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## Investigating a Neutrino

**Objectives:** Students will perform simple research on a neutrino.  
Students will analyze the history, structure, and relevance of the neutrino.  
Students will draw a neutrino.

**Level:** Middle School to High School

**Time:** One - two 50 minute class period(s)

**Materials:** Computer with Internet access  
Physics textbooks (if available)  
Newspaper clippings about neutrinos (see 2 attached articles)  
Colored pencils, crayons, etc

**Method:** The goal of this lesson is to familiarize students with the neutrino. The research will be useful background information to those students planning to tour the lab. For upper level classes, this might also be a great place to introduce The Standard Model in terms of neutrinos as leptons. If you opt to discuss The Standard Model, be sure to mention that neutrinos don't have mass in this model. The MINOS Project will tell us more about the mass of the elusive neutrino.

The following websites will be helpful; you may give them to your students as a time-saver.

<http://www.sudan/umn.edu> - Soudan Underground Lab

<http://www.lapp.in2p3.fr/neutrinos/aneut.html> - A complete history  
of neutrinos

<http://www.mpi-hd.mpg.de/hfm/CosmicRay/CosmicRaySites.html>

Links to several neutrino projects

<http://www.madsci.org/> - A site that allows students to ask

Scientists questions

<http://www-numi.fnal.gov/public/index.html> - Fermi National Accelerator

Lab site

<http://particleadventure.org/particleadventure/> - A fun, interactive tour of  
of modern physics. GREAT SITE - A MUST SEE

**Conclusion:** The questions posed in the activity are designed to engage students in active research. The students may have a difficult time answering all of the questions- some don't even have a single answer. However, the students will inherently increase their knowledge of the neutrino as they research the questions. It is imperative that you discuss the "answers" provided in the key with the class at the end of the lesson. Urge students to find discrepancies in their answers and ask them for probable sources of error.

The tour will address most of the questions posed in this activity; it will prepare the students for the concepts and terms used by the tour guide. Students will gain a better understanding and leave more excited about the MINOS when they come to the lab with some background information. Use the following background information to familiarize yourself and the class with the MINOS Project.

### *Background Information:*

A neutrino is a sub-atomic particle with no charge and very little mass. Neutrinos are produced from fusion reactions in the sun and radioactive decay. There are also neutrinos left over from the big bang; some estimate that there are about 330 neutrinos per  $\text{cm}^3$  of the Universe. Neutrinos are extremely small; in fact, they are so small they travel through ordinary matter like rocks, walls, and even you. Neutrinos are known to change, or oscillate, from one type to another. There are three different types (flavors) of neutrinos: muon, tau, and electron. The symbols for these neutrinos, respectively, are  $\nu_\mu$ ,  $\nu_\tau$ , and  $\nu_e$ .

The majority of research being performed on the neutrino involves its oscillation and mass. If we can accurately predict the mass of a neutrino, we might be able to account for some of the missing matter of the Universe. By examining how quickly stars travel in the outer disk of our own Milky Way Galaxy and rotational velocity curves of galactic clusters we are able to determine that there must be other matter that we cannot see this is responsible for gravity we know is present. In fact, these discrepancies suggest that 80% of the matter in the Universe may be in a form we have not detected yet - dark matter. This dark matter may be a significant part of the missing matter of the Universe; the mass of neutrinos is believed to make up some of this dark matter. If we can determine the mass of this dark matter, we can learn more about our size, shape, and life cycle of our Universe.

The MINOS (main injector neutrino oscillation search) Project will analyze the oscillation of neutrinos. The Fermi Lab will shoot beams of neutrinos from their facility in Batavia, Illinois to the 5,500-ton target of steel at the Soudan Underground Lab in Soudan Minnesota. The Fermi Lab will produce, almost exclusively the muon types of neutrino. It is expected that during the .0025 second 735-kilometer trip from Batavia to Soudan the muon neutrino will oscillate into one of the two other types of neutrinos. When the beam reaches Soudan it will hit the target; it consists of 486 one-inch thick plates of steel with 484 plastic scintillator sheets sandwiched between each plate. The scintillator along with fiber optics running through it is the heart of the detector. Most of the neutrinos will pass right through the target and continue to Canada and ultimately the end of the Universe. A few of the neutrinos, however, will collide with the nucleus of an atom in the steel and produce one of three particles. The particle produced will produce a unique light pattern; this pattern will tell us which type of neutrino hit the target. By comparing the neutrinos that left Batavia to the neutrinos that arrive in Soudan physicists will determine the probability of neutrino oscillations. Using quantum mechanics physicists will use this probability to determine the mass difference between the neutrinos. This mass difference will ultimately tell us more about the mass of the mysterious neutrino and the mass of our Universe.

**May 21<sup>st</sup>, 2002**

## **Scientists Try to Pin Down Elusive Neutrinos**

**By Bijal P. Trivedi**

**National Geographic Today**

Deep in a 19th-century iron mine in a Minnesota state park, in a football-field-size cavern, physicists are building a 6,000-ton steel trap for neutrinos, sub-atomic particles so elusive scientists don't even know if they have any mass.

Neutrinos rarely interact with other matter but are essential in the running of the universe. The sun, for instance, couldn't shine without them.

"There are 300 neutrinos in every cubic centimeter of the entire universe," says Stanley Wojcicki, a Stanford University physics professor with MINOS (Main Injector Neutrino Oscillation Search), an international consortium determined to pin down the neutrinos, which have been around since the universe began. More are generated each time a star collapses.

The U.S. \$160 million project is designed to encourage the ghost-like particles to stop by long enough for scientists to take a closer look at just what they are, how they behave and what it all means in understanding the nature of the universe. Several hundred researchers from 30 institutions in the United States, Great Britain, Russia, China, and Greece are involved.

Scientists want to know if the neutrinos change form as they travel, which would suggest they have mass after all. The findings may challenge prevailing theories about how it all began and overturn fundamental laws of physics, predicts

Janet Conrad, a neutrino physicist at Columbia University.

"If a neutrino has mass, that tells you that the Standard Model is wrong. And that is exciting," she says. Since the 1960s, physicists have used the Standard Model to explain how the universe works. In that model, neutrino mass should be zero.

To encounter enough of the shy particles for the study, MINOS will send an intense beam of neutrinos from an accelerator at the Fermilab near Chicago to a detection chamber in Minnesota, one-half mile below the Soudan Underground Mine State Park, not far from the Canadian border.

The neutrinos will be shot 450 miles (735 kilometers) through the Earth, making the trip in a fraction of a second, in a series of experiments beginning in 2005. The Soudan laboratory, one of a handful of underground physics laboratories around the world, has also been used in researching proton decay as a way of unraveling the mysteries of the universe.

Accelerating the stream and trapping the neutrinos in an underground physics lab will increase the chances of meeting up with the particles, but it will take trillions of neutrinos to obtain even a few thousand interaction "events," as the scientists call them.

Most neutrinos will pass through all of the nearly 500, 12-ton steel plates in the trap without ever bumping to any of the steel atoms. A few, however, will collide with atomic nuclei in the plates, generating a shower of electrically charged particles to trigger a flash of light.

Wolfgang Pauli, who won the Nobel Prize in physics in 1945, suggested the existence of neutrinos in 1930 as an explanation for an apparent nonconservation of energy when radioactive particles decayed, but it wasn't until 1956 that anyone ever detected one. Subsequent research identified three neutrino species—electron, muon, and tau.

In 1998 a detector in Japan called the Super-Kamiokande indicated that muon neutrinos generated in the upper atmosphere were disappearing. Scientists suspected that the muons were transforming into heavier neutrinos Super-Kamiokande could not detect.

"The disappearance of these neutrinos was a shock because it implied they had mass," says Dr. Conrad. "MINOS will try to determine what the mass is and where the neutrinos are going—those are the big questions."

In a world where neutrinos have mass, undiscovered particles may exist in dimensions beyond the three spatial dimensions and a fourth dimension of time that man usually uses to describe phenomena.

If neutrinos have mass, they would also be associated with gravity, says Conrad. Neutrinos could "smooth out the universe" by pulling and tugging at other objects. "Without neutrinos' mass we might have a much lumpier universe," she suggests.

With so many neutrinos in the universe, their combined mass would be truly astronomical. "The neutrino mass would rival the mass of all the stars and galaxies you can see," says Wojcicki. "It's very exciting from the point of view that we really may be probing very, very new physics."

*This story aired on National Geographic Today  
Wednesday, May 22, 2002*

**August 14, 2003**

**Data-Taking Begins at MINOS Neutrino Detector, Half a Mile Underground**

**Press contact: Kurt Riesselmann,  
Fermilab Public Affairs, 630-840-3351,  
[kurtr@fnal.gov](mailto:kurtr@fnal.gov)**

*Photos are available at*

[http://www.fnal.gov/pub/presspass/press\\_releases/MINOS\\_photos/index.html](http://www.fnal.gov/pub/presspass/press_releases/MINOS_photos/index.html)

*More information on the experiment at*

<http://www-numi.fnal.gov/>

Batavia, Ill.-Scientists of the MINOS collaboration at the Department of Energy's Fermi National Accelerator Laboratory today (August 14) announced the official start of data-taking with the 6,000-ton detector for the Main Injector Neutrino Oscillation Search. Physicists will use the MINOS detector, located deep in an historic iron mine in northern Minnesota, to explore the phenomenon of neutrino mass.

In July, after four years of mining and construction, workers finished building the first of two detectors of the ambitious MINOS particle physics experiment. Today, after completing the hardware and testing the detector's systems, scientists announced the official startup of data-taking with the MINOS "far" detector, ahead of the scheduled completion in April 2004. Technicians will complete the assembly of a "near" detector, smaller in size than the far detector, at Fermilab in August 2004.

"This is an important milestone in the worldwide quest to develop neutrino science," said Dr. Raymond L. Orbach, director of DOE's

Office of Science. "The MINOS detector in Soudan, Minnesota, together with the new Fermilab neutrino beam line, will provide a detailed look at the secrets behind neutrino oscillations. It will complement the large-scale neutrino projects in Japan, Canada and Europe. Significantly, the completion of the detector comes nine months ahead of schedule."

The looming 100-foot-long detector consists of 486 massive octagonal planes, lined up like the slices of a loaf of bread. Each plane consists of a sheet of steel about 25 feet high and one inch thick, covered on one side with a layer of scintillating plastic. To construct the detector, technicians had to transport all detector components in small sections via a narrow mine shaft in a tiny historic elevator cage that once transported miners underground.

"It was like building a ship in a bottle," said MINOS spokesperson Stanley Wojcicki, physics professor at Stanford University. "We needed to bring all the material underground and assemble it right there. The last step was to install a magnetic coil and energize it. MINOS is the only large-scale neutrino experiment underground that can separate neutrino and antineutrino interactions, allowing us to look for differences in their behavior."

At present, the new detector is recording cosmic ray showers penetrating the earth. The data will provide first tests of matter-antimatter symmetry in neutrino processes. In early 2005, when the construction of a neutrino beamline at Fermilab is complete, the experiment will enter its next phase. Scientists will use the far detector to "catch" neutrinos created at Fermilab's Main

Injector accelerator in Batavia, Illinois. The neutrinos will travel 450 miles straight through the earth from Fermilab to Soudan - no tunnel needed. The detector will allow scientists to directly study the oscillation of muon neutrinos into electron neutrinos or tau neutrinos under laboratory conditions. More than a trillion man-made neutrinos per year will pass through the MINOS detector in Soudan. Because neutrinos rarely interact with their surroundings, only about 1,500 of them will make a collision with an atomic nucleus inside the detector. The rest will traverse the detector without leaving a track.

Scientists have discovered three different types of neutrinos: electron neutrinos, muon neutrinos, and tau neutrinos. The particles play an important role in stellar processes like the creation of energy in stars as well as supernova explosions. Experimental results obtained over the last five years have confirmed that the

evasive particles have mass and switch back and forth among their three different identities while traveling through space and matter. Scientists expect the MINOS experiment to provide the best measurement of neutrino properties associated with the so-called "atmospheric" oscillations.

Funding for the MINOS experiment has come from the Office of Science of the U.S.

Department of Energy, the British Particle Physics and Astronomy Research Council, the U.S. National Science Foundation, the State of Minnesota and the University of Minnesota. More than 200 scientists from Brazil, France, Greece, Russia, United Kingdom and the United States are involved in the project.

Fermilab is a national laboratory funded by the Office of Science of the U.S. Department of Energy, operated by Universities Research Association, Inc.

List of institutions collaborating on MINOS: <http://www-numi.fnal.gov/collab/institut.html>

**Brazil:**

University of Campinas  
University of Sao Paulo

**France:**

College de France

**Greece :**

University of Athens

**Russia:**

ITEP-Moscow  
Lebedev Physical Institute  
IHEP-Protvino

**United Kingdom:**

University of Cambridge  
University College London, London  
University of Oxford  
Rutherford Appleton Laboratory  
University of Sussex

**United States:**

Argonne National Laboratory  
Brookhaven National Laboratory  
California Institute of Technology  
Fermi National Accelerator Laboratory  
Harvard University  
Illinois Institute of Technology  
Indiana University  
Livermore National Laboratory  
Macalester College, Minnesota  
University of Minnesota, Minneapolis  
University of Minnesota, Duluth  
University of Pittsburgh  
Soudan Underground Laboratory  
University of South Carolina  
Stanford University  
Texas A&M University  
University of Texas at Austin  
Tufts University  
Western Washington University  
University of Wisconsin-Madison





## Investigating a Neutrino

Name \_\_\_\_\_

Date \_\_\_\_\_

Class \_\_\_\_\_

**What exactly is a neutrino? Neutrinos are the subject of intense research across the world. Some scientists hypothesize that they may be a critical part of the missing mass of the Universe.**

**You have been hired to draw a neutrino; however, no person has ever *seen* a neutrino. In order to draw your neutrino successfully you will need to research the sub-atomic particle to learn what they are and how they behave.**

**Some good places to research a neutrino are the Internet, physics books, and newspapers.**

**Answer the following questions before you begin:**

**1. Who was the neutrino proposed by (a)? When (b)?**

(a) \_\_\_\_\_

(b) \_\_\_\_\_

**2. How was the neutrino discovered (a)? When (b)?**

(a) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(b) \_\_\_\_\_

**3. What is a neutrino? Does it have mass-how much or little? How fast does it travel? Where does it come from? What is its function?**

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4. **How is the neutrino similar to an atom? How is it different?**

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5. **What kind of research is being performed on the neutrino? Where?**

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6. **What is dark matter? Why is it important to the Universe? How does it relate to neutrinos? Have we detected it? (If so, where? If not, why?)**

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7. **Write down 3 interesting facts about a neutrino.**

1. 

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2. 

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3. 

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8. **Draw your neutrino on a piece of paper. Include any relevant information from your research in order to support *why* you drew *what* you drew. Remember, we can't actually *see* a neutrino but we can see how it interacts with matter; however, you will draw what you *hypothesize* it looks like on the very smallest, particle level.**

## Answer Key

**1. Who was the neutrino proposed by (a)? When (b)?**

Wolfgang Pauli  
1930

**2. How was the neutrino discovered (a)? When (b)?**

In 1930 Wolfgang Pauli proposed a solution to the missing energy in nuclear beta decays, namely that it was carried by a neutral particle. This was in a letter to the Tubingen Congress. Enrico Fermi in 1933 named the particle the “neutrino” and formulated a theory for calculating the simultaneous emission of an electron with a neutrino. Pauli received the Nobel Prize in 1945 and Fermi in 1938. The problem in detection was that the neutrinos could penetrate several light years depth of ordinary matter before they would be stopped.

**3. What is a neutrino? Does it have mass-how much or little? How fast does it travel? Where does it come from? What is its function?**

A neutrino is a sub-atomic particle with no charge and very little mass.

The mass of a neutrino is the subject of intense research across the globe.

If it has mass, it is a small amount; however, due to the sheer number of neutrinos the mass of all of them would be significant.

The neutrino travels at almost the speed of light.

Neutrinos are emitted during beta decay.

Sources of the neutrino include the big bang and sun.

Accept any answer for a function-is there a function?

**4. How is the neutrino similar to an atom? How is it different?**

The neutrino is similar to an atom because it’s electrically neutral.

Neutrinos are much smaller and move much more quickly.

An atom is composed of many smaller particles (quarks, leptons, and gluons)

Whereas a neutrino just “is” – it is a sub-atomic particle.

All atoms are much more massive than a neutrino.

**5. What kind of research is being performed on the neutrino? Where?**

The main research being performed on neutrinos are oscillation experiments.

These experiments try to tell us more about the mass of a neutrino. GALLEX,

HOMESTAKE, CHOOZ, NOMAD, AND MINOS might be some possible answers; this list is by no means exhaustive.

**6. What is dark matter? Why is it important to the Universe? How does it relate to neutrinos? Have we detected it? (If so, where? If not, why?)**

Dark matter is matter that does not absorb electromagnetic radiation. Scientists theorize that as much as 96% of the Universe consists of dark matter.

We know the dark matter is there due to the gravitational interactions we witness; there simply has to be more matter to account for the gravity we “see”.

Neutrino mass may contribute to some of this dark matter mass.

As of 2003, we have not detected dark matter.

**7. Write down 3 interesting facts about a neutrino.**

Accept all reasonable answers.

Students will no doubt find it interesting that neutrinos will pass right through ordinary matter.

**8. Draw your neutrino on a piece of paper. Include any relevant information from your research in order to support *why* you drew *what* you drew. Remember, we can't actually *see* a neutrino but we can see how it interacts with matter; however, you will draw what you *hypothesize* it looks like on the very smallest, particle level.**

Accept all reasonable drawings.

Remind students that we cannot see a neutrino because they are too small. At the MINOS Project we are actually detecting the particles emitted from the interaction of neutrino and iron nucleus via fiber optics, not the neutrinos themselves.

Artist Joseph Giannetti has created a mural that is his artistic rendition of the neutrino/nucleus interaction. The mural is located at the Soudan Lab site, 2341 feet underground, and is included in the tour.

