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MASTER

On the Problem of Detecting Solar Neutrinos

JOHN N. BAHCALL*

California Institute of Technology, Pasadena, California

and

RAYMOND DAVIS, JR.[†]

Brookhaven National Laboratory, Upton, New York

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The evidence supporting the theory of nuclear energy generation in stars is indirect. This evidence is based largely upon observations of electromagnetic radiation emitted from the surface of stars and upon theoretical stellar models that have not been subject to independent experimental tests. It is interesting, therefore, to try to think of a way of testing directly the theory of stellar energy generation in stars. In order to make such a test, one would like to be able to "see" into the deep interior of a star where the nuclear reactions are believed to occur. Thus an information carrier with a mean free path of the order of 10^{+11} cm ($\sim R_{\odot}$) is required. In the interior of a star like the sun, light has a mean free path of less than a centimeter. Only neutrinos, which have extremely small interaction cross sections, can enable us to "see" into the interior of a star. Thus the observation of solar neutrinos would constitute the most direct test that we can think of

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for the hypothesis that hydrogen burning nuclear reactions provide the main energy source for stars like the sun. Moreover, the requirement that a theoretical solar model would have to yield the observed solar neutrino flux would provide an additional, and rather restrictive, condition on acceptable solar models.

Recent theoretical and observational results¹⁻³⁾ have changed qualitatively our ideas concerning the possibility of detecting solar neutrinos. Detailed descriptions of these new results have been given elsewhere; we summarize in this talk the main conclusions.

The hydrogen-burning fusion reactions in the sun are believed to be initiated by the sequence ${}^1\text{H}(p, e^+ \nu){}^2\text{H}(p, \gamma){}^3\text{He}$ and terminated by the sequences (i) ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$; (ii) ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}(e^-, \gamma){}^7\text{Li}(p, \alpha){}^4\text{He}$; and (iii) ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}(p, \gamma){}^8\text{B}(e^+ \nu){}^8\text{Be}^*(\alpha){}^4\text{He}$. The CNO-cycle is believed³⁾ to contribute only a few percent of the energy generation in the sun and a negligible amount of the observable solar neutrino flux. The neutrino fluxes from the hydrogen-burning fusion reactions just listed have been calculated by Sears³⁻⁵⁾ and others using detailed solar models. When these results are combined with a theoretical discussion of the nuclear physics involved in detecting neutrinos by inverse electron capture, it is found^{1,2)} that the neutrinos from B^8 decay (sequence (iii)) produce 90% of the observable reactions although they constitute less than 0.1% of the total solar neutrino flux.

The method that will be used to detect solar neutrinos makes use of the inverse electron capture process ${}^{37}\text{Cl}(e^-, \nu){}^{37}\text{Ar}$ and has been extensively discussed by one of us (R.D.) elsewhere.^{1,6)} On the basis of experience gained in a preliminary experiment¹⁾ involving two

500-gallon tanks of perchlorethylene, C_2Cl_4 , Davis is undertaking an experiment that utilizes a 100,000-gallon tank of perchlorethylene as a detector (roughly equivalent to an Olympic-sized swimming pool of cleaning fluid). The most important features of the detection method being employed are that tiny amounts of neutrino-produced ^{37}Ar can be removed from the large volume of liquid detector by the simple procedure of sweeping with helium and that the characteristic decay of ^{37}Ar can be observed in a counter with essentially zero background. Background effects in an experiment using chemically pure perchlorethylene in a mine 4500 feet deep are expected to be at least a factor of ten below the predicted rate for solar neutrinos.

Sears³⁾ has investigated the uncertainties in the predicted neutrino fluxes due to uncertainties in nuclear cross sections, as well as solar composition, opacity, and age. They are, in addition, uncertainties²⁾ in the predicted neutrino absorption cross sections for the reaction $^{37}Cl(\nu, e^-)^{37}Ar$ due to our incomplete knowledge of the nuclear structure of ^{37}Cl and ^{37}Ar ; experimental studies are currently underway in a number of laboratories in this country that are designed to remove the major gaps in our knowledge of ^{37}Cl and ^{37}Ar . When the best current estimates of solar and nuclear physics uncertainties were combined, the total predicted number of neutrinos captures was found to be:²⁾

$(3.6 \pm 2) \times 10^{-35}$ per ^{37}Cl atom per sec. This rate corresponds to between 4 and 11 predicted solar neutrino captures per day in the 100,000-gallon deep-mine experiment.

In order to illustrate how the observation of the solar neutrino flux can be used to determine parameters in the solar interior, we recall that the ^8B neutrino flux is extremely sensitive to the central temperature of the sun.⁷⁾ This extreme temperature sensitivity is due to the large Coulomb barrier, compared to solar thermal energies, for the reaction $^7\text{Be}(p,\gamma)^8\text{B}$ of sequence (iii). An experimental upper limit on the central temperature of the sun can therefore be obtained by combining the results of the preliminary experiment,¹⁾ which provide an upper limit on the neutrino captures per sec per ^{37}Cl atom, with the predicted rate and the known temperature dependence of the $^7\text{Be}(p,\gamma)^8\text{B}$ reaction. Keeping the solar luminosity constant, one finds¹⁾ that the central temperature of the sun must be less than 20 million degrees and that a measurement of the ^8B neutrino flux accurate to $\pm 50\%$ would determine the central temperature of the sun to better than $\pm 10\%$.¹⁾

It should be noted that a positive result from an experiment of the kind described here would be subject to some ambiguity in interpretation due to the possibility of a galactic source of neutrinos, although present estimates of the probable galactic background indicate it is negligibly small. 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% difference in solar neutrino intensity between aphelion and perihelion. With a signal as low as 7 captures per day, such an experiment would be marginal, but if a somewhat higher signal is observed a test for the seasonal variation of the neutrino flux will be possible.

Postscript: Since the above talk was given, Reines and Kropp⁸⁾ have proposed an experiment to detect solar neutrinos by observing recoil electrons from neutrino-electron scattering. Reines and Kropp point out that such an experiment, which is complimentary to the one described in our talk, can in principle give information about the neutrino energy spectrum. In addition, Bahcall⁹⁾ has shown that under the experimental conditions suggested by Reines and Kropp all the observed recoil electrons will be confined to a cone of opening angle $\approx 10^\circ$ with respect to the incident neutrino direction. Thus the observation of electron scattering by neutrinos can in principle enable one to determine the direction (presumably toward the sun) of an extraterrestrial neutrino signal.

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