Chemist Travels World to Study Mysterious Properties of Neutrinos

August 19 2008

In the quest to better understand one of nature's most "ghostly" elementary particles — the neutrino — scientists at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory are spreading their expertise from the mines of Canada to the mountains of China. Richard L. Hahn, a senior chemist at Brookhaven Lab, will discuss some of the neutrino's mysterious properties and two new neutrino research projects at the 236th National Meeting of the American Chemical Society on Tuesday, August 19, 2008.

Neutrinos are uncharged elementary particles created by nuclear reactions in the sun, by cosmic rays in our atmosphere, and in nuclear reactors and accelerators on Earth. The properties of neutrinos continue to fascinate scientists as they analyze the role of neutrinos in the universe.

Brookhaven's history of solar neutrino research dates to the early 1970s, when scientist Ray Davis' pioneering work in a South Dakota gold mine sent the neutrino world into an uproar by documenting that fewer electron neutrinos (the type produced by the sun) were detected than should have been based on theory. Davis (along with Masatoshi Koshiba of Japan and Riccardo Giacconi of the U.S.) was awarded a Nobel Prize in Physics for this work in 2002.

That same year, scientists at the Sudbury Neutrino Observatory (SNO) in Ontario, including Hahn and members of his Brookhaven group, solved Davis' "solar neutrino problem" by determining that neutrinos "oscillate," or switch, between three different types as they travel from the sun to Earth. Thus, Davis' observed electron neutrinos were only a fraction of the total number reaching earth. The rest had changed into muon or tau neutrinos that were not detected in Davis' original experiments.

Now, researchers at Brookhaven and across the world are turning their attention to two new efforts in the neutrino field: the experiment at the Daya Bay Nuclear Power Plant in China, and the SNO upgrade, called SNO+. In his talk, Hahn will provide the details of these large-scale experiments.

"In these experiments, we are asking a very fundamental question: How can we better understand the detailed properties of neutrinos?" Hahn said.

Researchers have clearly characterized two of the neutrino oscillations between different flavors, but they still do not know the details of the third oscillation. The goal of the Daya Bay experiment, a collaboration among researchers in the United States, China, Hong Kong, Taiwan, Russia, and the Czech Republic, is to measure an essential parameter of this third oscillation known as the mixing angle θ13 (pronounced "theta-one-three").

"In order to understand neutrino mixing and oscillations, we must know the value of the unknown mixing angle," Hahn said. "All we know so far is that it is small."

To determine this angle, researchers will use eight 80-ton detectors to look at antineutrinos, the antiparticles of neutrinos, which are produced in nuclear reactors. Each detector contains a metal organic liquid mixture in the center that is surrounded by organic liquid without any metal, both of which Hahn and his group at Brookhaven have helped to develop. When neutrinos pass through the metal organic liquid mixture, flashes of light are produced. By placing detectors at different distances from the reactors, Hahn and colleagues will be able to map antineutrino oscillations from one flavor to another.

Hahn and his group are developing another metal organic liquid mixture to detect neutrinos in the SNO+ experiment. This experiment will use the same general set-up from the completed SNO experiment — a large, round, acrylic vessel the size of a 10-story building (described as the world's largest round-bottomed flask) placed 6,800 feet underground in the International Nickel Company's Creighton Mine. SNO+ researchers will replace the heavy water used for SNO with metal organic liquid mixture.

The researchers working on SNO+ will be studying double-beta decay, a rarely seen radioactive decay mode — in which two neutrons are changed into protons, emitting two electrons and (most often) two neutrinos. A main goal of the experiment will be to search for double beta decay in which no neutrinos are emitted — a mode that has never been seen before

"This would show that the neutrino is its own antiparticle," Hahn said. "Currently, some evidence suggests that neutrinos are different from antineutrinos, while certain theories predict that they are actually the same particle. It is important to understand whether those theories are true or not."

"There should have been equal amounts of matter and anti-matter present at the Big Bang, the beginning of the universe," Hahn said. "Today, however, matter dominates our Earth — explaining why we don't annihilate each other when we shake hands. If the neutrino turns out to be its own antiparticle, this might help us to understand more about this imbalance.

"This experiment asks key questions about how our corner of the universe exists today as it does — with matter but no anti-matter."

Source: Brookhaven National Laboratory