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ABSTRACT

A radiochemical ^{71}Ga -^{71}Ge experiment to determine the primary flux of neutrinos from the Sun began measurements of the solar neutrino flux at the Baksan Neutrino Observatory in 1990. The number of ^{71}Ge atoms extracted from 30 tons of gallium in 1990 and from 57 tons of gallium in 1991 was measured in twelve runs during the period of January 1990 to December 1991. The combined 1990 and 1991 data sets give a value of 58 +17/-24 (stat) $\pm$ 14 (syst) SNU. This is to be compared with 132 SNU predicted by the Standard Solar Model.

1. Introduction

A fundamental problem during the last two decades has been the large deficit of the solar neutrino flux[1] compared with the theoretical predictions[2] based on the Standard Solar Model (SSM). These results may be explained by deficiencies in the solar model in predicting the ^{8}B neutrino flux or may indicate the possible existence of new properties of the neutrino. An experiment using ^{71}Ga as the capture material provides the only feasible means at present to measure low energy solar neutrinos produced in the proton-proton (p-p) reaction. Two such experiments, SAGE and GALLEX, are now online. In this paper we present measurements of the solar neutrino flux by the Soviet-American Gallium solar neutrino Experiment (SAGE) during 1990 and 1991 carried out at the Baksan Neutrino Observatory.

2. Measurement of the Solar Neutrino Flux

A gallium solar neutrino experiment counts the ^{71}Ge atoms produced in the reaction $^{71}\text{Ga}+\nu \rightarrow {}^{71}\text{Ge}+e^-$. Each measurement of the solar neutrino flux begins by adding approximately 700 micrograms of natural Ge carrier equally divided among the reactors holding the gallium. After a typical exposure interval of 1 month, the Ge carrier and any ^{71}Ge atoms that have been produced by neutrino capture are chemically extracted from the Ga. The experimental layout as well as the chemical and counting procedures have been described previously[3].

The end product of the chemical extraction is the synthesis of germane gas (GeH_4) that is filled into a low-background proportional counter. The counter is placed in the well of a NaI detector inside a large passive shield and counted for 2-4 months. Pulse shape discrimination based on rise time measurements is used to separate the ^{71}Ge decays from background. The energy, amplitude of the differentiated pulse, and any associated NaI signal are recorded for each event in the counter. The K-peak acceptance window is determined by extrapolation from an ^{55}Fe calibration peak.

The data analysis selects events that have no NaI activity in coincidence within the ^{71}Ge K-peak acceptance window. The K-peak acceptance window in energy is a 2 FWHM wide energy cut centered on the K-peak. The inverse rise time cuts are 95% acceptance. A maximum likelihood analysis is then carried out on these events by fitting the time distribution to an 11.4-day half-life exponential decay plus a constant rate background. The results of the maximum likelihood analysis for each of the 12 runs may be found in Ref. 6.

The systematic uncertainties in the chemical extraction and counting efficiencies were typically 6% and 10%, respectively. While all available information leads one to expect that the chemical extraction efficiency for ^{71}Ge produced by solar neutrinos should be the same as for the carrier, one must test this assumption. We have performed several separate experiments[4] aimed at discovering potential loss mechanisms for ^{71}Ge atoms. No anomalies in the extraction efficiencies were revealed. The systematic uncertainty in extrapolating the inverse rise-time cuts is estimated using a cut that includes all events not in coincidence with the NaI counter which are within the energy cut of the K-peak acceptance window with no cut made on inverse rise time. This results in an uncertainty of 9 SNU (68% CL) for the combined 1990 and 1991 data.

We have considered the possibility of a time varying background within the individual data sets[4]. There is no evidence for any time variation in the 1990 or the combined 1990 and 1991 data; therefore, we assume the background is constant in time and do not assign any systematic uncertainty for a possible time variation in the background to the 1991 and the combined 1990 and 1991 data sets.

The final possible systematic effect is due to possible background reactions which could produce ^{71}Ge and the possible presence of radon, which can mimic a ^{71}Ge signal. The total background production rate in 30 tons of liquid gallium metal of all germanium activities from external neutrons, internal radioactivity, and cosmic ray muons results in an uncertainty of 3 SNU (68% CL). Radon checks included looking at overflow events (due to alpha decays in the radon chain), looking outside of the K-peak acceptance window, looking for delayed coincidences of events (due to subsequent decays in the radon chain), and fitting the data to allow for both ^{71}Ge and radon. No evidence for radon was found and a systematic uncertainty of

8 SNU (68% CL) was assigned to the combined 1990 and 1991 data.

For the entire data set, the capture rate of ^{71}Ga was determined to be:

$$^{71}\text{Ga Capture Rate} = 58 + 17/-24(\text{stat}) \pm 14(\text{syst})\ \text{SNU} \quad (1)$$

This assumes that the extraction efficiency for ^{71}Ge atoms produced by solar neutrinos is the same as that measured using natural Ge carrier. This corresponds to 24 counts assigned to ^{71}Ge decay, compared to the SSM prediction of 55 counts.

4. Conclusions

With the combined 1990 and 1991 data sets, SAGE is now observing a signal consistent with ^{71}Ge produced by solar neutrinos. The first results from SAGE[5], and the data from 1991 appear consistent taking into account the systematic uncertainties. The combined data sets show a good overall fit to a value of 58 SNU (44% of the predicted flux); however, these results are still based on limited statistics. It is clearly necessary to accumulate more data with higher signal to noise and better efficiencies, as well as to test the extraction efficiency. We are continuing to study possible systematic effects, including possible background sources and Monte Carlo simulations.

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