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The Soviet American Gallium Experiment (SAGE)

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ABSTRACT

A radiochemical experiment using the reaction $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$ to determine the integral flux of low-energy neutrinos from the sun is currently under preparation at the Baksan Neutrino Observatory in the USSR. Measurements are scheduled to commence by late 1988 using ~30 tonnes of metallic gallium. With this amount of gallium it should be possible to obtain a fractional statistical accuracy of 12-15% after one year (assuming the standard solar model neutrino flux). While initial measurements are in progress, installation of the remaining 30 tonnes of gallium will proceed in order to perform the full 60 tonne experiment.

1. Introduction

The sun is believed to produce a copious flux of electron neutrinos in the process of the fusion of four protons to ^4He. The failure to observe these neutrinos in the expected number constitutes the solar neutrino problem. The radiochemical Cl-Ar experiment of Davis and colleagues[1] and the water

Cherenkov counter in the Kamioka mine[2] both show that the flux of "high"-energy neutrinos from the decay of ^{8}B is much less than predicted by the standard solar model[3].

Many hypotheses have been advanced to explain this discrepancy, ranging from errc in the astrophysical input for the calculations, through errors in the calculations themselves, to particle-physics solutions such as neutrino oscillations or exotic massive particles at the core of the sun. While the proposed astrophysical solutions all seem to run into difficulties with other observables, several particle-physics solutions are apparently viable. Interest in this possibility has been heightened by the theoretical discovery of the Mikheyev-Smirnov-Wolfenstein effect[4], whereby neutrino oscillation phenomena can be enhanced in matter. Whatever the solution, it is clear that the limited data available permit only judicious speculation.

A basic question is whether the initial step of the fusion cycle, the proton-proton fusion, is occurring at the expected rate. While the reactions forming ^{8}B are a very minor branch, with little influence on energy production, the pp reaction is fundamentally linked to the total luminosity of a steady-state sun. Failure to observe the pp neutrinos with the flux predicted by the standard model would strongly indicate the presence of neutrino oscillations. An experiment with ^{71}Ga as the sensitive medium is capable of registering these low-energy neutrinos because of the inverse beta decay's low energy threshold (233 keV). By using between 40-65 tonnes of natural gallium metal, the SAGE collaboration should be able to address this fundamental question.

2. Experimental Overview

In the gallium radiochemical neutrino experiment the metallic gallium is exposed to a source of neutrinos for a given time (21-30 days) after which the ^{71}Ge atoms that have been produced by neutrino capture are extracted via a chemical procedure. A schematic representation of the procedure is illustrated in Fig. 1. Detailed pilot studies with 7 tonnes of metallic gallium at the Institute for Nuclear Research (INR)[5] and independent studies with 10 kg of metallic gallium at Brookhaven National Laboratory[6] have demonstrated the viability of the metallic based extraction technique.

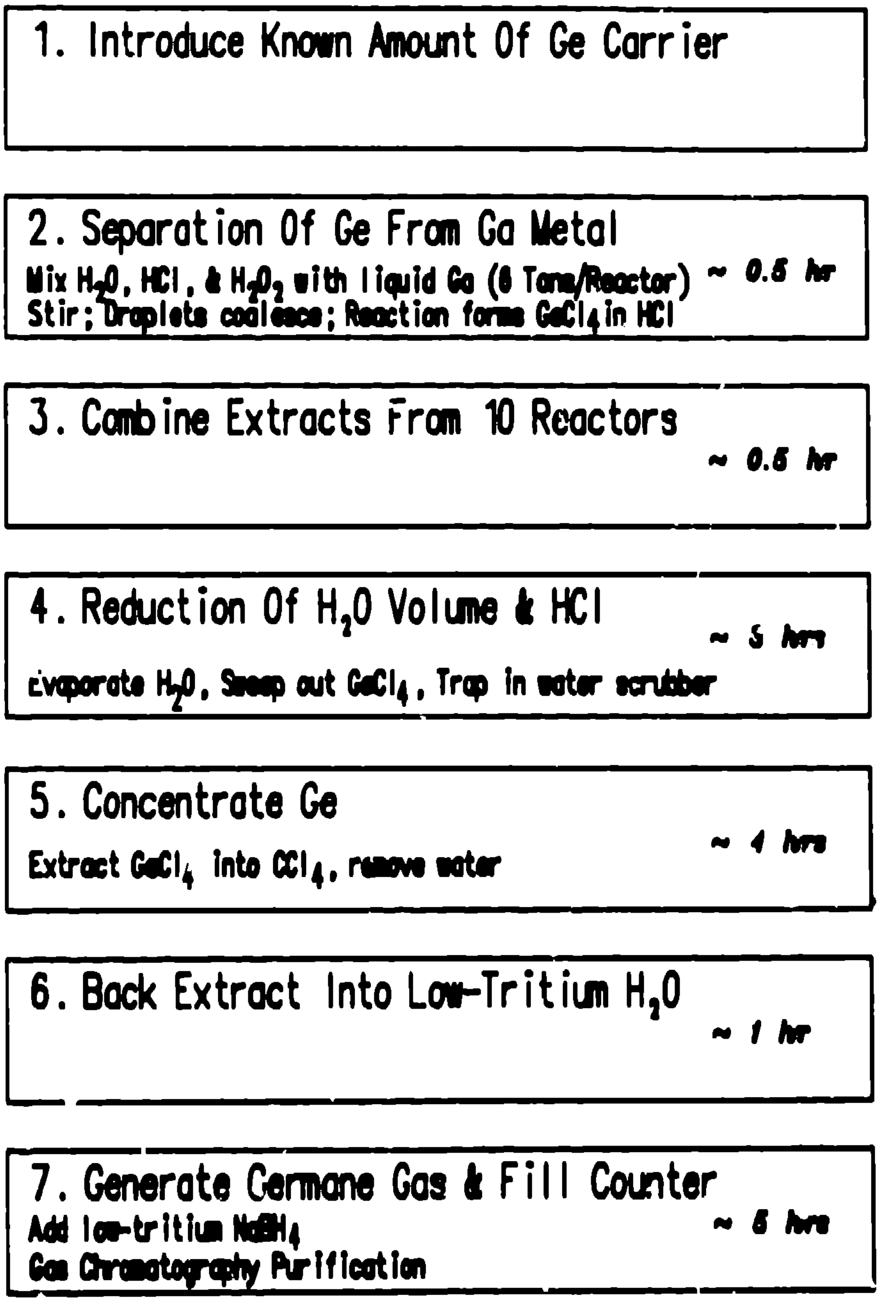

Fig. 1. Schematic diagram of the Ga-Ge chemical extraction procedure.

Presently, over 60 extractions have been performed on the INR pilot system with an average extraction efficiency in excess of 90%.

After the extraction, the germanium is synthesized into germane (GeH_4) gas which is then combined with Xe and inserted into a small volume (~0.5 cc) ultra-low-background gas proportional counter, where the ^{71}Ge decays are counted. For extraction from 30 tonnes and assuming a standard model based solar neutrino flux of 132 SNU (1 SNU = 10^{-36} captures per second per target atom), one expects only 8.3 ^{71}Ge atoms present after a 21-day exposure. Thus, extremely sensitive low-background counters are required. These are allowed to count for a long period of time (3-6 months) after filling in order to allow for the complete decay of the ^{71}Ge so that the detector backgrounds can be accurately determined.

3. SAGE Collaboration

Scientists at INR initiated work on the Ga-Ge measurement in the mid-1970's. By 1985 this effort had resulted in the excavation of the shielded chamber at the Baksan Neutrino Observatory of the INR, the procurement of over 60 tonnes of gallium metal, the construction and testing of a chemical extraction system, and the development of a low-background detector counting system. In 1986 several US institutions were invited to join the INR effort and the SAGE collaboration was born. The addition of the US scientists was primarily for the purpose of providing more support in the area of detector counting systems as well as to assist in some details of the germane chemistry generation and purification. A further motivation in forming the collaboration was to try and accelerate the measurement schedule.

4. Status

The SAGE experiment is situated in a specially fabricated and shielded chamber of the Baksan Neutrino Observatory of the INR in the Caucasus Mountains in the USSR. The 60 m long, 10 m wide, 12 m high chamber is located 3500 meters from the entrance of the horizontal adit at a depth of 4800 hg/cm^2. At this shielding depth the effect of the cosmic-ray background is reduced to a negligible level (<1%). Construction of the chamber is complete. It is sealed and watertight with a full coating of low-background concrete. The electrical utilities, chilled water, air conditioning, process steam, and the system for purification and cooling of the H_2O, H_2O_2 and HCl are in place and functional.

The ten chemical reactor vessels needed to hold the 60 tonnes of gallium are in place on the chamber floor and four have been cleaned and wired for use in the initial measurement. Each reactor holds ~ 7 tonnes of gallium metal. The 30 tonnes of gallium metal to be used in the initial measurement is now at Baksan and has recently been installed in the reactors. Construction of the glassware and apparatus necessary to perform extractions on the initial 30 tonne experiment is now being completed.

An INR constructed four-counter counting system has been developed and is now located in the chamber. A US built four-counter system is scheduled to be shipped to Baksan by mid-Summer 1988. Data analysis techniques using digitizer based rise-time discrimination methods are being developed and tested both in the USSR and the US.

The present schedule calls for extractions to purify 30 tons of gallium (by removing ^{68}Ge that accumulated in the Ga before it was installed underground) to commence by the summer of 1988. After shake-down of this system, neutrino flux measurements should start near the end of 1988. Assuming no unforeseen difficulties or delays, it is expected that an initial result from the 30 tonne gallium measurements will be obtained in 1989. If after one year of measurement the standard solar model neutrino flux were to be observed, this result would have a fractional statistical accuracy of 12-15%. This is certainly sufficient to determine whether the pp flux from the sun is a factor of three down from the predicted standard solar model value as is the case for the "high"-energy solar neutrinos.

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