PHY983 2009
HW6 Solutions

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This set is easier done if one first does problem 2.

2.) Solar luminosity: $L_{\odot rad} = 3.839 \cdot 10^{33}$ erg/s (radiation)

Energy released per $4p \rightarrow {}^4He$ reaction (regardless of wheather it is pp-chain or CNO) $Q = 26.731$ MeV

(this includes e^+e^- annihilation)

$Q = 4\Delta_H - \Delta_{^4He}$ using <u>atomic</u> mass excesses

Number of neutrinoes N_ν is then (per second)

$R_\nu = \frac{L_\odot}{Q} \cdot 2$ ← 2 ν's per reaction

In principle, L includes the energy emitted in neutrinoes

$L_\odot = L_{\odot rad} + L_{\odot\nu}$

from lecture notes $L_{\odot\nu} = L_\odot \cdot 0.023$

↳ $L_\odot = \frac{L_{\odot rad}}{(1-0.023)} = 3.929 \cdot 10^{33}$ erg/s

so this is a small correction that is not essential with that $\rightarrow$ $R_\nu = 1.835 \cdot 10^{38}$ /s

Flux at earth $\phi = \frac{N_\nu}{4\pi d^2}$ $d = 1.49 \cdot 10^{13}$ cm

$\hookrightarrow \phi = 6.58 \cdot 10^{10}$ $1/\text{s cm}^2$

1.) Using this result, the CNO neutrino flux can be estimated from the ratio of CNO cycling/pp-rate. This still requires typical temperature, but its only a second order effect as only the rate ratio matters. This way one does not need the burning volume.

$$\frac{r_{CNO}}{r_{pp}} = \frac{Y_p Y_{14N} \rho^2 N_A^2 \langle\sigma v\rangle_{14N(p,\gamma)}}{\frac{1}{2} Y_p^2 \rho^2 N_A^2 \langle\sigma v\rangle_{pp}} \cdot 2$$

↑ assume all pp I so need 2 pp reactions for each fusion

$$= \frac{4 Y_{14N} N_A \langle\sigma v\rangle_{14N(p,\gamma)}}{Y_p N_A \langle\sigma v\rangle_{pp}}$$

in center:

$Y_{14N} = 3.73 \cdot 10^{-3}$

$Y_p = 0.36462$

$T = 1.548 \cdot 10^7$ K

$N_A \langle\sigma v\rangle_{14N(p,\gamma)} = 1.288 \cdot 10^{-18}$

$N_A \langle\sigma v\rangle_{pp} = 9.1785 \cdot 10^{-20}$

$\frac{r_{CNO}}{r_{pp}} = 0.041$

$\frac{CNO}{CNO+pp} = \frac{1}{1+\frac{1}{r}} = 0.039$

$\sim 4\%$ CNO neutrinos or $2.59 \cdot 10^9$ $1/\text{s cm}^2$

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: In steady flow $Y \cdot \langle \sigma v \rangle = \text{const}$

	X	Y	$N_A \langle \sigma v \rangle$	$Y \cdot N_A \langle \sigma v \rangle$
^{12}C	$7.79 \cdot 10^{-6}$	$6.49 \cdot 10^{-7}$	$4.99 \cdot 10^{-16}$	$3.24 \cdot 10^{-22}$
^{14}N	$3.73 \cdot 10^{-3}$	$2.66 \cdot 10^{-4}$	$1.29 \cdot 10^{-18}$	$3.43 \cdot 10^{-22}$

↑ numbers are close

some deviation through neglect of screening in reaction rate calculation is expected