King’s College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 2002

Time allowed: **THREE** hours

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

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

Avagadro's constant	N_A	=	6.022×10^{23} mol^{-1}
Atomic mass unit	m_u	=	1.660×10^{-27} kg
Elementary charge	e	=	1.602×10^{-19} C
Permittivity of vacuum	e_0	=	8.854×10^{-12} F m^{-1}
Planck constant	h	=	6.626×10^{-34} J s
Speed of light	c	=	2.998×10^{8} m s^{-1}
Rest mass of an electron	m_e	=	9.109×10^{-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 SIX parts from this section.

1.1) 1 g of ^{225}Ra has an activity of 1 curie which corresponds to 3.70×10^{10} Bq. Use this information to calculate the decay constant and half-life of ^{225}Ra.

[7 Marks]

1.2) The shell model of the nucleus explains why stable light nuclei have approximately equal numbers of neutrons and protons. Use this model to suggest the form of decay that the radioactive nuclei $^{14}_{6}$C and $^{14}_{8}$O will undergo.

[7 Marks]

1.3) $^{64}_{29}$Cu can decay by β^+ emission to $^{64}_{28}$Ni or β^- decay to $^{64}_{30}$Zn. Calculate the Q values for these processes given that the atomic masses in m_u are $^{64}_{29}$Cu, 63.929766, $^{64}_{28}$Ni, 63.927968 and $^{64}_{30}$Zn, 63.929145.

[7 Marks]

1.4) A beam of 5 MeV α particles is scattered by a thin film of $^{197}_{79}$Au. Ignoring recoil of the Au nucleus, calculate the distance of closest approach between an α particle and an Au nucleus.

[7 Marks]

1.5) Electrons pass through a liquid with refractive index 1.33. Cherenkov radiation from the electrons is detected at an angle of 30 degrees to the electron direction. Calculate the speed of the electrons.

[7 Marks]

1.6) A scintillation counter is used to record the pulse height spectrum produced by 2.3 MeV γ-rays. In addition to the total absorption peak, single and double escape peaks are produced as a result of the pair production process. Calculate the energies in the spectrum at which these will be observed and describe the processes that give rise to them.

[7 Marks]

1.7) The track of a β^- particle, observed in a cloud chamber, has a radius of curvature of 5.0 cm in a magnetic field of flux density 0.1 T. Determine the energy of the β^- particle in MeV .

[7 Marks]

1.8) Explain why leptons are considered to be fundamental particles but hadrons are not.

[7 Marks]

SECTION B - Answer TWO questions.

2) Outline how quantum mechanical tunnelling may be used to account for α-decay.

[15 Marks]

α-decay of $^{228}_{90}\mathrm{Th}$ produces $^{224}_{88}\mathrm{Ra}$. Calculate the Q value for the decay using the atomic masses given below.

[5 Marks]

Calculate the recoil velocity of the daughter nucleus by considering conservation of energy and momentum for the decay.

[10 Marks]

[Atomic masses in m_u are $^{228}_{90}\mathrm{Th}$, 228.028715 , $^{224}_{88}\mathrm{Ra}$, 224.020186 and $^{4}_{2}\mathrm{He}$, 4.002603.]

3) The binding energy B in MeV of a nucleus for which the atomic mass number A is odd is 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 each term in the above equation. 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, given above, to find the atomic number of the element having $A = 209$ which has the highest binding energy.

[10 Marks]

4) Outline the operation of an electron-synchrotron explaining how it is able to accelerate electrons to relativistic velocities.

[14 Marks]

Briefly describe one application of synchrotrons in particle physics and one in X-ray physics.

[6 Marks]

A synchrotron will accelerate electrons to an energy of 3.0 GeV in an approximately circular path. Calculate the radius of curvature of the electron beam in a bending magnet given that the bending magnets provide a flux density of 1.4 T .

[10 Marks]

5) Discuss the physical principles in the operation of a thermal nuclear reactor.

[20 Marks]

When a $^{235}_{92}U$ nucleus undergoes fission, about 200 MeV of energy is released. A thermal nuclear power station has an electrical power output of 3000 MW and converts 30% of the fission energy into electrical power. Find a) the number of uranium nuclei which must undergo fission per second to provide the output power and b) the mass of $^{235}_{92}U$ consumed during 24 hours of continuous operation.

[10 Marks]