BNL 7660

Solar Neutrinos: II. Experimental*

Raymond Davis, Jr.

Chemistry Department, Brookhaven National Laboratory, Upton, New York

The prospect of observing solar neutrinos by means of the inverse beta process $Cl^{37}(\nu,e^-)Ar^{37}$ induced us to place the apparatus previously described[1] in a mine and make a preliminary search. This experiment served to place an upper limit on the flux of extraterrestrial neutrinos. These results will be reported, and a discussion will be given of the possibility of extending the sensitivity of the method to a degree capable of measuring the solar neutrino flux calculated by Bahcall in the preceding paper.[2]

The apparatus consists of two 500-gallon tanks of perchlorethylene, C_2Cl_4, equipped with agitators and an auxiliary system for purging with helium. It is located in a limestone mine 2300 feet below the surface[3] (1800 meters of water equivalent shielding, m.w.e.). Initially the tanks were swept completely free of air argon by purging the tanks with a stream of helium gas. Ar^{36} carrier (0.10 cm^3) was introduced and the tanks exposed for periods of four months or more to allow the 35-d Ar^{37} activity to reach nearly the saturation value. Carrier argon along with any Ar^{37} produced were removed from the tanks by sweeping them in series with 5000 liters of helium. Argon was extracted from the helium gas stream with activated charcoal at 78°K. Finally the argon was desorbed from the charcoal, purified and counted. The overall efficiency of the processing was determined by Ar^{36} isotopic analysis

* Research performed under the auspices of the U. S. Atomic Energy Commission.

DISCLAIMER

of the recovered argon. The recovery of carrier argon was always greater than 95 percent. The entire argon sample was placed in a small proportional counter 1.2 cm long and 0.3 cm in diameter to measure the Ar^{37} activity. Pulse height analysis was used, and counts were recorded in anticoincidence with a ring of proportional counters, and an enveloping NaI crystal. The counter was provided with an end-window to permit exposure of the counting volume to Fe^{55} X-rays for energy calibration and determination of the resolution of the counter. The resolution, full width at half height for the 2.8 keV Auger electrons from the Ar^{37} decay, was 26 percent. The overall counter efficiency for Ar^{37} in the full peak was 46 percent. The counting rate with the sample was three counts in 18 days, the background rate for the counter. Assuming this rate corresponds to real events and using the efficiencies mentioned, the neutrino capture rate in 1000 gallons of C_2Cl_4 was $\leq$ 0.5 per day, or the $\phi\bar{\sigma} \leq 3 \times 10^{-34}$ sec^{-1} Cl^{37} $atom^{-1}$.

From a comparison of the limit set by this experiment to the calculated capture rate of $(4 \pm 2) \times 10^{-35}$ sec^{-1} Cl^{37} $atom^{-1}$ [2] it is clear that the sensitivity of the experiment will have to be increased by a factor of 100 to measure accurately the solar neutrino flux. If the volume of perchlorethylene were increased to 100,000 gallons one would expect 4 to 11 solar neutrino captures per day. On the basis of experience obtained with the present experiment an increase in the volume of liquid to 100,000 gallons would not present any insuperable difficulties. The result of such an experiment would provide a valid test for the present theory of the solar energy generation process. The important features of the method are that small amounts of Ar^{37} can be removed efficiently from large volumes of liquid by the simple procedure of sweeping with helium and that the characteristic decay of Ar^{37} can be observed in a counter with an essentially zero background. There are, however, a number of other processes that could produce Ar^{37} at these low levels in a tank of perchlorethylene in an undergound mine; these other effects constitute an undesirable background. Alvarez[4] made a thorough analysis of these unwanted effects in his original proposal some years ago. In general, background effects may arise from cosmic ray muons, from fast neutrons from the surrounding rock wall, and from nuclear reactions arising from internal contaminations in the liquid.

Cosmic ray background effects underground arise by the $Cl^{37}(p,n)Ar^{37}$ reaction from the protons produced in muon interactions. The magnitude of this background effect can be calculated from measurements made at a depth of 25 m.w.e.[5] where the nucleonic component is essentially eliminated, and the Ar^{37} is produced by muons. At this depth an Ar^{37} production rate of 210 atoms per day was observed in 3000 gallons of CCl_4. Below this depth the Ar^{37} production should decrease with the product of the muon intensity and the cross section for star production by muons. The following table lists the muon intensities[6] and cross sections[7] used to calculate the Ar^{37} production by muons at 1800 and 4000 m.w.e.

Table I

Depth below surface, m.w.e.	Muon intensity μ's cm^{-2} sec^{-1} $ster^{-1}$	Muon star production cross section, cm^2/nucleon	Ar^{37} production rate per day for 10^5 gallons C_2Cl_4
25	2×10^{-3}	3×10^{-30}	6500 (measured)
1800	2×10^{-7}	17×10^{-30}	3.5
4000	6×10^{-9}	22×10^{-30}	0.14

It may be noted from Table I that the calculated rate at 1800 m.w.e. is below the limit set by the present 1000-gallon experiment. However it is clear that a large scale experiment would have to be performed at a much greater depth. If the proposed experiment were conducted in a mine approximately 4500 feet deep (4000 m.w.e.) the muon produced Ar^{37} would be a factor of 30 below the expected rate of 4 to 11 per day from solar neutrinos.

Ar^{37} may also be produced in the liquid by energetic neutrons. Neutrons having an energy above 0.97 MeV will produce protons by the exothermic $Cl^{35}(n,p)S^{35}$ reaction with sufficient energy to produce Ar^{37} by the $Cl^{37}(p,n)Ar^{37}$ reaction. This effect was evaluated by irradiating the liquid with a Pu-Be neutron source. These measurements gave a yield of one Ar^{37} atom per 1.4×10^6 neutrons absorbed. Fast neutrons from the surrounding rock could produce one Ar^{37} atom per day if the neutron flux on the surface of the 100,000-gallon tank (26 ft diameter x 26 ft high) were 4×10^{-4} neutrons cm^{-2} min^{-1}. The fast neutron flux may be kept below this value by a water shield, the thickness depending on the uranium and thorium content of the rock wall.

Internal contaminations leading to Ar^{37} production in the materials of the tank or the liquid itself cannot be shielded out, and would serve as an inherent background that could not be separated from a neutrino signal. We have, however, found that the thorium and uranium content of perchlorethylene was less than 2×10^{-9} gm per gram. At this level internal neutron production is unimportant, less than 0.01 Ar^{37} would be produced per day by these neutrons. However, even at this uranium and thorium level the sulfur content must be below 0.5 percent to reduce the Ar^{37} produced by the $S^{34}(\alpha,n)Ar^{37}$ reaction to less than one per day.

We may conclude from the above considerations that an experiment using 100,000 gallons of pure perchlorethylene in a mine 4500 feet deep, properly shielded from fast neutrons would have a background Ar^{37} production rate at least a factor of ten below the expected rate from solar neutrinos. It should be noted that if a positive result were obtained from such an experiment there would remain a small ambiguity in interpretation because of the possibility of a galactic source of neutrinos. A possible method of distinguishing between solar and galactic neutrinos would be to take advantage of the eccentricity of the earth's orbit and measure the 7 percent difference in solar neutrino intensity between aphelion and perihelion. With a signal as low as 7 per day (a total of 350 Ar^{37} atoms) such an experiment would be marginal, but if a somewhat higher signal was observed such a test would be possible.

Dr. John Bahcall, Dr. R. L. Sears and Prof. W. A. Fowler of the California Institute of Technology have provided much of the theoretical and experimental information that makes this experiment meaningful. I would like to thank them for keeping me informed of these developments. Also I would like to acknowledge the assistance of Robert L. Chase for designing the low background counting system.

References

1. R. Davis Jr., Radioisotopes in Scientific Research, Vol. 1 (Proc. 1st UNESCO Intl. Conf., Paris, 1957) Pergamon Press: London, New York and Paris, 1958.

2. J. Bahcall, preceding paper.

   If only ground state transitions are considered a solar neutrino capture rate in 10^5 gallons of C_2Cl_4 from Be^7 and B^8 neutrinos would be 0.6 and 0.3 per day. An additional contribution to the rate of 5.7 per day would be expected from B^8 neutrinos captured to form excited states in Ar^{37} (approximately 50 percent error in flux). It is the contribution from excited states that produces an amount of Ar^{37} in 10^5 gallons of C_2Cl_4 well above that expected from background effects.

3. The chemical division of the Pittsburgh Plate Glass Co. kindly allowed us to use their limestone mine at Barberton, Ohio for this experiment. A more complete report will be published.

4. L. W. Alvarez, UCRL 328 (1949).

5. R. Davis Jr. and D. S. Harmer, to be published.

6. P. H. Barrett, L. M. Bollinger, G. Cocconi, Y. Eisenberg and K. Greisen, Revs. Modern Phys. 24, 133 (1952) and J. Pine, R. J. Davisson and K. Greisen, Nuovo Cim. 14, 1181 (1959).

7. The interactions of μ-mesons with matter, G. N. Fowler and A. W. Wolfendale, Prog. in Elementary Particle and Cosmic Ray Physics, Vol. IV, North-Holland Publishing Co., Amsterdam, 1958.