UNIVERSITY OF EMBU

2016/2017 ACADEMIC YEAR

SECOND SEMESTER EXAMINATION

FOURTH YEAR EXAMINATION FOR THE DEGREE OF BACHELOR OF SCIENCE

SPH 402: NUCLEAR PHYSICS

DATE: APRIL 7, 2017 **TIME: 8:30-10:30AM**

INSTRUCTIONS:

Answer Question ONE and ANY Other TWO Questions.

Constants: Unless otherwise specified, take;

m_e	$9.1093897 \times 10^{-31}$ kg	h	$6.6260755(40) \times 10^{-34}$	J-s
m_μ	$1.8835327 \times 10^{-28}$ kg	$\hbar = \frac{h}{2\pi}$	$1.05457266(63) \times 10^{-34}$	J-s
$\pi^{\pm}$	$2.4880187 \times 10^{-28}$ kg	$\hbar c$		
π^0	2.406120×10^{-28} kg	c	299792458	m/s
M_p	$1.6726231 \times 10^{-27}$ kg	e	$1.60217733(49) \times 10^{-19}$	C
M_n	$1.6749286 \times 10^{-27}$ kg			

QUESTION ONE (30 MARKS)

a) Discuss 4 independent arguments against electrons existing inside the nucleus. (8 marks)

b) A beam of protons of 5MeV kinetic energy traverses a gold foil, one particle in 5×10^6 is scattered so as to hit a surface 0.5 cm^2 in area at a distance 10 cm from the foil and in a direction making an angle of 60◦ with the initial direction of the beam. What is the thickness of the foil? (5 marks)

c) A sodium iodide crystal is used with a ten-stage photomultiplier to observe protons of energy 5MeV. The phosphor gives one photon per 100 eV of energy loss. If the optical collection efficiency is 60% and the conversion efficiency of the photo-cathode is 5%, calculate the

average size and the standard deviation of the output voltage pulses when the mean gain per stage of the multiplier is 3 and the collector capacity is 12 PF.

(5 marks)

d) A linear accelerator produces 50 pulses per second of about 5×10^{11} electrons with a final energy of 2GeV. Calculate (i) the average beam current (ii) the power output. (5 marks)

e) In the Fermi gas model the internal energy is given by $U = \frac{3}{5}AE_F$, where U = 35 is the mass number and E_F is the Fermi energy. For a nucleus of volume V with $N = Z = A/2$.

$A = KVE_F^{3/2}$ where K is a constant. Using the thermodynamic relation, $p = -(\frac{\partial U}{\partial V})_s$ show that the pressure is given, $p = \frac{2}{5}\rho nAE_F$, where ρn is the nucleon density. (7 marks)

QUESTION TWO (20 MARKS)

a) Define *Mossbaver Effect* (2 marks)

b) The 129 keV gamma ray transition in ^{191}Ir was used in a *Mossbaver* experiment in which a line shift equivalent to the full width at half maximum (Γ) was observed for a source speed of 1 cms^{-1}. Estimate the value of Γ and the mean lifetime of the excited state in ^{191}Ir.

(4 marks)

c) An experiment was performed to verify the Red shift predicted by general theory of Relativity. The experiment consisted of the use of 14 keV γ -ray ^{57}Fe source placed on the top of a tower 22.6m high and the absorber at the bottom. The red shift was detected by the *Mossbaver* technique. What velocity of the absorber foil was required to compensate the red shift, and in which direction? (4 marks)

d) It is possible to measure the frequency in shift in (c), in the laboratory using the *Mossbaver* Effect. Describe such an experiment. (10 marks)

QUESTION THREE (20 MARKS)

a) What are the essential features of the liquid-drop model of the nucleus? Indicate what properties of the nucleus are well predicted by the model, and how the model is applied.

(5 marks)

b) Construct an energy-versus-separation plot which can be used to explain nuclear fission. Describe qualitatively the relation of the features of this plot to the liquid-drop model.

(5 marks)

c) i) Deduce that with $a_c = 0.72$MeV and $a_s = 23$MeV the ratio Z min/A is approximately 0.5 for light nuclei and 0.4 for heavy nuclei. (4 marks)

ii) Determine the most stable isobar with mass number $A = 64$. (2 marks)

(iii) The masses (amu) of the mirror nuclei $^{27}_{13}$Al and $^{27}_{14}$Si are 26.981539 and 26.9867 respectively. Determine the Coulomb's coefficient in the semi-empirical mass formula. (4 marks)

QUESTION FOUR (20 MARKS)

a) i) Define Radioactivity (1 mark)

ii) A relic is found to give an activity count of 12 cpm (counts per minute) for each gram of carbon. If living trees give a count of 16 cpm, find the approximate age of the relic. ($t_{1/2}$ for $^{14}_{6}C^{14}$ is $\approx$ 5700 years). (2 marks)

b) A sealed box was found indicated to have contained an alloy composed of equal parts by weight of two metals A and B. These metals are radioactive, with half lives of 12 years and 18 years, respectively and when the container was opened it was found to contain 0.53 kg of A and 2.20 kg of B. Deduce the age of the alloy. (7 marks)

c) Calculate the energy to be imparted to an α-particle to force it into the nucleus of $^{238}_{92}$U (r_0 = 1.2 fm) (5 marks)

d) A small volume of solution, which contained a radioactive isotope of sodium had an activity of 16,000 disintegrations per minute/cm^3 when it was injected into the blood stream of a patient. After 30 h, the activity of 1.0 cm^3 of the blood was found to be 0.8 disintegrations per minute. If the half-life of the sodium isotope is taken as 15 h, estimate the volume of the blood in the patient. (5marks)

QUESTION FIVE (20 MARKS)

a) The density of lead is 11.35 g/cm^3, and its atomic weight is 207.2. Assume that 1.000 cm of lead reduces a beam of 1-MeV gamma rays to 28.65% of its initial intensity.

i) How much lead is required to reduce the beam to 10^{-4} of its initial intensity?

ii) What is the effective cross section of a lead atom for a 1-MeV photon? (10 marks)

b) An electrical power plant operates on the basis of thermal energy generated in a pressurized water reactor. The electrical power output of the plant is 1GW, and its efficiency is 30%.

i) Find the total power generated by the reactor.

ii) How much power is discharged to the environment as waste heat?

iii) Calculate the rate of fission events in the reactor core.

iv) Calculate the mass of 235U used up in one year.

v) Using the results from (i), determine the rate at which fuel is converted to energy (in kg/s) in the reactor core, and compare your answer with the result from (iv).

(10 marks)

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