THE COPPERBELT UNIVERSITY

IN ASSOCIATION WITH

THE TECHNICAL AND VOCATIONAL TEACHERS' COLLEGE

BACHELOR OF SCIENCE IN MATHEMATICS AND SCIENCE WITH EDUCATION

THIRD YEAR - ODL

ATOMIC AND NUCLEAR PHYSICS (PHY 320)

DECEMBER 2022 PROMOTIONAL EXAMINATION

TOTAL MARKS – 100%

TIME ALLOWED: THREE (3) HOURS

INSTRUCTIONS AND INFORMATION TO CANDIDATES

1. All questions carry equal marks of 20 marks each.
2. The marks are shown in brackets.
3. This paper contains seven questions. Answer **any five** questions of your choice.
4. Show clearly all the necessary calculations.
5. Marks will be awarded for neat and well-drawn diagrams.
6. Clearly indicate on the answer booklet cover page which questions you have attempted.

DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO DO SO

WHEREVER NECESSARY USE:

$g = 9.81 m/s^2$

$c = 3.0 \times 10^8 m/s$

$1eV = 1.60 \times 10^{-19} J$

$G = 6.67 \times 10^{-11} Nm^2/kg^2$

$1Ci = 3.7 \times 10^{10} Bq$

$\mu_0 = 4\pi \times 10^{-7} Tm/A$

$\varepsilon_0 = 8.85 \times 10^{-12} F/m$

$m_e = 9.11 \times 10^{-31} kg$

$k_e = 8.99 \times 10^9 Nm^2/C^2$

$e = 1.60 \times 10^{-19} C$

$\hbar = 1.05 \times 10^{-34} Js$

$R_H = 1.097 \times 10^7 m^{-1}$

$\sigma = 5.669 \times 10^{-8} W/m^2 K^4$

$h = 6.626 \times 10^{-34} Js$

Question One

a. What is an X-ray? [1 mark]

b. Medical X-ray machines typically operate at a potential difference of 1.00×10^5 V. Calculate the minimum wavelength their X-ray tubes produce when electrons are accelerated through this potential difference. [3 marks]

c. Describe the production of X-rays. [4 marks]

d. Explain six (6) uses of X-rays. [12 marks]

Question Two

a. State the Uncertainty Principle and write its mathematical expression. [3 marks]

b. Compare the de Broglie wavelength for an electron moving at a speed equal to 1.00×10^7 m/s with that of a baseball of mass 0.145 kg pitched at 45.0 m/s. [5 marks]

c. The speed of an electron is measured to be 5.00×10^3 m/s to an accuracy of 0.003%. Find the minimum uncertainty in determining the position of this electron. [7 marks]

d. Mention five (5) properties of X-rays. [5 marks]

Question Three

a. What is radioactivity? [2 marks]

b. The half-life of ^{131}I is 8.04 days.

i. Convert the half-life to seconds. [2 marks]
ii. Calculate the decay constant for this isotope. [3 marks]
iii. Convert 0.500μCi to the SI unit the Becquerel. [2 marks]
iv. Find the number of ^{131}I nuclei necessary to produce a sample with an activity of 0.500μCi. [2 marks]

c. Explain the Alpha decay, Beta-minus decay and Gamma decay processes and write their decay equations using the symbols X and Y to represent the parent and daughter nuclides respectively. [9 marks]

Question Four

a. Rutherford and his students (Hans Geiger and Ernest Marsden) bombarded very thin gold foil with α-particles. In this experiment, he studied the trajectory of the α-particles after interaction with the thin sheet of gold.

i. What three observations were made in this experiment? [3 marks]
ii. On the basis of the observations made during the experiment, what conclusions were made? [3 marks]

b. What are the frequency and wavelength of a photon emitted during a transition from $n=5$ state to the $n=2$ state in the hydrogen atom? [4 marks]

c. All the possible subshells for the energy levels $n = 1$ up to $n = 4$ are tabulated below.

Principal Quantum No.	Azimuthal Quantum No.	Subshell	Orbitals	Electrons	Total
$n = 1$					
$n = 2$					
$n = 3$					
$n = 4$					

Fill in the columns of the table with correct information concerning the azimuthal quantum number, the subshells, the number of orbitals, the number of electrons in the subshell and the total number of electrons in the energy level. [10 marks]

Question Five

a. Bohr's model of the atom was no doubt an improvement over Rutherford's nuclear model, as it could account for the stability and line spectra of hydrogen atom. However, it has some limitations. Explain two limitations of Bohr's model of the atom. [4 marks]

b. Write the electronic configuration for the following atoms.

i. Iron (26 electrons) [1 mark]

ii. Gallium (31 electrons) [1 mark]

iii. Aluminium (13 electrons) [1 mark]

iv. Calcium (20 electrons) [1 mark]

v. Boron (5 electrons) [1 mark]

vi. Carbon (6 electrons) [1 mark]

vii. Nitrogen (7 electrons) [1 mark]

viii. Oxygen (8 electrons) [1 mark]

ix. Fluorine (9 electrons) [1 mark]

x. Neon (10 electrons) [1 mark]

c. Show that the general formula for the electron orbital energy (the sum of its kinetic and potential energy) is given by; $E = \frac{1}{2} m_e v^2 - k_e \frac{e^2}{r}$. [6 marks]

Question Six

a. State the Pauli Exclusion Principle. [2 marks]

b. The electron energy for the hydrogen atom in terms of energy levels is given by;

$$E_n = -\frac{m_e k_e^2 e^4}{2\hbar^2}\left(\frac{1}{n^2}\right)$$

By using the values of the constants, appropriate conversions and by showing the cancellation of units, without skipping any steps, show that this expression can be simplified to $E_n = -\frac{13.6}{n^2} eV$. [6 marks]

c. An electron in the hydrogen atom transitions to the first excited state ($n = 2$) with a velocity of 1.09×10^6m/s. Using the Bohr theory of the atom, calculate;

i. the radius of the orbit [2 marks]
ii. the kinetic energy in eV [2 marks]
iii. the potential energy in eV [2 marks]
iv. the total energy in eV [2 marks]

d. Explain the following;

i. Emission spectra [2 marks]
ii. Absorption spectra [2 marks]

Question Seven

a. What is half-life? [1 mark]

b. The table below summarises the properties of Alpha, Beta and Gamma radiation. Complete the table by filling in the correct information. The first one is done for you.

Property	**α ray**	**β ray**	**γ ray**
Nature	**i.** Helium nucleus	Negatively charged particles (electrons)	Uncharged electromagnetic radiation
Charge	+2e	-e	**ii.** _____
Penetrating power	Low. Can be stopped by a thin sheet of paper	Moderate. Can be stopped by an aluminium sheet	**iii.** _____
Deflection by magnetic field	They are deflected less than beta particles because they have a higher mass	**iv.** _____	They are not deflected by magnetic field.
Ionizing ability	**v.** _____	Medium	0

[4 marks]

c. The half-life of the radioactive nucleus ${}^{226}_{88}Ra$ is 1.6×10^3 years. If a sample initially contains 3.0×10^{16} such nuclei, determine

i. The initial activity in curies. [5 marks]
ii. The number of radium nuclei remaining after 4.8×10^3 years [4 marks]

d. Starting from the equation $N = N_0 e^{-\lambda t}$, derive the expression for the half-life of a radioactive element. [6 marks]

END OF EXAMINATION