PHYS30322

ONE HOUR THIRTY MINUTES

A list of constants is enclosed

UNIVERSITY OF MANCHESTER

Nuclear Physics

19th May 2008

9:45 am – 11:15 am

Answer **ALL** parts of question 1 and **TWO** other questions

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Electronic calculators may be used, provided that they cannot store text.

The numbers are given as a guide to the relative weights of the different parts of each question.

P.T.O.

$1\ u = 931.5\ MeV / c^2$, $R = 1.2\ A^{1/3}$ fm, $1\ u = 1.67 \times 10^{-27}$ kg.

1 (a) Briefly explain the significance of the ratio of excitation energies for the first and second excited states in nuclei. If the lowest 2^+ state in ^{180}Hf (Z=72) has excitation energy of 93 keV, estimate the energy of the lowest 4^+ state.

[5 marks]

(b) An $I^{\Pi} = 2^-$ state in a ^{208}Pb nucleus decays to an $I^{\Pi} = 0^+$ state with the emission of a 150-keV gamma ray. Estimate the single-particle half-life for this transition using the following information:

$\lambda(E1) = 1.0 \times 10^{14} A^{2/3} E^3$,
$\lambda(E2) = 7.3 \times 10^7 A^{4/3} E^5$,
$\lambda(M1) = 5.6 \times 10^{13} E^3$,
$\lambda(M2) = 3.5 \times 10^7 A^{2/3} E^5$,

where E is the transition energy in MeV and λ is in s^{-1}.

Are there any other processes which can compete with this decay?

[5 marks]

(c) Many spherical even-even nuclei have a relatively low-lying $I^{\Pi} = 3^-$ level. What is the significance of such a state?

[5 marks]

(d) In the shell model, a certain odd-parity state has total and orbital quantum numbers, j and l, respectively. If the state has a degeneracy of 16, what are the values of j and l?

[5 marks]

(e) Experimental nuclear Binding Energy data show an energy staggering between odd-odd and even-even isobars. Briefly explain the origin of this effect.

[5 marks]

P.T.O.

2 Describe with the aid of a sketch the main features of the nuclear charge density distribution for a medium-mass nucleus.

[4 marks]

Describe how X-ray isotope shifts may be used to measure the charge radius of a nucleus.

[10 marks]

A beam of electrons of energy 250 MeV is elastically scattered through an angle of 60 degrees by a heavy nucleus. The differential cross section measured is 20% of that expected for a point nucleus. Given that the form factor for low momentum transfers is given by:

$$F(q) = 1 - q^2 \langle r^2 \rangle / 6 ,$$

estimate the root-mean-square radius of the nucleus.

[7 marks]

Briefly explain why the experimental charge distribution in the central region of the nucleus is not known to as high a precision as that near the nuclear radius.

[4 marks]

3 Give a brief description of the alpha-decay process. What Q-value condition must be satisfied for nucleus (A,Z) to undergo alpha decay?

[7 marks]

Briefly explain why in heavy nuclei alpha emission is favoured over proton or ^{14}C emission.

[4 marks]

Discuss the factors which determine the decay rate for alpha emission.

[6 marks]

If the Q value for ^{241}Am alpha decay is 4 MeV, estimate the maximum angular momentum the alpha particle can carry away. The mass of the alpha particle is 4.002603 u.

[4 marks]

Alpha emission is generally seen in heavy-mass nuclei. Briefly explain why a region of alpha emitters may also be found in the proton-rich nuclei with neutron number 84.

[4 marks]

P.T.O.

4 Sketch the general shape of the electron kinetic energy spectrum for beta-minus decay. Briefly explain how the mass of the neutrino affects this plot.

[5 marks]

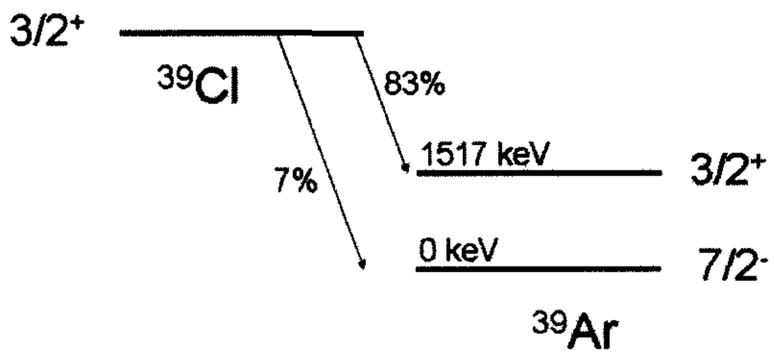
Briefly explain the difference between Fermi and Gamov-Teller allowed beta decays.

[8 marks]

Explain what is meant by a forbidden beta decay.

[4 marks]

The diagram below shows the beta decay of ^{39}Cl into ^{39}Ar.



The beta decay of ^{39}Cl into ^{39}Ar.

Write down the full characterisation of the two beta decays and briefly explain why the majority of the decays are to the 1517-keV level in ^{39}Ar.

[8 marks]

END OF EXAMINATION PAPER

PHYSICAL CONSTANTS AND CONVERSION FACTORS

SYMBOL	DESCRIPTION	NUMERICAL VALUE
c	Velocity of light in vacuum	299 792 458 m s^{-1}, exactly
μ_0	Permeability of vacuum	$4\pi \times 10^{-7}$ N A^{-2}, exactly
ϵ_0	Permittivity of vacuum where $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$	8.854×10^{-12} C^2 N^{-1} m^{-2}
h	Planck constant	6.626×10^{-34} J s
$\hbar$	$h/2\pi$	1.055×10^{-34} J s
G	Gravitational constant	6.674×10^{-11} m^3 kg^{-1} s^{-2}
e	Elementary charge	1.602×10^{-19} C
eV	Electronvolt	1.602×10^{-19} J
α	Fine-structure constant, $\frac{e^2}{4\pi\epsilon_0\hbar c}$	$\frac{1}{137.0}$
m_e	Electron mass	9.109×10^{-31} kg
m_ec^2	Electron rest-mass energy	0.511 MeV
μ_B	Bohr magneton, $\frac{e\hbar}{2m_e}$	9.274×10^{-24} J T^{-1}
R_∞	Rydberg energy $\frac{\alpha^2 m_e c^2}{2}$	13.61 eV
a_0	Bohr radius $\frac{1}{\alpha}\frac{\hbar}{m_e c}$	0.5292×10^{-10} m
Å	Angstrom	10^{-10} m
m_p	Proton mass	1.673×10^{-27} kg
m_pc^2	Proton rest-mass energy	938.272 MeV
m_nc^2	Neutron rest-mass energy	939.566 MeV
μ_N	Nuclear magneton, $\frac{e\hbar}{2m_p}$	5.051×10^{-27} J T^{-1}
fm	Femtometre or fermi	10^{-15} m
b	Barn	10^{-28} m^2
u	Atomic mass unit, $\frac{1}{12} m(^{12}C$ atom)	1.661×10^{-27} kg
N_A	Avogadro constant, atoms in gram mol	6.022×10^{23} mol^{-1}
T_t	Triple-point temperature	273.16 K
k	Boltzmann constant	1.381×10^{-23} J K^{-1}
R	Molar gas constant, $N_A k$	8.315 J mol^{-1} K^{-1}
σ	Stefan-Boltzmann constant, $\frac{\pi^2}{60}\frac{k^4}{\hbar^3 c^2}$	5.670×10^{-8} W m^{-2} K^{-4}
M_E	Mass of Earth	5.97×10^{24} kg
R_E	Mean radius of Earth	6.4×10^6 m
g	Standard acceleration of gravity	9.806 65 m s^{-2}, exactly
atm	Standard atmosphere	101 325 Pa, exactly
$M_\odot$	Solar mass	1.989×10^{30} kg
$R_\odot$	Solar radius	6.961×10^8 m
$L_\odot$	Solar luminosity	3.846×10^{26} W
$T_\odot$	Solar effective temperature	5800 K
AU	Astronomical unit, mean Earth-Sun distance	1.496×10^{11} m
pc	Parsec	3.086×10^{16} m
	Year	3.156×10^7 s