columns where students can list which items are magnetic and which are not.

Exploring magnetic attraction In the Classroom

We recommend that you guide the students in their explorations in two main parts.

Part A

1. Provide each student with a magnet (or work have students work in small teams). Tell students that they are going to investigate a variety of objects around the room to find out what types of materials are magnetic. To avoid losing focus, assign students an area of the room they are to stay in. An alternative is to provide students with a box filled with a variety of different objects or materials. Be sure to include magnetic and nonmagnetic objects or materials. Instruct students that to determine if a material is magnetic they should use the magnet to see if there is any interaction between the magnet and the object or material. They should be careful to observe what the interaction is, if there is one. Some students might use the word “stick” to describe what happens between the magnet and a magnetic material.
2. As the students explore, help them record their results in a large class chart. You might use the board or a large sheet of paper with a marker. On the chart draw two columns, one labeled “Magnetic” and another labeled

“Non-Magnetic.” As students explore with their magnets, instruct them to write the type of material they investigated under the appropriate column.

3. After the chart has several materials listed in both columns, bring the group back together. Ask the students what patterns they can see by observing the kinds of materials in each of the columns. Discuss any surprises that the students might identify in the chart.

Part B

1. Have students work in small teams. Provide each team with several paper clips.
2. Let each team choose a single magnet from the kit.
3. Instruct students to add one paper clip at a time to the end of the bar magnet and to determine how many can hold on, as shown in the figure below. They should add one paper clip at a time, placing the paperclips so that they touch end to end. The goal is to hold as many paper clips as possible, end to end.
4. As they try this, begin the discussion. They should have already identified a paperclip as a ferromagnetic metal, but if not, ask them to discuss why the paperclips “stick” to the magnet.
5. Then, ask why they think the paperclips hold on to each other. This is an important point to make. Initially, our claim is that ‘certain things are attracted to magnets’, but now we can alter that to be ‘certain things are attracted to other things, because the other things are in contact with a magnet’.
6. Have teams report to determine which magnet (or team) picked up the most paper clips, and talk about why different magnets will pick up more than others (they should answer that some magnets are stronger than others, and they’re right!).



Figure 11-Picking up Paper Clips with a magnet

Activity: Exploring Magnetism

This activity allows students to explore with magnets and compasses to get a further understanding of magnets, especially the interactions of multiple magnets. In the previous activity, students should have determined that magnets are attracted to certain materials. Here students will begin to investigate the interactions between magnets, reaching the finding that magnets are attracted or repelled by one another, and like poles repel one another and opposite poles attract.

Objectives

- Given two magnets, students will be able to identify which poles will attract and which poles will repel.
- Given a compass and a magnet, students will be able to “map out” the magnetic field of the magnet.

Materials (to be given to each group)

- 2 bar magnets
- 1 compass
- Copy of compass directions worksheet

Exploring magnet interactions in the Classroom

1. Start with a reminder about the how magnets interact with various materials. Ask students what sorts of materials magnets are attracted to, as a refresher. Frequently, students will remember that iron is magnetic. If no one knows, consider trying the first activity in this section, or giving students five minutes to test things around them. Bring up the other ferromagnetic materials (iron, nickel, cobalt) after discussion.
2. Ask students what else they know about magnets. If they mention poles, that is great. If not, point out that all magnets have two poles, a north and a south. Encourage students to talk to each other to come up with ‘rules’ magnets follow, and have students write down what they come up with. Have the students try putting either two north poles together or two south poles together and see what happens. They will feel the magnets ‘pushing’ each other apart.
3. Ask a few students to share what they wrote down. Make sure they understand that like poles of magnets repel. Now let them explore what will happen if two opposite poles are brought together. Again, let students try this for themselves so they can feel the magnets attract, have them talk to each other and again have them write down what happened. Ask a few students to share their observations. Make sure that they understand that opposite poles of magnets attract each other.
4. Next, introduce the compass. Before allowing the students to explore with the compass, show them a compass, and ask students how a compass works. They may answer that a compass points to the North Pole, that explorers use it, etc.
5. Once this idea is discussed, instruct groups of students to use their compass to identify which direction is north, based on what their compass shows. Have students explore to see what happens when you place a compass near a magnet, and then have them discuss the effects. Discuss results, and establish that *essentially, a compass is a magnet*.
6. Hand out the worksheets with the outline of a bar magnet and circles around it. Have students place a compass in each of the circles on the sheet, with the magnet place in the center. Instruct students to record where the compass points (the red end is the pointing end) using arrows on their sheet. Students can place the magnet and

compass directly on the worksheet, and draw the direction the compass needle is pointing when it is placed on each of the circles. Students will be essentially tracing the magnetic field. \

7. After students have completed this mapping, ask them to discuss their results. Have groups compare their maps and through questioning lead them to some conclusions about the direction of the compass needle around the bar magnet. These directional markers tell us about how the bar magnet affects the space around it. They should note that in general, arrows point *toward the south pole of the bar magnet and away from the north pole of the magnet*. This observation is a clue to the understanding of the concept of “field”. From these observations, we know that the magnet affects the space around it in a very specific way that can be detected by observing the orientation of the compass needle – which is also a small magnet.

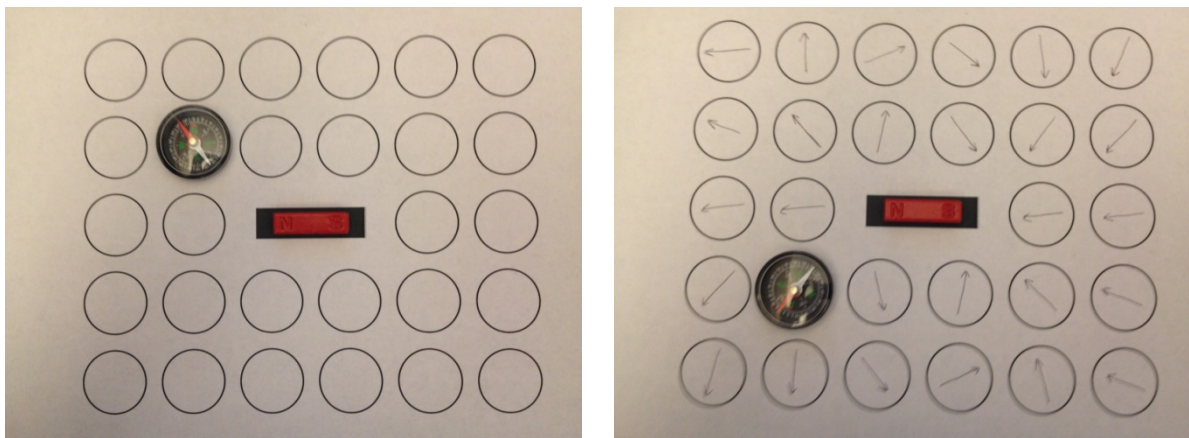


Figure 12: Set up for the compass directions measurement

(LEFT) Setup for mapping the magnetic field. Students should be instructed to place the compass in each of the circles. Observe the direction of the compass needle, and record that direction by using an arrow. The arrow head should point in the direction toward the red (North) end of the compass needle. (RIGHT) Mapping the magnetic field with the arrows drawn in.

Extension for more advanced students: Discuss the behavior of the compass in the Earth’s magnetic field. How does the map drawn on the paper differ from how the compass behaves when only affected by the Earth’s field? This brings the opportunity to discuss that when the compass needle north end points toward the north geographic direction, it is actually telling us that this “NORTH GEOGRAPHIC POLE” is actually the SOUTH MAGNETIC POLE. Likewise, the south geographic pole is actually the north magnetic pole.

Activity: Viewing Magnetic Fields

Magnets have a magnetic field that fills all the space surrounding them. Because iron is attracted to magnets, iron filings are a tool we can use to 'see', or visualize the magnetic field. This activity allows students to explore the magnetic fields of different types of magnets using iron filings and a plastic viewing box.

Objectives

- Given a picture of a magnet, students will be able to draw the field lines.
- Given an iron filing pattern, students will be able to identify the location of the poles.
- Students will be able to distinguish between the net field of two bar magnets with like poles together and the net field of two bar magnets with unlike poles together.

Materials

- Magnetic field viewer (clear plastic box)
- Various shaped magnets (ring, bar, horseshoe, disk, multipole, refrigerator, neodymium)
- Iron filings
- Shelf liner
- White paper
- Magnetic viewing film
- Flashlight

Advanced Preparation:

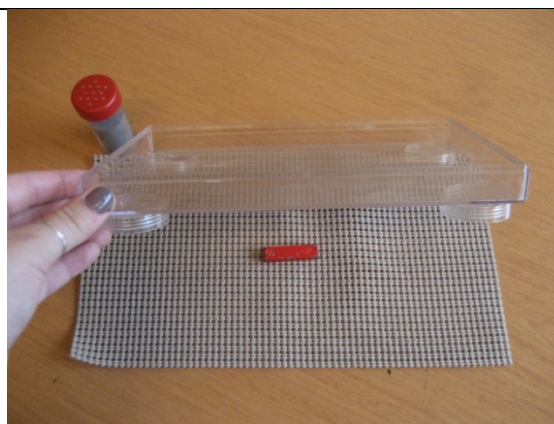
- Place the shelf liner on the surface you wish to use (this will be used to place the magnets on in order to keep them from sliding). Place the magnetic field viewer on top of the shelf liner.
- It also helps to put a sheet of white paper inside the magnetic field viewer in order to see the iron filings more easily. Lay the piece of white paper flat on the bottom of the box before sprinkling in the iron filings.
IMPORTANT NOTE: It is important to keep the magnets from getting covered in iron filings. The magnets will be placed UNDER the magnetic field viewer (and on top of the shelf liner) and the iron filings will be sprinkled into the white paper in the magnetic field viewer.

Exploring Magnetic Field Lines in the Classroom

1. Start by placing a bar magnet on the shelf liner under the magnetic field viewer.
2. Ask a student to carefully shake iron filings onto the magnetic field viewer. It is important not to coat the surface too thickly with the iron filings because the field will not be seen as well. It also helps to tap the magnetic field viewer with your finger to help align the iron filings. See Figure 13.
3. Once you have a good pattern, ask the students to describe what they see. They should see lines running from one pole to the other (even though some of the lines don't make it back around to the other pole, they still curve in the direction of the other pole).
4. Now clear the magnetic field viewer by tilting the container so the iron filings all go off to the side. You may need to tap gently.

5. Next, place two bar magnets under the field viewer, with like poles facing toward each other. The magnets should be just far enough apart that they will not be repelled and move from their positions. Replace the viewing box with the white paper.
6. Have a student sprinkle the iron filings again. Again, ask students to observe the pattern. Point out the 'dead zone' between the two magnets. This is the region between the two like poles where there is little or no iron filings. Physically, this is a region in space where the two magnetic field of the two magnets have summed to very nearly zero; it represents a region where there is little to no net magnetic field.
7. Now clear the magnetic field viewer again.
8. Repeat step 5 and 6, but this time place the two magnets so that opposite poles are facing each other but are just far enough apart that they will not move toward each other. After having a student sprinkle iron filings and tapping the container, ask students what is different about this one compared to the last one. They should notice that instead of the 'dead zone' there is now a 'bridge' of iron filings connecting the two magnets. This is due to the fact that opposite poles attract. This means that the magnetic field between the two opposite poles is in the same direction for each magnet.
9. Repeat these steps with various other magnets provided in the SOCK. One thing that students should discover is that that not all magnets have poles on the ends; some are top and bottom. Some magnets also have more than one north and south pole. An example of this is the multipole magnet provided in the kit.*

*When you are examining the multipole magnet, you may wish to point out that this is similar to the magnet found in the SOCK flashlight, which uses a moving magnet when you crank the flashlight to generate electricity, which causes the bulb to light up in the flashlight! For an easy way to view the field from this magnet, we have included in the kit a small piece of magnetic field viewing paper. Hold the paper in contact with the magnet and observe the variation in green color on the paper. This variation is sometimes easier to see than the iron filings. We suggest doing this BEFORE using the iron filing viewing box in order to observe the more complicated field line configuration.



(A)

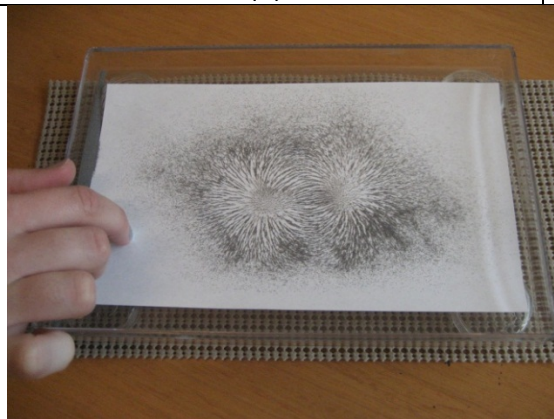
Figure 13: Setup to view magnetic field lines

(A) To set up the field viewer, place the bar magnet on the shelf liner and place the field viewing box on top



(B)

(B) Place a piece of white paper in the bottom of the viewing box
(C) Lightly sprinkle iron filings onto the white piece of paper. Be careful not to sprinkle too many. Fewer is better. Tap the white paper gently to allow the filings to move around and align with the field lines of the magnet.



(C)

WARNING: Do not allow the iron filings to come in to contact with magnets. The filings are difficult to remove, particularly from the Nd magnets. If this accidental contact happens, we recommend using sticky tape to help remove the iron filings from the magnet. Simply place the sticky tape in contact with the iron filings and pull them away from the surface of the magnet.

Activity: Finding Magnets by Unveiling Their Fields a.k.a. “Magnetic Hide and Seek”

This activity allows students to apply their knowledge of the characteristics of magnetic fields to predict the hidden magnet or arrangement of magnets associated with a net field. Using iron filings allows us to make invisible net fields visible. Students have both an opportunity to set up configurations of magnets and to sprinkle iron filings to discover where the magnets are hidden. This activity is fun for younger elementary students.

Objectives

- Students will be able to locate a hidden magnet and identify the location of the poles by looking at the iron filing pattern.
- Students will be able to apply their knowledge of the field lines of one bar magnet to decipher a more complex net field.

Materials

- Magnetic field viewer
- Magnets
- Iron filings
- Shelf liner
- White paper

Advanced preparation:

- Set up the magnetic field viewer as described in Figure 18.

In the Classroom

1. Divide the group into two teams. Assign one team to be the ‘hiders’ and one team to be the ‘seekers’. The hiders will hide the magnets and the seekers will then find the magnets.
2. Hiders begin by arranging 2-3 magnets on the shelf liner. When the magnets are in place, have the hiders place a piece of copy paper into the dish of the magnetic field viewer, so that the other team will not see where the magnets are.
3. Seekers find magnets by sprinkling iron filings into the magnetic field viewer and looking for field patterns of magnets they have become familiar with. Once they agree with each other about where the magnets are hidden, have them look under the viewer to see if they are correct. After the first round, the hiders should become the seekers and the seekers should become the hiders.

Activity: Net Magnetic Field Game

Magnets will produce a net magnetic field that can be viewed using iron filings. By applying knowledge of a bar magnet's magnetic fields, specifically the field between attracting and repelling poles, participants can predict the arrangement of magnets/poles creating the net field and test their predictions.

Objectives

- Students will be able to apply their knowledge of the field lines of one bar magnet to decipher a more complex net field.

Materials

- Magnetic field viewer (plastic box)
- 4 bar magnets
- Iron filings
- Shelf liner
- Slides

Advanced Preparation

- Distribute worksheets
- Set up PowerPoint if desired to show challenge pattern (included on the CD)

In the Classroom

1. Group into two teams. Say “Now that everyone has some experience visualizing magnetic fields, we have a challenge for you. By arranging 2-4 bar magnets, we have created net magnetic fields and exposed them with iron filings. It is your job to figure out the arrangement of magnets that produced these net fields”.
2. Have students discuss their ideas for their arrangement, sketching them on their worksheets, and then have them test their ideas using the magnetic field viewers.
3. Give an adequate amount of time (we gave about 20 minutes) for students to make a guess for each one. Use the PowerPoint to go over solutions as a group, and if desired, score teams to see who won.

Option: rather than using projected images for the challenge, allow groups to work at their own pace by handing out copies of the challenge sheets (on the CD). You might give them one sheet at a time and score each one, or give each team a packet and make it a race.

Bonus Activity: Floating Ring Magnets

A magnetic force can be strong enough to overcome gravity, causing magnets to 'levitate' above opposing poles. This activity shows that the magnetic force increases as the distance decreases. This activity allows students to measure the height of a levitating magnet as they vary the weight load on a levitated magnet. This activity is most suitable for older students who have some experience in constructing graphs.

Objectives

- Students will be able to record and analyze data to draw conclusions.
- Students will be able to compare the strengths of gravity and magnetism.

Materials

- Floating ring magnets kit: 4 donut-shaped magnets on a plastic ring stand
- Brass washers

In the Classroom

1. Set up the activity by placing a single ring magnet on the ring stand and placing another ring magnet on the ring stand so that the same poles of both magnets are facing each other. The second magnet will float above the first magnet. If allowing students to do this, care must be taken not to allow these strong magnets to hit together, as they may crack. In addition, the repulsion is sufficient in some cases to propel the top magnet off of the ring stand. Because the magnets are brittle, care must be taken not to drop them on the floor.
2. Start by asking the students what forces are acting on the levitating ring. They should answer that gravity is pulling it down, but the magnet beneath it is repelling it upward. This upward force must be due to the interactions between the two magnets. We call this effect magnetic force. For older students, you may discuss the idea of equilibrium. Since neither magnet is moving, the system is at equilibrium. This means that the downward force due to gravity must be equal to the upward magnetic force on the levitating magnet. This upwardly directed magnetic force is caused by the interaction of the two magnetic fields.
3. Next, try gently pushing the levitated magnet downward slightly toward the lower magnet. When you release the magnet, it will begin to oscillate briefly. Ask students why they think the top magnet bobs up and down, and why it eventually stops. Show them that as you push it closer to the stationary magnet, the magnetic force will propel it with greater strength, but then when it gets above its equilibrium, gravity pulls it back down. This process repeats, causing the oscillations about the equilibrium point. They may or may not recognize that is is friction that causes most of the damping, but you can ask what they suspect is at work.
4. Each kit comes with four magnets. We recommend that you try several different groupings. With each configuration, explore to see how the levitating magnet responds. Then, try levitating multiple magnets.
5. Now go back to one magnet at the base of the stand and one levitating above it. Have students record the distance between the levitating magnet and the stationary one. Be sure to select a point on the levitating washer as the measurement point. You should use the stationary base as the reference point. To teach good experimental practice, make several measurements.
6. Now, add brass washers one at a time. Make several measurements between each addition to determine the distance between the levitating magnet and the stationary one (or from the base used as a reference point). Note: Brass is used because it is not magnetic, and therefore does not distort the magnetic field.

7. Continue the measurements by adding one washer at a time, and record the separation distance as a function of the mass of the levitating ring and washers. For more advanced students, or if a scale is available, use the measured masses. If not, you may use the measurement we made for simplicity:

Each bass washer is 4 grams

The donut shaped magnets are 10 grams each

8. After several points have been measured and recorded, ask students what kind of a relationship exists between the distance and the number of washers. At first, discuss general relationships. For example, if one measured value gets larger, does the other one get larger or smaller. Ask them if this is what they expected.

9. Once you have discussed a general relationship between the two measured values, have students make a graph by plotting mass vs. separation distance. The graph of these points will not form a straight line! An example set of data and example graph are shown in Figure 14, below.



Figure 14 – Measurements using the levitating ring magnet kit

(Left) Setup for experiment, one ring magnet levitating. Right: Ring magnet after washers have been added. Be sure to measure from the base of the ring stand to the same point on the levitated washer each time.

Distance (cm)	Mass (g)
3.5	10
3.0	14
2.6	18
2.4	22
2.3	26
2.0	30
1.9	34
1.8	38
1.8	42

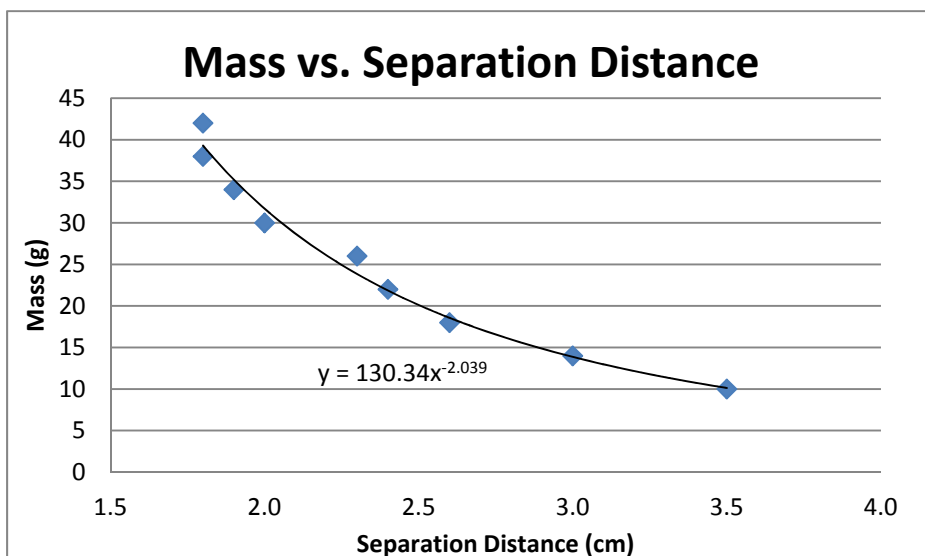


Figure 15: Example Data and Graph for Levitating magnets (LEFT) Example data table taken using the levitating magnet kit similar to the one provided in the SOCK; (RIGHT) Example plot of mass in grams versus separation distance (in cm). Note that the relationship is not linear. Also shown is a power curve fit to the data, with the equation for the best fit line displayed on the graph. Note the good agreement between the exponent value and the expected quadratic relationship.

Notes about the forces and equilibrium condition:

Because the levitating magnet is at rest, not accelerating, we can write the following equilibrium condition for forces acting in the vertical direction on the levitated magnet:

$$\sum F = 0$$

Further, we know that the only two forces acting on the magnet are those due to gravity and magnetism, so that we can also write

$$\begin{aligned} F_{gravity} + F_{magnetism} &= 0 \\ F_{gravity} &= -F_{magnetism} \end{aligned}$$

Where the minus sign simply means that these two forces act in different directions, so that

$$|F_{gravity}| = |F_{magnetism}|$$

Because we can compute the force due to gravity acting on any mass as the product of the mass and the acceleration due to gravity, we know that as the mass increases (i.e., by placing washers on the levitated magnet), the force due to gravity increases. If the system is to remain in equilibrium then the upward magnetic force must also increase.

Bonus Activity: Deflecting Compass

Because a compass needle is magnetized, the needle will be influenced and align with any external magnetic field, including the relatively weak magnetic field of the Earth. When placed in an external field, the magnetic needle experiences a magnetic force. This force can produce torque, causing the magnet to move until the torque vanishes. We know that the compass needle will align along the North – South geographic directions. We can influence the direction of this needle alignment by placing another magnet to vary the strength of the magnetic field nearby. When a bar magnetic is held near the compass it can produce an additional force (and torque) on the compass needle.

Objectives

- Students will be able to compare the force produced on a compass need due to a bar magnet with the force due to the Earth’s magnetic field.
- Students will be able to record and analyze data to draw conclusions.

Materials

- 2 Bar magnets
- Ruler
- Compass
- Sheets of graph paper
- Tape
- Clear Plastic Protractor
- Calculators for computing the tangent of the measured angle

Advanced Preparation

- Place compass at the top of a piece of graph paper so that one set of lines on the graph paper are parallel with the compass needle. Once this is accomplished, tape the compass onto the graph paper. See Figure 16 on the following page.
- Rotate paper/compass so that the compass is pointing north. Turn the compass until the red side of the needle lines up with the N. Tape the paper to the table.
- Place ruler so that it is parallel with and tangent to the “E” point on the compass. The ruler will serve as a guide to slide the bar magnet toward the compass along the “E” direction. Tape the ruler in place.

Exploring Magnetic Field Interactions in the Classroom

1. If you have not done any other exercises that involve the compass with your students, begin with a discussion of the compass. Ask students if they know what a compass is and how it works. Ask why a compass points north (they should answer that the Earth has a magnetic field and the compass points to the North Pole). You can explain that the North Pole is actually the north *seeking* pole if desired. So the north end of a compass points to the North Pole, because the North Pole is a *magnetic south pole*. Ultimately you want to convey that a compass is a small magnet that is aligning itself with the magnetic field of the earth.
2. Have students place the bar magnet at least 25 cm away from the compass along the edge of the ruler (see figures below). The bar magnet must be set up perpendicular to the direction that the compass needle is pointing because if the compass is pointing toward the magnet in the beginning, it won’t be deflected. Ask the students to predict what will happen, if anything, to the compass needle as they push the magnet towards the compass.

3. Once they have made a prediction, instruct them to slide the bar magnet along the ruler toward the compass. They should observe that the compass needle will deflect toward the magnet.

4. Now that they see what will happen, a more quantitative experiment can be performed. Instruct students to push the magnet toward the compass along the ruler at regular increments. Use the lines on the ruler to measure the distance of the bar magnet from the compass. You can have students choose their increments, however we recommend 0.5 cm.

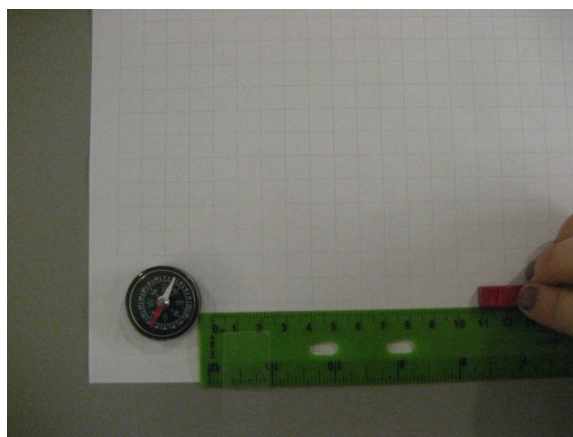
5. Students should work together, having one student move the magnet while another student observes the angle of the compass needle. Have students record the angle and distance for several values of distance. To record the angle, place a clear plastic protractor on top of the compass. At the beginning, when the compass needle is aligned along the North-South direction in the Earth's magnetic field and unaffected by the bar magnet, the angle is equal to zero. As the bar magnet is moved closer the angle of deflection increases. At some point (as shown in (C) above) the deflection angle will be equal to 90 degrees.

6. Ask students if they notice a relationship between the two values. Discuss the general relationship. If one quantity gets larger, what happens to the other quantity?

(THE FOLLOWING STEPS ARE OPTIONAL and involve calculations of trig functions, graphing and curve fitting analysis. They should be used only with advanced students)



(A)



(B)



(C)

Figure 16-Experiment to find the angle of compass deflection vs. the distance of the bar magnet from the compass

(A) Begin the experiment with magnet far away from the compass, so that the magnetic field of the bar magnet has no influence on the compass needle. The compass needle should be aligned with the magnetic field of the earth. (B) As the magnet is moved closer, the compass needle begins to deflect toward the bar magnet (clockwise). The angle of deflection should be measured with respect to the undeflected position. (Positive angle clockwise) (C) At some point, the compass needle will be oriented along the lines of the magnetic field of the bar magnet. This deflection angle is 90 degrees.

7. If students have experience using trigonometric functions, they may make a graph of this data, plotting the tangent of the measured angle vs. the distance of the bar magnet from the compass.

8. **Notes about the plot:** We set up this experiment by arranging the compass, ruler and bar magnet so that the magnetic field from the Earth and the magnetic field from the magnet are approximately perpendicular. As we move the magnet closer to the compass, the magnetic field from the magnet has an increasing influence on the compass needle, and cause it to deflect from its aligned position along the Earth's magnetic field lines. We can draw a right triangle with the hypotenuse as the compass needle, and the sides as the Earth's magnetic field and magnetic field of the bar magnet. From this triangle, we can write the tangent of the measured angle of deflection as the ratio of the magnetic field of the bar magnet to the magnetic field of the earth:

$$\tan \theta = \frac{B_{\text{bar magnet}}}{B_{\text{Earth}}}$$

Then, we can use algebra to solve for the magnetic field of the bar magnet in terms of the magnetic field of the Earth

$$B_{\text{bar}} = \tan(\theta) * B_{\text{Earth}}$$

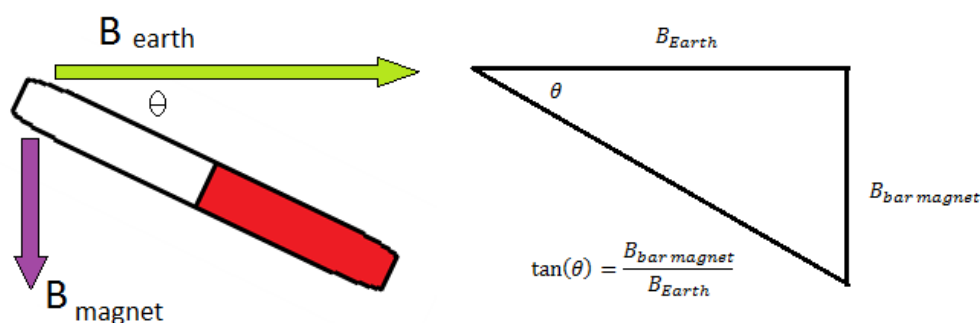


Figure 17: Relationship between angle of deflection and the two interacting magnetic fields
(Left) Compass needle with the Earth's magnetic field and magnet's magnetic field acting on it.
(Right) Vector addition of the Earth's magnetic field and the magnet's magnetic field.

In our experiment, the magnetic field of the Earth is not changing. By moving the bar magnet closer or further from the compass, the strength of the magnetic field, and thus the force on the compass needle, is changing. If we increase the distance between the compass and the bar magnet, the force on the needle due to the

bar magnet decreases until the compass needle aligns with B_{Earth} . If we move the bar magnet close enough to the compass, the angle of deflection will become 90 degrees; this is when the compass needle is in line with the bar magnet. In between these two points, the magnetic field of the bar magnet at the position of the compass can be

shown to follow an inverse square law relationship. Students can see this relationship by making a graph of $\tan(\theta)$ vs. d , where d is distance. Note that the fit shown on the graph below yields a somewhat larger value (2.047) for the exponent. Note that this is an approximation, where we have built the analysis by using the electric dipole analogy. This is a fairly common laboratory technique that is quite useful when exploring the magnetic field of the Earth.

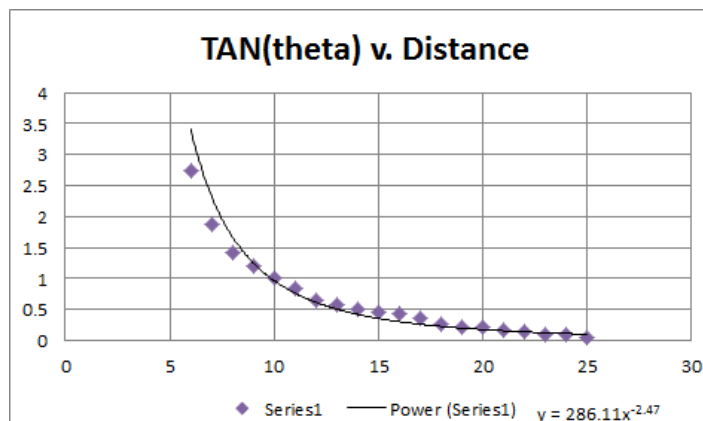


Figure 18: Example of graph of $\tan(\theta)$ vs. distance.

Bonus Activity: Ferrofluid – A magnetic liquid demonstration

Iron filings are only one way to 'see' a magnetic field. Ferrofluid is a combination of oil, surfactant and iron nanoparticles. In the presence of a magnetic field, Ferrofluid will align itself with the field lines in the form of spindles and spikes (why are they this shape? More to come!), and it will also change its viscosity as the strength of the field changes. Ferrofluid has practical applications, as its shape, rigidity, and ability to withstand pressure can be varied using external magnets.

Objectives

- Students will be able to identify at least two applications of Ferrofluid.
- Students will be able to describe the effects of a magnetic field on Ferrofluid.

Materials

- Ferrofluid
- Gloves
- Neodymium magnets
- Screw
- Plastic container

Advanced Preparation

- Ferrofluid is messy and easily stains; to avoid tough clean up, put down cardboard, newspaper, or paper plates where you will be using the Ferrofluid.
- Place a small amount of the Ferrofluid in the container provided. It is easiest to use an eyedropper or a disposable pipette.
- To be sure not to get Ferrofluid on the magnet you are using, place the magnet in a plastic bag.

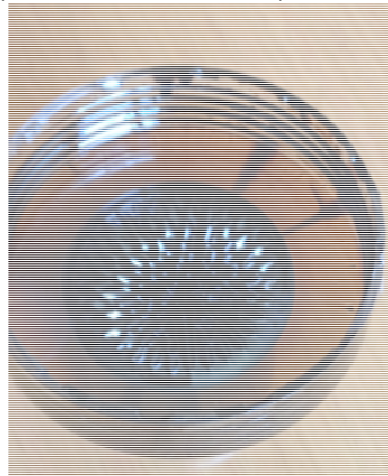
In the Classroom

1. Have students gather around the Ferrofluid setup. Begin by discussing how iron filings allow us to see the magnetic field. Ask if they could think of any other ways to see the magnetic field (some may have suggestions, like staples or compasses, etc.). Explain that Ferrofluid is a mixture of oil, surfactants, and Nano scale iron particles. (For students who ask how small that is a cell membrane is about 10 nm thick – the same size as the iron particles!) These iron particles, like the iron filings, will align themselves with a magnetic field.
2. Ask students what they think will happen if you hold a magnet against the bottom of the dish. Slowly bring a neodymium magnet close to the bottom of the Ferrofluid dish so that a pole is facing up. Ask students what they think is happening as the spindles appear in the Ferrofluid. Explain that fields are three dimensional, and that the spindles are tracing magnetic field lines
3. Ask what will happen to the Ferrofluid if you rotate the magnet so that the side of the magnet is next to the Ferrofluid instead of the end. Slowly rotate the magnet, so that the Ferrofluid is hovering above the field lines running from pole to pole. Ask why the spindles have disappeared and why the Ferrofluid has a smoother, raised surface. Explain that there are two major reasons: 1. the field lines are parallel to the surface of the fluid not perpendicular and 2. the field is not as strong here – it is strongest at the poles.
4. GENTLY place a screw so it is standing up on the flat part in the dish containing the Ferrofluid, so that it is being magnetized through the bottom of the dish by the magnet beneath. Ask students what the Ferrofluid will do around the screw. Use pipette to drop Ferrofluid onto or next to the screw. Notice the small spindles and spikes

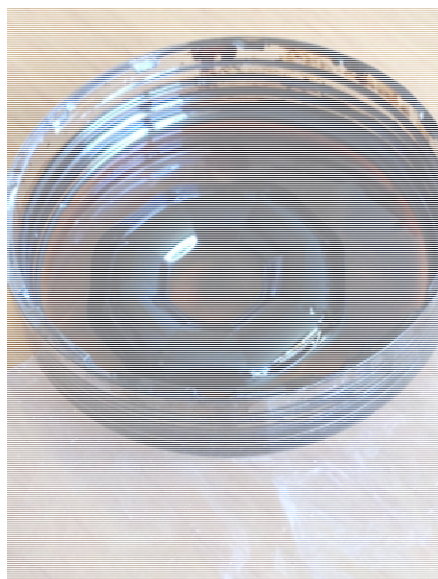
appearing around the threading of the screw – this is because the screw is now magnetized and has a field of its own. Point out that droplets of Ferrofluid falling next to the nail zoom over to it because the iron particles are attracted to the now magnetized nail. Point out that the strongest point of the field is the point of the screw.



(A)



(B)



(C)



(D)

Figure 19: Working with ferrofluid

(A) Materials needed for ferrofluid; protective gloves are highly recommended. (B) Spikes formed by a magnet held underneath the outside of the tray. (C) Multipole magnet stuck underneath the outside of the tray. (D) Spikes from a different magnet held underneath the tray

Notes about Ferrofluid

What is Ferrofluid?

Ferrofluid was discovered in the 1960's by NASA as they were trying to invent ways to control liquids in space. A ferrofluid is any liquid that exhibits the magnetic properties of a solid. Ferrofluid can be shaped-controlled by the presence of a magnetic field. A Ferrofluid is made by adding a magnetic powder (whose particles are only about 10 nm in size) to a liquid. The most common type of magnetic material that is added is magnetite. In order to keep the magnetite particles from attracting each other, a special molecule called a surfactant must be added. This surfactant attaches to the magnetite and prevents the magnetite from sticking together or accumulating. This allows the magnetite particles to spread out evenly throughout the fluid. When in the presence of a magnetic field, the Ferrofluid is influenced by the magnetic field and will be reshaped by it. Typically as the fluid becomes aligned with an external field, spikes appear in the direction of the magnetic field lines. This is a three dimensional visualization of the magnetic field.

Are there practical applications for Ferrofluid

Ferrofluid offers a wide variety of practical applications, ranging from electronics to medicine and anywhere in between. Since Ferrofluid is easily controlled by magnets but also acts like a liquid, and liquids are able to fill in cracks, it makes an incredibly airtight seal that can be held in place by magnets. This airtight seal formed by the Ferrofluid is very useful in devices that contain moving parts must form an airtight seal. The seal formed by the ferrofluid has very little friction. This allows for a seal that is not stationary. An example is the ferrofluid seals used in disk drives to keep dust out. Ferrofluid are also used to improve the quality of loudspeakers, through both heat dissipation and resonance damping.

Appendix 1: The Story behind 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. The SOCK program has been a big success, with hundreds of SOCKs distributed around the country since the effort began.

Though the SOCKs have changed over the years, many of the original concepts have become staple components of the SOCK. For younger students the SOCK includes qualitative lessons to introduce critical thinking and brainstorming skills. For more advanced students, the SOCK also includes more quantitative aspects of the lessons, reinforcing critical thinking skills and learning to apply mathematics to real situations. All the SOCK experiments and demonstrations are hands-on to encourage active participation. Developers focus on making sure that the lessons can be adjusted to fit any situation.

2001 *Rainbow Suite* explored 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 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 50th 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 on the results of the Gold Foil Experiment. It includes a gold robbery mystery, a collision activity, a reformation 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.*

2012 *Fabric of the Cosmos* is inspired by NOVA's program of the same name and focuses on two of the many invisible fields in our cosmos, gravity and magnetism. It includes Spandex as a modeling tool for gravitational fields, a new twist on traditional iron filing experiments, and other magnetic wonders such as multi pole magnets and Ferrofluid! *Created by Melissa Hoffman and Meredith Woy.*

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.

Appendix 2 Standards: Looking to the future

The *Next Generation Science Standards* are now being developed by the National Research Council and are expected to be completed in the fall of 2012 (by the time you receive your SOCK, this date may have already passed!). Although states have the choice whether to adopt these standards, most state standards are based on them. The new standards will be based on the *Framework for K-12 Science Education*. Since our SOCK goes to many different states, we have provided a list of Core and Component Ideas from the *Framework for K-12 Science Education* that are relevant to the SOCK for this year.

Core Idea PS2 Motion and Stability: Forces and Interactions

PS2.A Forces and Motion

PS2.B Types of Interactions

Core Idea ESS1 Earth's Place in the Universe

ESS1.A The Universe and Its Stars

ESS1.B Earth and the Solar System

Below is a list of standards from the draft of the *Next Generation Science Standards* that are relevant to the SOCK:

1.PC Patterns and Cycles

3.IF Interactions of Forces

5.SSS Stars and the Solar System

MS.ESS-SS and HS.ESS.SS Space Systems

MS.PS-FM and HS.PS-FM Forces and Motion

MS.PS-IF and HS.PS-IF Interaction of Forces

For further information on the *Next Generation Science Standards*, visit:

<http://www.nextgenscience.org/>

The *Framework for K-12 Science Education* can be accessed online for free at

http://www.nap.edu/catalog.php?record_id=13165

Appendix 3: Vendor List

This list is meant to be a starting point for people who want to expand or create their own SOCK. It is not an exhaustive list and SPS does not endorse any of the vendors.

Activity	Item	Source	Price (approximate)
Spandex	Spandex	Spandex House, or general craft and fabric stores	\$8/yd
	Fiberglass Poles	Coleman	\$10.56 for 5 poles
	Wooden Balls 1"	General craft store	\$9.95 for 100
	Glass Marbles 1"	Megaglass	\$28.12 for 125
	Binder Clips	Office Supply Stores	\$1.69/box of 12
	Glass Marbles 5/8"	Dollar store	\$1 per bag
Magnetism	Iron Filings	The Chemical Store	\$11 for 12 oz.
	Floating Magnet Set	Office Playground or Think Geek	\$2.99
	Rulers	Office Supply Stores	\$0.41
	Brass Washers	Bolt Depot	\$24.23/set of 100
	Multipole Magnets	Arbor Scientific	\$6
	Disk Magnets	Magnet4Sale	\$0.21
	Ferrofluid Kit	Magnet4Sale	\$11.49
	Neodymium Magnets	Magnet4Sale	\$5.25/set of 10
	Viewing Film	Magnet4Sale	\$3.49
	Compass	a1 Components	\$0.59
	Flashlight	Ali Express	\$18.26/set of 10
	Horseshoe Magnets	Amazon	\$15.15/set of 25
	Bar Magnets	Amazon	\$23.91/set of 100
	Jewelry Bead Organizer	JoAnn Fabrics	\$9.99
	Shelf Liner	Target	\$4.00

Appendix 4 Notes on the Physics of Tides

Anyone who has been to a beach has heard the phrases “high tide” and “low tide” to indicate the levels of the ocean throughout the day. There are actually two high tides and two low tides each day. But why there are two high tides may mystify some people.

One easy way to visualize this is to picture two ice-skaters with long hair, as shown in the figure below. Imagine the two skaters holding hands and spinning. We can compare this with the system of the Earth and moon. As they spin, they each experience a force in their arms and hands, the point at which they are holding hands.

As they spin faster and faster, we can notice that their hair flies out behind them. This is a simplified illustration of the movement of the ocean as a result of tides.

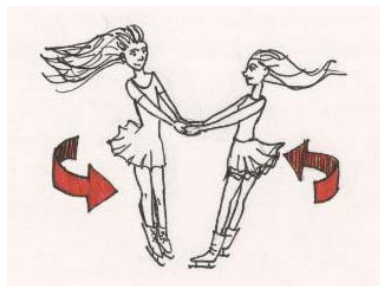


Figure 20: Two figure skaters spinning

You may be familiar with a reasonable but grossly oversimplified answer for why there are two tides: that the moon pulls on the ocean on the near-side of the Earth away from the Earth. This seems reasonable, since this is where gravity is strongest. Gravity also pulls the Earth away from the ocean on the far-side of the Earth, but here the gravity is a little weaker. Gravity’s pull is weakest on the ocean on the far side of Earth. So, the more reasonable consideration is to say that the tides are caused by the *difference* in gravitational forces. We have tidal effects because gravity produces a distance-dependent force and the Earth is large enough that the difference from one side of the planet to the other is significant. While this simplified picture seems reasonable, this is not the full picture. One of the most important aspects of the tidal forces that is often overlooked is the consideration that the Earth and moon are in an accelerating system. This means that there are more forces involved in the complicated motion than we considered in our simplistic approach.

Another interesting aspect that most people do not consider is that while the word “tide” usually connotes some aqueous-related phenomenon, it turns out that both the Earth and moon undergo **land tides** as well. The tidal bulges of the Earth’s land mass are about 10 cm and the moon has bulges of 20 m at its surface (Carroll).

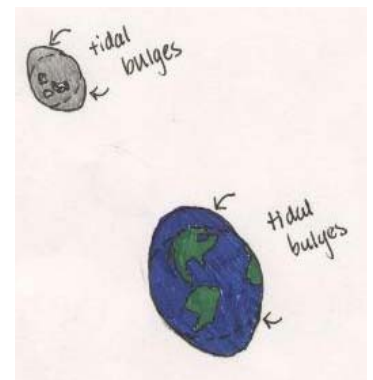


Figure 21: Sketch of “land tides” on Earth and on the moon

Appendix 5: the Physics of Magnets

One fundamental question that is difficult to address in doing a conceptual outreach is : Where does magnetism come from? The answer requires an understanding of atoms and atom interactions within a material. One simple explanation is that at the atomic level, magnetism originates from the motion and properties of electrons. Electrons have an intrinsic angular momentum called *spin*. The spin of an electron creates a strong magnetic field, which can have one of two possible orientations. In many elements electrons with opposite spin pair off, but in certain materials there are unpaired electrons that group together with others that have the same spin. These materials are called ferromagnetic.

In ferromagnetic materials like iron, there are regions, called *domains*, where the magnetic fields of the electrons all point in the same direction. A large piece of iron may have many randomly aligned domains that amount to a net magnetic field of about zero, until the iron is exposed to an external magnetic field. This causes the domains to all point in the same direction, which causes the iron to become magnetic. Only certain elements (iron, nickel, cobalt, gadolinium, and at low temperatures, dysprosium) have the necessary unbalanced spin to produce this effect.

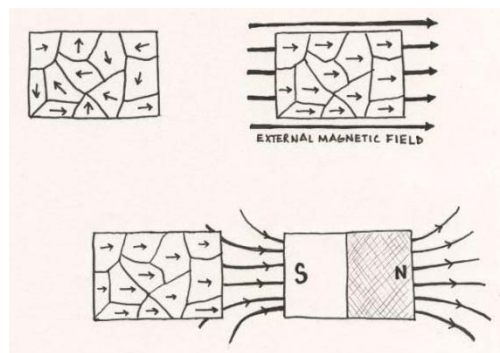


Figure 22: Illustrations of magnetic domains in a solid material

Some selected but important applications of Magnets

Many younger students have probably encountered a refrigerator magnet at some point. We should encourage students to consider what other important uses magnets have, to ask the question “What other things can magnets do?”. The answer to this question is not always so obvious, because magnets are often used inside other devices. For example, students may not be aware that an audio speaker contains a permanent magnet attached to the frame of the speaker, as well as a voice coil which acts like an electromagnet attached to the diaphragm of the speaker. Current flows to the voice coil, and when the current changes direction so does the polar orientation of the coil. This in turn attracts or repels the permanent magnet, causing the diaphragm of the speaker to oscillate (Harris). Magnets are also used in hard drives of computers (before the advent of solid state drives, of course!). While this technology is rapidly becoming outdated, these magnetic hard drives revolutionized computing. In these devices, magnets are used to read information off of a specially prepared magnetic coating on a glass or aluminum disk, called the ‘platter’. The magnetic coating is where the information is stored. Most students may not realize that every credit card has a magnet on it that gives the card its functionality. Credit cards contain iron based particles in the stripe on the back of the card. The magnetic stripe on the credit card holds information that the computer then checks to make sure the card is valid and the store will get paid (Magnetic Stripe).

One very important application of magnets is in the production of electrical energy using the relationship between electricity and magnetism discovered by Oersted and Faraday. When a moving coil is in the presence of a magnetic field, voltage is induced in the coil (Lenz’s Law). Most generators consist of a very strong stationary magnet near a coil that is being rotated by wind, falling water, steam, etc. Electricity can also be generated when a magnet moving near a coil of wire creates a changing flux. This is how the hand crank flashlights, included in your SOCK, are powered. When you squeeze the handle, the multipole magnet spins, therefore inducing a current in the coil of wire.

The applications of magnets in our daily living are too numerous to mention, making possible a wide variety of important devices. One such application is the Magnetic Resonance Image system (MRI). This important tool for medical diagnostics uses a powerful magnetic field and a sensitive detector in order to measure extremely small changes in the total magnetic field due to interactions with molecules inside a human body. In Japan, strong magnetic fields are used to levitate a train, reduce friction and reach extremely high speeds. Your students may be able to come up with a long list of magnet related devices, tools and systems!

Appendix 6: Resources, References and Links

GRAVITY

- Gravity and Spacetime
 - <http://einstein.stanford.edu/SPACETIME/spacetime2.html>
 - This article details Einstein's theories and revelations that introduced and refined his theory of General Relativity, which included his concept of spacetime.
 - http://www.youtube.com/watch?v=p_o4aY7xkXg
 - This video is a "Minute Physics" video, created by Henry Reich. We love Minute Physics, as they are concise, fun, and relevant videos that anyone can enjoy, from the physics major to the everyday Joe! We have three videos of his in this section, including this one.
- Orbits
 - http://cse.ssl.berkeley.edu/segwayed/lessons/cometstale/frame_orbits.html
 - This website specializes in comet orbits, which we address using coins as an analogy on the Spandex.
 - <http://www.youtube.com/watch?v=uhS8K4gFu4s&list=PLED25F943F8D6081C&index=6&feature=plcp>
 - Another Minute Physics video that explains why the Earth doesn't crash into the sun!
- Binary Systems
 - <http://www.astro.cornell.edu/academics/courses/astro201/binstar.htm>
 - This is a very brief description of classification of binary stars. It is useful for the science student to read, however only gives the very basics of binary star classification.
 - http://chandra.harvard.edu/xray_sources/binary_stars.html
 - This website is from NASA's Chandra X-Ray telescope. It explains a binary system and highlights characteristics and features, and walks through a detailed example with two red giants.
- Roche Limit
 - <http://www.astro.washington.edu/users/smith/Astro150/Tutorials/Roche/>
 - This explanation of the Roche limit from the University of Washington's Department of Astronomy is supplemented with lots of clear diagrams, making it easy to follow.
- Tides
 - <http://www.youtube.com/watch?v=gftT3wHJGtg>
 - The tides are one of the hardest subjects to conquer, we believe, and once again Minute Physics comes to the rescue, but keep in mind that this is for a stationary system.
- Formation of the Solar System
 - http://www.windows2universe.org/our_solar_system/formation.html
 - This website is 'brought to you by National Earth Science Teachers Association' and is a very brief paragraph on a theory of the formation of the solar system. This complements our demo very well!
 - <http://www.astronomy.org/astronomy-survival/solform.html>
 - This webpage describes a possible sequence of events for the formation of the solar system.

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MAGNETISM

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