Title
The Sudbury Neutrino Observatory

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Publication Date
1992-11-01

LBL-33304
UC-413

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Presented at the APS Division of Particles and Fields Meeting,
Batavia, IL, November 11–14, 1992, and to be published in the Proceedings

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November 1992

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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LBL - 33304

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This work was supported by the Director, Office of Energy Research Division
of Nuclear Physics of the Office of High Energy and Nuclear Physics of the
U.S. Department of Energy under Contract DE-AC03-76SF00098

1. Introduction

Two experiments now in progress have reported measurements of the flux of high energy neutrinos from the Sun. Since about 1970, Davis and his co-workers[1] have been using a ^{37}Cl-based detector to measure the ^7Be and ^8B solar neutrino flux and have found it to be at least a factor of three lower than that predicted by the Standard Solar Model[2] (SSM). The Kamiokande collaboration[3] has been taking data since 1986 using a large light-water Cerenkov detector and have confirmed that the flux is about two times lower than predicted. Recent results from the SAGE[4] and GALLEX[5] gallium-based detectors show that there is also a deficit of the low energy pp solar neutrinos. These discrepancies between experiment and theory could arise because of inadequacies in the theoretical models of solar energy generation or because of previously unobserved properties of neutrinos. The Sudbury Neutrino Observatory (SNO) will provide the information necessary to decide which of these solutions to the "solar neutrino problem" is correct.

2. The SNO Detector

The Sudbury Neutrino Observatory will consist of a 1000 tonne heavy water (D_2O) Cerenkov detector that is designed to measure the flux, energy spectrum, and direction of neutrinos from the Sun and from such other sources as supernovae. It is presently under construction in a very low background environment 2000 meters underground in the Creighton mine near Sudbury, Ontario, Canada. This is an operating nickel mine owned by INCO, Ltd. The D_2O used in the detector will be on loan from Atomic Energy of Canada Limited.

The basic measurements that will be made with the SNO detector are:

1) the flux and energy spectrum of electron-type neutrinos reaching the Earth, and
2) the total flux of all neutrino types above an energy of 2.2 MeV.

With these two measurements, it will be possible to :

1) determine if neutrino oscillations occur, and
2) independently test solar models by determining the production rate of high energy electron-type neutrinos in the solar core.

The SNO detector utilizes three complementary neutrino interactions with the heavy water.

1) The neutrino-electron elastic scattering (ES) reaction: $\nu_x + e^- \rightarrow \nu_x + e^-$.

The observed signal in the detector is the Cerenkov light produced by the recoiling electron. This is the primary detection mechanism for light water detectors such as the Kamioka detector. It is sensitive to all neutrino types, but is dominated by the electron neutrino. The recoiling electrons from the ES reaction are strongly forward peaked and give excellent directional information. However, information about the energy spectrum of the neutrinos is more difficult to extract because of averaging over the outgoing neutrinos.

2) The charged current (CC) reaction: $\nu_e + d \rightarrow p + p + e^-$ (Q = -1.44 MeV).

This reaction of the electron-type neutrino on the deuteron is unique to the SNO detector. It has a relatively large cross section for ^8B neutrinos and would produce about 10 events per day for one third of the SSM flux. This is greater than fifty times more sensitive than existing solar neutrino experiments. The electron energy is $E_e = E_\nu - 1.44$

MeV and the energy resolution is approximately 20%. This reaction gives good spectral information on the ^8B neutrinos and thus provides good sensitivity to the MSW effect. This reaction will also identify electron neutrinos from the initial burst of a supernova.

3) The neutral current (NC) reaction: $\nu_x + d \rightarrow \nu_x' + p + n$ (Q = -2.2 MeV).

This reaction can be observed by the detection of the gamma rays resulting from the subsequent neutron capture or by a neutron detector array in the heavy water. This reaction is sensitive to all types of neutrinos equally and would be used to measure the total flux of neutrinos above the threshold energy of 2.2 MeV. The expected counting rate for the full SSM is approximately 10 per day. This will give a direct measure of the total solar ^8B neutrino production independent of neutrino oscillation effects. It will also detect all types of neutrinos from supernovae explosions.

The D_2O target of the SNO detector will be contained in a transparent spherical acrylic vessel with a diameter of 12 m and a wall thickness of 5 cm. Approximately 2.5 m outside the acrylic vessel, there will be about 9600 photomultipliers (PMTs) with 20-cm diameters uniformly arranged and held in place by a geodesic support structure. A reflector is mounted in front of each PMT to increase the light collection to yield a total effective photocathode coverage of approximately 60%. The PMT array is sensitive to Cerenkov radiation produced by relativistic electrons and other particles in the central regions of the detector. The acrylic vessel, PMTs, and the support structure are immersed in 7300 tonnes of ultrapure H_2O. This reduces the background in the heavy water from radioactive impurities in the rock walls and in the detector components. The cavity which will house the detector is barrel shaped with a diameter of 22 m and a height of 30 m. The excavation of the cavity is expected to be completed early in 1993. The PMT support structure and acrylic vessel will then be assembled and installed underground. The initial water fill is scheduled to begin near the end of 1994, with a view toward completing commissioning tests and starting to take data in 1995. The data taking sequence that will be used in the experiment is still under discussion. It may begin with a H_2O fill of the acrylic vessel followed by a D_2O fill. The NC measurement may then be made either by adding 2.5 tonnes of NaCl to the D_2O (in order to raise the energy of the capture gamma rays) or through the use of discrete neutron detectors (such as ^3He counters) installed in the D_2O.

3. Acknowledgements

This research is supported by the National Science and Engineering Research Council, National Research Council, Ministry of Industry, Science and Technology, and Northern Ontario Heritage Fund Corporation, all in Canada, the Department of Energy in the United States, and the Science and Engineering Research Council in the United Kingdom. The loan of heavy water from Atomic Energy of Canada Limited is greatly appreciated.

4. References

1. R. Davis, Jr. *et al.*, *Phys. Rev. Lett.* **20** (1968) 1205.
   J.K.Rowley *et al.*, in *Solar Neutrinos and Astronomy*, eds. M. L. Cherry, W. A. Fowler, and K. Lande (AIP, New York, 1985).
2. J. N. Bahcall, *Neutrino Astrophysics* (Cambridge Univ. Press, Cambridge, 1989).
3. K. Hirata *et al.*, *Phys. Rev. Lett.* **65** (1990) 1297.
4. A. Abuzov *et al.*, *Phys. Rev. Lett.* **67** (1991) 3332.
5. P. Anselmann *et al.*, *Phys. Lett.* **B285** (1992) 376.

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