King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 1999

Time allowed: THREE hours

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

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

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

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}
Speed of light	c	=	2.998×10^{8} ms^{-1}
Rest mass of an electron	m_e	=	9.019×10^{-31} kg

You may assume that for relativistic particles with total energy E and momentum p, $E^2 = E_0^2 + p^2c^2$.

Section A - Answer any SIX parts from this section.

1.1) Use the nuclear shell model to explain why for stable light nuclei the proton number Z is approximately equal to the neutron number N, while for heavy nuclei $N>Z$. Use this to suggest how the radioactive nuclei $^{14}_{6}$C and $^{14}_{8}$O will decay.

[7 Marks]

1.2) Geiger and Marsden's measurements on the scattering of 6.05 MeV α-particles by $^{107}_{47}$Ag nuclei showed that the scattering followed Rutherford's predictions. Calculate an upper limit for the radius of the $^{107}_{47}$Ag nucleus. You may assume that the effect of nuclear recoil is negligible.

[7 Marks]

1.3) $^{88}_{36}$Kr decays to $^{88}_{37}$Rb with the emission of β^- particles with maximum energy of 2.4 MeV. The track of a particular β^- particle from this process, observed in a cloud chamber, has a radius of curvature of 6.1 cm in a magnetic field of flux density 0.1 T. Determine the energy of the β^- particle in MeV and that of the associated antineutrino.

[7 Marks]

1.4) $^{64}_{29}$Cu can decay by β^+ emission to $^{64}_{28}$Ni or β^- emission to $^{64}_{30}$Zn . Use the atomic masses to calculate the Q values in MeV for these processes. Atomic masses in m_u are $^{64}_{29}$Cu, 63.929766**,** $^{64}_{28}$Ni, 63.927968 and $^{64}_{30}$Zn, 63.929145 .

[7 Marks]

1.5) Explain how pair production can give rise to single and double escape peaks observed in the pulse height spectrum produced when a γ-ray is detected using a scintillation counter.

[7 Marks]

1.6) A cyclotron of diameter 50 cm and a magnetic field of flux density 1.0 T is used to accelerate α-particles . Find the maximum energy of the α-particles assuming that they remain classical .

[7 Marks]

1.7) Discuss the importance of a) the moderator and b) the control rods in the operation of a thermal nuclear reactor.

[7 Marks]

1.8) Define what is meant by a “fundamental particle.” Explain why leptons are considered to be fundamental particles and hadrons are not.

[7 Marks]

SECTION B - Answer any TWO questions.

2) Describe how electron diffraction can be used to measure nuclear diameters . Comment on the conclusions that can be drawn from such measurements and discuss to what extent they are compatible with the liquid drop model of the nucleus.

[20 Marks]

The semi-empirical equation for the binding energy *B* (in MeV) of a nucleus of mass number *A* (where *A* is odd) and atomic number *Z*, based largely on the liquid drop model be written

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

Use this equation to find the value of *Z* which corresponds to the highest binding energy for isobars with $A = 35$.

[10 Marks]

3) Briefly describe the shell model of the nucleus and discuss how it can be used to account for nuclear magic numbers and α-decay .

[15 Marks]

α-particles from the decay of ^{251}Fm are observed with energies of 7.305 MeV, 7.251 MeV and 7.184 MeV. Assuming that the highest energy α-particle corresponds to a transition to the ground state of ^{247}Cf, calculate the energies of the γ-rays which could be emitted by the ^{247}Cf formed.

[15 Marks]

4) Describe the operation of a fixed frequency cyclotron deriving expressions for the cyclotron frequency and the maximum energy achievable.

[12 Marks]

Explain how electrons can be accelerated to relativistic energies in a synchrotron.

[8 Marks]

In the LEP accelerator beams of electrons and positrons are accelerated to 50 GeV before they collide. What magnetic field will cause the particles to travel in a circular path with a radius of curvature of 1.67 km ?

[10 Marks]

5) Draw eightfold way diagrams to show how the charge, isospin and strangeness of spin 1/2 baryons and spin 3/2 baryons can be explained in terms of the possible combinations of the three quarks listed below .

[20 Marks]

Explain why the concept of colour is needed to justify the spin 3/2 diagram. How does the exchange of gluons hold the quarks together in a baryon ?

[10 Marks]

Flavour	Charge Q	Isospin T_3	Strangeness S
Up	+2/3	+1/2	0
Down	–1/3	–1/2	0
Strange	–1/3	0	–1