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	:	**30-APR-01**
TIME	:	**10.00**
TIME ALLOWED	:	**2 hours 30 minutes**

01-C1134-3-140

TURN OVER

Answer **THREE** questions.

The numbers in square brackets in the right hand margin indicate the provisional allocation of maximum marks per sub–section per question.

The physical constants that you may need are as follows :

1 b (barn) = 10^{-28} m^2
1 eV (electron volt) = 1.6 x 10^{-19} J
R (ideal gas constant) = 8.314 $Jmol^{-1}K^{-1}$ = 8.314 Pa $m^3mol^{-1}K^{-1}$
N_A (Avogadro's Number) = 6 x 10^{23} mol^{-1}

Q1 i) The semi–empirical mass formula for the mass, M, of an atom with atomic number Z and mass number A is :

$$M(A,Z) = Zm_H + (A-Z)m_n$$
$$- a_1A + a_2A^{2/3} + a_3(Z-A/2)^2/A + a_4Z^2/A^{1/3} \pm \delta/A$$ [7]

where m_H is the mass of a hydrogen atom and m_n is the mass of the neutron. Explain the physical assumptions associated with the terms in this formula.

(a_1 = 15.7 MeV, a_2 = 17.8 MeV, a_3 = 94.8 MeV, a_4 = 0.7 MeV, δ = 39 MeV)

ii) The fission of ${}^{235}_{92}U$ induced by neutron capture is asymmetric. For the two fission fragments : ${}^{92}_{37}Rb$, ${}^{140}_{55}Cs$ calculate the energy release (in MeV) per fission. Why are neutrons needed for the fission to occur ? [5]

iii) An average of one neutron per ${}^{235}_{92}U$ fission escapes the core of a spherical 100 MW reactor, of radius = 1.0m. What is the neutron flux at the outer surface (r = 1.0m) of the reactor if the fission process is that of part (ii) ? [4]

iv) The spherical core surface is uniformly surrounded by 1.345m^3 of ideal gas maintained at a pressure of 101325Pa and a temperature of 298K. All neutrons escaping the reactor pass through the gas. If the interaction cross section between the neutrons and the gas is 1 mb, what is the rate of interactions in the gas from neutrons ? [4]

Q2 i) If the flux of electron and muon neutrinos on the surface of the Earth is due to the decay of charged pions in the upper atmosphere. State with reasons what one would expect the ratio of the number of electron to muon neutrinos at the Earth's surface to be. Explain how this ratio changes as the energy of the pions increases. [6]

ii) Draw two Feynman diagrams, labeling all particles, showing how an electron neutrino could interact with a proton. [4]

iii) Outline an experiment that could be used to determine the ratio of electron and muon neutrinos incident on the Earth. Describe the type of detector you would use and the physical principles underlying its operation. [6]

iv) An electron of energy = 2 GeV passes through 0.1m of water which has a radiation length of 0.361m. What is the energy of the electron after it has passed through the water. If instead a 2 GeV muon passed through the water explain how the energy loss would change. [4]

Q3 i) Describe three pieces of experimental evidence which support the theory that hadrons are made up of quarks. [6]

ii) How does the colour charge of the strong interaction influence the decay rates of W bosons into quark and anti–quark final states in comparison with the W decay to a lepton and neutrino final state ? Given that the total width of the W^+ boson is Γ_{tot} = 2.1 GeV, deduce the value for the partial widths $\Gamma(W^+ \rightarrow$ leptons) and $\Gamma(W^+ \rightarrow$ hadrons). State the assumptions and approximations that you make. [4]

iii) Draw one Feynman diagram showing how one might produce a pair of W bosons in a e^+e^- collision. What would the experimental signature, in a typical e^+e^- experimental detector, of such an event be if one W decayed to muon+neutrino and the other to quark anti–quark ? [7]

iv) How would you measure the width of the W boson from such events ? [3]

Q4 At the HERA collider, 30 GeV electrons collide with 820 GeV protons. These collisions can be considered as being due to electrons scattering off the quarks in the proton.

i) What is the highest mass particle that can be produced in such a collision in the approximation that a quark carries $1/6^{th}$ of the proton's momentum ? [4]

ii) In an interaction involving the exchange of a Z boson, the final state electron is measured to be 60 GeV at an angle of 120^0 to the original electron direction. What is the value of the square of the 4–momentum transfer in this interaction ? [4]

iii) How could the energy of the scattered electron be measured ? Give a brief description of the detector(s) involved. [4]

iv) Why is it easier to accelerate protons to higher energies than electrons ? How could one accelerate an electron to 500 GeV ? [4]

v) How does the propagator for the weak charged current and electromagnetic interactions vary with the 4–momentum transfer, Q ? Hence explain the fact that at low $|Q^2|$ the rate of events where neutrinos are produced in the final state is small compared to the rate at which electrons are produced whereas at very high $|Q^2|$ values the rates are approximately the same. [4]

Q5 i) Describe briefly the physical processes occurring in α emission. [3]

ii) Explain why the mean lifetimes of α–emitting nuclei vary so drastically from ~ 10^{-20} sec to 10^{10} years. [5]

iii) A space craft is powered by the α decay : $^{238}Pu \rightarrow {}^{234}U + \alpha +$ 5.49 MeV, which has a mean life of 128 years. The mean life of ^{234}U is much longer, 2.5 x 10^5 years. Estimate the mass of ^{238}Pu needed to supply a minimum of 1kW of power for 50 years. [6]

iv) An excited state ^{116}In decays by emitting photons with energies in the range 0.2 – 6 MeV. These photons can be detected by their energy loss as they pass through a NaI crystal. Describe the energy loss processes occurring and their relative importance as the energy of the photon is increased. [6]