UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:–

B.Sc. *M.Sci.*

Physics 3C24: Nuclear and Particle Physics

COURSE CODE	:	**PHYS3C24**
UNIT VALUE	:	**0.50**
DATE	:	**12–MAY–05**
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.

Write down the elementary particles which form the 3 generations of leptons in the Standard Model? [2 marks]
Show how a study of the Z^0 boson decay width can be used to demonstrate that there exists only 3 generations of leptons [4 marks]

Question 2.

The semi-empirical mass formula (SEMF) has a form of

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

Explain briefly the physics basis of each term in this expression

[8 marks]

Question 3.

A reaction involving elementary particles is dominated in lowest order by the exchange of a particle of mass M_X. Write down an expression that gives the general structure of the corresponding scattering amplitude, explaining the symbols you use. Use your formula to explain qualitatively why electromagnetic interactions appear to be very much stronger than weak interactions at low energies, but of comparable strength at high energies.

[6 marks]

Question 4.

What are particle physics calorimeters and what do they measure?

[3 marks]

State two main differences between hadronic and electromagnetic calorimeters.

[5 marks]

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Question 5.

Define the terms spontaneous and induced fission. [3 marks]

Explain why relatively light nuclei (A<100) do not undergo spontaneous fission. [3 marks]

Question 6.

Explain briefly what is known as scaling? [3 marks]

Explain qualitatively how QCD accounts for scaling violation? [3 marks]

CONTINUED

SECTION B

Question 7.

Draw at least two leading order Feynman diagrams for each of the two following processes and show that the quantum numbers: baryon number, lepton number, electric charge, are conserved. Identify which gauge boson is being exchanged:

a) $e^+ + e^- \rightarrow e^- + e^+$ [3 marks]

b) $e^- + \nu_e \rightarrow e^- + \nu_e$ [3 marks]

At an electron-proton collider, a 30 GeV electron beam collides head-on with a 820 GeV proton beam. Evaluate the total centre-of-mass energy. Calculate the energy of an electron beam that would be required to produce the same centre-of-mass energy in a fixed-target experiment using a proton target.

[8 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]

The Y^- decays by the reaction $Y^- \rightarrow \Lambda + \pi^-$. Give a rough estimate of its lifetime (range). [3 marks]

Explain what is meant by the radiation length.

[2 marks]

An electron with an initial energy of 3 GeV traverses 0.5 metres of water with a radiation length of 36 cm. Calculate its final energy. How would the energy loss change if the particle were a muon instead of electron?

[6 marks]

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Question 8.

Which of the following reactions are allowed and which are forbidden? Explain why.

a) $\pi^0 \rightarrow e^+ + e^-$ [3 marks]

b) $p \rightarrow n + e^+ + \nu_e$ [3 marks]

c) $\mu^+ \rightarrow e^+ + e^- + e^+$ [3 marks]

*d)** $K^+ + n \rightarrow \Sigma^+ + \pi^0$ [3 marks]

* Note: Strong interaction process. $\Sigma^+ = uus$

Explain the concepts of lepton universality and lepton-quark symmetry. [3 marks]

Using the above concepts and ignoring final states that are Cabibbo suppressed relative to the lepton modes estimate the branching ratio for the following decay:

$b \rightarrow c + e^- + \bar{\nu}_e$, where the b and c quarks are bound in hadrons [7 marks]

The Bethe-Bloch formula looks like this:

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

What does this equation say about the ionization energy loss as a function of the mass of the incident particle? Sketch the shape of this function and identify the interesting regions. [5 marks]

Describe briefly how the ionization energy loss data can be used for particle identification? [3 marks]

CONTINUED

Question 9.

Write down the shell model configuration of the nucleus $_3{}^7$Li and hence find its spin and parity.

[5 marks]

Assuming that only protons are excited, deduce the two most likely configurations for the first excited state.

[5 marks]

Explain what is meant by critical mass [2 marks]

1 mg of the isotope ^{239}Pu is placed inside a detector. ^{239}Pu α-decays with a half-life of $T_{1/2} = 24119$ yr. Calculate how many α-particles from the decay will be detected in 1 hour. (Assume 100% detection efficiency.)
The Avogadro constant is $N_A \approx 6.022\times10^{23}$ mol $^{-1}$

[6 marks]

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

[4 marks]

If the Sun were formed 4.6 billion years ago and initially consisted of 9×10^{56} hydrogen atoms and since then has been radiating energy via the PPI chain at a detectable rate of 3.86×10^{26} watts, how much longer will it be before the Sun's supply of hydrogen is exhausted?

[8 marks]

(*Reminder:* The PPI chain overall is $4(^1\text{H}) \rightarrow {}^4\text{He} + 2e^+ + 2\nu_e + 2\gamma + 24.68$ MeV
1 eV corresponds to 1.6×10^{-19} Joules; $m_e \approx 0.51$ MeV/c^2;
Each neutrino carries off 0.26 MeV of energy)

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Question 10.

Why are there very few odd-odd nuclei which are stable against β-decay? [5 marks]

Explain why thermal neutrons can induce fission in ^{235}U but can not in ^{238}U. [5 marks]

Describe briefly the three radioactive processes. [5 marks]

Explain what is meant by neutral current (NC) and charge (CC) current reactions. [2 marks]

Give one example for each kind of reactions (NC and CC) and draw their Feynman diagrams. [4 marks]

Which of the two processes

1) $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$

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

constitutes unambiguous evidence for weak neutral currents? Draw Feynman diagrams to prove your point. [6 marks]

What is the spectator model of quark interactions? Draw the Feynman diagram of the decay $\Lambda \rightarrow p + e^- + \bar{\nu}_e$ $(\Lambda = uds)$ at quark level. [3 marks]

END OF PAPER