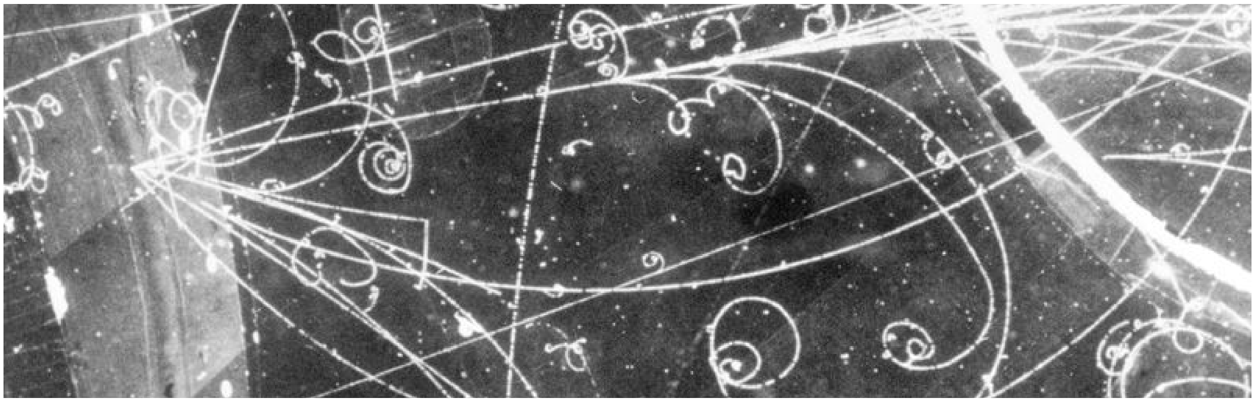

Beauty and Charm Sampler

Physical Science Teacher Workshop and Field Trip

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This sampler contains some of the content from the *Beauty and Charm Teacher's Guide*; those sections have an asterisk in the following Table of Contents.

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INTRODUCTION

Beauty and Charm at Fermilab

Beauty and Charm are the fanciful names of two of six fundamental particles called quarks. Part of the experimental verification for the existence of quarks occurred at Fermilab. The title, Beauty and Charm at Fermilab, however, was chosen with a second meaning also in mind.

Fermilab, as any visitor will attest, is a place of beauty—a high-rise main building with architecture inspired by a French cathedral and set on a prairie-like plain reminiscent of early Illinois. And Fermilab scientists, although a competitive breed in a rigorous and esoteric field, will charm you with their animated descriptions of particles, the universe, and with their cultural interests and human concerns.

This unit and the associated kit is a result of the cultural interests and human concerns of Fermilab Friends for Science Education (FFSE), an association devoted to the promotion of Fermilab as an education resource. With U.S. Department of Energy and FFSE funding and a good amount of volunteer effort, Beauty and Charm at Fermilab was created to provide junior high and middle school students with a view and an active experience of the excitement of science in a major national research facility.

The unit's investigations were chosen to present problems similar to what particle physicists face: How do you measure small things? How do you study something you can't see? What do you imagine the world inside the nucleus of an atom to be like? What can we see that tells us the tiny world of subatomic particles really exists? What is an accelerator or detector? How do these machines help scientists as they explore the world of particle physics?

The investigations are attempts to give students some feeling for how physicists try to answer these questions. And like physicists, students learn that the search for answers is never finished—and that is precisely why science is so challenging and fascinating.

The unit and kit contain several components to aid the teacher in conducting this quest: a teacher's guide with investigation guidance and background information; student sheets with directions and questions; materials for classroom activities; copies of the Quark Quest newspaper to inform about the people, research, and facilities at Fermilab; and a video to explain and tour Fermilab. The appendix contains a relevant vocabulary list as well as student and teacher background reading lists.

If you feel intimidated at the prospect of teaching about particle physics, be assured that the investigations were created and piloted by junior high, middle school and high school teachers. Physicists have carefully reviewed the materials for accuracy in their relationship to scientific ideas and processes. The purpose of these materials, however, is not to instill directly the language and concepts of particle physics—some of this may happen—but to provide an experience 6 of science to broaden and enrich attitudes and develop an appreciation for physics, the people and the work conducted at U.S. Department of Energy laboratories.

Beauty and Charm at Fermilab: The Journey Continues

Since the Large Hadron Collider in Switzerland has replaced the Tevatron as the world's largest and most powerful particle accelerator, Fermilab has adopted a new mission that focuses on the Intensity Frontier, the Cosmic Frontier and the Energy Frontier. This has created a fresh excitement that permeates Fermilab. There is an anticipation that answers to questions about matter, energy, space and time are closer than ever to being discovered and understood. Crossing previously hidden thresholds of knowledge in the Intensity Frontier motivates the men and women at Fermilab to strive to lead the world in the investigation of high-intensity particle beams and neutrino physics. Expanded use of Fermilab's world-class neutrino beam facilities will continue and additional facilities like the Long-Baseline Neutrino Experiment and the Project X accelerator complex are already planned. Additionally, Fermilab's expertise in accelerator and detector technologies, coupled with its accurate and powerful computing infrastructure, will provide the necessary environment for the Cosmic and Energy Frontiers to make major advancements as well.

The Three Frontiers

The Cosmic Frontier

Particle physics experiments at the Cosmic Frontier use the cosmos as a laboratory to investigate the fundamental laws of physics. Researchers use detectors to study particles from space as they approach and enter our atmosphere in forms such as cosmic rays, gamma rays and neutrinos emitted by the sun. These experiments allow researchers to test theories about how the universe was formed, what it is made of and what its future holds.

Experiments at the Cosmic Frontier may have the best chance of discovering the nature of dark matter and dark energy. Theorists have concluded that these two mysterious materials constitute 96 percent of the universe and may be responsible for its formation and accelerating expansion.

WIMPs and Dark Matter

No one has ever directly observed dark matter, but two clues led astronomers to suspect its existence. First, when researchers measured the masses of all the stars and planets that make up galaxies, they discovered that the gravity of those objects alone would not be great enough to hold them together. Something they could not see must have been contributing mass and therefore gravitational pull. Second, they observed in space the kind of distortions of light usually caused by large masses in areas that seemed empty.

The composition of dark matter is unknown, and its existence shows that the Standard Model of particle physics is incomplete. Several theories of particle physics, such as supersymmetry, predict that weakly interacting massive particles, WIMPs, exist with properties suitable for explaining dark matter. The goal of several experiments at the Cosmic Frontier is to observe WIMPs directly.

Dark Energy

In the 20th century, astronomers first discovered that the universe was getting bigger. They found this by observing something similar to the Doppler effect in the light coming from distant galaxies. The Doppler effect is what causes a car horn to change in pitch from high to low as it approaches and passes. This happens because the sound waves are compressed as the car moves toward you, resulting in a higher pitch, and are stretched as it recedes, resulting in a lower pitch. As an object approaches you, the light waves coming from it compress. Astronomers call this blueshift. When light waves stretch as an object moves farther away, astronomers call it redshift.

By measuring the spectrum of an astronomical object, astronomers can tell how much the space between the object and observer has stretched as the light traveled through it. When astronomer Vesto Slipher measured light coming from other galaxies, he found that almost all were redshifted, or moving away. He found that those that seemed dimmer and farther away had even higher redshifts. The universe was expanding. This led astronomers to the idea of the Big Bang.

Astronomers assumed, however, that the force of gravity from all of the matter in the universe would slow the expansion. They were in for a surprise in 1998 when they discovered that the expansion was actually speeding up. Astronomers discovered this when they measured the brightness of the light coming from a certain type of supernova that always explodes with roughly the same energy. The dimmer the light from the supernova, the farther the distance it had traveled to Earth. They discovered that the supernovae were farther away than their redshift measurements predicted. The universe was expanding at an accelerating rate.

Some particle astrophysicists think this is happening because a force with a repulsive gravity is pushing the universe apart. They call this force dark energy. Many experiments at the Cosmic Frontier seek to study the nature of dark energy.

The Energy Frontier

Collider Physics

To explore the smallest particles, those inside an atom, physicists use the largest of scientific instruments, particle accelerators with a length measured in miles. These giant tools of particle physics can accelerate particles to very close to the speed of light.

All particle accelerators start from the principle that electrically charged objects exert a force on each other--opposite charges attract; like charges repel. If there are no other forces keeping the objects in place, the electric force will accelerate them. With an accelerator, physicists apply an electric force again and again to continually accelerate particles such as electrons, positrons, protons or antiprotons. In a circular accelerator, like Fermilab's Tevatron, the particles repeatedly pass the same force-exerting equipment and soon reach speeds close to the speed of light.

A Simple Accelerator

To make the simplest kind of accelerator, physicists use a battery and two parallel metal plates separated by a gap. We connect one plate to the positive battery terminal and the other to the negative terminal. The battery creates an electric field in the gap between the two plates. Positively charged particles that enter the gap near the positive plate experience a force and accelerate across the gap toward the negative plate, gaining an amount of energy that depends on the voltage of the battery. For a 10-volt battery, a proton gains 10 electron volts, or 10 eV, as it accelerates between the plates. Putting many power supplies in a row, physicists have accelerated particles to millions of electron volts (MeV).

More Powerful Accelerators

At some point it is impractical to increase the voltage between the metal plates, as sparks will begin to fly across the gap. To accelerate particles to even higher energy, physicists use a large number of metal plates, all with a hole in the middle. Using alternating currents, the plates can be charged either positively or negatively. A positively charged particle, such as a proton, is drawn to the negatively charged plate in front of it, flying toward the hole. When the proton passes through the hole, the voltage of the plate is switched to a positive value, giving the proton an extra push. At the same time the next plate in front of the proton becomes negatively charged, attracting and accelerating the proton. Hence every gap between two plates provides energy to the proton as long as the voltage of the plates is switched whenever the proton crosses a hole. In high-energy accelerators, switching the voltage happens several billion times per second, or gigahertz frequencies.

Putting many plates in a row, physicists create linear accelerators, or linacs, that can accelerate charged particles to billions of electron volts (GeV). The more plates and gaps a linac has, the higher the energy it can give to a particle—and the longer the linac gets.

Ring-shaped Accelerators

Rather than building longer and longer linacs, physicists are able to use magnets to guide charged particles in a circle. In doing so, physicists are able to send the particles again and again through the same set of plates, increasing the energy of the particles with each revolution.

As the particles gain energy, it is more and more difficult to keep them on the same circular path. The strength of the magnetic field must be increased. Ring-shaped particle accelerators operate the most powerful magnets in the world. The power of a ring-shaped proton accelerator is limited by its circumference and the strength of the magnets that are used. In the Tevatron, protons were accelerated to an energy of almost 100 billion electron volts, or 1000 GeV. This is also called 1 TeV, which inspired the name Tevatron.

The Intensity Frontier
Particle physics experiments at the Intensity Frontier explore fundamental particles and forces of nature using intense particle beams and highly sensitive detectors. One of the ways that researchers search for signals of new physics is to observe rarely interacting particles, such as neutrinos, and their corresponding antimatter particles. Some of these experiments search for evidence of the process theorists hypothesize allowed our universe full of matter to bloom rather than being annihilated by an equal amount of antimatter created in the Big Bang. Other experiments seek to observe rare processes that can give researchers a glimpse of unknown particles and unobserved interactions.

Neutrino Physics
Neutrinos are some of the most fascinating of the known particles. They abound in the universe but interact so little with other particles that trillions of them pass through our bodies each second without leaving a trace.

Neutrinos come in three types, called flavors: muon, electron and tau. They have no electric charge. Their mass is so small that the heaviest neutrino is at least a million times lighter than the lightest charged particle.

At Fermilab, physicists use a beam of protons from the Main Injector accelerator to create the most intense high-energy neutrino beam in the world. Magnets direct the protons onto a graphite target. When the protons strike this target, they take the form of new particles called pions. A magnetic lens called a horn focuses and collects the positively charged pions and discards the negatively charged ones. The positively charged pions travel through a long, empty space and ultimately decay into antimuons and muon neutrinos. Experimentalists filter the resulting mix of debris, antimuons, undecayed pions and muon neutrinos through a steel and concrete absorber, which stops all but the weakly interacting neutrinos. To make a beam of antineutrinos, they reverse the magnetic field of the horn to collect negatively charged pions that decay to negatively charged muons and muon antineutrinos.

The facility that creates Fermilab's neutrino beam is called NuMI, for Neutrinos at the Main Injector. The neutrinos travel between two detectors for an experiment called MINOS, or Main Injector Neutrino Oscillation Search. One sits at Fermilab; the other is located 450 miles away in the Soudan Underground Laboratory in Minnesota. The NuMI beamline is aimed downward at a 3.3° angle toward the underground laboratory. Neutrinos interact so rarely with other particles that they can pass untouched through the entire Earth.

Although the beam starts out at 150 feet below ground at Fermilab, it passes as much as 6 miles beneath the surface as it travels through the earth toward Soudan. Neutrinos travel at the speed of light and make the trip from Illinois to Minnesota in just two and a half thousandths of a second. Researchers at Fermilab use the NuMI beamline as a source of neutrinos for other intensity-frontier experiments as well.

Muon Physics

Muons are the heavy cousins of electrons. They have the same electric charge and interact with matter in a similar way: muons and electrons belong to the same family of particles known as leptons. Unlike protons, which comprise subatomic particles called quarks, muons and electrons come in one piece: they are elementary particles.

Muons could eliminate a big problem that scientists face when accelerating electrons: in a circular accelerator, electrons emit light and lose energy as they go around the ring. This puts a limit on the maximum energy that the electrons can reach in such a machine.

Because muons are 200 times heavier than electrons, they emit less light and lose less energy when traveling in a circle than electrons do. Hence scientists are developing the concept of a circular muon accelerator. Sending the muons through the same loop and the same accelerating cavities repeatedly reduces the number of cavities needed and the footprint necessary to accommodate a collider.

Teaching the Unit

A Note on Philosophy

It is no accident that we labeled Beauty and Charm lessons as “investigations.” We chose this term carefully to reflect the most effective way to teach the unit. We designed the investigations to enable students to discover relationships for themselves. Questions which may at first glance appear vague are actually lead questions intended to encourage student inquiry and help them make real life connections with their learning.

While the investigations are simple, they represent some ways that particle physicists gather indirect evidence and think about the unseen world of subatomic particles. The process skills listed with each section suggest categories of thinking and acting that students should be encouraged to perform. The appendix lists and defines the process skills. It also provides valuable information on how the Beauty and Charm activities support the Illinois State Learning Goals as well as the National Framework for K-12 Science Education. There is also a list of excellent audio-visual resources provided.

In teaching this unit, one may introduce some of the vocabulary of particle physics as a natural connection to discussion of the investigations. However, we have avoided including terms and definitions for memorization, because they tend to distract students from the primary goal of the unit, which is instilling in students positive attitudes toward science. Students should enjoy each investigation and be eager for the next.

Performing the investigation and carefully reviewing the student sheets before teaching is the best way to ensure a successful investigation for the students.

We present more investigations and supplemental investigations in this unit than one would use with one group of students. The teacher should preview the entire selection and decide which investigations best fit the available time, classroom resources, currently taught content and student ability and interest. All investigations have been successfully taught and evaluated.

Circulating from station to station, observing student behavior and asking probing or redirecting questions is normal teacher behavior with these materials, as is suggesting ways to attack problems where students are struggling. Students should feel the rewards and frustrations of a scientist who is trying to describe the behavior of something through indirect evidence. Students should know that scientists read to learn what research others have already completed. Also, high-ability students may catch a glimpse of the scope of knowledge they have yet to achieve by reading articles by Fermilab scientist Dr. Chris Quigg or other scientists. (See **Resources** section.)

Permission is granted to duplicate student sheets for classroom use only. It is easy to replace consumed unit materials. Rather than buying gridded boxes, you may find it more convenient to copy the grid and tape it to a box of your choice.

Safety in the Science Classroom

The laboratory activities included in this unit have been tested and been proven to provide in-depth and valuable investigation experiences for students. There are, however, safety precautions that need to be prepared for and observed during the labs. These safety precautions are discussed in the Teacher Background section of each lab. The teacher is strongly advised to read and follow the safety information with each lab. Provided below are suggested laboratory rules and guidelines provided by the National Science Teachers Association (NSTA). There is also a sample laboratory safety contract that can be used or modified to fit the teachers individual circumstances.

LABORATORY RULES AND REGULATIONS

1. Conduct yourself in a responsible manner at all times. Frivolous activities, mischievous behavior, throwing things and conducting pranks are prohibited.

2. Lab and safety information and procedures must be read ahead of time. All verbal and written instructions shall be followed in carrying out the activity or investigation.

3. Eating, drinking, gum chewing, applying cosmetics, manipulating contact lenses, and other unsafe activities are not permitted in the laboratory.

4. Working in the laboratory without an instructor present is prohibited.

5. Unauthorized activities or investigations are prohibited. Unsupervised work is not permitted.

6. Entering preparation or chemical storage areas is prohibited at all times.

7. Removing chemicals or equipment from the laboratory is prohibited unless authorized by the instructor.

8. NSI Z87.1 approved chemical splash goggles or safety glasses shall be worn at all times in the laboratory. This includes pre-laboratory setup and post-lab cleanup. Only your instructor can give permission to remove the goggles or safety glasses.

9. When an activity requires the use of a laboratory apron, the apron shall be appropriate to the size of the student as well as the hazard associated with the activity or investigation.

10. All accidents, chemical spills and injuries MUST be reported immediately to the instructor, no matter how trivial they may seem at the time. Follow your instructor's directions for immediate treatment.

11. Dress appropriately for laboratory work by protecting your body with clothing and shoes. Do not wear loose or baggy clothing or dangling jewelry. Open-toed shoes should not be worn in the lab.

12. Hair is very flammable. Long hair should be secured with a tie so it cannot combust.

13. Know the location of **and be able to operate** safety equipment in the classroom. This includes the eyewash station, the safety shower, the fire extinguishers, the fume hood and the safety blanket. Know where the master shutoff is for the gas and electric as well.

14. Know how to safely exit your laboratory classroom.

15. If your classroom contains living organisms including plants, fish, reptiles, etc., remember not to handle them without your instructor's permission and supervision.

16. If your laboratory activity requires wearing gloves, keep them on during the entire lab.

17. Avoid inhaling fumes that may be generated during a laboratory activity.

18. NEVER fill pipettes using mouth suction. Always use a suction bulb or pump.

19. Do not force glass tubing into rubber stoppers. Use glycerine as a lubricant and hold the tubing with a towel covering your hands as you ease the tubing into the stopper.

20. Light gas burners from the side, never directly over the top. Never reach over a lit burner. Never leave a lit gas burner unattended.

21. If you have to leave your lab station during a lab, turn off all gas, electric and water.

22. Hot glass looks the same as cold glass. Hot glass will remain hot for a long time. Cool hot glass on wire gauze. Approach, but do not touch hot glass directly to see if it is cool enough to touch.

23. Always read the chemical (reagent) bottle label twice before using the reagent to be sure you have the correct chemical. NEVER TASTE any chemical in the lab.

24. Replace the top of a reagent bottle immediately after using it and return it to its proper location. DO NOT RETURN UNUSED CHEMICALS TO THE REAGENT BOTTLE. Ask your instructor how to dispose of them safely.

25. NEVER ADD WATER TO ACID!!!! Always add acid slowly to water.

26. When heating test tubes in a flame always keep the open end of the tube pointed away from all other lab areas.

27. Dispose of used matches, papers, broken glass, unused liquid or solid chemicals properly according to your instructor's directions.

28. Keep your laboratory area clean at all times.

29. Put away all laboratory equipment properly at the conclusion of a lab. Wash and dry laboratory glassware carefully. Clean off your laboratory table for the next class.

30. **WASH YOUR HANDS** with soap and water before leaving the laboratory.

31. Listen carefully to directions, **BUT ALWAYS ask for help from your instructor if you are not sure what to do or need help.**

Student Laboratory Safety Contract

I have read the above Science Laboratory Rules and Regulations and participated in a discussion of their importance. I agree to follow them during any science course investigation, or activity. I acknowledge that these rules are necessary to prevent accidents and to ensure my own safety as well as the safety of other students around me. I will follow any additional instructions given by my instructor. I understand that I need to ask my instructor, at any time, about the rules and regulations if they are not clear to me. My failure to follow these science laboratory rules and regulations may result in discipline or removal from the lab.

________________________________ ______________________

Student Signature **Date**

________________________________ ______________________

Parent Signature **Date**

Investigation 1: Measuring Small

Purpose:
This investigation will enable students to realize the limitations of measuring devices. It will also make them aware that there is not universal understanding of nor agreement on the definition of the word measurement.

Objective:
Students will imitate scientists by using a variety of methods to measure the size of very small objects as accurately as possible.

Next Generation Science Standards:
Science and Engineering Practices 3, 4, 5, 6, and 8
Crosscutting Concepts 1 and 3
Disciplinary Core Ideas PS1.A, PS3.A

Materials:
Student Investigation Sheet - Measuring Small
Clear metric rulers
Mustard seeds
Hand lenses
Overhead transparency tables

Procedure:
1. Divide the class into seven or eight groups.
2. Distribute the clear plastic 15 cm rulers to students.
3. Have each group determine the size of a mustard seed.
   Note: If students are showing signs of difficulty, suggest that they place the seeds in a straight line and determine how many make 1 cm, and then divide to find the average size of a single seed.
4. Review measuring techniques and the scale used on their rulers. Tell students that they are to take 5-10 minutes to find the smallest measurable object in the room and measure it.
   Note: It is possible to measure to 0.05 cm (0.5 mm) on a ruler with 0.10 cm (1 mm) smallest subdivisions and to estimate to 0.01 cm (0.1 mm). If students have spent 2–3

minutes at this task and have not asked for magnifying tools, suggest that they use something to help "see" these small particles. Distribute hand lenses.

5. As students work on this task, move around the room to assist and encourage "thinking small."
6. After students have completed the task, form larger teams. Tell students that they are in data-sharing teams. Their task is to describe their smallest measurable particle, how it was measured, and what size it was. Teams should determine the smallest object measured by their data-sharing team. You may want to place these results on an overhead table to facilitate later discussion.
7. Have the students discuss their ideas of what measurement is. Have the students discuss why it might have been hard to use the ruler and why some of them estimated their measurements. Have the groups then discuss these ideas as a class.

   Note: Some of the groups will have different answers; discuss possible reasons for the differences. Topics in this discussion may include operational definitions, measurement standardization, and the use of common language.

Student Sheet
Investigation 1: Measuring Small

Name________________________

Date_________________________

Purpose:
This investigation will help you to realize the limitations of measuring devices. It will also make you aware that there is not universal understanding of nor agreement on the definition of the word *measurement*.

Materials:
Student Investigation Sheet - Measuring Small
Clear metric rulers
Mustard seeds
Hand lenses
Overhead transparency tables

Procedure:
1. Your teacher will divide you into lab teams and give each group a clear plastic ruler and several mustard seeds.

2. Measure a mustard seed. Record your data.

    ____

3. Describe the method you used to measure the mustard seed.

4. Record your data on the table at the front of the classroom.

5. Find the smallest measurable object in the classroom and measure it. Be as accurate as possible, using the smallest unit on your ruler.

    ____

6. Describe the smallest object you selected to measure.

7. Why did you choose this object?

8. Record the measurements of your object:

Length_________________ Width_________________ Height________________

9. Add these measurements to the class table at the front of the room.

10. Now that you have completed your measurements, your teacher will assign you to a discussion group where you will share your data. Your group is to explain to the other students in your data-sharing group how you found the smallest measurable object and its size.

11. List the objects that were measured by your group. What is the smallest object in your data sharing group?

12. Record the measurements of your group's smallest object.

Length________________ Width________________ Height________________

Conclusions:

1. What successes and difficulties did your group experience while doing this investigation?

2. How do you think this investigation relates to the work done at Fermilab?

Investigation 7: Studying Things You Can't See

Purpose:
Scientists often employ methods of indirect observation to investigate objects so small that they cannot be seen with the naked eye. In this investigation, students will use indirect observation on a set of small hidden objects to infer the identity of the objects.

Objective:
In this investigation, students will use methods of indirect observation to ascertain the "internal structure" of a mystery box.

Next Generation Science Standards:
Science and Engineering Practices 1, 2, 3, 4, 6, 7, and 8
Crosscutting Concepts 1, 2, 4, 5, and 6
Disciplinary Core Ideas PS1.A, PS2.A, PS2.B, PS3.A, PS3.C, PS4.B

Materials:
Scale or balance, preferably metric
1 empty mystery box
8 mystery boxes in which you have placed objects (See note below.) Label the boxes A–G.
8 directional compasses
8 strong ring magnets
8 metric rulers
Student Investigation Sheet - "Studying Things You Can't See"

Note: Scientists perform experiments involving indirect observation in their quest to understand the internal structure of the atom and subatomic particles. These elementary particles of matter are so small that methods which rely on direct observation (eyesight) invariably fail. Despite their inability to observe directly, scientists can gather indirect data from many different kinds of experiments, thus collecting enough "circumstantial evidence" to develop theories about the structure of matter.

Before the investigation begins, place the following five objects in each of the eight mystery boxes: a rubber stopper, a wooden block, a piece of steel wool, a small steel ball bearing and a cedar ball. (Substitute other objects if desired such as a pencil, coins, a wooden ruler, glass marbles, a paper clip, a strong-flavored fruit gum, etc.) If you wish, seal the boxes with masking *tape so that the students cannot gain access to the contents. You should have a collection of possible items that could be in the box available in case a student group wants to place it in an empty box for further investigation. Do not just give out these items. Students must ask for them. Also be prepared to make directional compasses, ring magnets and an empty box and scale available to your students.*

In a sense, the box is a simulation of an atom, a nucleus, a proton, or some other object with "internal structure." The quest to describe and identify the contents of the box simulates the physicists' quest to find out more about matter by "seeing" through experiment what their eyes will never be able to see.

Procedure:

1. Divide the class into research teams. There should be no more than one team per mystery box.
2. Be sure to have an empty box available for student use, should they choose to do some observational comparisons (e.g., massing the mystery box and the empty box to find the difference).
3. Distribute one labeled mystery box to each team. You need to decide whether all of the boxes are identical or different. You also need to decide if or when you will reveal this to the students. Students need to record the letter of their mystery box on the line at the top of the data chart.
4. Tell the students to follow the directions on their student sheet entitled "Studying Things You Can't See," and remind them that they are not to open the boxes. You need to explain to your students how to fill out the chart.

   Under the column titled "What tool did you use?" they would list items like my fingers, my nose, a magnet, my ears, etc.

   *Under the column titled "What did you do with this tool?" they would write, "I slowly dragged the magnet across the bottom of the box," or "I shook the box gently with my fingers placed under the bottom of the box," etc. Their statements should carfefully describe **how** they used the tool.*

   *Under the column titled "What evidence did you collect using this tool?" they would write, "I felt a **smooth, round, light** object roll **evenly** across my fingertips," or "I heard a **long** object slide **smoothly to the end of the box, but it did not slide very far**." Push your students to use multiple, descriptive adjectives. Remind students that they are NOT making guesses in this column, just gathering data.*

5. Have the students investigate the boxes for a full class period. Collect the boxes. During the next class period, be sure each team receives the same box. Have each team review the data they collected for five minutes. Then collect the boxes. Discuss as a class what they think is in the boxes. Students should collectively offer evidence from their research. If the class comes to consensus on a particular object, and they are correct, you should show the students the object they are describing. You should plan your class time so that class ends before all the objects can be identified. This simulates the analogy between this investigation and the work of particle physicists who often are unable to find all of the answers. Explain that there are some things of which no one is ever sure. As scientists develop better instruments and find new evidence, they improve their ideas about things unseen, but can never be certain they have the final answer.

Note: Here are some ideas for adjusting the difficulty of this investigation. It is fairly flexible.

- *Instead of a box with several items for each team, set up boxes with one item in each box and have the teams swap boxes until each team has examined four.*
- *List the following, and any other items on the chalkboard: battery, roll of tape, rubber stopper, washer, audiocassette, pencil, moth balls, wooden block, paper clip, safety pin, steel ball bearing, steel wool, piece of chalk, magnet, penny, marble. Teams can try to figure out which items from the list are in the box.*
- *For a more difficult investigation, or possibly as a supplemental follow-up, set up a new box for each team, but do not put the same items in every box. Include items that will be very hard to detect, such as cotton balls or rubber bands.*

Student Sheet
Investigation 7: Studying Things You Can't See

Name_________________________

Date__________________________

Purpose:
Scientists often investigate objects so small that the objects cannot be seen. To do this, they must use indirect observation. In this investigation you will use indirect methods, just like the scientists, to observe small hidden objects and infer what they are. Your team's job will be to identify the contents of a mystery box.

Materials:
Scale or balance, preferably metric
1 empty mystery box
8 mystery boxes in which you have placed objects (See note below.) Label the boxes A–G.
8 directional compasses
8 strong ring magnets
8 metric rulers
Student Investigation Sheet - "Studying Things You Can't See"

Procedure:
1. You may use any nonviolent, nonintrusive way you can think of to investigate the mystery box to determine what the objects are inside.
2. Obtain a mystery box from your teacher.
3. Place the ID letter on your box on the line at the top of your data chart.
4. Read carefully through the column descriptions to see what you are going to do. Your teacher will be giving you specific examples of things you might write in each column. Listen very carefully to these statements.
5. Remember that the purpose of the chart is to record indirect evidence – NOT TO GUESS THE IDENTITY OF THE ITEMS. That will happen later in the activity.
6. Here are some ideas for things you might try to help you discover what is in the box. YOU MAY NOT OPEN THE BOX FOR ANY REASON.

- Probe the box with your senses. Use your fingers, hands, nose, eyes and ears. DO NOT TASTE ANYTHING.
- Use a magnet. You may have to ask for this tool from your teacher.
- Use a directional compass. You may have to ask for this tool from your teacher.
- Find the mass of the box. You may have to ask your teacher for a balance and an empty box.

7. Can you think of any other ways to try to find what's in the box? List them.
   Note: Check with your teacher before you try them.

8. Complete the chart below by listing each tool you use in your investigation, how you used it, and what you learned by using it.

Box ID ________________

	What tool did you use?	What did you do with this tool?	What evidence did you collect using this tool?
1			
2			
3			
4			
5			

	What tool did you use?	What did you do with this tool?	What evidence did you collect using this tool?
6			
7			
8			
9			
10			

Conclusions:

1. In the spaces below, list the items you believe are in the box, and the evidence you have collected that suggests the presence of each item. Depending on the number of items your teacher has put in the box, you may not use all of these spaces, or you may need more than are here. The fact that there are seven spaces here does not mean that there are seven items.

One item in the box is a/an:____________________

The evidence that supports this conclusion is:

A second item in the box is a/an:____________________

The evidence that supports this conclusion is:

A third item in the box is a/an:____________________

The evidence that supports this conclusion is:

A fourth item in the box is a/an:____________________

The evidence that supports this conclusion is:

A fifth item in the box is a/an:____________________

The evidence that supports this conclusion is:

A sixth item in the box is a/an:____________________

The evidence that supports this conclusion is:

A seventh item in the box is a/an:____________________

The evidence that supports this conclusion is:

Discuss the following questions with your lab team and record your answers.

2. Describe other ways to investigate things without seeing them.

3. What other equipment or tools might have helped you guess what was in your mystery box?

4. Describe indirect observation in your own words.

5. Describe instances in your everyday life where you use indirect evidence to learn about something you can't see.

6. Describe examples of situations in which scientists use indirect observation.

7. How do Fermilab scientists use indirect observations to learn more about particles?

Investigation 11: Using Motion
to Find What You Can't See

Purpose:
The key probes used by particle physicists to investigate small objects are high-energy particles. Often, the magnetic field of the target deflects the particle probe. In this section, students will use ball bearings and hidden magnets to experience one way that physicists use particle probes to locate and describe unseen objects.

Objectives:
1. Using a moving probe, students will attempt to find a magnet taped to the underside of a mystery box.
2. Students will model the way physicists use particle probes to determine the properties of unseen objects.
3. Students will experience a situation analogous to that of particle physicists—a situation in which the objects they are investigating are really untouchable and very difficult to locate and identify using indirect methods.

Next Generation Science Standards:
Science and Engineering Practices 1, 2, 3, 4, 5, 6, 7, and 8
Crosscutting Concepts 1, 2, 3, 4, 5, 6, and 7
Disciplinary Core Ideas PS1.A, PS2.A, PS2.B, PS3.A, PS3.B, PS3.C, PS4.B

Materials (for each team):
1 prepared mystery box (See procedure step 1.)
1 ramp (6" grooved ruler) and stand (block with 3 slots; see diagram procedure step 2.)
5 steel ball bearings, various sizes (container to hold the ball bearings)
1 catcher tray (Box lids or carpet remnants work well.)
Grid paper copies
Student Investigation Sheets - "Using Motion to Find What You Can't See"

Note: In a previous investigation, students utilized their senses and hand-held probes to gather indirect evidence about the contents of a mystery box. Physicists, however, cannot use manual *probes nor physically handle an atom. The identification of the parts of an atom must be accomplished by using high-energy particle probes that are not touched. The physicists use smaller and more energetic probes as "bullets" to obtain increasingly accurate data about the inside of the atom.*

This investigation is a simulation of a particle probe traveling at various speeds towards its target. Just like Fermilab scientists, students will see complete misses of the target. Use this to emphasize the idea that matter and atoms are ***mostly empty space****. When a probe nears the target a change in the direction of the probe's path may occur. With each directional change, students will know more about the position of the target. Smaller and smaller probes will help distinguish the shape of the hidden object.*

When a particle is given more energy at Fermilab, it behaves more like a smaller probe will in this investigation, in that it is better able to identify properties of the target.(i.e., size, shape and location). So, the smaller the object we are trying to "see," the more energy is needed to "see" it.

There are several similarities and differences between this investigation's steel ball bearings and the protons used at Fermilab. Proton probes have a positive electrical charge and are repelled by the positive charge of an atomic nucleus or other protons. Change in direction of the proton probe is usually a push away from another positively charged object. Steel ball bearing probes have no electrical charge but are attracted toward magnets due to their iron content. Change in direction of the steel ball bearing in this investigation is due to a pull toward the magnet.

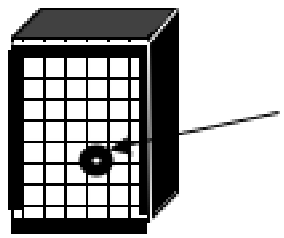
Most protons in the Fermilab accelerator beam pass by target particles or are deflected in a way similar to the ball bearing and magnet. The chief difference is that the proton is repelled, while the steel ball bearing is always attracted.

The proton collision "events" of greatest interest to Fermilab physicists are ones in which the proton probe and the target object form new particles. An analogy with the ball bearings and magnet would be a head-on collision out of which little magnets and ball bearings fly out including some new ball bearing magnets that no one had ever seen. Such an "event" might tell us something new about the makeup of magnets and ball bearings.

Even though the probe and target in this investigation will not create new particles, we can observe the before-and-after motion of the ball bearings. This is essentially what physicists do in analyzing particle events at Fermilab: they analyze the mass, speed, and change of direction of particles before and after collisions. From this information scientists can learn which particles changed direction or what new particles were created.

Procedure:

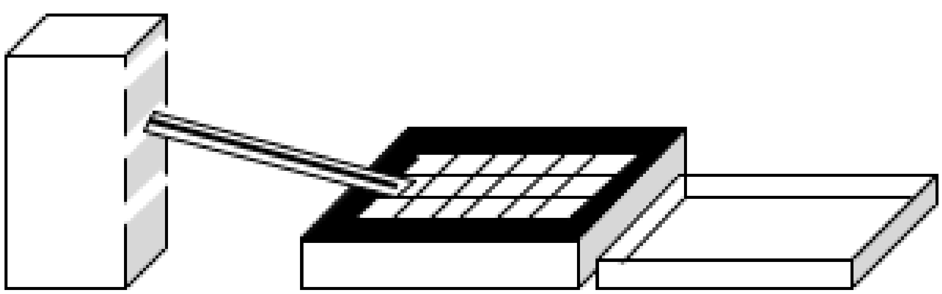
1. To prepare for this investigation, preposition a strong magnet at any location under the grid section of the top of the mystery box, so that students cannot see it. Various sizes and shapes of magnets can be used. If desired, seal the box with masking tape. Place the magnet in a different location in each box.



Tape magnet on underside of box lid.

2. Divide the class into teams and pass out the equipment. Demonstrate the setup of the ramp block and ramp. (See diagram.) The ramp needs to be inserted into the middle slot. The ramp tip must always be located on the black margin of the grid. Control as many variables as possible here, i.e., who releases the ball bearing, the spot on the ramp where the ball bearing is released, etc. Show the students how to catch the probes (ball bearings) in the separate catcher lid for safety and convenience.

Mystery Box



Catcher Lid

3. Discuss how students will record data on their grid paper. Students should run their first 30 trials covering each of the perimeter edge boxes (the four sides) of the grid sheet. After each trial, students should mark the trial results on their data sheet with a colored pencil. After the first 30 trials, students should begin to have a much better idea as to where the hidden object is and then they can concentrate additional trials in that area of the grid. Every trial result

needs to be added to the data sheet. As this happens, a picture of the location, size and shape of the hidden magnet should begin to appear.

4. Have the students collect data by launching the ball bearing and record it on the grid paper. **They should run at least 100-150 trials.**
5. Students should use a colored pencil to outline what they think is the final size, shape and location of the hidden magnet on the data grid sheet.
6. After getting permission from the teacher, students should open the box carefully. Then the student should accurately identify where the magnet was located. Using a different colored pencil, the student should draw the EXACT size, shape and location of the magnet on the data grid.
7. Have students complete the answers to the questions. Then they can share their results and the answers to the questions on their sheet in a class discussion. Emphasize everyday situations in which people investigate things they can't see, and analogies between this investigation and the work of Fermilab. (e.g., Fermilab scientists are constantly "launching" protons at things they can't see in order to find out more about them.)

Student Sheet
Investigation 11: Using Motion to Find What You Can't See

Name_________________________

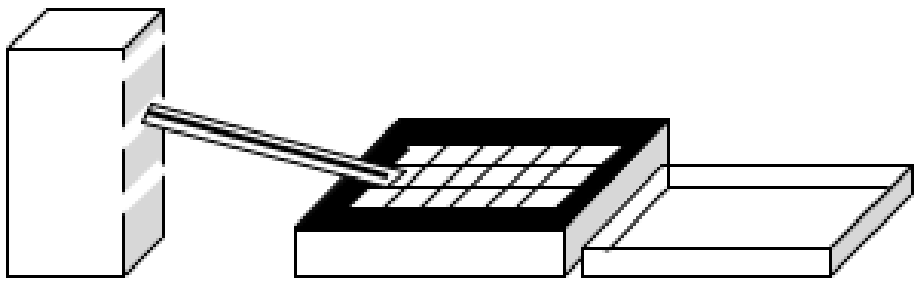
Date__________________________

Purpose:
By studying the motion of objects, scientists can learn about unseen events. In this investigation, you will model the way physicists use particle probes to locate and identify unseen objects.

Materials (for each team):
1 prepared mystery box (See procedure step 1.)
1 ramp (6" grooved ruler) and stand (block with 3 slots; see diagram procedure step 2.)
5 steel ball bearings, various sizes (container to hold the ball bearings)
1 catcher tray (Box lids or carpet remnants work well.)
Grid paper copies
Student Investigation Sheets - "Using Motion to Find What You Can't See"

Procedure:
1. Your job is to identify the shape, size and location of a mystery object attached to the inside of your mystery box underneath the grid by rolling ball bearings down a ramp and over the box.
2. Your team must follow these rules, which will help you control some of the variables in this lab:
    - No one can open the box.
    - The front edge of the ramp (ruler) must always be in the thick, black border of the grid.
    - The same person should always release the ball bearing.
    - Always release the ball bearing probes from the top of the ramp.
    - Do not place ball bearing probes directly on the top of the box.
3. Determine which ball bearing probe will provide you with the best data.
    a. Set up your equipment as demonstrated by your teacher, using the following diagram. The ramp must be inserted into the middle slot of the block.

Mystery Box



Catcher Lid

b. You will roll each ball bearing probe down the ramp (from the top!) at three locations along the short side of the box. Observe the ball bearing probe closely as it rolls across the box.
c. After observing each of the ball bearing probes, select one which you will use to determine the exact location and shape of the hidden object or objects in your mystery box.

Ball Bearing Probe Selection: We selected the (circle one):

small medium large extra-large

... ball bearing probe because ...

4. Place the ramp in the middle slot of the ramp block and position the front edge of the ramp on the black border of the grid system in front of a row of boxes.
5. Label the four sides of the grid system on top of the box A, B, C, and D.
6. Orient your copy of the grid sheet to the box top grid by writing the letters A, B, C, and D in the same location as on your mystery box.
7. Use your selected ball bearing probe to systematically search for the object.
   a. Start by lining up the ramp with a row of boxes on side A of the grid and rolling the ball bearing probe down (from the top of the ramp!).
   b. Observe the ball bearing probe closely as it rolls across the grid.

c. On your grid paper, sketch a line using a colored pencil to show how the ball bearing probe traveled across the grid.
d. Move the ramp to the next row of boxes and repeat. Run trials row by row across all of side A, then do the same for sides B, C, and D. Record each trial result you run on the data grid.

8. After finishing step 7, you will have run 30 trials; nine on each long side and six on each short side. You might not know exactly where or what shape the object is yet, but you should have a good idea of what part of the box you want to continue investigating.
9. Continue releasing your ball bearing probe and sketching its trails. ***You should run between 100 and 150 trials.*** You can release the ball bearing probe from any location on the perimeter of the box (remember that the end of the ramp needs to be within the black border and you must release the ball bearing probe from the top of the ramp) as often as necessary. If you run enough trials you should develop an excellent idea of the size, shape and location of the object. Use small spacing between trials. You might try to run trials at different angles. Remember to keep end of the ramp on the black border for every trial.

Conclusions:

1. How do you explain curved trails?

2. How do you explain straight trails?

3. What effects do you think changing the ramp height would have on your results?

4. What area(s) of the box did you choose to focus on in Step 9? (Use your A, B, C, D coordinates to help explain this.) Why?

5. Explain how this investigation relates to the work physicists do at Fermilab.

Grid for Boxes