King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 2001

Time allowed: **THREE** hours

Candidates must answer SIX parts of SECTION A,
And TWO questions from SECTION B.

Separate answer books must be used for each section of the paper.

The approximate mark for each part of a question is indicated in square brackets.

You must not use your own calculator for this paper.
Where necessary, a College calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

Atomic mass unit	m_u	=	1.660×10^{-27} kg
Elementary charge	e	=	1.602×10^{-19} C
Permittivity of vacuum	ε_0	=	8.854×10^{-12} Fm^{-1}
Planck constant	h	=	6.626×10^{-34} Js
Speed of light	c	=	2.998×10^{8} ms^{-1}
Rest mass of an electron	m_e	=	9.019×10^{-31} kg
Rest mass of a proton	m_p	=	1.673×10^{-27} kg
Rest mass of a neutron	m_n	=	1.675×10^{-27} kg

Properties of Up Down and Strange quarks.

	Charge Q	Isospin T_3	Strangeness S	Baryon No
Up	+2/3	+1/2	0	1/3
Down	−1/3	−1/2	0	1/3
Strange	−1/3	0	-1	1/3

SECTION A - Answer SIX parts from this section.

1.1) Thorium $^{230}_{90}$Th decays to radium $^{226}_{88}$Ra by α-emission. Calculate the Q-value for this decay in MeV.
Atomic masses in m_u are $^{230}_{90}$Th 230.033127 , $^{226}_{88}$Ra 226.025403 and $^{4}_{2}$He 4.002603.

[7 Marks]

1.2) Use the shell model of the nucleus to explain why stable light nuclei have approximately equal numbers of neutrons and protons.

[7 Marks]

1.3) The energy spectrum for electrons produced by β-decay shows line structure superimposed on top of a continuous distribution. The line structure is formed by processes occurring in the daughter nucleus. Describe briefly one such process.

[7 Marks]

1.4) A bone fragment found in a burial mound contains only 21% as much ^{14}C as an equal amount of carbon taken from living plant material. Calculate the approximate age of the sample and comment on any assumptions that you make.
The decay constant of ^{14}C is 3.83×10^{-12} s^{-1}.

[7 Marks]

1.5) Describe how a linear drift tube accelerator is used to accelerate charged particles.

[7 Marks]

1.6) State the purpose of the moderator in a thermonuclear reactor. On the basis of your answer explain why either graphite or heavy water have been used as moderators.

[7 Marks]

1.7) On the basis of quark properties suggest the possible quark content of a proton and a neutron showing that your suggestions are consistent with the known properties of these nucleons.

[7 Marks]

1.8) The following reaction is observed to occur in a head on collision between an electron and a positron with equal kinetic energy

$$e^{+} + e^{-} \rightarrow \pi^{+} + \pi^{-}$$

Given that the rest mass of the $\pi^{\pm}$ mesons is 139.56 MeV/c^2 calculate the electron energy at which this reaction can just occur.

[7 Marks]

SECTION B - Answer TWO questions.

2) The binding energy B in MeV of a nucleus for which the atomic mass number A is odd may be given by the semi-empirical expression

$$B(Z,A) = 15.84A - 18.33A^{2/3} - 0.71\,\frac{Z^2}{A^{1/3}} - 23.2\,\frac{(A-2Z)^2}{A}$$

where Z the atomic number.

Explain the origin of the terms in the above equation and describe the additional term that must be added if the expression is to be used to describe the binding energy of nuclei with even A values.

[20 Marks]

Use the semi-empirical binding energy expression to calculate an approximate Q-value in MeV for the β-decay reaction.

$${}^{11}_{4}\mathrm{Be} \rightarrow {}^{11}_{5}\mathrm{B} + e^{-} + \bar{\nu}\,.$$

[10 Marks]

3) Explain how electron diffraction by thin targets can be used to measure nuclear diameters. Discuss what additional information on the structure of the nucleus is provided by electron diffraction measurements.

[14 Marks]

248 MeV electrons are diffracted by a lead $^{208}_{82}Pb$ film and the first minimum in the diffraction pattern is observed to occur at $\theta = 25^0$.
Show that this information is consistent with a value of 7.22 fm. as an estimate for the radius of a lead nucleus
You may assume that the de Broglie wavelength λ of a highly relativistic electron of energy E is given by $\lambda = hc/E$.

[8 Marks]

Comment on the use of α-particle scattering in the determination of nuclear diameters and estimate the lowest energy of an α-particle for which the Rutherford description for α-particle scattering from lead will begin to break down.

[8 Marks]

4) Describe three processes by which γ-rays can interact with matter. Sketch the way in which you expect the cross-sections for the processes to vary with the energy of the γ-rays

[18 Marks]

The energy E_γ' of a γ-ray scattered through an angle θ by Compton scattering is given by

$$E_\gamma' = E_\gamma E_0 \,/\, (E_0 + E_\gamma(1-\cos\theta))$$

where E_γ is the initial energy of the γ-ray and E_0 is the rest energy of an electron.
Use this to find an expression for the maximum energy E_C that can be given to an electron in the Compton scattering process.

[12 Marks]

5) Use the quark properties given on page 2 to draw an eightfold way diagram for the nine possible spin zero mesons and predict their charge, strangeness and isospin.

[15 Marks]

By considering the possible quark combinations that lead to baryons show that there will be ten possible spin 3/2 baryons. Give reasons why only eight spin 1/2 baryons are observed.

[10 Marks]

Why was it necessary to introduce the concept referred to as colour to explain these combinations?

[5 Marks]