NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OFAPPLIED SCIENCE

DEPARTMENT OF APPLIED PHYSICS

BSc. (Hons) IN APPLIED PHYSICS PART IV

ELECTROMAGNETIC THEORY

SPH4106

Special Supplementary Examination Paper

August 2024

This examination paper consists of 4 pages

Time Allowed:	**3 hours**
Total Marks:	**100**
Special Requirements:	**None**
Examiner's Name:	**Dr. P. Baricholo**

INSTRUCTIONS

ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

Important Constants

Permittivity of Free Space	ε_0	$= 8.85 \times 10^{-12}$ F m^{-1}
Permeability of Free space	μ_0	$= 4\pi\times10^{-7}$ Hm^{-1}
Rest mass of an Electron	m	$= 9.1 \times 10^{-31}$ kg
Charge on an Electron	e	$= 1.6 \times 10^{-19}$ C
Speed of light	c	$= 3 \times 10^{8}$ ms^{-1}

SECTION A

1. a) A time-dependent electric field intensity is given as $\vec{E} = \hat{x}10\pi\cos(10^6 t - 50z)$V/m. The field exists in a material with properties $\varepsilon_r = 4$ and $\mu_r = 1$. Given that $\vec{J} = 0$and $\boldsymbol{\rho} = 0$, calculate the magnetic field intensity in the material. [4]

b) Determine the electric potential and the electric field intensity for two infinite radial plates with an interior angle α and boundary conditions as shown in Figure 1. [5]

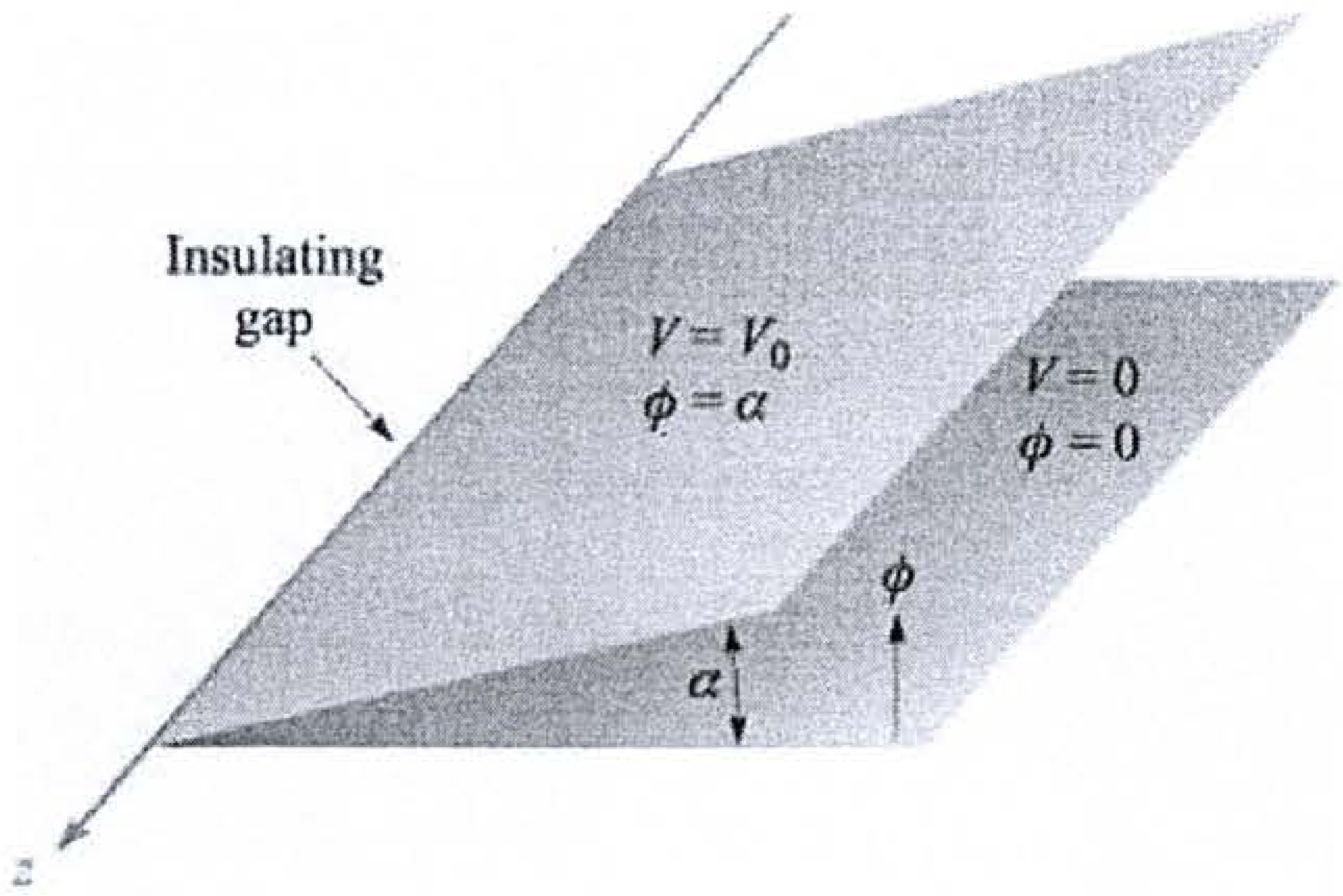

Figure 1

c) Define the Poynting vector and justify its units. [4]

d) A plane electromagnetic wave travels in free space with a peak electric field given by $E = 20\ Vm^{-1}$. Determine

i. the peak Poynting vector [3]

ii. the average Poynting vector and [3]

iii. the peak magnetic intensity. [3]

e) Most microwave ovens operate at 2.45 GHz, assume that $\sigma = 1.2 \times 10^{-6}\ S/m$ and $\mu_r = 500$ for stainless steel interior. If $E_s = 50\angle 0^o$ at the surface, find

i. the penetration depth or skin depth δ_s and [3]

ii. amplitude of the electric field E_s as a function of the angle. [3]

iii. Plot this electric field as it propagates in the stainless steel. [4]

f) i. Explain why **long distance radio broadcasts** use short-wave bands. [3]

ii. At an operating frequency of 300 MHz, a lossless 50-Ω air-spaced transmission line 2.5 m in length is terminated with an impedance $Z_L = (40+ j20)\ \Omega$. Find the input impedance. [5]

SECTION B

2. a) Show that the ratio of the amplitudes of the conduction current density and the displacement current density is $\frac{\sigma}{\omega\varepsilon}$ for the applied field $E = E_m \cos \omega t$. [6]

   b) The magnetic vector of a plane electromagnetic wave is described as follows:

$$\vec{\boldsymbol{B}} = \hat{\boldsymbol{k}} B_o cos[(10\ m^{-1})y + (3 \times 10^9 s^{-1})t]$$

   where $\hat{k}$ is a unit vector in the *z*-direction, *y* is in meters, and *t* is in seconds.

   i. What is the wavelength λ of the wave? [2]

   ii. What is the period *T* of the wave? [2]

   iii. In which direction does this wave propagate? *Briefly explain why you choose this direction.* [1, 2]

   iv. Find an expression for the electric vector $\vec{E}$ of the wave in terms of the quantities given and the speed of light *c*. [3]

   v. What is the time-dependent Poynting vector associated with this wave? [4]

3. a) Two infinite length, concentric and conducting cylinders of radii a and b are located on the z axis. If the region between cylinders is charged free and$\varepsilon = 3\varepsilon_o$, $V = V_o$ at a, $V = 0$ at b and $b > a$. Find the capacitance per meter length. [10]

   b) A time-dependent electric field intensity is given as $\vec{\boldsymbol{E}} = \hat{\boldsymbol{x}} 10\pi \cos(10^6 t - 50z)$V/m. The field exists in a material with properties $\varepsilon_r = 4$ and $\mu_r = 1$. Given that $\vec{\boldsymbol{J}} = 0$and $\rho = 0$, calculate

   i. the magnetic field intensity and [5]

   ii. magnetic flux density in the material. [2]

   iii. State 2 similarities and 2 differences between the propagation of plane waves in free space and conductive medium. [3]

4. a) Find the displacement current density associated with the magnetic field

$$\overrightarrow{\boldsymbol{H}} = A_1 \sin(4x) \cos(\omega t - \beta z)\, \hat{\boldsymbol{a}}_x + A_2 \cos(4x) \sin(\omega t - \beta z)\, \hat{\boldsymbol{a}}_z. \quad [5]$$

   b) Let $\mu = 3 \times 10^{-5}\ H/m$, $\varepsilon = 1.2 \times 10^{-10}\ F/m$, and $\sigma = 0$ everywhere. If $\overrightarrow{\boldsymbol{H}} = 2 \cos(10^{10} t - \beta x)\hat{\boldsymbol{a}}_z\ A/m$, use Maxwell's equations to obtain expressions for $\vec{\boldsymbol{B}}$, $\vec{\boldsymbol{D}}$, $\vec{\boldsymbol{E}}$ and β. [1, 5, 1, 3]

c) A lossless line whose Z_o is 50 Ω is connected to a load $Z_L = 50/\underline{25.99^o}\Omega$. Find Z_{in} at $l = \lambda/8$. [5]

5. a) Two infinite and parallel conducting planes are separated by a distance of d meter, with one of the conductor in the x = 0 plane at V = 0 Volt and the other in the $x = d$ plane at $V = V_0$ Volt. Assume $\rho \neq 0$ and $\varepsilon = 4\varepsilon_o$ between the conductors.Find

   i. V in the range $0 < x < d$ and [7]

   ii. $\vec{E}$ between the conductors. [3]

   b) At a frequency of 4 MHz a parallel wire transmission line has the following parameters: R = 0.025 Ω /m, L = 2 μH/m, G = 0, C = 5.56 pF/m. The line is 100 meters long, terminated in a resistance of 300 Ω. Find

   i. the standing wave ratio and [5]

   ii. voltage reflection coefficient of the load. [3]

   c) Distinguish a lossless transmission line from a distortionless transmission line. [2]

6. a) A 50-Ω lossless transmission line is terminated in a load with impedance $Z_L = (30 - j50)\ \Omega$. The wavelength is 8 cm. Find:

   i. the reflection coefficient at the load, [3]

   ii. the standing-wave ratio on the line, [2]

   iii. the position of the voltage maximum nearest the load, [5]

   iv. the position of the current maximum nearest the load. [3]

   b) Discuss "gain" as applied to antennas. [4]

   c) Suggest the factors that influence the design structure of a waveguide. [3]

END OF EXAMINATION