

LAIKIPIA



PHYS 413

UNIVERSITY

UNIVERSITY EXAMINATIONS

FIRST SEMESTER 2025/2026 ACADEMIC YEAR

**FOURTH YEAR EXAMINATION FOR THE DEGREES OF
BACHELOR OF EDUCATION (SCIENCE) AND
BACHELOR OF SCIENCE (GENERAL)**

PHYS 413: ATOMIC AND NUCLEAR PHYSICS

STREAM: R

TIME: 2 HRS

DAY: MONDAY [8.30 – 10.30 A.M]

DATE: 02/02/2026

THIS QUESTION PAPER CONSISTS OF FIVE (5) PAGES

PLEASE DO NOT OPEN UNTIL THE INVIGILATOR SAYS SO.

INSTRUCTIONS TO CANDIDATES

- Answer question **ONE** and any **TWO** questions
- Question one carries **40 marks** while all other carry **15 marks**

You may use the following constants.

Permittivity constants $\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$

$K = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$

Electron charge $e = -1.6 \times 10^{-19} \text{ C}$

Mass of electron $m_e = 9.11 \times 10^{-31} \text{ kg}$

Mass of proton $m_p = 1.67 \times 10^{-27} \text{ kg}$

$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

$1\text{u}=931\text{MeV}$

$1\text{u}=1.66 \times 10^{-27} \text{ kg}$

$e/m=1.76 \times 10^{11} \text{ Ckg}^{-1}$

Plancks constant $h = 6.63 \times 10^{-34} \text{ Js}$

QUESTION ONE (40 MARKS)

(a) Differentiate between the following:

(i) Nuclear fusion and nuclear fission (2 Marks)

(ii) Nuclear reaction and Chemical reaction. (2 Marks)

(b) (i) What were the drawbacks in Rutherford's nuclear model of an atom? (2 Marks)

(ii) An atom has a symbol Y, mass number 14 and 6 electrons. Write the symbol of its nuclide.

(2 Marks)

- (c) (i) State any **two** factors that affect the stability of nuclides. (2 Marks)
- (ii) Why is it not advisable to store a high proton rich isotope in a carton? (2 Marks)
- (iii) State three ways by which radioactivity can be detected. (3 Marks)
- (d) What are the conditions that must be met for chain reactions to take place? (2 Marks)
- (e) State any radionuclide that is used for medical applications and explain how they are used. (3 Marks)
- (f) The nucleus of the hydrogen atom has a radius of about 10^{-15}m . The electron is normally at a distance of about $5.4 \times 10^{-11}\text{m}$ from the nucleus. Assuming the hydrogen atom is a sphere with a radius of $5.3 \times 10^{-11}\text{m}$. Find the:
- (i) Volume of the atom (2 Marks)
- (ii) Volume of the nucleus (2 Marks)
- (iii) Percentage of the volume of the atom that is occupied by the nucleus (2 Marks)
- (g) The radioactive nuclei $^{210}_{84}\text{Po}$ emits alpha particles of a single energy, the product nuclei being $^{206}_{82}\text{Pb}$. Using data below, Calculate the in MeV, released in each disintegration.
- $^{210}_{84}\text{Po} = 209.936730u$
- $^{206}_{82}\text{Pb} = 205.929421u$
- $\alpha \text{ particle} = 4.00150u$ (4 Marks)
- (h) (i) Define background radiation and state its two main sources. (3 Marks)
- (ii) A radioactive sample has a mass of 10g. What mass of the sample will be remaining after 64 days if its half-life is 4 days (2 Marks)
- (i) (i) Name two fundamental forces that held the nucleus together (2 Marks)
- (ii) Calculate the frequency f and the wavelength λ of the radiation emitted as a result of an electron transition from $n=4(-0.85\text{eV})$ to $n=3(-1.51\text{eV})$ (3 Marks)

QUESTION TWO (15 MARKS)

- (a) (i) In the Rutherford's scattering experiment, what led to conclusion that an atom has a massive centre which is positively charged? (2 Marks)
- (ii) Explain how Rutherford's shortcomings were removed in Bohr model. (2 Marks)
- (iii) Differentiate between Zeeman Effect and Stark effect. (2 Marks)
- (b) Derive the energy equation for the Bohr Hydrogen atom. (4 Marks)
- (c) Experiments show that 13.6eV is required to separate a hydrogen atom into a proton and electron. Find the orbital radius and velocity of the electron of the hydrogen atom. (3 Marks)
- (d) Calculate the velocity of an electron whose kinetic energy is 2MeV (2 Marks)

QUESTION THREE (15 MARKS)

- (a) State any **three** general properties of a nucleus (3 Marks)
- (b) Describe in details the following two nuclear models
- (i) Liquid drop model (3 Marks)
- (ii) Nuclear shell model (3 Marks)
- (c) Given that the rest mass of a proton $m_p = 1.67 \times 10^{-27} \text{ kg}$ and the rest mass of a neutron $m_n = 1.675 \times 10^{-27} \text{ kg}$. Compute the density of the nucleus whose mass number $A=100$, $Z=45$, $N=55$. (4 Marks)
- (d) In the nucleus of gold $^{197}_{79}\text{Au}$, what is the electrostatic force of repulsion between two protons, assuming the centers of the protons are located at opposite ends of a diameter of the gold nucleus. (2 Marks)

QUESTION FOUR (15 MARKS)

- (a) (i) A large number of hydrogen atoms are excited to state $n = 4$. What transitions and spectra lines are then possible? (3 Marks)

- (ii) State any **three** drawbacks of the Sommerfield relativistic model of the atom. **(3 Marks)**
- (b) (i) In natural radioactivity, the number of nuclei present at time t is given by,

$$N = N_0 e^{-\lambda t}$$

Where N_0 is the number of the nuclei present at $t=0$ and λ is the decay constant. Show that the decay constant λ of radioactivity is $\lambda = \frac{0.693}{t_{1/2}}$ **(3 Marks)**

- (ii) A Sample of radioactive material has a mass of $9.0 \times 10^{12} \text{g}$. The material has a half-life of 80.0 sec. How long will it take for the mass to fall to $2.0 \times 10^{12} \text{g}$ **(3 Marks)**
- (iii) A carbon specimen obtained from a cave contained $1/8$ as much C-14 as an equal sample obtained from living matter. Calculate the approximate age of the specimen if the half-life of C-14 is 5568 years. **(3 Marks)**

QUESTION FIVE (15 MARKS)

- (a) Each atom of U-235 causes a mass defect of 0.2154U due to nuclear fission. Calculate the total energy released in KWh when all atoms in 1 gram of U-235 undergo fission given that $1\text{U}=931.4 \text{Mev}$ and the Avogadro's number = 6.025×10^{23} **(5 Marks)**
- (b) Nuclear fission produces the energy generated by nuclear reactors. This energy is primarily used to generate electricity at nuclear power plants;
- (i) What common fuel used in nuclear reactors? **(1 Mark)**
- (ii) How would one ensure that chain reaction in nuclear reactors goes on and at the same time preventing it from racing out of control. **(2 Marks)**
- (iii) Explain why a dense concrete structure is usually built to enclose the reactor. **(2 Marks)**
- (iv) Explain why nuclear reactors must be serviced periodically **(2 Marks)**
- (v) Nuclear fusion is a promising source of energy and has a number of advantages over fission. What are these advantages? **(2 Marks)**
- (vi) Provide one disadvantage of nuclear fusion over nuclear fission. **(1 Mark)**