

**The Handbook of Mathematics, Physics and
Astronomy Data is provided**

KEELE UNIVERSITY

EXAMINATIONS, 2010/11

Level II

Tuesday 24th May 2011, 9.30–11.30

PHYSICS/ASTROPHYSICS

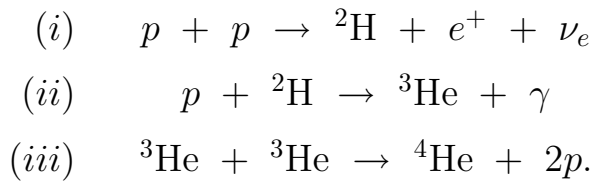
PHY-20002

STELLAR ASTROPHYSICS

Candidates should attempt to answer FOUR questions.

NOT TO BE REMOVED FROM THE EXAMINATION HALL

1. The main branch of the p - p chain consists of the reactions



Place the above reactions in order of their likelihood in the Sun's core, explaining and justifying your answer. [30]

Explain why the CNO cycle will be less probable at the temperature of the Sun's core. [10]

The p - p chain can be summarised as $4p \rightarrow {}^4\text{He} + 2\nu_e + 27.8 \text{ MeV}$. Calculate the expected flux of neutrinos at the Earth. [20]

Assume that a neutrino detector consists of 2000 kg of ${}^{37}\text{Cl}$ atoms, each of which has a cross-section to detection of neutrinos of 10^{-47} m^2 . Find the number of neutrinos detected each day. [20]

Discuss reasons why the above experiment might detect fewer neutrinos than your calculated number. [20]

[$L_{\odot} = 4 \times 10^{26} \text{ W}$; Radius of Earth's orbit = $1.5 \times 10^{11} \text{ m}$.]

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2. The semi-empirical mass formula for the binding energy of a nucleus is

$$B(Z, N) = a_1 A - a_2 A^{2/3} - a_3 Z^2 / A^{1/3} - a_4 (Z - N)^2 / A + \delta(Z, A)$$

where Z , N and A are the number of protons, neutrons and nucleons respectively ($a_2 = 17.23$ MeV and $a_3 = 0.697$ MeV).

Write down the equation for the triple-alpha reaction and use the above formula to estimate the energy it releases. [25]

Explain why that answer will not be accurate. Will it be less than or more than the true value? [10]

Despite the inaccuracy, use your answer to estimate the time that a $1-M_{\odot}$ star spends on the horizontal branch. Assume that while on the horizontal branch it burns He amounting to 10% of its mass and that it has a luminosity attributable to the triple-alpha reaction of $L = 40 L_{\odot}$. [25]

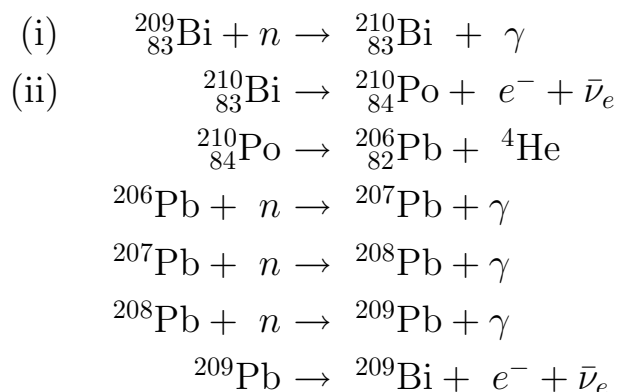
Why would the star's total luminosity be greater than the luminosity given in the last part? [10]

Describe the changes that take place, explaining the reasons for the changes, as the horizontal-branch star ascends the asymptotic giant branch. [30]

$$[M_{\odot} = 2 \times 10^{30} \text{ kg}; L_{\odot} = 4 \times 10^{26} \text{ W}.]$$

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3. The *s*-process path ends in the following loop.



Explain why the *s* process proceeds by *n* captures but not by *p* captures. [15]

By stating a condition for the *s* process, state which of the reactions (i) and (ii) has the shorter timescale. [15]

Identify one weak interaction in the above sequence. Draw a Feynman diagram (at the nucleon level) for that reaction. [20]

Identify the alpha decay in the above sequence. Explain why heavy nuclei are prone to alpha decay. Give a descriptive account of how alpha decay occurs in such a nucleus. [25]

Noting that the *s*-process path ends as above, give an account of how nuclei heavier than ${}^{210}_{84}\text{Po}$ are created. [25]

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4. The heavy particle D^+ consists of the quarks $(c\bar{d})$. It decays to a D^0 ($c\bar{u}$) and a π^+ ($u\bar{d}$). Draw a quark-level Feynman diagram for this decay. [20]

The D^0 then decays to a K^- ($\bar{u}s$) and another pion. Write down the equation for this decay and draw the Feynman diagram, stating which force mediates the decay. [20]

The pions that are created in the above reactions can decay to leptons of the muon family. Construct a valid equation for such a decay and draw the Feynman diagram. [20]

Now give a valid decay by which the charged muon from the last reaction can decay to a positron, and again draw the Feynman diagram. [20]

Give a possible decay of the K^- into lighter particles, again drawing the Feynman diagram. [20]

[The u quark has a charge of $+2/3$; the d has a charge of $-1/3$].

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5. The mass fractions of hydrogen, helium and heavier elements are denoted by X_1 , X_4 and X_A respectively, where the three together add up to 1. Consider the number of particles present when each element is ionized, and hence show that the mean mass of a particle in a stellar core is given by

$$\bar{m} = \frac{2m_H}{1 + 3X_1 + \frac{1}{2}X_4}$$

where m_H is the hydrogen mass. [30]

Discuss the effect of nuclear burning on \bar{m} and hence discuss the consequences of hydrogen burning on the core of the star. Hence outline the differences between a zero-age main-sequence star and a star that is about to leave the main sequence. [25]

After leaving the main sequence on a Hertzsprung–Russell diagram, a star evolves rapidly across the Hertzsprung Gap. Discuss what is happening to the star (in both the core and the envelope) and the reasons for the changes. [25]

What halts the rapid evolution of a star on the far side of the Hertzsprung Gap? Describe, with the aid of a schematic diagram, the different zones within a star at the start of the red giant branch. [20]

6. Discuss each of the following topics:

(i) Why the density of nuclei can be considered to be always the same. [25]

(ii) The ‘fusion window’. [25]

(iii) The nature and behaviour of a virtual (as opposed to real) particle. [25]

(iv) The change in the Hertzsprung–Russell diagram of a cluster with age. [25]