HAS A STANDARD PHYSICS SOLUTION TO THE SOLAR NEUTRINO PROBLEM BEEN FOUND? - A RESPONSE

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Abstract
In a recent paper Dar and Shaviv (1994) presented results of calculations with an improved standard solar model (SSM) that suggest a standard physics solution to the solar neutrino problem. In a subsequent publication with a similar title Bahcall et al. (1994) have claimed to refute the results obtained by Dar and Shaviv. Here we show that the criticism and conclusions of Bahcall et al. are unjustified. In particular, their attempts to reproduce the results of Dar and Shaviv failed because they did not use the same nuclear cross sections and did not include in their calculations major physics improvements which were included in the improved SSM code used by Dar and Shaviv.

Introduction
To facilitate understanding our response to a critique on our paper "A Standard Physics Solution To The Solar Neutrino Problem ?" (Dar and Shaviv, Phys. Rev. Lett. Submitted 1994), posted by 15 authors! (Bahcall et al. 1994) on this electronic bulletin board, we quote here (in italics) the main comments and criticism of these authors and insert our responses (in Roman fonts) between them.

Bahcall et al. abstract :
"The claim by Dar and Shaviv that they have found a standard model solution to the solar neutrino problem is based upon an incorrect assumption made in extrapolating nuclear cross sections and the selective use of a small fraction of the nuclear physics and of the neutrino data. In
addition, five different solar model codes show that the rate obtained for the chlorine experiment using the Dar-Shaviv stated parameters differs by at least $14\sigma$ from the observed rate."

DS Response:

Dar and Shaviv did not claim to have solved the Cl solar neutrino problem. Rather, they claimed agreement, within theoretical and experimental uncertainties, between the predictions of an improved standard solar model and all solar neutrino observations after 1986 (i.e., with all the published results of Kamiokande, SAGE and GALLEX and with the Homestake observations after 1986). This fact strongly suggests a standard physics solution to the solar neutrino problem.

Dar and Shaviv did consider all relevant nuclear data and did not introduce incorrect assumption in extrapolating nuclear cross sections to low energies (see below).

The five different SSM codes quoted by Bahcall et al. do not and should not reproduce the results of Dar and Shaviv when using their derived reaction rates for only two nuclear reactions and their value for the solar luminosity (Particle Data Group 1992): Although Dar and Shaviv have stated explicitly in their paper that for all the reactions, except for $^7\text{Be}(p,\gamma)^8\text{B}$ and $^3\text{He}(\alpha,\gamma)^7\text{Be}$, they have used the reactions rates compiled by Caughlan and Fowler (1988), Bahcall et al. chose to ”reproduce” the results of Dar and Shaviv with different reaction rates. Moreover, the Bahcall et al. codes include incorrect physical effects and unjustified physical approximations which were not used in the Dar-Shaviv calculations. In particular, these codes include incorrect screening enhancement of nuclear reaction rates in the Sun (omitted in the Dar-Shaviv code), assume nuclear equilibrium for the CNO bi cycle (not assumed in the Dar-Shaviv code), impose complete ionization of all elements everywhere in the Sun in calculating diffusion and the equation of state (not imposed in the Dar-Shaviv SSM code), replace a complex variety of heavy elements by a single effective element in calculating diffusion, opacities and the equation of state (80 different isotopes are included explicitly in the Dar-Shaviv SSM code. In particular, the Dar-Shaviv code follows the destruction of the light elements from Pre Main Sequence composition.
till the present day) and do not calculate the evolution of the Sun during the Pre Main Sequence stage (the Dar-Shaviv SSM calculations include the evolution of the Sun during the Hayashi phase). Most surprisingly, Bahcall et al. have ignored the fact that the Bahcall-Pinsonneault results were reproduced quite accurately by the code used by Dar and Shaviv when similar physical assumptions and approximations were used, i.e. before introducing the above improvements (see Kovetz and Shaviv 1994).

In their paper Dar and Shaviv have stated explicitly that the results of the Homestake experiment prior to 1986 are inconsistent with their improved SSM predictions but they also pointed out that these results look statistically incompatible with the Homestake results after 1986, assuming a constant Sun. The 14σ discrepancy, between the Bahcall et al. “reproduction” of the Dar-Shaviv prediction and the observed rate in the Cl experiment averaged over 23 years, is partly due to improper reproduction of the Dar-Shaviv results by Bahcall et al. and partly due to not including in σ the large theoretical uncertainty and the most probably large unknown systematic errors in the Cl results (as implied by the strong variation of the results as function of time).

The Homestake results after 1986 are compatible with those obtained by Kamiokande during the same time period. Furthermore, the results of GALLEX and SAGE can be predicted correctly from these observations and the solar luminosity using essentially only standard physics conservation laws (shown in the Dar-Shaviv paper). Therefore, Dar and Shaviv concluded that the solar neutrino experiments do not provide evidence for physics beyond the standard electroweak model and that only future experiments like SNO and Superkamiokande will be able to rule out a standard physics solution to the solar neutrino problem.

**Bahcall et al. claim:**

"2. Choosing Part of the Chlorine Solar-Neutrino Experimental Data

Dar and Shaviv chose to consider (see their Figure 1) only four years of data from the chlorine solar neutrino experiment beginning in 1987, although 23 years of data have been reported. For the period beginning in
1987, the experimental measurement of the chlorine rate is $2.8 \pm 0.3$ SNU. The measured rate for the entire period for which data has been reported is $2.28 \pm 0.23$ SNU. The measured rate in the chlorine experiment, during the short period considered by Dar and Shaviv, is still more than $4\sigma$ less than their calculated result of $4.2$ SNU and is more than $14\sigma$ from the value we calculate for their stated parameters.”

**DS Response:**

Dar and Shaviv stated clearly in their paper (in the abstract, text and conclusions) that they compared their predictions with all the reported solar neutrino observations after 1986, i.e., with all the reported results from Kamiokande, SAGE and GALLEX and from runs 90-120 of the Homestake Cl experiment during the time period 1986.8-1992.4, and not with “only four years of data”. In Fig. 1 they showed the data published by Homestake and Kamiokande for only the period 1987-1990 in order to avoid showing experimental data that was privately communicated to them by the authors prior to their publication.

The $^{37}$Ar average production rate observed in the Cl experiment in runs 90-120 (during the time period 1986.8-1992.4), which has been announced in recent international conferences and has been communicated to us also by K. Lande (who is one of the co-authors of the paper by Bahcall et al.), is $0.61 \pm 0.5$ atom/day. Since $1$ atom/day = 5.35 SNU, this rate corresponds to $3.26 \pm 0.28$ SNU before background subtraction and to $3.01 \pm 0.28$ SNU after background subtraction of $0.047 \pm 0.016$ atom/day. The last number is the present best estimate of the background in the Cl experiment, reported by Ray Davis at two recent international meetings: ”Neutrino Telescopes 1994” in Venice and ”The Solar Neutrino Problem - Astrophysical or Particle Physics Solution” in Grand Sasso.

The average production rate of $^{37}$Ar in Cl during the time period 1970.8 - 1985.3 observed by the Homestake experiment, as was communicated to us by K. Lande, is $0.47 \pm 0.04$ atoms/day which corresponds to $2.09 \pm 0.27$ SNU after $0.08 \pm 0.03$ atoms/day background subtraction, or to $2.26 \pm 0.023$ SNU after $0.047 \pm 0.016$ atoms/day background subtraction.

As explained in our paper, the Homestake results prior and after 1986
look statistically incompatible with a steady state Sun. The annual $^{37}$Ar production rate has increased by more than 50\% since the beginning of the Homestake experiment. One can ignore that and compare theory with the rate averaged over the whole live time of the Homestake experiment, assuming that the difference between the results before and after 1986 is due to a statistical fluctuation (with a rather small probability) as advocated by Bahcall et al. and by some other authors. Our approach is different. Kamiokande began its Solar Neutrino observations in 1987. It is only natural to compare the results of the Homestake and Kamiokande experiments during the time period when both were running, in particular, in view of the fact that Ray Davis and other authors proposed that solar neutrino flux is time dependent and anticorrelates with the solar activity. It is worth to note, and perhaps even significant, that after the installment of the new pumps in the Cl experiment in 1986 the results from the new Cl experiment (Homestake II, runs 90-120 during 1986.8-1992.4) are not in conflict with the results from Kamiokande. Moreover, during this time period neither the Homestake results nor the Kamiokande results showed any statistically significant anticorrelation with solar activity, nor any significant time variation, which have been claimed with high significance for the Cl data prior to 1986 by a few authors of the Bahcall et al. paper and by other authors.

In view of all these facts and in view of the agreement between our SSM predictions and the Kamiokande results for the $^8$B solar neutrinos, it is scientifically unjustified to overlook the possibility that the results after 1986 are closer to the truth than both (a) the results before 1986 and (b) the weighted average of the results before and after 1986.

The Dar-Shaviv prediction for the Cl experiment is $4.2 \pm 0.6$ SNU. The results from the uncalibrated Cl experiment after 1986 correspond to $3.01 \pm 0.28$ SNU, where the error is statistical only, not including possible systematic errors. Bahcall et al. concluded that the experimental result is $4\sigma$ below the theoretical prediction ignoring the theoretical uncertainty and possible systematic errors. We, however, consider the above results to be consistent within the theoretical and experimental uncertainties.

The impressive $14\sigma$ discrepancy between the expected rate in the Cl experiment, as calculated by Bahcall et al. with the Dar-Shaviv nuclear
parameters, and the average rate at Homestake obtained for the whole 23 years of observations is partly due to the incorrect physical approximations used in the Bahcall et al. calculations (see also below), partly due to ignoring the large uncertainty in the theoretical prediction, and perhaps due to possible unknown large systematic errors in the uncalibrated Cl experiment (as implied by the significant increase of the rate as a function of time since the starting of the Cl experiment).

**Bahcall et al. claim.**

"3. Extrapolating Nuclear Cross Sections with an ad hoc Assumption and Using Only Part of the Experimental Data

The theoretical models that have been used previously Johnson et al. 1992, Kajino et al. 1984, Parker and Rolfs 1991 to extrapolate the cross section data to solar energies properly take account of the finite nuclear size effects along with the other effects ..... These effects include nuclear structure, the strong interaction, energy dependent operators in the transition matrix elements, antisymmetrization between the colliding nucleons, finite nuclear size, the final-state phase space, and the contributions from other partial waves....

... Dar and Shaviv assumed incorrectly that the only energy-dependent effect besides point-nuclei barrier penetration is nuclear size... Dar and Shaviv did not take account of all the energy dependencies nor of all the available nuclear physics data... Their selective use of data and this incorrect assumption explain why the Dar and Shaviv answers for $S(0)$ differs from the standard values obtained by nuclear physicists ...”

**DS Response:**

Bahcall et al. describe a wishful idealistic situation, where nuclear reaction theory is an exact and tested theory which correctly predicts all cross sections (or at least their energy dependence over a wide range). This situation is far from reality. Actually, nuclear reaction theory is an approximate theory which generally provides only a reasonable parametrization of measured nuclear cross sections over a limited range of energy using many free parameters that are directly adjusted to fit the data. In fact,
for most reactions, including the major reactions in the Sun, it cannot
even distinguish which of the different measurements of a cross section
is the correct one (normalization as well as energy dependence). To
make our point more concrete, let us consider the model of Johnson et
al. (1992)) used "by the nuclear physicists" (together with an ad hoc
procedure) to extrapolate the various measurements of the cross section
for $^7\text{Be}(p,\gamma)^8\text{B}$ to zero energy to obtain $S17(0)=22.4 \text{ eV-b}$, the value
advocated by Bahcall et al. In spite of all the good features of that
model, which were listed by Bahcall et al., Johnson et al. (1992) have
not demonstrated that their model correctly predicts:

(i) the p-wave resonance (i.e. its position, width and magnitude),
(ii) the magnitude of the cross section,
(iii) the energy dependence of the cross section over the entire energy
range where it has been measured.

In fact Johnson et al. did not trust their model energy dependence
(which they refer to as "suspect theoretical calculations above 430 KeV"
cf. the last paragraph in Ap.J. 392,320,(1992) page 325) to extrapolate
the cross sections measured above the resonance energy by Kavanagh
1960, Parker 1966, 1968 and Vaughn et al. 1970, and choose instead
to extrapolate these data to low energies below the resonance according
to the energy dependence of the averaged Kavanagh et al. 1969 and
Filiponne et al. 1983 experiments (an ad hoc prescription).
Moreover,

(iv) for the $^7\text{Li}(n,\gamma)^8\text{Li}$ capture cross section Johnson et al. pre-
dicted 30.6 mb while the experimental values are $40.2 \pm 2 \text{ mb}$ (Imhof et
al. 1959) and $45 \pm 3.0 \text{ mb}$ (Lynn et al. 1991),

(v) for the $I=2$ $^7\text{Li}+n$ isotopic analog channel Johnson et al. pre-
dicted a scattering length $a_2 = 0.26 \text{ fm}$, while the experimental value is
$a_2 = -3.59 \pm 0.06 \text{ fm}$ .

This situation is rather typical (see for instance Descouvemont and
Baye 1994, in particular Figs. 5.6. therein).

The above points are not intended to criticize the otherwise good works
of Johnson et al., and Descouvemont and Bay, but rather to emphasize
our contention that since no exact theory exists for either the complicated quantum mechanical nuclear many body problem or the direct nuclear reactions, one should try to rely as much as possible on ”model independent” features rather than on the choice of a specific model for extrapolating cross sections to very low energies.

Three such features were used in our paper:

(1) The measured position, width and height of a low energy resonance in a given partial wave together with the effective range approximation determine uniquely the contribution of that partial wave to the total cross section all the way down to zero energy (Kim et al., 1994). It was used by us to subtract the p-wave contribution from the cross section for $^7\text{Be}(p,\gamma)^8\text{B}$.

(2) Because of the Coulomb and centrifugal barriers, the relative contribution of different non resonating partial waves to the total cross section, at energies well below the Coulomb barrier, are almost model independent, while the magnitude and energy dependence of the individual partial waves are model dependent. Thus, we used only the ratios calculated by various groups (but neither the magnitude nor the energy dependence) to extract from the measured cross section the s-wave contribution.

(3) Bound state wave functions decrease exponentially outside the nucleus while the incident Coulomb wave functions for energies well below the Coulomb barrier decrease exponentially from the classical turning point towards the nuclear surface. Consequently, most of the contribution to the overlap integrals comes from the vicinity of the nuclear surface. The s-wave cross section therefore, is proportional to the absolute magnitude squared of the incident Coulomb wave function near the nuclear surface, rather than at the origin, i.e. to the Gamow (WKB) barrier penetration factor for finite nuclear radii rather than the Gamow barrier penetration factor for point nuclei.

When extracting this energy dependence from the s-wave contributions to the measured cross sections for the three reactions, $^7\text{Be}(p,\gamma)^8\text{B}$, $^3\text{He}(\alpha,\gamma)^7\text{Be}$, and $^3\text{He}(^3\text{He},2p)^4\text{He}$, we found no evidence for any significant energy dependence of our defined $\bar{S}(E)$ for $E$ well below the Coulomb barrier. The
absence of any noticeable energy dependence in $\bar{S}(E)$ extracted from the measured cross sections for the above three reactions, while $S(E)$ shows strong energy dependence, which is not completely accounted for by the complicated theoretical models, is in our opinion, a further support for our simple extrapolation procedure.

Bahcall et al. claim: 

"For the determination of the low-energy cross section factor, $S_{34}$, for the $^3\text{He}(\alpha,\gamma)^7\text{Be}$ reaction, Dar and Shaviv apparently adjusted the radius parameter $R$ so that the energy dependence of $\bar{S}(E)$ is mostly removed for two of the nine (Parker and Rolfs 1991) existing experiments. (They seem not to have noticed that the value of $R$ that they obtain is very different from the measured radius of 2.8 fm determined by electron scattering.) They did not allow for the other energy dependencies discussed above and they only took account of two of the experiments."

DS Response: 

Dar and Shaviv did not adjust the radius parameter $R = R(^3\text{He}) + R(^4\text{He})$ so "that the energy dependence of $\bar{S}(E)$ is mostly removed for two of the nine existing experiments". Dar and Shaviv used $R = R(^3\text{He}) + R(^4\text{He}) \approx 3.6$ fm where $R(^3\text{He}) \approx 2.0$ fm and $R(^4\text{He}) \approx 1.6$ fm were determined from electron scattering measurements (e.g., Strueve et al. 1992; Wu et al. 1994) and from scattering of high energy strongly interacting particles (e.g., Tanihata et al. 1988), respectively, to calculate $\bar{S}_{37}(E)$ for all nine experiments (the world data). The straight line in Fig. 2 represents the weighted average of $\bar{S}_{37}(E)$ for these world data. (Dar and Shaviv were aware that $R(^7\text{Be}) \approx 2.8$ fm, but that is not the appropriate radius to be used).

Bahcall et al. claim: 

"Dar and Shaviv cited the preliminary Coulomb dissociation work described in preprint form (Motobayashi et al. 1994) as evidence for a lower-than-standard value for the crucial cross section factor for the $^7\text{Be}(p,\gamma)^8\text{B}$ reaction. When the $E2$ contribution to this reaction is
taken into account (Langanke and Shoppa 94), the preliminary Coulomb-
dissociation value differs from the six direct measurements (Parker and Rolfs 1991) of the $^7$Be($p, \gamma$)$^8$B cross section by a factor of two while the estimated uncertainty (Johnson et al. 1992) in direct measurements is only 11%. Moreover, there are still some unanswered questions about the application of the Coulomb-dissociation method for determining radiative capture cross sections, aside from the experimental difficulties inherent in covering a sufficient range in energy and angle to validate the reliability of any inferences.”

**DS Response:**

The results described in the paper by Motobayashi et al. (1994) that was submitted for publication in Physical Review Letters and was cited by Dar and Shaviv were shown (Fig. 3 of Dar and Shaviv ) to be in good agreement with the ”world average” s-wave cross section that was extracted from the four measurements of the $^7$Be($p, \gamma$)$^8$B reaction in the same energy range, (which is smaller there by approximately a factor two than the total cross section) and in particular with that extracted from Vaughn (1970) and Filippone (1983) if one allows a small (< 10%) M1 contribution. The world data that includes that of Motobayashi et al. (1994) yield $S_{17}(0) = 17 \pm 2$ eV b. The data of Motobayashi et al. yields approximately the same value.

Neither the suggestion that the results of Motobayashi et al. (1994) are preliminary nor their analysis by Langanke and Shoppa (1994) justify their omission from the ”world data” that is used to determine $S_{17}(E)$. In fact, the analysis of Langanke and Shoppa of the Motobayashi et al. data is highly questionable. They used as input E2 nuclear matrix elements calculated by others (Kim, Park and Kim, 1987). But if instead one uses the E2 nuclear matrix element calculated by Descouvemenot and Baye (1994) one gets an effect that is approximately 2.4 times smaller at 0.6 MeV. In addition, Langanke and Shoppa find the largest E2 contribution at 0.6 MeV, which is on the M1 resonance. The E2 contribution of the resonance is of no direct relevance to the low energy (s-wave) cross section.

In the data points of Motobayashi et al. (1994), measured at 0.8
and 1.0 MeV, that Langanke and Shoppa analyzed, there is essentially no evidence for an E2 component, as they state themselves. In fact, in all 15 or so data points shown by Motobayashi et al. (1994) there is only one point at approximately $4^0$, 0.6 MeV bin (on resonance) where the data deviates by approximately $2 \sigma$ from a predicted pure E1 behavior (the E2 angular dependence is sufficiently different from the E1’s). A claim based on that one point (out of 15 shown and some 30 measured in total [Motobayashi et at. private communication] that there is evidence for E2 contribution in the Motobayashi et al. data is a bit too much.

Bahcall et al. claim:
"For other nuclear reactions, Dar and Shaviv have used the low-energy cross section factors from an earlier review (Caughlan and Fowler 1988) which provided fitting formulae suitable for use at temperatures ($\sim 10^9$ K) much higher than are reached in the Sun ($\sim 10^7$ K). The quantitative effect of these approximations is difficult to estimate, especially since other authors (see section 4) use—for solar calculations—explicit formulae that are suitable for the lower solar temperatures. However, an approximate discussion of using the fitting formulae for higher temperatures at solar temperatures has been given (Bahcall 1992); the principal effects of the high-temperature formulae are in the direction to decrease the predicted $^7$Be and $^8$B neutrino fluxes."

DS Response:
We have verified that for solar temperatures the reaction rates for all the reactions, except $^7$Be(p,γ)$^8$B and $^3$He(α,γ)$^7$Be, which were compiled by Caughlan and Fowler (1988) are not significantly different from those obtained by Bahcall and Ulrich (1989) and by us. In fact the Kovetz-Shaviv SSM code with the Caughlan - Fowler (1988) nuclear reaction rates (for all reactions) and all other assumptions and input as used by Bahcall and Pinsonneault 1992 reproduces their predicted pp, pep, hep, $^7$Be and $^8$B solar neutrino fluxes within 2% accuracy (see column KS of Table I of the Dar-Shaviv paper or Kovetz and Shaviv 1994).

Bahcall et al. comment:
“Dar and Shaviv discuss at some length the fact that the Debye-Hückel approximation to the screened nuclear potential is not correct everywhere in the Sun. It is not clear what they recommend (although they say the effect is small), nor if they are aware that modern screening calculations go well beyond what they discuss...”

**DS Response:**

Dar and Shaviv discuss at some length the reasons why the screening enhancement of the nuclear reaction rates near the center of the Sun are negligible. The conventional screening enhancement factors used by Bahcall et al. in their SSM codes should be taken out. This modification in the Bahcall-Pinsonneault SSM code will reduce significantly their predicted $^8$B solar neutrino flux (about 15%). It does not change significantly the predictions if this modification is introduced after implementing all our other suggested improvements.

**Bahcall et al.**

4. Solar Model Calculations

Six authors of this paper (Bahcall, Christensen-Dalsgaard, Degl’Innocenti, Glasner, Pinsonneault, and Proffitt) have repeated the solar model calculations of Dar and Shaviv using the non-standard parameters that Dar and Shaviv chose, namely, a solar luminosity of $3.826 \times 10^{33}$ erg s$^{-1}$ and low energy cross-section factors of $S_{34}(0) = 0.45$ KeV-b and $S_{17}(0) = 17$ eV-b. Dar and Shaviv did not specify in their preprint many of the important input quantities in their model; they did not state what they used for the element abundances, the radiative opacities, the equation of state, and the neutrino cross sections. They did not say which of the several available prescriptions for diffusion they used. We have therefore carried out calculations using a variety of different choices for these quantities, namely, the choices made previously as their best estimates by the six different authors who used five independent stellar evolution codes ... None of the well-tested solar codes that we have used are able to reproduce the Dar and Shaviv results for neutrino fluxes.

**DS Response:**
The input physics used by Dar and Shaviv is the most updated one. The
detailed SSM code with all input physics which was used by Dar and Sha-
viv is documented in detail in the paper of Kovetz and Shaviv (Ap. J,
May 1, 1994) which is cited by Dar and Shaviv. The Kovetz-Shaviv
paper is and was available in a preprint form upon request. Bahcall et
al. apparently overlooked this paper and many physical improvements
introduced by Dar and Shaviv in the SSM calculations. All the five dif-
ferent SSM codes of Bahcall et al. do not and should not reproduce the
results of Dar and Shaviv when using the same measured solar lumi-
nosity that was used by Dar and Shaviv and the same nuclear reaction
rates for two reactions only, $^7\text{Be}(p,\gamma)^8\text{B}$ and $^3\text{He}(\alpha,\gamma)^7\text{Be}$, because
these SSM codes use reaction rates different from the Caughlan-Fowler
(1988) reaction rates used by Dar and Shaviv for all other reactions,
and because they include incorrect physical effects and unjustified ap-
proximations which were avoided in the Dar-Shaviv calculations: They
include incorrect screening enhancements of nuclear reaction rates in
the Sun (which were not included in the Dar-Shaviv calculations), as-
sume (some of them) nuclear equilibrium for the CNO bi cycle (which
was not assumed by Dar and Shaviv), impose complete ionization of all
elements everywhere in the Sun in calculating diffusion and the equa-
tion of state (which was not imposed by Dar-Shaviv), replace a complex
variety of heavy elements by a single effective element in calculating
diffusion, opacities and equations of state (while Dar-Shaviv considered
separately each of the 80 isotopes) and do not calculate the evolution of
the Sun during the pre main sequence stage (while Dar and Shaviv did).
Most surprisingly, Bahcall et al. have ignored the fact that the Bahcall-
Pinsonneault results are reproduced quite accurately by the code used by
Dar and Shaviv when they imposed the same physical approximations
that were used by Bahcall and Pinsonneault. (The Dar-Shaviv code
also includes several improvements and enhancements in the accuracy of
evolutionary models calculations never applied before).

In particular, Bahcall (1992) found the following empirical depen-
dence of the $^8\text{B}$ solar neutrino flux on the cross sections for the major
nuclear reactions in the Sun:

$$\phi_{\nu\odot}(^8\text{B}) \sim \sigma_{11}^{-2.6} \sigma_{33}^{-0.4} \sigma_{34}^{0.8} \sigma_{17}^{1.0}.$$
Thus, the use of our values (MeV-b units), $S_{11} = 4.07 \times 10^{-22}$, $S_{33} = 5.60 \times 10^3$, $S_{34} = 0.45$ and $S_{17} = 0.017$ instead of the values $S_{11} = 4.00 \times 10^{-22}$, $S_{33} = 5.0 \times 10^3$, $S_{34} = 0.533$ and $S_{17} = 0.0224$ which were used by Bahcall et al. should decrease the Bahcall - Pinsonneault (1992) prediction for $\phi_{\nu}(^{8}\text{B})$ by a factor $\approx 0.61$. Similarly, the omission of the weak screening enhancement factors, $\exp(U(0)/kT)$ where $U(0) \approx Z_1 Z_2 e^2 / R_D$, from the nuclear reaction rates should decrease the $^{8}\text{B}$ neutrino production rate near the center of the Sun ($T_c \approx 1.571 \times 10^7$ K and $R_D \approx 2.8 \times 10^{-9} cm$) by a factor $\approx 0.89$. Thus, the combined effect of the use of the Dar-Shaviv reaction rates and the omission of the weak screening enhancement, according to Bahcall 1992, is to reduce the Bahcall - Pinsonneault (1992) prediction, $\phi_{\nu}(^{8}\text{B}) \approx 5.69 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$, by a factor $\approx 0.54$, i.e., to $\phi_{\nu}(^{8}\text{B}) \approx 3.09 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$. The reduced solar luminosity brings it down by additional 5% and all other improvements/changes introduced by Dar and Shaviv should bring it further down (to their calculated value, $\phi_{\nu}(^{8}\text{B}) \approx 2.77 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$).

In view of all these, we find no point in discussing the conclusions of Bahcall et al. which are based on misleading comparisons. Bahcall et al. should have introduced all the suggested improvements/changes in their independent codes and then try to reproduce the Dar-Shaviv results before drawing their conclusions.

**Bahcall et al.**

5. **Conclusions:**

“Dar and Shaviv did not succeed in solving the solar neutrino problem... Their failure to solve the problem is not surprising since it has been demonstrated elsewhere (Bahcall and Bethe 1993) that the chlorine and the Kamiokande experiments are inconsistent another (if one assumes standard electroweak theory)...”

**DS Response:**

Dar and Shaviv did not claim to have solved the Cl solar neutrino problem. They claimed agreement, within theoretical and experimental uncertainties, between the predictions of an improved standard solar model and all solar neutrino observations after 1986 (i.e., with all the published results of Kamiokande, SAGE and GALLEX and with the
Homestake observations after 1986. That suggest a standard physics solution to the solar neutrino problem. Moreover, the Homestake results after 1986 are consistent with those obtained by Kamiokande during the same time period. Their results together with the observed solar luminosity predict correctly the observed production rate in GALLEX and SAGE, using essentially only standard physics conservation laws (see Dar and Shaviv 1994). Finally, the spectrum of $^8$B neutrinos measured by Kamiokande is not different from that predicted by the standard electroweak model. In view of all these facts Dar and Shaviv concluded that the solar neutrino experiments do not provide solid evidence for physics beyond the standard electroweak model. Only future experiments with large statistics and precise measurements of the energy spectrum and the lepton flavor content of solar neutrinos, such as the Superkamiokande light water experiment and the SNO heavy water experiment will be able to provide reliable evidence for physics beyond the standard electroweak model, which has not been found so far in all precision tests of the standard electroweak model at accelerators.

In fact, the standard solar model, which is only an approximate description of the Sun, is surprisingly successful in predicting the results of the pioneering solar neutrino observations, in particular those obtained after 1986. It is our considered opinion that both the standard solar model and the solar neutrino experimental results consist a great triumph for theoretical and experimental physics, in spite of the so called "solar neutrino problem".
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