Teacher's Guide

BEAUTY AND CHARM AT FERMILAB

An Introduction to Particle Physics

Fourth Edition

Sponsored by

Friends of Fermilab Association

Fermi National Accelerator Laboratory
Batavia, Illinois 60510

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Introduction

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 Friends of Fermilab (FFLA), an association devoted to the promotion of Fermilab as an education resource. With U.S. Department of Energy and FFLA 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 videotape to explain and tour Fermilab.

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 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.

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.

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.

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, 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. Similarly, the *Quark Quest* newspaper provided in the kit may be informative. 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.)

The *Quark Quest* newspaper can be utilized in many different ways. The following are suggestions from teachers:

1. Assign sections as homework.
2. Use it as an introductory lesson.
3. Suggest that students share it with their parents so that they become familiar with Fermilab and take an interest in their children’s study of science.
4. Use the puzzles as extra-credit opportunities.
5. Have students write reviews of the articles.

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. The *Quark Quest* newspaper is available through Fermilab’s Lederman Science Center for a nominal charge. Call 630-840-8258 for details.

Section 1: METHODS OF SCIENCE

Introduction and Purpose:

There are many ways to look at the world and to try to understand how things interrelate. For example, painters, sculptors, and poets can express their views of nature in very different styles which all lead to deeper understanding. Scientists also look to interpret the natural world, but in a way that has common themes and procedures.

As apprentice scientists, students should gain exposure to and practice in these methods. Gaining confidence in the use of the tools of a scientist strengthens scientific ability just as gaining confidence in the use of paints strengthens artistic ability.

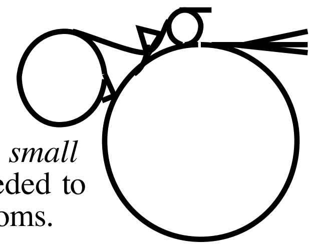
Scientists use various methods to measure objects of different sizes. Since particle physicists study very small objects, this section will explore measurement at small scales.

Objectives:

By the end of this unit, students will:

1. Understand the processes of and emulate Fermilab scientists in:
    a. identifying problems.
    b. setting up experiments.
    c. collecting data in systematic ways.
    d. drawing conclusions and identifying patterns when present.
    e. explaining and reporting results.
    f. studying matter.
2. Generalize that the smaller the size of an object, the more precise an instrument is needed to measure it.

Investigation 1: Measuring Small



Purpose:
When scientists study the atom they have to measure very small objects. This investigation will allow students to begin to discover what the word *small* means, and will help them develop the skills and learn the techniques needed to measure small things. This will be important as they begin to investigate atoms.

Objectives:
Students will use a microscope to measure an object 1/1000th of a centimeter in size. Students will work cooperatively in data-gathering teams. Students will speculate on the process of measuring subatomic particles.

Materials:
Student Investigation Sheet - Measuring Small
Clear metric ruler
Microscope
Paramecium slide
Sand
Salt
Lens Paper
Set of magnified lens paper images

Procedure:
1. Describe the term *macrocosm*, a large system such as the world or universe. *Macro* = large or enlarged; *cosmos* = a complete and orderly system.
2. Describe the term *microcosm*, a very small system such as a little world or miniature universe. *Micro* = little or small; *cosmos* = a complete and orderly system.
3. Tell students that in the unit *Beauty and Charm at Fermilab* they will learn how scientists study the infinitely small microcosm that is inside the atom. This world of particle physics is as interesting and as little-known as the universe beyond our solar system.
4. Review microscope use and care with students. (Student ability may vary due to prior experience.)

   Note: This investigation requires that students correctly measure the diameter of the field of vision in a microscope. Students will need to rotate the low-power objective into position. Students should place a clear, thin, plastic centimeter ruler on the stage under the objective. Have the students focus the low-power objectives on the millimeter marks of a plastic metric ruler. Knowing the diameter of the field makes it much easier for a student to estimate the size of an object under the microscope. If an object covers one-half of the field, it is one-half of the field's diameter.
5. Have students measure the diameter of the field under low power as follows:

   Line up one of the black marks on the far left side of the field of view. Count how many spaces there are between the marks that are visible. (Remember the space between marks equals one millimeter!) A 40X magnification produces a field approximately 4 mm wide. A 100X magnification produces a field approximately 1.8-2.0 mm wide.
6. Have students then measure under low power the length of a paramecium, the width of either a grain of sand or a salt crystal, and the width of a human hair. Finally, have them draw a sketch of a piece of lens paper as it appears under low power.
7. Have students share their measurements by creating a class data table. If time allows, have some students discuss how they performed these measurements.
8. Next, display the set of magnified lens paper images, one at a time. Show the students exactly which section of the picture is being enlarged each time. Explain that each successive picture is approximately 20% larger than the previous one. The original picture was taken at 175X. The

table below will aid the discussion of each new magnification with the students. Have students describe how the images change in each successive "blow-up."

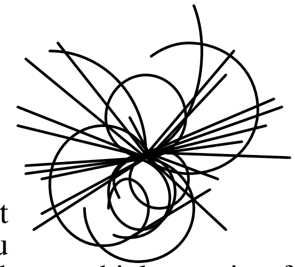
Original photo 175X

Magnification number one	210X
Magnification number two	250X
Magnification number three	300X
Magnification number four	360X
Magnification number five	430X
Magnification number six	515X
Magnification number seven	620X
Magnification number eight	745X
Magnification number nine	895X
Magnification number ten	1075X
Magnification number eleven	1290X
Magnification number twelve	1550X

9. Be sure that the students realize that the lens paper is mostly empty space. One of the major concepts of particle physics is that ordinary matter is primarily space among interacting particles. Take time to emphasize this point.

   Ask students to name and discuss the smallest particle of which they have ever heard. Have them speculate on how the size of this particle might be measured. Accept suggestions but do not try to evaluate them. (Many students will suggest electrons or protons. Some students may mention quarks.)

Student Sheet Investigation 1: Measuring Small



Name______________________
Date_______________________

Purpose:
How would you teach another student what the word *small* means? What techniques or skills do you think would be important to use when you measure an object? If you were to shrink yourself to microscopic size, what do you think a grain of salt or a piece of tissue paper would look like?
In beginning a study of atoms these are questions that you will investigate, and you may find some surprising answers as you make observations and gather your data.

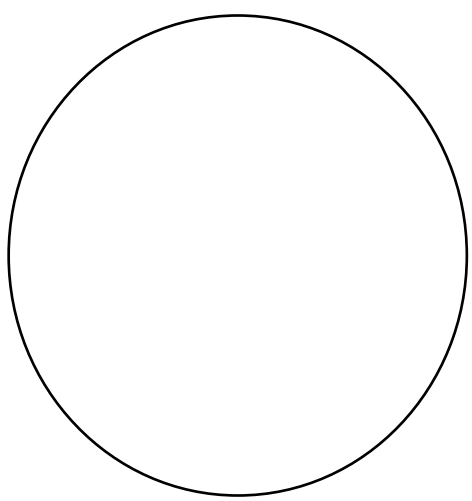
Procedure:
1. Obtain a clear metric ruler from your teacher.
2. Measure the diameter of the field by focusing your **low-power** objective on the millimeter marks of a plastic metric ruler. Place the center of one mark on the left edge of the field. (The field of the microscope is the lighted circle you see when you look into the microscope.)
3. What is the diameter of the field under low power?

4. Obtain a prepared slide of a paramecium from your teacher. Measure the length of the paramecium and record its length here.

5. Take a sand or salt crystal and place it on a glass microscope slide. Place the slide in the microscope under low power. Record the width of the crystal here.

6. Take a strand of hair and mount it on a microscope slide. Record the width of the hair strand here.

7. Prepare a slide of a piece of lens paper. Make a drawing below of the lens paper as you see it under low power.

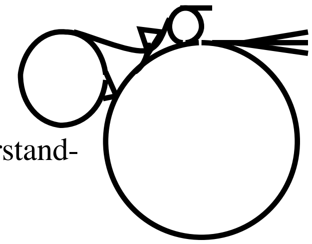


8. Look at the lens paper in the microscope. Based on your field of vision, what percent of the lens paper would you estimate to be empty space?

9. Record observations your lab team made while doing this investigation. You should also record class data based on the discussion of the investigation.

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

Investigation 2: Measuring Smaller



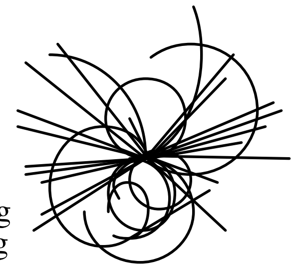
Purpose:
This investigation will enable students to realize the limitations of measuring devices. It will also make them aware that there is not universal understanding of nor agreement on the definition of the word *measurement*.

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

Materials:
Student Investigation Sheet - Measuring Smaller

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 to 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.
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: If the groups 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 2: Measuring Smaller



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*.

Procedure:

1. Your teacher will divide you into lab teams and give each group a clear plastic ruler and several mustard seeds.
2. Measure the size of a mustard seed.
3. Describe the method you used to measure the mustard seed.

4. What size is the mustard seed? ____________mm

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. 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.
10. What is the smallest object in your data sharing group?

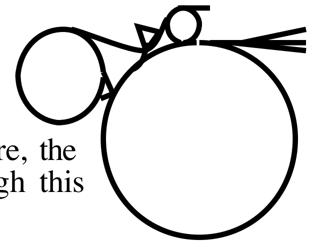
11. Record the measurements of your object.

    length_________________ width_________________ height________________

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

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

Investigation 3: Cutting Paper to Protons



Purpose:
Physicists observe and measure tiny particles and their interactions. Though many students may express understanding of how small these are, the subatomic scale is not something they can conceptualize easily. Through this simple investigation, students will better realize how small "small" is.

Objective:
Students will gain some sense of the minute sizes and spaces particle physicists measure.

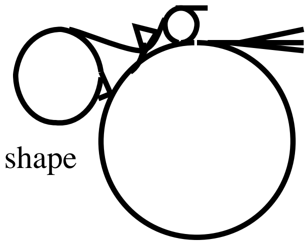
Materials:
8 1/2" x 11" paper
Scissors

Procedure:
1. Begin this investigation with a review of the small things students measured in the previous investigation. Reinforce the idea that the particles studied at Fermilab are much smaller, and through this investigation, they may get a better sense of how small we really mean.
2. Give each student a sheet of 8 1/2" x 11" paper. Have them cut the paper (or fold and tear it) in half, the short way.
3. Then, have the students cut one of the resulting halves in half, again the short way. Have the students cut one of the resulting halves in half. Let them continue cutting the paper in half in this manner as many times as they physically can. Tell the students to count the number of cuts they make.
4. When the students are done cutting, have them measure the smallest-size remaining piece of paper.
5. Explain that about 31 cuts would reduce the paper to the size of an atom, and about 60 more cuts (for a total of 91) would get it to the size of a proton. (It is assumed that successive cuts are at 90 degrees to each other. Therefore, the length and width of the original paper are halved once with every two cuts.)
6. For discussion, pose these questions to your students:
   - How can scientists observe the really small?
   - How do we know it's there if we can't see it?

   The next two investigations will help students understand some of the answers to these questions.

   Note: This investigation is important because it is the first model the students will encounter in Beauty and Charm. It reinforces the idea that the smaller an object is, the harder it is to visualize and manipulate it.

Investigation 4: Obscertainers



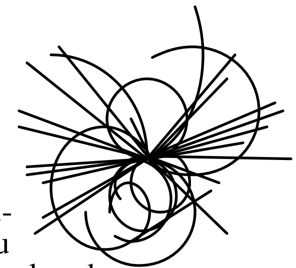
Purpose:
Scientists use indirect observations to make hypotheses about objects that are too small to be seen. In this investigation, students will determine the shape and configuration of partition(s) inside a closed container.

Objectives:
Students will use indirect observations to draw conclusions about the shape and configuration of the inside of the Obscertainer Kits. Students will report their conclusions in the form of drawings.

Materials:
LAB-AIDS #100 Obscertainer Kit (contains 24 obscertainers)
Student Investigation Sheets - "Obscertainers"
Pencils

Procedure:
1. Explain that this is an investigation on indirect observation. The closed Obscertainers have partitions inside and a steel ball that can move freely around on the inside. The students are to determine the shape of the partition(s) in four of the Obscertainers by indirect means.
2. Review (or introduce) the terms *indirect observation*, *hypothesis*, *retest*, and *actual* as they are used on the student pages.
3. Pass out Obscertainers (1 per student). Tell the students to move the steel ball around by carefully shaking and tilting the Obscertainer. By listening to the sound and "feeling" the path of the steel ball, they can determine the shape and location of the partition(s). Some of the Obscertainers are more difficult than others; the students should make careful observations. Have them indicate the number of the Obscertainer and draw their hypothesis in the "Hypothesis" circle on the investigation sheet. They should then retest their hypothesis and indicate any changes they want to make in the "Retest" circle. This should be their final decision.
4. After five or six minutes, have the students switch Obscertainers with a student near them. **Do not allow the students to open any Obscertainers until so instructed.** Students should study at least four different containers.
5. Once every student has completed drawings for at least four Obscertainers, allow them to open them and compare their drawings to the actual configurations. Actual shapes may be drawn in the "Actual" circle.
6. Have students answer the questions at the bottom of the student investigation sheet.
7. In a class discussion, ask students to share successes and difficulties and their reasons for certain answers.

Student Sheet Investigation 4: Obscertainers



Name_________________
Date__________________

Purpose:
Scientists use indirect observations to make hypotheses and draw conclusions about objects that are too small to be seen. In this investigation, you are to determine the shape and configuration of the partition(s) inside a closed container.

Procedure:
1. Your teacher will pass out the closed containers called Obscertainers. You may not open them. These containers have a steel ball that may roll freely inside, blocked only by partitions within the containers.
2. Your job is to determine the shape of the partition(s) in the bottom of each closed Obscertainer without opening the container.
3. You may move the steel ball around by carefully shaking and tilting the Obscertainer.
4. Using your senses, determine the shape and location of the partition(s).
5. Record the number of the Obscertainer in an indicated blank, and then sketch your hypothesis in the left-hand ("Hypothesis") circle under the Obscertainer number.
6. Retest your hypothesis and indicate any changes you want to make in the middle ("Retest") circle. This should be your final decision. **Do not open the Obscertainer until so instructed by your teacher.**
7. Do at least four Obscertainers. Switch containers with other students when so instructed by your teacher. Although some Obscertainers are more difficult than others, you should not spend more than five minutes with each Obscertainer.

DO NOT OPEN THE OBSCERTAINER UNTIL YOUR TEACHER TELLS YOU TO!

HYPOTHESIS RETEST ACTUAL

Obscertainer #_______

Obscertainer #_______

Obscertainer #_______

Obscertainer #_______

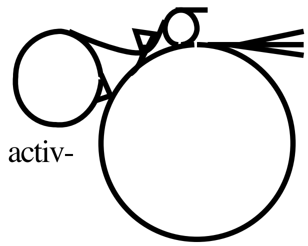
1. What difficulties did you have doing this investigation?

2. What things were you able to determine through indirect observation?

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

Adapted from LAB-AIDS #100 OBSCERTAINER KIT instructions and guide.

Investigation 5: Mysterious Pushrod Boxes



Purpose:
Scientists make hypotheses about the structure and mechanism of something they don't fully understand based on its observable behavior. In this activity, students will model this process using three pushrod boxes.

Objective:
Students will construct hypotheses about the internal structure of the mysterious pushrod boxes based on the described behavior.

Materials:
Student Investigation Sheets

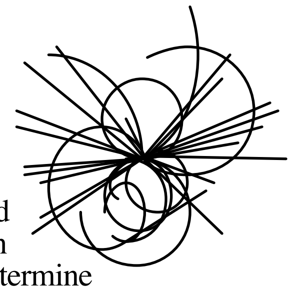
Procedure:
1. These problems are designed to stimulate thinking! Students should study the problems and examine the behaviors described. Students should sketch what they think is inside the box to explain the behaviors.
2. Pass out investigation sheets. Explain to students that they are to read through each problem carefully and try to infer the internal structure of each box.
3. Have the students sketch their hypothesis of the internal structure of each box.
4. After their sketches are complete, have the students discuss their answers with each other.

Supplemental Investigations:

<u>Supplemental Investigation 5A</u>: Construct working models of the pushrod boxes from pencil boxes, pasteboard cutouts and paper fasteners. Have students observe the problems and sketch as above.

<u>Supplemental Investigation 5B</u>: Have students invent an original mysterious pushrod box. Then build it! Once students have built their boxes, they can challenge each other to determine what's inside.

Student Sheet Investigation 5: Mysterious Pushrod Boxes

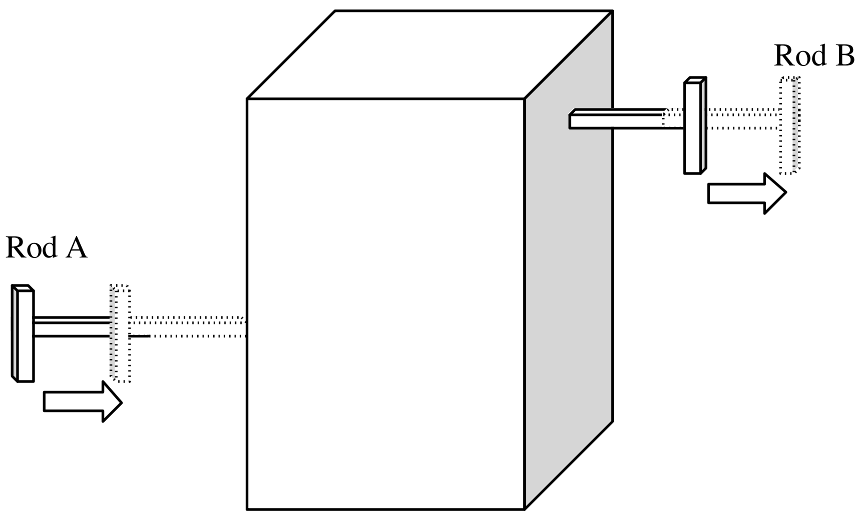


Name___________________
Date____________________

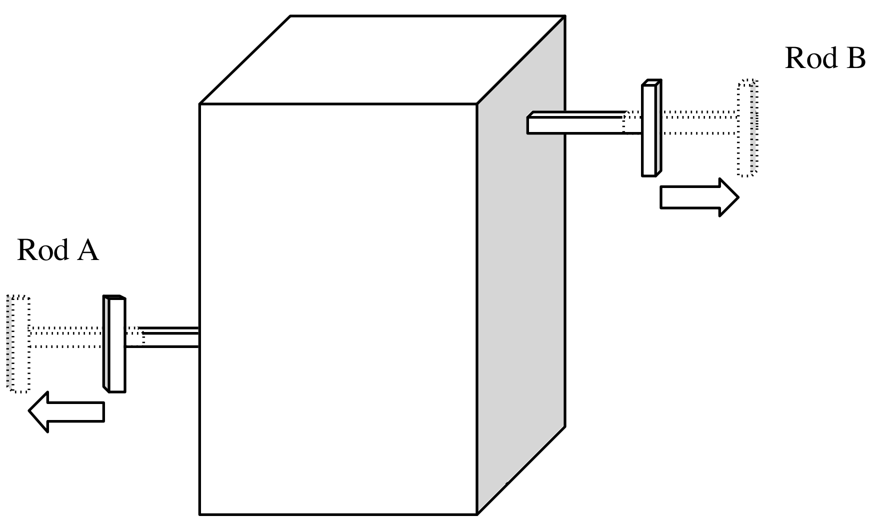
Purpose:
Scientists make hypotheses about something they don't fully understand even if they cannot see its internal structure. They base their hypotheses on its observable behavior. In this investigation, you will use this method to determine the mechanical workings of three pushrod boxes.

Procedure:
1. Read each problem carefully. Try to infer what the inside of each box looks like and how it works.
2. Sketch your inference on the drawing provided.
3. Discuss your inferences with your classmates as directed by your teacher.

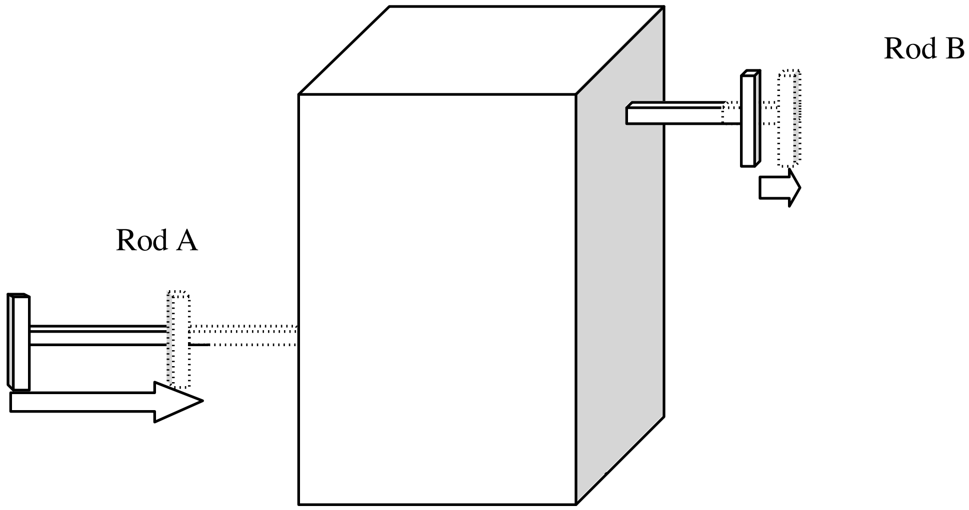
Pushrod Box Problem 1: When Rod A is pushed in, Rod B moves out exactly the same distance Rod A is pushed in. When Rod B is pushed in, Rod A moves out an equal distance.



Pushrod Box Problem 2: When Rod A is pulled out, Rod B moves out also and to exactly the same distance as does Rod A. When either of the rods is pushed back in, the other rod moves in also.

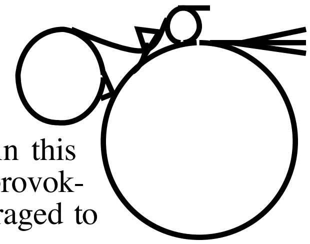


Pushrod Box Problem 3: When Rod A is pushed in a long distance, Rod B moves out a short distance in the same direction. When Rod B is moved out a short distance, Rod A responds by moving in a long distance in the same direction.



Adapted from Alan J. McCormack's Inventors Workshop, pp. 12-13.

Investigation 6: Journaling and Science



Purpose:
On the field trip to Fermilab, students will have an opportunity to meet and talk with a Fermilab scientist. As they learn about particle physics in this unit, students may come up with related questions that are very thought-provoking or not easy to answer. In this journaling activity, students are encouraged to record their thoughts and ideas, much as scientists do.

Objectives:
Students will journal their ideas, questions, drawings, reflections, etc., throughout the unit.
Students will reflect on their journals and formulate questions to ask the scientist on their Fermilab visit.

Materials:
Leo Bellantoni journal pages
One journal per student (This may be a small spiral notebook, or other book.)

Procedure:
1. Ask students if they have ever kept a journal or diary. Have the students discuss the kinds of things they might record in one. (Some things might be: personal thoughts or feelings, doodles, ideas they've had, lists of things that are important to them, words to a song or poem they're writing, and so on.)
2. Explain that many scientists keep journals, too. Ask the students to imagine what kinds of things scientists might record. Many items may be the same as those above, but scientists often focus their journaling on their work.
3. Have the students, in small groups, look over the pages of two scientists' journals—Drasko Jovanovic and Leo Bellantoni. Using a team approach, ask the students to identify what is similar and what is different about these two journals. Have each team report their similarities and differences to the class.
4. Give each student a journal. Tell them that for their whole study of particle physics, they will be scientists. During discussions or investigations, they are to record questions they may have, drawings of other experimental ideas they have, ideas on how to do an investigation better, notes about things they've heard of that may relate, and so on. Remind students that just as scientists differ in how they record their thoughts, their journals will differ as well. Also emphasize that the purpose of a journal is to create a "road map" of thoughts over the course of a project. If students decide not to write down some of their thoughts, their journal will be like a map from New York to Los Angeles that's missing Pennsylvania, Ohio, Indiana, Missouri, and Oklahoma—not very useful.
5. If desired, "assign" students journaling as homework at various points throughout the unit. Collecting the journals and writing brief comments about what they have written will provide students with feedback, and can be used to assess some of their processes.
6. Before the field trip to Fermilab, have the students extract any unanswered questions from their journal and bring them. This will be a very effective way for students to get answers to their questions, and will help them avoid being tongue-tied when they are faced with a real live scientist.

   Note: The scientists who meet with students on field trips are prepared to talk with students about their work, physics concepts, current theories of physics and cosmology, or almost any science question students will ask. They enjoy knowing that students have given careful thought to their class studies.

   Some scientists may also respond to questions about things like their interests and hobbies, years of schooling, their most exciting professional moment, families, classes that were most important, salary ranges, and so on. This may be useful in helping middle school students to see scientists as "real people" with interesting lives and not just *"nerds." Other scientists may respectfully decline to answer these more personal questions.*

No matter what questions are asked and answered, know that the scientist has donated time to be available. The scientists do this because they value the chance to talk with students and enjoy the experience. Please remember to thank them for their time. Think about recording the scientist's name somewhere easy to find so that students can ask them questions later in the unit or in the year.

Section 2: ACCELERATORS

Introduction and Purpose:

Early in the study of physics and astronomy, scientists realized that two distinct kinds of motion existed. One kind of motion was steady. Objects that moved in this way covered the same distance every second (or minute, or hour, etc.). These objects today are said to move with a *constant speed*.

A second kind of motion proved to be more difficult to understand. A lack of precise clocks certainly didn't help! This motion, today called *acceleration*, can be characterized by a change in the speed (or direction) of an object.

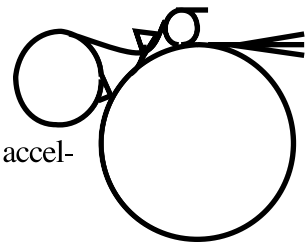
Scientists at Fermilab build machines to accelerate particles so that they can better understand nature. Because this process is fundamental to the understanding of what is done at Fermilab, this section will explore just what is meant by *acceleration* and how Fermilab scientists use it.

Objectives:

By the end of this unit, students will understand that:

1. Acceleration is a change in speed.
2. Acceleration (in the common sense of the word) results in greater energy.
3. Physicists accelerate particles at Fermilab.

Investigation/Demonstration 7: Energy Tracks

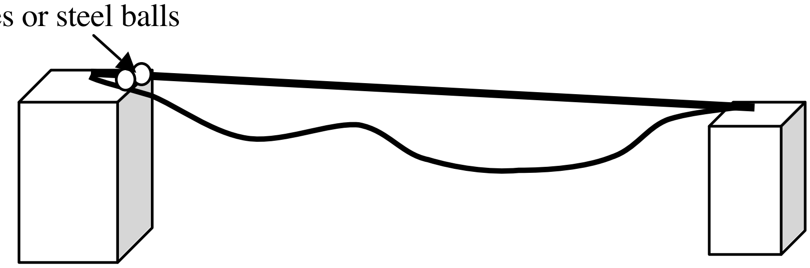


Purpose:
This demonstration will help students become familiar with the difference between speed and acceleration. It will also help students understand that acceleration is needed to increase energy.

Objective:
In this teacher demonstration, students will predict the eventual winner in a race between two marbles on two different tracks. The students need to know what acceleration is and will have the chance to learn about energy as well.

Materials:
2 Ramps
2 Steel Marbles
2 Supports

Procedure:
1. Show the two ramps to the students and set them up on the same supports (bricks, books, or something similar). There needs to be a slight difference in height between the supports so that the marble on the straight track will roll, but the closer to even the supports are, the more effective the demonstration will be.



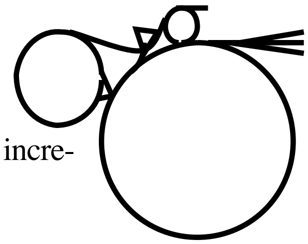
2. Explain that the tracks are the same *length* (just not the same *shape*), and that the balls will start rolling from the top of each ramp at the same time. It is the students' job to determine which ball will win the race to the other end of the track.
3. Encourage discussion in which the students have to support their answers with an explanation. If time allows, it may be useful to start the discussion with the students in small groups. Each group can then report on their discussion to the class.
4. Before the experiment, have students individually write down their prediction for the race. This will engage the students and give them a personal stake in the experiment. It can also lead to a very effective discrepant event for those students who think they know what will happen.
5. After students have written their answers, try the experiment. The ball that runs along the bent track will "win" easily.

   Note: The reason the ball on the bent track wins goes back to two common middle school science topics: potential and kinetic energy. Students might think that the balls will finish at the same time because they start and end at the same height and thus have the same potential energy. The difference is that throughout the middle section of the track, the ball on the bent track has less potential energy, and therefore more kinetic energy (due to the Law of Conservation of Energy) than the ball on the straight track. Since the ball on the bent track has more kinetic energy, it's moving faster, and will therefore get to the end before the ball on the straight track.

   Also point out to students that because of the steeper slope at the beginning of the bent track, the ball on it accelerates *faster and so travels at a greater speed for the entire race.*

6. After the experiment, the students may want to see it again to make sure it wasn't a fluke. Encourage this skepticism and repeat the experiment.
7. Close with a class discussion about acceleration and energy. Encourage students to describe their observations and thoughts in their journals.

Investigation 8: Step-Up Accelerators

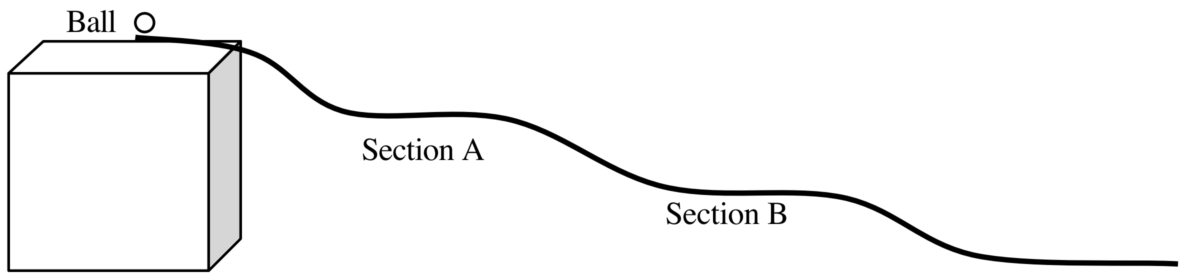


Purpose:
Students can use graphing techniques to help them understand *acceleration* as a change in speed. Students will gain a deeper understanding of incremental increases in speed through the use of a step accelerator.

Objective:
Students will study the acceleration of a ball down a complex ramp. Students will describe how the speed of the ball changes on different parts of the ramp and will relate this to acceleration. Students will compare this accelerator to Fermilab's Linear Accelerator.

Materials:
Stepped accelerator ramps
Stopwatches
Rulers
Steel balls or marbles

Procedure:
1. Provide each team of four or five students with a ramp bent so that it looks like the picture below. Have them start by rolling the ball down the ramp several times, both to qualitatively observe its behavior, and to make sure that it rolls smoothly without jumping off the surface.
   Note: Any material that will allow a ball to roll down smoothly will work fine for the ramp. One option is to use shelving brackets inexpensively available at home improvement stores. The material is easily bent by hand.



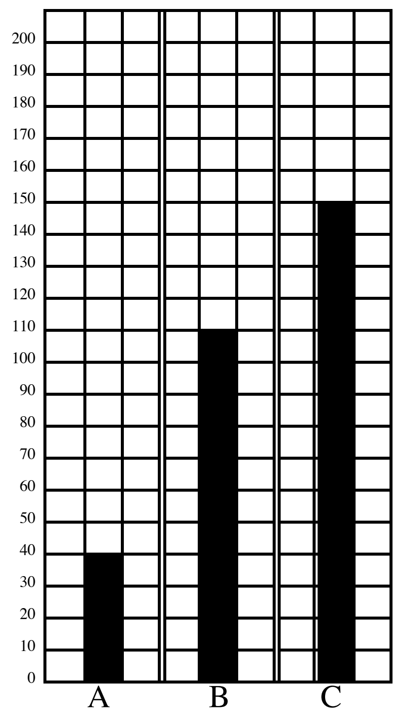
2. Have each team mark the beginning and end of sections A, B and C on their track. The easiest way to do this is to affix a small piece of masking tape to the side of the track at the beginning and end of each section. Students should be careful to affix the tape so that it doesn't affect the way the ball rolls.
3. Next, the students need to measure the distance between their tape marks for each section and record this information in their data table.
4. Each team will then roll the ball down the ramp several times to collect data. The goal is to determine the time the marble spends crossing each of the three labeled sections, A, B, and C. Make sure students understand that they do not have to time all three sections in the same run—they should expect to need to roll the ball at least ten, and maybe even twenty or thirty times to get the data they need. Also encourage them to practice timing the ball—it can be difficult.
5. There is a data table on the student sheet in which students can record their data. If they would like to take more data in order that their averages will be more accurate, encourage them to remake the table in their journals with room for more times in the "Times of travel" column.

6. After the teams have collected data, have them calculate the average speed of the ball on each section of track.

   Note: This might be a good time to review that average speed is calculated by dividing the distance of a section by the average time it took the ball to cross the section.

7. Ask the students to plot a bar graph in which they show the average speed of the ball on each section of the track. Be sure that they label the tick marks on the side of their graph. An example:

Speed of a marble on each section of track (cm/s)

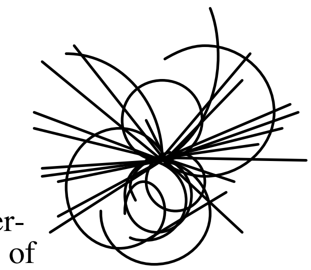


8. Have the groups compare their results in a class discussion.

   Note: In the discussion, try to elicit the ideas of speed *and* acceleration *from the students. Once they start discussing speed and acceleration, try to get them to be specific about this system. Make sure students understand that the ball does not accelerate on the flat sections of the track (A, B, & C), but only on the sloped ("in-between") sections. On the flat sections, the speed of the ball is constant.*

9. Let students know that one of the machines they will see at Fermilab, the Linear Accelerator, accelerates particles in a similar fashion to this ramp: brief periods of acceleration interspersed with brief periods of non-acceleration (called "drift"). Discuss the importance of increasing the speed of a particle to the men and women of Fermilab.

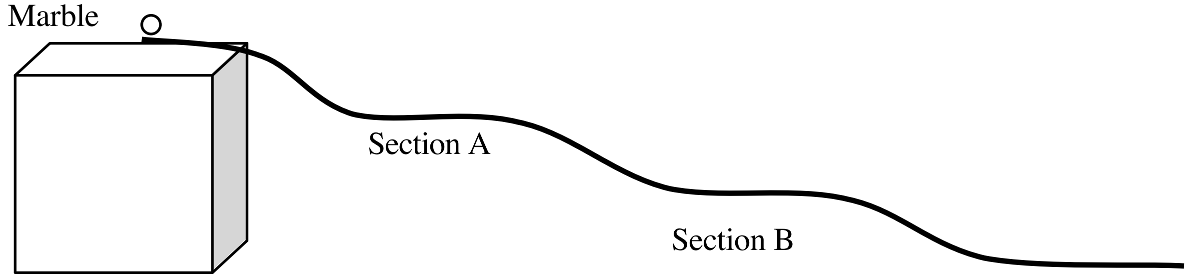
Student Sheet Investigation 8: Step-Up Accelerators



Name______________
Date_______________

Purpose:
Scientists often need to carefully define terms they use if they are to understand how the world works. Today your class will work toward a definition of *acceleration*.

Procedure:
1. Your teacher will give your research team stopwatches, rulers, a ramp, and a steel ball or marble.
2. Set up the ramp on a supporting box or stack of books as shown below. Adjust the height so that the sections labeled below as Section A, Section B, and Section C are as level as possible. Ideally, a marble placed in the middle of one of these sections will not roll in either direction.



3. Release the marble from the top of the ramp and observe it as it rolls down. Do this several times, and then describe in your own words what happens to the marble. Be as specific as you can without taking measurements.

4. You can get a better understanding of acceleration by measuring what the ball does. Start by marking the beginning and end of sections A, B, and C in the way that your teacher instructs.

5. Next, measure the lengths of each of the sections you just marked and record them in the data table below.

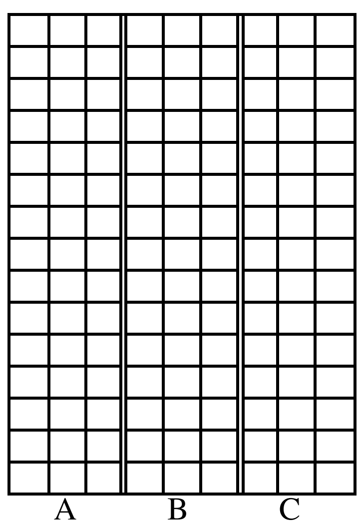
DATA TABLE

Track Section	Section length (cm)	Time (s)	Average time (s)	Average speed (cm/s)
A				
B				
C				

6. Roll the ball down the ramp several times. Your goal is to determine the time the marble spends crossing each of the three labeled sections, A, B, and C. You do not have to time all three sections in the same run—in fact, it will probably be easier if you concentrate your energies on successfully timing one section per run. There is room in the data table above for you to record three times for each section. If you would like more accurate results, recreate the data table in your journal with more spaces in the "Times of travel" column.
7. Now calculate the average time, and then average speed of each section of track. Across which section did the ball move fastest?

8. For a visual representation of the ball's travel, make a bar graph of speed versus section of track. You will need to label the y-axis with values and a unit of speed.

Speed of a marble on each section of track



9. What is happening as the ball travels along the track?

10. In light of your graph, is the same thing happening between sections A and B that happens between sections B and C? If not, what's different?

11. Define the words *speed* and *acceleration* in your group. Write your definitions here. If you develop class definitions as a result of a discussion, write them next to your group definitions. What is different between your two sets of definitions?

12. Why are scientists at Fermilab so interested in accelerating particles? What is special about acceleration?

SECTION 3: SEEING THE UNSEEN

Introduction and Purpose:

Scientists often investigate objects so small that they cannot use direct methods of observation. At Fermilab, “particle-probes” (see next paragraph) may miss a target object, be deflected by it or have a high-energy collision with the object. Whether the particles hit or miss, tell-tale tracks are left in detectors.

The key probes used by particle physicists to investigate small objects are high-energy (high-speed) particles. These “particle-probes” don’t always hit their targets, but when they do, the information they uncover is invaluable.

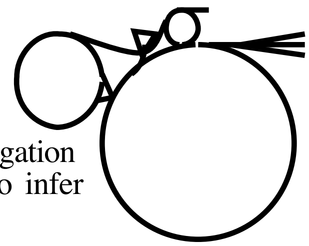
In this section, students will analyze tracks made by moving objects to model how Fermilab physicists use electronically recorded tracks, and how they used to use bubble chambers and cloud chambers to identify and learn about particles.

Objectives:

By the end of this unit, students will:

1. Learn about matter they cannot observe directly.
2. Use patterns to make inferences.
3. Recognize that Fermilab scientists:
   a. are able to learn about matter they cannot observe directly.
   b. analyze patterns to make inferences.
   c. manipulate special tools called detectors to observe particles indirectly.

Investigation 9: 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 what the objects are.

Objective:
In this investigation, students will use methods of indirect observation to ascertain the "internal structure" 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.)
8 directional compasses
8 ring magnets
8 rulers
Student Investigation Sheet - "Studying Things You Can't See"

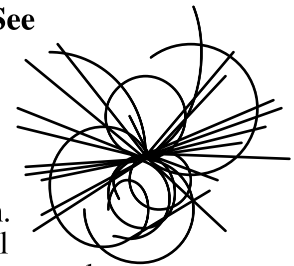
> *Note: Scientists perform experiments involving indirect observation in their quest to understand the internal structure of the atom and subatomic particles. These elementary particles of matter are so small that methods which rely on direct observation (eyesight) invariably fail. Despite their inability 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 steel ball and a cedar ball. (Substitute other objects if desired.) If you wish, seal the boxes with masking tape so that the students cannot gain access to the contents.*
> *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 mystery box to each team.
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.
5. After the students have worked for about fifteen minutes, collect the boxes and bring the class together. Have them discuss as a class what they think is in the boxes. When the class comes to consensus on a particular object, if they are correct, show the students the object they are describing. To further the analogy between this investigation and the work of particle physicists, keep several objects "unseen" to simulate scientists' inability to find all 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, 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 9: 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.

Procedure:
1. You may use any nonviolent, nonintrusive way you can think of to determine what the mysterious objects are. Here are some ideas for things you might try to help you discover what is in the box.
   - Probe the box with your senses.
   - Use a magnet.
   - Use a directional compass.
   - Find the mass of the box.
2. 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.

3. List any equipment you used in your investigation, how you used it, and what you learned by using it in the chart below.

Item	What equipment did you use?	What did you do with this equipment?	What evidence did you collect using this equipment?
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

4. 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 ten spaces here does not mean that there are ten or fewer 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:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

A tenth 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.

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

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

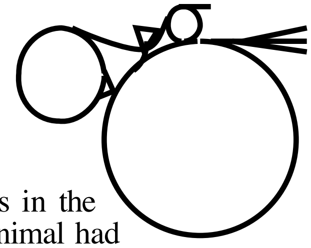
7. Describe indirect observation in your own words.

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

9. Describe examples of situations in which scientists use indirect observation?

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

Investigation 10: Flat-Form Detectors



This teacher page is for the next three student activities. Do as many as time and equipment permit.

Purpose:
Indirect evidence for observing nature is a common scientific tool. Tracks in the snow or sand that an animal leaves behind give clues as to what kind of animal had passed by. The snow or sand in this case is an animal detector. Scientists use various instruments to detect properties of unseen objects. The activities in this section are designed to heighten your awareness of detectors and their uses in understanding the world.

Objectives:
Through investigation, students will explore different detectors used by scientists.
Students will learn that different detectors are not equally suited for any particular job.
Students will use detectors to make inferences about and describe unseen objects.

Note: There is a different kit for each of the next three investigations. Research teams will work on different kits, switching when they're done, until each team has worked with every kit. A greater number of each type of kit will keep the size of research teams down. Three copies of each kit should be sufficient for a typical class.

Materials:

Kit 1:
- An assortment of different types of magnets (bar, disc, refrigerator, etc.)
- Magnetic viewing film
- Scissors
- Student Investigation Sheet for Magnet Detector

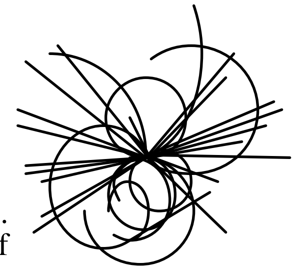
Kit 2:
- Thermal film
- Plastic cups for warm and cold water
- Student Investigation Sheet for Thermal Detector

Kit 3:
- Shadow wall squares
- Light sources (flashlights and lamps)
- Student Investigation Sheet for Light Detector

Procedure:

1. Divide the class into research teams of three or four.
2. Give each team one kit with the items described.
3. Explain to the students that several different investigations will be taking place in the class period at one time. They will need to follow the instructions pertaining to each investigation as they work.
4. Have students answer questions on the Investigation Sheets that follow.
5. Students should rotate through all three investigations before the class discussion. (Students doing Investigation 10C will need a dark room or a dark place to work.)
6. Have each group share their results with the rest of the class through discussion. Topics to emphasize in the discussion include:
    - What sorts of things could you “see” with detectors that you couldn’t see with your eyes?
    - Can you think of other detectors from your everyday life that allow you to “see” things you normally can’t?
    - Will all detectors work equally well in all instances? Explain which detectors are best for each job.
    - Do detectors increase your ability to understand the natural world? Cite specific examples that you discovered in this investigation.

Student Sheet Investigation 10A: Magnetic Detectors



Name_______________________
Date_________________________

Purpose:
Scientists use various instruments to detect properties about unseen objects. In this investigation, you are to explore the magnetization patterns of different kinds of magnets using magnetic viewing film.

Procedure:
1. Your teacher will pass out a kit containing an assortment of magnets and magnetic viewing film. Place a magnet under the magnetic viewing film. Observe the magnetization pattern and sketch it in the space below.

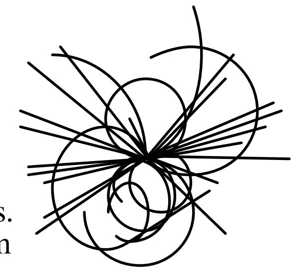
2. Using the magnetic viewing film, repeat this step for each magnet. Draw your sketches below. Use the back of this sheet if you need more room.

3. What would happen to the magnetization pattern of the thin, flat magnet if you were to cut it in half? Write your prediction and draw a sketch here.

4. Now test your prediction by using scissors to cut the thin, flat magnet in half. Was your prediction accurate? If not, sketch the actual pattern here.

5. Can you think of any other devices that would be useful in the detection of magnetization patterns? List some examples.

Student Sheet Investigation 10B: Thermal Detectors



Name___________________________
Date____________________________

Purpose:
Scientists use various instruments to detect properties about unseen objects. In this investigation, you will explore various heat sources using thermal film as your detector.

Procedure:
1. Your teacher will pass out a kit containing plastic cups for warm and cold water and a piece of thermal film.
2. Fill one cup with hot water and the other with cold water. Place the thermal film next to each cup and record the color seen on the thermal film.

   Hot water ______________ Cold water_____________

3. Place the piece of thermal film on the inside of your forearm. Observe the results. Describe or draw them.

4. Warm the thermal film in your hands until it turns deep blue. Record the length of time it takes to cool down if you hold it by one corner in midair.

   Time to cool_______________

5. Warm the thermal film in your hands until it turns deep blue again. Record the length of time it takes to cool down if you press it against a tabletop or desktop.

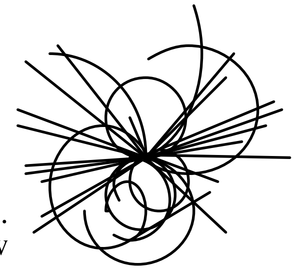
   Time to cool_______________

6. Does the color change faster in the air or when the thermal film is against a table?

7. Why is there a difference in the time required to cool in these two situations?

8. Can you think of any other devices that would be useful to detect heat? List some examples.

Student Sheet Investigation 10C: Light Detectors



Name___________________
Date____________________

Purpose:
Scientists use various instruments to detect properties about unseen objects. In this investigation, you will explore various light sources using shadow wall squares as your detector.

Procedure:
1. Your teacher will divide you into groups and provide each group with a kit containing a shadow wall square and a flashlight.
2. Hold the shadow wall square in front of a flashlight. What happens?

3. Move the flashlight away from the shadow wall square and observe what happens over the next two minutes. Record your observations below.

4. Select a team member to find a small object in the classroom and place it on the shadow wall while the other team members are not looking. The team member will then shine the light on the object for fifteen seconds. After fifteen seconds, the team member will shut the light off and then remove and hide the object.
   Note: It is important to shut off the light before removing the object.
5. The other team members will then try to identify the mystery object from the shadow the object leaves behind. Were they able to? What was the object?

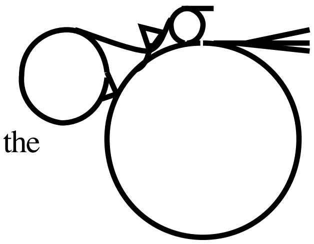
6. Be sure that everyone gets a chance to try a different object. Write down all the objects chosen and whether or not the group correctly identified them here.

7. What kinds of objects did you find easiest to identify using the shadow wall? Why?

8. What kinds of objects did you find most difficult to identify using the shadow wall? Why?

9. What are some ways in which you might be able to use this material in your everyday life?

Investigation 11: Seeing Tracks in Clouds



Purpose:
One of the earliest ways physicists were able to see tracks from subatomic particles was with the cloud chamber. In this activity, students will observe the tracks of subatomic particles as the tracks are created.

Objectives:
Using a cloud chamber, students will observe the fresh tracks of subatomic particles emitted by a radioactive source.
Students will attempt to observe two different types of particle tracks and compare these to photos of bubble chamber tracks.
Students will experience the excitement of observing first-hand the indirect evidence of subatomic particle events as they happen.

Materials:
1 cloud chamber
1 particle source
1 pint 90% isopropanol (rubbing alcohol [school supply])
Dry ice (purchase from local ice cream shop or other source and store in thick Styrofoam cooler)
Intense beam light source (small krypton bulb flashlights, projectors, desk lamps, etc. from school supply)
Paper or plastic dish or tray with vermiculite (to hold and insulate dry ice [school supply])
1 set of bubble chamber photos
Eyedroppers or dropper bottles
Hammer and chisel to break dry ice
Gloves
Student Investigation Sheets - "Seeing Tracks in Clouds"

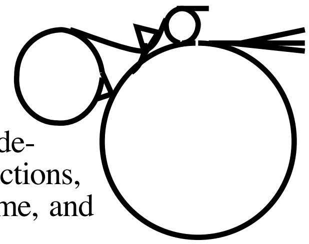
Note: Radioactive elements continually undergo a process of radioactive decay during which their nuclei emit high-speed particles and photons that are too small to be seen under a microscope. The cloud chamber is an instrument designed for the study of the trails, or tracks, of these radioactive emissions.
Cloud chambers work as follows: The air in the cloud chamber <u>must</u> be saturated with alcohol vapor. In this investigation, that is accomplished by soaking the felt in the chamber. When the high-energy particles plow through the air, electrons are knocked loose from some of the molecules and form ions. Ions act as excellent centers for condensation. This condensation, however, must be stimulated by cooling the air. In this investigation, the dry ice cools the air. The alcohol vapor condenses on the ions in the cool air, leaving a droplet trail that clearly reveals the path of the particles.
Three types of radiation may be emitted by a radioactive element. These are α-particles (alpha-particles), which consist of two protons and two neutrons; β-particles (beta-particles), high-speed electrons; and γ-ray (gamma-ray) photons, electromagnetic packets of energy similar to x-rays and light.
When observing the cloud chamber, one can tell the difference between the tracks left by the different types of particles. α-particle tracks are thick and heavy, while β-particle tracks are thinner and much more difficult to see, requiring an intense light source, such as a high-power flashlight or the light beam from a slide projector. α-particles travel more slowly than β-particles, although the difference is difficult to see with the naked eye. The reason for these differences is the difference in mass of the particles: α-particles are about 8,000 times more massive than β-particles, so they travel more slowly and leave a thicker trail. γ-rays will not be visible since they are uncharged and therefore do not interact readily with charged particles to form ions.

Use care and observe all safety precautions when handling the dry ice. Wear gloves and do not allow students to touch the dry ice. One suggestion is to place small chunks of dry ice in a small box or tray partially filled with vermiculite. This will allow students to move the dry ice safely as well as slow down its sublimation rate.
If you are using the cloud chambers for more than one class you should make sure that the chambers are removed from the dry ice and left open between classes. <u>This is very important, as it is necessary for the cloud chambers to dry out in order to work effectively for the next class</u>.

Procedure:

1. Divide the class into one team per cloud chamber.
2. Discuss the background information on cloud chamber function, particles and set-up. (See Teacher Notes.)
3. Provide the student teams with cloud chambers and trays with the dry ice in vermiculite.
4. Model the following procedure for the class:
   A. Saturate the felt (blotter) band on the inside of the cloud chamber with alcohol.
   B. Place the particle source on the bottom center of the chamber and replace the cover.
   C. Place the cloud chamber on the surface of the dry ice. (The dry ice should be placed on a paper plate or a piece of aluminum foil or in vermiculite in a small box.)
   D. Wait for the appearance of clouds.
   Note: The alcohol will evaporate into the air within the chamber forming a gas cloud. As it descends toward the bottom of the chilled chamber, the alcohol reaches a supersaturated condition in which tracks left by the particles are visible in a strong light. It will take a minute or two for the chamber to cool sufficiently for proper operations after it has been placed on the dry ice. Viewing will be much better if the room lights are turned off.
5. View the particle tracks by shining a strong light through the side of the chamber, or from above, onto the black surface of the chamber. (Try both approaches and choose the best effect.) Any strong beam will work as a light source. A powerful flashlight or a projector will work best.
6. Show bubble chamber photographs after the students have completed the cloud chamber portion of the investigation. If time allows, identify and discuss tracks of different types of particles.

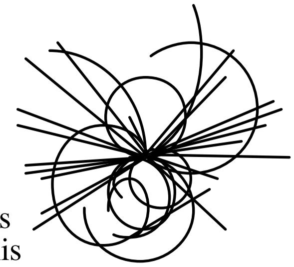
Supplemental Investigation 11A: Counting Particles



To extend the previous investigation, have the students use their problem-solving abilities to design a method for counting and classifying the observed particles. One approach the students could take might involve devising a method of visually cutting the circle of the chamber into sections, counting what is happening in their particular section for a period of time, and multiplying by the number of sections.

Also, devices such as a wooden splint, broken into four places and placed on edge around the radioactive sample will help separate the α-particles from the β-particles. The β-particles are small and fast enough to shoot through the wood, but the wood traps the slower, heavier α-particles. A strong rare earth magnet (such as the Mega-Magnet available from Flinn Scientific) may be used to bend the path of the particles.

Student Sheet Investigation 11: Seeing Tracks in Clouds



Name______________________
Date_______________________

Purpose:
The cloud chamber experiment was an early method by which physicists could see and photograph the tracks of subatomic particles. In this investigation, you will observe tracks of subatomic particles as these particles are created by a radio-active source, just as physicists did.

Procedure:
1. Set up your cloud chamber as directed by the teacher. Do not touch the dry ice. Dry ice will cause severe skin damage if touched without proper precautions and protection.
2. Carefully observe the tracks of the invisible particles in the cloud chamber.
3. Can you distinguish between different types of tracks? Describe the different types of tracks you see.

4. Examine the bubble chamber photographs. What do you observe about these tracks? How do they compare to the tracks in your cloud chamber?

5. What is the purpose of the dry ice?

6. Why is there a black bottom on the cloud chamber?

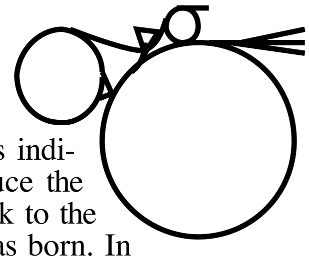
7. What do the differences in the types of tracks you observed (see #3) indicate about the types of particles that created them? Explain your ideas.

8. The tracks you're seeing are made by two different types of particles: α particles (alpha particles) and β particles (beta particles). An α particle is made of two protons and two neutrons. A β particle is a single electron. Which type of particle do you think makes a heavier track, α or β? Why?

9. Which type of particle do you think travels more quickly, α or β? Why?

10. Why is seeing the tracks of invisible particles useful? Why would it be especially useful to scientists at Fermilab?

Investigation 12: Soda Bubble Tracks Teacher Demo



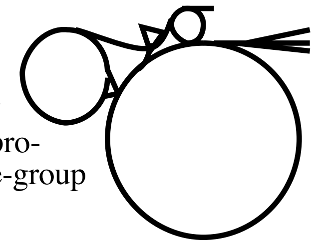
Purpose:
Inspiration may come from the strangest places! A group of physicists were informally discussing how they might be able to observe particles indirectly. When one individual shook some salt into his beverage to reduce the carbonation, all eyes went to the trail of bubbles that formed as the salt sank to the bottom of the glass. From that event, the first bubble chamber detector was born. In this investigation, students will observe the particle trails created in this historical event, which was an inspiration to the future of particle physics.

Objective:
Students will observe the particle trails created by salt particles falling through a carbonated beverage.

Materials:
Salt
Clear carbonated beverage
Clear cup

Procedure:
1. Fill a transparent glass with a clear beverage, such as club soda, 7UP, or sparkling water. Let the cup settle until no carbonation bubbles are rising to the surface.
2. Gather the class around your demonstration table, then slowly drop a few grains of salt into the cup. (Alternatively, you can place the cup on the overhead and have students watch the screen as the demonstration is projected.)
3. Have the students carefully observe what happens as the salt crystals sink to the bottom.
4. To facilitate discussion, you may want to pose the following questions:
    - How do we know where the salt crystals went?
    - What may have caused the bubbles to form?
    - What are some other examples of "trails" such as the bubbles that mark where something has been?
    - Using the bubbles, what could we learn about the salt or the liquid? What could we measure?
5. You may want to conclude this discussion with the story of how this actually inspired the creation of the first bubble chamber detectors, and show the photos of bubble chamber experiments.

Investigation 13: Breaking through Walls Group Project



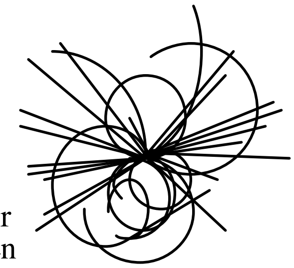
Purpose:
Why do we build such huge machines to look at such tiny parts of nature? It is important for students to know that large machines are necessary to provide the energy necessary to break nature into smaller pieces. This large-group activity will help students understand this idea.

Objective:
By constructing an accelerator and a target to explore, students will determine that "bigger is better" is often true when it comes to designing accelerated probes.

Materials:
100 dominoes per each pair of teams
1 "Hot Wheels" or similar car per each pair of teams
Several pieces of Hot Wheels ramp
Several books
"Treasure"—a pile of candy, a secret written on a piece of paper, or anything of value
Student Investigation Sheet - "Breaking through Walls"

Procedure:
1. Break the class into an even number of teams and then pair the teams up. In each pair of teams:
    - One team is to build a "fort" consisting of the dominoes arranged in whatever way they think will best keep the "treasure" safe from the car.
    - The other team will construct a ramp of car tracks and books to allow for the car to travel down and "discover" the "treasure."
2. Both teams should record in their journals their efforts to design a better "fort" or ramp.
3. As the students work at these two tasks, look for opportunities to point out that no matter how cleverly the fort is built, a more energetic car will always be able to break down the walls.
4. After the "fort" is built, have the students building the ramp launch the car toward the fort in an effort to break through to the "treasure."
5. Next, have the teams switch roles and repeat the investigation. Encourage them to record in their journals their observations on the first attempt and what they are doing to improve on the other team's efforts.
6. After the second attempt, discuss the observations students make as well as answers to questions from the student sheet.

Student Sheet Investigation 13: Breaking Through Walls



Name___________________________
Date____________________________

Purpose:
Scientists often explore tiny objects by sending probes inside the object. For example, you probably have seen pictures of the insides of your teeth when you visited the dentist. Your dentist took these pictures by sending x-rays into your teeth. Today you will try to see how machines can help you explore the insides of an object.

Procedure:
1. Each of you will be on a team that will be competing against one other team.
2. Team 1 will have a “treasure” and dominoes to protect it. Arrange the dominoes to make a “fort” protecting the treasure.
3. Team 2 will have several pieces of car track and a car that they will launch at the fort. Their objective is to make their way to the treasure. The car may only be launched by sending it down the ramp.
4. The car may be launched only as many times as your teacher permits. How would you suggest that the ramp be set up so that the treasure will be reached using the fewest launches of the car?
5. Draw the fort and ramp set-up in the space below.

6. Was the car able to reach the treasure?_______

7. How many launches were needed?_______
8. Now switch places. Team 2 will build the fort, and Team 1 will build the ramp and try to break through.
9. Draw the new fort and ramp set-up in the space below.

10. Was the car able to reach the treasure?_______

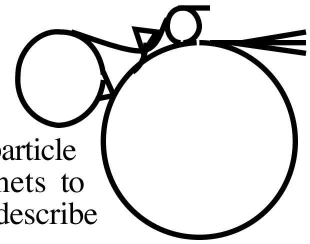
11. How many launches were needed?_______
12. Based on your experience, what would you do to make the fort the strongest it can be?

13. Based on your experience, how would you build your ramp to give yourself the best chance of reaching the treasure on the first try?

14. What "treasures" do Fermilab scientists try to discover?

15. How does this investigation resemble their search?

Investigation 14: 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 metal balls and hidden magnets to experience one way that physicists use particle probes to locate and describe unseen objects.

Objectives:
Using a moving probe, students will attempt to find a magnet taped to the underside of a mystery box.
Students will model the way physicists use particle probes to determine the properties of unseen objects.
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.

Materials (for each team):
1 prepared mystery box (See *Note*.)
1 ramp (ruler) and stand (block with groove)
5 steel ball bearings, various sizes
1 catcher (Box lids or carpet remnants work well.)
Grid paper copies
1 ruler
Student Investigation Sheets - "Using Motion to Find What You Can't See"

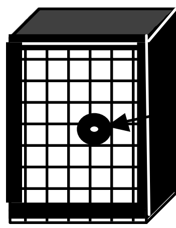
Note: In a previous investigation, students utilized their senses and hand-held probes to gather indirect evidence about the contents of a mystery box. Physicists, however, cannot use manual probes nor physically handle an atom. The identification of the parts of an atom must be accomplished by using 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 deflection of the probe's path may occur. With each deflection, students will know more about the position of the target. Smaller and smaller probes will help distinguish the shape of the hidden object.
At Fermilab, when a particle is given more energy, it behaves like a smaller probe will in this investigation. So, the smaller the object focus of the investigation, 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. Deflection 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. Deflection 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 metal ball 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 metal ball

and magnet would be a head-on collision out of which little magnets and metal balls flew including some new metal ball magnets that no one had ever seen. Such an "event" might tell us something new about the makeup of magnets and metal balls.

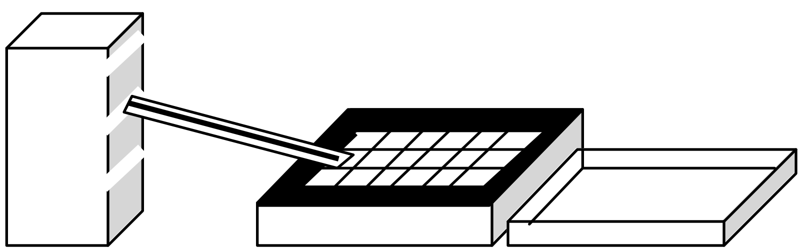
Even though the probe and target in this investigation will not create new particles, we can observe the before-and-after motion of the metal ball probe. This is essentially what physicists do in analyzing particle events at Fermilab: they analyze the mass, speed, and angle of deflection of particles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

Procedure:

1. To prepare for this investigation, tape a circular magnet to the inside of the box, under the surface grid, so that students cannot see it. If desired, seal the box with masking tape. Place the magnet in a different location in each box.

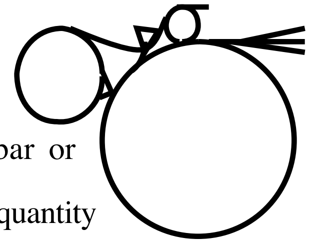


2. Divide the class into teams of four. and pass out the equipment. Demonstrate the setup of the ramp block and ramp. (See diagram.) Show the students how to catch the probes (ball bearings) in the separate catcher lid for safety and convenience.



3. Discuss how students will record data on their grid paper.
4. Have the teams collect data by launching the ball and record it on the grid paper.
5. Have students 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.)

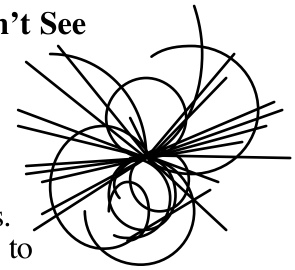
Supplemental Investigation 14A: More Hidden Magnets



There are many possibilities for modification of this investigation that would provide students with an additional challenge:

1. Set up mystery boxes using a variety of types of magnets (e.g., bar or horseshoe).
2. Change other variables, possibly including the size, strength, shape, or quantity of magnets in the box.
3. Use different sizes of steel ball bearings.
4. Change the height of the ramp. (Raising it makes the investigation more challenging, while lowering it makes the investigation easier.)

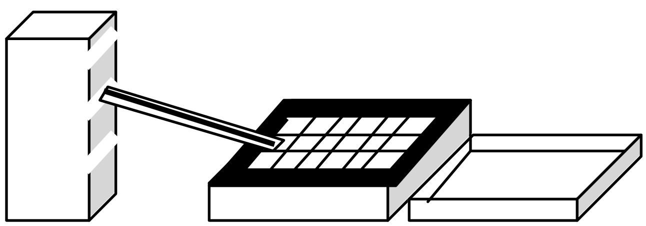
Student Sheet Investigation 14: Using Motion to Find What You Can't See



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.

Procedure:
1. Your team's 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 steel ball bearings down a ramp and over the box.
2. Your team must follow these rules:
   - You cannot open the box.
   - The front edge of the ramp (ruler) must always be in the thick, black border of the grid.
   - 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.



   b) Your group 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 fixed object or objects in your mystery box.

Ball Probe Selection

We selected the: small medium large extra-large

ball-bearing probe because . . .

4. Place the ramp in the top 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. Transfer these letters to your copy of the grid.

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 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 that shows how your ball-bearing probe traveled across the grid.
   d) Move the ramp to the next row of boxes and repeat.
8. After finishing step 7, you will have run 26 trials; eight on each long side and five 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 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.
10. How do you explain curved trails?

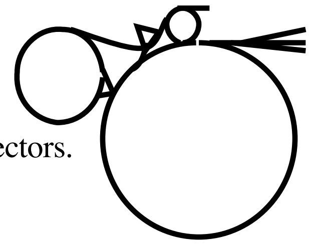
11. How do you explain straight trails?

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

13. What area(s) of the box did you choose to focus on in Step 9? Why?

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

Investigation 15: Magnet Trails

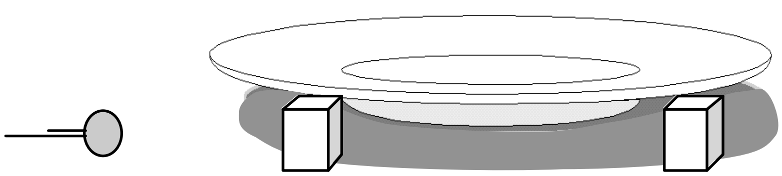


Purpose:
This investigation will allow students to develop their indirect measurement skills. It will also help students understand how particles leave tracks in detectors.

Objective:
Students will explore a method of indirect observation.

Materials:
Each lab group should get the following:
1 plastic dinner plate
4 magnetic marbles
1 ring magnet
1 film canister filled with iron filings
2 marbles
2 large washers
3 or 4 small blocks of wood or spools

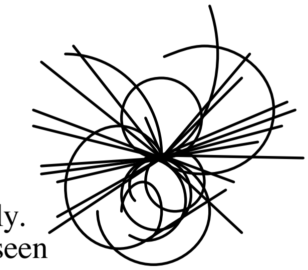
Procedure:
1. Discuss with students how people learn about their world. In the discussion, incorporate examples of how all our senses help us understand our world.
2. Ask how a person can extend the use of the five senses. Examples might include glasses, hearing aids, televisions, or computers.
3. Discuss the process scientists use to construct a model of some unseen part of nature as they learn about the object through experimentation. One common example is the understanding students have about their own body and the organs within it despite the fact that they have never seen their own internal organs. For example, we can infer the existence of the heart without actually seeing it.
4. Divide the class into teams of twos.
5. Give each team the equipment listed above and ask them to set up the plate on the blocks or spools as shown below.



6. Have the students sprinkle iron filings onto the plate from a height of about 20 cm so that a fine, even layer is created.
7. Ask each team to experiment with rolling the magnetic marbles and other items under the plate to see how the filings react. The patterns students create in the filings will be useful to infer how things travel and collide under the plate.
8. Students now can set up experiments for each other. One student turns her back while her partner arranges magnets, washers or marbles under the plate. After he is finished, she may turn around and begin rolling marbles under the plate to try to discover what her partner placed under the plate.
9. Have the student who sets up the materials under the plate draw the arrangement, and have the other student make a drawing of what she believes is under the plate as she investigates it by rolling marbles.
10. As the students experiment and make observations, move around the class and help them form clear inferences (right or wrong) about the experimental set-up.

11. After the investigation, have the class discuss the results. Be sure to ask if their inferences became more or less accurate as they rolled more marbles.
12. Have your students discuss how this investigation is similar or different from experiments at Fermilab. Some questions to discuss with them might be:
    - What do Fermilab scientists use as probes instead of marbles? (Protons.)
    - What are Fermilab targets? (Various. In the collider detectors, they are antiprotons, but in other experiments they can be many other things. They are often some type of metal.)
    - What are Fermilab detectors? (Again, many answers are possible. There are two main types: thin wires that get an electrical charge when charged particles go past them, and scintillating materials that emit light when charged particles travel through them.)

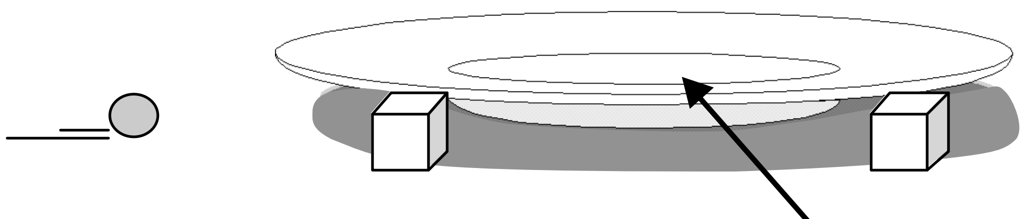
Student Sheet Investigation 15: Magnet Trails



Name________________________
Date_________________________

Purpose:
Scientists are often asked to understand things that they cannot see directly. The purpose of this investigation is to let you predict properties of unseen objects.

Procedure, Part A:
1. After your teacher has given you equipment, set up the experiment with the plastic plate resting on wooden blocks or spools.
2. Sprinkle iron filings in an even layer on the plate. It is best to sprinkle the filings from about 20 cm above the plate. Roll a magnetic marble under the plate as shown below.



3. Watch the iron filings as the magnetic marble rolls under the plate. Record your observations after the questions below.

Questions:
1. Describe and draw what you see when a magnetic marble rolls under the plate.

2. Describe what you see when you roll a regular marble under the plate.

3. What do the iron filings look like when you place a ring magnet under the plate?

4. What do the iron filings look like when you place a steel washer under the plate?

Procedure, Part B:

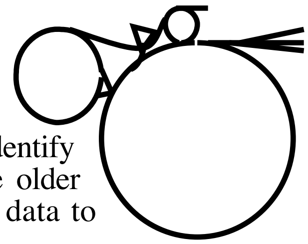
1. Ask your partner to arrange some combination of donut magnet, steel washer, magnetic marbles and regular marbles under the plate while you look away. Your partner does not have to use all of the materials mentioned. (It is often better to use fewer objects.) When your partner is finished, try to determine what is there and how it is arranged by rolling magnetic marbles under the plate. You get six rolls, so think about how you want to use them. Do not look under the plate. Use the patterns produced in the iron filings to answer these questions.
2. Draw a picture in the space below of the objects you believe are under the plate and how you believe they are arranged. Label all of the objects.

3. Now check with your partner about the items under the plate. How successful were you at predicting what was under the plate?

4. What are some ways in which you could you improve your predictions?

5. What skills and techniques used here are also used by Fermilab scientists as they study new particles?

Investigation 16: Tracking What Happened in an Unseen Event

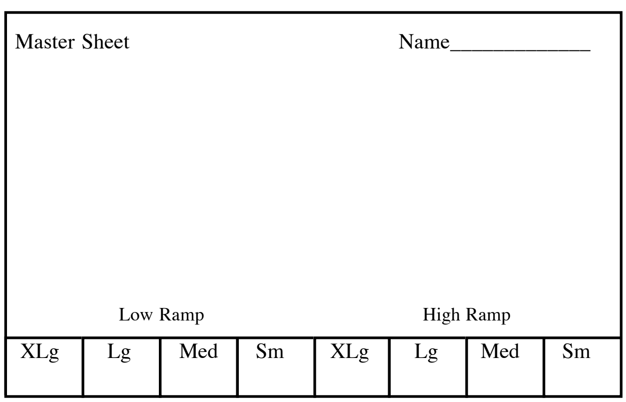


Purpose:
Particle tracks give physicists indirect evidence about the particles involved in high-energy collisions. In this investigation, students will analyze and identify tracks made by colliding objects. Students will model how scientists use older bubble chamber photographs and current electronically recorded track data to identify particles inside the atom.

Objectives:
Students will create a "Master Sheet" of tracks as a key or control to identify unknown tracks.
Students will analyze and identify tracks made by moving objects from an unseen collision.

Materials:
Each group should get the following:
1 Master Sheet (one copy provided in guidebook)
1 ramp
1 ramp block
1 sheet of unlined paper (school supply)
1 sheet of carbon paper
4 metal balls - sizes from extra large to small (Use all metal balls in the kit except the BB-sized ones.)
1 set of bubble chamber photographs (in teacher assistance package)
Student Investigation Sheets - "Tracking What Happens in an Unseen Event"

Procedure:
1. Demonstrate how the ramp block set-up can be used to form an 8-cm "high ramp" or a 4-cm "low ramp."
2. Have students place the "Master Sheet" that has been provided, on a smooth, level, hard surface, and then place a sheet of carbon paper face down on top of the "Master Sheet" so that the labels on the long side are visible. Taping the sheets to the desktop will help secure them.



3. Next, have students set up the "low-ramp." Tell them to make sure that the bottom end of their ramps (rulers) are sitting on the carbon paper so that they will record the first mark the ball bearing makes on the data sheet.
4. Have them roll each of the four sizes of balls down the ramp and across the carbon paper at the appropriately marked spots, then move the ramp to the 8-cm "high ramp" height and finish the "Master Sheet."

5. Before they move on encourage students to identify at least three characteristics of the tracks that vary. For instance, are the high-ramp, extra-large-ball tracks the same size as the low-ramp, extra-large-ball tracks? How are they different? What about the high-ramp, extra-large-ball tracks and the high-ramp, small-ball tracks? Encourage students to differentiate tracks in as many ways as they can.
6. *Note: You may want to experiment with a wide variety of carbon papers to determine which is most effective. (It has been the developers' experience that cheap, low-quality carbon paper works best.) Also, to ensure good tracks, the surface on which the balls roll must be smooth and hard.*When students have completed their "Master Sheets" they will design and test a real collision by setting up balls on a blank sheet of paper with carbon paper over it and rolling another ball down either the high or low ramp to collide with them. Have them sketch their setup on a separate piece of paper, labeling the ball size and giving the ramp height and the size of the ball they launched.

   Note: Encourage them to try their setup and collision without the carbon paper a few times so that they know it will do what they want it to before they put the carbon paper down.
7. Each group will turn in their real collision sheet (unlabeled). Give each group's unlabeled sheet to another group to analyze. Keep the sketched copy to check the analyzing group's results.

   Note: You may want to create one collision prior to the start of this activity so that the first group to turn in their real collision sheet has a new one to analyze.
8. Upon completion of this investigation discuss the bubble chamber photograph as well as the electronic detector image provided in the kit with the class. Ask the students to explain how the trails in these pictures are different and how they might be used to identify particles.

   Note: Two features distinguish the tracks made by the metal balls: the darkness or intensity of the carbon mark as an indication of the ball's weight (or mass) and the spacing of the dashed carbon marks as an indication of the ball's speed.

   By contrast, bubble chamber particle tracks have three distinguishing features: length, curvature, and intensity. Length usually indicates the distance over which the particle traveled before decaying into some other kind of particle or being absorbed by a nearby atom. Particle decay can be identified by the new track of one of the decay-product particles.

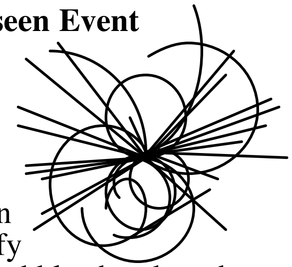
   Curvature of a particle trail is an indication of particle speed and mass (or weight) and is caused by the charged particle moving through a magnetic field. The field is caused by large electromagnet coils around the chamber. The particle's curved path is much like the curving of protons around the circle of Fermilab's accelerator. The curvature is not caused by gravity nor by the commonly experienced attraction of metal objects to a magnet.

   Intensity of the tracks is a result of the combination of charge and speed. Therefore, intensity cannot be used without other evidence as a certain indicator of particle properties.

   Finally, only charged particles (electrons, protons, etc., not neutrons, photons, etc.) make tracks in bubble chambers.

   The main similarity between this tracking investigation and the bubble chamber is that both use tracks to draw conclusions about the mass and speed of objects in unseen collisions.

Student Sheet Investigation 16: Tracking What Happened in an Unseen Event



Name___________________________
Date____________________________

Purpose:
Particle tracks give physicists indirect evidence about the particles involved in high-energy collisions. In this investigation, you will analyze and identify tracks made by colliding objects. You will model how scientists use older bubble chamber photographs and current electronically recorded track data to identify particles inside the atom.

Procedure:
1. Place the "Master Sheet" on a smooth, level, hard surface. Place a sheet of carbon paper face down on top of the "Master Sheet" so that the labels on the long side are visible. Use tape to secure the sheets to the desktop.
2. Set up the ramp block and ramp as demonstrated by your teacher. Be sure that the front end of the ramp (ruler) is sitting on the carbon paper so that you will be sure to record the first mark the ball bearing makes on the data sheet.
3. Place the ramp at the 4-cm ("low ramp") height.
4. When all four balls have been released from the low ramp, repeat step 3 for the 8-cm "high ramp."
5. Your "Master Sheet" should have eight clear tracks on it. Keep this sheet to help you analyze a collision produced by another group later in this investigation.
6. Identify at least three characteristics of the track marks that vary. For instance, are the high-ramp, extra-large-ball tracks the same size as the low-ramp, extra-large-ball tracks? How are they different? What about the high-ramp, extra-large-ball tracks and the high-ramp, small-ball tracks?
7. Next, lay down a sheet of unlined paper. Place a combination of ball bearings on the blank paper wherever you want them. These ball bearings represent your target. Decide if you want to use the high ramp or the low ramp to create a collision with an incoming probe. Practice the collision a couple of times to be sure it is going to do what you want it to.
8. Now begin your collision again but cover the blank paper with carbon paper. Be careful as you set the collision up that you do not inadvertently create extra, confusing dots and marks on the collision sheet. Run the collision.
9. After the collision, sketch what happened on a separate piece of paper. Draw the ball bearings and their movement. Be sure to label which ball made each track and what height ramp was used.
10. Now, write the name of your group on both your real (unlabeled) collision sheet and your (labeled) answer key and turn them in to your teacher.
11. Your teacher will give you a real collision sheet produced by another group in your class. Analyze the tracks on this paper by comparing it with your "Master Sheet."
12. Identify the tracks on the other group's collision sheet with the size of the metal ball that produced them. Also identify the ramp height used for releasing the ball.
13. To check the results of your analysis, recreate this experiment with another sheet of paper and carbon. See if you can produce similar results.
14. When sure of your findings, write your group's name on the collision sheet you analyzed. Turn it in with your answers to the analysis questions.

Conclusions:
Answer the following questions.

1. From what ramp height did the other group release their ball probe?

2.What were the characteristics of the tracks that helped you determine the ramp's height?

3.What size metal ball(s) produced the tracks you analyzed?

4.What were the characteristics you used to make your decision in Question 3?

5. How did your "Master Sheet" help you reach your conclusions in this experiment?

6. How is this investigation different from Investigation 15? How is this investigation similar to what scientists do at Fermilab?

Low Ramp				High Ramp			
X Lg	Lg	Med	Sm	X Lg	Lg	Med	Sm

Section 4: IDEAS

Introduction and Purpose:

Particle physicists use many different mathematical models and conceptual schemes to develop theories about the unseen world. Fermilab scientists make use of symmetry, classification, scaling, and ideas about relative size in their search for understanding. Each of these strategies can be used in many different ways and in many different situations.

These strategies or tools allow the physicist to organize and systemize efforts to discover some of nature's most cleverly hidden truths. An awareness of how these tools assist people every day gives us a peek into the life of a physicist at work.

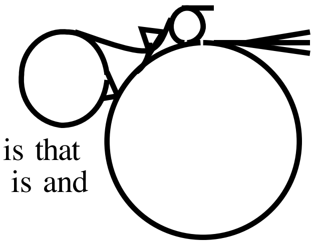
In this section students will explore how many different ideas can help in solving problems and creating new conceptual frameworks.

Objectives:

By the end of this unit, students will:

1. Use a variety of strategies to solve problems or visualize concepts. (These may include classification, symmetry, and modeling.)
2. Be able to describe ways in which Fermilab scientists:
    - use these strategies to solve problems or visualize concepts.
    - use these strategies to create and continually develop an understanding of nature's inner workings called the Standard Model.

Investigation 17: The Symmetry Scavenger Hunt

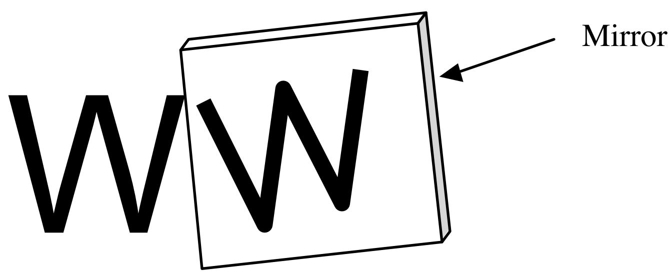


Purpose:
Symmetry is a very common tool particle physicists use to solve problems and discover new particles. The reason symmetry is such a powerful tool is that nature often has symmetric properties. Students will learn what symmetry is and how to use it to solve problems in which little evidence appears to exist.

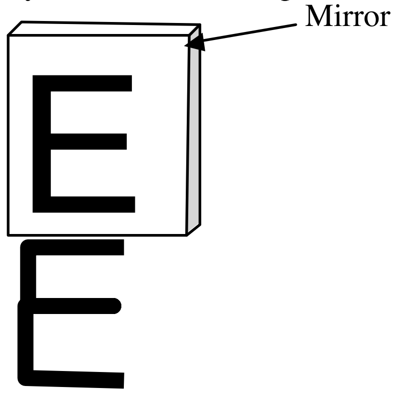
Objectives:
1. Students will become familiar with bilateral symmetry (also known as mirror symmetry).
2. Students will search for symmetry in the alphabet.
3. Students will identify symmetry in objects around them.
4. Students will explain how symmetry is important in particle physics.

Materials:
Paper and pencils
Small mirrors for each student

Procedure:
1. Explain what symmetry is to the students by pointing out that people are generally symmetric left and right. That is, the left side of our bodies generally looks like the right side. Take the time to note interesting differences in people as well. (Handedness is an excellent example of a break in the left-right symmetry in people.)
2. Explain that our alphabet is made of many letters that are also symmetric. The letter W, for example, is left-right symmetric. This means that if you look at a W in a mirror that is placed next to the letter it still looks like a W!



3. Point out that W is not symmetric in a mirror placed above it, so it is not up-down symmetric. The letter E, however, is up-down symmetric, even though it is not left-right symmetric.

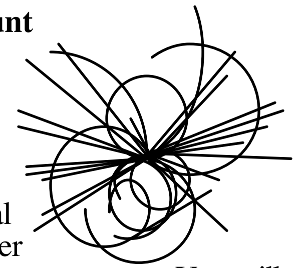


4. Ask the students to write the entire alphabet on a piece of paper and use the mirror vertically (as it is with W in the illustration above). Their goal is to list the left-right symmetric letters.

   Note: If desired, use a computer to produce neat, clean letters for the students. Be certain to choose a font that gives simple, clear letters. Arial is a good font for this.
5. Have them repeat the procedure with the mirror held horizontally (as it is with E in the illustration above). Ask them to list the up-down symmetric letters. Ask them if there are any letters that exhibit both left-right and up-down symmetry.
6. Now that students have had some exposure to the concept of symmetry, ask them to go on a symmetry scavenger hunt in the room. Have the students make a list of objects they find that exhibit left-right or up-down symmetry.
7. Discuss how the idea of symmetry may be important to an paleontologist trying to determine what an entire dinosaur looked like based on only a small number of bones.
8. Ask the students to discuss how a scientist at Fermilab might use symmetry to discover new unseen particles.

   Note: You may wish to point out that often certain particles are not found immediately, but through the use of symmetry, scientists believe that the particle will eventually be found. An excellent example is the most recently discovered quark, the top quark. It was presumed to exist long before it was found because the bottom quark, the other member of its "family," had been discovered in 1977. The missing member was called "top" for many years before it was actually seen for the first time at Fermilab.

Student Sheet Investigation 17: The Symmetry Scavenger Hunt



Name____________________________
Date____________________________

Purpose:
One of the most common ways physicists try to discover secrets of the natural world is to predict what an unseen particle might look like based on another particle that is well known. One process that helps the scientist is recognizing symmetry. You will model how scientists look for symmetry in the natural world by first discovering it in the alphabet and then looking for it in your classroom.

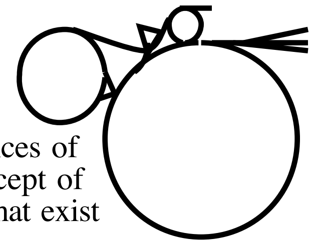
Procedure:

1. Print all of the capital letters of the alphabet. Make the letters large and as neat as you can. Leave space between the letters as well.
2. Set up a mirror to either the left or the right of each letter as your teacher illustrates. Some will appear backwards in the mirror, like E and Ǝ. Others will appear the same in both the mirror image and the paper image like A and A. Make a list of all letters that are the same both on paper and in the mirror in the space below. These are left-right symmetric letters.
3. Now check the alphabet again, holding the mirror above each letter. Notice this time that the letter A appears like ∀ in the mirror. It is symmetric left-right but not up-down! E, however is up-down symmetric. Make a new list of the letters that are the same both on paper and in the mirror in the space below. These are up-down symmetric letters.
4. Compare your lists to those of other students in the room. Do you agree? Did you miss any letters?
5. The symmetry you have discovered helps us to group letters in ways we had not before. In a similar way, scientists look for properties in nature which show some symmetry. Look around the classroom and find objects that have symmetry. Make a list of them here:
6. Compare your list with someone else's. Do you agree on all symmetries? What do you have that he or she doesn't? What is on your partner's list, but not yours? Why?

7. Can you think of any ways that symmetry might help a scientist solve a mystery? Describe a situation where symmetry might be used to solve a scientific mystery. Write a short explanation below.

8. How might particle physicists at Fermilab use symmetry to learn more about particles?

Investigation 18: *Cosmic Voyage* Film



Purpose:
Cosmic Voyage is an inspirational and educational journey. Students will "travel" from the depths of subatomic structure across the immense distances of our universe. Through the movie they will explore the mathematical concept of powers of ten and how it exponentially helps us understand the distances that exist between particles that make up the world around us.

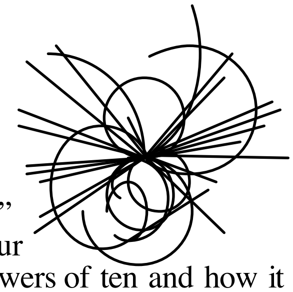
Objectives:
Students will develop an appreciation of relative size and orders of magnitude (powers of ten).
Students will be able to compare the macrocosm of outer space to the microcosm of inner space.

Materials:
Cosmic Voyage film
Student Investigation Sheet: *Cosmic Voyage* Film

Note: The movie can be viewed as an introduction to the concept of powers of ten or as a means to apply student understanding from a classroom discussion to real life measurements in the study of matter.
This investigation includes worksheet containing questions designed to focus student thinking, as well as a teacher answer key. Reading over these questions with students prior to viewing the video will enhance their understanding. Students understanding of just how much of matter is composed of empty space should definitely be part of your lesson planning for the unit.
Show students the movie Cosmic Voyage in order to develop an appreciation (don't expect complete understanding) of relative size and orders of magnitude (powers of ten). The cosmic scale banner found in the teacher assistance package of the kit can be displayed and the decimal point moved in order to review steps in Cosmic Voyage. We have included a sample worksheet to be used in conjunction with this movie. You may wish to show the film more than once to increase your students' appreciation and understanding of the concept.

Procedure:
1. Hand out the student investigation sheet.
2. Read through the questions in order to prepare the students for what they are going to see.
3. Display the cosmic scale banner from the teacher assistance package. Briefly "walk" through the powers represented on the banner.
4. Show the film *Cosmic Voyage*.
5. Determine ahead of time how students will be accountable for the video content. Ideas might be to have them taking notes during the presentation, individually after the presentation, or in small groups after the presentation?
6. Follow up the presentation with discussion.

Student Sheet Investigation 18: *Cosmic Voyage*



Name___________________
Date____________________

Purpose:
Cosmic Voyage is an inspirational and educational journey. You will "travel" from the depths of subatomic structure across the immense distances of our universe. Through the movie you will explore the mathematical concept of powers of ten and how it helps us understand the distances that exist between particles that make up the world around us.

Procedure:
1. Watch the video *Cosmic Voyage*.
2. After the video follow your teacher's instructions regarding how he/she wants you to report on the content. It may be individually on the worksheet, through class discussion, or through a small group effort on the worksheet.

Cosmic Voyage reflection and discussion worksheet
1. What object in the video is equal to the 100th power of ten?

2. What landmark can be seen at the 102nd power of ten?

3. What object is visible at the 107th power of ten?

4. What power of ten is equal to the farthest reaches of human travel into our solar system?

5. At what power of ten is our solar system visible?

6. How many powers of ten is one light year?

7. What is a light year?

8. How long would it take at present-day spacecraft speeds to reach our nearest star?

9. At what power of ten is the Milky Way galaxy visible?

10. What do we currently believe exists 15,000,000,000 light years from Venice?

11. What evidence did you find in this video that would support the idea that the universe is expanding?

12. What objects of measurement do we use in our everyday lives to determine whether something is large or small?

13. Under what circumstances might you use a different scale of large and small?

14. Why are Fermilab scientists trying to duplicate the conditions that existed at the start of the universe? How are they doing this?

15. Some scientists might say that the farther we look into space, the farther back in time we can see. What does this mean?

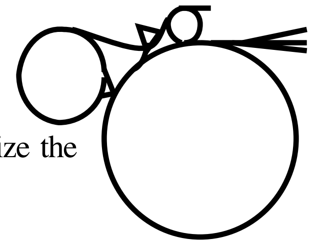
16. Compare the distribution of matter in outer space with the matter in atoms.

17. If an atom were as large as an Omnimax theater, how large would the nucleus be?

18. Do you believe that there is life present on other planets or in other galaxies? Why or why not?

19. What was the most difficult idea in part of this video for you to understand? Explain why.

Investigation 19: Visualizing Smallest



Purpose:
The following model will allow students to see and actually participate in building a life-size model of a hydrogen atom, which will help them visualize the scale of what scientists study at Fermilab.

Objective:
This investigation will help students understand the vast empty areas within the atom or nucleus. By roping off occupied areas, one can visualize how atoms are arranged.

Materials:
Rubber stopper
Straight pin
Meter stick (school supply)
Two pieces of heavy string - 10 meters, 23 meters
3 BBs

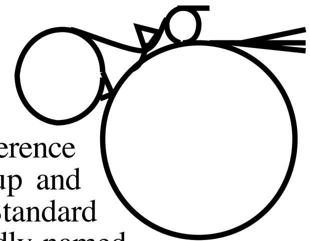
Procedure:

Note: Envisioning the vast distances of outer space may be a difficult task for middle school students. The distances in subatomic space are even more mind-bending, and therefore it is necessary to give students the opportunity to visualize and measure the relative distances involved with atomic and subatomic space.

1. Perform the following simulation models with your students by actually measuring or estimating the distances.
   A. If the nucleus of a hydrogen atom were the size of the head of a pin (1 mm), then the first electron in the atom would be an average of 10 meters away.
   B. If you allow the average BB (2 mm) to represent the size of a quark, then the proton (which is a hydrogen nucleus) would be represented by a circle 8 meters in diameter. (Use string or yarn to make this 23-meter-circumference circle.)
2. Using the quarks-in-the-proton model in B above, ask your students to estimate how far the electron in A above would now be from the 8-meter-diameter proton. (80,000 meters or about 50 miles)

   Note: There are three quarks in a proton. The quarks are assumed to be in rapid motion and held within the proton space by spring-like forces carried by other particles called "gluons." At any given point in time, a quark could be said to be occupying any part of this sphere. This is why we can say that the three quarks "fill" or occupy the entire empty space.
3. Any additional simulations that your students can experience will help them to develop an appreciation of the relative spaces and emptiness in the universe, both outer space and atomic space. (Scale modeling of the sun - earth - moon or the entire solar system are some other examples.)

Investigation 20: The Standard Model



Purpose:
Jargon is used in almost every aspect of science, and particle physics is no exception. Even in a sport like baseball, it is important to know the difference between a double play and a double. You need to know when to "tag up and run" and when to "tag the runner." Familiarity with the jargon of the Standard Model helps students feel a bit more like the scientist who studies the oddly-named particles that are members of the team.

Objectives:
Students will become familiar with the names of the six quarks: Up, Down, Strange, Charm, Bottom, and Top.
Students will learn about fractional charge and how quarks combine to make baryons.

Materials:
One deck of "Quark Cards" consisting of 20 Up, 20 Down, 5 Strange, 5 Charm, 1 Bottom, and 1 Top card. (Make these cards using the template provided on the page at the end of this section or have students to make the cards themselves.)

Note: Students will need to know a few things about how quarks combine to play this game. It may be best to write the following information on the board and have the game reinforce these ideas as play continues:

1. *Quarks have the names Up, Down, Strange, Charm, Bottom, and Top.*
2. *Quarks have either a +2/3 or -1/3 charge.*
3. *Baryons are always three quarks.*
4. *Baryons may only have integer total charges. Examples: a +2 total charge* ($+^{2}/_{3}$, $+^{2}/_{3}$, $+^{2}/_{3}$)*, a +1 total charge* ($+^{2}/_{3}$, $+^{2}/_{3}$, $-^{1}/_{3}$)*, zero total charge* ($+^{2}/_{3}$, $-^{1}/_{3}$, $-^{1}/_{3}$)*, and a -1 total charge* ($-^{1}/_{3}$, $-^{1}/_{3}$, $-^{1}/_{3}$)
5. *Two special baryons are up-up-down (a proton) and down-down-up (a neutron).*
6. *Quarks are not found in equal numbers. The most common quarks are up and down, and the rarest quarks are bottom and top.*

Procedure:
1. Explain the rules to the students and then help them as they work their way through the game. After a short time, the students will understand the basics of this investigation. The rules are:
   - Divide the class into teams. It is best to start with two or three students on each team.
   - Give each pair of teams one deck and shuffle the cards.
   - Have one member of each team draw five cards.
   - After the players on the first team look at their cards, they may consult and place any three cards into a baryon. When they do this they shout out "baryon" and the three quarks that make it up (for example: "charm, up, strange"). Then they announce the total charge of their baryon, and if it is a proton or neutron, name it for a bonus point.
   - Next, they record the points for that turn according to the table below and replace the three cards by drawing three cards from the deck.
   - The second team now takes its turn, and the teams continue alternating until the deck is exhausted. When the deck is gone, each team will have two cards left. These are simply discarded.
   - The teams may wish to hold on to valuable cards so that they can create rare baryons with the relatively few strange, charm, bottom, and top quarks that are available in the deck.

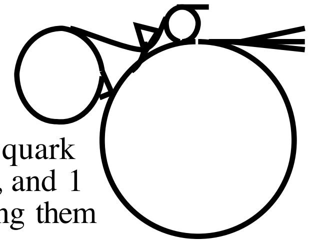
Scoring Chart:

Baryon made of only up and down quarks	Bonus for naming a proton or neutron	Baryon containing one strange or charm quark	Baryon containing two strange or charm quarks	Baryon containing three strange or charm quarks
1 Point	1 Point	2 Points	4 Points	6 Points

Baryon containing one bottom or top quark	Baryon containing one strange or charm quark and one bottom or top quark	Baryon containing two strange or charm quarks and one bottom or top quark	Baryon containing two bottom or top quarks	Baryon containing one strange or charm quark and two bottom or top quarks
7 Points	9 Points	11 Points	15 Points	17 Points

2. At the end of the game, summarize the results and point out that the simple rules students used to build baryons are what scientists use in determining how nature works. This scheme is part of what is known as the "Standard Model."
3. Show the students the Standard Model chart. Discuss the components that make up our current understanding of matter.

Supplemental Investigation 20A: The Advanced Game



If the class enjoys the simple version of this game, consider adding a level of complexity by introducing antiquarks into the game. Make a second set of cards using the antiquark template with the same distribution as the quark deck (20 Antiup, 20 Antidown, 5 Antistrange, 5 Anticharm, 1 Antibottom, and 1 Antitop). To further distinguish them from the quark cards, consider making them on different colored paper.

Here are the additional rules for making antibaryons and mesons that students will need to know:

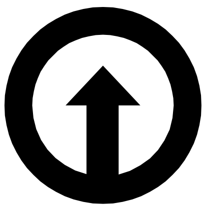
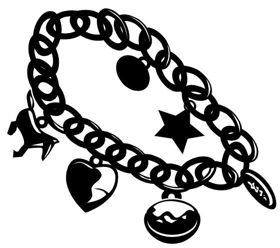
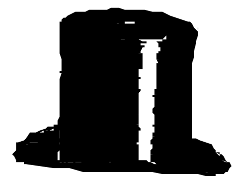
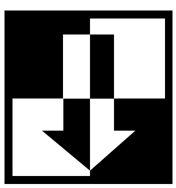
- Antibaryons are made exactly like baryons, only with three antiquarks instead of three quarks.
- Mesons are made from one quark and one antiquark. They must also have a total charge equal to an integer: -2, -1, 0, +1, or +2.

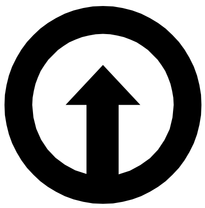
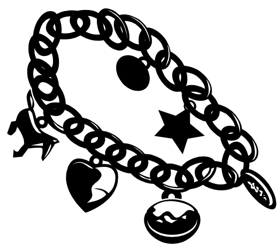
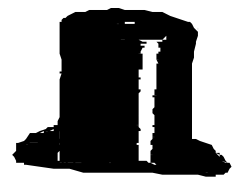
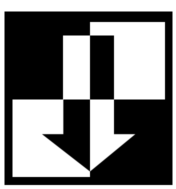
Meson Scoring for the Advanced Game (baryons and antibaryons are scored using the chart for the Basic Game):

Meson made of only up and down (anti)quarks	Meson containing one strange or charm (anti)quark	Meson containing two strange or charm (anti)quarks
1 Point	2 Points	3 Points

Meson containing one bottom or top (anti)quark	Meson containing one strange or charm (anti)quark <u>and</u> one bottom or top (anti)quark	Meson containing two bottom or top (anti)quarks
5 Points	7 Points	12 Points

Template for Standard Model Quark Cards

+2/3 Up 	+2/3 Charm 	+2/3 Top 
-1/3 Down 	-1/3 Strange 	-1/3 Bottom 

-2/3 Antiup 	-2/3 Anticharm 	-2/3 Antitop 
+1/3 Antidown 	+1/3 Antistrange 	+1/3 Antibottom 

Hadron Names: For the Curious Only

As your students play the Standard Model card game and start making hadrons (baryons and mesons), they may want to know the names of some of them beyond the proton and neutron. Below is an incomplete table containing the name of a baryon or meson formed by each combination of quarks. Only spin $^1/_2$ baryons and pseudoscalar (spin 0) mesons are included. A plus or minus after a symbol indicates the particle's electrical charge. If there is no such symbol, the charge is zero.

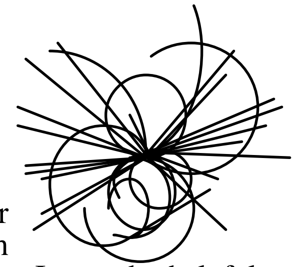
Baryons: The baryon table contains only baryons consisting of three quarks. To name a baryon consisting of three antiquarks, find its quark analog and append the prefix "anti-."

uud	Proton	uus	Σ^+ (sigma-plus)	uss	Ξ^0 (xi-zero)
udd	Neutron	dds	Σ^- (sigma-minus)	dss	Ξ^- (xi-minus)
uds	Λ (lambda) or Σ^0 (sigma-zero)			udc	Λ_c^+ (lambda-c-plus)

Mesons: The mesons are listed quark first, then antiquark. An antiquark is represented by putting a bar over the quark symbol, so, for example, an antiup quark would be represented as $\bar{u}$.

$u\bar{d}$	π^+ (pi-plus)	$c\bar{d}$	D^+ (D-plus)	$u\bar{b}$	B^+ (B-plus)
$d\bar{u}$	π^- (pi-minus)	$d\bar{c}$	D^- (D-minus)	$b\bar{u}$	B^- (B-minus)
$u\bar{s}$	K^+ (K-plus)	$c\bar{u}$	D^0 (D-zero)	$d\bar{b}$	B^0 (B-zero)
$s\bar{u}$	K^- (K-minus)	$u\bar{c}$	$\bar{D}^0$ (anti D-zero)	$b\bar{d}$	$\bar{B}^0$ (anti B-zero)
$d\bar{s}$	K^0 (K-zero)	$c\bar{s}$	D_s^+ (D-s-plus)	$c\bar{c}$	η_c (eta-c)
$s\bar{d}$	$\bar{K}^0$ (anti K-zero)	$s\bar{c}$	D_s^- (D-s-minus)		

Student Sheet Investigation 20: The Standard Model



Name______________________
Date______________________

Purpose:
Particle physicists have invented names for the objects they discover in their detectors. These names may sound a bit silly because you are unfamiliar with them. Today you will learn these names while you play a card game in class. It may be helpful to know several of the words you will use before the game starts.

Vocabulary List:
Quarks – There are six of these. Two of them, the up quark and down quark, make up much of the world around us.

- Up Quark – very common, has a $+^{2}/_{3}$ charge
- Down Quark – very common, has a $-^{1}/_{3}$ charge
- Strange Quark – much less common, has a $-^{1}/_{3}$ charge
- Charm Quark – much less common, has a $+^{2}/_{3}$ charge
- Bottom Quark – very uncommon, has a $-^{1}/_{3}$ charge
- Top Quark – the least common of all, has a $+^{2}/_{3}$ charge

Baryon – a particle made of three quarks (may have a +1 or zero charge)
Proton – a baryon made of two Ups and a Down
Neutron – a baryon made of two Downs and an Up

Playing the Game:
The rules for the game are best understood by playing an "open hand" where everyone starts to understand how points are accumulated. Your teacher will tell you a bit about baryons and quarks. In the beginning you may need to refer to these facts often. The rules for The Standard Model card game are:

- Divide into teams as your teacher directs.
- Shuffle the cards.
- Have one member of each team draw five cards.
- After the players on the first team look at their cards, they may consult and place any three cards into a baryon. When they do this they shout out "baryon" and the three quarks that make it up (for example: "charm, up, strange"). Then they announce the total charge of their baryon, and name it (if it is a proton or neutron) for a bonus point.
- Next, they record the points for that turn according to the table on the next page and replace the three cards by drawing three cards from the deck.
- The second team now takes its turn, and the teams continue alternating until the deck is exhausted. When the deck is gone, each team will have two cards left. These are simply discarded.
- The teams may wish to hold on to valuable cards so that they can create rare baryons with the relatively few strange, charm, bottom, and top quarks that are available in the deck.

Scoring Chart:

Baryon made of only up and down quarks	Bonus for naming a proton or neutron	Baryon containing one strange or charm quark	Baryon containing two strange or charm quarks	Baryon containing three strange or charm quarks
1 Point	1 Point	2 Points	4 Points	6 Points

Baryon containing one bottom or top quark	Baryon containing one strange or charm quark and one bottom or top quark	Baryon containing two strange or charm quarks and one bottom or top quark	Baryon containing two bottom or top quarks	Baryon containing one strange or charm quark and two bottom or top quarks
7 Points	9 Points	11 Points	15 Points	17 Points

Answer the following questions after your game:

1. List the combinations of quarks that your team made into baryons in this game.

2. How many protons did you make?

3. How many neutrons did you make?

Section 5: HUMAN ELEMENT

Introduction and Purpose:

We often speak of the thrill of discovery in a historical manner. We remember the Wright brothers, Marie Curie, and, Albert Einstein, among countless others, many years after their work because of the contributions they made to science and our society. Who are the men and women that will enjoy a similar place in history in the next century? Where do they work and what do they do?

To answer these questions, we need to look to those who are pushing into new frontiers of human understanding—the men and women who try to discover what has never been known, to see what others have not seen. These are the men and women of Fermilab.

All the employees of the Lab share a common bond: They have come from all over the world, to work in jobs of all descriptions, in an effort to understand some of nature's deepest secrets.

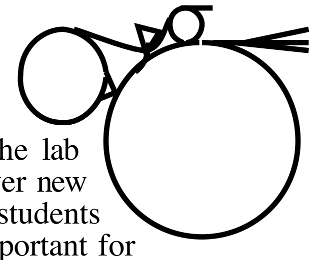
In this section, we will explore the excitement and pride that these teams of people feel as they combine their efforts in their search for understanding. Students will gain insight into the human element of the operation of Fermilab.

Objectives:

By the end of this unit, students will understand that:

1. Scientists find beauty in the work they do.
2. Fermilab has one of the premier accelerators in the world, which enhances the great pride staff members have in their work.
3. Experiments at Fermilab are of an enormous scale, often including hundreds of people.
4. Experiments at Fermilab are international efforts with men and women from all over the globe working together.
5. It takes many different kinds of workers, in addition to physicists, to make Fermilab operate smoothly.

Investigation 21: A Sense of Scale



Purpose:
One of the more challenging aspects of this unit is helping students gain the perspective that scientists are real people doing jobs they enjoy. The lab work, activities, and discussion questions simulate how scientists discover new knowledge about things that they cannot see. This 1998 video will help students view these discoverers from a fresh, quite human point of view. It is important for students to realize these men and women choose their careers because they are excited about searching for the missing pieces that will someday help complete the Standard Model.

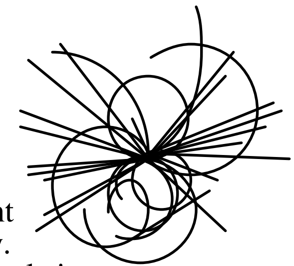
Objectives:
Students will realize that discovery and learning, although time-consuming and expensive at times, can be very rewarding.
Students will hear scientists discuss how they got interested in their various fields of study and what they have gotten out of it.
Students will gain the perspective that scientists are real people doing a job that they enjoy.

Materials:
A Sense of Scale
Student Investigation Sheet - *A Sense of Scale*

> *Note: Discussion questions and a teacher key are available in the teacher manual for this video. This aspect of this unit is an extremely important one on which to spend some time. Students will be solving problems for their entire lives, and realizing that problem-solving is an ability that all people in all walks of life need is a valuable lesson. They will also be working with all kinds of people and they must begin to build the respect for those relationships now. Being able to work successfully with many different types of people is a required skill in our society today.*

Procedure:
1. Discuss with your students why they think that people choose the careers they do.
2. Then ask them specifically why someone might want to become a physicist.
3. Discuss with your students what they think is meant by the “human element” of Fermilab. (We use it to refer to the variety of people here as it concerns their strengths and weaknesses, their likes and dislikes, etc.) How does it affect the work that the physicists do on a daily basis?
4. Read through the activity sheet with your students to prepare them better for what they will see in the film.
5. Watch *A Sense of Scale* video.
6. Determine ahead of time how the students will be held accountable for the video content. Will they take notes during the video, during pauses between sections, or at the end of the entire video? Will they take notes individually, or in small groups?

Student Sheet Investigation 21: ***A Sense of Scale***



Name____________________
Date_____________________

Purpose:
One of the more challenging aspects of this unit is to help you as a student gain the perspective that scientists are real people doing a job that they enjoy. The lab work, activities, and discussion questions do a very good job of simulating how scientists discover new knowledge about things that they cannot see. This new video will help you view these discoverers from a fresh, quite human point of view. It is important for you to realize these men and women actually chose their careers because they are excited about searching for the missing pieces that will help complete the Standard Model someday.

Procedure:
After watching the video, follow your teacher's instructions regarding how you are to report on the content. It may be individually on this worksheet, through class discussion, through a small group effort on the worksheet, or in a completely different way. The major sections of the video are listed in capital letters.

1. "To understand nature, we have to break it down into its constituent components." How are scientists at Fermilab trying to do this?

RUNNING THE RING

2. The Tevatron is a ring almost four miles in circumference containing one thousand twenty-ton superconducting magnets buried thirty feet underground. The machine directs one trillion protons around the ring in a beam thinner than a human hair while electric fields are used to push the particles to higher energies. The energy in each proton and antiproton in the Tevatron is equal to that of six semi-trucks moving down a highway at 60 mph. Why do scientists need such an enormous machine that creates so much energy?

3. What is the main challenge for the physicists today as they operate this machine, parts of which were made in the 1970s?

STARTING THE BEAM

4. What is the purpose of each succeeding accelerator at Fermilab?

A PERFECT IDEA

5. "We are fascinated by the challenge of understanding the real world. We have a love of trying to figure things out. The more you think about something, the more you want to explore it." What qualities, personality traits and values do you think it takes to be a Fermilab scientist?

COLLISIONS

6. How long has it been since collisions like the ones occurring at Fermilab now have happened naturally?

7. Do you think it is important to spend money to create these collisions and study them? Why or why not?

DETECTORS

8. Fermilab's detectors are so massive and monitor so many collisions per second that it takes as many as 400 physicists to build and operate one. Yet, according to two of the physicists in the video, getting people to work together is as interesting a problem as getting the equipment to work correctly. Reflect on these two statements. How can so many diverse people make something like this work?

9. List and briefly describe the advantages of current electronic detectors when compared to older detectors such as the bubble chamber.

THE STANDARD MODEL

10. Name the six quarks and the six leptons that are part of the current Standard Model.

11. What is peer review? How can it benefit any science experiment?

UNFINISHED BUSINESS

12. “The whole idea in science is to make links between different phenomena.” How does this statement relate to the work that is done at Fermilab?

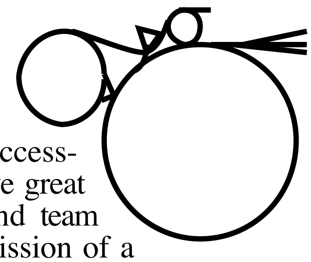
13. Summarize at least three of the remaining questions that face scientists at Fermilab. Areas for discussion can include: top quark, antiprotons, neutrinos, calculations

14. Fermilab scientist Chris Quigg said, “Ideas that I did not even know that I had came together.” What do you think he meant?

15. Have you ever had an experience like Dr. Quigg’s before? Describe it.

16. “The curiosity of children is why so many physicists work so hard.” How curious are you about the world around you? What do you wonder about?

Investigation 22: Name that Career!



Purpose:

Fermilab is like a small city, in which many people have many different careers. Without each person in each job, the Lab would not function as successfully as it does. A common link between Fermilab workers is that they have great pride in what they do. Individuals truly believe that their individual and team efforts help make the lab productive. They are proud to contribute to the mission of a world-class institution and believe their work is important. They respect and value each other. In this activity, students will become more familiar with the variety of jobs people have at Fermilab.

Objectives:

Students will become familiar with the range of careers represented at Fermilab.
Students will understand that each job serves an important function at Fermilab.

Materials

Index career cards, one per student
Student Investigation Sheets - "Name That Career!"

Procedure:

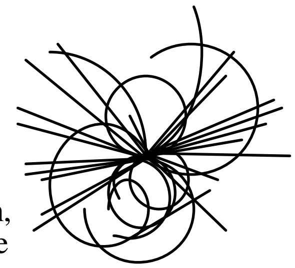
1. On each index card, before class begins, write the name of one Fermilab job from the list on the next page.
2. Distribute one career card and one investigation sheet to each student. Ask the students not to share their identity with others.
3. Allow the students a moment to think about what that job might involve, where at Fermilab it might take place, how someone in that job might go about doing their work, etc.
4. Instruct the students to write their thoughts down on their sheet so that they can refer to them during the investigation.
5. Break your class up into groups of no more than six students per group.
6. Have one student from each group stand up. Allow the other students in his or her group to ask two questions each. The student will do his or her best to answer the questions. Then ask the other students to write down the name of the job they believe was being portrayed on their Student Investigation Sheets.
7. Continue this investigation until each of the students have represented their careers.
8. When the groups have finished their guessing, have them join the large group again. Ask each student to tell the class what job they had represented.
9. Discuss the range of jobs and their importance to Fermilab. Use the Student Investigation Sheet questions as a starting point for this discussion.

Fermilab Jobs List:

Below is a table that represents several of the jobs at Fermilab. This list does not include every job and your students may wish to add other jobs based on people they know who work at the Lab.

Accountant	Director	Nurse
Activities Planner	Dormitory Manager	Painter
Architect	Educator	Photographer
Artist	Electrical Engineer	Public Relations
Astrophysicist	Experimental Physicist	Purchaser
Auto Mechanic	Fire Fighter	Refrigeration Expert
Bank Teller	Health and Safety Officer	Secretary
Biologist	Health Club Coordinator	Security Officer
Carpenter	Herdsman	Taxi Driver
Chef	Human Resources Expert	Telecommunications
Computer Engineer	Inventor	Theoretical Physicist
Construction Worker	Lawyer	Travel Planner
Custodian	Librarian	Videographer
Day Care Teacher	Machine Technician	Welder

Student Sheet Investigation 22: Name that Career



Name____________________
Date______________________

Purpose:
It takes a wide variety of people to make Fermilab work. In this investigation, you will pretend to be a Fermilab employee and become familiar with the variety of jobs people have at Fermilab.

Investigation:
1. Look at the career you have been given. Don't share your career with classmates. Think about your job; for instance, where it might take place, with whom, and how you might go about doing your work. Write down some of your thoughts about your job here:

2. Have your research teams pick one person to be interviewed first.
3. You may ask this person two questions about their job.
4. After all research team members have asked their two questions, make the best guess you can and record the career on the lines below.
5. Repeat the process for all the students on your team.

Student	Job
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________

6. Pick any three roles from number 5 and explain how you think they contribute to making Fermilab work.

7. Explain how Fermilab is very much like a city.

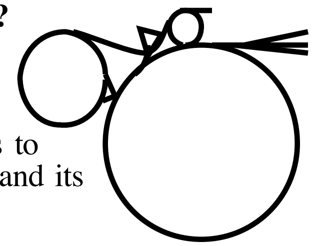
8. As a research team, discuss and answer the following questions.
   a) Fermilab has approximately 2,000 workers, many from countries other than the United States. Can you think of any challenges to having so many diverse people at one place? Can you think of any solutions to these challenges? List them.

      <u>Challenges</u> <u>Solutions</u>

   b) The first Fermilab director, Robert Wilson, wanted people of all kinds and all roles to talk to and learn from each other. There is a story at Fermilab that says that this is why he designed Wilson Hall (the main high-rise) to have too few elevators that move very slowly. Why might this work? Can you think of any other ways to get people to "mix?"

   c) Why might Fermilab need jobs such as a recreation coordinator, activities coordinator, lifeguard, arts series coordinator, etc?

Investigation 23: How Much Do You Really Know About Fermilab?



Purpose:
At this point in the Beauty and Charm unit, students may feel as if they are experts on Fermilab. The following investigation will allow students to see how much they really know or don't know about Fermilab, its people and its experiments.

Objectives:
Students will answer questions about Fermilab to assess what they know.

Materials:
Student Investigation Sheets - "How Much Do You Really Know about Fermilab?"

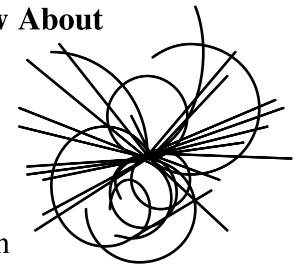
Procedure:
1. Have students answer these questions individually or in small research teams. If time is short, consider giving different teams different subsets of the questions.
2. After the students have completed the page, discuss the answers with short discussions of the concepts, as needed.

<u>How Much Do You Really Know about Fermilab?</u>
<u>Sample Answers</u>

1. What is the main scientific work done at Fermilab?
   Particle physics. Scientists are learning more about the structure and interaction of subatomic particles. Astrophysics is also done at Fermilab. Through this work, scientists are learning more about the correlation between the macrocosm of the universe and the microcosm of atoms.
2. Why is it important to do this scientific work?
   Pure research, learning more simply for the sake of learning more, adds to our knowledge of the universe and how it works. Humans are driven to find out more, answer mysteries and be able to predict based on their knowledge. Also, new technologies are always needed to push back the frontiers of knowledge. Many of these new technologies benefit society in a practical way.
3. How many people work on a Fermilab experiment?
   There are a wide variety of experiments going on at Fermilab at any given time. Small experiments may have twenty to thirty participants, while the collider detector collaborations number 300-400.
4. Why are there chalkboards in almost every office?
   To allow people at Fermilab the opportunity to record any thoughts at any time and to illustrate conversations as needed.
5. Why do you think there are flags from twenty-one different countries (including the United States) flying outside of Wilson Hall?
   To represent the countries that work in collaboration at Fermilab. There are actually scientists from more than twenty-one countries, so the twenty flags that fly in the line in front of Wilson hall are those of the twenty foreign countries with the most scientists present at the Lab.
6. How do you imagine the offices of Fermilab employees are decorated? Do you think there are differences between the office of a theoretical physicist, an astrophysicist, an experimental physicist, an educator, or a computer engineer? What might be some differences?
   Office decoration is a matter of individual taste. At Fermilab this may be "wacky" or austere or somewhere in between.

7. What is a quark? Why is the top quark so interesting?
   A quark is one of the fundamental constituents of matter. In an atom, three quarks make up each proton or neutron. There are six types of quarks: up, down, strange, charm, bottom, and top. The top quark was the last one to be discovered (at Fermilab in 1995) and the most massive by far.
8. What is used at Fermilab for treating cancer? Where does it come from?
   A beam of neutrons is used in treating cancer at Fermilab. The neutrons are the result of a collision of hydride (negatively charged hydrogen) ions with a target partway down the Linear Accelerator (also called the "Linac"). The beam that produces these neutrons is diverted from the Linac beam as it passes the Neutron Therapy Facility.
9. Why does Fermilab spend time and money caring for biological things, like bison and prairies, when it is a physics laboratory?
   There are many different answers to this question. One reason may be that the first director of the Lab, Robert Wilson, brought bison to Illinois to help restore and maintain the area's natural beauty. Another reason might be that many, including Dr. Wilson, felt that Fermilab should try to bring the land back to a pre-settlement condition with prairies and woods.
10. As more, higher-powered accelerators are built elsewhere in the world, what do you imagine the future will hold for Fermilab and its scientists?
    Fermilab will continue for many years as a research facility. It will also grow in its role as a teaching center for particle physics.
11. Why would someone want to be a scientist? What do they find satisfying about their work?
    Some enjoy finding out about something that no one has known before. Others enjoy discovering the laws of nature. Others enjoy the puzzles and challenges Fermilab provides. There are probably as many answers to this question as there are people at Fermilab.

Student Sheet Investigation 23: How Much Do You Really Know About Fermilab?



Name________________________
Date__________________________

Purpose:
At this point in the Beauty and Charm unit, you may feel as if you are an expert on Fermilab. Answer these questions to see how much you really know or don't know about Fermilab, its people, and its experiments.

Procedure:
Answer the following questions:

How Much Do You Really Know about Fermilab?

1. What is the main scientific work done at Fermilab?

2. Why is it important to do this scientific work?

3. How many people work on a Fermilab experiment?

4. Why are there chalkboards in almost every office?

5. Why do you think there are flags from twenty-one different countries (including the United States) flying outside of Wilson Hall?

6. How do you imagine the offices of Fermilab employees are decorated? Do you think there are differences between the office of a theoretical physicist, an astrophysicist, an experimental physicist, an educator, or a computer engineer? What might be some differences?

7. What is a quark? Why is the top quark so interesting?

8. What is used at Fermilab for treating cancer? Where does it come from?

9. Why does Fermilab spend time and money caring for biological things, like bison and prairies, when it is a physics laboratory?

10. As more, higher-powered accelerators are built elsewhere in the world, what do you imagine the future will hold for Fermilab and its scientists?

11. Why would someone want to be a scientist? What do they find satisfying about their work?

Section 6: FIELD TRIP

Introduction and Purpose:

Fermilab is a unique research facility. Hundreds of men and women combine their efforts to imagine, construct, and operate machines unlike any others on Earth. Many of the people working at Fermilab proudly represent their home country as participants selected from many hundreds of candidates to come to Illinois to work.

Fermilab has held the position as the world's highest-energy particle accelerator for longer than any other lab over the last quarter century. This fact alone makes it the premier place to study particle physics.

It is a unique opportunity to visit a facility of this reputation. It is an unforgettable experience to speak with scientists and other workers at the lab. In your trip to Fermilab you will meet the men and women of Fermilab, see their experiments and enjoy a visit to the Leon M. Lederman Science Education Center.

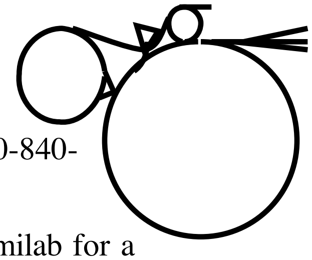
This Center was constructed with students in mind. Particle physics is made "kid-friendly" through interactive experiments designed to teach some of the critical ideas covered in this course.

Objectives:

At the completion of the *Beauty and Charm* field trip, the students will have:

1. Transferred knowledge gained in classroom models to understanding the activities at Fermilab.
2. Seen first-hand several of the special tools used by Fermilab scientists.
3. Acquired some familiarity with how these tools work.
4. Met and talked with a Fermilab scientist.
5. Experienced some of the unique ambiance ("flavor") of Fermilab. This may include its size, people, art, connections with nature, general aesthetics, casual atmosphere, writing opportunities, and connections with history.

Before a Trip to Fermilab



Normally, students of junior high/middle school age are not allowed group tours of Fermilab. Your use of this instructional unit may provide an opportunity for a tour. Contact the Fermilab Education Office at 630-840-5588 for more information.

It is imperative that any teacher who is planning to bring students to Fermilab for a field trip teach this unit to his or her students. Students who have not studied the terminology, purpose and processes intrinsic to Fermilab will not be able to benefit from the tour and can potentially create behavior problems for docents or staff.

If available, before you visit Fermilab, show the Hawkhill sound filmstrip titled *Fermilab*. This will aid your students in the overall understanding of what they will experience during their visit. Other related videotapes are available for purchase through the Fermilab Office of Public Affairs.

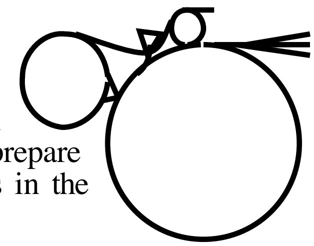
You may also supplement classroom activities with various articles and puzzles found in the *Quark Quest* newspaper, which is available through the Lederman Science Center. Call 630-840-8258 for details.

Work with your students in advance to prepare questions to ask the docent guide and physicists while at Fermilab.

Preview a map of the Fermilab site to help students recognize major features on the trip that they will be able to see from the high-rise or when riding on the bus.

After the trip, encourage your students to take a parent to Fermilab and its Leon M. Lederman Science Education Center to explore further on their own.

Investigation 24: Beauty and Charm Student Tour



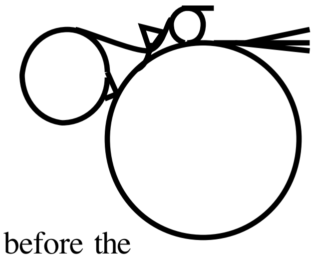
Purpose:
Seeing first-hand where science is done can be a powerful and meaningful experience for students. It is important that you make every effort to prepare them for this important part of the program. Student preparation begins in the classroom and will be completed on site.

Objective:
Students will see the machines and meet the men and women who build, operate and understand these machines and the secrets the machines reveal.

Materials:
Students may wish to bring paper and pencil to take notes.
Cameras are welcome on tours.

Procedure:
1. Before leaving on the field trip to Fermilab, explain to students that Fermilab is a working laboratory. The machines students will see are being used in experiments even as they are there. The men and women at the Lab are involved in current research and the students' visit is a rare chance to glimpse what it is like to be a scientist at this time.
2. Stress that the students must stay with the group and follow all directions given by the Fermilab docents (tour guides). Safety is of prime importance, so the students should not touch anything nor should they enter any areas unless they are directed to do so.
3. Upon arrival, the docents will give some reminders of safety procedures and general group directions. Please make sure the students listen.
4. Students will visit the Lederman Science Center with docents and have an opportunity to work with the exhibits in this Center. Docents will provide details of this portion of the visit.
5. Students will visit the first two stages of the acceleration process with docents. The first two accelerators are called the Cockcroft-Walton and the Linear Accelerator, or "Linac." If time permits, the students may also see the Main Control Room.
6. The students will go to the 15th-floor exhibits in Wilson Hall with docents. Here they will have an overview of the entire Fermilab property and the accelerator complex, which the docents will explain.
7. Students will meet with a scientist at the Lab. Here they will be able to ask questions they have prepared in advance, as well as any that have occurred to them during the day.
8. A very good follow-up activity is to have the students process what they saw and heard about when they get back to school. Some teachers may prefer a journaling activity, while others will prefer a verbal discussion. In any event, it is good practice to let the students sort through the information they have acquired when they get back to school.

Field Trip Checklist and Chaperone Guide



In an effort to make the field trip as successful as possible, there are several things that you should know. We include the following as a guideline. You may discover that other things work well for your situation.

Teacher Checklist:

1. Student List - Assign students to equal-size groups of twenty or fewer before the trip. Give each group a number for quick identification on arrival at the Lab.
2. Parent Permission Sheets (district or school provided)
3. Emergency Sheets (district or school provided)
4. Extra Handouts (if you wish for them to have something)
5. Call a local restaurant if you are intending to eat there.
6. If you are planning to eat at Wilson Hall, check with Fermilab personnel first. (Call 630-840-5588.)
7. Call the Docent Coordinator at 630-840-5058 two or three days prior to the trip to find out what type of a program they are currently running. (No surprises!)
8. Each student should bring:
   - 8.1. Journals (each with a pre-written question for the scientist).
   - 8.2. Pencil or pen.
   - 8.3. A lunch (unless you are making provisions at another location).
   - 8.4. Clothing appropriate for travel outside from the Lederman Science Center to Wilson Hall.

Chaperone Information:

Your job today is important for a number of reasons. You and your students will be visiting a place of business where people are actually performing scientific experiments during your visit. There is a certain amount of danger inherent in this situation so you need to be alert to where the students are at all times. Do not let them wander off!

The students may be asked to do several experiments during their visit. You need to help them (primarily by listening to the docents and by reading directions to them) as they move through the Lederman Science Center. Please try to avoid getting so involved in the experiments that you lose track of the students you have been asked to watch.

The teacher will be asking you to work with the students, talk with them and be a helper. However, please do not answer all their questions, but simply help them discover the answers to the questions through their own exploration.

Rarely, a student may be disruptive on the trip. Should this happen, you may be asked to bring that student to the teacher or you may be asked to shadow that student. The Fermilab docents will not tolerate poor behavior and it is always better to shadow a troublesome child than to sit on the bus with that child while the rest of the class enjoys the trip.

Finally, enjoy your day with the students. Watch them. They have a natural curiosity and are not afraid of topics that adults often think are too difficult. You will enjoy your day much more if you catch the excitement the students have when learning in a new setting.

Content Background for Teachers

What is particle physics?

Dr. Leon M. Lederman, recipient of the 1988 Nobel Prize in physics and former director of Fermilab, has defined physics and particle physics in the following terms:

> Physics is essentially a cultural activity . . . there is a need to know-there is a heritage handed down—a vision that the human brain can "solve" or put into rational order the physical problems of our own existence, starting with the creation of the universe in a big bang and predicting its evolution to the infinite future.
>
> Physics is thought to be very difficult by most physicists, **but** this is the creation of new physics. Understanding of what has been done requires no more patience and intelligence than finding out what has been done in art, music, and literature. Physics is vital to a large number of other disciplines for which it furnishes either the basic laws or the instruments or both.
>
> Particle physics is a search for the most primitive, primordial, unchanging and indestructible forms of matter and the rules by which they combine to compose all the things of the physical world. It deals with matter, energy, space, and time.
>
> The objectives of particle physics are to identify the **most simple** objects out of which all matter is composed and to understand the **forces** which cause them to interact and combine to make more complex things.

Particle physicists use basic terms and concepts when describing their research. Some of those terms and concepts are summarized below, not necessarily to be taught to students, but to provide a background for the teacher for questions that may arise. Other information is presented in the Teacher Notes associated with individual activities. (The *Focus on Fermilab* booklet available through Fermilab provides a more detailed introduction. Also you may wish to consult one of the references listed at the end of the Background section.)

Some Particle Properties

A particle, increasing its speed because of some force acting on it, gains energy of motion. An electron (negatively charged) gains **one electron volt** (eV) of energy in accelerating through a vacuum from the negative end to the positive end of a one-volt battery. The one eV of energy is given up to other particles as the electron crashes into the positive end.

A proton (positively charged) traveling from positive to negative pole through the vacuum would also gain one eV of energy and give it up in its collision with particles in the negative end. This proton collision is similar to the proton beam collision with a target at Fermilab, but at Fermilab the proton energy is much greater.

As a particle's speed approaches the speed of light (almost 300,000,000 meters per second), most of the energy it gains is not in the form of greater speed, but greater mass. When the particle slows down or collides with another particle, the extra mass may be converted back to energy of motion or it may form new particles. For example, a proton at its maximum speed in the Fermilab accelerator has more than 800 times the mass it had when not moving (rest mass). This mass may appear as new particles after a collision.

Since energy can become mass and mass can become energy (from Einstein's famous equation $E=mc^2$), both are aspects of the same thing. Since subatomic masses are so small, it is easiest to express them in the very small electron-volt (eV) unit.*

*The approximate conversion factors are:

1 gram = 6×10^{26} million electron volts (MeV)
1 electron volt = 1.6×10^{-33} grams
1 MeV = 1.6×10^{-27} grams

Every particle has either no rest mass or a rest mass that is unchanging. For example, an electron's rest mass is .511 MeV, a proton's is 936.2 MeV, and an upsilon's is 9402 MeV. A photon (a particle of light) has no rest mass, only mass when in motion at its normal speed—the speed of light.

Every particle is either neutral or has an electrical charge that never changes. The charge of an electron is negative. Its magnitude is often used as a unit of electric charge (e). An α-particle (alpha-particle—2 protons and 2 neutrons—see Investigation 11) has 2e positive charges. (The quantity of charge "e" exists in both positive and negative form.)

There are other quantifiable properties of particles including spin and magnetism. The quark, considered to be one of the most fundamental particles, has additional properties given fanciful names such as color and flavor.

The Need for Large Accelerators

In order to study small particles, scientists must generate a high-energy beam of particles. The reason is that the higher the energy, the more finely penetrating and discriminating a particle probe can be and the smaller the structure that can be studied. Also, the more energy (mass) available to a particle or particles in a collision, the more new or more massive particles can be created by that collision of the particle with a target particle.

Fermilab produces charged particle (proton) beams with billions of electron volts of energy in order to study the makeup of particles in the tiny, dense nuclei of atoms. Fermilab's 1985 modification to the four-mile circumference Main Ring accelerator allowed Fermilab scientists to accelerate protons to 1,000 billion electron volts (expressed 1,000 GeV, G for giga- meaning 10^9), which is equivalent to one trillion electron volts (expressed 1 TeV, T for tera- meaning 10^{12}). The modified accelerator is thus called the Tevatron. The most recent (1999) improvement is the addition of the Main Injector. This will increase the luminosity (number of collisions per second) by a factor of five and allow both types of Fermilab experiment, "fixed target" and "collider" to run simultaneously.

Particles were first used to probe the inside of atoms in about 1910. Ernest Rutherford used naturally emitted α-particles from a radioactive source to bombard thin gold foil. He found that most α-particles passed through the foil undeflected, while a few bounced back at sharp angles, apparently due to hitting tiny, solid objects. This was the first experimental evidence that there was a small, heavy, positively charged core to the atom and that the rest of the atom was mostly empty space.

In the 1930s, 40s, and 50s the study of the nucleus (nuclear physics) grew and included the details of the patterns of radioactive decay of nuclei and the forces that hold the nucleus together. Particle physics, also known as high-energy physics, developed as a branch of nuclear physics to investigate the structure of nuclear particles using high-energy particle probes.

The first circular particle accelerators were small instruments called cyclotrons ranging in diameter from a few inches to a few feet. Two fundamental limitations on particle speed required that larger accelerators be built to create the higher-energy particle probes necessary to study nuclear particles.

1. In circular accelerators such as Fermilab's, particle paths are made to curve by a magnetic field passing vertically down through each section of the accelerator ring. The faster the particle, the stronger the magnetic field must be to keep the particle in the fixed radius ring. However, there are upper limits (some of them financial) on how strong a magnet can be. By making the circle larger, the particle can go faster while the magnetic field strength remains the same.

2. When charged particles travel in curved paths they give up energy in the form of radiation such as light. The sharper the curve the particles are forced to turn, the greater the energy lost to radiation. At some point, all the new energy being input to the accelerator to push the particle faster will be immediately radiated away with no net gain in particle energy. By making the curve more gentle (larger circle), the radiation loss is less and the particles retain more energy.

Since forcing the charged particles to follow curves seems to be the source of problems in accelerating a particle, why not accelerate them in a straight line? This is done in the second-stage accelerator, called the Linac, at Fermilab, and on a larger scale at the Stanford Linear Accelerator Center in California. However, the advantage of the circular accelerator is that each time around the circle the particles can be given a new push, similar to the way a playground merry-go-round can be given many pushes by a person standing in one place. To gain the equivalent number of pushes, a linear accelerator would have to be incredibly long and expensive.

Each bunch of protons in Fermilab's Tevatron is pushed 40,000 times each second by passing through just one "pushing station" on each four-mile trip around the circle. The fully accelerated protons travel at more than 99.999% the speed of light and have more than 800 times their rest mass. The distance the proton travels in one second is four miles times 40,000 which is 160,000 miles, or the equivalent of almost $6^1/_2$ trips around the earth.

The Present Theory of Fundamental Particles and Forces

Before World War II, it was known that the nucleus was composed of closely packed protons and neutrons, but little was known about the "strong force" that kept them together. From 1950 to 1970, scientists built accelerators which were designed to probe nuclei with higher speed and more energetic, charged particles such as electrons and protons. The result was the discovery of hundreds of new particles and the determination of their properties.

In 1963, Murray Gell-Mann proposed a theory that a major group of these particles, called hadrons, could be thought of as made from a few, more fundamental particles, called quarks. Protons and neutrons are members of the hadron group.

Gell-Mann proposed quarks to be the simplest, irreducible, structureless building blocks of hadrons. The Quark Hypothesis states that quarks in combinations of two or three make all the observed hadrons. In 1963, the three known quarks were named: up (u), down (d), and strange (s). A neutron is composed of three quarks, u d d; a proton, u u d; and a lambda, u d s. In 1974, the existence of the charm quark (c) was revealed and in 1977, Leon Lederman and his colleagues at Fermilab uncovered the fifth quark, bottom (b). The final quark, top (t), was proposed almost immediately after the discovery of bottom to account for additional particle properties, and was discovered at Fermilab in 1995.

Electrons, neutrinos, and a few other particles make up another group of particles called leptons. Leptons are not thought to be divisible and are not made up of quarks.

The results of particle physicists' theoretical and experimental work up to 1995 might be summarized this way:

> All matter is thought to be made up of quarks and leptons and the force carriers through which they interact. There are six quarks. (Each comes in three "colors," making 18 particles, and each has an antiparticle, making 36 quarks in total.) The six quarks are named up (u), down (d), strange (s), charm (c), bottom (b), and top (t). (The last two are sometimes fancifully referred to as "beauty" and "truth.") The top quark was discovered at Fermilab in 1995. All six quarks have been confirmed through indirect observations, but not isolated as individual particles.
>
> The other six particles (also appearing in antiparticle form, making 12 total) are the leptons. These include electrons (e), electron neutrinos (ν_e), muons (m), muon neutrinos (ν_m), tau particles (t), and tau neutrinos (ν_t).
>
> The twelve particles (48 in all if you include colors and antiparticles) are subject to the four fundamental forces of nature. These forces are gravity, electromagnetic, strong, and weak. Each force is defined by the way it interacts with particles to build up composite form of matter: protons, neutrons, nuclei, atoms, molecules, planets, stars, and so on.
>
> Each of the forces has a strength, a range, and a "carrier" particle as outlined in the table below.

Force: Weakest to Strongest	**Range**	**Carrier**	**Observed**
Gravity	All Distances	Graviton	No
Weak	Nuclear Distances	W^+, W^-, Z^0	Yes (1983)
Electromagnetic	All Distances	Photon	Yes (1923)
Strong	Nuclear Distances	Gluon	Yes (1978)

One of the fundamental quests of the Fermilab scientists is to find an underlying link to unify the four basic forces. This Unification Theory would link all particles and forces into a coherent and simple description of nature.

In order to "observe" the basic particles of matter and collect data that may be of use toward theory development and perhaps the Unification Theory, physicists need particle probes with great amounts of energy. The protons with 1,000 GeV (1 TeV) energy now available in Fermilab's accelerator will help in this quest. By creating head-on collisions between these protons and 1,000 GeV antiprotons (generated earlier in stationary target collisions in a nearby storage ring) circulating in the opposite direction, 2,000 GeV collision data will be generated.

The main purpose of Fermilab and other large particle accelerators is to collect data that will support or refute theories. The need for new and better data is continuous. Numerous experiments remain to be done and each new theory and the related attempts at experimental verification inevitably lead to new insights as well as new questions about the most fundamental particles and forces that form all matter.

Quantum Mechanics

Perhaps more than any other theory of the past century, quantum mechanics forced us to reevaluate how we view the world. It shook Einstein and totally changed the way scientists view the universe by creating a world of probability rather than definite answers.

Quantum mechanics is most prominent in the smallest particles in our world. As the view widens from the quark level on to the molecular level, quantum effects are less important. In fact, by the time we get to objects the size of the head of a pin, the effects are almost always impossible to discern.

In the very tiny world, we discover that objects effervesce into and out of existence without having a great effect on the larger object of which they may be a part. Particles move, not as balls vibrating or bouncing from place to place, but rather as clouds or waves whose position is never quite well known.

Even energy follows this pattern. One cannot turn up the energy of an atom, for example, so that it gradually increases. Instead the energy increases in hops or jumps. These incremental changes are known as "quantized" changes and are characteristic of the very small world of quarks and leptons.

In a simple view, one can think of objects and energy existing in certain states but not existing in adjacent states. Movement between these discrete states is accomplished by a "hopping" from one state to the next. While the jump is occurring, the particle or energy cannot be defined and is thus not really there.

This unnerving world of "jumping" particles and energies is what quantum mechanics is all about, and the lack of clear definition is troublesome to most. In an effort to rectify the fact that existence is so fleeting, scientists have found help in the use of probability. In other words, the probability that a particular object or energy will be found in a particular locale is often calculated and tied to the existence of the objects themselves.

This idea was even troublesome to Albert Einstein who said, "God does not play dice with the universe."

Accelerators at the Lederman Science Education Center

At Fermilab, the machine that is used to bring particles to great energies is called an accelerator. This marvelous collection of wires, pipes, magnets and metal is a testament to this important process of changing speed. The understanding of acceleration itself is critical to a clear understanding of what is done at Fermilab.

Acceleration, the change in speed with respect to time, is at the very core of exploring modern particle physics. The interactive displays in the accelerator room at the Leon M. Lederman Science Education Center will assist students in understanding acceleration and accelerators.

Detectors at the Lederman Science Education Center

Our senses of taste, touch, smell, hearing and sight allow us to understand the world around us. As we go through each day, these are our guides to the physical surroundings. They help us decide where to go, what to do and how things operate.

When we lose part or all of one of these senses, medical doctors can provide help. Many people have hearing aids or use glasses to help them extend their own abilities to explore the world. In a sense, that is exactly what particle physics detectors do. They extend our eyes or ears to the physical world that is too small for us to see.

A Geiger counter marks the decay of a nucleus with an audible “tick.” We interpret many things from this sound without ever seeing the actual cause of the “tick” we have encountered. In a similar way, complicated computer drawings of a collision of particles (detector plots) allows our eyes to interpret an “event” whose participants are the smallest known particles in the universe.

Scientists become so familiar with detector plots that they know them to be as real as the markings on this page are to those reading them through lenses. In other words, glasses and particle physics detectors are in many ways different sides of the same coin. They both help us see clearly a world that would otherwise be hidden to us.

There are many types of detectors at Fermilab, but they all have the same goal: to allow scientists the opportunity to explore worlds too small or to fleeting to be seen otherwise. The interactive displays in the Detector room at the Leon M. Lederman Science Education Center will assist students in understanding the importance of detectors.

Collisions and Scattering at the Lederman Science Education Center

Everyone has been in the situation where he or she has had to describe what took place in a short period of time. A particularly useful example of this might be an automobile collision. In this case, there is seldom a camera available to film exactly what took place. Rather, the aftermath of car parts, broken and scattered, along with tire marks and other debris must tell the story.

In court, police and lawyers alike try to make sense of these details to understand the collision. Ultimately, the sound judgement of the jury or judge is called into play as a final decision is reached. The collision is determined to be of a particular nature with cars going particular directions at certain speeds and the results point to a better understanding of what happened to cause the collision.

Particle physicists make use of these same strategies as they look at the debris (in the form of energy) left in detectors after a particle collision. They try to decipher the clues left behind to understand the nature of the participants in the collision, and in some cases, they even try to understand what new particles are created in these collisions.

In particle physics, the most exciting aspect of looking at scattered debris is that in this debris, new particles are sometimes found. A new type of matter never before seen may be created in the collision of two well-understood particles. This is the real “sleuthing” of particle physics. It is in this searching that these men and women gain deeper understanding of our world and the particle species found here.

This exciting search for nature’s secrets is highlighted in the Methods room of the Leon M. Lederman Science Education Center. The interactive displays in the room assist students in understanding the process of looking through debris for unusual or familiar patterns to understand our world.

GLOSSARY

This glossary is provided for teacher reference only and is not intended for direct teaching or memorization.

Accelerator—A machine that serves as a source for a well-defined beam of high-speed particles for studies in nuclear science and high-energy (or particle) physics.

Antiparticle—Particle with the same mass but opposite charge as another particle under normal conditions.

Atom—The basic structural unit of each of the elements in the Periodic Table. Atoms are composed of protons, neutrons and electrons.

Bohr Model—Model of the atom proposed by Niels Bohr in 1913. It showed electrons in fixed orbits around the nucleus, but acting in some ways like waves.

Bubble Chamber—A container filled with a liquid under low pressure so that a moving, charged particle initiates "boiling" in the liquid along its path. This track of bubbles is recorded on stereophotographs.

Circular Accelerator—Scientific machine in which particles are accelerated as they travel around a circular path.

Decay—Spontaneous disintegration of a particle into other particles as in the case of a neutron decaying into a proton, an electron and a neutrino.

Electromagnetic Force— Attraction or repulsion due to the electric charge of matter.

Electron—A point-like particle with a negative charge; member of the lepton group and thus not divisible into more fundamental particles.

Electron Cloud Model—Current model of the atom in which electrons are located in regions according to rules of probability rather than in defined orbits.

Electron Volt (eV)—The amount of energy given to an electron as it is accelerated from the negative end to the positive end of a one-volt battery.

GeV—billion electron volts (10^9)

Gluon—Carrier of the strong force which binds quarks together in protons, neutrons, and other particles.

Graviton—A massless particle whose exchange between masses is thought to produce the gravitational force.

Gravity—The attraction of mass to all other mass. Gravity is the weakest known force in nature at normal energies.

Hadron—Particles made up of two or three quarks bound together by the strong force.

Ion—an atom that has acquired a net electric charge either by losing one or more electrons (positive ion) or gaining one or more extra electrons (negative ions). Ions are commonly created when an energetic charged particle passes through matter.

keV—thousand electron volts (10^3)

Lepton—An indivisible fundamental particle. There are six leptons plus their antiparticles.

Linear Accelerator—Also called a Linac, a scientific machine in which particles are accelerated in groups along a straight line path.

Macrocosm—A large system.

Meson—A particle that is typically intermediate in mass between a lepton and a proton or neutron. The commonest are the π-meson ("pion") and the K-meson ("kaon").

Microcosm—A very small system, such as an atom.

Muon—A charged lepton with a mass 105 times that of an electron. Muons "decay" spontaneously into an electron and a neutrino.

Neutrino—A lepton of very small mass and zero electric charge.

Neutron—A particle with mass slightly larger than that of the proton, but with zero electric charge; a neutron is a hadron and is made up of three quarks.

Nucleus—Positively charged central core of an atom that is responsible for almost the entire mass of an atom. It is made up of protons and neutrons.

Photon—A particle with zero rest mass that transmits the electromagnetic force. Light is made up of photons whose energy depends on the wavelength of light.

Positron—The antiparticle of an electron. It has the same mass as an electron but a positive charge.

Proton—A positively charged particle 2,000 times more massive than an electron that, with neutrons, forms all nuclear matter; a proton is a hadron and is made up of three quarks.

Quark—A fundamental particle. There are six quarks plus their antiquarks. Each quark and antiquark exists in three "colors."

Scatter—Deflect. A particle that is deflected from its original course by a collision (or near collision) with another particle is said to have been scattered.

Strong Force—Force that binds quarks and holds the nucleus of an atom together. It is the strongest force in nature.

Superconductor—A metal that when cooled below a critical temperature exhibits no electrical resistance. Twenty-five elements and many alloys and compounds have been found to be superconducting. The critical temperatures range from .002 K to 18 K (-273 °C to -255 °C).

Unified Field Theory—The single physical principle or law that would explain the link between the four known forces of nature.

Weak Force—The interaction that controls radioactive decay.

MeV—million electron volts (10^6)

TeV—trillion electron volts (10^{12})

PROCESS SKILLS

Each section of the unit lists inquiry process skills that students might use in performing the section's activities. Process categories become increasingly interrelated with corresponding development of other processes and thus form a web of interrelated skills. The following web and definitions of process skills are to assist in understanding their importance in this unit.

WEB OF INQUIRY PROCESSES

Observing: Identifying objects and object properties.

Communicating: Transmission of information to others and describing a variety of objects and changes.

Classifying: Categorizing of objects and events.

Using Numbers: Ordering and counting, using arithmetic operations and recognizing powers of ten.

Measuring: Identifying and ordering lengths, weights, speeds, and other properties.

Inferring: Drawing relationships among things observed and generalizing upon experiences.

Predicting: Simple estimates and extrapolations.

Controlling Variables: Identifying and manipulating the factors that will or will not affect the outcome of an experiment.

Defining Operationally: Defining a word or concept in terms of an operation (measurement or task) that is performable and common to all of those using it.

Interpreting Data: Simple description based on previous experiences, especially numerical data analysis.

Experimenting: Trial and error manipulation of discovery activities.

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Wilson, Robert R., "The Batavia Accelerator," *Scientific American*, February 1974, v. 230, no. 2, pp. 72-83.

<u>Teacher Resources: Audio-Visual</u>:
The following pricing and availability information is current as of October 1993.
The Atom, VHS, 36 minutes, color, 1992.
On-location searches for the secrets of the atom. Part 1: "How we found out about atoms" and Part 2: "What is an atom" take the viewer to places such as the Cavendish Laboratory, Fermilab, IBM and Oak Ridge Laboratories as well as others. Available through Hawkhill, Madison, WI ($129.00) and includes a *Powerbook* for students.

The Atom - Future Quest, VHS, 27 minutes, color, 1992.
Physicists from the world's premier center for atomic research, Fermilab, discuss the future of atomic studies. Includes discussion of basic questions in cosmology as well as spin-offs from superconductivity, supercomputers and more. Available through Hawkhill, Madison, WI ($69.00) and includes a *Powerbook*.

Creation of the Universe, VHS, 90 minutes, color, 1986.

Explains our ideas about the origin and evolution of the universe in everyday terms with interviews with Stephen Hawking and Allan Sandage, among others. Available through Friends of Fermilab at a cost of $15.00 which includes a teacher and student guidebook. Videodisc is available through the Astronomical Society of the Pacific ($49.95).

Particle Detectives, VHS, 26 minutes, color, 1987.
Explanation and tour of Fermilab with two physicists interacting with three junior high school students. Contents are divided into five 3- to 5-minute segments covering accelerators, the Rutherford Experiment and detectors as well as other concepts. Available through Friends of Fermilab at a cost of $10.00.

Powers of Ten, VHS, 21 minutes, color, 1978.
A classic. A narrated journey into space where every step propels you ten times farther outward. After reaching clusters of galaxies, you return to Earth and travel into the microscopic realm until you reach the nucleus of an atom. Available locally with a $10.00 deposit on loan from the Lederman Science Center. May be purchased from the Astronomical Society of the Pacific in video ($39.95) or Videodiscover, Inc., Seattle WA videodisc ($99.00). This video may also be available for borrowing through AVID or your local library system. University of Illinois Film and Video Center rents this video for $17.00.