Teacher's Guide

Beauty and Charm at Fermilab

An Introduction to Particle Physics

Fifth Edition

Sponsored by
Fermilab Friends for Science Education

Fermi National Accelerator Laboratory
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INTRODUCTION

Beauty and Charm at Fermilab

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

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

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

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

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

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

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

Beauty and Charm at Fermilab: The Journey Continues

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

The Three Frontiers

The Cosmic Frontier

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

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

WIMPs and Dark Matter

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

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

The goal of several experiments at the Cosmic Frontier is to observe WIMPs directly.

Dark Energy

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

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

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

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

The Energy Frontier

Collider Physics

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

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

A Simple Accelerator

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

More Powerful Accelerators

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

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

Ring-shaped Accelerators

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

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

The Intensity Frontier

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

Neutrino Physics

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

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

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

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

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

Muon Physics

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

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

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

Teaching the Unit

A Note on Philosophy

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

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

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

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

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

Circulating from station to station, observing student behavior and asking probing or redirecting questions is normal teacher behavior with these materials, as is suggesting ways to attack problems where students are struggling. Students should feel the rewards and frustrations of a scientist who is trying to describe the behavior of something through indirect evidence. Students should know that scientists read to learn what research others have already completed. 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 used in many different ways. The following are suggestions from teachers:

1. Assign sections as homework.
2. Use it in 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.
6. Use the articles as either pre- or post-field trip investigations or discussions.

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.

Beauty and Charm Scope and Sequence Teaching Chart

Investigation	#	Teaching Tips	# of Periods to Teach (based on 45-minute periods)
Video – *Fermilab: Science at Work*	19	Monday: "Time to Start Learning"	½
Journaling in Science	5	The teacher needs to decide, before the unit begins, what they are going to expect from the students in terms of written work. Teachers need to read ALL teacher background material for each investigation before you decide whether you want your students to keep a journal, lab book, take notes or complete individual lab write-ups. There should also be a decision on how these products will be evaluated so that students clearly understand these expectations. Be sure to communicate these decisions clearly to the students.	1–2
Measuring Small	1	This activity sets the "tone" for the entire unit. Seeing and being able to think about small things is essential to the success of the unit.	1
Measuring Smaller	2	Review how to use the microscope – more than parts and functions.	1–2
Cutting Paper to Protons	3	SAFETY CAUTION – Scissors Save and line up each piece.	½
Video – *Powers of Ten*	14	Plan to show the video twice. Review questions prior to viewing.	1
OB-Scertainers®	4		1

Investigation	**#**	**Teaching Tips**	**# of Periods to Teach** (based on 45-minute periods)
Visualizing Smallest	17	A large area is needed – gym, multipurpose room, outside.	½–1
Studying Things You Can't See	7	Be sure to set up the boxes ahead of class time. Have extra boxes ready for special ed, cross-categorical, gifted.	3
Video – *Fermilab: Science at Work*	19	Tuesday: *We Start with a Bottle of Hydrogen*	½
Energy Tracks – Demo	6	Bend tracks and set up ahead of class time. Run tests ahead of time to be sure your demonstration will produce the desired results.	1
Flatform Detectors	8		1
Soda Bubble Tracks – Demo	10	Liquid MUST be cold.	½
Magnet Trails	12	SAFETY CAUTION – Goggles needed.	1
Using Motion to Find What You Can't See	11	Set up boxes ahead of class time. Have extra collision/key sets available.	1
Video – *Fermilab: Science at Work*	19	Wednesday: *I Want to See Neutrino Interactions*	½
The Physics of Neutrino Oscillations	18	Choose one or more ideas from the B&C workshop.	1–2
Video – *Fermilab: Science at Work*	19	Thursday*: Emotionally Attached to Chalkboards*	½
Tracking What Happens in an Unseen Event	13	Find gooey, messy carbon paper.	1–2

Investigation	**#**	**Teaching Tips**	**# of Periods to Teach** (based on 45-minute periods)
Video – *Fermilab: Science at Work*	19	Friday: *The Most Exciting Time* Saturday: *We Are Trying to Understand the Universe*	½
Seeing Tracks in Clouds	9	Carefully observe ALL safety procedures.	1
How Does It All Fit?	15	Carefully plan research time several days ahead of activity. Have patience and encourage discussion	2
Video – Cosmic Voyage	16	Longer alternative to *Powers of Ten*.	1–2
Video – *Sense of Scale*	20	Can be used as a whole or in segments.	1
How Much Do You Really Know about Fermilab?	21	Could be a "Jeopardy"-style game or other fun intro or review activity; a good pre- or post- Fermilab field trip activity.	1
Quark Quest Newspaper	22	Good for reading assignments or homework or research.	1

Materials & Equipment List for Beauty and Charm

N.B.: Suppliers in this section are listed as examples of places materials can be found. No endorsement should be inferred.

Black: Materials in purchased B&C Kit
Red: Materials supplied by teacher

1	50-gallon storage container Rubbermaid or comparable	Target

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Investigation 1: Measuring Small

1 pkg.	Mustard seeds	Garden store
8	3” triple-view student hand lenses	Carolina Biological
8	2 oz. clear plastic cups	Target
8	6” clear plastic metric rulers	Office Max or Target
	Overhead transparency sheets for data reporting	

Investigation 2: Measuring Smaller

8	6” clear plastic metric rulers	Office Max or Target
20	2 oz. clear plastic cups	Target
8	*Paramecium caudatum* slides	Carolina Biological
8	Clear glass microscope slides	Carolina Biological
1 pkg.	Lens paper (4” × 6”), 50 count	Carolina Biological
1	Sand, 500 g	Garden store
8	Microscopes	
	Salt	
	Magnified lens paper images	Flash drive from workshop

Investigation 3: Cutting Paper to Protons

32 sheets	8½” × 11” paper
32 pairs	Scissors

Investigation 4: OB-Scertainers®

LAB-AIDS #100 OB-Scertainer® Kit	Lab-Aids

Investigation 5: Journaling in Science

Journal or logbook examples	Flash drive from workshop
Journals—small spiral or composition book	

Investigation/Demonstration 6: Energy Tracks

1	48” straight ramp	Beauty & Charm workshop
1	48” curved ramp	Beauty & Charm workshop
2	Steel ball bearings or golf balls	
2	Supports	

Investigation 7: Studying Things You Can’t See

9	Mystery boxes	Fermilab Education Office
8	#8 rubber stoppers	American Science & Surplus
1 pkg.	Steel wool	Hardware store
8	1” steel ball bearings	American Science & Surplus
8	¾” steel ball bearings	American Science & Surplus
8	½” steel ball bearings	American Science & Surplus
8	¼” steel ball bearings	American Science & Surplus
8	⅛” steel ball bearings	American Science & Surplus
16	6-oz. clear plastic party cups	Target
8	Medium strong ring magnets	Carolina Biological
8	Small directional compasses	Carolina Biological
8	Custom-cut wooden block ramps	Fermilab Education Office
8	6” grooved wooden rulers with no center holes	Fermilab Education Office
1	Scale or balance, preferably metric	
8	Small wooden blocks	
8	Large paper clips	
8	Pencils	
24	Assorted coins (pennies, dimes, quarters, etc.)	

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8	Glass marbles	
8	6” wooden rulers	
8 pieces	Strongly-flavored gum	

Investigation 8: Flatform Detectors

1	12” × 12” square of magnetic viewing film (to be cut by teacher)	Educational Innovations
1	12” × 12” thermal liquid crystal sheet (30–35 °C) (to be cut by teacher)	Educational Innovations
1	12” × 12” sheet of phosphorescent vinyl (to be cut by teacher)	Educational Innovations

2 Beakers (for warm and cold water)
Assortment of different types of magnets (bar, refrigerator, horseshoe, etc.)
Scissors
Colored pencils
Light sources (flashlights or lamps)
Assortment of small items (e.g. paper clips, bolts, coins, bottles)

Investigation 9: Seeing Tracks in Clouds

1	Cloud chamber with particle source	Flinn Scientific
1	100-mL polypropylene wash bottle with spout for isopropyl alcohol	Carolina Biological
1 pint	Isopropyl (rubbing) alcohol (90%)	Drugstore
2–3 lb.	Dry ice (per class)	Ice cream shops or grocery stores

Insulated gloves	
Plastic container (to hold cloud chamber)	Target or dollar store
Vermiculite (insulating material for dry ice)	Garden store
Intense beam light source (e.g., krypton bulb)	
Bubble chamber photos	Flash Drive
Hammer and chisel	
Strong magnets (optional)	
Wood splints (optional)	

Investigation 10: Soda Bubble Tracks Teacher Demo

Salt
Clear, carbonated beverage
Clear glass or mug

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

8	Prepared mystery boxes with magnet secured under grid
8	Wooden custom blocks with three cut slots
8	6" wooden grooved ruler
8	Sets of five steel ball bearings of various sizes
8	Clear plastic cups to hold ball bearings
8	Catcher lids or trays
8	Copies of box grids

Investigation 12: Magnet Trails

8	Plastic white or light-colored dinner plates	Party store
2 pkgs. × 20	Magnetic marbles (40 total)	Educational Innovations
40	Clear glass marbles	American Science & Surplus, Hobby Lobby
1	Container of iron filings (500 g, non-rusting)	American Science & Surplus
16	1½" metal washers	Hardware store
24	1½" wooden spools	Hobby Lobby, Michael's
2 pkgs.	Velcro circles (24)	Hardware store
8	Medium strong ring magnets	
8	Film canisters (to hold iron filings)	
	Safety goggles for each student	

Investigation 13: Tracking What Happens in an Unseen Event

8	Blank master sheets	Flash drive from workshop
8	Wooden custom blocks with three cut slots	
8	6" wooden grooved rulers	

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8	Sets of 5 steel ball bearings of various sizes	
8	Clear plastic cups to hold ball bearings	
1 ream	Unlined copy paper	
8 sheets	Messy carbon paper	
1 set	Bubble chamber photos	Flash drive from workshop

Investigation 14: *Powers of Ten*

1	*Powers of Ten* DVD or online presentation

Investigation 15: How Does It All Fit?

1 set	Puzzle piece templates
8–16	Fine point Sharpie-style markers
12 pairs	Scissors
50 sets	Velcro pieces (both sides)
1	Mounting board
32	Computers for student research (unless the research is to be done at home)

Investigation 16: *Cosmic Voyage*

1	*Cosmic Voyage* DVD

Investigation 17: Visualizing Smallest

1	#8 rubber stopper	American Science & Surplus
1	10 m string	Fermilab Education Office
1	23 m string	Fermilab Education Office
1	Pin with brightly-colored 1-mm head	Fermilab Education Office
12	BBs	Fermilab Education Office

Investigation 18: The Physics of Neutrino Oscillation

Choose one or more ideas from the Beauty & Charm workshop.

Investigation 19: *Fermilab: Science at Work*

1	*Fermilab: Science at Work* DVD	Visual Media Services

Investigation 20: *A Sense of Scale*

1	*A Sense of Scale* DVD	Visual Media Services

Investigation 21: How Much Do You Really Know about Fermilab?

1	*Fermilab: Science at Work* DVD	Visual Media Services

32	*Quark Quest*	Fermilab Education Office

Safety in the Science Classroom

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

LABORATORY RULES AND REGULATIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

14. Know how to safely exit your laboratory classroom.

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

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

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

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

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

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

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

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

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

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

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

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

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

28. Keep your laboratory area clean at all times.

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

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

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

Student Laboratory Safety Contract

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

______________________________ ____________________

Student Signature **Date**

______________________________ ____________________

Parent Signature **Date**

SECTION 1: METHODS OF SCIENCE

Introduction and Purpose

There are many ways to look at the world 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:

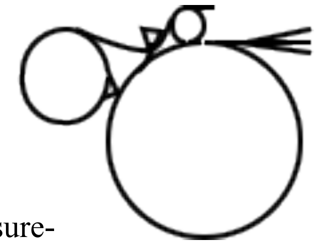
I. Understand the processes of and emulate Fermilab scientists in:
   - A. identifying problems.
   - B. setting up experiments.
   - C. collecting data in systematic ways.
   - D. drawing conclusions and identifying patterns when present.
   - E. explaining and reporting results.
   - F. studying matter.

II. Generalize that the smaller the size of the object, the more precise an instrument is needed to measure it.

It is strongly recommended that the teacher do the following before teaching this unit:

- Review the metric system with students.
- Review laboratory safety and laboratory procedures with students.
- Review the microscope—its parts and functions—with students.
- Clarify how to take good, useful lab notes during a lab.

Investigation 1: Measuring Small



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

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

Illinois State Standards:
11.A.3c, 11.A.3d, 11.A.3e, 11.A.3f, 11.A3g, 13.A.3a

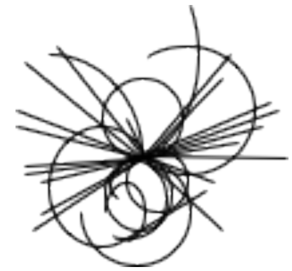
Materials:
Student Investigation Sheet - Measuring Small
Clear metric rulers
Mustard seeds
Hand lenses
Overhead transparency tables

Procedure:
1. Divide the class into seven or eight groups.
2. Distribute the clear plastic 15 cm rulers to students.
3. Have each group determine the size of a mustard seed.
   Note: If students are showing signs of difficulty, suggest that they place the seeds in a straight line and determine how many make 1 cm, and then divide to find the average size of a single seed.
4. Review measuring techniques and the scale used on their rulers. Tell students that they are to take 5-10 minutes to find the smallest measurable object in the room and measure it.
   Note: It is possible to measure to 0.05 cm (0.5 mm) on a ruler with 0.10 cm (1 mm) smallest subdivisions and to estimate to 0.01 cm (0.1 mm). If students have spent 2–3 minutes at this task and have not asked for magnifying tools, suggest that they use something to help "see" these small particles. Distribute hand lenses.
5. As students work on this task, move around the room to assist and encourage "thinking small."
6. After students have completed the task, form larger teams. Tell students that they are in data-sharing teams. Their task is to describe their smallest measurable particle, how it was measured, and what size it was. Teams should determine the smallest object measured by their data-sharing team. You may want to place these results on an overhead table to facilitate later discussion.

7. Have the students discuss their ideas of what measurement is. Have the students discuss why it might have been hard to use the ruler and why some of them estimated their measurements. Have the groups then discuss these ideas as a class.

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

Student Sheet
Investigation 1: Measuring Small



Name_________________________

Date__________________________

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

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

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

2. Measure a mustard seed. Record your data.

   ____

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

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

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

   ____

6. Describe the smallest object you selected to measure.

7. Why did you choose this object?

8. Record the measurements of your object:

   Length_________________ Width_________________ Height________________

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

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

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

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

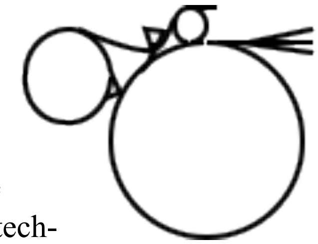
    Length_________________ Width_________________ Height________________

Conclusions:

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

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

Investigation 2: Measuring Smaller



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:
1. Students will use a microscope to measure an object 1/1000th of a centimeter in size. (It is preferable to have microscopes with at least 4X and 10X objectives.)
2. Students will work cooperatively in teams to gather data.
3. Students will simulate the process of measuring subatomic particles.

Illinois State Standards:
11.A.3a, 11A.3b, 11.A.3c, 11.A.3d, 11.A.3e, 11.A.3f, 11.A3g, 13.A.3a

Materials:
Student Investigation Sheet - Measuring Smaller
Clear metric ruler
Microscope
Clear glass slides
Paramecium slide
Small plastic cups
Sand and salt
Lens paper (cut into small squares)
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 of both the scanning and low power in a microscope. Students will need to rotate the scanning and low-power objectives into position. Students should place a clear, thin, plastic centimeter ruler on the stage under the objective. Have the students focus the *scanning and 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 scanning and 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 1 mm!)

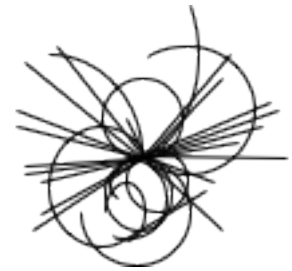
   A 40X magnification produces a field approximately 4 mm wide. A 100X magnification produces a field approximately 1.8–2.0 mm wide.
6. Using the low-power objective, have students measure the length of a paramecium, the width of a grain of sand and a salt crystal, and the width of a human hair. Finally, have them draw a sketch of a piece of lens paper as it appears under low power. **This sketch needs to be VERY accurate.**
7. If time allows, have students share their measurements by creating a class data table and discussing how they determined their 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 enlargement.

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.
10. 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 2: Measuring Smaller



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.

Materials:
Student Investigation Sheet - Measuring Smaller
Clear metric ruler
Microscope
Clear glass slides
Cover slips
Paramecium slide
Small plastic cups
Sand and salt
Lens paper
Set of magnified lens paper images

Procedure: You will be working with either a partner or in a group during this activity.

1. Take the clear metric ruler at your work station.

2. Place the clear plastic ruler on the stage of the microscope under the scanning power objective. Use your coarse and fine adjustment knobs to focus in on the marks on the ruler. Measure the diameter of the field of the microscope by:
   a. Placing 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.)
   b. Counting the number of bold marks you see, remembering that 1 mm is the distance between two marks.

3. What is the diameter of the field under scanning power?

4. Repeat steps 1 and 2 to determine the field diameter under low power.

5. What is the diameter of the field under low power?

6. Obtain a prepared slide of a paramecium from your work station. Measure the length of the paramecium under low power and record its length here.

7. Take a salt crystal and place it on a glass microscope slide. Place the slide on the stage of the microscope under low power. Record the width of the salt crystal here.

8. Take a grain of sand and place it on a glass microscope slide. Place the slide on the stage of the microscope under low power. Record the width of the grain of sand here.

9. Take a strand of hair from your head and mount it on a microscope slide using a cover slip. Measure the width of the hair under low power and record the width of the hair strand here.

10. Place a small square of lens paper on a glass slide and cover it with a cover slip. Place the slide under the low-power objective and focus in on the lens paper. Make a drawing below of the lens paper as you see it under low power.

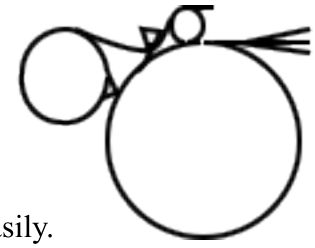
11. Look at the lens paper in the microscope. What percent of the lens paper would you estimate to be empty space?

Conclusions:

1. Use the observations your lab team made while doing this investigation to make a conclusion (claim) about measuring objects. Support your claim with sound reasoning.

2. 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.

Illinois State Standards:
12.C.3b, 13.A.3a

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. (SAFELY) Suggest to students to keep track the number of cuts they make by using tally marks. [Do not throw away the other half of each cut; instead line them up as you cut as a visual.]
4. When the students are done cutting, have them observe the smallest-size remaining piece of paper. Discuss how many cuts it took each student to reach their smallest piece.
5. Have students estimate how many cuts would be necessary to reach the size of an atom. Then have them estimate how many cuts would be necessary to reach the size of a proton.
6. Explain that about 60* cuts would reduce the paper to the size of an atom, and about 30* more cuts (for a total of 90*) 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.)

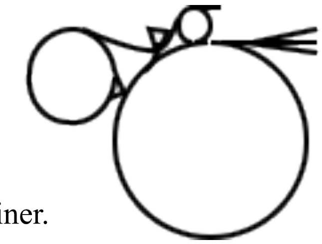
*Calculations indicate that the actual numbers would be 63 cuts to reduce paper to the size of an atom, and 31 more (for a total of 94) to get it to the size of a proton. Decide for yourself what level of detail the discussion warrants.

7. For discussion, pose these questions to your students: (This could be a valuable writing assignment for homework.)
    - 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: OB-Scertainers®



Purpose:
Scientists use indirect observations to make hypotheses (claims) 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.

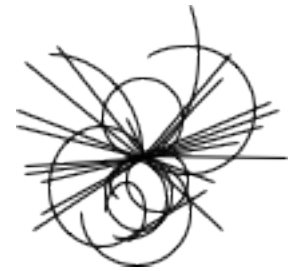
Objectives:
1. Students will use indirect observations to draw conclusions about the shape and configuration of the inside of the OB-Scertainer® Kits.
2. Students will report their conclusions in the form of drawings.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A3g, 13.A.3a

Materials:
LAB-AIDS #100 OB-Scertainer® Kit (contains 24 OB-Scertainers®)
Student Investigation Sheets - "OB-Scertainers®"
Pencils

Procedure:
1. Explain that this is an investigation on indirect observation. The closed OB-Scertainers® have partitions inside and a steel ball bearing that can move freely around on the inside. The students are to determine the shape of the partition(s) in 4 of the OB-Scertainers® 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 OB-Scertainers® (1 per student). Tell the students to move the steel ball bearing by carefully shaking and tilting the OB-Scertainer®. By listening to the sound and "feeling" the path of the steel ball bearing, they can determine the shape and location of the partition(s). Some of the OB-Scertainers® are more difficult than others; the students should make careful observations. Have them indicate the number of the OB-Scertainer® 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 OB-Scertainers® with a student near them. **Do not allow the students to open any OB-Scertainers® until so instructed**. Students should study at least four different containers.
5. Once every student has completed drawings for at least four OB-Scertainers®, 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: OB-Scertainers®



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.

Materials:
LAB-AIDS #100 OB-Scertainer® Kit (contains 24 OB-Scertainers®)
Student Investigation Sheets - "OB-Scertainers®"
Pencils

Procedure:
1. Your teacher will pass out the closed containers called OB-Scertainers®. You may not open them. These containers have a steel ball bearing 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 OB-Scertainer® without opening the container.
3. You may move the steel ball bearing around by carefully shaking and tilting the OB-Scertainer®.
4. Using your senses, determine the shape and location of the partition(s).
5. Record the number of the OB-Scertainer® in an indicated blank, and then sketch your hypothesis in the left-hand ("Hypothesis") circle under the OB-Scertainer® 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 OB-Scertainer® until so instructed by your teacher.**
7. Do at least four OB-Scertainers®. Switch containers with other students when so instructed by your teacher. Although some OB-Scertainers® are more difficult than others, you should not spend more than five minutes with each OB-Scertainer®.

DO NOT OPEN THE OB-SCERTAINER® UNTIL YOUR TEACHER TELLS YOU TO!

HYPOTHESIS RETEST ACTUAL

OB-Scertainer® #_______

OB-Scertainer® #_______

OB-Scertainer® #_______

OB-Scertainer® #_______

OB-Scertainer® #_______

Conclusions:

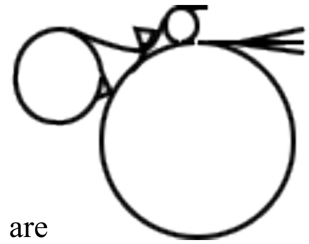
1. What difficulties did you have doing this investigation?

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 OB-SCERTAINER® KIT instructions and guide.

Investigation 5: 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:
1. Students will journal their ideas, questions, drawings, reflections, etc., throughout the unit.
2. Students will reflect on their journals and formulate questions to ask the scientist on their Fermilab visit.

Illinois State Standards:
11.A.3c, 11.A.3f, 11.A.3g

Materials:
Journal or logbook examples (See logbook examples folder in the Diagrams and Pictures folder on the Resource flash drive.)
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. 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 or engineer.

    Note: The scientists or engineers 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 or engineers 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 or engineers 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 or engineer has donated time to be available. The scientists and engineers 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 or engineer’s name somewhere easy to find so that students can ask them questions later in the unit or in the year.
7. Journaling can be accomplished in a variety of ways. The flash drive has a resource folder titled “Articles on Reading and Writing in Science Journaling.”

SECTION 2: ACCELERATORS

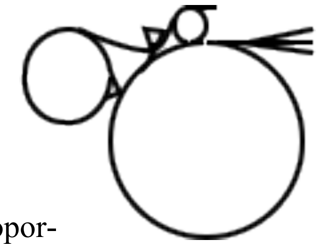
Introduction and Purpose:
Early in the study of physics and astronomy, scientists realized that two distinct kinds of motion existed. One kind of motion was steady. Objects that moved in this way covered the same distance every second (or minute, or hour, etc.). These objects today are said to move with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

A second kind of motion is *acceleration*, which proved to be more difficult to understand. A lack of precise clocks made calculating this quantity more difficult since accurate timing was harder to achieve. 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 6: Energy Tracks



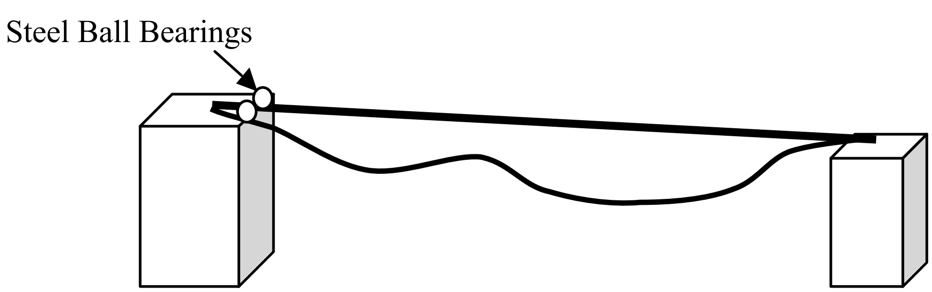
Purpose:
This demonstration will help students become familiar with the difference between speed and acceleration. It will also help students understand that an increase or decrease in acceleration results in a directly proportional increase or decrease in energy.

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 how changes in acceleration result in changes in the amount of energy the marbles (particles) possess.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 11.B.3c, 11.B.3d, 11.B.3e, 12.D.3a, 12.D.3b, 13.A.3a

Materials:
2 ramps – 1 straight and 1 pre-bent with curves
2 steel ball bearings
2 supports – See diagram.

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 ball bearings on the both tracks will roll. For the most effective demonstration, keep the ramps as close to even as possible.



2. Explain that the tracks are the same length (just not the same shape). The teacher will release the ball bearings so that they will start rolling from the top of each ramp at the same time.
3. **Have the students write down their prediction as to which ball bearing will win the race and why.**
4. 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. 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 bearing that runs along the bent track will "win" easily.

   Note: The ball bearing on the bent track winning can be explained using two common middle school science concepts: potential and kinetic energy. At the beginning of the experiment the ball bearings are at rest and have equal amounts of potential energy. Once the ball bearings are released, the ball bearing on the bent track loses potential energy and thus gains kinetic energy more quickly than the ball bearing on the straight track; this is due to the Law of Conservation of Energy. Since the ball bearing on the bent track has more kinetic energy, it's moving faster, and will therefore get to the end of the track before the ball bearing on the straight track. Also point out to students that because of the steeper slope at the beginning of the bent track, the ball bearing on it accelerates faster and so travels at a greater speed for the entire race. (Think about the changes in acceleration on a roller coaster.)

6. Verify the data by replicating the experiment 5 to 10 times. Discuss the results. Look for any discrepant events in the data. Accept any student skepticism or questions and help students understand that real scientists often have to explain unexpected results in data.
7. Close with a class discussion about acceleration and energy. Encourage students to describe their observations and thoughts in their journals.

SECTION 3: SEEING THE UNSEEN

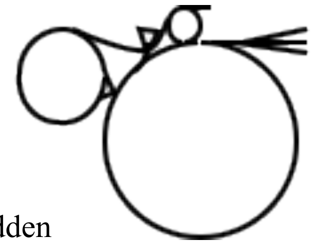
Introduction and Purpose:
Scientists often investigate objects so small that they cannot use direct methods of observation. Instead they must rely on indirect evidence to make inferences about the data that has been gathered. At Fermilab, "particle probes" (see next paragraph) may miss a target object, be deflected by it or have a high-energy collision with the object. Whether the particles hit or miss, tell-tale tracks or other data 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 and other evidence left by moving objects to model how Fermilab physicists use electronically recorded data and how they 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. manipulate special tools called detectors to observe particles indirectly.
   c. analyze patterns to make inferences.

Investigation 7: Studying Things You Can't See



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

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

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.D.3a, 12.D.3b, 13.A.3a

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

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

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

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

Procedure:

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

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

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

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

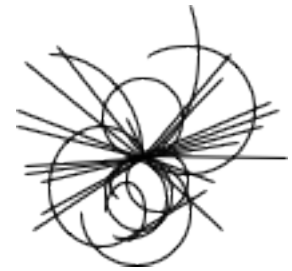
5. Have the students investigate the boxes for a full class period. Collect the boxes. During the next class period, be sure each team receives the same box. Have each team review the data they collected for five minutes. Then collect the boxes. Discuss as a class what they think is in the boxes. Students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

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

   - *Instead of a box with several items for each team, set up boxes with one item in each box and have the teams swap boxes until each team has examined four.*

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

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



Name_________________________

Date__________________________

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

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

Procedure:
1. You may use any nonviolent, nonintrusive way you can think of to investigate the mystery box to determine what the objects are inside.
2. Obtain a mystery box from your teacher.
3. Place the ID letter on your box on the line at the top of your data chart.
4. Read carefully through the column descriptions to see what you are going to do. Your teacher will be giving you specific examples of things you might write in each column. Listen very carefully to these statements.
5. Remember that the purpose of the chart is to record indirect evidence – NOT TO GUESS THE IDENTITY OF THE ITEMS. That will happen later in the activity.
6. Here are some ideas for things you might try to help you discover what is in the box. YOU MAY NOT OPEN THE BOX FOR ANY REASON.
   - Probe the box with your senses. Use your fingers, hands, nose, eyes and ears. DO NOT TASTE ANYTHING.
   - Use a magnet. You may have to ask for this tool from your teacher.
   - Use a directional compass. You may have to ask for this tool from your teacher.
   - Find the mass of the box. You may have to ask your teacher for a balance and an empty box.
7. Can you think of any other ways to try to find what's in the box? List them.

   Note: Check with your teacher before you try them.

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

Box ID ________________

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

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

Conclusions:

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

One item in the box is a/an:____________________

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

The evidence that supports this conclusion is:

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

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

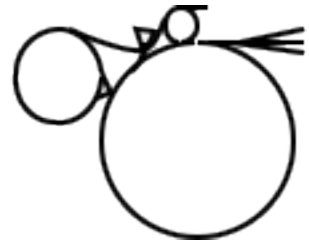
3. What other equipment or tools might have helped you guess what was in your mystery box?

4. Describe indirect observation in your own words.

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

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

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



Investigation 8: Flatform 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:
1. Through investigation, students will explore different detectors used by scientists.
2. Students will learn that different detectors are not equally suited for any particular job.
3. 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.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.C.3a, 13.A.3a

Materials:
Investigation 10A:
- An assortment of different types of magnets (bar, disc, refrigerator, etc.)
- Magnetic viewing film
- Scissors
- Student Investigation Sheet for Magnet Detector
- Colored pencils

Investigation 10B:
- Thermal film (liquid crystal sheets), 2 sheets (same temperature range; 30–35 °C is a suggestion.)
- 2 beakers for hot and cold water (same size)
- Timing device
- Student Investigation Sheet for Thermal Detector

Investigation 10C:
- Shadow wall squares (phosphorescent vinyl)
- Light sources (flashlights and/or lamps)
- An assortment of small items (i.e., paper clips, screws, bolts, coins, bottles, etc.)
- Student Investigation Sheet for Light Detector

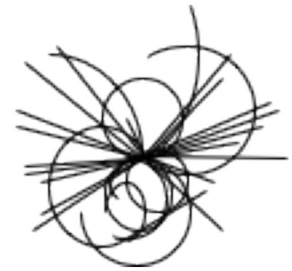
Procedure:

1. Divide the class into research teams of three or four.
2. Provide the needed materials at student work stations.
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.

Conclusions:

1. What sorts of things could you “see” with detectors that you couldn’t see with your eyes?
2. Can you think of other detectors from your everyday life that allow you to “see” things you normally can’t?
3. Will all detectors work equally well in all instances? Explain which detectors are best for each job.
4. Do detectors increase your ability to understand the natural world? Cite specific examples that you discovered in this investigation.

Investigation 8A
Magnetic Detectors Student Sheet



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.

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

Procedure:
1. Place a magnet under the magnetic viewing film. Observe the magnetization pattern and sketch it in the space below.

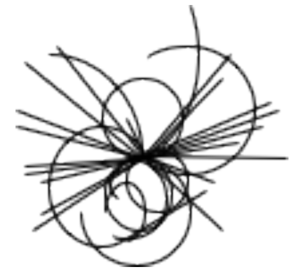
2. Using the magnetic viewing film, repeat this step for each magnet. Draw your sketches below.

3. Predict 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. Sketch the pattern you see and compare it to the sketch in question 3. How accurate was your prediction?

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

Investigation 8B
Thermal Detectors Student Sheet



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.

Materials: Kit 2
Thermal film (liquid crystal sheets) 2 sheets (same temperature range; 30–35 °C is a suggestion.)
2 beakers for hot and cold water (same size)
Timing device
Student Investigation Sheet for Thermal Detector

Procedure:

1. Fill one beaker with hot water and the other with cold water. Holding by the edge, place a piece of thermal film on top of each beaker and record the color(s) seen on the thermal film.

   Hot water ______________ Cold water_____________

2. Place a piece of thermal film on the inside of your forearm. Observe the results. Describe or draw them using colored pencils.

3. 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_______________

4. 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 place it on a tabletop or desktop.

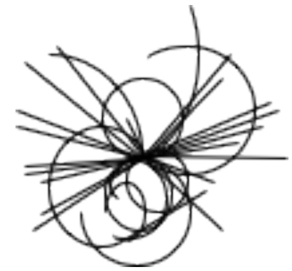
   Time to cool_______________

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

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

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

Investigation 8C
Light Detectors Student Sheet



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.

Materials: Kit 3
Shadow wall squares (phosphorescent vinyl)
Light sources (flashlights and lamps)
An assortment of small items (i.e., paper clips, screws, bolts, coins, bottles, etc.)
Student Investigation Sheet for Light Detector

Procedure:
1. Hold the shadow wall square in front of a flashlight. What happens?

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

3. 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.

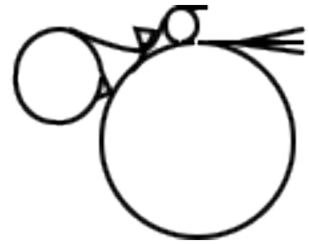
4 The other team members will then try to identify the mystery object from the shadow the object leaves behind. Were they able to? What was the object?

5. 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.

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

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

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



Investigation 9: 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:
1. Using a cloud chamber, students will observe the fresh tracks of subatomic particles emitted by a radioactive source.
2. Students will attempt to observe two different types of particle tracks and compare these to photos of bubble chamber tracks.
3. Students will experience the excitement of observing firsthand the indirect evidence of subatomic particle events as they happen.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.C.3a, 12.C.3b, 13.A.3a

Materials	Teaching Notes
1 cloud chamber	If done as a teacher demonstration
6–8 cloud chambers	If done in student groups
Particle source	A source for alpha and beta radiation (original Fiestaware, yellowcake, etc.)
1 100-mL wash bottle	Used to apply alcohol to black felt in cloud chamber
1 pint 90% isopropanol (rubbing alcohol)	Cooled by dry ice and creates “cloud” in cloud chamber
Dry ice (2–3 lbs. per class)	Possible sources include ice cream shops, grocery stores and also refrigeration companies
Intense light source (1 per group)	Krypton bulb (or similar)
Container with vermiculite (1 per group)	Holds and insulates dry ice
Vermiculite (1 large bag)	Available at garden stores
Bubble chamber photos	Flash drive from workshop
Hammer and chisel	Used to cut dry ice

Materials	Teaching Notes
Insulated gloves	Used to handle dry ice
Student investigation sheets	Flash drive from workshop
Safety goggles	
Strong magnets	Optional

ADDITIONAL DRY ICE INSTRUCTIONS

- Always use insulated gloves when handling the dry ice.
- If the dry ice is purchased the night before, use you may loose up to one-half of it.
- Store the dry ice by wrapping it tightly in several layers of newspaper and placing it in a cheap styrofoam cooler.
- The dry ice needs to be prepared ahead of time into 4” X 4” blocks and placed into the vermiculite. First, score the dry ice block into the sized blocks you want to cut. Then chisel the block into pieces. If at all possible, cover the dry ice blocks between classes to reduce sublimation.
- Dispose of the remaining dry ice carefully at the end of the day. Do not put dry ice down a sink. The best disposal method is to allow it to sublimate into the atmosphere. Be sure the leftover ice can not be accessed by students while it is sublimating.
- You will probably want to purchase the dry ice the evening before you use it; HOWEVER, you will lose up to 50% overnight due to sublimation, so plan for that loss. Wrap it in several layers of newspaper and store in a styrofoam cooler.)
- You will need approximately 10 lbs. of dry ice for up to six classes if it is going to last all day.

DO NOT ALLOW STUDENTS TO TOUCH OR PLACE ANYTHING ON THE DRY ICE.

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 must be saturated with alcohol vapor; that is accomplished by soaking the felt in the chamber with alcohol from the wash bottle. Gently blot the felt on a cloth or paper towel to remove excess alcohol. Next, place the particle source in the bottom of the cloud chamber, cover it and set on top of the dry ice. It will take about a minute for the alcohol to cool and condense into the vapor cloud inside the chamber.

As the particle emits radiation, the charged ions leave particle trails throughout the vapor in the chamber. To see the particle trails, hold the flashlight on the side of the cloud chamber shining straight into the vapor. HOWEVER, look down from above the chamber to actually see the trails.

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. 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.

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. ***This is very important, as it is necessary for the cloud chambers to dry out in order to work effectively for the next class.***

Procedure:

1. Divide the class into teams based on the number of cloud chambers or teacher demonstration.
2. Discuss the safety aspects of this lab.
3. Discuss the background information on how cloud chambers make it possible to see radioactive particle trails. (See note above.)
4. Provide the student teams with cloud chamber materials.
5. Explain the steps for setting up the cloud chamber.
6. Saturate the felt (blotter) band on the inside of the cloud chamber with alcohol.
7. Oversee the students as they set up their cloud chambers.
   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.

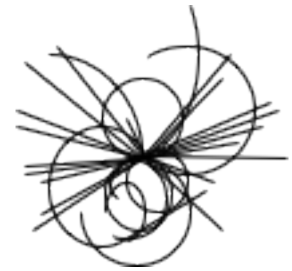
8. View the particle tracks by shining a strong light through the side of the chamber, or from above, onto the black surface of the chamber. (Try both approaches and choose the best effect.) Any strong beam will work as a light source. A powerful flashlight will work best. Students should identify and describe as many kinds of particles as possible.

   Note: 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.

9. Summarize the lab by doing the following:
   a. Discuss the characteristics of the types of particles the students saw.
   b. Show bubble chamber photographs after the students have completed the cloud chamber portion of the investigation. If time allows discuss the differences in the trails on the photographs.

Student Sheet
Investigation 9: 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 radioactive source, just as physicists did.

Materials:
1 cloud chamber
1 particle source
100-mL wash bottle for applying the alcohol to the cloud chamber felt
1 pint 90% isopropanol (rubbing alcohol)
Dry ice
Intense light source
Container with vermiculite (to hold and insulate dry ice) 1 per group
1 set of bubble chamber photos
Insulated gloves
Student Investigation Sheets—"Seeing Tracks in Clouds"
Optional Materials: Strong magnets, wood splints

Procedure:
1. Set up your cloud chamber as directed by the teacher. **DO NOT TOUCH THE DRY ICE OR SET ANYTHING ON TOP OF IT**. 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. Describe the characteristics of the different types of particle tracks you see.

4. 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.

5. 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?

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

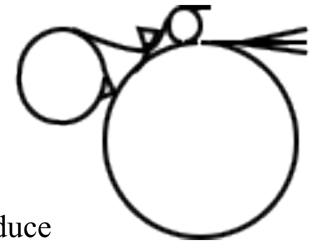
7. Why is seeing the tracks of invisible particles useful? Why would it be especially useful to scientists at Fermilab?

8. What is the purpose of the dry ice?

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

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

Investigation 10: 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.

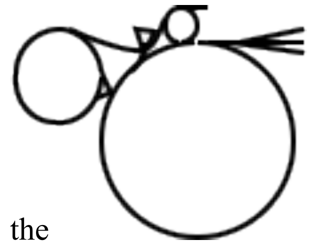
Objective:
Students will observe the particle trails created by salt particles falling through a clear, cold, carbonated beverage.

Illinois State Standards:
11.A.3a, 13.A.3a, 13.B.3b

Materials:
Salt
Clear, cold, carbonated beverage
Clear glass or mug

Procedure:
1. Gather the class around your demonstration table.
2. Fill a transparent glass with a clear, cold, carbonated beverage such as club soda, 7 UP, or sparkling water. Let the liquid settle until no carbonation bubbles are rising to the surface. Then slowly drop a few grains of salt into the liquid in the glass. (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” that you have seen in everyday life, 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 11: Using Motion to Find What You Can't See



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

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

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.C.3a, 12.D.3a, 12.D.3b, 13.A.3a

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

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

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

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

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

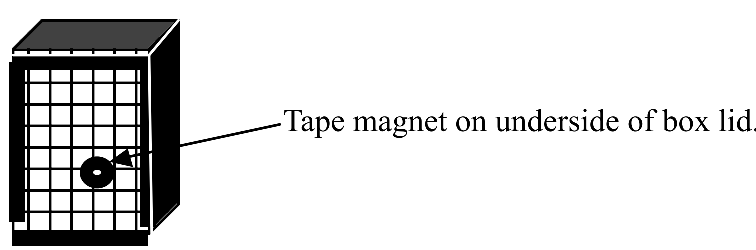
Most protons in the Fermilab accelerator beam pass by target particles or are deflected in a way similar to the ball bearing and magnet. The chief difference is that the proton is repelled, while the steel ball bearing is always attracted.

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

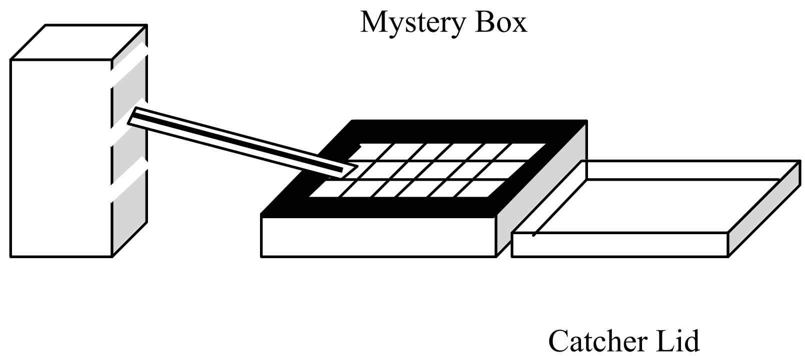
Even though the probe and target in this investigation will not create new particles, we can observe the before-and-after motion of the ball bearings. This is essentially what physicists do in analyzing particle events at Fermilab: they analyze the mass, speed, and change of direction of particles before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

Procedure:

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

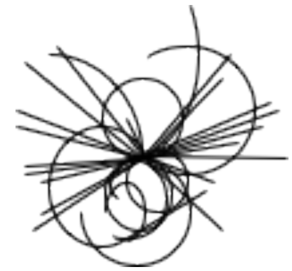


2. Divide the class into teams and pass out the equipment. Demonstrate the setup of the ramp block and ramp. (See diagram.) The ramp needs to be inserted into the middle slot. The ramp tip must always be located on the black margin of the grid. Control as many variables as possible here, i.e., who releases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



3. Discuss how students will record data on their grid paper. Students should run their first 30 trials covering each of the perimeter edge boxes (the four sides) of the grid sheet. After each trial, students should mark the trial results on their data sheet with a colored pencil. After the first 30 trials, students should begin to have a much better idea as to where the hidden object is and then they can concentrate additional trials in that area of the grid. Every trial result needs to be added to the data sheet. As this happens, a picture of the location, size and shape of the hidden magnet should begin to appear.
4. Have the students collect data by launching the ball bearing and record it on the grid paper. **<u>They should run at least 100-150 trials.</u>**
5. Students should use a colored pencil to outline what they think is the final size, shape and location of the hidden magnet on the data grid sheet.
6. After getting permission from the teacher, students should open the box carefully. Then the student should accurately identify where the magnet was located. Using a different colored pencil, the student should draw the EXACT size, shape and location of the magnet on the data grid.
7. Have students complete the answers to the questions. Then they can share their results and the answers to the questions on their sheet in a class discussion. Emphasize everyday situations in which people investigate things they can't see, and analogies between this investigation and the work of Fermilab. (e.g., Fermilab scientists are constantly "launching" protons at things they can't see in order to find out more about them.)

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



Name________________________

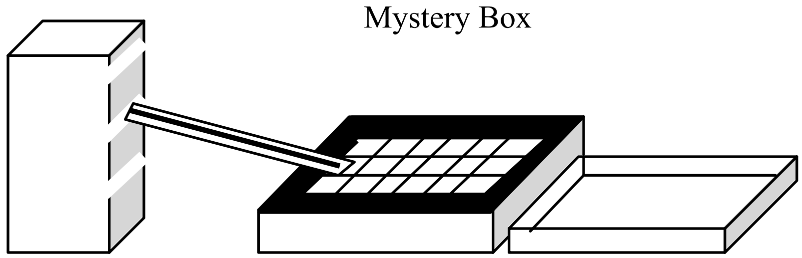
Date_________________________

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

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

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

Mystery Box



Catcher Lid

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

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

small   medium   large   extra-large

... ball bearing probe because ...

4. Place the ramp in the middle slot of the ramp block and position the front edge of the ramp on the black border of the grid system in front of a row of boxes.
5. Label the four sides of the grid system on top of the box A, B, C, and D.
6. Orient your copy of the grid sheet to the box top grid by writing the letters A, B, C, and D in the same location as on your mystery box.
7. Use your selected ball bearing probe to systematically search for the object.
   a. Start by lining up the ramp with a row of boxes on side A of the grid and rolling the ball bearing probe down (from the top of the ramp!).
   b. Observe the ball bearing probe closely as it rolls across the grid.
   c. On your grid paper, sketch a line using a colored pencil to show how the ball bearing probe traveled across the grid.
   d. Move the ramp to the next row of boxes and repeat. Run trials row by row across all of side A, then do the same for sides B, C, and D. Record each trial result you run on the data grid.
8. After finishing step 7, you will have run 30 trials; nine on each long side and six on each short side. You might not know exactly where or what shape the object is yet, but you should have a good idea of what part of the box you want to continue investigating.
9. Continue releasing your ball bearing probe and sketching its trails. ***You should run between 100 and 150 trials.*** You can release the ball bearing probe from any location on the perimeter of the box (remember that the end of the ramp needs to be within the black border and you must release the ball bearing probe from the top of the ramp) as often as necessary. If you run enough trials you should develop an excellent idea of the size, shape and location of the object. Use small spacing between trials. You might try to run trials at different angles. Remember to keep end of the ramp on the black border for every trial.

Conclusions:

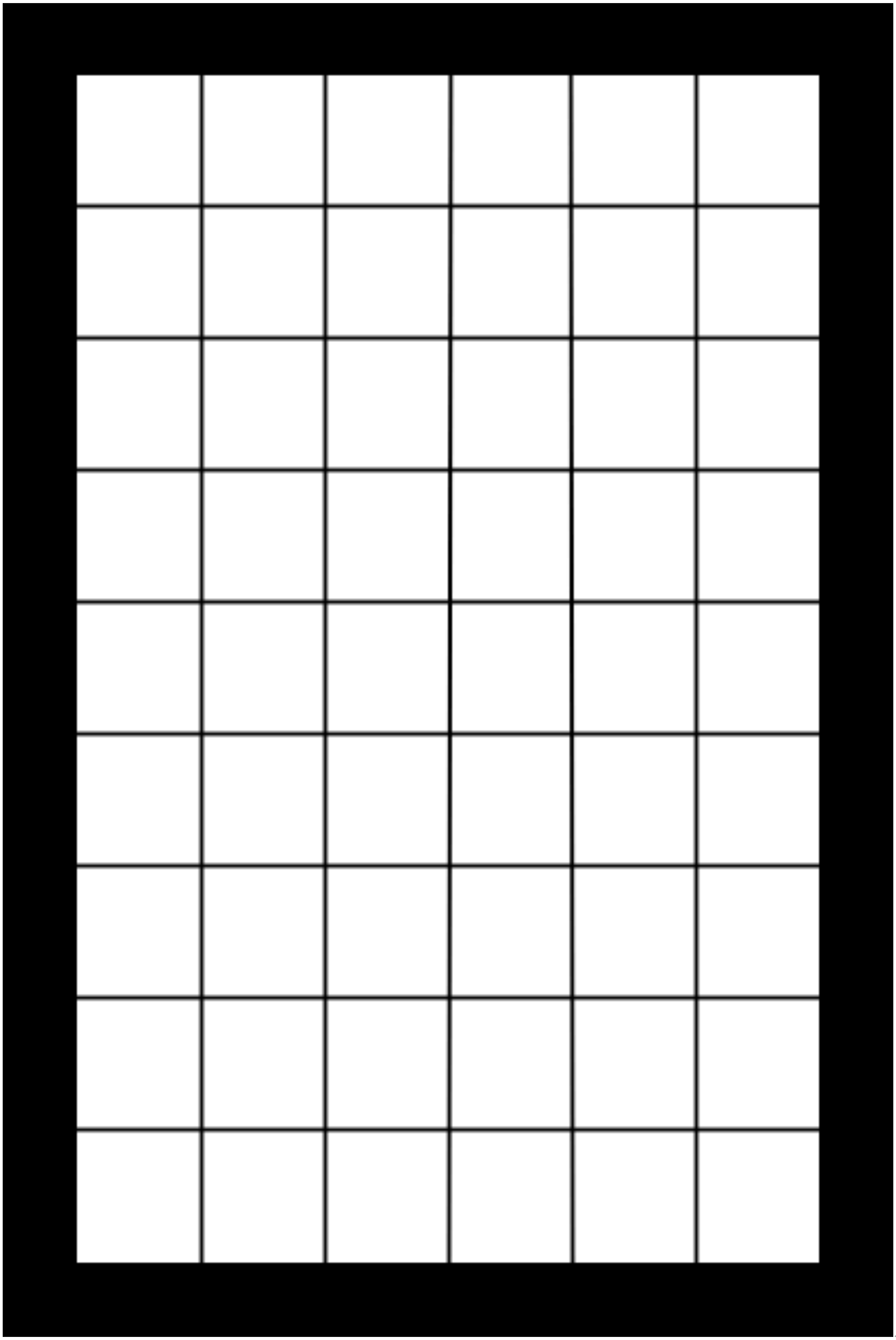
1. How do you explain curved trails?

2. How do you explain straight trails?

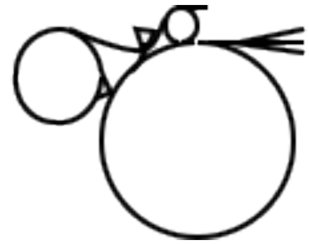
3. What effects do you think changing the ramp height would have on your results?

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

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



Investigation 12: 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.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.C.3a, 12.D.3a, 12.D.3b, 13.A.3a

Objective:
Students will explore a method of indirect observation.

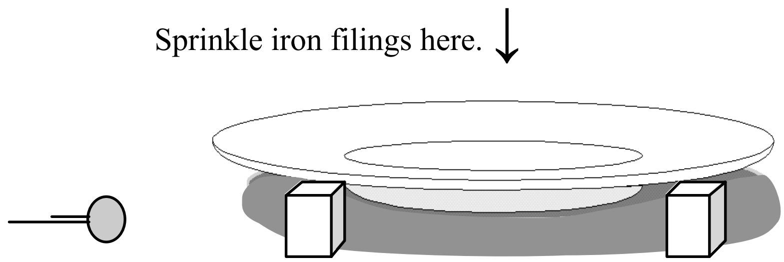
Materials:
Each lab group should get the following:
1 plastic dinner plate (light color)
Velcro
3 or 4 small blocks of wood or spools
4 magnetic marbles
2 glass marbles
1 ring magnet
2 large washers
1 small container such as a film canister filled with iron filings

> *Safety Note: Students should always wear their goggles during this lab. Iron filings can damage the eyes, nose and ears and even irritate fingertips and skin. The teacher could consider having all students wear plastic gloves. However, the minimum safety precaution here should be to have all students thoroughly wash their hands before leaving the lab.*

Goggles for each team member

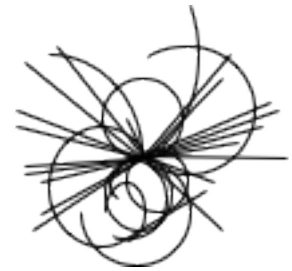
Procedure:
1. Discuss with students how people learn about their world. In the discussion, incorporate examples of how all of our senses help us understand our world.
2. Ask how a person can extend the use of the five senses. Examples might include glasses, hearing aids, televisions, or computers.
3. 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 two students each.

5. Give each team the equipment listed above. Have students attach the spools or blocks to the plates with the Velcro.



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 looks way while the other partner arranges magnets, washers or marbles under the plate. This student should draw the arrangement they have made and turn it face down.
9. Now the student who has been waiting turns around and begins rolling marbles under the plate to try to discover what items are under the plate and how they were arranged. This student should also make a sketch of what is under the plate. This student should be ready to defend their prediction.
10. Now both students should share their sketches with each other and discuss the similarities and differences between them.
11. As the students experiment and make observations, move around the class and help them form clear inferences (right or wrong) about the experimental setup.
12. 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.
13. 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's 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 kind of detectors does Fermilab use? (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 12: 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.

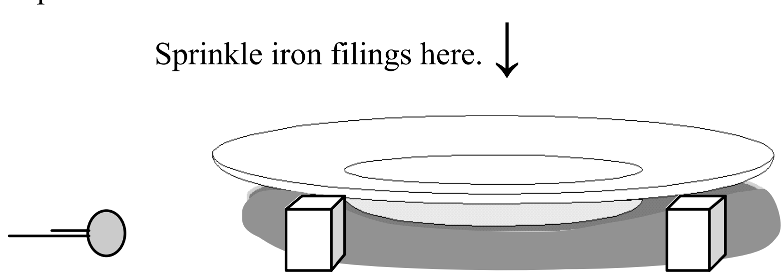
Materials:
Each lab group should get the following:
1 plastic dinner plate (light color)
Velcro
3 or 4 small blocks of wood or spools
4 magnetic marbles
2 glass marbles
1 ring magnet
2 large washers
1 small container such as a film canister filled with iron filings

> *Safety Note: Students should always wear their goggles during this lab. Iron filings can damage the eyes, nose and ears and even irritate fingertips and skin. The teacher could consider having all students wear plastic gloves. However, the minimum safety precaution here should be to have all students thoroughly wash their hands before leaving the lab.*

Goggles for each team member

Procedure – Part A:
1. Set up the experiment by attaching the wooden blocks or spools to the plastic plate with the pieces of Velcro.

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.



3. Roll a glass marble under the plate as shown and record your observations below.

4. Next, roll a magnetic marble under the plate. Watch the behavior of the iron filings and record your observations below.

Conclusions:

1. Describe what you see when you roll a glass marble under the plate. What do the iron filings look like when you place a ring magnet under the plate?

2. Describe and draw what you see when a magnetic marble rolls under the plate.

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

Procedure – Part B:

Ask your partner to arrange some combination of donut magnet, steel washer, magnetic marbles and regular marbles under the plate while you look away; then make a sketch of the arrangement (on the back of this sheet). 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.

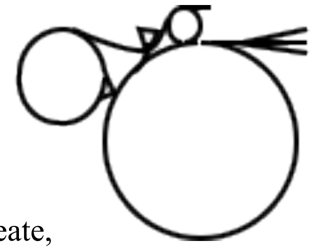
1. Draw a picture in the space below of the objects you believe are under the plate and how you believe they are arranged. Label all of the objects.

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

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

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

Investigation 13: Tracking What Happens in an Unseen Event



Purpose:
Particle tracks give physicists indirect evidence about the particles involved in high-energy collisions. In this investigation, students will create, 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 design and create and then analyze and identify tracks made by moving objects from an unseen collision using the Master Sheet.

Illinois State Standards:
11.A.3a, 11.A.3b, 11.A.3c, 11.A.3d, 11.A.3f, 11.A.3g, 12.D.3a, 12.D.3b, 13.A.3a

Materials:
Each group should get the following:
1 blank Master Sheet (one copy provided in guidebook)
1 ramp (6" wood, grooved ruler)
1 ramp block
1 sheet of unlined paper (school supply)
1 sheet of carbon paper (The softer and messier the carbon paper, the better.)
4 ball bearings - sizes from extra large to small (Use all ball bearings in the kit except the BB-sized ones.)
1 set of bubble chamber photographs
Student Investigation Sheets - "Tracking What Happens in an Unseen Event"

Procedure:
1. Demonstrate how the ramp block setup can be used to form an 8 cm "high ramp" or a 4 cm "low ramp" depending on which groove of the ramp block is used with the ruler.
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. Lightly 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 ball bearings 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 bearing tracks the same size as the low ramp, extra-large ball bearing tracks? How are they different? What about the high ramp, extra-large ball bearing tracks and the high ramp, small ball bearing tracks? Encourage students to differentiate tracks in as many ways as they can. (i.e., darkness of the mark, distance between the marks, etc.)

   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, soft, low-quality carbon paper works best.) Also, to ensure good tracks, the surface on which the ball bearings roll must be smooth and hard.

Master Sheet Name_____________

Low Ramp				High Ramp			
XLg	Lg	Med	Sm	XLg	Lg	Med	Sm

6. When students have completed their "Master Sheets," they will design and test a real collision by setting up the ball bearings on a blank sheet of paper to be sure that the collision will work properly. Once the collision has been tested and any adjustments made, a fresh piece of paper with carbon paper over it can be used to make the "real" collision. Collisions can utilize the ramp and block or just involve rolling one ball bearing across the table into other ball bearings. At least one target and one "probe" ball bearing must be used. DO NOT allow students to drop ball bearing down onto other ball bearings.

   Note: Encourage students 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. Students now need to make an answer key for the collision that clearly shows all the pieces used in the collision, their positions at the beginning of the collision and how they moved

after the collision. Have them sketch their setup on a separate piece of paper, labeling the ball bearing size(s) and giving the ramp height (if a ramp was used) and the size of the ball bearing they launched.

8. Each group will fasten their unlabeled, real collision sheet to their answer key and turn them into the teacher. The teacher will redistribute the collisions as needed to other student groups when they are ready to analyze a collision. The teacher should keep the answer key until the student group is ready to check its results.

    Note: You may want to create a few extra collisions 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.

9. Students should use their own Master Sheet as well as the experiences from creating their own collisions to analyze the mystery collision given them by the teacher. When the students believe that they have discovered how the collision was created, they need to write out their claim and the reasoning behind that claim. Then they need to ask their teacher for the collision key so that they can verify their claim.

    Note: Students should be encouraged to try to replicate the collision before asking for the key. Scientists must be able to replicate experiments and get the same results before those results will be accepted and published.

10. Upon completion of this investigation, discuss the bubble chamber photographs as well as the electronic detector images (provided on the flash drive.) Ask the students to explain how the trails in these pictures are similar or different and how they might be used to identify particles in a collision.

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

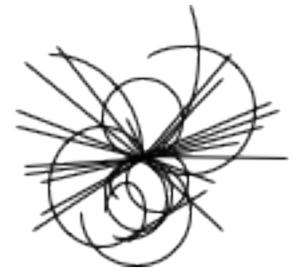
    Curvature of a particle trail is an indication of particle speed and mass (or weight) and is caused by the charged particle moving through a magnetic field. The field is caused by large electromagnet coils around the chamber. The particle's curved path is much like the curving of protons around the circle 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 13: Tracking What Happens 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 create, 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.

Materials:
Each group should get the following:
1 blank Master Sheet (one copy provided in guidebook)
1 ramp (6” wood, grooved ruler)
1 ramp block
1 sheet of unlined paper (school supply)
1 sheet of carbon paper (The softer and messier, the better.)
4 ball bearings - sizes from extra large to small (Use all ball bearings in the kit except the BB-sized ones.)
1 set of bubble chamber photographs
Student Investigation Sheets - “Tracking What Happens in an Unseen Event”

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 lightly 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. Insert the ramp in the 4 cm (“low ramp”) height. (Lowest groove on the block)
4. Starting with the extra large ball bearing, release the ball bearing from the top of the ramp allowing it to roll down the ramp and across the Master Sheet. Repeat this procedure with the large, medium and small ball bearings on the appropriate sections of the Master Sheet.
5. When all four ball bearings have been released from the low ramp, repeat steps 3 and 4 for the 8 cm “high ramp.”
6. Your “Master Sheet” should have eight clear tracks across it. Keep this sheet to help you analyze a collision produced by another group later in this investigation.
7. Identify at least three characteristics of the track marks that vary. For instance, are the high ramp, extra-large ball bearing tracks the same size as the low ramp, extra-large ball bearing

tracks? How are they different? What about the high ramp, extra-large ball bearing tracks and the high ramp, small ball bearing tracks?

8. Next, lay down a sheet of unlined paper. Cluster 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 or no ramp to create a collision with an incoming probe. Practice the collision a couple of times to be sure it is going to work.
9. 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.
10. After the collision, carefully draw what happened on a separate piece of paper. Show where the cluster of ball bearings was located as well as the location of the probe ball bearing. Also, carefully illustrate the movement of all the ball bearings during and after the collision. Be sure to label which ball bearing made each track, the location and height of any ramp used and use arrows to show ball bearing directions. Accuracy of this drawing is critical because it is your ANSWER KEY.
11. Now, write the name of your group on both your unlabeled real collision sheet and your labeled answer key, paper clip them together and turn them in to your teacher.
12. Your teacher will give your group a real collision sheet produced by another group in your class. Analyze the tracks on this paper by comparing it with your group's "Master Sheet" and using what you learned from your own collision. Your group should discuss thoroughly your ideas as to what happened. When your group believes that it has figured out what was done and what happened, you need to write down your claim and provide the reasoning behind it.
13. Label the trails and other collision components on the other group's collision sheet. Include the ball bearing size, beginning and ending locations, direction of movement, ramp location and height, etc.
14. Verify the results of your analysis by trying to replicate this experiment with another sheet of paper.
15. Get the answer key for your mystery collision from your teacher and compare the key to your claim by answering the questions below.
16. Your teacher will lead a discussion that will give your group a chance to explain how well you were able to decipher the collision you analyzed.

Conclusions:

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

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

3. What size ball bearing(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 #11?

7. How is this investigation similar to what scientists do at Fermilab?

Master Sheet **Name**_______________

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.

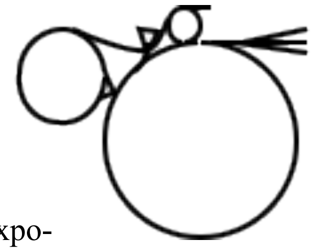
In this section, students will explore how many different ideas can help in solving problems and creating new conceptual frameworks.

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 14: *Powers of Ten*



Purpose:
Powers of Ten is a short video that takes students across the vast distances of our universe and back again to the depths of subatomic structure. Through the video they will explore the mathematical concept of exponents (powers of ten); helping them to understand the distances that exist between particles that make up the world around us.

> *Note: It is a very short video and can be shown more than once during a class period. Be sure to have the students read through the questions before showing the video. The teacher should also involve the students in a follow-up discussion.*

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

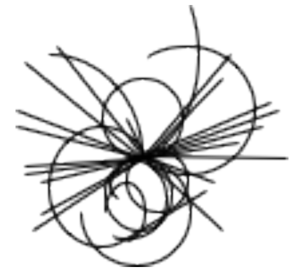
Illinois State Standards:
12.F.3b, 12.F.3c, 13.B.3a, CC.5.NBT.2

Materials:
Powers of Ten video (or online source)
Student Investigation Sheet: *Powers of Ten*

> *Note: The video can assist students in understanding real life measurements in the study of matter.*
>
> *This investigation includes a 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 of the material in the video. Student understanding of just how much of matter is composed of empty space should be a definite goal for the unit.*

Procedure:
1. Hand out the student investigation sheet.
2. Read through the questions in order to prepare the students.
3. Show the Powers of Ten video.
4. Have students answer questions on worksheet.
5. Determine ahead of time how students will be accountable for the video content.
6. Follow up with small group or class discussion of video content.

Student Sheet
Investigation 14: *Powers of Ten*



Name_________________________

Date__________________________

1. What is pictured at 10^0 meters?

2. What is the greatest distance that we can currently "see" into outer space? What power of ten does this represent?

3. What is located at this distance?

4. What is the smallest distance that we can currently "see" into inner space? What is the power of ten does this represent?

5. What is located at this distance?

6. How many powers of ten is it from the smallest to the largest things that we can currently "see" in our universe?

7. What characteristic do inner and outer space have most in common?

8. What is a light year?

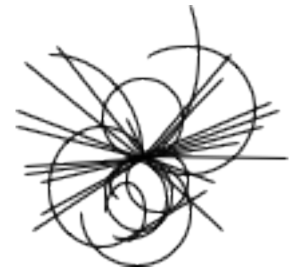
9. How fast does light travel?

10. What is the distance of one light year?

POWERS OF TEN VIDEO WORKSHEET ANSWER KEY

1. A couple at a picnic on the lakeshore in Chicago
2. 10^{24}
3. Empty space – blackness
4. 10^{-16}
5. Quarks
6. 40 Powers of Ten
7. There is almost nothing there—empty space.
8. How far light travels in one year
9. 3×10^{8} m/s
10. 10^{16} meters

Student Sheet
Investigation 14A: *Powers of Ten Supplemental Worksheet*



Name_________________________

Date_________________________

Read these questions over before watching the video. Answer the questions after you are done watching.

1. What is the width of the field of view when the earth is observed as a sphere?

2. At 10^{12} power, the center of our solar system is seen in the field. Name the object.

3. How far is a distance of one light year?

4. What is the largest thing you see in Powers of Ten?

5. What is the smallest thing pictured in Powers of Ten?

6. How does the journey from Earth to outer space compare to what is known about the structure of the atom?

7. In the first part of the video, the field of view grows 10 times larger with each step away from the man on the lawn. For example, at step one, it is 10 times larger; at step two, it is 10 times 10 or 100 times larger; at step three, it is 10 times 10 times 10 or 1,000 times larger. How much larger is it at:

   Step four?

   Step six?

   Step eight?

8. The list below gives every fourth step in the video. The picture in each fourth step is 10,000 larger than the previous fourth step. For example, the heart of the city is 10,000 times larger than the man on the lawn, and the clouds of stars are 10,000 times larger than one light year.

10^{24} m	Cluster of galaxies
10^{20} m	Clouds of stars
10^{16} m	One light year
10^{12} m	Jupiter's orbit
10^{8} m	Inside of the Moon's orbit
10^{4} m	Heart of the city
10^{0} m	Man on the lawn
10^{-4} m	Inside a skin layer
10^{-8} m	Close-up of DNA
10^{-12} m	Inside an atom
10^{-16} m	Inside a proton

How much larger is:

a. The inside of the Moon's orbit compared to the heart of the city?

b. The man on the lawn compared to the inside of a skin layer?

c. The inside of an atom compared to the inside of a proton?

d. One light year compared to the inside of the Moon's orbit?

e. The inside of a skin layer compared to the inside of an atom?

9. How many steps in the video is it from the inside of a proton to the man on the lawn?

10. How many steps in the video is it from the inside of a proton to the cluster of galaxies?

POWERS OF TEN SUPPLEMENTAL WORKSHEET ANSWER KEY

1. 10^7

2. The sun

3. 10^{16}

4. The Virgo Cluster of Galaxies

5. A quark (inside a proton)

6. Most of space is empty.

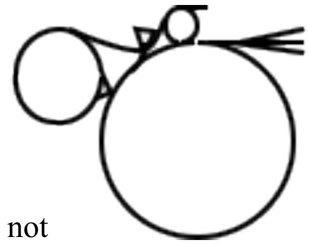
7. 10,000 times
   1,000,000 times
   100,000,000 times

8a. 10,000 times larger
8b. 10,000 times larger
8c. 10,000 times larger
8d. 100,000,000 times larger
8e. 100,000,000 times larger

9. 16 steps

10. 40 steps

Investigation 15: How Does It All Fit?



Purpose:
Every day when scientists and technicians come to work at Fermilab they know that there is a great deal more to discover about the behavior and structure of matter. They know that new questions, some that have not even been thought of yet, will have to be asked and investigated. They know that it is going to take many people, working many hours, cooperating with each other, to combine what they learn, and to find answers to the new questions and figure out how all the information fits together. It is a challenging but fun job. It takes patience and good communication. It takes accurate work and trust in what has been done by each other to advance the knowledge. Ultimately, it is the pursuit of how all of the pieces fit into the puzzle.

This activity is going to give your students the chance to experience many of these very real situations in a similar manner.

> *Note: The degree to which your students experience success and learning will, at least in large part, depend on how well you "set the tone" and then how carefully you guide them through the research, discussions and assembly of the final jigsaw puzzle. You should plan to spend from 2–3 class periods on this activity. Do not rush the final product. Guide its development, but let it come together on its own.*
>
> *The suggested order for you to follow would be to introduce the activity and begin research during the first class period. Try to check each student's progress and give any suggestions needed to focus students before they go home. Answer(s) should be due at the beginning of the second class period. Take a very small amount of time to check the student's work and then move ahead. The students must now begin to organize themselves into five groups (see procedure.) Listen, circulate and guide the discussion. Encourage students to debate and defend their responses and ideas. The goal on this second day is to have the five groups correctly formed and, if possible, organize the words under the correct heading word.*
>
> *On the third day the students should carefully and neatly construct their puzzle pieces and them assemble the finished jigsaw puzzle. Save a few minutes to look at the puzzle as a class and discuss topics like how the research, discussions, debates, and eventual construction of the puzzle pieces are a very good simulation of what goes on at Fermilab every day.*

Illinois State Standards:
13.B.3a, 13.B.3b, 13.B.3c

Materials:
Puzzle piece templates
Fine point Sharpie markers
Scissors
Velcro pieces
Mounting board
Computers

Procedure:

1. Assign each student a different research question. Their goal is to discover a key word or phrase that will describe an important idea or activity here at Fermilab.
   As they do their research encourage them to use resources like ed.fnal.gov. They should develop several pieces of evidence that they can use to convince their fellow scientists that they are correct. When the whole class reconvenes the students should be ready to discuss everyone's work and help with the process of sorting and organizing the research into groups of related data that make sense and connect with each other. The final class effort will be to display the work visually and spend some time studying and learning from it.
   You will need to review each student's work. Give guidance and focus where it is really needed. Completing the research should be homework.

2. Note that there are five sets of five related terms and phrases. During the class discussion remind all the students that they must defend the answer to their research question to the group. This discussion is designed to sort the answers into their related groups and organize them under a heading.

3. The students will need to collaborate with other students to discover to which set of terms they are related. The class will need to organize itself into five main groups of five related terms each.

4. Each group will then need to organize their terms, select one to be a category heading, and list the rest underneath. An ideal situation would find the students defending their thinking to each other and working together to organize their terms in such a way that all students in the group agree.

5. Review the work of each group to be sure the class is ready to move ahead.

6. Now the groups need to come together and as a whole class and discuss their work with the other groups.

7. Each group should now get the colored puzzle piece templates from you, Each piece of tagboard will have two IDENTICAL puzzle pieces already traced onto it.

8. Encourage the students to carefully cut out the identical tagboard puzzle pieces.

9. Students will need to compare the puzzle pieces to the master puzzle to determine which COLUMN of pieces their group has been given. They need to CHECK THIS OUT VERY CAREFULLY AS SOME PUZZLE PIECES ARE IDENTICAL TO PIECES FROM ANOTHER COLUMN. They then accurately determine which piece goes where in the column.

10. The students should carefully CENTER a FUZZY Velcro piece on the BACK of each tagboard piece.

11. They should then make sure that the orientation of their puzzle pieces are correct, and PRINT their research question onto one of the tagboard pieces.

12. Then the students should CENTER their grooved Velcro piece onto the front of the other puzzle piece. They should CHECK THE ORIENTATION OF THIS PIECE AGAIN and then PRINT their answer onto the front of this piece.

13. Finally the students should place the answer piece onto the master puzzle, and then cover it with the question.
    Then you need to lead a class discussion that covers topics like how the research, discussions, debates, and eventual construction of the puzzle pieces is a very good simulation of what goes on at Fermilab every day.

Conclusions:
Students should answer the following questions.

1. State your research question.

2. List the resources you used for your research. (For example: a specific website, magazine article, book title, or person interviewed)

3. List the word or phrases that you came up with from your research.

4. Discuss the techniques of communication the class used to organize the data both individually and as a group.

5. What was difficult about this activity?

6. How is this activity like what really happens at Fermilab on a daily basis?

Clues/Answers for Student Research
(PP = puzzle piece number)

PP1. **Standard Model** – Physicists have observed or measured a number of things about the universe leading them to develop a representation of the basic structure of matter called __________.

PP2. **Testable Ideas** – attempting to prove the unknowns

PP3. **Scientific Instruments** – These tools enable physicists to observe and collect data about the subatomic particles that make up our world.

PP4. **Data/Claims/Reasoning** – information, proof and "the why"

PP5. **New Physics** – the study of new symmetries, undiscovered particles, and unexplained phenomenon in the 21st century

PP6. **Quarks** – These six fundamental particles make up protons and neutrons.

PP7. **Unanswered Questions** – The Standard Model explains much about our world but still leaves many _______ _______. (2 words)

PP8. **Accelerators** – These machines propel subatomic particles to high rates of speed in preparation for collisions.

PP9. **Statistics** – accurate numerical data

PP10. **Energy Frontier** – This area of scientific study will reveal unknown forces of nature and new physical principles at multiple TeV levels.

PP11. **Leptons** – the other type of fundamental matter particles of which three have an electric charge and three do not

PP12. **Symmetry** – Fundamental principles dictate the basic laws of physics, control the structure of matter, and define the fundamental forces in nature ("sameness under some altered scrutiny").

PP13. **Detectors** – These machines "see" particle collisions and their results using their electrical discharges and other particle characteristics.

PP14. **Replication** – verification of data by duplicating an experiment

PP15. Cosmic Frontier – This area of scientific study attempts to understand dark energy and dark matter.

PP16. Forces – Fundamental particles are acted upon by four ________.

PP17. Investigative Techniques – methods of discovering and testing ideas

PP18. Computers – These machines mathematically analyze the data collected by an experiment.

PP19. Statistical Uncertainty – the variances associated with measurements and numerical data

PP20. Intensity Frontier – This area of scientific study focuses on the phenomena caused by the interactions of huge numbers of particles such as neutrinos.

PP21. Force Carriers – These particles mediate the interactions between the other fundamental particles.

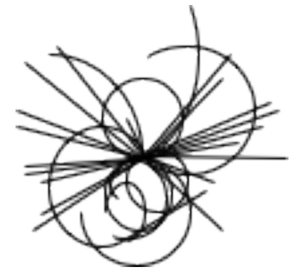
PP22. Models – representations of an idea created by the interpretation of data

PP23. Human Observation / Problem Analysis – using one or more of our five senses to obtain and understand information

PP24. Indirect Evidence – the data using techniques that do not involve using firsthand observation, providing a basis for inference

PP25. Benefits to Society – the application of innovative ideas and technologies of particle physics to transform the way we live

Student Sheet
Investigation 15: How Does It All Fit?



Name________________________

Date_________________________

Purpose:
Every day when scientists and technicians come to work at Fermilab, they know that there is a great deal more to discover about the behavior and structure of matter. They know that new questions, some that have not even been thought of yet, will have to be asked and investigated. They know that it is going to take many people, working many hours, cooperating with each other, to combine what they learn, and to find answers to the new questions and figure out how all the information fits together. It is a challenging but fun job. It takes patience and good communication. It takes accurate work and trust in what has been done by each other to advance the knowledge. Ultimately, it is the pursuit of how all of the pieces fit into the puzzle.

You are going to have a chance to experience many of these very real situations in this activity.

Materials:
Puzzle piece templates
Fine point Sharpie markers
Scissors
Velcro pieces
Mounting board
Computers

Procedure:
1. You will be given research to do. Your goal is to discover a key word or phrase that will describe an important idea or activity here at Fermilab.
   As you do your research use resources like the Education pages at Fermilab's Education website (ed.fnal.gov). Try to develop several pieces of evidence that you can use to convince your fellow scientists that you are correct. When the whole class reconvenes be ready to discuss everyone's work and help with the process of sorting and organizing the research into groups of related data that make sense and connect with each other. The final class effort will be to display the work visually and spend some time studying and learning from it.
   You will need to review your work with your teacher before you move ahead.

2. There will be five sets of five related terms and phrases. During class discussion be prepared to defend the answer to your research question.

3. You will also need to collaborate with other students to discover to which set of terms you are related. The class will need to organize itself into five main groups of five related terms each.

4. Each group will then need to organize their terms, select one to be a category heading, and list the rest underneath. Be prepared to defend your thinking as to why these five terms and phrases are definitely related.

5. Review your work with your teacher to be sure you are ready to move ahead.

6. Each group now needs to discuss its work with the other groups and defend its composition. It is possible that one member of the group may need to exchange places with someone from another group.

7. Each group should now get the colored puzzle piece templates from the teacher. Each piece of tagboard will have two IDENTICAL puzzle pieces already traced onto it.

8. Carefully cut out the identical tagboard puzzle pieces.

9. Compare the puzzle pieces to the master puzzle to determine which COLUMN of pieces your group has been given. CHECK THIS OUT VERY CAREFULLY AS SOME PUZZLE PIECES ARE IDENTICAL TO PIECES FROM ANOTHER COLUMN. Accurately determine which piece goes where in the column.

10. Carefully CENTER a FUZZY Velcro piece on the BACK of each tagboard piece.

11. Making sure that the orientation of your puzzle pieces is correct, PRINT your research question onto one of the tagboard pieces.

12. CENTER your grooved Velcro piece onto the front of the other puzzle piece. CHECK THE ORIENTATION OF THIS PIECE AGAIN and then PRINT your answer onto the front of this piece.

13. Finally place the answer piece onto the master puzzle, and then cover it with the question.

Conclusions:
Answer the following questions.

1. State your research question.

2. List the resources you used for your research. (For example: a specific website, magazine article, book title, or person interviewed)

3. List the word or phrases that you came up with from your research.

4. Discuss the techniques of communication the class used to organize the data both individually and as a group.

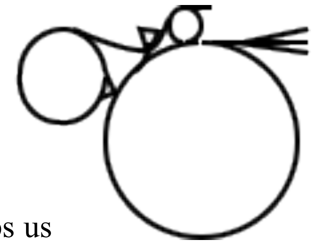
   Individually:

   Group:

5. What was difficult about this activity?

6. How is this activity like what really happens at Fermilab on a daily basis?

Investigation 16: *Cosmic Voyage*



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.

Note: It is a very long video and the teacher must prepare students by reading through the questions ahead of time with the students. The teacher also needs to involve the students in a follow-up discussion in order to make the best use of this video.

Objectives:

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

Illinois State Standards:

12.F.3b, 12.F.3c, 13.B.3a, CC.5.NBT.2

Materials:

Cosmic Voyage video
Student Investigation Sheet: Cosmic Voyage

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.

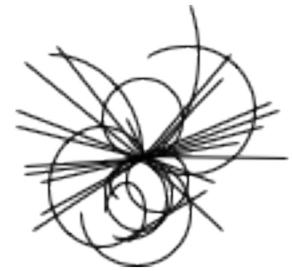
This investigation includes a worksheet containing questions designed to focus student thinking, as well as a teacher answer key. Reading over these questions with students prior to viewing the video will enhance their understanding of the material in the video. Students understanding of just how much 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 coordinate the showing of this video with Powers of Ten to increase student understanding of this 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 Cosmic Voyage video. (37 minutes)
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 16: *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.

Materials:
Cosmic Voyage video
Student Investigation Sheet: Cosmic Voyage

Procedure:
Watch the *Cosmic Voyage* video.
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.

Conclusions.
1. What object in the video is equal to 10^0?

2. What landmark can be seen at 10^2?

3. What object is visible at 10^7?

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?

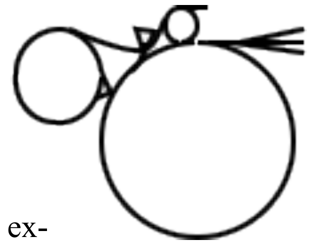
15. Some scientists might say that the farther we look into space, the farther back in time we can see. What does this mean?

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

Investigation 17: 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. This is an extremely important demonstration. Take your time and be clear as you proceed.

Objective:
This investigation will help students understand the vast empty areas within the atom or nucleus and that the atom is mostly empty space.

Illinois State Standards:
12.C.3b, 12.D.3b, 13.A.3a

Materials:
Rubber stopper
Pin with brightly-colored 1-mm head
Meter stick (school supply) - to measure string
Two pieces of heavy string - 10 m, 23 m
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. Circle your students around you in the classroom or any other space where they can form a circle.

2. Use the rubber stopper and 10 m string. Attach the string to the head of the pin which has been stuck into the bottom of the rubber stopper. Have a student help stretch out the string.

3. 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.

4. 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 circle that is 23meters in circumference.) Have all of the students hold onto the string to shape it into a circle. Remind your students that the atom is three dimensional and your model extends both above their heads and down below the floor.

5. Ask your students what occupies the large sphere representing either a proton or neutron. When they remember that three quarks "fill" the space, ask them how large the quarks would appear? Carefully place the three BBs as equidistant throughout the circle as possible. Wait for student reaction and spend time discussing what they are seeing. Finally, ask your students to estimate how far the electron in the first part of the demonstration would now be from the proton, which has a diameter of 8 meters. (80,000 m 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.

6. 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.)

SECTION 5: THE 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.

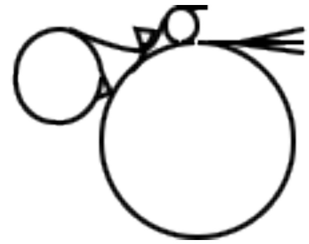
All the employees of the Lab share a common bond: They have come from all over the world to work in jobs of all descriptions in an effort to understand some of nature's deepest secrets.

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 beings that operate 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 who have to work together. Experiments at Fermilab are international efforts with men and women from all over the globe who must depend upon each other to find success.
4. It takes many different kinds of workers, in addition to physicists, to make Fermilab operate smoothly.

Investigation 18: The Physics of Neutrino Oscillations



Purpose:
The following display and/or demonstration(s) will simulate the concept of neutrino oscillation.

Objective:
The simulations will help students understand more about particles called neutrinos.

Illinois State Standards:
12.C.3b, 12.D.3b, 13.A.3c

Materials:
See each idea listed.

Procedure:
Discuss neutrinos and the intensity frontier; including the idea of neutrino oscillation. Use one or more of the ideas discussed in the summer B&C workshop to simulate this concept.

Ideas from Summer Workshop:
Display board (made in class) – shows definition of neutrino, along with information; Standard Model; shows neutrino oscillation using comparison of one child throwing a baseball, but has changed to a football when caught by another child (one type neutrino oscillating between/to the other types of neutrinos).

Oscillation animal (received one in class) – can demonstrate by tossing between students so the animal lights up with the three different-colored lights (simulating neutrinos oscillating from one type to another).

Oscillation jars (made in class) – 3 small jars (clear) with 3 different-colored beads to represent the three types of neutrinos; 3 tall jars with varying levels of the three types of beads to represent oscillation

Neutrino Appearance Experiment (received in class) – 3 plastic cups of different colors, labels, 1 ping-pong ball.

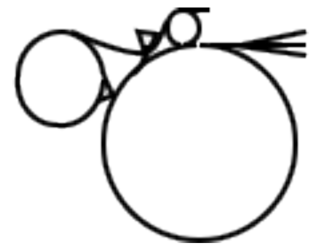
Deck of randomly mixed index cards (3 colors) (received in class) – Hold or staple so you can fan quickly to simulate one neutrino oscillaing into other types.

Oscillation board: 9 animals or balls (3 each of 3 different colors or types), yarn (if no loops), magnetic hooks; hang the animals or balls from the magnetic hooks in a path varying the colors or types of animals or balls to demonstrate oscillation of a neutrino.

Oscillation tube: 4-foot fluorescent light tube (found at Menard's or Home Depot), 3 of each of 3 different colors of small rubber balls (or ping-pong balls if using a larger diameter of tube); place nine balls (3 of each color) mixing up the order of colors in the light tube; place cap back in placer; place clear tape over each end; place bands of black duct tape at varying distances on the tube; holding the tube horizontally, slowly tip the tube back and forth to simulate neutrino oscillation. (If using ping-pong balls, try holding the tube vertically when tipping back and forth.)

Investigation 19: *Fermilab: Science at Work*

Five-part movie to accompany Beauty and Charm unit



Illinois State Standards:
13.B.3a, 13.B.3b, 13.B.3c

Teacher Introduction and Notes:
Although taking your students on a field trip to Fermilab to see firsthand what goes on is an ideal goal, we understand that not every teacher will always be able to accomplish this goal. *Fermilab: Science at Work* explores significant points of interest of the facility and introduces students to many fascinating people who work here; has been several years in the making. For purposes of the unit, the video has been divided into five shorter segments to make it easier to use. Each segment has been matched to the section of the B&C unit that it best supports. The video can be shown in its entirety, but is best utilized as five segmented presentations during the various activities of the unit. See the viewing schedule on next page or follow the summer workshop positioning of the video segments.

The video takes students on a six-day journey of the lab. The storyline of the video is that after being shut down for several weeks for adjustments and maintenance, Fermilab accelerators are being prepared for start-up at the end of a normal workweek. New experiments are getting ready to begin just as soon as the beam begins to operate effectively. The video follows many of these preparations as well as highlighting many of the people it takes to accomplish such a tremendous task. The intricacy of the machine, along with the human investment of time, ideas, and intense cooperation are the broad overall themes. Students quickly understand how it all has to work together if it is going to work at all.

Simple worksheets have been developed for use in conjunction with each segment as a means of stimulating discussion and understanding. Teachers are free to use, modify, or ignore them as time and emphasis allow. They should, however, help students locate and discuss many of the more important ideas from the video. Students should read over the questions BEFORE watching a video segment.

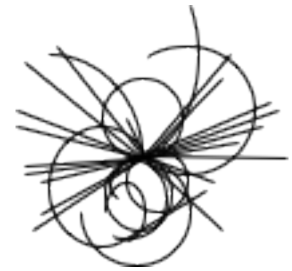
Video Viewing Schedule

Part One:	Monday – "Time to Start Learning" Show before or after "Measuring Small."	(starts at 0:00)
Part Two:	Tuesday – "We Start with a Bottle of Hydrogen" Show after "Studying Things You Can't See."	(starts at 7:45)
Part Three:	Wednesday – "I Want to See Neutrino Interactions" Show before "Neutrino Oscillations."	(starts at 14:08)
Part Four:	Thursday – "Emotionally Attached to Chalkboards" Show before "How Does It Fit?"	(starts at 23:21)
Part Five:	Friday – "The Most Exciting Time" Saturday – "We Are Trying to Understand the Universe" Show before "Tracking What Happens in an Unseen Event."	(starts at 29:22) (starts at 37:09)

The time notations after each segment correspond to the BEGINNING counter number for that segment.

Fermilab: Science At Work

Monday—"Time to Start Learning" Student Sheet



Name_________________________

Date__________________________

1. Why do you think that the video starts with physicist Brendan Casey sending his children to school to learn?

2. What is it about working at Fermilab that Brendan Casey finds so exciting?

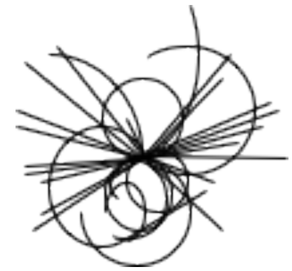
3. Explain in your own words what Fermilab scientists are trying to discover at the energy frontier.

4. Explain in your own words what Fermilab scientists are trying to discover at the intensity frontier.

5. Explain in your own words what Fermilab scientists are trying to discover at the cosmic frontier.

6. The Large Hadron Collider at CERN is now the world's highest-energy particle accelerator. How does Fermilab's work support the work at CERN?

7. In what area of physics research is Fermilab the current world leader?



Fermilab: Science At Work

Tuesday—"We Start With a Bottle of Hydrogen"

Student Sheet

Name_________________________

Date__________________________

1. Explain Denton Morris's analogy between Fermilab and a car.

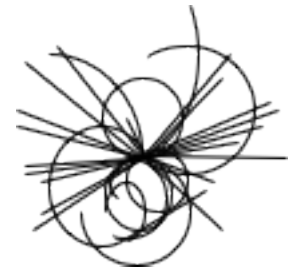
2. What kinds of things are done to the machines at Fermilab when they are shut down?

3. Describe the journey of a proton through Fermilab's accelerators, from start to finish.

4. Why is the computing division at Fermilab called its Fort Knox?

5. Describe at least four jobs at Fermilab other than physicist.

Fermilab: Science At Work
Wednesday—"I Want to See Neutrino Interactions"
Student Sheet



Name________________________

Date_________________________

1. Why is it so important for the scientists and those who support their work to work well together?

2. Explain the importance of learning "time management."

3. What are neutrino "flavors"?

4. Share three facts you learned about neutrinos.

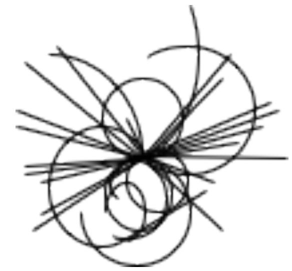
5. Use what you learned about neutrino "flavors" to explain how oscillation experiments may help us understand neutrinos.

6. How might neutrinos and antimatter be connected?

7. What does the billiard analogy help us understand?

8. What is the "Eureka" moment at Fermilab?

Fermilab: Science At Work
Thursday—"Emotionally Attached to Chalkboards"
Student Sheet



Name_________________________

Date__________________________

1. What kind of last minute things have to be done before the Tevatron can be started up again?

2. Why did Fermilab build a simulation dark energy telescope before building the real thing?

3. How do we know dark energy exists?

4. Share three other facts you learned about dark energy.

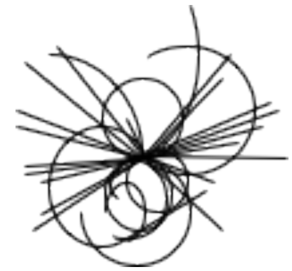
5. What do scientists mean when they say "We can only see 5% of the universe"?

6. What makes up this 5%?

7. What makes up the rest of the universe?

8. How do scientists think indirect evidence will help us understand dark matter?

Fermilab: Science At Work
Friday and Saturday Student Sheet



Name________________________

Date_________________________

1. Why do you think so much of this video was devoted to showing you things like “Daughters And Sons To Work Day,” the bison, the architecture, the flags, etc.?

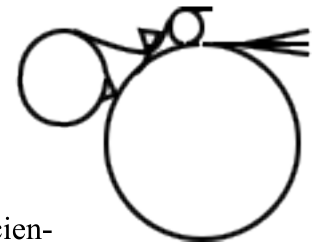
2. Why is it so important to maintain clear, precise communication between Fermilab and CERN?

3. Do you still think that “… only very smart people can understand and do science”? Why or why not?

4. Explain this quote from the video: “We need people who know when to make educated guesses, and people who know that they do not have enough information to do so.”

5. What was Deborah Harris trying to say when she was talking about the olive trees?

Investigation 20: *A Sense of Scale*



Purpose:
One of the more challenging aspects of this unit is to help students gain the perspective that scientists are real people doing a job that they enjoy. The lab work, activities, and discussion questions simulate how scientists discover knowledge about things that they cannot see. This new 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:
1. Students will realize that discovery and learning, although time-consuming and expensive at times, can be very rewarding.
2. Students will hear scientists discuss how they got interested in their various fields of study and what they have gotten out of it.
3. Students will gain the perspective that scientists are real people doing a job that they enjoy.

Illinois State Standards:
12.F.3b, 12.F.3c, 13.B.3a, CC.5.NBT.2

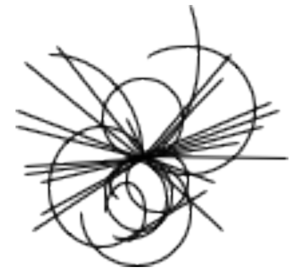
Materials:
A Sense of Scale video
Student Investigation Sheet - A Sense of Scale

> *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 video.

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 presentation, individually after the presentation, in small groups after the presentation?

Student Sheet
Investigation 20: *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 were excited about searching for the missing pieces that will help complete the Standard Model someday.

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

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.

Conclusions:
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?

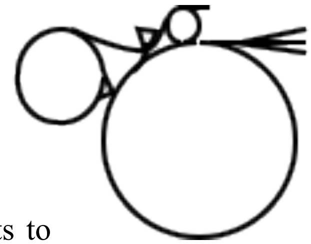
13. Summarize at least three of the remaining questions that face scientists at Fermilab. Areas for discussion can include: top quark, antiprotons, neutrinos, calculations.

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 21: 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.

Note: An alternative use of this activity would be to use it as a Jeopardy game utilizing the template on the flash drive.

Illinois State Standards:
13.B.3c

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 their questions, discuss the answers with short discussions of the concepts, as needed.

How Much Do You Really Know about Fermilab?
Sample Answers

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 20–30 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.

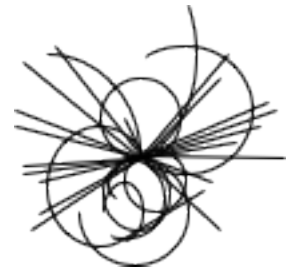
10. As more, higher-powered accelerators are built elsewhere in the world, what do you imagine the future will hold for Fermilab and its scientists?

    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 21: 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.

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

Procedure:
Using any and all of the information you have learned and have access to from this unit, 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. During your trip, you will meet the men and women of Fermilab, see their experiments, and enjoy a visit to the Leon M. Lederman Science Education Center.

The Lederman 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 ambience ("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 to schedule a field trip.

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.

You may also supplement classroom activities with various articles and puzzles found in the *Quark Quest* newspaper, which is available at http://ed.fnal.gov/qquest/qquest.html. 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.

Beauty and Charm Student Tour

Seeing firsthand 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.

> *Note: The Beauty and Charm student tour is constantly being updated to reflect current discoveries, research and changes at Fermilab.*
>
> *Students will see some of the machines and meet the men and women who build, operate and understand these machines and the secrets the machines reveal.*
>
> *Students may wish to bring paper or journal and pencil to take notes.*
>
> *Cameras are welcome on tours.*
>
> *Students need to dress for safety. This includes sturdy, close-toed shoes and clothing that cannot catch on machinery during the walking tour.*
>
> *Name tags need to be worn so that they are visible to the docents.*

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 in this decade.
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 may visit areas of Fermilab such as the Cockcroft-Walton and the Linear Accelerator, or "Linac." If time permits, the students may also see a Control Room.
6. The students will go to the 15^{th}-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. Call the Docent Coordinator at 630-840-5058 two or three days prior to the trip to coordinate your trip.
2. Student List
3. Parent Permission Sheets (district or school provided)
4. Emergency Sheets (district or school provided)
5. Assignments (If you wish your students to have them.)
6. Name tags for each student
7. Coordinate your lunch plans with the Docent Coordinator. (Eating at Wilson or bringing bag lunches)
8. Call a local restaurant if you are intending to eat there.
9. Each student should bring:
    a. Journals (each with a pre-written question for the scientist).
    b. Pencil or pen.
    c. A lunch (unless you are making provisions at another location).
    d. Clothing appropriate for travel outside from the Lederman Science Center to Wilson Hall.
10. Remind the bus driver that he/she MUST stay on site.

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 will 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.

APPENDIX A: 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 *Frontiers of Discovery* 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=mc2), 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 x 10^{26} million electron volts (MeV)
1 electron volt	=	1.6 x 10^{-33} grams
1 MeV	=	1.6 x 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 0.511 MeV, a proton's is 936.2 MeV, and an upsilon's is 9,402 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 increased the luminosity (number of collisions per second) by a factor of five and allowed both types of Fermilab experiments, “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 was 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 traveled at more than 99.999% the speed of light and had more than 800 times their rest mass. The distance the proton traveled in one second was four miles times 40,000 which was 160,000 miles, or the equivalent of almost 6½ 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: Weak to Strong	Range Scale	Carrier	Carrier Observed
Gravity	Infinite	Graviton	No
Weak Nuclear	Nuclear	W^+, W^-, Z^0	Yes (1983)
Electromagnetic	Infinite	Photon	Yes (1923)
Strong Nuclear	Nuclear	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."

The Large Hadron Collider (LHC)

Just a short drive from Geneva, Switzerland, buried 100 meters underground, lies the largest most powerful microscope ever built. Taking more than nine years to build, the 17-mile circumference mammoth machine will peer further into the atom and the forces that make up our universe than any scientific experiment has ever done before. More than 5000 scientists, engineers, and students work to discover the very tiny secrets of particle physics. This gigantic particle accelerator sends subatomic particles called "hadrons"—either protons or lead ions—in opposite directions around the ring. They are propelled by incredibly powerful superconducting magnets and cooled to 3 degrees Kelvin by liquid helium and liquid nitrogen, gaining energy with each lap. Then, the two beams of particles are collided at the highest possible energies to try and mimic what occurred in the moments of time during and after the Big Bang. Multiple types of detectors "peer" into the collision aftermath to "see" the particles that are present and analyze what they turn into as they decay to more stable types of matter. The LHC (Large Hadron Collider) has to be so powerful in order to pack tremendous amounts of energy into the protons.

Even though a great deal of information about atomic structure has already been discovered, a great deal still remains to be understood and explained. The LHC will be looking for evidence of the elusive Higgs particle as well as other strange particles like, gluinos, photinos, squarks and winos. It is also trying how these and other yet undiscovered particles and forces relate to dark matter and dark energy.

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 Accelerators 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.

Run Like a Proton at the Lederman Science Center

The Run Like a Proton exhibit is a limestone path with the footprint of the Fermilab Accelerator Complex. Students and other visitors will assume the roles of protons or antiprotons traversing the circuit that the particles would take under various scenarios.

Be a proton! Accelerate through the complex by starting at the Cockcroft-Walton, through the Linac, two laps counterclockwise around the Booster, two laps counterclockwise around the Main Injector and clockwise around the Tevatron until you collide (high five) into an antiproton traveling in the opposite direction at CDF or DØ.

Or be an antiproton! Accelerate through the complex by starting at the Antiproton Source, two laps clockwise around the Main Injector and counterclockwise around the Tevatron until you collide (high five) into a proton traveling in the opposite direction at CDF or DØ.

APPENDIX B: Glossary

This glossary is provided for teacher and student reference during the unit activities and is not intended for memorization.

Scientific Instruments

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

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 stereo photographs.

CDF – The Collider Detector at Fermilab was the location on the Main Ring where collisions of protons and antiprotons occurred using the highest energies available prior to construction of the Large Hadron Collider at CERN.

Circular Accelerator – A scientific machine in which particles are accelerated as they travel around a circular path (also known as a synchrotron).

Cryogenics – The technology of the production and effects of very low temperatures. Liquid hydrogen and liquid helium are used to cool various parts of the accelerators at Fermilab, including the superconducting magnets.

Detectors – Machines that "see" particle collisions and their results using their electrical discharges and other particle characteristics. Examples would be DØ and CDF at Fermilab.

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

Fixed Target – Any stationary spot to which the beam of protons is directed and with which the beam interacts. This could be a piece of metal, liquid hydrogen or some other detector.

GeV – Billion electron volts (10^9)

keV – Thousand electron volts (10^3)

Large Hadron Collider – The largest circular accelerator in the world. It is located near Geneva, Switzerland.

Linear Accelerator – Also called a Linac; a scientific machine in which particles are accelerated along a straight-line path. The Linac at Fermilab accepts protons from the Cockcroft-Walton accelerator at 750 kV, accelerates them to 200 MeV, and injects them into the Booster accelerator.

MeV – Million electron volts (10^6)

Superconducting Magnet – A magnet whose coils are made from superconducting material. Their magnetic field is much more intense that standard iron or copper magnets. They are cooled to 4 K and lose virtually all resistance to the flow of electrons.

Superconductor – A material that when cooled below its critical temperature exhibits no electrical resistance. The critical temperatures range from .002 K to 18 K (-273 °C to -255 °C).

Synchrotron – A circular machine that accelerates subatomic particles to high energy by the repeated action of electric forces on the particles at each revolution. The particles are made to move in constant circular orbits by magnetic forces that continually increase in magnitude.

Tevatron – This circular accelerator was located at Fermi National Laboratory in Batavia, Illinois. Its pioneering superconducting magnets helped discover many nuclear particles including the bottom and top quarks. It also established the early parameters for research on the Higgs particle.

Particle Vocabulary

Antiparticles – Each particle has a partner, called an antiparticle, which is identical except that all of its charge-like properties (electric charge, strangeness, charm, etc.) are opposite to those of the particles. Examples are proton-antiproton, electron-positron, and neutrino-antineutrino. Collisions result in annihilation.

Atom – A particle of matter indivisible by chemical means. Atoms are the fundamental building blocks of all matter. Each element consists of a different kind of atom. All atoms are made up of a central, dense core (nucleus) made up of protons and neutrons (quarks) and orbiting electrons. Atoms are electrically neutral.

Collision – A close approach of two or more particles—protons, atoms or nuclei—during which quantities such as energy, momentum, and sometimes charges are exchanged.

Decay – Spontaneous disintegration of a particle into other particles as in the case of a neutron decaying into a proton, an electron or a neutrino. The total rest energy is less than the rest energy of the original object.

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

Hadron – Particles made up of two or three quarks bound together by the strong force (either a meson or a baryon).

Higgs boson – A very heavy, at present, theoretical elementary particle being intensively sought at the LHC. It would explain the difference between the massless photon and the massive W and Z bosons.

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

Lepton – An indivisible fundamental particle. There are six leptons plus their antiparticles. These particles do not undergo strong interactions.

Meson – The particle that is typically intermediate in mass between a lepton and a proton or neutron. The most common are the π-meson ("pion") and the K-meson ("kaon"). They are strongly interacting, short-lived elementary particles.

Muon – A charged lepton with a mass 10^5 times that of an electron. Muons decay spontaneously into an electron and a neutrino. (Intensity Frontier)

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

Neutron – A particle with a mass slightly larger than that of a proton, but with zero charge. A neutron is a hadron and is made up of three quarks (two down and one up).

Neutrino Oscillations – The process whereby a neutrino created with a specific lepton flavor (electron, muon, or tau) can later be measured to have a different flavor.

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

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. Protons do not decay and make up most of the matter in the universe.

Quark – A fundamental particle. There are six quarks and six antiquarks. Each quark and antiquark exists in three "colors." The names of the quarks are: up-down-strange-charm-bottom and top. The last two are sometimes referred to as beauty and truth.

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. Collision results are displayed as lego plots or jet trails.

Forces and Force Carriers

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

Gauge Bosons – These force-carrying particles mediate the interactions between weaker elementary particles. The W and Z bosons are the force carriers for the weak radioactive interactions. The photon is the force carrier for electromagnetic force and the graviton is the force carrier for gravity.

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

Graviton – A massless particle whose exchange between masses is thought to result in the gravitational force.

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

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.

Radiation – Emitted energy in the form of electromagnetic waves (photons) or ionizing particles (electrons, helium nuclei, etc.).

Strong Force – Force that binds quarks and holds the nucleus of the atom together. It is the strongest force in nature. Carried by gluons.

Weak Force – The interaction that controls radioactive decay.

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

Related Vocabulary

Acceleration – Any change in speed.

Astrophysicist – A scientist that studies the physical properties of celestial bodies and the interaction between matter and radiation in the interior of celestial bodies in interstellar space.

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.

Cosmic Frontier – Uses underground experiments and telescopes to reveal the nature of dark matter and dark energy using high-energy particles from space.

Dark Matter and Dark Energy – Make up 95% of the matter and energy of the universe. Dark matter makes up 23% of the universe and cannot be observed directly. Its existence is inferred from the gravitational tug it exerts on visible matter like galaxies. Dark energy makes up 72% of the universe. It is invisible but its existence is inferred from the accelerating expansion of the universe.

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.

Energy Frontier – Uses high-energy colliders to discover new particles and how their interactions can explain the architecture of the fundamental forces.

Experimental Physicist – A scientist who performs experiments to gather and interpret data in order to gain a better understanding of the universe.

Indirect Evidence – The data gathered using techniques that do not involve firsthand observation; evidence providing only a basis for making an inference.

Indirect Observation – The process of discerning information about an object or situation without seeing it with the naked eye.

Intensity Frontier – Uses intense (huge number) particle beams to uncover properties of neutrinos and observe rare processes that will tell us about new physics beyond the Standard Model.

Luminosity – The number of collisions per second in an experiment.

Macrocosm – A large system.

Matter – Anything that takes up space, has mass and is made of atoms.

Mass – Amount of matter (atoms and molecules) an object contains.

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

Radiation – Energy released in waves from the nucleus of an atom.

Radioactive – Undergoing spontaneous emission of energy as the nucleus breaks down.

Standard Model – The currently held representation of the twelve quarks and antiquarks along with the force carrying particles that makes up all matter.

Symmetry – A principle in which there is no change at all; sameness under some altered scrutiny.

Supersymmetry – A hypothesized extension of the Standard Model, which contains a complete symmetry between forces and particles. It would require the existence of yet unseen new particles and forces called superpartners.

Theoretical Physicist – A scientist who provides explanations for the data gathered by experimental physicists. They also devise experiments to observe and collect data in order to gain a better understanding of the universe.

APPENDIX C: Basic Science Process Skills

Skill	**Definition**	**Example**
Observing	Using the senses (or extensions of the senses) to gather information about an object or event.	Describing a pencil as yellow; looking at a melting ice cube to determine its changing shape; feeling water from a melting ice cube to determine its slipperiness / coldness.
Inferring	Making an educated guess (not just a guess) about an object or event based on previously gathered data or information, or making a conclusion based on reasoning cause and effect to explain an observation.	Saying that the person who used a pencil made a lot of mistakes because the eraser was well-worn; or stating that heat caused the melting of an ice cube that had been placed in water.
Measuring	Using both standard and non-standard measures or estimates to describe the dimensions of an object or event; i.e., making quantitative observations.	Using a meter stick to measure the length of a table in centimeters; using a clock to measure the time needed for an ice cube to melt; computing the average time for a 10-cc ice cube to melt.
Communicating	Using words or graphic symbols to describe an action, object, or event; applying mathematical rules and formulas to calculate quantities or determine relationships from basic measurements.	Describing verbally, in writing, or through a graphic, the change in height of a plant over time; computing the average time for a 10-cc ice cube to melt.
Classifying	Grouping, ordering, arranging, or distributing objects, events, or information into categories based on properties or criteria, according to some method or system.	Placing all rocks having a certain grain size or hardness into one group; taking objects such as buttons from a mixed collection and placing them in groups by some characteristic or arranging them in order according to some measure.

Skill	**Definition**	**Example**
Predicting	Stating the outcome of a future event or of future conditions expected to exist based on a pattern of evidence.	Predicting the height of a plant in two weeks based on a graph of its growth during the previous four weeks; stating, "an ice cube whose weight is twice that of another ice cube will require twice the time to melt."
Manipulating Materials	Handling or treating materials and equipment skillfully, effectively, and safely.	Arranging equipment and materials needed to conduct an investigation, handling chemicals in a safe manner; understanding sterile techniques.
Replicating	Performing acts that duplicate demonstrated symbols, patterns, or procedures.	Correctly repeating a series of actions following demonstrated or written instructions.

APPENDIX D: Integrated Science Process Skills

Skill	Definition	Example
Identifying and Controlling Variables	Being able to identify variables that will be constant or change under different conditions, and understanding how to design an experiment to get a meaningful outcome by holding most variables constant while manipulating independent and measuring dependent variables.	Listing or describing the factors that influence the rate at which an ice cube melts in air or water.
Creating Operational Definitions	Stating how to measure a variable in an experiment; defining the variable according to the actions or operations to be performed on or with it.	Stating that bean growth will be defined as the amount of change in height as measured from the top of the soil to the tip of the longest stem, in centimeters per week.
Formulating Hypotheses	Stating or constructing a testable statement, based on prior knowledge and logic, about the expected outcome of an experiment.	Making a statement to be used as the basis for an experiment, e.g. “if one ice cube is placed in cool water and an identical cube is placed in warm water, then the cube in the warmer water will melt first.”
Recording and Interpreting	Collecting bits of information about events that illustrate a specific situation; organizing and analyzing data that have been collected and drawing conclusions from it by looking for patterns.	Recording data from an experiment and forming a conclusion that relates trends in data to variables; studying a graph of data on possibly related variables and looking for a relationship.
Experimenting	Being able to conduct an experiment, including asking an appropriate question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing an unbiased experiment, and interpreting its results.	The entire process of conducting an experiment to determine the relationship between soil conditions and plant growth, populations and pollution, etc.

Skill	**Definition**	**Example**
Formulating Models	Creating a mental or physical model of a process, object, or event.	Drawing a diagram; producing a picture that illustrates information about ice cube melting; writing a description of the process of evaporation and condensation in the water cycle; illustrating by analogy.
Making Decisions	Identifying and choosing from alternatives after basing the judgment for the selection on justifiable reasons.	Predicting the consequences of different courses of action after analyzing differences in cost, social effects, environmental effects, etc.; using these reasons as the basis for making decisions.

APPENDIX E: Resources

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