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Collective Plasma Corrections to the Solar Opacity

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This report contains a final table of opacity changes by several collective effects previously not taken into account in the calculation of the solar opacity. Since the neutrino solar flux is very sensitive to small changes in the solar opacity we calculate all corrections with a 5 place accuracy, but present only in % to significant two figures after the point. The calculations were performed by MCAD programs which give 5 figures after the point. This accuracy is needed since all corrections are finally described by triple or fourth integrals and one should keep the accuracy at each step of the calculation of the inner integrals. To calculate some of the integrals the time was of order of 100 hours. The calculations present the Rosseland opacity κ. κ_o denotes the Rosseland opacity previously taken into account in which the collective scattering only included the first approximation. In the table we give the ratio $\frac{\delta\kappa_s}{\kappa_o}$ where $\delta\kappa_s$ are corrections to Rosseland opacity $s = 1...12$. The table is given as a percentage and for following parameters $T_7 = 1.55K, v_{Te} \simeq 1.53 \times 10^9 cm/s, \frac{v_{Te}}{c} \simeq \frac{1}{20}, \rho(g/cm^3) = 142$, $x_H \simeq 0.36$, $x_{He} = 0.62, n_e \simeq 5.74 \times 10^{25} cm^{-3}$; $\omega_{pe} = 4.27 \times 10^{17} s^{-1}$; $\omega \simeq \frac{T}{\hbar} \simeq 2.10^{18} s^{-1}$; $v_{Te} = \sqrt{T/m_e}$; $\omega_{pe} = \sqrt{4\pi n_e e^2/m_e}$ We also include the heavy elements C, N, O according to their abundance in the standard solar model. The line absorption contribution in the opacity is not taken into account for C, N, O both in κ and κ_o, the H and He is fully ionized ($\beta \equiv \sum_i n_i Z_i^2 / \sum_i n_i Z_i$ n_i - ion concentration of space i according to standard solar abundance), therefore $\beta \simeq 1.51$.

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Table

N	Name of the effect	$\delta\kappa/\kappa_o$ (in %)
1	Relativistic Doppler broadening and shifting of Raman resonance in scattering by electron polarization cloud	-08.13
2	Raman scattering on thermal plasmons	+0.20
3	Relativistic correction in the nonlinear response of the electron polarization cloud for scattering on ions	-0.30
4	The same as 3 but for scattering on electrons	-0.92
5	Collective effects in bremsstrahlung	-0.61
6	Interference in the relativistic corrections to Thompson scattering and scattering by the electron cloud	-0.30
7	Relativistic effects in bremsstrahlung	-3.02
8	Stimulated scattering on electrons	-1.02
9	Frequency diffusion during radiative energy transfer	-0.71
10	Density inhomogeniety	-0.71
11	Refractive index corrections	-0.17
12	Electron degeneracy effects	-2.25
	Sum of the effects	-17.94%

We calculated also the following effects

1. Scattering through virtual transverse wave
2. Collective effects in electron-electron collision bremsstrahlung

3. Collective effects in ion-ion collision bremsstrahlung
4. Tail formation in proton distribution due to thermonuclear α-particle relaxation
5. Transport of energy by plasmons
6. Convection of plasmons by flux of particles taking part in heat transfer
7. Convection of plasmons by flux of photons

All these effects can reduce the opacity by not more than 0.02% and can therefore be ignored. We calculate also how $\left|\frac{\delta\kappa}{\kappa_o}\right|$ decreases as the distance from the centre of the sun increases. At a distance less than $1/3R_o$ this decrease is not large. At the present time we can only give an estimate of $\left|\frac{\delta\kappa}{\kappa_o}\right|$ averaged over the distance $1/3R_o$ from the center which gives $\left|\frac{\delta\kappa}{\kappa_o}\right| > 20\%$