Queen Mary
University of London

BSc Examination by course unit/ BA by Special Regulations/ MSc Examination

Thursday 1st May 2008 14:30 - 16:45

PHY302 Nuclear Physics and Astrophysics Duration 2 hours 15 minutes

**YOU ARE NOT PERMITTED TO START READING THIS QUESTION PAPER UNTIL INSTRUCTED TO DO SO BY AN INVIGILATOR.**

Answer ALL questions in section A. Section A will consist of 40% of the total exam mark.

Answer ONLY TWO questions in section B. Section B will consist of 60% of the total exam mark.

An indicative mark scheme is shown in square brackets [] after each part of a question.

**CALCULATORS ARE PERMITTED IN THIS EXAMINATION. PLEASE STATE ON YOUR ANSWER BOOK THE NAME AND TYPE OF MACHINE USED.**

**COMPLETE ALL ROUGH WORKINGS IN THE ANSWER BOOK AND CROSS THROUGH ANY WORK WHICH IS NOT TO BE ASSESSED.**

## Data

| | | | |
|---|---|---|---|
| **Electronic charge** | **e** | **$1.602 \times 10^{-19}$ C** | |
| **Electron mass** | **$m_e$** | **0.511003 MeV/$c^2$** | **$5.485803 \times 10^{-4}$ 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/$c^2$** | |
| **Avogadro constant** | **$N_a$** | **$6.022045 \times 10^{23}$ g $mol^{-1}$** | |
| **electron volt** | **eV** | **$1.602189 \times 10^{-19}$ J** | |
| **Boltzmann constant** | **k** | **$8.6174 \times 10^{-11}$ MeV/K** | |
| **ħc = 200 MeV fm** | | $e^2/4\pi\varepsilon_0$ **1.439976 MeV fm** | |

| | Mass | | Mass |
|---|---|---|---|
| $^{2}H$ | **2.014102 u** | $^{3}H$ | **3.016049 u** |
| $^{3}He$ | **3.016029 u** | $^{4}He$ | **4.002603 u** |
| $^{236}U$ | **236.045563 u** | $^{240}Pu$ | **240.053808 u** |

**Examiners:**

Dr. E. Rizvi

Prof. J. Charap

**Section A. Answer all questions.**

1) Nuclear and atomic masses are often expressed using the atomic mass unit u. In these units what is the mass of one atom of $^{12}C$?

**[2 mark]**

2) What is the approximate formula relating the nuclear radius to the atomic mass number A of a particular isotope? Give an estimate of any numerical factors in the formula.

**[3 marks]**

3) Boron (B) is the fifth element in the periodic table. An isotope of this element is known as Boron-8. Give the atomic number, atomic mass and neutron number of Boron-8.

**[3 marks]**

4) Define the mean lifetime of a sample of radioactively decaying isotope.

**[2 marks]**

5) By comparing the different properties of $^{235}U$ and $^{238}U$ explain why the process of enrichment is necessary and how it is performed in order to produce fuel for nuclear power stations.

**[5 marks]**

6) Very briefly with the aid of a diagram describe the principles of operation of a Geiger counter.

**[5 marks]**

7) Sketch graphs showing the measured energy spectra of alpha, beta and gamma emissions in radioactive decays. Explain why the beta decay spectrum differs from the others. Mark the end point of the beta decay spectrum and explain its significance.

**[5 marks]**

8) The weak interaction violates charge conservation. True or false?

**[2 marks]**

9) What is meant by a nuclear reaction cross section, and what are the units in which it is measured? Why is it not a probability?

**[3 marks]**

10) Name and very briefly describe two methods of using nuclear physics to image inside our bodies.

**[4 marks]**

11) The binding energy per nucleon for $^{235}_{92}U$ is 7.5 MeV, whilst for the fission fragments $^{92}_{36}Kr$ and $^{141}_{56}Ba$ the binding energy per nucleon is 8.5 MeV. Estimate the energy release in this fission process.

**[4 marks]**

12) A synthetic isotope of gold, $^{195}_{79}Au$ can decay via the process of electron capture to an isotope of platinum, Pt. Write down the equation of this process giving the A and Z values of the nuclei involved.

**[2 marks]**

**Section B. Answer two questions only.**

**Question B1**

a) Define a Bequerel.

**[2 marks]**

b) Write down the relationship between the total mean lifetime and the individual mean lifetimes for a nuclide that simultaneously decays via alpha and beta decay with decay constants $\lambda_\alpha$ and $\lambda_\beta$ respectively.

**[5 marks]**

c) $^{212}_{83}\mathrm{Bi}$ undergoes $\alpha$ decay to Titanium (Ti) and $\beta^-$ decay to Polonium (Po). Write down the equations for both of these reactions giving the A and Z values. If the half life of $\alpha$ decay is 14.71 s and the total decay rate is 0.536 $s^{-1}$ what is the half life of the $\beta^-$ decay mode?

**[4 marks]**

d) A radioisotope with decay constant $\lambda$ is produced at a constant rate of $10^{10}$ $s^{-1}$. Derive an expression for *N(t)* the number of nuclei present at time *t*.

**[5 marks]**

e) What is carbon dating and explain the principles behind this method.

**[6 marks]**

f) An organic archaeological item of mass 2g is excavated in Stratford and found to have an activity of 0.035 Bq assumed to come from decays of $^{14}C$ which has a decay constant of $1.209 \times 10^{-4}$ $y^{-1}$. What is the mean lifetime and the half life of $^{14}C$? Assuming living matter has an abundance of $1.0 \times 10^{-12}$ of $^{14}C$, and that the artefact is all carbon, what is the age of the artefact?

**[6 marks]**

g) Suggest a process that may affect the isotopic abundances of carbon and thereby lead to inaccuracies in the carbon dating method.

**[2 marks]**

**Question B2**

a) Name the four fundamental forces of nature. The Standard Model of particle physics (SM) successfully describes the interactions of three of these forces. Which of the forces is not part of the SM? Why?

**[5 marks]**

b) Give two tables listing the names and electric charge (in units of the electron charge) of the 6 quarks and the 6 leptons that make up the fundamental particles of the SM. Your tables should be divided into 3 generations of particles starting with the first generation.

**[5 marks]**

c) In the Standard Model of particle physics all sub atomic processes are described by the exchange of gauge bosons: particles responsible for interactions between the quarks and leptons. Name each of these particles, giving the electric charge of each and list which force each is responsible for.

**[4 marks]**

d) The atomic nucleons are not a fundamental particle but consists of quarks. What is the quark content of the neutron and proton?

**[4 marks]**

e) A free neutron decays to a proton with a lifetime of approximately 10 mins. By considering the decay as the spontaneous emission of a gauge boson by one of the quarks, followed by the decay of the gauge boson to two leptons, draw a diagram showing this process and label each of the particles

**[4 marks]**

f) The W boson is responsible for the weak nuclear force in β decay, and was discovered in 1983 at CERN. Its mass is determined to be 80 GeV/$c^2$ (where 1 GeV = $10^9$ eV). By using the uncertainty principle estimate the range of the weak nuclear force in fm assuming the W travels at velocity c.

**[4 marks]**

g) Distinguish between the terms meson and baryon. Determine the possible electric charges that a meson can take.

**[4 marks]**

**Question B3**

a) Elements that are observed in the universe today were produced in three different processes shortly after the big bang, in stellar burning and in supernova explosions. List the main types of nuclei produced in each of these stages, describing very briefly the processes involved. Distinguish between the r and s processes.

**[8 marks]**

b) Define the Q of a reaction in terms of the masses of the particles involved. Calculate the Q values in MeV for the fusion reaction:

i) $d + d \rightarrow {}^{3}He + n$

**[6 marks]**

c) Assuming that the deuterons behave as spheres and need to have touching surfaces for fusion to occur, calculate the energy that must be supplied to overcome the electrostatic repulsion, and determine the approximate temperature this corresponds to.

**[5 marks]**

d) Find the total kinetic energy of the outgoing particles for this reaction.

**[6 marks]**

e) The ordering of the lowest nuclear shells is: $1s_{\frac{1}{2}}\ 1p_{\frac{3}{2}}\ 1p_{\frac{1}{2}}\ 1d_{\frac{5}{2}}\ 1d_{\frac{3}{2}}$ explain this notation. Give the shell model spin and parity assignments of the following nuclei:

i) ${}^{7}_{3}Li$

ii) ${}^{13}_{6}C$

**[5 marks]**

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**End of Paper**