The p–p reactions on the sun ($p+p\rightarrow D+e^{+}+\nu$ and $p+p+e\rightarrow D+\nu$)

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The contribution of exchange currents in p–p reactions on the sun is considered. Arguments are advanced favoring calculations that lead to small corrections. The analysis is based on the establishment of a connection between the investigated reactions and the well known process of radiative n–p capture (likewise at thermal energies). The excepted corrections to the p–p reaction amplitudes for the exchange interband currents amount to $\delta = 2$–3%, which is insufficient to explain the measured intensity of the solar-neutrino flux.

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In a recent paper, Andreev *et al.*[1] advanced an argument that the contribution of exchange meson currents to the amplitudes of the p–p and p–e–p reactions on the sun can increase the cross section by a factor of two. This contradicts the result obtained in Ref. 2, where a value 4.4% was obtained for the effect of the exchange currents.

Since the cross section of the p–p reactions is a critical parameter for the estimate of the yield of solar neutrinos, this question calls for additional discussion. The argument that the cross section can increase is based principally on the fact that we do not know the behavior of the wave functions of the dueteron and of the p–p system at short distances between the nucleons. We shall see below, however, that there are limitations on the values of the wave functions in the short-distance region, as deduced from the precision measurement of the cross section of the quite similar radiative n–p capture ($n+p\rightarrow D+\gamma$). (This reaction remained puzzling for a long time, but by now it has been explained quite satisfactorily, see Refs. 3 and 4).

We consider the two processes

$$({}^{1}S_{0})\ n+p\rightarrow D+\gamma\ ,$$

$$({}^{1}S_{0})\ p+p\rightarrow D+e^{+}+\nu \tag{1}$$

at one and the same energy (for details see Ref. 5). As seen from (1), both reactions are ${}^{1}S_{0}\rightarrow{}^{3}S_{1}+D_{1}^{3}$ transitions. The single-particle and two-particle (corresponding to exchange currents) operators can be written in the form

$$O_{1}=\frac{G}{2}\,(\tau_{1}-\tau_{2})^{a}(\vec{\sigma}_{1}-\vec{\sigma}_{2})\ ,$$

$$O_{2}=\frac{G}{2}\ \{[(\vec{\sigma}_{1}\times\vec{\sigma}_{2})\,q_{\mathrm{I}}+T_{12}^{(x)}\,g_{\mathrm{II}}](\tau_{1}\times\tau_{2})^{a}$$

$$+ [(\vec{\sigma}_1 - \vec{\sigma}_2)(h_{\mathrm{I}} + h^{\tau}_{\mathrm{II}}\, p^{\tau}_{12} + h^{\sigma}_{\mathrm{I}}\, p^{\sigma}_{12})$$

$$+ \quad T^{(\mp)}_{12}(h_{\mathrm{III}} + h^{\tau}_{\mathrm{II}}\, p^{\tau}_{12} + h^{\sigma}_{\mathrm{II}}\, p^{\alpha}_{12})\,](\vec{r}_1 - \vec{r}_2)^{a}. \qquad (3)$$

For the magnetic dipole transition we have

$$G = \mu_B, \qquad a = Z\ .$$

Analogously, for the Gamow–Teller transitions we have

$$G = - g_A, \qquad a = \pm(\text{i.e., } \tau^{\pm} = \tau_1 \pm i\tau_2),$$

$g_{\mathrm{I}}, g_{\mathrm{II}}, n_{\mathrm{I}}, n_{\mathrm{II}}$ are quantities determined by the contribution of the meson-exchange effects. We emphasize the significant connection between the single-particle and two-particle operators of the magnetic dipole and Gamow–Teller transitions.

A careful analysis with allowance for the meson-nucleon form factors and for the corrections for exchange of heavy mesons, yields for the radiative *n–p* capture cross section an exchange-current correction ranging from 10.1% to 10.8%. The experimental result ($\sigma_{\mathrm{exp}} = 334.2 \pm 0.5$ mb) necessitates a correction of 10.55%. A similar approach yields for the meson effects in *p–p* reactions a cross-section correction of approximately 5%.

If we wish to change the wave functions in the *p–p* system, we must do the same in the case of *n–p*. Therefore, by greatly increasing the *p–p* reaction cross section, we change the radiative *n–p* capture cross section by the same amount, and this contradicts the experimental data. Of course, it can always be assumed that at very short distances the wave functions of the *p–p* and *n–p* systems have nothing in common, but this seems quite doubtful.

It should be noted in conclusion that the possibility of treating *p–p* reactions as the aforementioned magnetic dipole transition is indeed a fortunate circumstance, since this transition appears to be one of the best understood in nuclear physics.

Our analysis yields

$$\delta = \frac{\langle D + e^{+} + \nu \,|\, O_1 \,|\, pp \rangle}{\langle D + e^{+} + \nu \,|\, O_2 \,|\, pp \rangle} = 2\text{–}3\%.$$

A more detailed elucidation of the question is contained in Ref. 5.

[1] Yu.M. Andreev, E.V. Bugaev, and Yu.S. Kopysov, Pis'ma Zh. Eksp. Teor. Fiz. **25**, 593 (1977) [JETP Lett. **25**, 557 (1977)].

[2] M. Gari and A.H. Huffman, Astroph. J. **178**, 543 (1972).

[3] D.O. Riska and G.E. Brown, Phys. Lett. B **38**, 193 (1972).

[4] M. Gari and A.H. Huffman, Phys. Rev. C 7, 994 (1973).

[5] M. Gari, The Solar *p–p* reaction—a well known quantity? Proc. of the Solar Neutrino Conf., Brookhaven National Lab., Jan 5–7, 1978, G. Friedlander, to be published.