UNIVERSITY OF LONDON

MSci EXAMINATION 2000

For Internal Students of

Royal Holloway

DO NOT TURN OVER UNTIL TOLD TO BEGIN

PH4511A: NUCLEAR PHYSICS

Time Allowed: TWO AND A HALF hours

Answer THREE QUESTIONS only

No credit will be given for attempting any further questions

Approximate part-marks for questions are given in the right-hand margin

Calculators ARE permitted

PH4511A/30

GENERAL PHYSICAL CONSTANTS

Permeability of vacuum	m_0	=	$4\pi \times 10^{-7}$	H m^{-1}
Permittivity of vacuum	e_0	=	8.85×10^{-12}	F m^{-1}
	$1/4\pi e_0$	=	9.0×10^{9}	m F^{-1}
Speed of light in vacuum	c	=	3.00×10^{8}	m s^{-1}
Elementary charge	e	=	1.60×10^{-19}	C
Electron (rest) mass	m_e	=	9.11×10^{-31}	kg
Unified atomic mass constant	m_u	=	1.66×10^{-27}	kg
Proton rest mass	m_p	=	1.67×10^{-27}	kg
Neutron rest mass	m_n	=	1.67×10^{-27}	kg
Ratio of electronic charge to mass	e/m_e	=	1.76×10^{11}	C kg^{-1}
Planck constant	h	=	6.63×10^{-34}	J s
	$\hbar = h/2\pi$	=	1.05×10^{-34}	J s
Boltzmann constant	k	=	1.38×10^{-23}	J K^{-1}
Stefan-Boltzmann constant	s	=	5.67×10^{-8}	W m^{-2} K^{-4}
Gas constant	R	=	8.31	J mol^{-1} K^{-1}
Avogadro constant	N_A	=	6.02×10^{23}	mol^{-1}
Gravitational constant	G	=	6.67×10^{-11}	N m^{2} kg^{-2}
Acceleration due to gravity	g	=	9.81	m s^{-2}
Volume of one mole of an ideal gas at STP		=	2.24×10^{-2}	m^{3}
One standard atmosphere	P_0	=	1.01×10^{5}	N m^{-2}

MATHEMATICAL CONSTANTS

$e \cong 2.718$ $\pi \cong 3.142$ $\log_e 10 \cong 2.303$

PART MARKS

1. Compare the resonance fluorescence of an atomic system with that of a nucleus emitting γ rays in a transition to the ground state. Why is the former easily observable whereas the latter is not? **[4]**

Explain the Mössbauer effect with reference to Mössbauer's experiments. **[8]**

Explain, giving TWO examples, how observations of this effect can provide information about the properties of nuclear states, and the environment of the emitting or absorbing nucleus in a solid. **[8]**

2. (a) Assuming that the deuteron can be considered as a non-relativistic neutron-proton bound pair with binding energy ε and reduced mass μ in a spherically symmetrical square-well potential of depth V_0 and radius R, show that

$$K\cot(KR) = -k\,,$$

where

$$k^2 = \frac{2\mu\varepsilon}{\hbar^2} \quad \text{and} \quad K^2 = \frac{2\mu}{\hbar^2}[V_0 - \varepsilon]\,.$$

[12]

(b) Using the approximation that

$$U(r) = r\psi(r) = C\exp(-kr)\,,$$

is valid for the deuteron from $r = 0$ to $r = \infty$, find the normalisation constant C.

Hence if $k = 0.232\ \text{fm}^{-1}$ find the probability that the neutron-proton separation in the deuteron exceeds 2 fm. Find also the average distance of interaction for this wavefunction. **[8]**

3. Review *briefly* the evidence for a shell model of the nucleus. **[4]**

Explain how such a model uses potentials such as a square well and a harmonic oscillator to try and predict the magic numbers. **[8]**

Explain how the spins, parities and magnetic moments of a nucleus in both the ground state and excited states may be predicted by the shell model and give three nuclei as examples. **[6]**

Discuss *briefly* the failures of the shell model. **[2]**

PART MARKS

4. Explain the classification of beta-decay transitions as Fermi or Gamow-Teller and as allowed or forbidden.

Classsify the following transitions (the spin parity, J^P, of the nuclear states are given in brackets):-

$$^{14}O \rightarrow {}^{14}N^* + e^+ + \upsilon \qquad \left(0^+ \rightarrow 0^+\right)$$

$$^{6}He \rightarrow {}^{6}Li + e^- + \overline{\upsilon} \qquad \left(0^+ \rightarrow 1^+\right)$$

Why is the transition

$$^{17}F \rightarrow {}^{17}O + e^+ + \upsilon \qquad \left({}^{5}\!/_{2}{}^{+} \rightarrow {}^{5}\!/_{2}{}^{+}\right)$$

called a super-allowed transition? **[10]**

Describe *briefly* the experiment of Wu *et al* on the beta-decay,

$$^{60}_{27}Co \rightarrow {}^{60}_{28}Ni^* + e^- + \overline{\upsilon} \quad \left(5^+ \rightarrow 4^+\right)$$

explaining carefully why their results show that parity is not conserved in this transition. **[10]**

5. Discuss the problems involved in heavy-ion fusion and suggest why certain heavy-ion collisions lead to the formation of heavy elements and others do not. **[8]**

Describe how new elements with $Z > 107$ have been produced and identified following heavy-ion collisions in the Separator for Heavy Ion Products (SHIP) at Darmstadt. **[8]**

A recent experiment at the 88-inch cyclotron at the Lawrence Berkeley National Laboratory used a fusion reaction between 118 MeV $^{22}_{10}Ne$ ions and $^{247}_{97}Bk$ target to produce a new, long-lived isotope, $^{267}_{107}Bh$. State why this experiment is important and give the decay chain by which the isotope was identified. **[4]**

END