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$$1.3(/\text{ton}/10^{18}) \cdot 0.1 \text{ tons} \cdot 7\text{x}10^{18} \cdot 0.1 \cdot \frac{0.03}{0.2} \cdot 0.6 \cdot 2 = 0.016 \text{ events}$$

where 0.2 is the branching ratio of $D^{\pm} \rightarrow e\nu X$, 0.6 is the cross section ratio $\sigma(\nu_\tau)/\sigma(\nu_e)$ and the last factor 2 takes care of the presence of two ν_τ's in the chain decay $F \rightarrow \tau\nu_\tau$, $\tau \rightarrow \nu_\tau X$. Thus, though this estimate is crude, we are not able to expect any significant prompt ν_τ events in this experiment.

SOLAR NEUTRINOS AND NEUTRINO OSCILLATIONS

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The topics I will cover are, in order: an overview of the subject of solar neutrinos, a brief summary of the theory of stellar evolution, a description of the main sources of solar neutrinos, a brief summary of the results of the Brookhaven ^{37}Cl experiment, an analysis of the principal new solar neutrino experiments that have been proposed, and some new calculations related to averages that must be done if oscillations are important in solar neutrino experiments. Most of the information contained in this talk has been summarized in recent reviews[1,2,3,4,5].

The most important fact about the subject I am reviewing is that there is a serious discrepancy between the standard theory and observation.

One may well ask: Why devote so much effort in trying to understand a backyard problem like the sun's thermonuclear furnace when there are so many exciting and exotic discoveries occurring in astronomy? Most natural scientists believe that we understand the process by which the sun's heat is produced - that is, in thermonuclear reactions that fuse light elements into heavier ones, thus converting mass into energy. However, no one has found an easy way to test the extent of our understanding because the sun's thermonuclear furnace is deep in the interior, where it is hidden by an enormous mass of cooler material. Hence conventional astronomical instruments can only record the photons emitted by the outermost layers of the sun (and other stars). The theory of solar energy generation is sufficiently important to the general understanding of stellar evolution that one would like to find a more definitive test.

There is a way to directly and quantitatively test the theory of nuclear energy generation in stars like the sun. Of the particles released by the assumed thermonuclear reactions in the solar interior, only one has the ability to penetrate from the center of the sun to the surface and escape into space: the neutrino. Thus neutrinos offer us a unique possibility of "looking" into the solar interior. Moreover, the theory of stellar aging by thermonuclear burning is widely used in interpreting many kinds of astronomical information and is a necessary link in establishing such basic data as the ages of the stars and the abundances of the elements. The parameters of the sun (its age, mass, luminosity, and chemical composition) are better known than those of any other star, and it is in the simplest and best understood stage of stellar evolution, the quiescent main sequence stage. Thus an experiment designed to capture neutrinos produced by solar thermonuclear reactions is a crucial one for the theory of stellar evolution. We also hoped originally that the application of a new observing technique would provide added insight and detailed information. It is for all of these reasons (a unique opportunity to see inside a star, a well-posed prediction of a widely used theory, and the hope for new insights) that so much effort has been devoted to the solar neutrino problem.

A number of exotic solutions to the solar neutrino problem, modifying either the physics or the astronomy (and in some cases both), have been proposed. Even if one grants that the source of the discrepancy is astronomical, there is no general agreement as to what aspect of the theory is most likely to be incorrect. As indicated above, many of the proposed solutions of the solar neutrino problem have broad implications for conventional astronomy and cosmology. Some of them would change the theoretical ages of old stars or the inferred primordial element abundances.

On the other hand, modified theories of the weak interactions have been proposed in which neutrinos may disappear by mixing[6,7,8] or decay[9] in transit from the sun to the earth, but for which there are no terrestrially measurable consequences. The organizers of this conference have played a tremendously important role by their recent articles on the subject[10,11] in stimulating new experiments and ideas in this area. These ideas have been discussed extensively by experts at this conference and so I will say little about the subject except to indicate where solar neutrinos fit into the problem and to stress the need for averaging over the spectrum[12] when considering the implications of the results for the solar neutrino problem.

Boris Kayser told me that the main thing people want to know from me at this conference is whether or not the solar neutrino problem should be considered as evidence for neutrino oscillations. I will try to give you sufficient information to make up your own mind on this question.

STELLAR EVOLUTION

I have listed on Slide I (Table I) everything that I think you need to know about stellar evolution. There are many more things in stellar evolution theory, but I don't think you have to know them in order to understand solar neutrino experiments, certainly not for the purposes of this talk. Table I summarizes the principles that are required for constructing solar models and that are tested by solar neutrino experiments.

Table I Three Minute Course In Stellar Evolution Principle

Hydrostatic Equilibrium
Spherical Sun
Nuclear Energy Source
Energy Transport by Radiation & Convection
Uniform Primordial Composition = Surface Composition
Evolution (age = 5×10^9 yrs.)

BOTTOM LINE: Only ^{37}Cl Experiment Inconsistent with Standard Theory

The first principle is hydrostatic equilibrium, which in practice is used together with the special assumption of spherical symmetry. The second principle is that the energy source is postulated to be nuclear; the rates of the nuclear reactions depend on the density (ρ) and the temperature (T), and the composition (X_i). The practical part of this principle is that the rate at which the nuclear reactions produce energy when integrated over the whole sun is equal to the observed solar luminosity today. The "today" is an essential part of this principle.

The third principle is that the energy is transported from the deep interior to the surface via radiation and convection. In practice, for most (but not quite all) of the models, the great bulk of the energy is transported by radiation. The key quantities are the gradient of the temperature (dT/dr) and the opacity of the solar matter.

The assumption that the initial composition was uniform and is equal to the presently observed surface composition is closely related to the question of which opacity should be used. It is plausible that the surface composition has not changed much because of nuclear reactions since the sun was formed. It is not quite so obvious that nothing has been added to the solar surface since the sun was born. However, that is the assumption which is widely used throughout astronomy and is the basis for making the standard calculations.

The final principle is that the sun evolves because it burns its nuclear fuel. It has burned for something like 5 billion years so far. One mocks up this evolution by computing several quasistatic models which march along in time.

The bottom line of this brief course in stellar evolution is: within our store of observational information about stars, only the Brookhaven Chlorine 37 experiment of Ray Davis and his colleagues is inconsistent with the standard theory of stellar evolution. It is the only place where we don't see a way out of observational difficulties unless we modify something among the basic assumptions.

NUCLEAR FUSION IN THE SUN

I shall now outline briefly the conventional wisdom[13,14] regarding nuclear fusion as the energy source for main sequence stars like the sun. It is assumed that the sun shines because of fusion reactions similar to those envisioned for terrestrial fusion reactors. The basic solar process is the fusion of four protons to form an alpha particle, two positrons (e^+), and two neutrinos (ν), that is, $4p \rightarrow \alpha + 2e^+ + 2\nu_e$. The principal reactions are shown in Table 2 with a column indicating in what percentage of the solar terminations of the proton-proton chain each reaction occurs. The rate for the initiating proton-proton (PP) reaction, number 1 in Table 2, is largely determined by the total luminosity of the sun. Unfortunately, these neutrinos are below the threshold, which is 0.81 Mev, for the ^{37}Cl experiment. Several of the proposed new experiments, especially the ^{71}Ga and ^{115}In experiments, will be primarily sensitive to neutrinos from the p-p reaction. The PEP reaction (number 2), which is the same as the familiar PP reaction except for having the electron in the initial state, is detectable in the ^{37}Cl experiment.

The ratio of PEP to PP neutrinos is approximately independent of which model (see below) one uses for the solar properties. Two other reactions in Table 2 are of special interest. The capture of electrons by ^7Be (reaction 6) produces detectable neutrinos in the ^{37}Cl experiment. The ^8B beta decay, reaction 9, was expected to be the main source of neutrinos for the ^{37}Cl experiment because of their relatively high energy (14 Mev), although it is a rare reaction in the sun (see Table 2). There are also some less important neutrino-producing reactions from the carbon-nitrogen-oxygen (CNO) cycle, but we shall not discuss them in detail since the CNO cycle is believed to play a rather small role in the energy-production budget of the sun.

Table II The proton-proton chain in the sun

Number	Reaction	Solar[23] terminations (%)	Maximum Neutrino Energy (Mev)
1	$p+p\to{}^2H+e^++\nu$	(99.75)	0.420
2	or $p+e^-+p\to{}^2H+\nu$	(0.25)	1.44 (monoenergetic)
3	$^2H+p\to{}^3He+\nu$	(100)	
4	$^3He+{}^3He\to{}^4He+2p$	(87)	
5	or $^3He+{}^4He\to{}^7Be+\nu$	(13)	
6	$^7Be+e^-\to{}^7Li+\nu$		0.861 (90%), 0.383 (10%) (Both monoenergetic)
7	$^7Li+p\to2{}^4He$		
8	or $^7Be+p\to{}^8B+\nu$	(0:02)	
9	$^8B\to{}^8Be^*+e^++\nu$		14.06
10	$^8Be^*\to2{}^4He$		

NEUTRINO ABSORPTION CROSS SECTIONS

The expected capture rate is the sum of products of: (solar neutrino flux) times (capture cross section). The capture cross sections must be known accurately in order to compare with expectations based upon stellar evolution theory or weak interaction phenomenology. This has been my job for many years.

I consider the capture cross sections well known, or equivalently a proposed detector well calibrated, if I can calculate the absorption cross sections to an accuracy of ten percent or better for the expected solar neutrino spectrum. There have been many proposals for using different targets over the years, some of the most interesting of which have not been pursued because I found that the cross sections could not be calculated accurately. You might think that once the machinery has been developed to calculate the average cross sections for one target then it would be a completely straightforward job to calculate the cross section for any other target. However, this is not so. Every nucleus has its own peculiarities and individualities, particularly with regard to the contribution of excited states.

The details of the calculations have been described elsewhere[1,15] I will only mention that the basic ingredient is the theory of (charge-changing) nuclear beta-decay, the Hamiltonian for which is well-known from laboratory experiments. A number of special effects must be evaluated accurately: including electron screening, averages over broad nuclear states $^8Be^*$, relativistic effects for the bound electrons (used in interpreting the reverse electron capture reactions), precise phase-space factors (f-values), etc.

The most complicated (and often the most important) question concerns the contribution of transitions from the ground state of the target nucleus to the various excited states of the daughter nucleus. The relative contributions of the excited states must be estimated quantitatively for each target using all the available nuclear data and numerical calculations for different assumed solar neutrino spectra.

In the best cases (e.g., ^{37}Cl or ^{71}Ga), the matrix elements for the ground-state to ground-state transitions can be determined from measurements of the inverse electron capture reactions. Of course, in order to interpret the electron-capture rates accurate bound electron wave functions must be used.

The transition from the ground-state of ^{37}Cl to the isotopic analogue state of ^{37}Ar determines most of the expected capture rate for the Chlorine experiment. This rate can be calculated accurately from theory[1,15]. Moreover, the other nuclear matrix elements from the ground state of ^{37}Cl to the various excited states of ^{37}Ar can be determined by studying the beta-decay of $^{37}_{20}Ca_{17}$ to $^{37}_{19}K_{18}$, which essentially allows us to determine via isotopic spin invariance the experimental values of the nuclear matrix elements for the $^{37}_{17}Cl_{20}$ - $^{37}_{18}Ar_{19}$ transitions.

THE BROOKHAVEN SOLAR NEUTRINO EXPERIMENT

The Brookhaven solar neutrino detector which Ray has discussed in detail is based on the neutrino capture reaction[17,18,19,20,21]:

$$\nu + {}^{37}Cl \underset{decay}{\overset{capture}{\rightleftarrows}} {}^{37}Ar + e^- \quad , \tag{1}$$

which is the inverse of the electron capture decay of ^{37}Ar. The radioactive decay occurs with a half-life of 35 days. This reaction was chosen for the Brookhaven solar neutrino experiment because of its unique combination of physical and chemical characteristics, which were favorable for building a large-scale solar neutrino detector. Neutrino capture to form ^{37}Ar in the ground state has a relatively low energy threshold (0.81 Mev) and a favorable cross section, nuclear properties that are important for observing neutrinos from ^{7}Be, ^{13}N, and ^{15}O decay and the PEP reaction.

A set of experimental runs carried out in the Brookhaven ^{37}Cl experiment over the last 10 years show that the ^{37}Ar production rate in the tank is about 0.50 ± 0.06 ^{37}Ar atoms per day (see the discussion by Davis in this proceeding for details). Even though the tank is nearly a mile underground, a small amount of ^{37}Ar is produced by cosmic rays. An evaluation of data obtained by exposing 7500 liters of C_2Cl_4 at various depths underground suggests that the cosmic-ray production rate in the detector may be 0.08 ± 0.03 ^{37}Ar atoms per day. Fireman's[22] measurements of the muon background using a ^{37}K detector suggest a background rate of (0.18 ± 0.09) ^{37}Ar atoms/day. If this background rate is correct then there is no evidence for any solar neutrino detection beyond the 3-σ level of significance. Ray is continuing further measurements of the background, which are extremely important. There are also important uncertainties in the background rate calculated for neutrinos produced by the decays of cosmic ray secondaries.

If the background rate determined from the C_2Cl_4 measurements is assumed, then a positive signal of (2.2 ± 0.4) SNU is inferred (1SNU = 10^{-36} captures per target particle per second).

The predicted capture rates for the currently best standard solar model[23] are shown in Table 3. The results are expressed in terms of SNU's = 10^{-36} captures per target atom per second, the characteristic counting rate for solar neutrino experiments. We find a predicted rate of about 7.8 SNU. The neutrino absorption cross sections used to compute the rates given in Table 3 are from reference 1.

The best values to use for various parameters has recently been investigated[23] and the estimated uncertainties were found to amount to about 1.5 SNU.

Thus the best current theoretical estimate is 7.5 ± 1.5 SNU, appreciably lower than the 2.2 SNU production rate that is observed. Uncertainties due to the solar composition are estimated to be about ± 1 SNU, errors in the opacity may contribute of order ± 0.5 SNU, and the known statistical errors in the nuclear reactions correspond to about ± 1 SNU.

OBSERVATIONAL IMPLICATIONS

The ^{37}Cl experiment tests theoretical ideas at different levels of meaning, depending on the counting rate being discussed. The various counting rates and their significance are summarized in Table 4. It is obvious from a comparison of Table 4 with the experimental results given above that the value of 28 SNU's based on the CNO cycle is ruled out. More surprisingly, the best current models based on standard theory, which imply ~ 6 to 9 SNU's are also inconsistent with the observations. This disagreement between standard theory and observation has led to many speculative suggestions

Table III Predicted Capture Rates for a

Recently Computed Standard Solar Model[1,23]

Neutrino Source	Capture Rate (SNU's)
p-p	0
^{8}B	6.3
PEP	0.2
^{7}Be	1.0
^{13}N	0.08
^{15}O	0.25

Total = 7.8 SNU

Table IV Significance of counting rates in the ^{37}Cl experiment. One solar neutrino unit (SNU) = 10^{-36} captures per target per second

Counting Rate (SNU)	Significance of counting rate
28	Expected if the CNO cycle produces the solar luminosity
7.5±1.5	Predictions of standard models
1.5	Expected as a lower limit consistent with standard ideas of stellar evolution
0.3	Expected from the PEP reaction. Hence a test of the basic ideas of nuclear fusion as the energy source for main sequence stars

of what might be wrong. One such suggestion[24], that in the solar interior the heavy element abundance is at least a factor of 10 less than the observed surface abundance, leads to an expected counting rate of 1.5 SNU's (see Table 4), which is about as low a prediction as one can obtain from solar models without seriously changing current ideas about the physics of the solar interior. Present and future versions of the ^{37}Cl experiment are not likely to reach a sensitivity as low as 0.3 SNU, the minimum counting rate (from reaction 2 of Table 2) that can be expected if the basic idea of nuclear fusion as the energy source for main sequence stars is correct.

RETROSPECTIVE

It is instructive to look back over the history of this subject and to see how the observational and theoretical values have changed with time. This may be the best indicator of the uncertainties.

Figure 1 shows all the published values since 1964 in which Ray and I participated. This figure is taken from a paper Ray and I have prepared for the Willy Fowler festschrift.

A few remarks need to be made about the theoretical error bars in Figure 1. These uncertainties are more "experimental" than "theoretical" since the basic theory has not changed since 1964. What have changed are the best-estimates for many different input parameters (see the earlier discussion under 1968). The error bars shown in Figure 1 for the theoretical points were taken in all cases from the original papers (see caption to Figure 1) and represent the range of capture rates that were calculated at the time from standard solar models when the various nuclear and atomic parameters were allowed to vary over the range conventionally regarded as acceptable when the calculations were made. A number of detailed theoretical studies and improvements have been introduced into the stellar model calculations over the past fifteen years at great expense in personal effort and computing time, but these theoretical refinements have had only relatively minor effects on the calculated capture rates compared to the rather large changes produced by new measurements of experimental parameters. The various ups and downs in the best-estimate theoretical values since 1968 represent the largely statistical variations in the uncertainties in the many input parameters. The current theoretical estimate is (7.5 ± 1.5) SNU, where the quoted uncertainty takes account of known uncertainties in opacities, primordial chemical composition, and nuclear reaction parameters[23].

The procedures for analyzing the data have evolved with time; the techniques are discussed fully in the report by Davis[20]. All of the published capture rates prior to 1977 were described in the original papers (see caption to figure 1) as one-standard-deviation upper limits. The sensitivity of the experiment has improved greatly with time as experience has been gained with the operating system and the extremely low count rates.

It appears from figure 1 that the published estimates for the

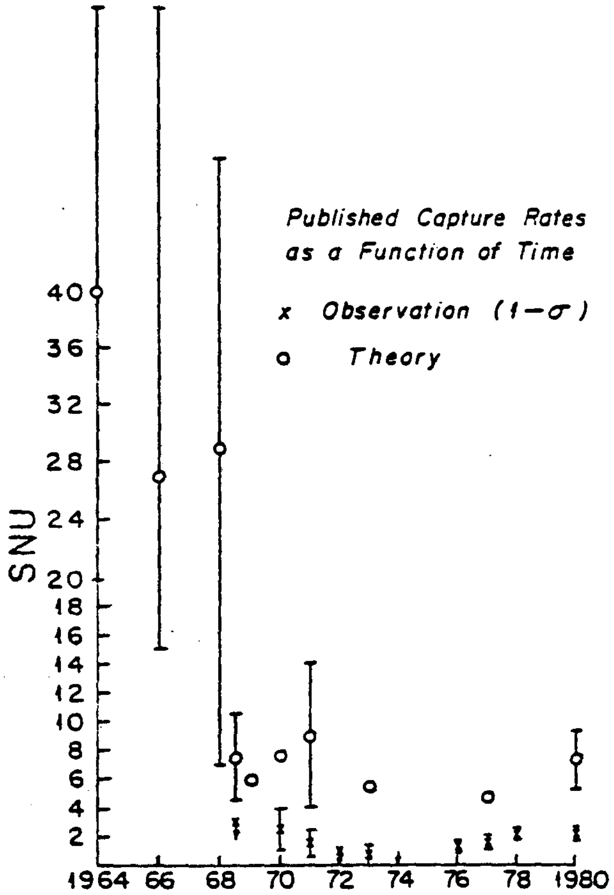

Fig. 1. Published Values of the Predicted and Observed Neutrino Capture Rates from 1964 to 1980. The detailed references are contained in the paper by J. N. Bahcall and R. Davis, Jr. that will appear in the Willy Fowler festschrift.

capture rate were at a minimum in 1972-1974. This effect is due almost entirely to the change in the method of analyzing the data (see reference 20); all of the later points include the earlier data as well. In order to check this interpretation, Bruce Cleveland has reanalyzed the data using his maximum likelihood method. For the data available in 1972, Cleveland finds 1.3 ± 1 SNU (compared to the earlier published value of less than 1 SNU) and for the 1974 data Cleveland finds 2.0 ± 0.4 SNU (compared to the earlier published value of 1.3 SNU). The main difference between the present analyses and the earlier calculations is due to the fact that the statistical uncertainty for a very small number of events is now properly taken into account.

The current difference between theory and observation using the best available estimates for the parameters is about a factor of three. Experiments to remeasure at low energies and with the most modern techniques the cross-section factors for the ^{3}He-^{3}He, ^{3}He-^{4}He, and ^{7}Be-p reactions are needed urgently (experiments are underway to remeasure the second of these reactions, which is being studied by Claus Rolfs and his associates in Germany and also by an impressive crew at Kellogg Laboratories). Of the total 7.8 SNU predicted by the current best-estimate model, 6.3 SNU is from the ^{7}Be(p,γ)^{8}B reaction, last studied in detail in 1969 by Ralph Kavanagh and his associates in an unpublished investigation. It is worth stressing again that the entire difference between the theoretical and observational values in Figure 1 is due to neutrinos from ^{8}B produced in the above-mentioned p-gamma reaction. The total capture rate also depends sensitively upon the ^{3}He(α,γ)^{7}Be reaction, approximately as: (cross-section factor)$^{0.8}$.

I have now done all I can to answer the question that Boris Kayser raised. There is a solar neutrino problem, but you will have to judge for yourselves whether or not it is related to neutrino oscillations. My own feeling is that we will not know for sure the answer to this question until someone completes a new solar neutrino experiment, one which focuses on the astronomically secure p-p neutrinos.

NEW EXPERIMENTS

Another experiment is required to settle the issue of whether our astronomy or our physics is the cause of the solar neutrino problems. Fortunately one can make a testable distinction. The flux of low energy neutrinos from the PP and PEP reactions (numbers 1 and 2 in Table II) is almost entirely independent of astronomical uncertainties and can be calculated from the observed solar luminosity, provided only that the basic physical ideas of nuclear fusion as the energy source for the sun and of stable neutrinos are correct. If these low energy solar neutrinos are detected in a future experiment, we will know that the present crisis is caused by a lack of astrnomical understanding. If the low energy neutrinos are absent, we will know that the present discrepancy between theory and observation is due at least in part to simplifications in our physics, not just poorly understood astrophysics.

I have recently analyzed in detail the theoretical aspects of eleven experiments that have been studied by various experimental groups as possible new solar neutrino experiments[1]. Those targets were examined for the following information: (a). whether the total cross-section solar neutrinos can be calculated to an accuracy of at least ten percent; (b). whether something new will be learned about the solar interior, or neutrino physics, by performing the proposed experiment; and (c). whether (in my opinion) the experiment is feasible with current technology.

The detectors for solar neutrinos can be classified according to their relative sensitivity to different parts of the solar neutrino spectrum. Five of the experiments are primarily sensitive to ^{8}B neutrinos; these are ^{2}H, ^{37}Cl, ^{51}V, ^{55}Mn, and neutrino-electron scattering.

Four detectors, ^{71}Ga, ^{87}Rb, ^{115}In and ^{205}Tℓ, are primarily sensitive to neutrinos from the proton-proton reactions. The expected capture rates for these detectors are practically independent of the astronomical assumptions that are made provided only that the sun produces, in a steady-state fashion and via the proton-proton chain, the energy that it radiates from its surface.

Raghavan has described to you already the unique characteristics of the ^{115}In detection system. He has certainly developed the most sophisticated and clever detection scheme of any of the experiments[16]

The pep neutrinos (reaction 2, Table II) are expected to make the largest single contribution to the capture rate of a ^{7}Li detector, even for the standard solar model. The observational results from the ^{37}Cl experiment show, moreover, that the higher energy ^{8}B neutrinos should contribute, for a ^{7}Li target, at most one-half the capture rate due to pep neutrinos. Since the pep neutrinos are as good a measure of the proton-proton reaction rate as are the p-p neutrinos, one can also classify the ^{7}Li detector as a p-p sensitive target. The ^{7}Li and ^{115}In targets share the property of being reasonably sensitive to more than one neutrino branch (the pep, ^{7}Be, ^{8}B, and ^{15}O branches for the ^{7}Li detector; the p-p and ^{7}Be branches for the ^{115}In target). The p-p and ^{7}Be capture rates could be determined separately for the ^{115}In experiment since the energies of the individual electrons could be measured.

The ^{81}Br detector is primarily sensitive to ^{7}Be neutrinos.

The ^{115}In and neutrino-electron scattering experiments could in principle be used to measure the direction of the electrons that are produced and thus to establish that the incident neutrinos come from the sun.

In order for a solar neutrino experiment to be most useful, the absorption cross sections must be accurately known. Of the new targets discussed in this paper, only ^{2}H, ^{7}Li, ^{71}Ga, ^{87}Rb, ^{115}In (with some reservations), and neutrino-electron scattering satisfy this requirement. A new detector should also help discriminate between the possible explanations of the discrepancy between theory and observation in the ^{37}Cl experiment. Experiments with ^{2}H or neutrino-electron scattering are sensitive primarily to ^{8}B neutrinos, as is the ^{37}Cl experiment. In order to provide new information of astrophysical importance, these experiments must be sensitive to a

^{8}B flux that is significantly below that already reached by the Brookhaven ^{37}Cl experiment. There has not been a recent and detailed experimental feasibility study for the proposed ^{87}Rb experiment, perhaps because of the uncomfortably short lifetime (2.8^{hrs}) of the daughter nucleus, ^{87}Sr. If we set aside ^{87}Rb because of the absence of a feasibility study, then the preferred targets are: ^{7}Li, ^{71}Ga, ^{115}In, and either ^{2}H or electron scattering (if sufficiently sensitive).

There are four major neutrino branches that must be measured in order to carry out a program of neutrino spectroscopy of the solar interior. These branches are the p-p, ^{7}Be, ^{8}B, and ^{13}N + ^{15}O neutrinos. The future experimental solar neutrino program should include all of the preferred new detectors. The ^{71}Ga experiment is primarily sensitive to p-p neutrinos and the ^{37}Cl experiment to ^{8}B neutrinos. The ^{7}Li and ^{115}In experiments provide additional information about the ^{7}Be and ^{13}N + ^{15}O fluxes. Taken together, the results of the four experiments (^{7}Li, ^{37}Cl, ^{71}Ga, and ^{115}In) should allow us to solve for the parameters of the solar interior (temperature range, density and composition). An ^{2}H or an electron-neutrino experiment should also be performed at some future date in order to check on the upper limit to the ^{8}B flux determined by the ^{37}Cl experiment. If a feasible experiment is proposed in which a ^{8}B flux as low as twenty percent of the prediction from the standard model could be measured then this would also be a preferred experiment since it would provide qualitatively new astrophysical information.

Either a ^{71}Ga or an ^{115}In experiment can distinguish between explanations that are based on presumed inadequacies in, respectively, the astronomical theory or the weak interaction theory provided only that the sun produces in a steady-state fashion the energy it radiates from its surface. A low counting rate in either of these experiments could also arise, in principle, if the sun is now in an abnormal phase in which its nuclear energy generation is much less than its surface luminosity. However, for most of the models of this kind that have appeared in the literature, the reduction in the counting rate of a ^{71}Ga or an ^{115}In experiment would not be nearly as great as is expected on either the oscillation or the decay hypothesis. Moreover, these latter two processes lead to specific predictions for the ^{71}Ga and ^{115}In experiments when combined with the results of the ^{37}Cl experiment.

A large scale Gallium experiment could be carried out with the technology available today[25]; a 1.3 ton pilot experiment recently was completed. We are hopeful that funding will be available for an American-German collaboration (with the Heidelberg group of T. Kirsten).

NEUTRINO OSCILLATIONS

I want to make just one point about oscillations that was not discussed carefully by Gribov and Pontecorvo[26] (nor even Bilenky and Pontecorvo[4]) and which has been overlooked in many of the modern rediscussions.

The proton-proton neutrinos (which are most important in the gallium and indium experiments) and the ^{8}B neutrinos (most important in the ^{37}Cl experiment) are really continuum fluxes. In order to calculate the expected capture rates, due to these sources, one must average over these continuua. This continuum average eliminates (see reference 12) the time-dependence due to the position of the earth in its orbit (an effect first suggested by I. Pomeranchuk[26] and independently by the CERN[27] group).

In order to calculate the average over the continuum neutrino spectra, one must know the relevant fluxes and cross sections as a function of energy. Numerical values are given in Figures 2 and 3 for the normalized ^{8}B and the proton-proton fluxes and in Table V for the ^{71}Ga neutrino absorption cross section (as a function of energy); the corresponding cross sections for ^{37}Cl are given in Table VII of reference 1.

Table V Absorption Cross Sections for p-p Neutrinos on ^{71}Ga

Neutrino Energy (MeV)	Cross Section (10^{-46}cm^2)
0.250	12.25
0.275	13.50
0.300	14.97
0.325	16.54
0.350	18.20
0.375	19.93
0.400	21.72
0.410	22.45
0.415	22.82

ACKNOWLEDGMENTS

I am indebted to Boris Kayser for asking the question that served as the theme for this talk. I am grateful to K. Whisnant for requesting that I reproduce the individual numerical values of cross sections and fluxes that would allow other workers to carry out proper averages over the continuous solar neutrino spectra.

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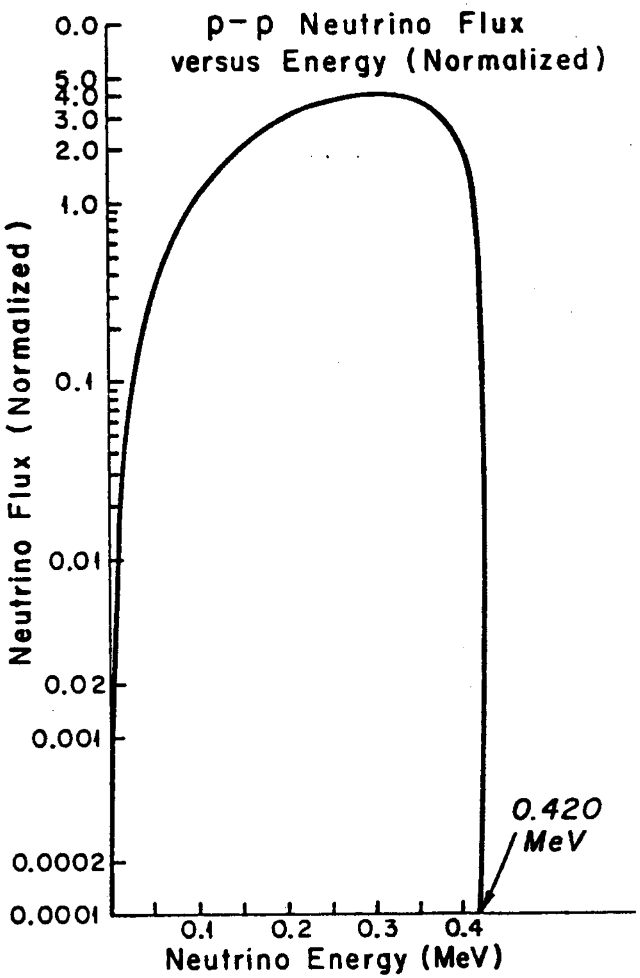

Fig. 2. p-p Neutrino Flux versus Energy (Normalized).

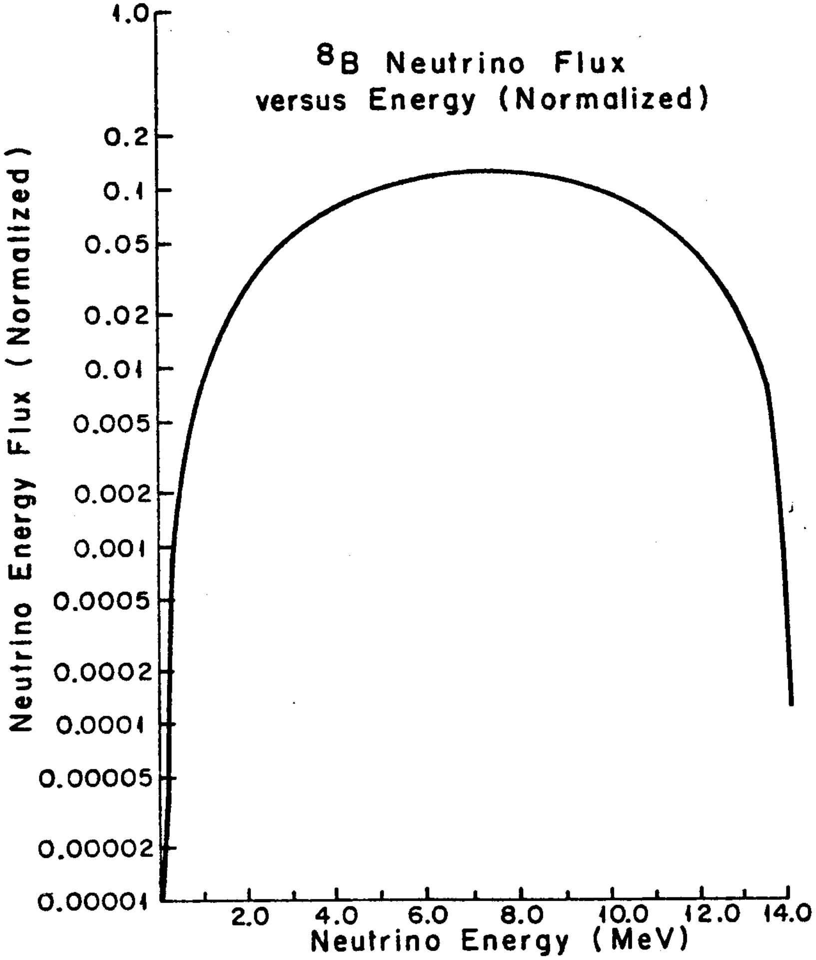

Fig. 3. ^{8}B Neutrino Flux versus Energy (Normalized).

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SOLAR NEUTRINO EXPERIMENTS AND A TEST FOR NEUTRINO OSCILLATIONS WITH RADIOACTIVE SOURCES

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ABSTRACT

The results of the Brookhaven solar neutrino experiment are given and compared to the most recent standard solar model calculations. The observations are about a factor of 4 below theoretical expectations. In view of the uncertainties involved in the theoretical models of the sun we do not consider the discrepancy to be evidence for neutrino oscillations. The status of the development of a gallium solar neutrino detector is described.

Radiochemical neutrino detectors can be used to search for ν_e oscillations by using megacurie sources of monoenergetic neutrinos like ^{65}Zn. A quantitative evaluation of possible experiments using the Brookhaven chlorine solar neutrino detector and a gallium detector is given.

INTRODUCTION

In this report we will give the results of the Brookhaven solar neutrino experiment that has been operating for 12 years. This experiment has always observed a solar neutrino capture rate in ^{37}Cl below the rate expected from standard solar models. In recent years the observed rate has been approximately a factor of four below theoretical expectation. Among the various explanations advanced for the low solar neutrino (ν_e) flux is neutrino oscillation. We will discuss this question briefly and point out that the dominant solar neutrino flux signal expected to be observed by the ^{37}Cl experiment according to the standard solar model arises from ^{8}B decays in the sun, and that the flux of these neutrinos may not be reliably calculated. Therefore one should exercise great caution in using results of the ^{37}Cl solar neutrino experiment as evidence for ν_e oscillations. Since the flux of low energy neutrinos from the chain initiating proton-proton reaction can be reliably calculated, observing the flux of this component of the solar neutrino spectrum could give more direct information on the question of neutrino oscillations. A radiochemical solar neutrino detector based upon the neutrino capture reaction $^{71}\mathrm{Ga}(\nu_e,e^-)^{71}\mathrm{Ge}$ has a sufficiently low energy threshold to observe p-p neutrinos. A gallium solar neutrino experiment can search for oscillations of electron neutrinos with an average energy of 300 keV over distances of one astronomical unit (1.5 x 10^{11} m). Progress on and the status of the development of a gallium solar neutrino detector will be described.

Radiochemical solar neutrino detectors can also be used to search for ν_e oscillations by using a source of neutrinos of well-defined energy such as ^{65}Zn. Plans for carrying out experiments