



# Breakthrough Under Ground

**Do neutrinos change type as they travel from the sun to the Earth? Scientists at the Sudbury Neutrino Observatory have answered this key question of physics, using special glass from Schott.**

▶ Hardly any particle provides such profound insights into the processes and history of our universe as the neutrino. Wolfgang Pauli predicted its existence back in 1930. Yet it was long regarded as a “ghost particle,” until Frederick Reines and Clyde Cowan succeeded in detecting it in a series of experiments in 1956. Now, researchers at Canada’s Sudbury Neutrino Observatory (SNO) are sure they have elicited another of the neutrino’s secrets.

There are three types of neutrinos. All have a very low active cross-section, so they hardly react with other particles. That is why scientists see them as “incorruptible witnesses” telling the history of the universe in unadulterated form. Sadly, this virtue is combined with difficulties because their low active cross-section makes very high demands on the neutrino detectors designed to identify their presence.

## The Riddle of Solar Neutrinos

One way neutrinos form is when hydrogen is fused into helium, producing electron neutrinos. This process also supplies solar energy and ultimately makes life on Earth possible. For many years, physicists faced a riddle. Only around half the expected number of solar neutrinos actually reach Earth. Now, for the first time in their experiments, physicists and astronomers at SNO have succeeded in detecting both tau and muon neutrinos. The sum total of particles counted corresponds approximately to the number of solar neutrinos predicted. The scientists credit this to neutrino oscillation, whereby neutrinos change from one type to another on their way from the sun to the Earth.

Expenditure on these experiments is reflected in the SNO neutrino telescope’s impressive dimensions. It is the size of a 10-

story building and buried two kilometers underground down a nickel mine. The aim is to filter out background cosmic radiation that otherwise distorts measurements. The heart of the detector is around 1,000 tons of highly pure heavy water contained in a plastic sphere 12 meters in diameter. The heavy water is made up of oxygen and deuterium. This heavy form of hydrogen is required to produce the detection reactions.



Glass bulbs with their excellent optical and chemical properties are important factors determining the quality of neutrino measurements.

## Eyes with Special Glass

As they travel through the heavy water, the neutrinos generate a very, very small number of individual light particles known as photons. Their small number makes them very hard to detect. This is done with the help of photomultipliers, extremely sensitive instruments that can detect even a single photon by transforming it into a boosted electrical signal. Distributed across the entire surface of the water-filled sphere, they are the detector’s eyes. Thanks to this arrangement and the purity of the water, the SNO can measure not only the neutrinos’ energy, but also determine the direction from which they are coming. As the photomultipliers only work in a vacuum, they are surrounded by a glass vacuum flask.

Ordinary glass is not suitable for this purpose because the photons are comprised of ultraviolet radiation that cannot penetrate normal glass. In the case of eyeglass lenses, for example, this is a good thing, because it protects the eye from solar radiation. But it is not acceptable for the high-precision experiment in Canada. That is why SNO scientists approached Schott. “The specifications were very exacting,” recalls Peter Brix, head of Schott’s technical glasses material development department, “even we couldn’t supply a glass like that off the shelf.”

## Purest Glass

The glass specialists took up the challenge. “In the auto industry they would probably call it extremely fine tuning,” Brix said with a grin. “That’s precisely what we did with our 8246 type glass.” In the choice of raw materials, the specially constructed melting tanks, transportation and even the testing tools, the glassmakers always

worked at the cutting edge of what was technically feasible, and ultra-purity was always the standard. They succeeded in supplying a total of 12,000 units, all made by hand, and no complaints were received about a single one!

With this vast quantity of eagle eyes, even the coy neutrinos found it hard to remain undetected. The scientists can even distinguish between three ways they react with the heavy water, though in each case the reaction ends with them producing the flash of ultraviolet light mentioned above. Known as Cherenkov radiation, this is then registered by the photomultipliers.

## The Optic Supersonic Bang

If, for instance, an electron neutrino meets up with a deuterium nucleus, it disintegrates. Its two original components, a

The detector is the heart of the neutrino telescope, buried two kilometers deep in a nickel mine. Approximately 10,000 sensors, or photomultipliers, have been installed in the barrel-like shell.

positively charged proton and a neutral neutron, become two protons and a negatively charged electron. Most of the neutrino's energy goes into the electron, which then moves away at the speed of light, or rather faster than the actual light, which is "braked" by the water and moves more slowly than it would in a vacuum. The luminous cone of Cherenkov radiation that the electron propels in front of it, is therefore comparable to a supersonic bang. The measurements produced by the photomultipliers enable physicists to deduce the neutrinos' frequency and energy. This enables them to know whether neutrino oscillations have occurred. For on the way from sun to Earth neutrinos constantly change type.

These findings have far-reaching consequences, as transformations of this kind are only possible if neutrinos have a rest mass like other elementary particles. The Standard Model of elementary particle physics, in its present form, does not allow for this. The so-called lepton number would no longer be sufficient to ensure their conservation, and the model would have to be expanded. In addition, the existence of neutrino mass would contribute to the amount of "dark matter" in the universe. As neutrinos are so numerous, they could, for example, account for the missing mass in galaxies.

#### A Cube of Ice

The neutrino still harbors many secrets, which is why new projects like IceCube are underway worldwide. This neutrino telescope consists of a cube of ice with sides one kilometer long that extend two and a half kilometers below the Antarctic ice shelf. What heavy water is to the SNO, Antarctic ice is to IceCube. Nowhere on Earth does a purer medium exist. What is more, the Earth itself acts as a northern protective filter against unwanted radiation. "Scientifically a most attractive project," says Brix. "I think Schott could also contribute valuable technology and know-how to this international project." As an example, he cited "Duran" containers that remain stable under pressure and can hold and protect IceCube's roughly 5,000 photomultipliers. One of the most interesting research fields in present-day physics, the neutrino is the focus of many projects. The bashful ghost particle will have no peace, it seems, until it has revealed all its secrets to science. ◀

## New Window on the Universe

**IceCube is an international project based near the South Pole and aimed at conducting further research into neutrinos – a new window on the universe. The team headed by Prof. Lutz Koepke of the Institute for Physics at Johannes Gutenberg University in Mainz plays a key role in this project.**

*Professor Koepke, all over the world, neutrino research is being pursued at great expense. What makes neutrinos so interesting, and research into them so important?*

**Koepke:** For around 30 years we have had a successful Standard Theory of elementary particles and the forces that act between these 12 basic components of matter. Neutrinos play a very special role. They are the only particles that engage exclusively in weak interaction. This makes them particularly suitable for investigating this type of interaction. We are not entirely happy with our Standard Theory, even though it has described measurements extremely well so far. We know already that neutrinos contradict the Standard Theory in that they possess a minuscule mass. However, as yet we are unable to attribute a precise value to it. This fact can influence the entire universe, its development and end, and even the structures observed. I am always fascinated by how the smallest, lightest particles can influence the whole world!

*IceCube certainly has an extraordinary location. What are the project's other special features, and what results are you hoping for?*

**Koepke:** Scientists have been saying since the 1950s that it should be possible to detect transitory neutrinos astronomically. After many failed attempts, neutrino telescopes have been in operation in Lake Baikal and at the South Pole for some years. They function very successfully, but to our great regret, no neutrinos from other galaxies have been discovered so far! It is now clear that building the 200 times more powerful and more sensitive IceCube telescope is technically and financially feasible. Theoretical estimates assure us that such a telescope ought to enable us to detect neutrinos from distant galaxies. Then we can solve the riddle of the origin of ultra high-energy cosmic radiation, and study processes in the vicinity of black holes.

*There is talk of all the photomultipliers being surrounded by "Duran" flasks. What is the function of these capsules?*

**Koepke:** Pressure beneath the 2,000-meter-thick ice shelf is 200 times as high as in the atmosphere above. The sensitive photomultipliers and electronics have to be protected. High-durability "Duran" borosilicate glass is an obvious choice for the pressure flask. We are very pleased that Schott is developing a type of glass for us that is permeable to ultraviolet rays, with 50% higher permeability for the weak "neutrino flashes." ◀



Professor Lutz Koepke at the South Pole. He and his team are hoping to prove the existence of neutrinos in far-away galaxies with the Ice Cube project.