The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2009/10

Level III

Wednesday 13th January 2010, 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

/Cont'd

1. (a) Explain, in terms of the wave functions involved, the possible spin quantum numbers for all baryons, specifically including the case of baryons composed of 3 quarks of identical flavours. [30]

(b) The Δ^{++} baryon has quark structure uuu.

i. Explain how many members there are of the multiplet to which the Δ^{++} belongs and from particle charges deduce the 3 axis isospin quantum number T_3 for the Δ^{++}. [25]

ii. Deduce, with explanation, the isospin quantum number T for the multiplet. [10]

(c) The Δ^{++} decays via the strong interaction to a π^+ and a proton. These particles have masses 1230, 140 and 938 MeV/c^2 respectively.

i. Discuss the binding energies of the baryons involved. [15]

ii. Calculate the kinetic energy available to the π^+ and proton from a Δ^{++} decaying at rest. [5]

iii. Draw a quark level Feynman diagram for the decay. [10]

iv. If at decay the u quark in the π^+ is red, explain the colours of the $\bar{\text{d}}$ quark and each quark in the proton. [5]

/Cont'd

2. (a) A particle of momentum p and charge state q travelling through a magn field B follows a path of radius of curvature r. The magnetic rigidity is

$$\rho = Br = \frac{p}{qe}$$

State what is meant by the *cyclotronfrequency*, f, for particles in a cyclotron, with reference to both their motion and the voltage between the cyclotron dees and show that the magnetic rigidity equation leads to

$$f = \frac{qeB}{2\pi m}$$

for a particle of mass m. [15]

(b) Explain the operational implications of the second equation of part (a) in the case of acceleration in a cyclotron to non-relativistic and relativistic energies and the consequent development and key features of the AVF cyclotron and the synchrocyclotron. [50]

(c) Calculate the cyclotron frequency, in a magnetic field of 1.3T, of

i. non-relativistic protons and [10]

ii. protons having a kinetic energy of 1GeV. [15]

(d) In a particular synchrocyclotron the frequency is reduced by a factor of two as a pulse of beam is accelerated. Determine the ratio of the final and initial total energies. [10]

/Cont'd

3. (a) Describe, with the aid of a diagram showing the electric fields involved, principles of particle acceleration within a low energy linear accelerator. [30]

(b) Sketch a graph of the voltage used in a linear accelerator as a function of time and explain the amount and direction of the acceleration experienced by the particles at the relevant time periods. [20]

(c) Show that the length of the nth drift tube is

$$L_n = \frac{1}{f}\sqrt{\frac{nqeV}{2m}}$$

for a particle of mass m and charge state q if AC of optimum accelerating voltage V is used having frequency f. [10]

(d) If a linear accelerator with a 500 kV, 100 MHz voltage is used to accelerate α particles from 0.5 MeV to 50 MeV calculate:

i. the number of drift tubes needed, [10]

ii. the length of the first drift tube and [10]

iii. the length of the last drift tube. [10]

(e) Contrast the design of a linear accelerator for use at high energies with the low energy linear accelerator of part (a). [10]

/Cont'd

4. (a) Define what is meant by *mean free path* and explain why this is large neutrons in matter. [10]

(b) Describe the most common interactions of neutrons with a nucleus and comment on the effects of these on neutron flux or neutron energy. [15]

(c) Give reasons why water is a good choice of moderator for use in a reactor and describe its main disadvantage. [15]

(d) Describe the main design differences between a boiling water reactor and a pressurised water reactor, explaining which is the best design. [30]

(e) For a flux of $5\times10^{13}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$ of thermal neutrons passing through 1kg of water, calculate the reaction rate for radiative capture, for which the cross section for water molecules is $6.6\times10^{-29}\,\mathrm{m}^2$. [15]

(f) Explain what is meant by *thermal utilisation factor* and calculate this for a reactor operating at critical condition with a mean number of fission neutrons per thermal neutron of 1.6, a fast fission factor of 1.02 and a resonance escape probability of 0.8. [15]

/Cont'd

5. (a) Define and describe the process of enrichment of uranium reactor fuel. [

(b) The thermal neutron fission cross section for ^{235}U is 584 b. The thermal neutron absorption cross sections for ^{235}U and ^{238}U are 97 b and 2.75 b respectively. Calculate:

i. the fission cross section for natural uranium containing 0.72% ^{235}U, [5]

ii. the absorption cross section for natural uranium, [5]

iii. the fission cross section for uranium enriched to 2% ^{235}U and [5]

iv. the absorption cross section for uranium enriched to 2% ^{235}U. [5]

(c) The mean number of neutrons produced in thermal neutron induced fission reactions on ^{235}U is 2.5. Calculate the mean number of fission neutrons produced per thermal neutron in a reactor for

i. natural uranium and [10]

ii. uranium enriched to 2% ^{235}U. [10]

(d) Calculate the percentage ^{235}U content which would give a mean number of fission neutrons per thermal neutron of 2. [20]

(e) Discuss the suitability of natural uranium as a fuel for use in a graphite moderated gas cooled reactor, a pressurised water reactor and a Canadian deuterium-uranium (CANDU) reactor. [20]

END OF PAPER