

The Nobel Prize in Physics 2002 for the Observation of Cosmic Neutrinos

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The first half of the Nobel Prize in physics for 2002 has been shared by Raymond Davis, Jr. and Masatoshi Koshiba for their observations of cosmic neutrinos. On two earlier occasions, Nobel Prizes have been awarded for discovery of neutrinos from controlled experiments: in 1988 to Leon M Lederman, Melvin Schwartz and Jack Steinberger for the discovery of the muon type neutrino and the neutrino beam method, and in 1995 to Frederick Reines for the discovery of the electron type neutrino (discovered jointly with the by then deceased Clyde L Cowan, Jr.), who shared the prize with Martin Perl for his discovery of the tau lepton. Neutrinos are particles that participate only in the weak interactions, apart from participating in the gravitational interactions. The existence of the electron type neutrino was postulated in 1930 by Wolfgang Pauli in order to account for energy and angular momentum conservation in nuclear beta decay. They do not carry electric charge and the so-called color charge of the strong interactions. With the discovery of the muon in the 1940's and the tau lepton in the 1970's, heavier cousins of the electron, the electron type neutrino found cousins in the muon type and tau type neutrinos.

The name of Ray Davis is a legendary one

and is associated with the 'solar neutrinos' which he observed through decades of painstaking observations in a deep underground experiment located in the Homestake Mine, in South Dakota, USA. As the name suggests, the neutrinos that he sought to observe are those that are produced in copious numbers in the Sun during the many processes that power it. An extraordinarily large number of low-energy neutrinos that are produced in the core travel outwards practically unhindered, due to the very small interaction cross-section of these weakly interacting particles. In order to have observable events induced by this small cross-section, despite the large flux of neutrinos at the distance of 1 astronomical unit (distance between the Earth and the Sun), one must have a very large number of targets. Davis' achievement was to construct such an experiment: the targets were the nuclei of chlorine atoms present in a common cleaning liquid, tetrachloroethylene, which he stored in a large tank in the underground experiment, and the products of the neutrino capture by the nuclei of the chlorine atoms were a radioactive isotope of the noble gas argon. The idea of using chlorine nuclei as targets was due to the Italian born Soviet physicist Bruno Pontecorvo and was realized ingeniously by the experiment of Davis. It must be noted, however, that the number of reaction products in the over 615 tonnes of fluid that were exposed to the solar neutrinos, during a run of a month was of the order of 20 argon atoms. The ingenuity of Davis was to devise a technique to flush out these argon atoms. He used a method by

which the tank was flushed with helium, another noble gas. He was able to demonstrate the efficacy of this method to actually collect the argon atoms so produced. He thus established that solar neutrinos in fact exist, the first experimental demonstration of the prediction from the models of the Sun. The 'solar neutrino problem' however, was that the numbers of argon atoms so collected by Davis was systematically lower than what was predicted by the models, by as much as a factor of a third or a fourth. Through dedicated experiments, he was able to show that none of the argon atoms produced were being lost during the procedure of extraction, and that the problem was to stay for many decades.

The existence of the solar neutrino problem was confirmed by the experiment Kamiokande, located in the Mozumi mine in Kamioka-cho, Gifu, in Japan (Kamiokande: Kamioka Nucleon Decay Experiment) and with which the person sharing the Prize with Davis, M Koshiya is identified. The experiment was established to search for nucleon decay, predicted by grand unified theories of the fundamental interactions. The experiment proved to be versatile enough to serve as a 'neutrino telescope'. The experiment uses the principle that neutrinos coming from cosmic sources when entering a large tank of water would interact with the electrons in the water and scatter elastically off the electrons. These ultra-relativistic electrons emit characteristic Čerenkov radiation which is detected by photomultiplier tubes on the

periphery of the container of the water. At Kamiokande, 3000 tonnes of water were surrounded with 1000 photomultiplier tubes. Unlike the Davis experiment, the measurements here were 'real time' and also had information of the direction from which the observed neutrino was coming. These experiments were able to spectacularly confirm the existence of the solar neutrino problem. Another unexpected and brilliant observation of the Kamiokande experiment was that of 11 neutrino events in the year 1987 associated with the collapse of the neutrino-sphere of the supernova 1987A. The supernova which exploded in the Large Magellanic cloud, one of the two companions of the Milky Way galaxy, was also observed optically and in other regions of the electromagnetic spectrum, and its light curve was carefully monitored. This was the first ever supernova to be explored in this remarkable manner. The standard picture of the supernova explosion requires that a significant fraction of the energy transport out of the supernova be in the form of that transported by neutrinos in a spectacular burst. The event rates calculated for Kamiokande proved to be in agreement with what was observed. Supernova neutrinos were also observed by the experiments IMB (Irvine-Michigan-Brookhaven) and the Baksan mine experiments, which confirmed that the neutrinos observed by Kamiokande were indeed supernova neutrinos.

The direct observation of the neutrino oscillations by the Sudbury Neutrino Observa-



tory has recently resolved the solar neutrino problem in favor of a particle physics scenario whereby the electron type neutrino that is produced at the core of the Sun has a finite probability of oscillating into a muon or tau type neutrino. Furthermore, no modification of the standard solar model based on which the fluxes of neutrinos are calculated is necessary (see article in *Resonance*, Vol. 7, No. 10, pp. 79, 2002).

The award of the Nobel Prize to Davis is one that would do the Prize proud. During the 30 or years of the running of his experiment, around 2000 argon atoms were collected! At age 87, he stands as an example of the rare dedication and perseverance that is required to make a truly outstanding contribution to science. A chemist by training, Davis is

Professor Emeritus at the University of Pennsylvania.

The award to Koshiba is no less deserving; the courage to design outstanding and brilliant experiments to search for the unusual and to prove the versatility of experiments. At the age of 76, Koshiba is Professor Emeritus at the University of Tokyo.

For recent articles in *Resonance* of related interest, see

- [1] B Ananthanarayan and Ritesh K Singh, Vol. 7, No. 10, pp. 79, 2002.
- [2] S M Chitre, *Resonance*, Vol. 7, No. 8, pp. 67, 2002.

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