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KEELE UNIVERSITY

EXAMINATIONS, 2010/11

Level III

Wednesday 4th May 2011, 9.30-11.30

PHYSICS/ASTROPHYSICS

PHY-30023

PARTICLES, ACCELERATORS AND REACTOR PHYSICS

Candidates should attempt to answer THREE questions.

NOT TO BE REMOVED FROM THE EXAMINATION HALL

1. (a) For each of the following weak decays of the bottom meson to particles including the $\overline{D^0}$, discuss conservation of baryon number, all lepton numbers, charm and strangeness and draw a quark level Feynman diagram for the decay:

   i. $B^+ \rightarrow \overline{D^0} + \mu^+ + \nu_\mu$ [20]

   ii. $B^+ \rightarrow \overline{D^0} + \pi^+$ [20]

   iii. $B^+ \rightarrow \overline{D^0} + D_S^+$ [20]

   [B$^+$ has quark structure $u\bar{b}$, $\overline{D^0}$ has quark structure $u\bar{c}$, D_S^+ has charm 1 and strangeness 1.]

   (b) Using the full Gell-Mann-Nishijima formula to include strangeness, charm, bottomness and topness, determine the 3 axis isospin component T_3 for each of the mesons of part (a). [20]

   (c) Draw a charm versus T_3 diagram showing the positions of all possible combinations of a d, u, c quark and a $\bar{d}, \bar{u}, \bar{c}$ antiquark and indicate the location of all mesons from part (a) which are restricted to these structures and their antiparticles. [20]

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2. (a) With reference to the magnetic rigidity equation

$$Br = \frac{mv}{qe}$$

which describes a particle of charge state q, mass m and velocity v travelling in a circle of radius r perpendicular to magnetic field B, briefly explain the principles used in a synchrotron and the way the electric and magnetic fields are utilised. [15]

(b) Write down an expression for the orbital frequency f of a particle in a synchrotron in terms of v and r and deduce an expression directly relating f to B, r and proton rest mass, but not velocity, for protons accelerated to relativistic energies in a synchrotron. [25]

(c) State the main components of a cyclic collider and describe how particles are sent in opposite directions to facilitate the collisions. [20]

(d) A Higgs boson, H_o, may be produced by collision of protons at the LHC, in a weak interaction involving the emission of oppositely charged field particles, by a quark from each proton. The field particles then combine to form the H_o and leave two other baryons after the reaction. Assume the final baryons contain only up and down quarks. Explain what happens to the quarks involved, which field particles each produces, the quark structure of the baryons produced and illustrate this by a quark level Feynman diagram of the process. [40]

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3. (a) Explain the magnitude and purpose of electric and magnetic fields in a cyclotron and a tandem accelerator. [25]

(b) It is required to produce $^{12}C^{4+}$ ions accelerated to 50MeV using a cyclotron employing a magnetic field of 1.2 T or using a single stripping tandem accelerator.

i. Determine the frequency of the AC voltage used in the cyclotron. [25]

ii. Determine the radius of extraction needed from the cyclotron. [15]

iii. Determine the terminal voltage required for the tandem. [15]

(c) Discuss and compare the quality of the particle beam emerging from the cyclotron and tandem of part (b). [20]

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4. (a) Describe and explain the neutron cycle in a thermal fission reactor, referring to the four factor formula and all the terms contributing to this formula. [50]

(b) Explain why the neutron reproduction factor is in reality less than that given by the four-factor formula and the steps taken to keep this high. [20]

(c) In a particular reactor the ratio of fission to absorption cross sections is 1.2, the fast fission factor is 1.02 and other contributors to the four factor formula are both 0.9. The actual neutron reproduction factor in the critical condition is 93% of the value from the four factor formula. Calculate the average number of neutrons released when a fission reaction takes place. [30]

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5. (a) The steady state equation for a reactor is given by

$$\frac{\lambda}{3}\nabla^2\Phi - N\sigma_a\Phi + S = 0$$

for neutron flux Φ, production rate S, number of nuclei per unit volume N, neutron absorption cross section σ_a and mean free path λ. Explain

i. what quantity and process each of the three terms is describing, [30]

ii. why the right hand side of the equation is zero and [5]

iii. what is meant by *mean free path.* [5]

(b) Write down an expression for the neutron reproduction factor k_∞ in terms of quantities in part (a) and hence deduce the reactor equation

$$\nabla^2\Phi + B^2\Phi = 0$$

where

$$B^2 = \frac{k_\infty - 1}{L^2}$$

and diffusion length

$$L = \sqrt{\frac{\lambda}{3N\sigma_a}}$$ [35]

(c) The minimum volume of a spherical reactor, to achieve criticality is

$$V = \frac{130}{B^3}$$

where the quantities are in SI units. For a neutron reproduction factor of 1.07 and a diffusion length of 0.4 m, calculate the minimum radius for a critical spherical reactor. [25]