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BOREX*: SOLAR NEUTRINO EXPERIMENT VIA WEAK NEUTRAL AND CHARGED CURRENTS IN BORON-11**

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ABSTRACT

Borex, an experiment to observe solar neutrinos using boron loaded liquid scintillation techniques, is being developed for operation at the Gran Sasso underground laboratory. It aims to observe the spectrum of electron type ^{8}B solar neutrinos via charged current inverse β-decay of ^{11}B and the total flux of solar neutrinos regardless of flavor by excitation of ^{11}B via the weak neutral current.

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The flux of electron type neutrinos emitted by the sun as measured by the Homestake chlorine detector (J. K. Rowley et al 1985, R. Davis Jr. 1989) has consistently shown a deficit in comparision with theoretical predictions based on the standard solar model (SSM). This problem, the "solar neutrino problem", has been confirmed by recent results from the Kamiokande-II water Cerenkov detector (Hirata et al 1989). The observed deficit of neutrino flux could be due either to new physics e.g., neutrino oscillations or to new astrophysical aspects beyond the framework of the SSM. A crucial experiment is necessary to resolve the ambiguity.

Borex, a new type of solar neutrino detector being developed for operation at the Gran Sasso Laboratory, aims at such an experiment. The main feature is the simultaneous measurement of both the electron neutrino flux and the total neutrino flux regardless of flavor, the former by inverse β-decay of ^{11}B (the target nucleus in Borex) and the latter by excitation of bound states of ^{11}B. Comparison of the fluxes measured by the two detection modes can thus resolve the solar neutrino problem. The experimental approach of Borex is based on a massive boron loaded liquid scintillator observed by a number of phototubes. This technique allows energy resolution and low energy sensitivity significantly better than that possible in present or future Cerenkov type solar neutrino detectors.

NEUTRINO DETECTION IN BOREX

Four basic reactions may be observed in Borex:

a) $\nu + {}^{11}B \rightarrow \nu' + [{}^{11}B(E_i) \rightarrow {}^{11}B + \gamma(E_i)]$

b) $\nu_e + {}^{11}B \rightarrow e^- + [{}^{11}C(E'_i) \rightarrow \gamma(E'_i) + [{}^{11}C \rightarrow {}^{11}B + e^+ + \nu_e]]$

c) $\nu + e^- \rightarrow \nu + e^-$

d) $\overline{\nu}_e + p \rightarrow e^+ + n$ followed by $n + {}^{10}B \rightarrow \alpha + {}^7Li + 0.48MeV\gamma$

Reaction (a), specific to ^{11}B, operates by the weak neutral current (NC) and involves excitation of the levels of ^{11}B at E_i=4.5 and 5 MeV. This reaction is flavor blind. It thus measures the total flux of neutrinos by observing the deexcitation γ-rays with the sharp energies E_i = 4.5 and 5 MeV. The neutrino threshold is just E_i. Reaction (b) is activated only by electron neutrinos ν_e. Charged current (CC) inverse β-decay induces transitions from ^{11}B to the ground and excited states of ^{11}C at energies E'_i (Fig. 1). The thresholds for this reaction are given by $E_{th} = E'_i + \Delta$ where Δ is the $^{11}B - ^{11}C$ mass difference (1.98 MeV). The emitted electron has an energy $E_e = E_{\nu_e} - E_{th}$; in the case of excited state transitions, it is accompanied by a γ-ray of energy E'_i. With a visible energy of $E = E'_i + E_e = E_\nu - \Delta$, these CC events reflect the incident solar ν_e spectrum.

Two non-boron reactions are also available in Borex. Reaction (c), operating by a mixture of CC and NC amplitudes, applies to all electrons in the Borex liquid scintillator. The electron signals from (b) and (c) can be distinguished by the fact that

(b) is always followed in time by a positron (with a minimum visible energy of 1.02 MeV from annihilation to a maximum of 1.98 MeV) emitted in the decay of the ^{11}C. Reaction (d) applies to the free protons in the liquid scintillator. The $\overline{\nu}_e$ spectrum is given by the spectrum of the emitted positrons. The neutrons in (d) are absorbed (after a short delay) in ^{10}B, generating a 0.48 MeV γ-ray. This signature allows identification of $\overline{\nu}_e$'s above a threshold energy of 1.8 MeV.

The cross-sections for reactions (a) and (b) have been derived using the relatively complete nuclear physics data on the $^{11}B-^{11}C$ system (Raghavan, Pakvasa and Brown 1986, Raghavan and Pakvasa 1988, Raghavan et al 1988 (App. I)). The signal rates evaluated using these cross-sections are given in Table I. They apply to a target mass of 200 tons of natural Boron and event energy >3.5 MeV. The SSM flux of $6x10^6/cm^2sec$ of ^8B solar neutrinos of the standard type has been assumed.

TABLE I

Reaction	Events/year
(a) NC	128
(b) CC	2373
(c) (e-ν)	1550

THE BOREX DETECTOR

A detailed first study of various design and physics aspects of Borex has been made and a conceptual design of the detector has been formulated (Raghavan et al 1988). The preferred design approach is a central vessel holding the boron liquid scintillator, protected from external radiations by shielding layers of increasing radiopurity towards the center. The central vessel is submerged in a transparent liquid contained by an outer tank which in turn is submerged in a large pool of water. The scintillation light emerging from the central vessel is radially guided to phototubes fixed to wall of the outer tank using light pipes placed in the buffer space between the outer and inner vessels.

The liquid scintillator in Borex consists of a commonly available boron reagent mixed with a modest amount (typically 15%) of aromatic solvent. The boron reagents of choice are trimethylborate (TMB) (boron ~10%) or trimethoxyboroxine (TMBX), a TMB derivative with higher boron content (~18.5%). Preliminary studies of TMB scintillators show that their scintillation and optical properties are suitable for Borex (Raghavan and Hurlbutt 1988).

Montecarlo simulations of signal events and their reconstruction have been carried out (Bonetti and Manno 1989, Deutsch and Rothschild 1989) for typical Borex geometries using measured scintillator parameters. They suggest an energy resolution $\Delta E/E < 10\%$ (FWHM) for a 5 MeV event and a spatial resolution of <10 cm (1σ) for a point-like event of this energy. They also show that, with standard phototube timing and scintillator lifetimes, single-point events (electrons) can be usefully distinguished from some types of delocalized events such as $\beta-\gamma$ cascades from reaction (b) and less efficiently from others such as single 5 MeV γ-rays.

SIGNAL QUALITY AND SCINTILLATOR RADIOPURITY

The spectrum of events estimated in a typical Borex design is shown in Fig. 2. The total background (dashed curve) >5 MeV is low enough that reactions (b) and (c) are practically free of noise for most of their spectral range. At ~5 MeV, in the region of the NC signal, the tail of the background becomes significant and rises rapidly at low energies. The dominant part of this background arises from the traces of U/Th decay chains and K in the boron liquid scintillator. Since the NC signal is a major objective, radiopurity of the liquid scintillator is a design priority of Borex.

The background in Fig. 2 assumes the following trace element levels in the liquid scintillator: 10^{-15} g^{238}U/g; 10^{-15} g^{232}Th/g; and 10^{-13} g K/g. The U and Th levels were suggested by assay of commercial TMB (Mitchell et al 1987, Mitchell and Raghavan 1988), carried out by distillation and mass spectrometric (MS) analysis of the residue. The residual concentrations were $<10^{-13}$gU/g and $\sim 10^{-12}$gTh/g. The trace levels in the distillate were estimated (and used in Fig. 2), using the measured value of ~1000 for the decontamination factor in distillation. This datum was determined by control distillations of TMB samples spiked separately with U and Th and analysis of the spiked samples, distillates and residues by γ-ray and atomic spectroscopy and MS techniques. More extensive radiopurity measurements with several improvements including MS analysis of much higher sensitivity are now in progress. Preliminary data have already limited the residual concentrations of U and Th to several femtograms/gm of TMB (de Bari et al 1989). With detailed systematics of blank values, we expect the limits to be lowered still further.

The background profile of Fig. 2 also assumes that the ^{238}U and ^{232}Th decay chains are in equilibrium with their daughters, especially long-lived Ra isotopes. Since the background tail at ~5 MeV follows the decay of ^{228}Ra it is necessary to determine also the Ra trace levels in the liquid scintillator. The method adopted is separation of the emanate ^{222}Rn (as a general Ra tracer) by purging the sample liquids by a He stream and counting the emitted α particles. Laboratory scale (5 liter) experiments have demonstrated detectability of Ra at a level equivalent to that in equilibrium with ^{238}U in the few picogram/g range (Steinberg et al 1989). Larger sample volumes will enable detection of significantly lower Ra concentrations. Construction of a moderately large (1 ton) radon detection facility is nearing completion (Bellini et al 1989). The overall research program on the radiopurity of the liquid scintillator will thus provide in the near future, a fairly detailed clarification of the internal background that can be expected in Borex.

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