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KEELE UNIVERSITY

EXAMINATIONS, 2011/12

Level III

Monday 27th February 2012, 14.15-15:45

PHYSICS/ASTROPHYSICS

PHY-30023

PARTICLES, ACCELERATORS AND REACTOR PHYSICS

Candidates should attempt to answer TWO questions.

NOT TO BE REMOVED FROM THE EXAMINATION HALL

1. (a) Explain what is meant by *isospin* and *isospin multiplet* and quote the relevant quantum numbers for a proton and a neutron. [25]

(b) State the Gell-Mann-Nishijima formula which applies to hadrons composed of down, up and strange quarks (and their antiquarks) only. Sketch a diagram of strangeness S versus T_3, the 3 axis isospin component quantum number, showing the positions of these three quarks and their anti-quarks. [15]

(c) For each of the following spin 3/2 baryon multiplets; state the isospin quantum number T and use the formula of part (b) to determine the strangeness S.

i. Δ^{++} Δ^{+} Δ^{0} Δ^{-} quartet. [5]

ii. Σ^{*+} Σ^{*0} Σ^{*-} triplet. [5]

iii. Ξ^{*0} Ξ^{*-} doublet. [5]

iv. Ω^{-} singlet. [5]

(d) Position all the particles of part (c) on an S vs T_3 diagram and determine the quark structure of each. [40]

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2. (a) Discuss the conservation of baryon and lepton numbers, strangeness, charm and isospin for particles interacting via each of the electromagnetic, strong nuclear and weak nuclear interactions. [20]

(b) Discuss the conservation of strangeness and lepton numbers for

i. the decay of the strangeness $S = 0$, ϕ meson to the $S = -1$, K^- meson and its antiparticle:

$$\phi \rightarrow K^- + K^+ \qquad [10]$$

ii. the decay of the K^- particle:

$$K^- \rightarrow \mu^- + \bar{\nu}_\mu \qquad [10]$$

(c) The K^- has zero charm and does not contain top or bottom quarks. Determine

i. its quark structure and [10]

ii. its 3 axis component of isospin T_3. [5]

(d) State and explain which field particle is involved in the decay of the K^- in part (b)ii. [5]

(e) Write down and illustrate charge conservation, for each of the individual quarks in this K^- decay. [20]

(f) Discuss why particle physics experiments tend to produce an abundance of mesons, but free quarks are not observed. [20]

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3. (a) Compare and contrast the operation of a *simple cyclotron*, a *synchrocyclotron*, an *azimuthally varying field cyclotron* and a *synchrotron*. Your answer should include a discussion of the following points:

- acceleration and direction control mechanisms;
- relativisitic effects;
- variation of key parameters, e.g., magnetic field, during operation;
- beam properties.

[60]

(b) By assuming that the orbital frequency for a particle of charge qe and relativistic total energy E in a magnetic field B is

$$f = \frac{qeBc^2}{2\pi E}$$

show that

$$f = \frac{c}{2\pi r}$$

for an electron synchrotron of radius r. [20]

(c) Electrons are extracted from an 80m radius synchrotron by a magnetic field of 0.7T. Calculate their energy in GeV. [10]

(d) Explain why the simple relationship of frequency to radius in part (b) does not apply for a proton synchrotron. [10]

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4. (a) Describe the different ways in which a neutron may interact with a nucleus on collision. [30]

   (b) The cross section for the ^{59}Co(n,γ)^{60}Co reaction for thermal neutrons is 22barns. Calculate the mass of ^{59}Co to be placed in a thermal neutron flux of $10^{14}\text{m}^{-2}\text{s}^{-1}$ in order to produce ^{60}Co nuclei at a rate of 10^{10}s^{-1}. (1barn=10^{-28}m^2.) [15]

   (c) Explain what is meant by *neutron reproduction factor* in a nuclear reactor. [10]

   (d) The minimum volume of a cubic reactor is given by

$$V = \frac{161}{B^3}$$

where SI units are used and

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

for neutron diffusion length L and neutron reproduction factor k_∞ assuming an infinite assembly.

   i. Determine the length of the side of the cube for $L = 0.4\,\text{m}$ and k_∞ =1.07 [10]

   ii. Explain how the minimum volume of a spherical reactor compares with that of the cubic reactor and why. [10]

   iii. Explain how a realistic neutron reproduction factor k compares with k_∞ and why. [15]

   iv. Explain why it is advantageous to surround the core of a thermal fission reactor with graphite. [10]