

**UNIVERSITY COLLEGE LONDON**

**EXAMINATION FOR INTERNAL STUDENTS**

**MODULE CODE : PHAS3224**

**ASSESSMENT : PHAS3224A  
PATTERN**

**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

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**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**

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**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]

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## SECTION B

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### Question 7.

Which of the following reactions:

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

$$\Omega^- \rightarrow \pi^- + K^0 \quad \Omega^- = sss \quad [3 \text{ marks}]$$

$$p + p \rightarrow e^+ + K^+ \quad [3 \text{ marks}]$$

$$e^+ + e^- \rightarrow \tau^+ + \tau^- \quad [3 \text{ marks}]$$

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:

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

Numerical data:

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

[9 marks]

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

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

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

[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

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

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

[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]

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### Question 9.

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

[3 marks]

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

[3 marks]

Using the semi-empirical mass formula (SEMF):

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

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

[6 marks]

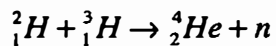
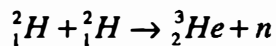
Write down the Shell-Model configuration for the ground state of the isotope  $^{25}_{11}\text{Na}$  and deduce its spin-parity  $J^P$ .

[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:



gives a better energy output, and why?

[3 marks]

Is the isotope  $^{16}_8\text{O}$  stable against  $\beta$ -decay? Explain your reasoning.

[5 marks]

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### Question 10.

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

[4 marks]

Assuming that only protons are excited, deduce the two most likely Shell-Model configurations for the first excited state of  ${}^7_3\text{Li}$ .

[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]

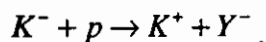
Calculate the threshold energy of a  $\nu_\tau$  beam incident on a fixed target necessary to produce  $\tau$ -leptons via the reaction  $\nu_\tau + n \rightarrow \tau^- + p$ . Assume  $m_\tau = 1.78 \text{ GeV}/c^2$ .

[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



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

[5 marks]

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END OF PAPER