Level 2 Stars

David Alexander

Problem Set S.4

(1) What is the name of the main nuclear-fusion chain that occurs at the centre of the Sun? What direct observational evidence provides strong support for nuclear fusion as the power source of the Sun?

[2 marks]

Solution

The main nuclear-fusion chain that occurs at the centre of the Sun is the proton-proton chain. [1 mark]

The direction observational evidence for nuclear fusion is the detection of neutrinos from the Sun with an abundance consistent with that predicted from the proto-proton chain, given the central core properties of the Sun. [1 mark]

(2) On the basis of the conservation laws for nuclear reactions, which of the following sets of products can result from a collision between a deuteron ($^{2}H_{1}$) and a $^{4}He_{2}$ nucleus?

[3 marks]

(i) $^{3}He_{2} + {}^{1}H_{1}$ (ii) $^{6}He_{2} + e^{+} + \nu$

(iii) $^{6}Li_{3} + e^{-} + \bar{\nu}$ (iv) $^{6}Li_{3} + \gamma$

(v) $^{6}Be_{4} + \gamma$ (vi) $^{6}Be_{4} + e^{-} + \bar{\nu}$

Solution

The final state must have charge +3, nucleon number 6 and lepton number zero.

Product set	*Charge*	*Nucleon Number*	*Lepton Number*	*OK?*
(i)	*3*	*4*	*0*	✗
(ii)	*3*	*6*	*-1+1=0*	✓
(iii)	*2*	*6*	*-1+1=0*	✗
(iv)	*3*	*6*	*0*	✓
(v)	*4*	*6*	*0*	✗
(vi)	*3*	*6*	*-1+1=0*	✓

[1 mark for each correctly identified reaction; however, if list more than 3 answers then deduct 1 mark for each extra answer]

(3) Estimate the number of PPI reaction chains per second required to produce the luminosity of the sun, assuming that all of the energy released in this chain is due to thermal processes. Assuming that 2 neutrinos are released for each PPI reaction chain, estimate the number of neutrinos per square metre per second at the Earth.

[5 marks]

Solution

Energy released in each PPI reaction chain: $E = 26.73MeV$ *[1 mark]*

Number of PPI chain reactions is $N_{chain} = \frac{L}{E}$ *[1 mark]*

$$N_{chain} = \frac{3.84 \times 10^{26}}{26.73 \times 10^{6} \times 1.603 \times 10^{-19}}$$

$$N_{chain} = 8.96 \times 10^{37} \quad \textit{[1 mark]}$$

Neutrino flux: $N_{neutrino} = \frac{2 \times N_{chain}}{4\pi r^2}$, *where r=Earth-Sun distance* *[1 mark]*

$$N_{neutrino} = \frac{2 \times 8.96 \times 10^{37}}{4\pi \times \left(1.50 \times 10^{11}\right)^2}$$

Giving: $N_{neutrino} = 6.34 \times 10^{14} s^{-1} m^{-2}$ *[1 mark]*