MACHAKOS UNIVERSITY
University Examinations 2021/2022

SCHOOL OF PURE AND APPLIED SCIENCES

DEPARTMENT OF PHYSICAL SCIENCES

FOURTH YEAR SECOND SEMESTER EXAMINATION FOR THE BACHELOR SCIENCE IN APPLIED PHYSICS AND TECHNOLOGY

SPH 451: RADIATION AND ENVIRONMENT

DATE: **TIME: 2 Hours**

INSTRUCTIONS:

- The paper consists of **two** sections.
- Section **A** is **compulsory** (30 marks).
- Answer any **two** questions from section **B** (each 20 marks).

Data for Computation of Stopping Power for Heavy Charged Particles, formulas for calculation of mean excitation energies, constants, relativistic quantities, atomic numbers (Z) and data for computing sun's declination angle are provided on the last three pages.

SECTION ONE

QUESTION ONE (COMPULSORY) (30 MARKS)

a) Position appropriately both extra-terrestrial and terrestrial radiation in the electromagnetic spectrum (2 marks)

b) Explain with a diagram the factors that influence of hours of daylight and darkness, and the changing of the seasons. (4 marks)

c) Calculate the sun's declination angle, on 13th November 2023 (2 marks)

d) A researcher in Machakos University measures sun's zenith angle as 45^o and atmospheric local pressure as 101300 pa. If atmospheric pressure at sea level is

101325 pa, calculate the fraction of the length of atmospheric air mass, the sun rays will have to traverse to reach the earth's surface. (3 marks)

e) Given that the temperature of the sun is 6500 K and that of the earth is 450 K. Show that the sun and earth radiate energy in the shortwave and longwave respectively. (2 marks)

f) State three reason why study of ionizing radiation is of profound significance. (3 marks)

g) Unlike heavy charged particles, electrons and positrons do not generally travel through matter in straight lines. Why? (2 marks)

h) An alpha particle with kinetic energy T = 2.6-MeV traversing through water, with time rate of energy loss, $-dE/dt = 6.19\times10^{11}$ MeVs^{-1}. Compute slow down time. (4 marks)

i) The stopping power of water is found to be 296 MeVcm^{-1}. A proton with kinetic energy 0.89 MeV is directed through the water, calculate its time of flight (4 marks)

j) Define the following terms

i) Radiation tolerance dose (2 marks)

ii) Extra-terrestrial radiation (2 marks)

SECTION TWO

QUESTION TWO (20 MARKS)

a) A proton traverse through water with kinetic energy T = 8.6 MeV, find its

i) Its velocity (3 marks)

ii) Rate of energy loss given stopping power for water as 273 MeVcm^{-1} (3 marks)

b) Calculate the maximum energy that a 3-MeV kaon of mass M= 976m can lose in a single collision with an electron of mass m = 9.1 x 10^{-31}kg. Calculate

i) Rest energy of the kaon (4 marks)

ii) Rest energy of the electron (2 marks)

iii) The relativistic $\gamma - gamma$ (2 marks)

iv) maximum energy that the kaon can lose using

1. Non-relativistic formula (3 marks)
2. Relativistic formula (3 marks)

QUESTION THREE (20 MARKS)

A charged particle (proton) of mass M travelling with a velocity V = 3.02 x 10^{8}m/s collides with an electron of mass m which is initially at rest. After the collision which for maximum energy transfer is head on, moves with speeds V^1 and v^1 along the initial line of travel of the incident particle. Assume the total kinetic energy and momentum are conserved during collision.

i) Represent the scenario diagrammatically. (2 marks)

ii) Find an expression for the final velocity V^1 of the incident particle (4 marks)

iii) Hence determine numerical value of final velocity of the incident particle. (3 marks)

iv) Determine an expression for the maximum energy transfer. (3 marks)

v) Calculate the initial kinetic energy of the incident particle. (3 marks)

vi) Calculate the maximum energy transferred. (3 marks)

vii) Unlike heavy charged particles, electrons and positrons do not generally travel through matter in straight lines. Why? (2 marks)

QUESTION FOUR (20 MARKS)

a) In a laboratory set up, a proton is directed incident to a water surface

i) Calculate the mean excitation energy for water H_2O . (4 marks)

ii) Calculate the electron density *n* of water. (4 marks)

iii) Compute the stopping power for water. (6 marks)

b) Write down the Bethe formula for stopping power of a heavy particle in a material. (2 marks)

c) Show how the Bethe formula can be reduced to (4 marks)

$$-\frac{dE}{dX} = \frac{5.08\ x\ 10^{-31} Z^2 n}{\beta^2}\left[\left(In\ \frac{1.02\ x\ 10^6 \beta^2}{1-\beta^2} - \beta^2\right) - In\ I_{eV}\right]$$

QUESTION FIVE (20 MARKS)

a) Show that the Bethe formula for stopping power can be written as (4 marks)

$$-\frac{dE}{dX} = \frac{5.08\ x\ 10^{-31} Z^2 n}{\beta^2}\left[F(\beta) - In\ I_{eV}\right]$$

Where $F(\beta) = \left(In\ \frac{1.02\ x\ 10^6 \beta^2}{1-\beta^2} - \beta^2\right)$

b) Hence calculate the stopping power for glycerine. (4 marks)

c) Calculate the mean excitation energy for

i) Glycerine $C_2\ H_6\ O_2$ (6 marks)

ii) Potassium permanganate $KMnO_4$ (6 marks)

Important information to students

1. *Data for Computation of Stopping Power for Heavy Charged Particles*

Proton Kinetic Energy (MeV)	β^2	$F(\beta)$ Eq. (5.34)
0.01	0.000021	2.179
0.02	0.000043	3.775
0.04	0.000085	4.468
0.06	0.000128	4.873
0.08	0.000171	5.161
0.10	0.000213	5.384
0.20	0.000426	6.077
0.40	0.000852	6.771
0.60	0.001278	7.175
0.80	0.001703	7.462
1.00	0.002129	7.685
2.00	0.004252	8.376
4.00	0.008476	9.066
6.00	0.01267	9.469
8.00	0.01685	9.753
10.00	0.02099	9.972

2. Constants

Planck's constant, $h = 6.6261 \times 10^{-34}$ J s
$\hbar = h/2\pi = 1.05457 \times 10^{-34}$ J s
Electron charge, $e = -1.6022 \times 10^{-19}$ C $= -4.8033 \times 10^{-10}$ esu
Velocity of light in vacuum, $c = 2.997925 \times 10^{8}$ m s^{-1}
Avogadro's number, $N_0 = 6.0221 \times 10^{23}$ mole^{-1}
Molar volume at STP (0°C, 760 torr) = 22.414 L
Density of air at STP (0°C, 760 torr) = 1.293 kg m^{-3}
$= 1.293 \times 10^{-3}$ g cm^{-3}
Rydberg constant, $R_\infty = 1.09737 \times 10^{7}$ m^{-1}
First Bohr orbit radius in hydrogen, $a_0 = 5.2918 \times 10^{-11}$ m
Ratio proton and electron masses = 1836.15
Electron mass, $m = 0.00054858$ AMU = 0.51100 MeV = 9.1094×10^{-31} kg
Proton mass = 1.0073 AMU = 938.27 MeV = 1.6726×10^{-27} kg
H atom mass = 1.0078 AMU = 938.77 MeV = 1.6735×10^{-27} kg
Neutron mass = 1.0087 AMU = 939.57 MeV = 1.6749×10^{-27} kg
Alpha-particle mass = 4.0015 AMU = 3727.4 MeV = 6.6447×10^{-27} kg
Boltzmann's constant, $k = 1.3807 \times 10^{-23}$ J K^{-1}

3. Atomic number (Z) for

Hydrogen (H) =1, Oxygen (O) = 8 and Carbon (C) = 6, Potassium (K) = 19, Manganese (Mn) = 25

4. Relativistic quantities

v = speed of object

c = speed of light in vacuum

$\beta = v/c$, dimensionless, $0 \le \beta < 1$

$\gamma = 1/\sqrt{1-\beta^2}$, dimensionless, $1 \le \gamma < \infty$

Rest energy, $E_0 = mc^2$, m = rest mass

Relativistic mass, $m/\sqrt{1-\beta^2} = \gamma m$

Total energy, $E_T = mc^2/\sqrt{1-\beta^2} = \gamma mc^2$

Kinetic energy = total energy—rest energy,

$$T = E_T - E_0 = mc^2(\gamma - 1) = mc^2\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right)$$

Momentum, $p = \gamma mv = mv/\sqrt{1-\beta^2}$

5. Formulas for estimation of mean excitation energy I- in eV for an element with atomic number Z.

$I \approx 19.0\ eV;\ Z = 1\ (e.g\ hydrogen)$

$I \approx 11.2\ eV + (11.7)(Z)eV;\ 2 \le Z \le 13)$

$I \approx 52.8\ eV + (8.71)(Z)eV; Z > 13)$

6. Data used to compute n for sun's declination angle

Month	n for the Day of the Month, D	Month	n for the Day of the Month, D
January	D	July	$181 + D$
February	$31 + D$	August	$212 + D$
March	$59 + D$	September	$243 + D$
April	$90 + D$	October	$273 + D$
May	$120 + D$	November	$304 + D$
June	$151 + D$	December	$334 + D$