with μ-e universality, the former to an accuracy of ~20 % and the latter to an accuracy of ~14 % when the present uncertainty in the ratio f_-/f_+ is taken into account.

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WHAT NEXT WITH SOLAR NEUTRINOS?*

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The capture rate of solar neutrinos is estimated for a number of targets that have been suggested previously as possible detectors of solar neutrinos. It is shown that the most important feasible experiment to be carried out in the future employs ^{7}Li as a detector.

The purpose of this Letter is to suggest that according to certain criteria the most important, feasible experiment involving solar neutrinos, following the ^{37}Cl experiment of Davis, Harmer, and Hoffman,[1] is one in which ^{7}Li is used as a detector. We first summarize the present theoretical and experimental situations regarding solar neutrinos and then present a table of the estimated capture rate of neutrinos for a number of possible targets. Using this table we show why, among the many experiments that have been proposed previously,[2-8] an experiment using ^{7}Li now seems most desirable.

Recent theoretical work has established the dependence of the estimated capture rate in the ^{37}Cl experiment on the parameters assumed and the assumptions made concerning the way nuclear fusion reactions generate the solar luminosity.[9] It is convenient in discussing solar neutrino experiments to introduce a solar neutrino unit: 1 SNU $= 10^{-36}$ capture per target particle per second.[10] If the CNO cycle is the dominant energy sourcs in the sun the expected capture rate is 35 SNU,[11] the rate estimated from the p-p chain using "standard values" for all nuclear and composition parameters is 6 SNU,[10,12] the rate determined by using[13] ^{7}Li$(n, n')^7$Li$(n, \gamma)^8$Li to estimate the low-energy cross-section factor (S_{17}) for the

Table I. Expected rate of neutrino captures for various targets. The total capture rate and the capture rate from the important individual sources are given. The unit is 1 SNU $=10^{-36}$ capture per second per target particle. The neutrino fluxes used are stated in the main text.

Target	Total Rate (SNU)	pep (SNU)	p-p (SNU)	^{7}Be (SNU)	^{8}B (SNU)	^{13}N + ^{15}O (SNU)
^{2}H	4	0	0	0	4	2×10^{-3}
^{3}H	4×10^3	6×10^7	3×10^3	5×10^2	8	8×10^1
^{7}Li	2×10^1	1×10^1	0	0	5	6
^{11}B	2	0	0	0	2	0
^{37}Cl	3	3×10^{-1}	0	8×10^{-1}	2	2×10^{-1}
^{51}V	1	2×10^{-1}	0	5×10^{-1}	6×10^{-1}	1×10^{-1}
^{55}Mn	4	1×10^{-1}	3	5×10^{-1}	1×10^{-2}	1×10^{-1}
^{71}Ga	3×10^2	6	2×10^2	4×10^1	8×10^{-1}	7
^{87}Rb	5×10^2	9	4×10^2	6×10^1	1×10^{-1}	1×10^1
ν-e scattering ($E_{\text{recoil energy}} \geq 8$ MeV)	6×10^{-3}	0	0	0	6×10^{-3}	0

crucial reaction $^7\mathrm{Be}(p,\gamma)^8\mathrm{B}$ is 3 SNU, general ideas about the solar interior imply a capture rate of 1-3 SNU more or less independent of nuclear cross-section factors,[9] and the basic idea that the sun shines because of nuclear reactions in its interior implies a minimum capture rate of 0.3 SNU from the reaction $p+e^-+p\to{}^2\mathrm{D}+\nu$.[14]

Davis, Harmer, and Hoffman have shown that the capture rate in the ^{37}Cl experiment is probably less than 3 SNU. The factor of 2 discrepancy between the rate estimated using "standard" values of all parameters and the observational result for the ^{37}Cl experiment has led to a number of papers that speculate[15-18] on various things that could be wrong with the current theory of solar models or weak interactions. Further information from solar neutrino experiments is required before one can decide if the present discrepancy between theory and observation is caused by inaccuracies in the "standard" parameters or requires a more fundamental revision of some aspect of current theory.

The expected number of neutrino-induced reactions per target particle are given in column 2 of Table I for ten targets that have been suggested previously as possible detectors of solar neutrinos.[2-8] The contribution to the total capture rate of the important neutrino sources in the sun are indicated separately. The absorption cross sections have been computed in the usual way.[19] The neutrino-producing reactions included in these calculations are (with their estimated[9] neutrino fluxes at Earth, given in parentheses, expressed in units of 10^{10} cm^{-2} sec^{-1}): $p+p\to{}^2\mathrm{D}+e^++\nu$ (6.35), $p+e^-+p\to{}^2\mathrm{D}+\nu$ (1.65×10^{-2}), $e^-+{}^7\mathrm{Be}\to{}^7\mathrm{Li}+\nu$ (2.9×10^{-1}), $^8\mathrm{B}\to{}^8\mathrm{Be}^*+e^++\nu$ (1.2×10^{-4}), and $^{13}\mathrm{N}\to{}^{13}\mathrm{C}+e^++\nu$ (2.2×10^{-2}). We assume in what follows that the ^{13}N and ^{15}O neutrino fluxes are equal; this simplification causes only negligible errors in our calculations for practical experiments.[20] In order to obtain consistency with the experimental results of Davis, Harmer, and Hoffman,[1] we have adopted the value of S_{17} determined[13] from experiments involving ^{7}Li (which is a factor of 3 smaller than the "standard" value[21] of S_{17}). We use this indirectly determined S_{17} because it enables us to make somewhat more plausible estimates for the rates of future solar neutrino experiments, not because of any criticism of the "standard" measurement.[21]

Several theoretical considerations are relevant in deciding what is the best target to use in future solar neutrino experiments. First, a feasible experiment should be possible with only neutrinos from the p-p or pep reactions in order to test (if necessary) the basic hypothesis that the sun shines because of nuclear fusion reactions in its interior (reason against using ^{2}H, ^{11}B targets and also against electron scattering as originally proposed[4]). Second, the estimated capture rate (cf. Table I) should contain a significant contribution ($\gtrsim\frac{1}{3}$) from neutrinos that are detectable in the ^{37}Cl experiment in order that interpretations of the new experiment and the ^{37}Cl experiment can serve as mutual checks (against ^{3}H, ^{55}Mn, ^{71}Ga, and ^{87}Rb). Third, the expected rate should contain a significant contribution from some neutrinos not believed to be important in the ^{37}Cl experiment in order that new information can be obtained about the solar interior (against ^{2}H, ^{11}B, ^{51}V). The only target listed in Table I that is not faulted by any of the above considerations is ^{7}Li. In addition, ^{7}Li requires the smallest weight of material with natural isotopic abundances for a given capture rate (4 tons of lithium per neutrino capture per day) and may be the least expensive target to use. The chief experimental difficulty is in counting the ^{7}Be atoms produced by the capture of solar neutrinos. Three schemes for counting the ^{7}Be atoms have been discussed briefly by Davis.[8]

In order to make clear which parts of the neutrino spectrum are observed in the ^{7}Li and ^{37}Cl experiments, we give below the capture rates (in SNU) for these two targets. Expressed in terms of the fluxes listed earlier (in units of 10^{10} cm^{-2} sec^{-1}), the rate for ^{7}Li is

$$10\left(\frac{\varphi(pep)}{1.65\times10^{-2}}\right)+5\left(\frac{\varphi(^{8}\mathrm{B})}{1.2\times10^{-4}}\right)+6\left(\frac{\varphi(^{13}\mathrm{N})}{2.2\times10^{-2}}\right), \tag{1a}$$

and the rate for ^{37}Cl is

$$0.3\left(\frac{\varphi(pep)}{1.65\times10^{-2}}\right)+1.6\left(\frac{\varphi(^{8}\mathrm{B})}{1.2\times10^{-4}}\right)+0.2\left(\frac{\varphi(^{13}\mathrm{N})}{2.2\times10^{-2}}\right)+0.8\left(\frac{\varphi(^{7}\mathrm{Be})}{2.9\times10^{-2}}\right). \tag{1b}$$

The expressions in parenthesis in the above equations are all equal to unity for the fluxes listed previously. Had we adopted the standard value for S_{17}, the parenthesis containing $\varphi(^{8}\mathrm{B})$ would have been equal to 3. For the convenience of other astrophysicists who may wish to calculate expected rates for the ^{7}Li experiment, we summarize the cross sections for neutrino absorption by ^{7}Li used to obtain Eq. (1a) (in units of 10^{-44} cm^{2}): $\sigma(pep)=5.9$, $\sigma(^{8}\mathrm{B})=4.5\times10^{2}$, $\sigma(^{13}\mathrm{N})=0.45$, and $\sigma(^{15}\mathrm{O})=2.3$. Note that the *pep* and CNO neutrinos together dominate the rate for the ^{7}Li experiment, and the ^{8}B and ^{7}Be neutrinos dominate the rate for the ^{37}Cl experiment.

One may consider two classes of explanation for the unexpectedly low counting rate in the ^{37}Cl experiment: (1) The high-energy ^{8}B neutrinos are even rarer than calculated originally,[15-17] or (2) some previously unknown phenomenon affects all neutrinos in their transit from the solar interior to the earth's surface (cf. Gribov and Pontecorvo[18]). These two classes of explanation lead to different expectations for the rate of the ^{7}Li experiment given the rate of ^{37}Cl experiment. If we assume that the usual theory of weak interactions is correct (i.e., ignore class-2 explanations), then a measurement of the capture rate with both ^{7}Li and ^{37}Cl targets would provide detailed information about the relative frequency of nuclear reactions in the solar interior. Such information would be a stringent test of the theory of stellar interiors and of the usual ideas about nuclear astrophysics.

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ARE ABSORPTIVE CORRECTIONS INCOMPATIBLE WITH UNITARITY?*

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We find that absorptive corrections to production amplitudes can generate, through unitarity, absorptive corrections to two-body amplitudes.

Theoretical and phenomenological arguments favor the existence of Regge cuts; this kind of singularity is spontaneously generated in the framework of some models by the iteration of "input" Regge poles, and therefore does not spoil the predictivity of the theory with the introduction of new parameters.

Two well-known models of this kind, the rescattering model[1,2] and the absorptive[3]-eikonal[4,5] model, have recently been compared by Finkelstein and Jacob[6] (FJ); they found that, to good approximation, the cuts predicted by the two models have the same structure, but opposite sign!

Let us briefly recall the results of the two models.[7]

(A) Absorptive-eikonal model.—The amplitude for an inelastic reaction is obtained by correcting the "Born" term (which we assume to be the exchange of a Regge pole R_{ab}) for the elastic rescattering in the initial and final states[3]:

$$T_{ab}=(S_{aa})^{1/2}\times R_{ab}\times(S_{bb})^{1/2}. \tag{1}$$

Assuming that $S_{aa}=S_{bb}=1+2iP$, where P is the amplitude for Pomeranchuk exchange, we obtain

$$T_{ab}=R_{ab}+2i(R_{ab}\times P). \tag{2}$$

A possible way of extending Eq. (2) to elastic scattering is to identify the eikonal phase with pure Pomeranchuk exchange,[4] obtaining

$$T_{aa}=P+i(P\times P)+\cdots. \tag{3}$$

(B) Rescattering.—The unitarity relation for an elastic scattering amplitude can be written, separating out the contribution of the elastic intermediate state, as

$$\operatorname{Im}T_{aa}=T_{aa}{}^*\times T_{aa}+\sum_{n\neq a}\int d\Phi_n\,T_{an}{}^*T_{an'}, \tag{4a}$$

the inelastic analog of (4a) being

$$\operatorname{Im}T_{ab}=\operatorname{Re}(T_{ab}{}^*\times T_{aa}+T_{bb}{}^*\times T_{ab})+\sum_{n\neq a,\,b}\int d\Phi_n\,T_{bn}{}^*T_{an}. \tag{4b}$$

Assuming a multiperipheral model (MPM) for the production amplitude, the sum over the multiparticle intermediate states behaves at large s as a Regge pole[1,11]:

$$\sum_{n\neq a}\int d\Phi_n\,M_{an}{}^*M_{an}=\operatorname{Im}P+\text{a low-lying cut}, \tag{5a}$$

$$\sum_{n\neq a,\,b}\int d\Phi_n\,M_{an}{}^*M_{bn}=\operatorname{Im}R_{ab}+\text{a low-lying cut}, \tag{5b}$$

where M_{an} is the multiperipheral production amplitude. In the approximation of neglecting $\operatorname{Re}T_{aa}$ and $\operatorname{Re}P$ with respect to $\operatorname{Im}T_{aa}$ and $\operatorname{Im}P$, on inserting Eqs. (5) in the unitarity relations (4) it is possible to solve them by iteration.[2] The solution has the form of a power series expansion in