King’s College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 2000

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 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 x 10^{-27} kg
Elementary charge	e	=	1.602 x 10^{-19} C
Permittivity of vacuum	ε_0	=	8.854 x 10^{-2} Fm^{-1}
Reduced Planck constant	$\hbar$	=	1.055 x 10^{-34} Js
Speed of light	c	=	2.998 x 10^{8} ms^{-1}
Rest mass of an electron	m_e	=	9.019 x 10^{-31} kg

SECTION A - Answer SIX parts from this section.

1.1) ${}^{132}_{53}I$ has a half life of 2.3 hours. A sample containing ${}^{132}_{53}I$ has an initial activity of 10^5 Bq. How many atoms of ${}^{132}_{53}I$ are contained in the sample.

[7 Marks]

1.2) ${}^{9}_{6}C$ decays by electron capture while ${}^{15}_{6}C$ decays by β^- emission. Use the shell model of the nucleus to explain these observations.

[7 Marks]

1.3) Calculate Q values in MeV for the following β-decay processes.

$${}^{23}_{10}Ne \rightarrow {}^{23}_{11}Na + e^- + \overline{\nu}$$

$${}^{25}_{13}Al \rightarrow {}^{25}_{12}Mg + e^+ + \nu.$$

Atomic masses in m_u are ${}^{23}_{10}Ne$ 22.994465, ${}^{23}_{11}Na$ 22.989768, ${}^{25}_{13}Al$ 24.990429 and ${}^{25}_{12}Mg$ 24.985837.

[7 Marks]

1.4) The α-decay of ${}^{220}_{81}Tl$ has a Q value of 8.95 MeV. Use this to find the recoil velocity of the daughter Au nucleus. You may assume that the mass of a nucleus in m_u is equal to its mass number.

[7 Marks]

1.5) Explain why delayed neutrons and prompt neutrons are both important for the operation of a thermal nuclear reactor.

[7 Marks]

1.6) Explain how a simple cyclotron can be used to accelerate charged particles.

[7 Marks]

1.7) Sketch the pulse height spectrum produced by a scintillation counter detecting 0.8MeV γ-rays and briefly describe the processes giving rise to the observed features.

[7 Marks]

1.8) Yukawa interpreted the strong nuclear force occuring between nucleons as resulting from the exchange of virtual mesons with a mass of the order of 200 MeV/c^2. Use the uncertainty principle to estimate the range of the strong nuclear force between two nucleons.

[7 Marks]

SECTION B - Answer TWO questions.

2) Use the liquid drop model of the nucleus to explain why nuclei are normally spherical with uniform density.
Use the shell model of the nucleus to explain why for nuclei with a low mass number *A* the atomic number *Z* is approximately equal to the number of neutrons *N* while for large *A* nuclei $N > Z$.

[15Marks]

The binding energy *B*(MeV) for an odd *A* nucleus may be given by the semi-empirical expression

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

Use this to find the values of *Z* which give the highest binding energy for isobars with $A = 19$ and 209. Find the *N/Z* ratio for these nuclei.

[15 Marks]

3) Explain how the results of α scattering from thin films can be used to give an estimate of the diameter of a nucleus.

[15 Marks]

The β-decay of ${}^{177}_{71}\mathrm{Lu}$ leads to ${}^{177}_{72}\mathrm{Hf}$. A Fermi-Kurie analysis of the β spectrum leads to Q values of 176 keV, 247 keV, 384 keV and 497 keV. Draw an energy level diagram to indicate the formation of the excited states and calculate the energies of the γ-rays that might be observed. Assume that all transitions are possible.

[15 Marks]

4) Explain how electrons are accelerated to relativistic energies in a linear accelerator.

[15 Marks]

The promised new British synchrotron, to be called Diamond, will accelerate electrons to an energy of 3.0 GeV in an approximately circular path. If the bending magnets provide a flux density of 1.4 T calculate the approximate radius of curvature of the electron beam in a bending magnet.

[10 Marks]

This type of accelerator is used as a source of synchrotron radiation rather than high energy electrons. Explain what is meant by synchrotron radiation. Assume for relativistic particles with energy E, rest energy E_0 and momentum p that $E^2 = E_0^2 + p^2c^2$.

[5 Marks]

5) Discuss the main points in the construction and operation of a thermal nuclear reactor.

[20 Marks]

When a $^{235}_{92}U$ nucleus undergoes fission, about 200 MeV of energy is released. For a thermal nuclear power station which has an electrical power output of 2000 MW and which converts 40% of the fission energy into electrical power, find a) the number of uranium nuclei which undergo fission per second and b) the mass of uranium which is used during 24 hours of continuous operation.

[10 Marks]