why are neutrinos important?

Inside the proton

In the 1970s physicists began using neutrinos to learn about what goes on inside protons and neutrons – the particles that make up the nuclei of atoms. In these experiments, billions of neutrinos were produced in high-energy particle accelerators at the European laboratory, CERN, near Geneva, and at the Fermi National Accelerator Laboratory in Illinois.

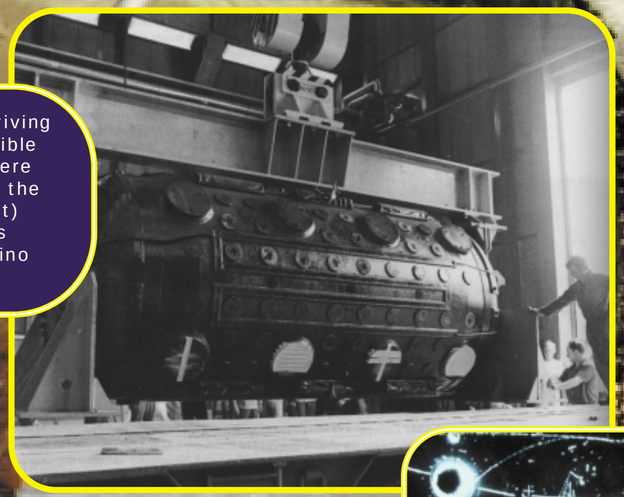
One of the most famous experiments was with a 4.8m long detector called Gargamelle, which was filled with 18 tonnes of liquid Freon, a compound of carbon, fluorine and bromine. This is a particularly dense liquid with the best chance of stopping a neutrino. Occasionally, a neutrino on its way through Gargamelle would interact with a proton or a neutron in the liquid, and the particles produced would leave visible trails of bubbles. This experiment, and others like it, showed that protons and neutrons are built from more fundamental particles, which are known as "quarks".

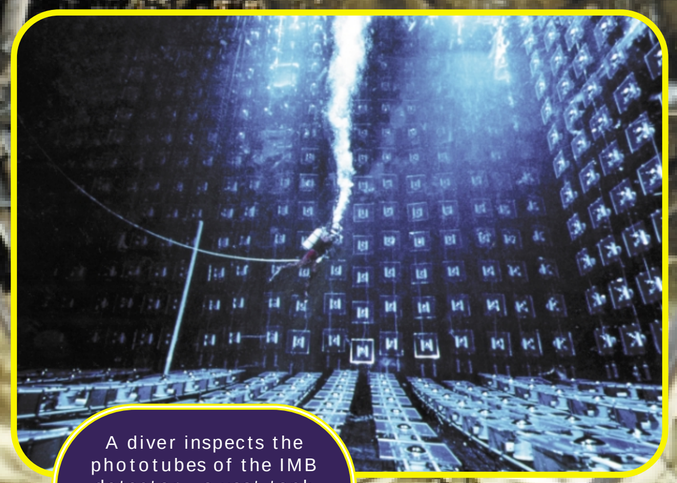
Inside the Sun

The Sun is mainly hydrogen, and it releases energy when nuclei of hydrogen (the lightest element) fuse to make helium (the next lightest) at its core. These reactions emit a continuous stream of neutrinos as protons change into neutrons in the first stage of the fusion process. The energy we see as light from the Sun takes an amazing 1 million years to travel from the centre of the Sun, but the weakly interacting neutrinos take only 3 seconds! So neutrinos give us a direct view into the very heart of the Sun.

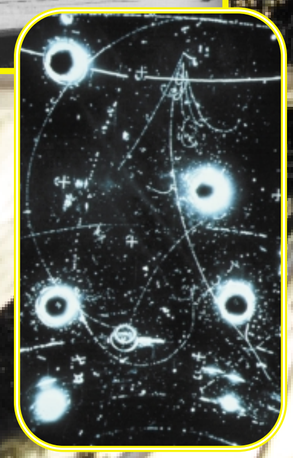
Physicists have been detecting neutrinos from the Sun since the 1960s. The first famous experiment to do so used 380,000 litres of perchloroethylene (dry cleaning fluid) contained in a tank 1500m below ground in a gold mine in South Dakota. This detector has been observing neutrinos at the rate of about 1 every 2 days for more than 25 years. However, this is only one-third of the rate expected. During the 1980s, several other experiments began to look for solar neutrinos, all using different techniques. They also detected too few neutrinos.

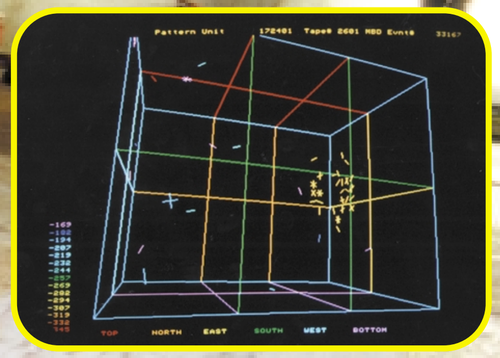
The bubble chamber Gargamelle arriving at CERN. Four "port holes" are visible along its length, where cameras were positioned to take photographs of the bubble-tracks inside. (lower right) Tracks from a spray of particles produced when an invisible neutrino hit a nucleus in the lqiuid.

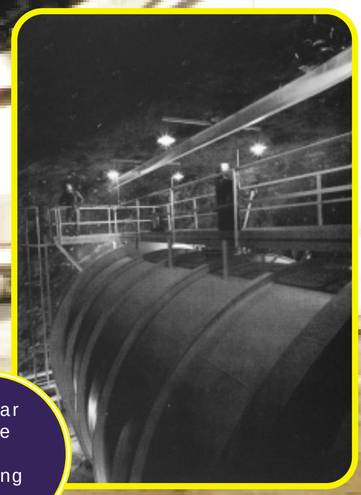




A diver inspects the phototubes of the IMB detector – a vast tank containing 8000 tonnes of water in a salt mine near Cleveland, Ohio. (below) Computer reconstruction of the interaction of a neutrino from supernova 1987a.







The main tank of the solar neutrino detector in the Homestake gold mine, South Dakota – 14.5m long and 6.1m across.

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Where are the missing solar neutrinos?

One exciting possibility is that, on their way out through all the material in the Sun, the neutrinos are changing type. The neutrinos emitted in the initial reactions will be electron-neutrinos, and so far the experiments have all been designed to detect electron-neutrinos. So if the electron-neutrinos changed into muon-neutrinos or tau-neutrinos on their way out of the Sun, they would not be detected. This possibility is exciting because theory shows that neutrinos can change in this way only if they have some mass – although this mass must be very small as no other kinds of experiment have succeeded in measuring it.

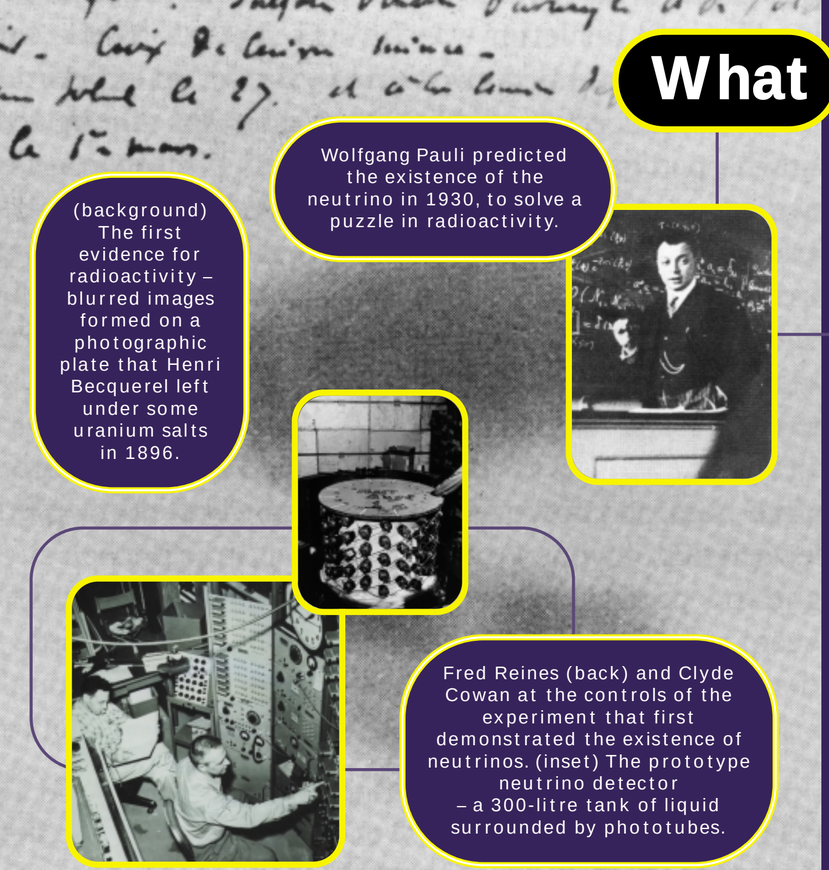
To test the idea of changing neutrino types, UK physicists have joined forces with others from Canada and the US to build a new solar neutrino detector. The Sudbury Neutrino Observatory, 2070m deep in a working nickel mine in Ontario, contains 1000 tonnes of 'heavy' water to detect the neutrinos. In heavy water, the hydrogen nuclei contain a neutron as well as a proton. This allows the neutrinos to react in different ways, so that muon- and tau-neutrinos can be detected, as well as electron-neutrinos.

Neutrinos in the Universe

Does it matter whether neutrinos have any mass? Neutrinos appear to be one of the truly fundamental types of particle in the Universe, together with electrons, muons, taus and various types of quark. These are the basic building blocks of the Universe, and it is important that any theory of the structure of matter should be able to describe them properly. The measurement of small masses for the neutrinos would have a tremendous impact on these theories.

Neutrinos with mass would also influence theories of the evolution of the Universe. Neutrinos are the commonest known particle, and if they have a small mass they could comprise some, if not all, of the so-called "dark matter" in the Universe. This is matter that astronomers know must exist from studying the motion of stars and galaxies, but which nevertheless does not shine, even invisibly through the emission of radio waves or X-rays, for example. If neutrinos turn out to make up a significant fraction of the dark matter, they would be true "masters of the Universe"!

Background picture: The main spherical vessel of the Sudbury Neutrino Observatory, in Canada, is constructed from transparent plastic. The geodesic structure surrounding it supports the 6400 phototubes that will detect light from neutrino interactions.



(background) The first evidence for radioactivity – blurred images formed on a photographic plate that Henri Becquerel left under some uranium salts in 1896.

Wolfgang Pauli predicted the existence of the neutrino in 1930, to solve a puzzle in radioactivity.

Fred Reines (back) and Clyde Cowan at the controls of the experiment that first demonstrated the existence of neutrinos. (inset) The prototype neutrino detector – a 300-litre tank of liquid surrounded by phototubes.

What is a neutrino?

Neutrinos are probably the nearest thing to nothing that something can be! They are tiny particles with no electric charge and very little mass, if any. They interact with other particles of matter so weakly that they can pass right through the Earth as if it were not there! But if neutrinos are almost nothing, how do we know they exist at all?

In the 1920s, scientists were puzzled because energy seemed to go missing in beta-decay. This is the form of radioactivity in which the radioactive nucleus emits an electron. To solve the problem, Wolfgang Pauli, an Austrian physicist, proposed that tiny neutral particles must be emitted together with the electrons. These neutral particles would escape undetected with some of the energy released in the process.

Pauli's particles became known as "neutrinos", but they were not proved to exist until the 1950s. By then, physicists had discovered nuclear fission, and knew that if neutrinos existed then billions would be emitted by the reactions in a nuclear bomb or a nuclear reactor. Two Americans, Clyde Cowan and Fred Reines, realised that a reactor would emit so many neutrinos that a few might interact in a detector, even though most of the neutrinos would go straight through. In 1956, they were able to send Pauli a telegram to say that they had succeeded – they had at last detected a neutrino.

Since then, physicists have discovered that there are three types of neutrino. The neutrinos emitted in beta-decay are related to the familiar electron. Indeed, they behave just like electrons with no electric charge. The other two types of neutrino are like uncharged versions of charged particles related to the electron – the "muon" and the "tau". To emphasise the differences between them, the three neutrinos are called the "electron-neutrino", the "muon-neutrino" and the "tau-neutrino".

more

Further Information

If you would like to know more about neutrinos, try the following resources:

World Wide Web sites
A first stop for particle physics in the UK
http://hepweb.rl.ac.uk/ppUK/

All about neutrinos
http://wwwlapp.in2p3.fr/~verkindt/neutrinos/aneut.html

The Sudbury Neutrino Observatory home page
http://www.sno.phy.queensu.ca/

An introduction to particle physics
http://durpdg.dur.ac.uk/lbl/cpep/adventure.html

Books
Christine Sutton
Spaceship Neutrino
Cambridge University Press 1992

Gordon Fraser, Egil Lillestol and Inge Sellevag
The Search for Infinity
Mitchell Beazley 1994

PPARC also publishes information on a variety of topics related to physics and astronomy, to help increase public awareness of the UK's achievements in science and technology. Find out more by visiting the PPARC World Wide Web site:
http://www.pparc.ac.uk

Particle Physics and Astronomy Research Council

The Particle Physics and Astronomy Research Council (PPARC) is the UK Government strategic science investment agency for research in:

- **Particle Physics**
- **Astronomy**
- **Space Science**

This support is provided by funding UK researchers and by ensuring that they have access to world-class facilities in the UK and overseas. The Council pays the UK's subscription to the science programmes of the European Laboratory for Particle Physics (CERN) and the European Space Agency (ESA).

PPARC recognises the importance of its science in assisting wealth creation; in post-graduate training; and in motivating young people towards an interest and career in science generally.

Front cover: Bubble-tracks created by particles produced in a neutrino collision inside the Big European Bubble Chamber at CERN, Switzerland.

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Acknowledgements:
Photos supplied by: AIP Niels Bohr Library, Los Alamos National Laboratory, IMB, CERN, European Southern Observatory, SNO and Scottish Nuclear Ltd

Neutrinos

the physics of the universe

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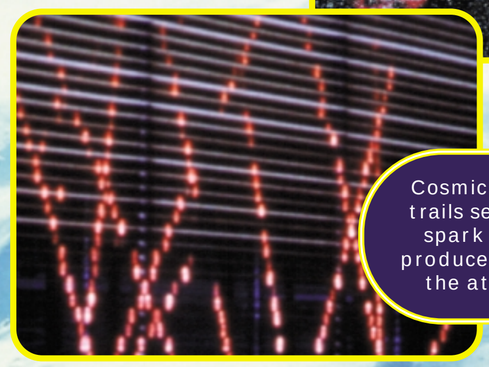
Where do neutrinos come from?

The Sun is a major source of neutrinos – by day and by night!

Supernova 1987a (ringed) appeared suddenly on 23 February 1987 – flooding space with neutrinos.



Cosmic rays – their trails seen here in a spark chamber – produce neutrinos in the atmosphere.

Neutrinos are also a by-product of nuclear power stations, such as this one at Torness, Scotland.

The Universe is full of neutrinos! Every cubic centimetre of space contains a few hundred neutrinos left over from the first seconds of the Universe. These neutrinos were made in the heat of the Big Bang with which the Universe began. However, neutrinos continue to be created in processes much closer to home.

The Sun bathes the Earth in a continuous stream of neutrinos. Each second around 60 billion neutrinos from the Sun pass through each square centimetre of the Earth's surface facing the Sun, and most of them pass swiftly out of the other side! These neutrinos are produced in the nuclear reactions that make the Sun – and other stars – shine. Stars also produce neutrinos when they die, in the spectacular stellar collapses known as supernovae. Indeed, most of the energy released in a supernova is carried away by the invisible neutrinos, rather than by the light we see.

Closer to Earth, neutrinos are created in the atmosphere when cosmic rays – energetic particles from outer space – collide with atomic nuclei in the upper atmosphere. Other neutrinos are emitted by the ground beneath our feet, in the beta-decay of naturally occurring radioactive nuclei in the Earth.

Neutrinos are a by-product of all nuclear reactors. They are emitted by the radioactive products of the reactions at the core of the reactor. They can also be made in controlled conditions at particle accelerator laboratories. Accelerators produce high-energy beams of particles such as protons. When the energetic protons hit something, neutrinos are among the products of the particle collisions.

How do you see a neutrino?

The main way for neutrinos to interact with other matter is through what is known as the "weak force". This is much weaker than the electromagnetic force that electrically charged particles, such as electrons, experience. So, while electrons can be easily stopped in matter, neutrinos can pass right through the Earth; indeed, it would take 1000 light years (10,000 billion km) of water to be sure of catching a neutrino from the Sun! Surprisingly enough, however, water is often used to detect neutrinos.

So how can we hope to observe a neutrino? Fortunately neutrino reactions are random, and although it takes an unimaginable amount of material to be sure of stopping a neutrino, there is a chance that a neutrino will interact sooner or later. For a distance of only a few metres this chance is very small indeed, but with a large enough number of neutrinos to begin with and a large detector – and a great deal of patience – physicists can detect neutrinos. The trick is to look for what happens when the neutrino interacts with another particle – like seeing an invisible man knock something over. In water, neutrinos can hit electrons out of atoms with so much force that the electrons emit light. Physicists can then detect the light. Neutrinos can also change protons in atomic nuclei into neutrons, which can then be detected through their reactions. In fact, this is the way that Cowan and Reines detected neutrinos in 1956.