The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2011/12

Level II

Thursday, 17th May 2012, 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 semi-empirical mass formula for the nuclear binding e

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

where Z, N and A are the number of protons, neutrons and nucleons respectively. [The coefficients are $a_1 = 15.8$, $a_2 = 17.8$, $a_3 = 0.697$, $a_4 = 23.3$, the δ term is $-12/\sqrt{A}$ for odd–odd nuclei, $+12/\sqrt{A}$ for even–even nuclei, and zero for odd–even nuclei; all values in MeV.]

What does the term 'semi-empirical' mean? [10]

Sketch the binding energy per nucleon as a function of A. Mark the locations of ^{1}H, ^{4}He, ^{12}C, ^{56}Fe and ^{235}U. [20]

Estimate the energy release in creating one ^{56}Ni nucleus from burning ^{12}C. Hence estimate the energy release resulting from burning one solar mass of ^{12}C to ^{56}Ni. [30]

Taking the gravitational potential energy of a uniform sphere to be $-\frac{3}{5}\frac{GM^2}{R}$, estimate the gravitational energy of a 1-solar-mass carbon white dwarf with a radius of 5000 km. Hence discuss the likely result of igniting carbon-to-nickel burning. [20]

^{56}Ni is not the most stable nucleus and is unstable. Using your knowledge of the semi-empirical mass formula, discuss and explain how ^{56}Ni is likely to decay, and name the end product. [20]

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2. Using the equation of hydrostatic evolution,

$$\frac{dP}{dr} = \frac{-Gm(r)\rho(r)}{r^2},$$

show that, if the density were constant at ρ, the pressure in a star would be

$$P(r) = P_c(1 - r^2/R^2)$$

where P_c is the central pressure and R the radius. [30]

Hence, use the perfect gas law to gain an expression for the temperature, $T(r)$, as a function of radius (assume a mean mass of particle of $\bar{m}$). [10]

Given that the *p–p*-chain energy generation rate *per volume* obeys

$$\epsilon_{p-p} \propto \rho^2 T^4$$

find an expression for the rate of energy generation as a function of distance r from the centre. [15]

What is the relative amount of energy being generated at $r = 0.1R$ compared to $r = 0.01R$? (You do not need to integrate to answer this.) [20]

Comment on your result, and discuss, with justifications, whether you would expect the true ratio to be higher or lower than your result. [15]

Again justifying your answer, would you expect the energy generation in a star burning by the *CNO*-cycle to be more or less centrally concentrated than in a star burning by the *p–p* chain? [10]

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3. (a) Draw an example Feynman diagram illustrating str binding between two nucleons (either protons or neutrons) in a nucleus. [2

(b) Draw a Feynman diagram for the reaction

$$e^+ + e^- \rightarrow \nu_\mu + \bar{\nu}_\mu$$

specifying the force involved. [20]

(c) The u, d and s quarks have charge $+\frac{2}{3}$, $-\frac{1}{3}$ and $-\frac{1}{3}$ respectively. The particles K^0 (consisting of quarks $d\bar{s}$) and Λ (quarks uds) can be created by

$$\pi^- \ + \ p \ \rightarrow \ K^0 \ + \ \Lambda.$$

Write out this reaction in quark terms and state the force by which it is most likely to proceed. Draw a quark-level Feynman diagram for the reaction. [20]

(d) The K^0 and Λ decay by

$$K^0 \ \rightarrow \ \pi^+ \ + \ \pi^-$$

and

$$\Lambda \ \rightarrow \ \pi^- \ + \ p.$$

For each of these, write down the reaction at the quark level, state the force most likely involved, and draw a quark-level Feynman diagram. [2×20]

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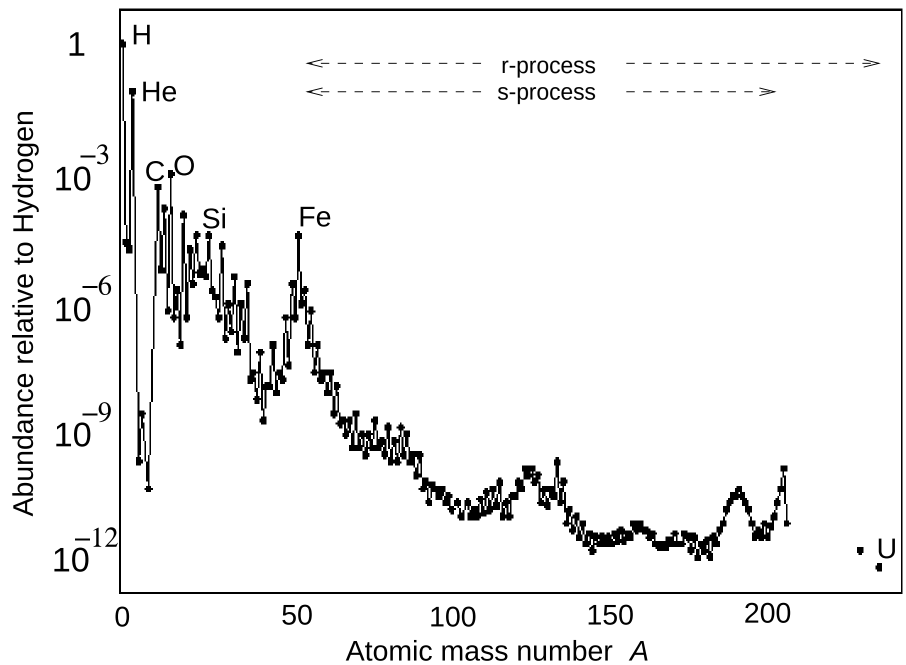
4. The plot below shows the relative abundance of the elemen[ts in the] universe today.



(a) Explain the high abundance of ^{4}He and the low abundances of $A = 5$–8 nuclei in the products of stellar nuclear burning. [20]

(b) Explain the main process by which ^{12}C is created in stars. [25]

(c) Explain the relatively high abundances of "iron peak" elements near ^{56}Fe compared to abundances of $A \approx 40$ elements. [15]

(d) Explain the ways in which elements beyond the iron peak are created. [25]

(e) Why is there a limit, near uranium, to the mass number of a nucleus? [15]

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5. For a low-mass star on the horizontal branch of the H–R
sketch and describe the different nuclear burning zones in the
Which zone is the main energy source in this star? [2

Discuss and explain the reasons why this star will evolve to follow the Asymptotic Giant Branch, explaining the changes in location on the H–R diagram, and sketch the burning zones in an AGB star. [30]

Explain the reasons for "shell flashes" on the ascent of the AGB. [30]

What happens to a low-mass star after being an AGB star? [20]

6. Discuss each of the following topics:

(i) The importance of the Gamow energy to nuclear fusion in stars. [25]

(ii) The ranges of the electromagnetic, strong and weak forces. [25]

(iii) Core collapse in the supernova stage of a massive star. [25]

(iv) Pulsating variable stars. [25]