Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	ELECTROMAGNETIC FIELDS AND WAVES
COURSE CODE	:	BEJ 20303/BEV 20303
PROGRAMME CODE	:	BEJ/BEV
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWER ALL QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

Q1 (a) A parallel plate capacitor is defined as

$$C = \frac{\varepsilon S}{d}$$

where: S is the area of the plates; d is the distance between the plates and ε is the permittivity constant of the material that is filled between the plates. Based on the above equation, identify **TWO (2)** factors that can increase the capacitance.

(2 marks)

(b) Gauss's law states that electric flux passing through any closed surface is equal to the total electric charge enclosed by that surface. In your own words, summarise the procedures of applying Gauss's law to obtain the electric field, ***E***. Support your answer with the help of a diagram.

(5 marks)

(c) Consider a dielectric spherical shell as shown in **Figure Q1 (c)** centered at (0, 0, 0) carries a volume charge density, ρ_v = 2 nC/m^3 with inner radius, a = 1 m and outer radius b = 3 m. In addition, a point charge with Q_1 = + 5 nC is located at the center of the spherical shell.

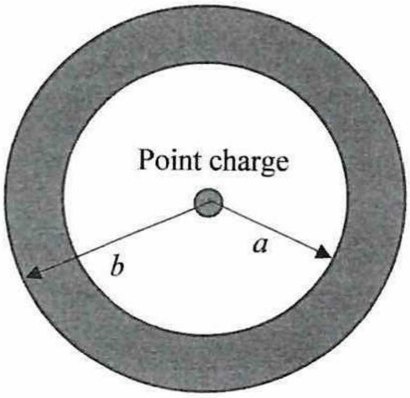

Figure Q1(c): Spherical shell.

(i) Sketch any possible Gaussian surfaces of the charges to obtain an electric field, ***E*** at everywhere.

(3 marks)

(ii) Calculate the total electric field, ***E*** at (0, 6, 4).

(15 marks)

Q2 (a) Define the Biot-Savart's and Ampere's Circuit laws.

(2 marks)

(b) With an aid of a suitable diagram, explain how the direction of magnetic field ***dH*** at any point due to a current element, ***Idl*** is determined.

(8 marks)

(c) A semi-infinite conductor is bent into an L shaped and located on the y and z axes. It carries a direct current, I of 3 A that flows from coordinate (0, 6, 0) to (0, 0, 0) and extends along the positive z-axis. Determine the magnetic field intensity, ***H*** at (-3, 6, 0).

(10 marks)

(d) Two infinite and parallel filamentary currents are separated by a distance, $d = 4$ m carrying a direct current, I of 6 A in an opposite direction along the x-axis. Determine the magnetic force per unit length, ***F/m*** on the current filament that lies on the x-axis.

(5 marks)

Q3 (a) Define the transformer electromotive force and motion electromotive force.

(2 marks)

(b) **Figure Q3 (b)** shows a rectangular loop with a conducting slide bar located at $x = 10t + 4t^3$. The separation distance, ab between the two rails is 40 cm. If the magnetic flux density, $\boldsymbol{B} = 0.8x^2z$ T, identify the voltmeter reading at $t = 1$ s.

(8 marks)

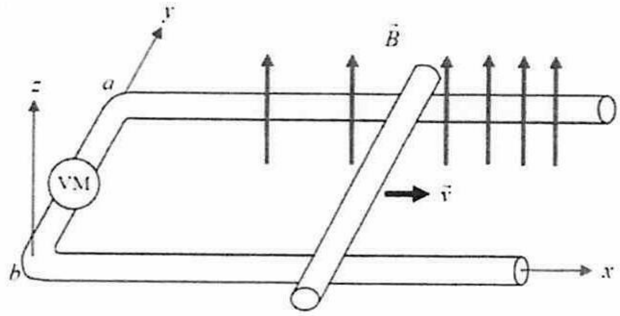

Figure Q3 (b)

(c) An inductor is formed by winding N turns of a thin conducting wire into a circular loop with a radius of 10 cm. The inductor loop is in the x-y plane with its center at the origin and connected to a resistor, $R = 1000\ \Omega$ as can be seen in **Figure Q3 (c)**. In the presence of magnetic field, $\boldsymbol{B} = 0.6 sin 10^3 t\ \boldsymbol{z}$ T, current, $I = 95 \cos 10^3 t$ mA is induced in the circuit.

(i) Find the number of turns, N.

(11 marks)

(ii) Suggest a method to obtain the induced current, I of $47.5 \cos 10^3 t$. Justify your answer.

(4 marks)

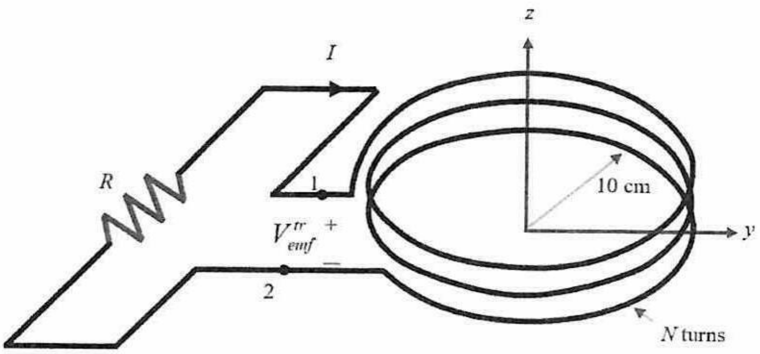

Figure Q3 (c)

Q4 (a) Radio waves and microwaves are two types of electromagnetic waves. Both waves can be used for communications and travel at the speed of light, c. State **TWO** (2) other properties of radio waves and microwaves.

(2 marks)

(d) In your own words, describe skin depth, δ. Illustrate your answer with the help of a diagram.

(4 marks)

(c) Assume that a microwave oven operates at 2.45 GHz or a wavelength of 122 mm. The interior of the microwave oven is made of stainless steel with $\sigma = 1.2 \times 10^6\ S/m$ and $\mu_r = 500$. Calculate the skin depth, δ of the microwave oven.

(4 marks)

(d) Seawater plays a vital role in submarine communication study. Assume that for seawater: $\sigma = 4$ S/m, $\varepsilon_r = 80$, $\mu_r = 1$ and $f = 100$ MHz.

(i) Show that the seawater is a good conductor.

(3 marks)

(ii) Calculate the attenuation constant, α and phase constant, β.

(4 marks)

(iii) Calculate the wave velocity, u.

(2 marks)

(iv) Calculate the wavelength, λ.

(2 marks)

(v) Calculate the intrinsic impedance, η.

(4 marks)

- END OF QUESTIONS -

APPENDIX A

FORMULA

	Cartesian	**Cylindrical**	**Spherical**
Coordinate parameters	x, y, z	r, ϕ, z	R, θ, ϕ
Vector $\vec{A}$	$A_x\hat{\mathbf{x}} + A_y\hat{\mathbf{y}} + A_z\hat{\mathbf{z}}$	$A_r\hat{\mathbf{r}} + A_\phi\hat{\boldsymbol{\varphi}} + A_z\hat{\mathbf{z}}$	$A_R\hat{\mathbf{R}} + A_\theta\hat{\boldsymbol{\theta}} + A_\phi\hat{\boldsymbol{\varphi}}$
Magnitude $\vec{A}$	$\sqrt{A_x^{\ 2} + A_y^{\ 2} + A_z^{\ 2}}$	$\sqrt{A_r^{\ 2} + A_\phi^{\ 2} + A_z^{\ 2}}$	$\sqrt{A_R^{\ 2} + A_\theta^{\ 2} + A_\phi^{\ 2}}$
Position vector, $\overrightarrow{OP}$	$x_1\hat{\mathbf{x}} + y_1\hat{\mathbf{y}} + z_1\hat{\mathbf{z}}$ for point $P(x_1,\ y_1,\ z_1)$	$r_1\hat{\mathbf{r}} + z_1\hat{\mathbf{z}}$ for point $P(r_1,\ \phi_1,\ z_1)$	$R_1\hat{\mathbf{R}}$ for point $P(R_1,\ \theta_1,\ \phi_1)$
Unit vector product	$\hat{\mathbf{x}}\bullet\hat{\mathbf{x}} = \hat{\mathbf{y}}\bullet\hat{\mathbf{y}} = \hat{\mathbf{z}}\bullet\hat{\mathbf{z}} = 1$ $\hat{\mathbf{x}}\bullet\hat{\mathbf{y}} = \hat{\mathbf{y}}\bullet\hat{\mathbf{z}} = \hat{\mathbf{z}}\bullet\hat{\mathbf{x}} = 0$ $\hat{\mathbf{x}}\times\hat{\mathbf{y}} = \hat{\mathbf{z}}$ $\hat{\mathbf{y}}\times\hat{\mathbf{z}} = \hat{\mathbf{x}}$ $\hat{\mathbf{z}}\times\hat{\mathbf{x}} = \hat{\mathbf{y}}$	$\hat{\mathbf{r}}\bullet\hat{\mathbf{r}} = \hat{\boldsymbol{\varphi}}\bullet\hat{\boldsymbol{\varphi}} = \hat{\mathbf{z}}\bullet\hat{\mathbf{z}} = 1$ $\hat{\mathbf{r}}\bullet\hat{\boldsymbol{\varphi}} = \hat{\boldsymbol{\varphi}}\bullet\hat{\mathbf{z}} = \hat{\mathbf{z}}\bullet\hat{\mathbf{r}} = 0$ $\hat{\mathbf{r}}\times\hat{\boldsymbol{\varphi}} = \hat{\mathbf{z}}$ $\hat{\boldsymbol{\varphi}}\times\hat{\mathbf{z}} = \hat{\mathbf{r}}$ $\hat{\mathbf{z}}\times\hat{\mathbf{r}} = \hat{\boldsymbol{\varphi}}$	$\hat{\mathbf{R}}\bullet\hat{\mathbf{R}} = \hat{\boldsymbol{\theta}}\bullet\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\varphi}}\bullet\hat{\boldsymbol{\varphi}} = 1$ $\hat{\mathbf{R}}\bullet\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\theta}}\bullet\hat{\boldsymbol{\varphi}} = \hat{\boldsymbol{\varphi}}\bullet\hat{\mathbf{R}} = 0$ $\hat{\mathbf{R}}\times\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\varphi}}$ $\hat{\boldsymbol{\theta}}\times\hat{\boldsymbol{\varphi}} = \hat{\mathbf{R}}$ $\hat{\boldsymbol{\varphi}}\times\hat{\mathbf{R}} = \hat{\boldsymbol{\theta}}$
Dot product $\vec{A}\bullet\vec{B}$	$A_xB_x + A_yB_y + A_zB_z$	$A_rB_r + A_\phi B_\phi + A_zB_z$	$A_RB_R + A_\theta B_\theta + A_\phi B_\phi$
Cross product $\vec{A}\times\vec{B}$	$\begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$	$\begin{vmatrix} \hat{\mathbf{r}} & \hat{\boldsymbol{\varphi}} & \hat{\mathbf{z}} \\ A_r & A_\phi & A_z \\ B_r & B_\phi & B_z \end{vmatrix}$	$\begin{vmatrix} \hat{\mathbf{R}} & \hat{\boldsymbol{\theta}} & \hat{\boldsymbol{\varphi}} \\ A_R & A_\theta & A_\phi \\ B_R & B_\theta & B_\phi \end{vmatrix}$
Differential length, $\overrightarrow{d\ell}$	$dx\,\hat{\mathbf{x}} + dy\,\hat{\mathbf{y}} + dz\,\hat{\mathbf{z}}$	$dr\,\hat{\mathbf{r}} + rd\phi\,\hat{\boldsymbol{\varphi}} + dz\,\hat{\mathbf{z}}$	$dR\,\hat{\mathbf{R}} + Rd\theta\,\hat{\boldsymbol{\theta}} + R\sin\theta\,d\phi\hat{\boldsymbol{\varphi}}$
Differential surface, $\overrightarrow{ds}$	$\overrightarrow{ds}_x = dy\,dz\,\hat{\mathbf{x}}$ $\overrightarrow{ds}_y = dx\,dz\,\hat{\mathbf{y}}$ $\overrightarrow{ds}_z = dx\,dy\,\hat{\mathbf{z}}$	$\overrightarrow{ds}_r = rd\phi\,dz\,\hat{\mathbf{r}}$ $\overrightarrow{ds}_\phi = dr\,dz\,\hat{\boldsymbol{\varphi}}$ $\overrightarrow{ds}_z = rdr\,d\phi\,\hat{\mathbf{z}}$	$\overrightarrow{ds}_R = R^2\sin\theta\,d\theta\,d\phi\,\hat{\mathbf{R}}$ $\overrightarrow{ds}_\theta = R\sin\theta\,dR\,d\phi\,\hat{\boldsymbol{\theta}}$ $\overrightarrow{ds}_\phi = R\,dR\,d\theta\,\hat{\boldsymbol{\varphi}}$
Differential volume, $\overrightarrow{dv}$	$dx\,dy\ dz$	$r\,dr\,d\phi\,dz$	$R^2\sin\theta\,dR\,d\theta\,d\phi$

APPENDIX B

FORMULA

$Q = \int \rho_\ell d\ell$

$Q = \int \rho_s dS$

$Q = \int \rho_v dv$

$\bar{F}_{12} = \frac{Q_1 Q_2}{4\pi\varepsilon_0 R^2}\hat{a}_{R_{12}}$

$\bar{E} = \frac{\bar{F}}{Q}$

$\bar{E} = \frac{Q}{4\pi\varepsilon_0 R^2}\hat{a}_R$

$\bar{E} = \int \frac{\rho_\ell d\ell}{4\pi\varepsilon_0 R^2}\hat{a}_R$

$\bar{E} = \int \frac{\rho_s dS}{4\pi\varepsilon_0 R^2}\hat{a}_R$

$\bar{E} = \int \frac{\rho_v dv}{4\pi\varepsilon_0 R^2}\hat{a}_R$

$\bar{D} = \varepsilon \bar{E}$

$\psi_e = \int \bar{D} \bullet d\bar{S}$

$Q_{enc} = \oint_S \bar{D} \bullet d\bar{S}$

$\rho_v = \nabla \bullet \bar{D}$

$V_{AB} = -\int_A^B \bar{E} \bullet d\bar{\ell} = \frac{W}{Q}$

$V = \frac{Q}{4\pi\varepsilon r}$

$V = \int \frac{\rho_\ell d\ell}{4\pi\varepsilon r}$

$\oint \bar{E} \bullet d\bar{\ell} = 0$

$\nabla \times \bar{E} = 0$

$\bar{E} = -\nabla V$

$\nabla^2 V = 0$

$R = \frac{\ell}{\sigma S}, C = \frac{\varepsilon S}{d}$

$C = \frac{2\pi\varepsilon L}{\ln\frac{b}{a}}, C = \frac{4\pi\varepsilon}{\frac{1}{a} - \frac{1}{b}}$

$I = \int \bar{J}.\bar{ds}$

$d\bar{H} = \frac{Id\bar{\ell} \times \bar{R}}{4\pi R^3}$

$Id\bar{\ell} \equiv \bar{J}_s dS \equiv \bar{J}dv$

$\oint \bar{H} \bullet d\bar{\ell} = I_{enc} = \int \bar{J}_s dS$

$\nabla \times \bar{H} = \bar{J}$

$\psi_m = \int_s \bar{B} \bullet d\bar{S}$

$\psi_m = \oint \bar{B} \bullet d\bar{S} = 0$

$\psi_m = \oint \bar{A} \bullet d\bar{\ell}$

$\nabla \bullet \bar{B} = 0$

$\bar{B} = \mu \bar{H}$

$\bar{B} = \nabla \times \bar{A}$

$\bar{A} = \int \frac{\mu_0 Id\bar{\ell}}{4\pi R}$

$\nabla^2 \bar{A} = -\mu_0 \bar{J}$

$\bar{F} = Q(\bar{E} + \bar{u} \times \bar{B}) = m\frac{d\bar{u}}{dt}$

$d\bar{F} = Id\bar{\ell} \times \bar{B}$

$\bar{T} = \bar{r} \times \bar{F} = \bar{m} \times \bar{B}$

$\bar{m} = IS\hat{a}_n$

$V_{emf} = -\frac{\partial \psi}{\partial t}$

$V_{emf} = -\int \frac{\partial \bar{B}}{\partial t} \bullet d\bar{S}$

$V_{emf} = \int (\bar{u} \times \bar{B}) \bullet d\bar{\ell}$

$I_d = \int J_d.d\bar{S}, J_d = \frac{\partial \bar{D}}{\partial t}$

$\gamma = \alpha + j\beta$

$\alpha = \omega \sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1 + \left[\frac{\sigma}{\omega\varepsilon}\right]^2} - 1\right]}$

$\beta = \omega \sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1 + \left[\frac{\sigma}{\omega\varepsilon}\right]^2} + 1\right]}$

$\bar{F}_1 = \frac{\mu I_1 I_2}{4\pi}\oint_{L1}\oint_{L2}\frac{d\bar{\ell}_1 \times (d\bar{\ell}_2 \times \hat{a}_{R_{21}})}{R_{21}^2}$

$|\eta| = \frac{\sqrt{\mu/\varepsilon}}{\left[1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2\right]^{\frac{1}{4}}}$

$\tan 2\theta_\eta = \frac{\sigma}{\omega\varepsilon}$

$\tan\theta = \frac{\sigma}{\omega\varepsilon} = \frac{\bar{J}_s}{\bar{J}_{ds}}$

$\delta = \frac{1}{\alpha}$

$\alpha = \sqrt{\pi f \mu\sigma}$ *(good conductor)*

$\varepsilon_0 = 8.854 \times 10^{-12}$ Fm^{-1}

$\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}

$\int \frac{dx}{(x^2 + c^2)^{3/2}} = \frac{x}{c^2(x^2 + c^2)^{1/2}}$

$\int \frac{xdx}{(x^2 + c^2)^{3/2}} = \frac{-1}{(x^2 + c^2)^{1/2}}$

$\int \frac{dx}{(x^2 \pm c^2)^{1/2}} = \ln\left(x + \sqrt{x^2 \pm c^2}\right)$

$\int \frac{dx}{(x^2 + c^2)} = \frac{1}{c}\tan^{-1}\left(\frac{x}{c}\right)$

$\int \frac{xdx}{(x^2 + c^2)} = \frac{1}{2}\ln(x^2 + c^2)$

$\int \frac{xdx}{(x^2 + c^2)^{1/2}} = \sqrt{x^2 + c^2}$