CONCERNING SOLAR NEUTRINOS

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A possible explanation of the discrepancy between the theoretical predictions and the results of the observation of the neutrino flux from the sun is considered. The initial assumption is that the temperature of the internal layers of the sun varies periodically with time. Under certain conditions, a situation is possible wherein the luminosity of the sun begins to vary sharply with time, and the photon luminosity remains practically constant.

The latest results reported by Davis [1] on the search for solar neutrinos, which contradict the predictions of the theoretical models [2, 3], has stimulated a number of discussions [4 - 6] of the possible causes of the resultant disparity. Some of the advanced hypotheses can be verified directly by experiments under terrestrial conditions. Verification of the others will probably require a refinement of our knowledge of the interstellar processes. In the main, the explanations of the discrepancy entail an analysis of the reactions that lead to the formation of Be^7 and Be^8. A number of the cited authors believe in this connection that the contradiction is as yet not serious enough to require a radical review of the existing concepts concerning the structure of solar matter. Somehow or other, the contradiction does exist and we consider it of interest to analyze one of the possibilities noted in [4 - 6]. We assume that the temperatures of the internal layers of the sun vary periodically with time, and disregard the possible causes of such variations. The characteristic time intervals during which the temperature changes will be assumed small in comparison with the relaxation time in which the radiation produced in the interior of the sun emerges to the outside.

In connection with the strong dependence of the intensity of the neutrino radiation on the temperature [4], the neutrinos are emitted mainly at those instants of time when the temperature is maximal. Since the neutrino hardly interacts with solar matter, a successful observation of the neutrino flux from the sun depends entirely on the instant of time at which the observation is carried out. Photon emission is also quite sensitive to temperature fluctuations. Unlike the neutrinos, however, which pass through the thickness of the sun almost instantaneously, the photons, the motion of which is diffuse, reach the surface of the sun after an average of $(2 - 3) \times 10^4$ years. If the periods of the temperature oscillations inside the sun, as assumed above, are much smaller than this quantity, then the temporal variation of the photon emission inside the sun has little effect on the surface phenomena that determine the luminosity of the sun. Thus, the temperature oscillations inside the sun can cause the neutrino luminosity to vary strongly in time, while the photon luminosity remains practically constant. Such is the qualitative description of the possibility under consideration. We turn now to quantitative estimates. We assume that the diffusion coefficient $D = \lambda c/3$ (λ is the photon mean free path) is constant and independent of the coordinates. The value of D can be determined if the sun's luminosity $L_\odot$ is known. To this end, we consider the case when the radiant energy is emitted continuously within a small region of radius $R \sim (0.1 - 0.2)R_\odot$, where $R_\odot$ is the radius of the sun. Outside this region, the radiant-energy density is obviously inversely proportional to the distance from the center of the star

$$f(r) = f_0 \frac{R}{r}, \tag{1}$$

f_0 is the energy density on the edge of the radiating region:

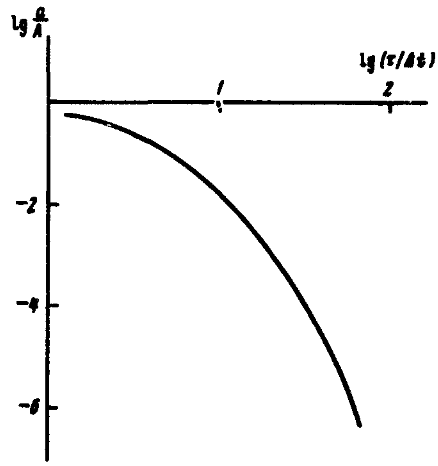
$$f_0 = \frac{\sigma}{c} T^4 .$$

σ is the Stefan-Boltzmann constant, c is the speed of light, and T is the temperature at the point r = R. Substituting f(r) in the equation for the luminosity

$$L_\odot = -4\pi r^2 D \nabla f , \quad (r \geqslant R), \tag{2}$$

we obtain

$$D = \frac{c L_\odot}{4\pi R \sigma T^4} . \tag{3}$$



We turn to the problem of the temperature oscillations and consider by way of example the case when the temperature of the internal layers of the sun varies like

$$T(t) = T_0 \left(1 + \frac{\Delta T}{T_0} \cos \frac{t}{\Delta t}\right). \tag{4}$$

The constant T_0 must be chosen such that the energy released in the form of radiation inside the sun, averaged over a time interval much larger than Δt, is equal to the energy calculated with the model with constant temperature T_{const}. The radiant-energy emission is proportional to the fifth power of the temperature [4]. T_0 can be set equal to T_{const} if the expansion of $[T(t)]^5$ in powers of ΔT can be confined to the first two terms

$$E_\gamma \sim [T(t)]^5 \approx T_0^5 \left(1 + 5 \frac{\Delta T}{T_0} \cos \frac{t}{\Delta t}\right). \tag{5}$$

Let us determine the time dependence of the emission from the sun's surface if the energy released in the interior is given by (5). The Green's function of the diffusion equation for a bounded medium with a constant diffusion coefficient is

$$G(r, 0; t, t') = \frac{1}{2R_\odot^2 r} \sum_{n=1}^{\infty} n \sin \frac{n\pi r}{R_\odot} \exp\left(-n^2 \frac{t - t'}{\tau}\right), \tag{6}$$

where $\tau = R_\odot^2/\pi^2 D$ is a certain relaxation time characteristic of the given problem, during which the radiation generated in the interior emerges to the outside. Choosing D in accordance with (3), we obtain

$$\tau \sim (1-2) \cdot 10^4 \text{ years.}$$

The radiation of the photons from the surface of the sun is proportional to

$$L_{\odot} \sim 4\pi R_{\odot}^2 \left[\frac{d}{dr} \int_{-\infty}^{t} G(r,0;t,t') E_y(t')dt' \right]_{r=R_{\odot}} \sim$$

$$\sim 1 + A \left\{ \left[1 - 2 \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{1+n^4(\Delta t/\tau)^2} \right] \cos \frac{t}{\Delta t} + \right. \tag{7}$$

$$\left. + 2(\Delta t/\tau) \sum_{n=1}^{\infty} \frac{(-1)^{n+1} n^2}{1+n^4(\Delta t/\tau)^2} \sin \frac{t}{\Delta t} \right\},$$

where $A = 5\Delta T/T_0$. The last expression can be represented in the form

$$L_{\odot} = L_0 \left[1 + a \cos\left(\frac{t}{\Delta t} + \delta \right) \right]. \tag{8}$$

The dependence of the ratio of the coefficients a and A' on the oscillation period Δt is shown in the figure. We see that this ratio decreases rapidly with increasing temperature-oscillation frequency, and consequently the luminosity at $\Delta t/\tau \ll 1$ is not very sensitive to the oscillations of the temperature inside the sun. Thus, for example, if the period of the oscillations is 1000 years, the ratio a/A is smaller than 0.01. At the same time, the neutrino luminosity, which varies with temperature like T^{25} (neutrinos from B^8 decay) [7] turns out to be extremely sensitive to temperature oscillations. Davis' result, which evidences that the flux of high-energy neutrinos is smaller than the expected value by approximately one order of magnitude, imposes the lower bound $\Delta T/T_0 > 0.1$ [4].

Neutrino production in proton-proton reactions is also quite sensitive to temperature changes, albeit to a lesser degree. The temperature dependence in this case is obviously the same as for light ($\sim T^5$). Therefore, if the possibility discussed here is actually realized, one should expect the low-energy neutrino flux to be weaker by approximately one-half.

In conclusion, a few remarks concerning the meaning of the quantity τ. V.S. Popov [8] obtained a formula for the average energence time for diffusion in a medium with a variable diffusion coefficient D(r):

$$\tau' = \frac{1}{3} \int_0^R \frac{r\,dr}{D(r)}. \tag{9}$$

we apply this formula to the diffusion of protons produced at the center of the sun, putting D(r) = D (= const). Then

$$\tau' = \frac{R_{\odot}^2}{6D},$$

from which we see that the relaxation time τ introduced by us is the same, apart from a numerical coefficient, as the average time τ' required for the photons to emerge from the center of the sun to the outside. If we calculate τ' from formula (9), knowing the D(r) dependence [9], we obtain $\tau' = 30\ 000$ years and $\tau = 6\tau'/\pi^2 = 20\ 000$ years, which agrees with the relaxation time estimated from the luminosity. It should be noted, however, that formula (9) does not take into account the photon multiplication during the diffusion process, so that the very concept of the average emergence time becomes somewhat arbitrary.

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After this article was sent to press, the author has learned of three other papers [10, 11, 12] dealing with solar neutrinos. Models with possible mixing of the internal layers of the sun are considered. It is shown that the mixing processes, whose periods range from 1 to 100 million years, can change the parameters of the central region of the sun and by the same token decrease the neutrino emission appreciably.

We note also that when assessing the effect of mixing on the photon luminosity the authors of [10, 11, 12], apparently following Fowler [4], assume the time of photon diffusion from the center of the sun to the outside to be equal to the Kelvin time of contraction, $\tau_K \sim 3 \times 10^7$ years. The latter, however, characterizes only the time during which the star can maintain its luminosity at the expense of gravitational energy.

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CONCERNING THE PHOTOSTIMULATED DIFFUSION IN SILICON

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Reply to remarks by Sh.R. Malkovich and I.V. Nistiryuk with regards to [1].

In connection with the remarks by Sh.R. Malkovich and I.V. Nistiryuk [2] we note the following: 1. Control experiment with complete elimination of the adsorption effect confirm the photosimulated diffusion (FSD) of gold in silicon (the depth of penetration for the conditions of [1] is $\sim 4\ \mu$). 2. The FSD depends on the character of the oxide film on which the gold is deposited. In the case of films with sufficiently perfect structure, a negative result may be obtained when FSD is obtained under the conditions of [1]. 3. The data on the acceleration of diffusion by low-energy radiation [3], obtained with the procedure of [1], require only slight quantitative refinement with allowance for the adsorption effect.

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