PH20016 : Particles, Nuclei and Stars   SRD Problem Sheet 1

Data : $M_\odot = 2 \times 10^{30}$ kg; $L_\odot = 4 \times 10^{26}$ W; $R_\odot = 7 \times 10^{8}$ m; mass of proton = 1.67×10^{-27} kg; Earth – Sun distance = 1 A.U. = 1.5×10^{11} m; 1 pc = 3×10^{16} m.

1. Consider two protons at the centre of the Sun, at a separation of $r = 10^{-15}$ m. By considering the average kinetic energy and electrostatic potential energy of the protons, what do you conclude about the mechanism responsible for fusion in the Sun?

2. The mass of a proton is 1.673×10^{-27} kg, whilst that of a helium nucleus is 6.644×10^{-27} kg. Estimate the number of p-p chain reactions occurring in our Sun every second.
[Assume the fusion reactions are of the simplified form $4\,{}^{1}\text{H} \rightarrow {}^{4}\text{He} + \text{energy}$.
Make a simple calculation using the mass defect and the known luminosity.]
[9.3×10^{37} s^{-1}]

3. Discuss whether the fusion reaction $${}^{12}_{6}\text{C} + {}^{12}_{6}\text{C} \rightarrow {}^{24}_{12}\text{Mg} + \gamma$$
(a) is possible, (b) could be an appreciable source of energy in Main Sequence stars?

4. Consider the first reaction in the p-p chain, in which two protons fuse to form a deuterium nucleus. Assume that the core of the Sun consists entirely of ionised hydrogen.

   Use the physical parameters for the core of the Sun that were given in Lecture 2.

   Assume that the fusion factor for this reaction is $S(E_0) = 3.8 \times 10^{-22}$ keV barns.

   (a) Calculate the reaction rate, R_{pp} for this first reaction. [~ 6×10^{14} m^{-3} s^{-1}]

   (b) Estimate the mean lifetime before fusing of a proton in the core of the Sun.
   [Much longer than you might think!]

5. Complete the following reaction sequences:

   (a) ${}^{27}_{14}\text{Si} \rightarrow {}^{?}_{13}\text{Al} + e^{+} + ?$

   (b) ${}^{?}_{13}\text{Al} + {}^{1}_{1}\text{H} \rightarrow {}^{24}_{12}\text{Mg} + {}^{4}_{?}?$

   (c) ${}^{35}_{17}\text{Cl} + {}^{1}_{1}\text{H} \rightarrow {}^{36}_{18}\text{Ar} + ?$

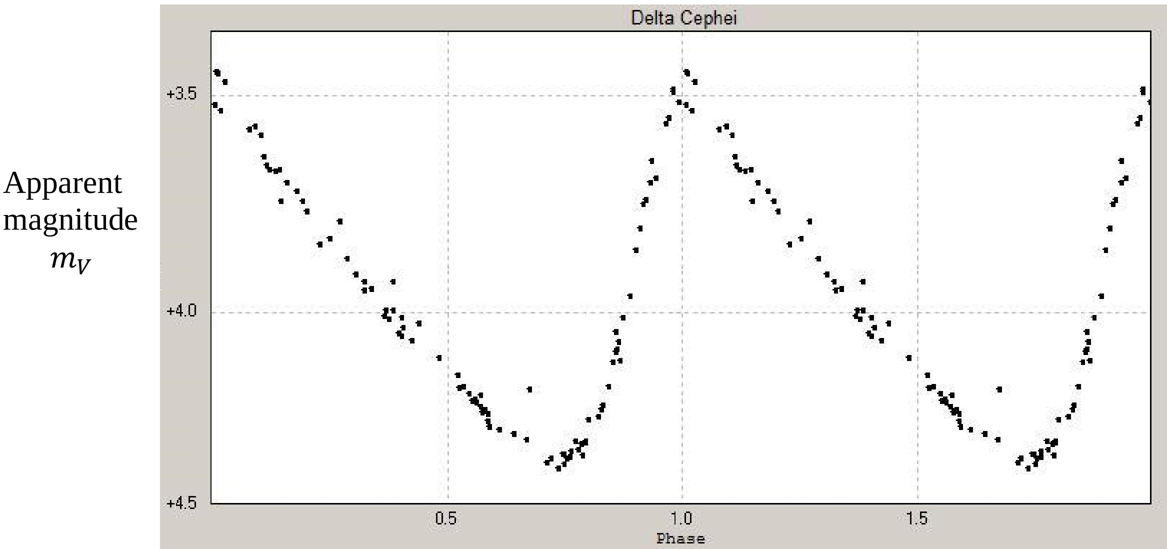
6. Make a simple estimate of the power density (in W.m^{-3}) in the core of the Sun due to fusion reactions. [Hint: Take a look at those units – what do you need to estimate?]

   You might be surprised at the result!

7. How does the average density of a white dwarf compare with that of the Sun? Quantify your answer with a simple estimate.

8. The time-averaged radio luminosity of a pulsar is about 10^{20} W. Compare the signal picked up by a radio astronomer from a pulsar at a distance of 10 kpc with that from a 100 kW radio transmitter 100 km away. Is life difficult being a radio astronomer?

9. The light curve for the Cepheid variable δ Cephei, measured in the V-band, is shown below.



The apparent magnitude has been corrected to remove the effects of interstellar extinction and the period of variability is measured to be 5.37 days.

Estimate the distance to δ Cephei. [~ 300 pc]