

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

GENERAL PHYSICAL CONSTANTS

Permeability of vacuum	μ_0	=	$4\pi \times 10^{-7}$	H m^{-1}
Permittivity of vacuum	ϵ_0	=	8.85×10^{-12}	F m^{-1}
	$1/4\pi\epsilon_0$	=	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	σ	=	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$
Gas constant	R	=	8.31	$\text{J mol}^{-1} \text{K}^{-1}$
Avogadro constant	N_A	=	6.02×10^{23}	mol^{-1}
Gravitational constant	G	=	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$
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

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

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

$$k^2 = \frac{2\mu\epsilon}{\hbar^2} \quad \text{and} \quad K^2 = \frac{2\mu}{\hbar^2} [V_0 - \epsilon]. \quad [12]$$

- (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]

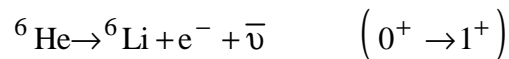
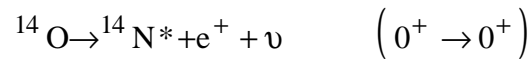
Explain how such a model uses potentials such as a square well and a harmonic oscillator to try and predict the magic numbers. [8]

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]

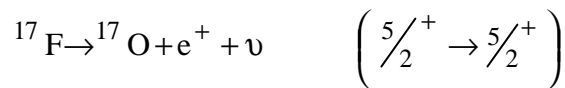
Discuss *briefly* the failures of the shell model. [2]

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

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

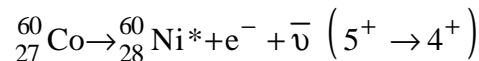


Why is the transition



called a super-allowed transition? [10]

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



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 ${}^{22}_{10}\text{Ne}$ ions and ${}^{247}_{97}\text{Bk}$ target to produce a new, long-lived isotope, ${}^{267}_{107}\text{Bh}$. State why this experiment is important and give the decay chain by which the isotope was identified. [4]