UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Sc. *M.Sc.* *M.Sci.*

Physics 3C24: Nuclear and Particle Physics

COURSE CODE	:	**PHYS3C24**
UNIT VALUE	:	**0.50**
DATE	:	**10-MAY-06**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

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.

Identify the fundamental fermions of the Standard Model and their electrical charges. [4 marks]

Which fundamental interactions do they participate in and what are the gauge bosons which carry these interactions? [3 marks]

Question 2.

Briefly describe three main processes by which photons interact with matter. [6 marks]

Question 3.

Explain what is meant by spontaneous fission. [2 marks]

Why is spontaneous fission only possible for heavy nuclei? [4 marks]

Question 4.

Explain what is meant by the lepton universality principle. [2 marks]

Briefly explain the terms colour confinement and asymptotic freedom. [4 marks]

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Question 5.

Name and briefly describe three main pieces of evidence for the existence of quarks.

[8 marks]

Question 6.

Why is the decay of a free proton forbidden in the Standard Model while a β^+ decay can take place within a nucleus?

[3 marks]

The semi-empirical mass formula (SEMF) in terms of binding energy B_E

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

can be explained invoking three different nuclear models: the liquid drop model, the Fermi gas model and the shell model. Identify which model explains each individual term of the SEMF.

[4 marks]

CONTINUED

SECTION B

Question 7.

At a collider, a 20 GeV electron beam collides with a 300 GeV proton beam. If the centre-of-mass energy E_{CM} = 150 GeV, what is the crossing angle between the beams?

[5 marks]

Calculate what beam energy would be required in a fixed-target experiment to achieve a total centre-of-mass energy of 100 GeV.

[4 marks]

Explain which interaction is responsible for the following reactions:

1) $D^- \rightarrow K^0 + \pi^-$ $\quad (D^- = d\bar{c})$

2) $\Lambda \rightarrow p + e^- + \bar{\nu}_e$ $\quad (\Lambda = uds)$

[3 marks]

Draw the lowest-order Feynman diagram at the quark level for these reactions.

[5 marks]

What are three factors which determine the magnitude of the invariant amplitude? Write down an expression which gives the general structure of the lowest-order amplitude f for a process involving elementary particles.

[4 marks]

Explain briefly why electromagnetic and weak interactions have approximately the same strength at high energies.

[3 marks]

Consider the following combinations of quantum numbers (Q, B, S, C, $\tilde{B}$), where Q = electric charge, B = baryon number, S = strangeness, C = charm and $\tilde{B}$ = beauty:

(a) (-1, 1, -2, 0, -1)
(b) (0, 0, 1, 0, 1)

Which of these possible states are compatible with the postulates of the quark model?

[6 marks]

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Question 8.

Which of the following reactions are allowed and which are forbidden? Explain why and draw their lowest order Feynman diagrams where possible.

$\nu_\mu + p \rightarrow e^+ + n$ [3 marks]

$\Sigma^- \rightarrow K^- + \pi^0 \qquad (\Sigma^- = dds)$ [3 marks]

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

$\mu^- \rightarrow e^- + \overline{\nu}_e + \nu_\mu$ [3 marks]

Explain why it was necessary to introduce the colour quantum number in the simple quark model.

[2 marks]

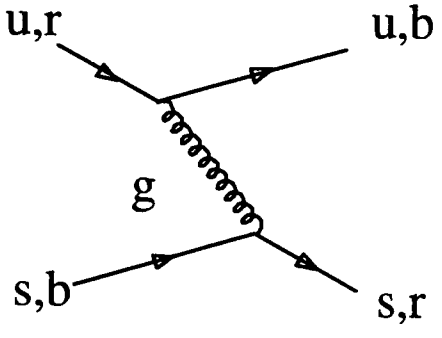
What experimental evidence do we have to support the claim that there are 3 colour charges?

[4 marks]

A 40 GeV e^+e^- collider has a diameter of 8 km. Each beam consists of 12 bunches each containing 3×10^{11} particles. The bunches have a cross-sectional area of 0.02 mm^2. What is the luminosity of the machine in units of $cm^{-2}s^{-1}$?

[7 marks]

The lowest-order Feynman diagram for the scattering of a red $u-$quark with a blue $s-$quark by gluon exchange is given below.



What does the existence of this diagram imply about the gluon-gluon interaction and how does this differ from the interaction of photons?

[5 marks]

CONTINUED

Question 9.

Explain what is meant by isotopes and isobars.

[1 mark]

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 of Z as a function of A for the stable isobars.

[7 marks]

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

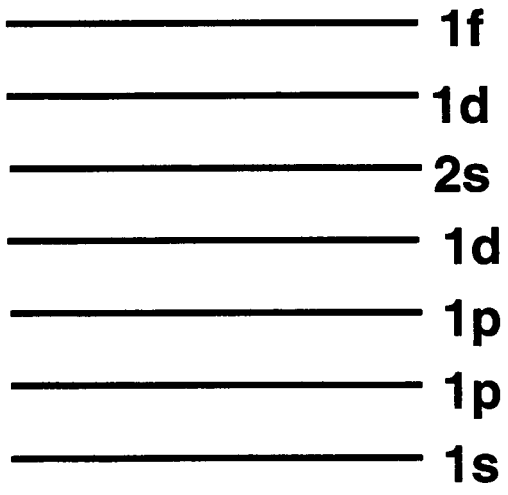
[2 marks]

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

[3 marks]

Write down the shell model configuration of the nucleus ${}^{40}_{18}Ar$ using the level diagram given below

[4 marks]



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Using the single-particle shell model predict the spin and parity (J^p) of ${}^{40}_{18}Ar$.

[4 marks]

Explain the difference between fissile and non fissile materials.

[2 marks]

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

[3 marks]

List two methods which can help overcome this difficulty when designing a thermal uranium-based reactor.

[2 marks]

Explain briefly the main idea of a fast breeder reactor.

[2 marks]

CONTINUED

Question 10.

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

(a) a pion of mass $140\text{MeV}/c^2$;
(b) a Z-boson of mass 91 GeV/c^2;
(c) a gluon.

[6 marks]

A $p\bar{p}$ collider with equal beam energies is used to produce a pair of top quarks. Draw a Feynman diagram for this process that involves a single gluon.

[3 marks]

If the three quarks of the proton (or antiproton) carry between them 50% of the hadron total energy-momentum, calculate the minimum beam momentum required to produce the $t\bar{t}$ pair. (assume t-quark mass $m_t = 175\ \text{GeV}/c^2$)

[8 marks]

Explain why the copper isotope ^{63}Cu is stable against α-decay.

[5 marks]

The two most promising reactions for a potential future fusion reactor are the fusion of two deuterium atoms and deuterium-tritium fusion. Write down these reactions in symbol form. Which one is more efficient and why?

[4 marks]

Why are the even-even nuclei usually stable against β-decay?

[4 marks]

END OF PAPER