King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 2003

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

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} Fm^{-1}
Planck constant	h	=	6.626×10^{-34} Js
Speed of light in vacuum	c	=	2.998×10^{8} ms^{-1}
Rest mass of an electron	m_e	=	9.109×10^{-31} kg
		=	0.511 MeV c^{-2}

SECTION A - Answer SIX parts from this section.

1.1) Define the decay constant of a radioactive element.
The half life of ${}^{14}_{6}C$ is 5730 yrs. If the activity due to the ${}^{14}_{6}C$ content of a wooden object is known to have fallen by 25% over its lifetime calculate the age of the object.

[7 Marks]

1.2) When a beam of high-energy electrons is diffracted by a thin metal foil the angle q of the first minimum in the diffracted intensity is given by

$$\sin q \approx 1.22 \frac{l}{a}$$

where l is the de Broglie wavelength of the electrons and a is the nuclear diameter. For a gold foil the first diffraction minimum observed for a beam of 300 MeV electrons is at 21^{o}. Use this information to calculate the diameter of the gold nucleus.
What information in addition to the nuclear diameter can be obtained from the intensity variation of the diffracted beam ?

[7 Marks]

1.3) α and β decay are frequently accompanied by the emission of γ radiation. Explain how this may be interpreted in the shell model of the nucleus.
When ${}^{126}_{53}I$ decays by β^{-} emission ${}^{126}_{54}Xe$ is formed in an excited state with an energy of 389 KeV. Determine the wavelength of the γ radiation emitted when the excited state relaxes to the ground state.

[7 Marks]

1.4) Explain why, in the liquid drop model of the nucleus, the average binding energy of nucleons in most nuclei is found to be approximately constant.
Why is surface tension an important consideration in this model?

[7 Marks]

1.5) Describe what occurs in the processes of a) electron capture and b) internal conversion.

[7 Marks]

1.6) Show that the cyclotron frequency f for an electron is given by the expression

$$f = \frac{Be}{2pm_e},$$

where B is the flux density of the magnetic field.

What limits the ultimate energy to which electrons can be accelerated in simple cyclotrons ?

[7 Marks]

1.7) The track of a high-energy electron in a cloud chamber has a radius of curvature of 4 cm in a magnetic field of flux density 0.1T. Determine the kinetic energy of the electron in MeV.

[7 Marks]

1.8) What are the main properties of a) a lepton and b) a meson ?

[7 Marks]

SECTION B - Answer TWO questions.

2) a) Define the following units which are used in the measurement of radioactivity or radioactive doses: i) the becquerel, ii) the gray, iii) the sievert.

[6 Marks]

b) When a sample of $^{55}_{25}\mathrm{Mn}$ is irradiated with thermal neutrons, $^{56}_{25}\mathrm{Mn}$ nuclei are formed at a constant rate of R s^{-1} by neutron capture. The $^{56}_{25}\mathrm{Mn}$ nuclei then undergo β-decay to form $^{56}_{26}\mathrm{Fe}$ with a decay constant l. Stating any assumptions show that the number of $^{56}_{25}\mathrm{Mn}$ nuclei present after t seconds of irradiation is given by

$$N = \frac{R}{l}(1\text{-}\exp(-l t)).$$

[15 Marks]

c) If $R = 10^{11}$ s^{-1} and the half life of $^{56}_{25}\mathrm{Mn}$ is 2.58 hours, what is the maximum number of $^{56}_{25}\mathrm{Mn}$ atoms that can be formed and what will be the activity due to $^{56}_{25}\mathrm{Mn}$ after 1 hour of irradiation ?

[9 Marks]

3) a) Describe the α-scattering experiments carried out by Geiger and Marsden. Give the main points of the model used by Rutherford to explain their observations.

[15 Marks]

b) A 4 MeV α particle is scattered through 180^0 by a $^{12}_{6}\mathrm{C}$ nucleus which is initially at rest. Calculate the distance of closest approach between the α particle and the $^{12}_{6}\mathrm{C}$ nucleus.

[15 Marks]

4) a) Describe three processes by which γ rays can interact with matter, indicating the energy regions where each is important.

[15 Marks]

b) The energy E_{γ}' of a γ-ray scattered through an angle θ in the Compton scattering process is given by

$$E_{\gamma}' = \frac{E_{\gamma} E_0}{E_0 + E_{\gamma}(1 - \cos\theta)}$$

where E_{γ} is the energy of the incident γ-ray and E_0 is the rest energy of an electron. Use this expression to predict the energy of the Compton edge observed when a scintillation counter is used to detect γ-rays of energy 2MeV.

[15 Marks]

5) a) Describe how natural uranium with 0.72% of ${}^{235}_{92}\mathrm{U}$ can be used as the fuel in a thermonuclear reactor to generate energy.

[17 Marks]

b) The collision of a thermal neutron with a ${}^{235}_{92}\mathrm{U}$ nucleus results in the fission reaction

$${}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{93}_{37}\mathrm{Rb} + {}^{141}_{55}\mathrm{Cs} + 2\,{}^{1}_{0}\mathrm{n}.$$

Calculate the energy in MeV released in this fission process.

Atomic masses in m_{u} are ${}^{235}_{92}\mathrm{U}$ = 235.04392, ${}^{93}_{37}\mathrm{Rb}$ = 92.92170, ${}^{141}_{55}\mathrm{Cs}$ = 140.91949 and ${}^{1}_{0}\mathrm{n}$ = 1.00866

[8 Marks]

c) Assuming that this is an average for the energy that is released in the fission of a ${}^{235}_{92}\mathrm{U}$ atom, determine how many fissions must take place each second to provide the power for a 1000 MW power station. Assume that the power station is 30% efficient.

[5 Marks]