UNIVERSITY COLLEGE LONDON

EXAMINATION FOR INTERNAL STUDENTS

MODULE CODE	:	**PHAS3224**
ASSESSMENT PATTERN	:	**PHAS3224A**
MODULE NAME	:	**Nuclear and Particle Physics**
DATE	:	**01-May-09**
TIME	:	**10:00**
TIME ALLOWED	:	**2 Hours 30 Minutes**

2008/09-PHAS3224A-001-EXAM-101

TURN OVER

ANSWER ALL QUESTIONS IN SECTION A AND TWO QUESTIONS FROM SECTION B.

The numbers in square brackets at the right-hand edge of the paper indicate the provisional allocation of maximum marks for each subsection of a question.

SECTION A

Question 1.

Briefly describe the main processes by which photons interact with matter.

[6 marks]

Question 2.

Explain why a sustained fission chain reaction is not possible in natural uranium.

[8 marks]

Question 3.

Explain the concepts of lepton universality and lepton-quark symmetry.

[4 marks]

Briefly discuss the role the Cabibbo angle plays in the weak interactions of quarks.

[3 marks]

Question 4.

Explain how Cerenkov radiation can be used for particle identification.

[6 marks]

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Question 5.

What is the binding energy of a nucleus and what is the physical meaning of the binding energy per nucleon B/A?

[3 marks]

Draw a rough sketch showing B/A as a function of A for stable nuclei.

[4 marks]

Question 6.

Why does the existence of the ground-state baryon $\Omega^- = sss$ (where s is a strange quark) imply that quarks possess the property called colour?

[6 marks]

CONTINUED

SECTION B

Question 7.

Which of the following reactions:

$\tau^+ \rightarrow \mu^+ + \nu_\mu + \bar{\nu}_\tau$ [3 marks]

$\Omega^- \rightarrow \pi^- + K^0$ $\qquad \Omega^- = sss$ [3 marks]

$p + p \rightarrow e^+ + K^+$ [3 marks]

$e^+ + e^- \rightarrow \tau^+ + \tau^-$ [3 marks]

are allowed and which are forbidden? Explain why and draw the lowest order Feynman diagrams for the allowed reactions.

A beam of electrons with a momentum of 10 GeV/*c* hits a liquid argon detector. Calculate the length of the detector (along the beam axis) necessary to reduce the momentum of the electrons to 1 GeV/*c*. The radiation length of liquid argon is 14 cm.

[5 marks]

Find the range of the force transmitted by the exchange of:

(I) a photon,
(II) a *W*-boson,
(III) a pion

in interactions where the momentum transfer is close to zero.

[6 marks]

What type of energy losses by a particle traversing a medium does the Bethe-Bloch formula shown below describe?

$$-\frac{dE}{dx} = \frac{4\pi N_0 z^2 e^4}{mv^2}\frac{Z}{A}\left[\ln\left(\frac{2mv^2}{I(1-\beta^2)}\right) - \beta^2 - \delta(\gamma)\right]$$

Sketch the shape of this function and identify the important regions.

[5 marks]

Describe briefly how the properties of the Bethe-Bloch formula can be exploited for particle identification?

[2 marks]

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Question 8.

Using the concepts of lepton universality and lepton-quark symmetry and ignoring final states that are strongly Cabibbo suppressed relative to the lepton modes estimate the branching ratio for the following decay:

$b \to c + e^- + \bar{\nu}_e$ where the b and c quarks are bound in hadrons.

Numerical data:

$m_\tau \approx 1.8\,GeV/c^2, m_u \approx m_d \approx 0.3\,GeV/c^2, m_s \approx 0.5\,GeV/c^2, m_c \approx 1.5\,GeV/c^2,$
$m_b \approx 4.5\,GeV/c^2, m_t \approx 175\,GeV/c^2.$

[9 marks]

Which of the following two processes occurs with the higher rate? Explain why.

$\pi^- \to \mu^- + \bar{\nu}_\mu$

$\pi^- \to e^- + \bar{\nu}_e$

[4 marks]

Draw the lowest order Feynman diagram for deep inelastic electron-proton scattering. Give an example of such a reaction, naming all final state particles, and making sure that all necessary quantum numbers are conserved.

[4 marks]

Estimate the cross-section ratio

$$R = \frac{\sigma(e^+e^- \to q\bar{q})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

obtained at an e^+e^- collider at the centre-of-mass energy $E_{CM} = 2$ GeV.

[6 marks]

Determine the threshold energy for charged pions to produce Cerenkov radiation in water (refractive index $n = 1.33$).

[4 marks]

Determine the angle of emission for Cerenkov radiation in water from an electron of energy 1 GeV.

[3 marks]

CONTINUED

Question 9.

Define the terms spontaneous and induced fission and explain what is meant by critical mass.

[3 marks]

Which of the two nuclides ^{235}U or ^{239}Pu has a smaller critical mass, and why?

[3 marks]

Using the semi-empirical mass formula (SEMF):

$$M(Z,A) = Zm_p + (A-Z)m_n - a_v A + a_s A^{2/3} + a_c Z^2 A^{-1/3} + a_a (Z - A/2)^2 A^{-1} \pm \delta a_p f(A)$$

obtain an expression for Z as a function of A for the stable isobars.

[6 marks]

Write down the Shell-Model configuration for the ground state of the isotope $^{25}_{11}Na$ and deduce its spin-parity J^P.

[6 marks]

What are the major difficulties associated with sustaining a fusion reaction in a controlled environment?

[4 marks]

Which of the following two reactions:

$$^2_1H + ^2_1H \rightarrow ^3_2He + n$$
$$^2_1H + ^3_1H \rightarrow ^4_2He + n$$

gives a better energy output, and why?

[3 marks]

Is the isotope $^{16}_{8}O$ stable against β-decay? Explain your reasoning.

[5 marks]

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Question 10.

Explain why thermal neutrons can induce fission in ^{235}U but cannot in ^{238}U.

[4 marks]

Assuming that only protons are excited, deduce the two most likely Shell-Model configurations for the first excited state of ${}^{7}_{3}Li$.

[6 marks]

The shell model is successful in predicting the spins of the ground states for even-even, even-odd and odd-even nuclei, but less successful in the case of odd-odd nuclei. Comment on the reason for this.

[5 marks]

Calculate the threshold energy of a ν_τ beam incident on a fixed target necessary to produce τ-leptons via the reaction $\nu_\tau + n \rightarrow \tau^- + p$. Assume $m_\tau = 1.78\, GeV/c^2$.

[7 marks]

Draw a leading order Feynman diagram of the $\nu_\tau + n \rightarrow \tau^- + p$ process.

[3 marks]

The particle Y^- can be produced in the strong interaction process

$$K^- + p \rightarrow K^+ + Y^-.$$

Deduce its baryon number, strangeness, charm and beauty, and using these its quark content.

[5 marks]

END OF PAPER