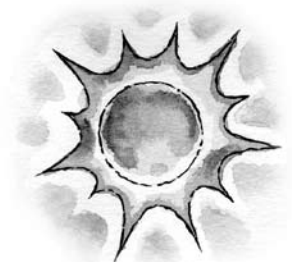
NOVA

Original broadcast: February 21, 2006

PBS

The Ghost Particle

PROGRAM OVERVIEW



NOVA explores the 70–year struggle so far to understand the most elusive of all elementary particles, the neutrino.

The program:

- relates how the neutrino first came to be theorized by physicist Wolfgang Pauli in 1930.
- notes the challenge of studying a particle with no electric charge.
- describes the first experiment that confirmed the existence of the neutrino in 1956.
- recounts how scientists came to believe that neutrinos—which are produced during radioactive decay—would also be involved in nuclear fusion, a process suspected as the fuel source for the sun.
- tells how theoretician John Bahcall and chemist Ray Davis began studying neutrinos to better understand how stars shine—Bahcall created the first mathematical model predicting the sun's solar neutrino production and Davis designed an experiment to measure solar neutrinos.
- details how Davis discovered only one-third of the neutrinos predicted and how those results prompted scientists to wonder over the years whether something was wrong with Davis' experiment, whether Bahcall's calculations were incorrect, or whether the sun was operating differently than first believed.
- notes how scientists later began to rethink their ideas about what a neutrino is and to wonder whether the different types of neutrino—electron, muon, and tau—could be the key to the problem.
- explains that while neutrinos can change from one type to another, the Standard Model predicted a massless neutrino that traveled at the speed of light and, therefore, could not experience time and would be unable to change.
- reports on a Japanese detector experiment that indicated that neutrinos do experience time, and therefore have mass and can change.
- describes how the first detector designed to detect all three types of neutrinos confirmed Bahcall's predicted number of neutrinos and verified that neutrinos do change as they travel from the sun to Earth.
- relates how future experiments are investigating the neutrino's properties and exploring whether the neutrino may have played a role in the creation of matter.

BEFORE WATCHING

1 Ask students if they can think of some things they cannot directly see but they know exist. Have them provide examples and reasoning for how they know these things exist. *(Some examples and evidence of their existence include: [bacteria and viruses—illnesses], [energy—heat from the sun], [magnetism—effect on a compass], and [gravity—objects falling towards Earth].)* How do scientists observe and measure things that cannot be seen with the naked eye? (They use instruments such as microscopes and telescopes, and they look at how unseen things affect other objects.)

2 Review the structure of an atom, including protons, neutrons, and electrons. Ask students what they know about subatomic particles, i.e., any of the various units of matter below the size of an atom. To help students better understand the size of some subatomic particles, develop an analogy with the class using the Atomic Scale found in the Background section on page 3.

AFTER WATCHING

1 Review with students the laws of conservation of mass and energy. (Matter can be converted from one form to another but neither created nor destroyed.) Ask why this law is important. *(Pauli predicted the neutrino existed because energy is conserved in reactions. Other scientists were able to predict the number of neutrinos they should be able to detect, because they know energy is conserved in reactions in the sun.)*

2 Some of the scientists in the program exhibit character traits that help them be successful in their work. How did patience, open-mindedness, and perseverance contribute to the discoveries and the scientists' success in this program?

CLASSROOM ACTIVITY

Activity Summary

Students collect evidence to make inferences about an object hidden inside a sealed box.

Materials for Each Student

- copy of "Black Box Mystery" student handout

Materials for Each Team

- box with unknown object inside

Background

In 1930, Wolfgang Pauli postulated the existence of a small elementary particle with no charge and very little or no mass. He proposed this particle because scientists were measuring less energy after a process known as beta decay than before it occurred, conflicting with the law of conservation of energy. Pauli's new theoretical particle balanced the energy equation. (The particle was later named the neutrino in 1934 by Enrico Fermi.) Further studies showed that the neutrino was also necessary to maintain the conservation laws of momentum and spin. There are currently three known types, or "flavors," of neutrinos: electron, muon, and tau neutrinos.

Billions of neutrinos pass through Earth each second, but since they are particles with no electric charge and have very little mass, they only interact weakly with other kinds of matter and are difficult to detect. Scientists study neutrinos indirectly by looking at the results of their interactions with other forms of matter such as heavy water or chlorine.

To help students understand the size of subatomic particles, you may want to share the chart on the following page with them and as a class develop a sample analogy regarding atomic sizes. (For example, one sample analogy would be "If an atom filled the distance from Boston to Cleveland, the nucleus would be about the length of a football field; a proton would be about the height of a three-story apartment building; and an electron and a subatomic particle called a quark would be about a centimeter wide, or the width of a blueberry.")

LEARNING OBJECTIVES

Students will be able to:

- think critically and logically to raise questions.
- identify questions that can be answered through investigation.
- formulate and test hypotheses.
- develop predictions and descriptions based on investigations.

KEY TERMS

conservation of energy: States that the total amount of energy in a closed system remains constant.

conservation of mass: States that the products of a chemical reaction have the same total mass as that of the reactants.

lepton: A family of elementary matter (or antimatter) particles that includes the electrically charged electron, muon, and tau and their antimatter counterparts. The family also includes the electrically neutral electron-neutrino, muon-neutrino, and tau-neutrino and their antimatter counterparts.

neutrino: A lepton with very little mass and no electric charge.

particle: A subatomic object with a definite mass and charge. Currently known elementary matter particles are grouped into categories of quarks and leptons and their antimatter counterparts.

CLASSROOM ACTIVITY (CONT.)

Atomic Scale

	scale in meters	scale in 10^{16} meters	sample analogy
atom	10^{-10}	1,000,000	something 100,000,000 cm or 1,000,000 m (distance from Boston to Cleveland)
nucleus of atom	10^{-14}	100	something 10,000 cm or 100 m (football field length)
proton	10^{-15}	10	something 1,000 cm or 10 m (height of 3-story apartment building)
quark or electron	$\leq 10^{-18}$	$\leq$.01	something about 1 cm such as a blueberry

Scientists have developed instruments to help them study subatomic particles, such as particle colliders and detectors. In this activity, students will experiment with what it is like to gain information about something they cannot physically see. Students will generate and test questions to try to identify an unseen object. Based on the evidence they gather, they will infer what is in their mystery box.

Procedure

1. Discuss how scientists sometimes collect evidence to infer the presence of objects they cannot see. Tell students that in this activity, they will collect evidence to make inferences about an object hidden inside a sealed box.
2. Create each mystery box by placing a common classroom object (such as a roll of tape, scissors, or a beaker) inside a box and sealing it with tape or a rubber band.
3. Set up a table that displays 10 to 15 common classroom objects, some of which are similar to or exactly the same as the objects in the mystery boxes. Provide additional empty boxes as well.
4. Organize students into groups and distribute the "Black Box Mystery" student handout to each student and a mystery box to each group. Explain that the challenge is to design ways to gather information about a mystery object that students can't see or test directly.
5. Point out that the mystery objects are similar to some of the objects on the display table. Students can use information they know about these objects to help them learn more about the unknown mystery objects.

STANDARDS CONNECTION

The "Black Box Mystery" activity aligns with the following National Science Education Standards (see books.nap.edu/html/nses).

Grades 5–8
Science Standard A
Science as Inquiry
Abilities necessary to do scientific inquiry

GRADES 9–12
Science Standard A
Science as Inquiry
Abilities necessary to do scientific inquiry

Video is not required for this activity.

Classroom Activity Author
Tanya Gregoire has taught at Brookline Public Schools in Massachusetts and is coauthor of "Museum of Science Activities for Kids." This classroom activity originally appeared in the companion Teacher's Guide for NOVA's "Hunt for Alien Worlds" program.

CLASSROOM ACTIVITY (CONT.)

6 After they have completed the activity, have students compare the process of inferring the identity of a mystery object sealed in a box to inferring the existence and number of neutrinos detected by their effect on another substance. Then have groups consider how inference plays a role in their daily lives. Explore group answers in a whole-class discussion.

7 As an extension, provide teams with a black box that has an object taped to the bottom of the box. Provide teams with skewers, rulers, pencils, and grid paper. Have teams measure their objects and draw them on grid paper. Ask whether measuring made the object easier to identify. Discuss how specific measurements sometimes help scientists better define things they cannot see.

ACTIVITY ANSWER

Students will design a variety of tests to gather information about the mystery object. For example, they might determine the weight of the object by comparing the weight of the mystery box to the weight of an empty box. They might shake the box and listen to the sound the object makes. Or they might try to determine the object's shape by the way it strikes different points of the box when shaken. They could then take a known object from the display table and put it through similar tests. Students might also rule out objects that are unlikely or impossible, such as objects that are too large to fit in the box.

If students arrive at immediate conclusions, direct them to return to the evidence by asking questions like *How do you know that?* Remind students to evaluate their inferences by comparing them to the evidence they've collected. Inferences that don't include all of the evidence are not necessarily wrong but may be less believable. Point out that there is a range of plausible explanations, some being more likely than others.

Discuss with students whether the real identity of the mystery object should be revealed. By not allowing students to see what the object is at the end, the focus of the activity remains not on getting the right answer but on developing plausible inferences, or conclusions, that are supported by evidence.

Student Handout Questions

1 What inferences can you make about the object? List them on a separate sheet and include the evidence that supports them. *Student answers will vary based on the tests they conducted.*

2 What situations in your daily life might call for inference? List the situations and the evidence you use to support those situations. *Student answers will vary. One example of a daily life inference might involve inferring whether someone is in the bathroom. Evidence such as a closed door, the sound of running water, and a bathrobe missing from a sibling's bedroom could be used to infer that someone is in the bathroom.*

Major funding for NOVA is provided by Google and BP. Additional funding is provided by the Howard Hughes Medical Institute, the Corporation for Public Broadcasting, and public television viewers.

Google
bp
HHMI
cpb

LINKS AND BOOKS

Links

NOVA—The Ghost Particle
www.pbs.org/nova/neutrino
Read seven steps to making a good science film, learn of two scientists who spent their careers searching for the solar neutrino, explore neutrino-hunting projects worldwide, and view a time line detailing the pursuit of the elusive particle.

How Do We Know Protons, Electrons, and Quarks Really Exist?
www.nsta.org/main/news/stories/science_and_children.php?category_ID=86&news_story_ID=51054
Suggests ways of addressing the existence of invisible particles.

Solving the Mystery of Missing Neutrinos
nobelprize.org/physics/articles/bahcall
Describes how scientists solved the solar neutrino mystery.

What's a Neutrino?
www.ps.uci.edu/~superk/neutrino.html
Provides a detailed look at the history of neutrinos, along with in-depth reviews of the different experiments and devices used to detect neutrinos.

Books

A Tour of the Subatomic Zoo: A Guide to Particle Physics
by Cindy Schwarz and Sheldon Glashow.
American Institute of Physics, 1996.
Introduces the ideas, terminology, and techniques of high-energy physics and provides historical views of matter from the atom to the quark.

The World of Atoms and Quarks
by Albert Stwertka.
Twenty-First Century Books, 1995.
Traces the history of atomic theory in physics and includes a guide to elementary particles.

Black Box Mystery

Seeing is believing, right? Well, just because you can't see something doesn't mean it isn't there. There's a lot you can learn about something without seeing it. Try the activity below and "see" for yourself.

Challenge

Hidden inside your box is an object. You can't see it, but your job is to find out as much as you can about it to support an inference of what it might be.

What kinds of questions might you ask to find out more about the object?

What kinds of tests can you design to help you answer these questions?

After you have completed your tests, answer the questions on this page.

Questions

Write your answers on a separate sheet of paper.

1 What inferences can you make about the object? List them on a separate sheet and include the evidence that supports them.

2 What situations in your daily life might call for inference? List the situations and the evidence you use to support those situations.

Test	Reason for Test	Evidence from Test