PART 2

NEUTRINOS

SOLAR NEUTRINO PROJECTS

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ABSTRACT. An overview of the solar neutrino projects is given, with an emphasis on the complementarity of the different experiments (gallium, indium, heavy water,...) to solve the solar neutrino problem that was raised by the chlorine and the Kamiokande results. The separation of the different sources of neutrinos in the Sun would contribute significantly to the astrophysical understanding of the Sun. Some of the planned experiments could be able to pinpoint neutrino oscillations (within a wide range of parameters) almost independently of solar models. Projects which are particularly sensitive to a variation of the neutrino flux with time are also discussed.

1. Introduction

Solar neutrino detection is a challenge for astrophysics (test of the standard model of the Sun and of the stars) and for particle physics (the observed deficiency may be due to neutrino oscillations). In this section we briefly summarize neutrino properties, neutrino production in the Sun and the different types of solar neutrino detectors.

There are three flavours of neutrinos, ν_e , ν_μ and ν_τ , with a generic name ν_x . They interact with matter either by producing their charged lepton partner (e^-, μ^- and τ^- respectively) via W^+ exchange, which is called charged current interaction, or via Z^o exchange, which is called neutral current interaction. These processes are shown in Fig. 1. If neutrinos have a mass ($m_1 \neq m_2 \neq m_3$) the mass eigenstates ν_1, ν_2 and ν_3 may be different from the weak interaction eigenstates ν_e , ν_μ and ν_τ as it is observed for quarks. In this case the flavour eigenstates are related to the mass eigenstates by mixing angles and there are oscillations between the different flavours. The parameters of the oscillation between two flavours are the squared mass difference Δm^2 and the mixing angle $\sin^2 2\theta$.

The Sun produces pure ν_e , via the four main reactions :

$$\begin{array}{ll}
p\ p \rightarrow d\ e^+\ \nu_e & \nu_{pp} \\
p\ e\ p \rightarrow d\ \nu_e & \nu_{pep} \\
{}^7Be\ e^- \rightarrow {}^7Li\ \nu_e & \nu_{Be} \\
{}^8B \rightarrow {}^8Be^*\ e^+\ \nu_e & \nu_B
\end{array}$$

G. Berthomieu and M. Cribier (eds.), Inside the Sun, 157–169.

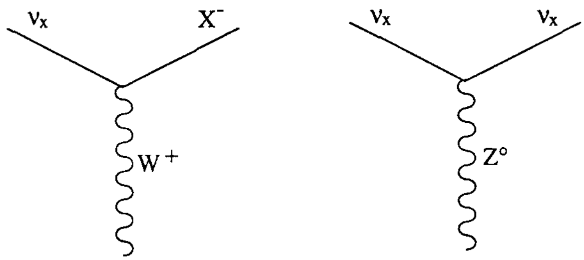

Figure 1 : Diagrams for neutrino interaction. a) charged current. b) neutral current. ν_x means ν_e , ν_μ or ν_τ and X^- means e^-, μ^- or τ^-.

These reactions are well known from nuclear and particle physics. The corresponding ν_e energy spectrum is displayed in Fig. 2. It extends to 0.420 MeV for ν_{pp} and 14 MeV for ν_B . On the contrary, the relative amount of these contributions may depend on details of the Sun model : central temperature, opacities, cross sections,... [1]. Only the ν_{pp} contribution is almost model independent, since it is fixed by the solar luminosity.

Solar neutrino experiments detect neutrinos via :

- charged current interactions : $\nu_x + (A,Z) \rightarrow X^- + (A,Z+1)$. Such experiments are only sensitive to ν_e . In the case where ν_e oscillate and become ν_μ or ν_τ , they cannot be detected by this process since the threshold for producing a muon (m = 106 MeV) or a tau (m = 1780 MeV) is well above the maximum solar neutrino energy. The produced electron is almost isotropic and does not give information on the neutrino direction. However the electron energy spectrum reflects directly the neutrino energy spectrum : $E_e = E_\nu - E_{threshold}$.

- neutral current interactions : $\nu_x + A \rightarrow \nu_x + A^*$. The detection is insensitive to the neutrino flavour. It integrates all types of neutrinos.

- elastic scattering on electron : $\nu_x + e^- \rightarrow \nu_x + e^-$. This reaction can occur via both charged and neutral current for ν_e , (see Fig. 3), and only via neutral current for ν_μ and ν_τ . Moreover the cross section for the charged current process is about 6 times larger than for the neutral current process. This means that, contrary to intuition, the elastic scattering of ν_e on electrons proceeds mainly via charged current process. An advantage of this reaction is that, for kinematical reasons, the scattered electron keeps the direction of the neutrino. This property is a great help for background reduction. The counterpart is that the electron energy spectrum does not reflect the neutrino energy spectrum.

Solar neutrino projects focus on three main physics goals.

1. Observation and separation of the neutrinos coming from the different sources in the Sun : ν_{pp} , ν_{pep} , ν_{Be} , ν_B . This can be achieved by combining the results of various radiochemical or real time experiments (chlorine, gallium, Kamiokande, indium, heavy water,...).

2. Oscillations of neutrinos from one flavour to another, between their production

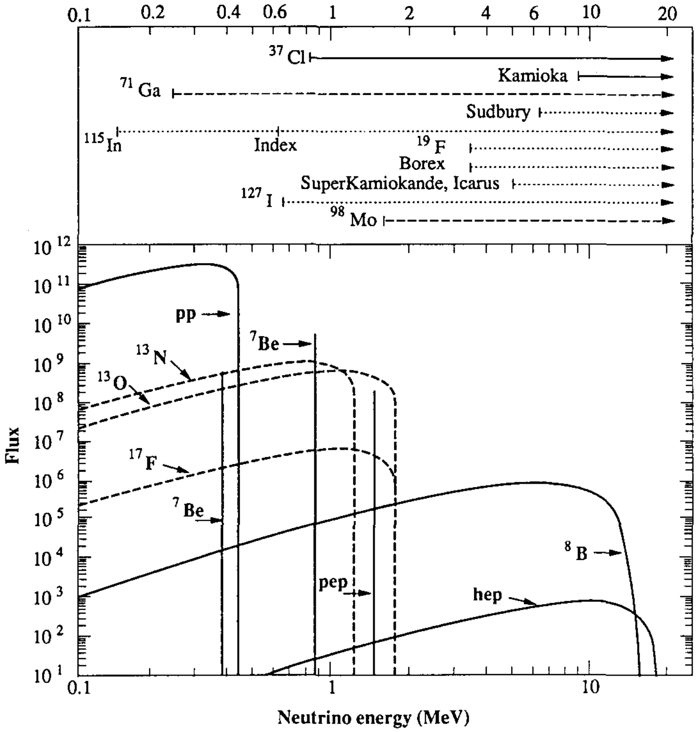

Figure 2 : Solar neutrino energy spectrum (adapted from [1]). Neutrino fluxes from continuum sources are in $cm^{-2}\,s^{-1}\,MeV^{-1}$. Line fluxes are in $cm^{-2}\,s^{-1}$. The insert above gives the sensitivity interval of the different detectors above the threshold. Full lines : existing detectors. Dashed lines : detectors in installation. Dotted lines : projects.

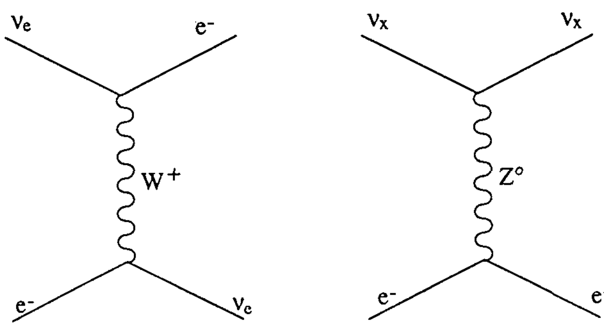

Figure 3 : Diagrams for neutrino electron interaction. a) charged current. b) neutral current. ν_x means ν_e , ν_μ or ν_τ .

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place to the detector location. This problem can be addressed in some of the solar neutrino projects **independently** of solar models by looking at i) the measurement of the total ν_{pp} flux, which is solar model independent (gallium), ii) a possible distortion in the ν_B energy spectrum (Sudbury, Borex, Icarus), iii) the ratio between charged current and neutral current interactions which is well predicted from particle physics only (Sudbury, Borex, Icarus), iv) day/night effects induced by the MSW mechanism.

3. Look at possible variations of the neutrino fluxes with time. This can be achieved by high statistics experiments (Sudbury, SuperKamiokande, iodine) for time scale variations of a few years (day/night, annual variations, solar cycle correlation). Larger time scales can rely only on geochemical experiments (molybdenum).

Some projects which did not progress significantly in the last years are not quoted. The reader is referred to the review by Kirsten [2] for a more exhaustive list of solar neutrino projects.

2. Measurement of the ν_{pp}, ν_{Be} and ν_B contributions

There are now two existing solar neutrino experiments (chlorine and Kamiokande), two funded (Gallex and Sage), and several projects at a different stage of design. Table 1 shows most of the possible targets for which the neutrino capture cross section is well known and which can then provide constraints on the different neutrino fluxes coming from the Sun. It will be completed by table 2. The different reaction thresholds are also presented in Fig. 2.

reaction	reaction threshold	experimental technique	ν contribution
$\nu_e + {}^{37}Cl \to {}^{37}Ar + e^-$	0.814 MeV	radiochemical	ν_{Be} and ν_B
$\nu_e + e^- \to \nu_e + e^-$	none	Cerenkov, H_2O	ν_B
$\nu_e + {}^{71}Ga \to {}^{71}Ge + e^-$	0.233 MeV	radiochemical	ν_{pp} , ν_{Be} , ν_B
$\nu_e + {}^{115}In \to {}^{115}Sn + e^-$	0.128 MeV	scintillator	ν_{Be} , ν_{pep}
$\nu_e + {}^{19}F \to {}^{19}Ne + e^-$	3.5 MeV	scintillator	ν_B
$\nu_e + D \to e^- + p + p$	1.44 MeV	Cerenkov, D_2O	ν_B

Table 1 : Main solar neutrino detectors.

The radiochemical Davis **chlorine** detector in Homestake (600 tons) [3] counts ^{37}Ar atoms every two months. The real time **Kamiokande** experiment (fiducial volume of 680 tons in 2140 tons of water) [4] detects Cerenkov light emitted by electrons with a detection threshold of 9 MeV. These two experiments, which detect mainly ν_B , have provided results which constitute the solar neutrino problem. An upscale version of the chlorine experiment is planned in USSR (3000 tons of C_2Cl_4 in the Baksan Underground Laboratory). In Japan, a significant extension of Kamiokande is proposed (SuperKamiokande) : 50000 tons of pure water with thousands of photomultipliers to detect Cerenkov light. The threshold for electrons could be lowered to 5 MeV, giving about 20 solar neutrinos per day in a 22000 tons fiducial volume.

The two radiochemical **gallium** experiments (30 tons in the form of $GaCl_3$ for Gallex in the Gran Sasso [5] and 60 tons of metallic Ga for Sage in Baksan [6]) are underway and should provide their first results within one year. Their main objective is the detection of ν_{pp} from the primordial pp fusion reaction. Their results are expected impatiently.

The idea of an **indium** target is from Raghavan [7]. The threshold is so low (128 keV) that it is very sensitive to ν_{pp} . However the natural radioactivity of ^{115}In (E_{max}=494 keV) is a formidable background in the low energy region and none of the many projects could fight against it. The detection of ν_{Be} and ν_{pep} should be much easier. Taking this in mind, the indium target has been revived recently [8]. This collaboration (Index) plans to use a scintillator detector (10 tons of In) to measure in real time the ν_e coming from the two neutrino line sources in the Sun (ν_{Be} and ν_{pep}). The detector would consist in plastic scintillating fibers surrounded by 3.5 μm of indium, and would be placed in a large tank of ultrapure water. Another solution would use directly liquid scintillator doped with indium. They expect about 50 events a year. The measurement of the ratio between these two lines gives a strong constraint on solar models and is almost free of systematics and uncertainty on capture cross section. Low temperature indium detectors are currently being investigated by various groups, with different approaches (superconducting junctions, superconducting granules) [9]. These are unfortunately still far from a real detector with several tons of indium.

A **fluorine** experiment, using a scintillator technique, sensitive only to ν_B , is now under study in Moscow [10]. The major difficulty is the separation of the ^{19}Ne signal which decays with a 20 s lifetime from the natural radioactivity background.

Three real time experiments (Sudbury, Borex and Icarus) aim to measure the ν_B contribution both in charged current and in neutral current. They can also detect the elastic interaction on electrons. Their main characteristics are displayed in table 2.

experiment	reaction	detection threshold	signature	events/yr
Sudbury 1000 tons D_2O Cerenkov	ν_e D $\rightarrow e^-$ p p	6.5 MeV	e > 5 MeV $(D_2O) - (H_2O)$	9750
	ν_x D $\rightarrow \nu_x$ p n	2.2 MeV	n capture on ^{35}Cl $(D_2O + NaCl) - (H_2O)$	2800
	$\nu_e\, e^- \rightarrow \nu_e\, e^-$	5 MeV	e > 5 MeV Sun direction	1100
Borex 2000 tons (200 t ^{11}B) scintillator	$\nu_e\ ^{11}B \rightarrow ^{11}C^*\ e^-$ $^{11}C^* \rightarrow ^{11}C\ \gamma$	6 MeV	e > 3.5 MeV no γ or γ(2,4.3,4.8 MeV)	2300
	$\nu_x\ ^{11}B \rightarrow ^{11}B^*\ \nu_x$ $^{11}B^* \rightarrow ^{11}B\ \gamma$	4.5 MeV	γ (4.4 or 5 MeV)	130
	$\nu_e\, e^- \rightarrow \nu_e\, e^-$	3.5 MeV	e > 3.5 MeV no Sun direction	1550
Icarus I 200 tons liquid argon drift chamber	$\nu_e\ ^{40}Ar \rightarrow ^{40}K^*\ e^-$ $^{40}K^* \rightarrow ^{40}K\ \gamma$	11 MeV	e > 5 MeV + γ 2.1 MeV	100
	$\nu_x\ ^{40}Ar \rightarrow ^{40}Ar^*\ \nu_x$	6 MeV	γ 6.1,7.8,9.6 MeV	20
	$\nu_e\, e^- \rightarrow \nu_e\, e^-$	5 MeV	e > 5 MeV Sun direction	80

Table 2 : Real time charged and neutral current sensitive detectors.

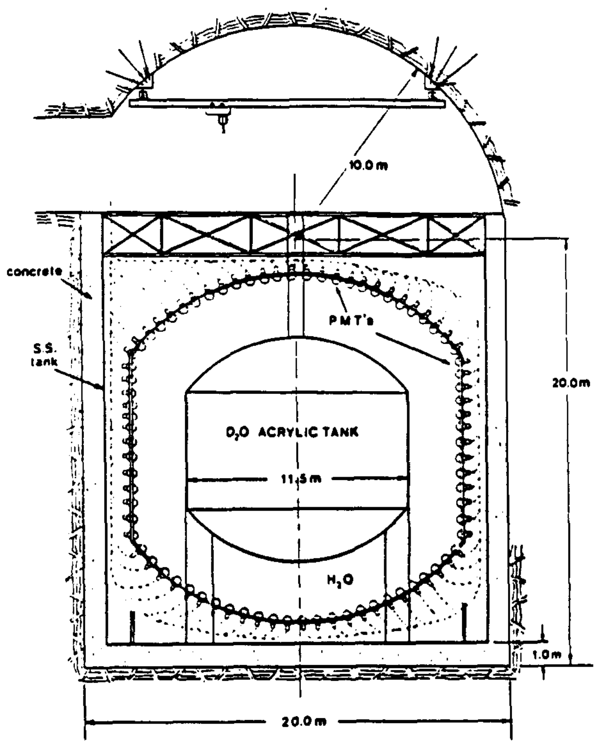


Figure 4 : Conceptual design of the Sudbury neutrino detector. Neutrinos interacting in the heavy water produce relativistic electrons which emit Cerenkov light. This light is detected by phototubes which cover 40 % of the surface.

The **Sudbury** project (Canada-USA-UK) [11] consists in 1000 tons of heavy water D_2O surrounded by 4 m of purified light water H_2O (see Fig. 4). The Cerenkov light emitted by the electrons is detected by photomultipliers as in the Kamiokande experiment. The detector which is almost funded will be installed in a deep mine near Sudbury in Canada (2070 m underground). The main difficulty of this experiment is to reduce the backgrounds at a very low level. This needs in particular the use of low activity materials : less than 10^{-15} g/g of U and Th; the high energy gamma rays from the U and Th chains can photodissociate the deuterium, emitting a neutron which can fake a neutral current process. This purity problem is essential for all similar experiments. The result is obtained by subtracting the H_2O signal to the D_2O signal, the internal target being filled alternatively with the two liquids. The addition of NaCl for some run should allow the measurement of the neutral current process with deuterium dissociation, by looking at the neutron capture by ^{35}Cl.

The **Borex** project [12] is a large tank containing 2000 tons of borated liquid scintillator (200 tons of ^{11}B) and immersed in pure water. It could be installed by an USA-Italy collaboration in the Gran Sasso Underground Laboratory (about 3300 m of water equivalent).

A major difficulty is also to obtain a very pure liquid scintillator. The charged current reaction is signed by an electron in coincidence with a photon. When there is no photon there is an ambiguity with the elastic scattering on e^- .

The **Icarus** project (Italy-USA) [13] is really ambitious with 3000 tons of liquid argon which would also be installed in the Gran Sasso. A major problem consists in the ability to drift ionization electrons over large distances, which needs among other things to have very pure argon. A smaller project, Icarus I, using 200 tons of liquid argon is being developed as a first step. This necessary step will allow the detection of solar neutrinos, but at smaller rate (about 200 / year) than Sudbury or Borex.

The use of ^{13}C as a target for solar neutrino detection in scintillation counters has been recently proposed by Arafune et al. [14]. The threshold is around 3 MeV and there are similarities with Borex about NC and CC detection. More work is however needed before writing a proposal.

The radiochemical experiments (Cl,Ga) measure only the integrated number of interactions over the whole ν_e energy spectrum above threshold. A combination of experiments is then necessary to separate the different contributions. In the standard solar model [1] the gallium detectors are sensitive to a linear contribution of ν_{pp} (56%), ν_{Be} (26%) and ν_B (11%) and the chlorine detects a linear combination of ν_{Be} (14%) and ν_B (77%) (the remaining small contributions are mainly due to the CNO cycle).

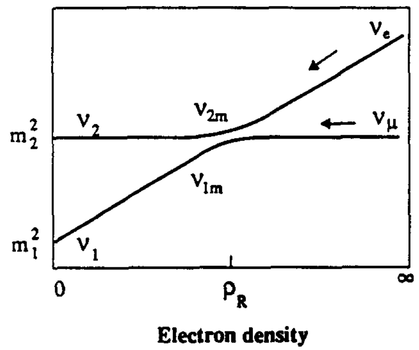
On the other hand Kamiokande or Sudbury, Borex, Icarus, or the fluorine experiment directly provide, with somewhat different thresholds, only the ν_B contribution.

In principle one should be able, by combining the gallium, the chlorine and the "only ν_B " sensitive experiments to disentangle all three contributions. However, by doing so, one expects rather large errors, especially on ν_{Be} . This last contribution would be best measured by an indium experiment which would provide a good ν_{pep} /ν_{Be} ratio (about 7% in the standard model but weakly model dependent).

3. Do neutrino oscillate ?

The idea that the solar neutrino problem is due to vacuum neutrino oscillations has been raised just after the first chlorine results in 1968. The main difficulty with that explanation is that a factor 3 reduction in the observed ν_e flux needs a maximum mixing between the three neutrino flavours. Although still possible, this is not the favoured scenario. The discovery of the MSW effect in 1985 was a real breakthrough, allowing a much more elegant and much less constrained explanation. Using the Wolfenstein formalism for neutrino propagation in matter, Mikheyev and Smirnov showed that an adiabatic transformation of solar ν_e into a mass eigenstate only weakly coupled to electrons could take place in the Sun [15]. This effect can lead to strong ν_e flux suppressions in a large range of the $(\Delta m^2 , \sin^2 2\theta)$ plane .

It is known from quantum mechanics that for infinite density the propagation eigenstates are the flavour eigenstates (ν_e and ν_μ in the two-flavour case), while at zero density (in the vacuum) these are the mass eigenstates (ν_1 and ν_2). The presence of a charged current diagram for ν_e and not for ν_μ breaks the symmetry between them and the eigenvalue of the total hamiltonian is larger for the ν_e than for the ν_μ at infinite density. What happens when density varies from infinity to a small or null value? The adiabatic theorem states that the instantaneous eigenstate of propagation goes smoothly from ν_e to ν_2 provided the density decreases sufficiently smoothly. The almost level crossing is for a given value ρ_R of the density (called the resonant density, because the rate of change between ν_e and ν_2 has a resonant shape for this value). This is illustrated in Fig. 5a, following Bethe [16]. If $\nu_2 = \nu_e \sin\theta + \nu_\mu \cos\theta$ the probability that ν_2 appears as a ν_e is then $\sin^2\theta$ which means that the smaller the mixing angle, the larger the reduction flux.



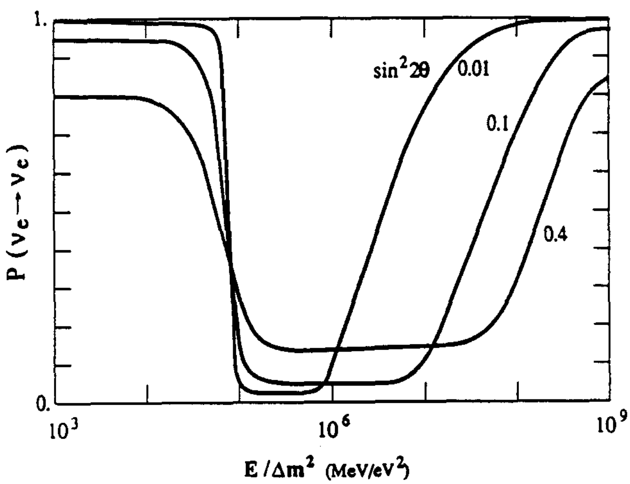


Figure 5 : a) Eigenvalues of the propagation eigenstates in the matter, ν_{1m} and ν_{2m}, as a function of the electron density. The level crossing is for a given value ρ_R (the resonant density). b) Probability for a neutrino ν_e created in the center of the Sun to escape from the Sun as a ν_e . The calculation is done as a function of $E/\Delta m^2$ for different values of the mixing angle.

Two physical conditions determine the ν_e energy region in which the flux is reduced by this factor $\sin^2\theta$ [17]. The minimum energy condition $E_{min}(\text{MeV}) = 10^5 \cos 2\theta$

$|\Delta m^2|\,(eV^2)$ is given by the electron density of the central Sun which must be higher than the resonant density. The maximum energy condition $E_{max}\,(MeV) \;=\; 2\,10^8 \sin 2\theta \tan 2\theta$ $|\Delta m^2|\,(eV^2)$ is the adiabatic condition for the transformation to happen smoothly. Fig. 5b shows the solar ν_e flux suppression as a function of $E/\Delta m^2$ for different mixing angles. The smaller θ, the smaller the energy interval with a suppression. If θ becomes too small, E_{max} becomes smaller than E_{min} and there is no more effect.

A day/night effect would be surprising as far as the solar neutrino flux is concerned. For detectors which are sensitive only to ν_e , this is no longer true. Let assume that the neutrino oscillation parameters are in the range where solar neutrinos are affected between their production place in the Sun and their detection on earth. There may be an amusing effect when neutrinos arrive during the night : if they have to cross the earth there may be regeneration of ν_e . This effect has been studied in particular in ref. [18]. There is a region in the $(\Delta m^2\,,\, \sin^2 2\theta)$ plane around $\Delta m^2 = 10^{-5} - 10^{-6} eV^2$ (which depends on the solar neutrino energy) where the day/night difference may be as large as a factor 3, which should be relatively easy to observe.

	$\sin^2 2\theta$		
	0.002	0.02	0.2
$\Delta m^2 = 10^{-4}$	$E_{min} = 10$ MeV $E_{max} = 40$ MeV ν_B spectrum NC/CC ratio	$E_{min} = 9.9$ MeV $E_{max} = 405$ MeV ν_B spectrum NC/CC ratio	$E_{min} = 8.9$ MeV $E_{max} = 4.5$ GeV ν_B spectrum NC/CC ratio
$\Delta m^2 = 10^{-5}$	$E_{min} = 1$ MeV $E_{max} = 4$ MeV none	$E_{min} = 1$ MeV $E_{max} = 40$ MeV NC/CC ratio day/night effect	$E_{min} = 0.9$ MeV $E_{max} = 450$ MeV NC/CC ratio day/night effect
$\Delta m^2 = 10^{-6}$	$E_{min} = 0.1$ MeV $E_{max} = 0.4$ MeV ν_{pp} suppression	$E_{min} = 0.1$ MeV $E_{max} = 4$ MeV ν_{pp} suppression	$E_{min} = 0.09$ MeV $E_{max} = 45$ MeV ν_{pp} suppression NC/CC ratio
$\Delta m^2 = 10^{-7}$	$E_{min} = 0$ $E_{max} = 0.04$ MeV none	$E_{min} = 0$ $E_{max} = 0.4$ MeV ν_{pp} suppression	$E_{min} = 0$ $E_{max} = 4.5$ MeV ν_{pp} suppression
$\Delta m^2 = 10^{-8}$	$E_{max} = 0$ none	$E_{max} = 0.04$ MeV none	$E_{min} = 0$ $E_{max} = 0.45$ MeV ν_{pp} suppression

Table 3 : $(\Delta m^2\,,\, \sin^2 2\theta)$ plane with sensitivity regions to different aspects of the MSW effect. E_{min} and E_{max} correspond to the neutrino energy interval in which the MSW suppression is maximum. (Δm^2 values are in eV^2).

Table 3 illustrates the regions of $(\Delta m^2\,,\, \sin^2 2\theta)$ plane where the MSW effect can affect one or another solar neutrino experiment. It corresponds to a large range of the neutrino oscillation parameters which is practically not accessible by any other non solar neutrino experiment. Grand unified theories are really in favour of this region for the neutrino mass and mixing angle parameters (see [19]) which still enhances the interest for solar neutrino detection.

The main feature of the MSW effect is a reduction of the ν_e flux, ν_e being transformed in ν_μ or ν_τ . But the reduction is not uniform at all. The ν_e energy spectrum is modified in a way which depends on the neutrino oscillation parameters. There are then several possibilities to evidence an effect, almost independently of solar models :

- suppression of the integrated ν_e flux.
- modification of the shape of the ν_e energy spectrum.
- modification of the NC/CC ratio. Indeed ν_μ and ν_τ coming from ν_e oscillation can induce neutral current interactions, modifying the NC/CC ratio.
- day-night differences.

These different approaches are listed in table 3 in the regions where they give a significant effect. We can now give more details, trying to isolate the MSW modifications which can lead to an interpretation almost independent of solar models.

The neutrino flux suppression may be observed in the case of ν_B sensible detectors. It is possible to interpret in this way the chlorine and Kamiokande experiments, which leads to the famous triangular region in the (Δm^2 , $\sin^2 2\theta$) plane (see for example [15,18]). However the ν_B flux is strongly model dependent and a model independent proof of the MSW effect would be the observation of a modified ν_e spectrum. This can be achieved by Sudbury, Borex and Icarus.

The neutrino flux suppression can also be observed in the forthcoming gallium experiments [5,6]. A global reduction flux would be model dependent. But these experiments are sensitive to the primordial ν_{pp} whose flux is directly connected to the solar luminosity and practically model independent. A value below the predicted ν_{pp} flux (i.e. below 70 SNU) would be a probable evidence for the MSW effect, which is now the only serious explanation for such a deficit.

The indium experiment which detects the ν_{pep} /ν_{Be} ratio would be sensitive to a variation of this ratio which is not strongly model dependent. A large statistics and a small error would be needed to do so.

When ν_e are transformed into ν_μ or ν_τ they become sterile for detectors which are sensitive only to ν_e (all radiochemical detectors for example). The neutral current of ν_μ and ν_τ has the same cross section as that of ν_e . An increase of the number of the observed NC or of the ratio NC/CC would clearly favour the MSW effect. The Sudbury, Borex and Icarus experiments have still the possibility of doing this.

Finally regeneration of ν_e into the earth could induce a day/night flux variation which would also be a unique and convincing evidence for MSW neutrino oscillations. Radiochemical experiments may have difficulties to do this. However the integration over days still induce some seasonal effects which could be observed by large statistics experiments as the chlorine in Baksan. It is very unlikely that the gallium experiments could observe something. The real time experiments are better adapted for such a purpose. Though Kamiokande is real time, the solar neutrino signal, after background subtraction, is not. Sudbury or SuperKamiokande should be better placed. In this case one year of running should be sufficient to observe a significant effect.

Moreover, one can see from table 3 that in the regions of the (Δm^2 , $\sin^2 2\theta$) plane where no distortion of the energy spectrum can be seen and where only the neutral/charged current ratio can be used as model independent evidence for neutrino oscillations, we get sizeable day/night effects (there may be a factor 3 difference between day and night). Such effects are likely to be much easier to detect than the neutral currents.

4. Variation of the neutrino flux with time

The interesting effects issued from the MSW mechanism and showing day/night differences were discussed in the previous section. The idea that the solar neutrino flux could vary slowly with time is far from evident because solar neutrinos are produced at the very center of the Sun (less than 0.3 solar radius). In this region the 11-yr solar cycle should not be seen since it is due to magnetic phenomena which affect almost exclusively the convection zone. Moreover one does not expect important variations of this flux since the last 100 million year. All these things have however to be investigated.

The first (and alone) possible experimental evidence for a variation of the solar neutrino flux comes from Davis in the chlorine experiment [3]. By comparing since 1970 the measured ^{37}Ar signal with the number of sunspots, which determines the 11-yr solar cycle, Davis seems to observe an anticorrelation : when the ^{37}Ar signal is low, the external activity of the Sun is maximum, and vice-versa. It is however too early to draw a definite conclusion, since the statistical significance of these observations is still marginal. As stated before there is no simple explanation to this phenomenon. This is why further investigation is needed, which needs mainly a larger statistics. Three forthcoming experiments are better placed to do this : Sudbury, the chlorine experiment in Baksan and SuperKamiokande. The answer to this question will not be immediate : about 10 years of data taking will be necessary to confirm or infirm the Davis suggestion. A new idea for an experiment using **iodine** has been proposed one year ago by Haxton [20] and could contribute to understand this point. The reaction (ν_e $^{127}\mathrm{I} \rightarrow {}^{127}\mathrm{Xe}\ e^-$) has a threshold of 664 keV and ^{127}Xe decays with a lifetime of 36.4 d. This radiochemical experiment, which could use any suitable iodine-bearing liquid is very similar to the chlorine one and is sensitive to ν_{Be} and ν_B . 380000 l of methylene iodide would give about 20 times more ^{127}Xe atoms than the ^{37}Ar atoms in the Davis chlorine experiment. No proposal has been yet written, but the idea remains attractive since it duplicates relatively closely the chlorine experiment, but with a different target.

There is a last class, the geochemical experiments, which may give information on the solar neutrino flux integrated over several million years. Solar ν_e are absorbed by ^{98}Mo (threshold = 1.7 MeV) which gives ^{98}Te which has a period of 4.2 million years. The present abundance of ^{98}Te in 1000 tons of a **molybdenum** ore is being measured by a Los Alamos group [21] which counts ^{98}Te atoms (about 10^7) using a dedicated mass-spectrometer. The analysis is in progress and should give results within few months. It has been shown [22] that the expected result should yield the same value for the ν_B flux as is determined by contemporary observations using the chlorine and Kamiokande detectors. Uncertainties on the ν_e capture cross section will however put limits on the interpretation. A similar experiment, **Lorex**, is planned to detect ^{205}Pb obtained from neutrino absorption in ^{205}Tl [23]. The reaction threshold is very small (54 keV) and the experiment is mostly sensitive to ν_{pp} . Unfortunately there are large uncertainties on the absorption cross section. The ore (lorandite or $TlAsS_2$) comes from the Allchar mine near the border between Yugoslavia and Greece, and is about 10^7 years old.

5. Conclusion

The ultimate goals of solar neutrino astronomy are to infer, from the rates of all neutrino producing reactions, whether the Sun behaves like it is supposed to do and to determine whether neutrino parameters like mass, mixing angle, lifetime and magnetic moment influence neutrino propagation to the Earth. To do this we need measurements in real time of the flux, flavour and energy spectrum of all individual sources of solar neutrinos. This unfortunately cannot be achieved in a single experiment. However, by performing various radiochemical, real time and geochemical experiments, one may hope to extract the basic information in a foreseeable future.

The main problems encountered in the present various projects are :

- size and cost of the experiments
- background
- uncertainties in some theoretical interaction rate of neutrinos.

However the growing interest in this field makes such a program more realistic than it was a few years ago.

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