Queen Mary
University of London

BSc EXAMINATION

PHY-302 Nuclear Physics and Astrophysics

Summer Resit

Time Allowed: 2 hour 15 minutes

Date: 12th May 2006
Time: 10:00

Answer ALL questions in total. All questions carry equal marks. An indicative marking-scheme is shown in square brackets [ ] after each part of a question.

The use of calculators is allowed.

Charge of the electron	e	1.602×10^{-19} C	
Electron mass	m_e	0.511003 MeV/c^2	5.485803×10^{-4} u
Proton mass	m_p	938.280 MeV/c^2	1.00727647 u
Neutron mass	m_n	939.573 MeV/c^2	1.00866501 u
Atomic mass unit	u	931.502 MeV/c^2	
Avogadros constant	N_a	6.022045×10^{23} g mol^{-1}	
electron volt	eV	1.602189×10^{-19} J	

Mass	$^{235}_{92}U$	235.043924 u
Mass	$^{196}_{80}Hg$	195.965807 u
Mass	$^{196}_{78}Pt$	195.964926 u
Mass	$^{196}_{79}Au$	195.966544 u
Mass	$^{14}_{7}N$	14.003074 u
Mass	$^{235}_{92}U$	235.043924 u

DO NOT TURN TO THE FIRST PAGE OF THE QUESTION PAPER UNTIL INSTRUCTED TO DO SO BY THE INVIGILATOR

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a) The isotope $^{14}{}_{8}O$ is a positron emitter, decaying to an excited state of $^{14}{}_{7}N$. The gamma rays from the excited nitrogen nucleus have an energy of 2.313 MeV and the maximum energy of the positrons is 1.835 MeV. The mass of $^{14}{}_{7}N$ is 14.003074u and that of the electron is 0.000549u. Write the equation for the decay of the oxygen isotope and sketch an energy level diagram for the process. Given that u = 931.502 MeV/c^2 find the mass of $^{14}{}_{8}O$ assuming neutrinos to be massless. [5]

b) In beta decay processes describe what is meant by allowed decays and first forbidden decays. Explain what is meant by the electron capture decay process, ε. [4]

c) Unstable isobars of constant A can achieve stability through chains of successive beta decays. Draw a sketch showing how the mass changes with Z for fixed A, with A even and with A odd. Show the β^+ and β^- decay chains, and mark the stable isobars. Explain the origin of any differences between the curves for odd A and even A nuclei. [6]

d) Find the Q values for the three decay processes β^+, β^- and ε for $^{196}{}_{79}Au$ using masses given and assuming negligible electron binding energy. [6]

e) Explain briefly how the existence of the neutrino was experimentally verified and how it was shown that the neutrino and anti-neutrino are different particles. [4]

[Total Marks 25]

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a) Of the four known fundamental forces of nature, gravity plays no role in nuclear physics. The others are responsible for α, β, and γ radiation. Identify these three types and identify the role of the three fundamental forces in these decays. [6]

b) Give the approximate ranges of each type of radiation in matter and give two examples of detection methods, describing briefly the physical principles behind the method. [5]

c) Consider a nucleus M with mass number A and atomic number Z. It decays into a nucleus D and the energy released in the decay is Q.

i) If the decay proceeds via α–decay, what is the atomic number and mass number of the nucleus D? Sketch the energy spectrum of the α–particles. [3]

ii) If the decay proceeds via β^- emission, what is the atomic number and mass number of the nucleus D? Sketch the energy spectrum of the β^- radiation. [3]

iii) If the decay proceeds via γ emission, what is the atomic number and mass number of the nucleus D? Sketch the energy spectrum of the γ radiation. [3]

d) α emitters have lifetimes which vary over many orders of magnitude. Explain briefly with the aid of a sketch the general behaviour of the variation of lifetime with energy release, Q. Explain the quantum mechanical process by which alpha decay occurs and how this qualitatively depends on the Coulomb potential around the nucleus. [5]

[Total Marks 25]

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a) Write down an equation defining the nuclear binding energy, B, in terms of atomic masses.

[2]

b) Sketch the binding energy per nucleon, B/A, in MeV, versus the mass number A for the region 1<A<240. Indicate on the curve the approximate position of ^{2}H, ^{4}He and ^{56}Fe. Give an explanation of the general behaviour of the curve for A>100. Indicate on the sketch where you would expect nuclei susceptible to fission and fusion to lie.

[8]

c) The Semi Empirical Mass Formula gives a quantitative prediction for the binding energy, B, given the mass number, A, and the proton number Z of a given nucleus:

$$B(Z,A) = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_{sym} \frac{(A-2Z)^2}{A} + \delta$$

Explain the origin of the first 4 terms. Your answer should include a motivation for the given A and Z dependence. [6]

Explain what is meant by even-even, odd-odd, and even-odd nuclei. The final term, δ, differs for even-even, odd-odd, and even-odd nuclei. Explain how. The explicit A dependence of this term is not required. [3]

d) The constants in the Semi Empirical Mass Formula are:

$a_V=15.56$, $a_s=17.23$, $a_c=0.697$, $a_{sym}=23.285$, $a_p=12$, and $\delta = a_P / A^{1/2}$.

Calculate the kinetic energy of the α–particle emitted in the α–decay of $^{242}_{98}Cf$ assuming no recoil of the daughter nucleus. The measured value of 7.5 MeV is obtained in experiment. Compare and comment on the calculated and measured values. [6]

[Total Marks 25]

End of Examination Paper **Dr E Rizvi**