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Internal Assesment Test-II									
Sub:	Electromagnetic Theory							Code:	BEC401
Date:	23/05/2025	Duration:	90 mins	Max Marks:	50	Sem:	4th	Branch:	ECE(A,B,C,D)
Answer any **FIVE FULL** Questions									

		Marks	**OBE** CO	RBT
1.a)	Starting from the Gauss's law deduce Poisson's and Laplace's equations. Write Laplace's equations in all three co-ordinate systems.	[07]	CO3	L2

Derive Poisson's and Laplace's equation

$$\vec{\nabla}\cdot\vec{D} = \rho_v \quad \ldots (1)$$

$$\vec{D} = \epsilon_0 \vec{E} \quad \ldots (2)$$

$$\vec{E} = -\vec{\nabla} V \quad \ldots (3)$$

$$\vec{\nabla}\cdot\vec{D} = \vec{\nabla}\cdot(\epsilon_0 \vec{E}) = \epsilon_0 (\vec{\nabla}\cdot\vec{E}) = \rho_v$$

$$\text{or} \quad \epsilon_0\left(\vec{\nabla}\cdot(-\vec{\nabla} V)\right) = \rho_v$$

$$\text{or} \quad -\epsilon_0 \, \vec{\nabla}\cdot(\vec{\nabla} V) = \rho_v \quad \ldots (4)$$

$$\cancel{\vec{\nabla}\cdot(\vec{\nabla} V} \quad \vec{\nabla}\cdot(\vec{\nabla} V)$$

$$= \left(\hat{a}_x \frac{\partial}{\partial x} + \hat{a}_y \frac{\partial}{\partial y} + \hat{a}_z \frac{\partial}{\partial z}\right)\cdot\left(\frac{\partial V}{\partial x}\hat{a}_x + \frac{\partial V}{\partial y}\hat{a}_y + \frac{\partial V}{\partial z}\hat{a}_z\right)$$

$$= \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$$

$$= \nabla^2 V$$

$\therefore$ eqn. (4) reduces to,

$$\epsilon_0 \nabla^2 V = -\rho_v$$

or $$\boxed{\nabla^2 V = -\frac{\rho_v}{\epsilon_0}}$$ → Poisson's equation.

Now if $\rho_v = 0$ → $\boxed{\nabla^2 V = 0}$ → Laplace's eqn.

→ zero volume charge density, but allowing point charges, line charge and surface density to exist at singular locations as sources of the field.

$\nabla^2 V$ → Laplacian of V.

In rectangular co-ordinate system,

$$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$$

In cylindrical co-ordinates,

$$\nabla^2 V = \frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \frac{\partial V}{\partial \rho}\right) + \frac{1}{\rho^2}\frac{\partial^2 V}{\partial \phi^2} + \frac{\partial^2 V}{\partial z^2}$$

In spherical co-ordinates,

$$\nabla^2 V = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial V}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 V}{\partial \phi^2}$$

1.b) Determine whether or not the following potential fields satisfy Laplace's equation $V = \rho\cos\phi + z$. [03] CO3 L3

(ii) $V = (\rho\cos\phi + z)$

$$\nabla^2 V = \underbrace{\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial V}{\partial\rho}\right)} + \frac{1}{\rho^2}\frac{\partial^2 V}{\partial\phi^2} + \frac{\partial^2 V}{\partial z^2}$$

$$\frac{\partial V}{\partial\rho} = \frac{\partial}{\partial\rho}(\rho\cos\phi + z) = \cos\phi.$$

$$\frac{\partial}{\partial\rho}(\rho\cos\phi) = \cos\phi$$

$$\text{1st term} = \frac{1}{\rho}\cos\phi.$$

$$\frac{\partial V}{\partial\phi} = \frac{\partial}{\partial\phi}(\rho\cos\phi + z) = -\rho\sin\phi.$$

$$\frac{\partial^2 V}{\partial\phi^2} = \frac{\partial}{\partial\phi}(-\rho\sin\phi) = -\rho\cos\phi$$

$$\text{2nd term} = \frac{1}{\rho^2}\frac{\partial^2 V}{\partial\phi^2} = \frac{1}{\rho^2}(-\rho\cos\phi) = -\frac{\cos\phi}{\rho}$$

$$\frac{\partial V}{\partial z} = \frac{\partial}{\partial z}(\rho\cos\phi + z) = 1$$

$$\frac{\partial^2 V}{\partial z^2} = 0 = \text{3rd term}$$

$$\therefore \nabla^2 V = \frac{\cos\phi}{\rho} - \frac{\cos\phi}{\rho} + 0 = 0$$

$\therefore$ Laplace's eqn. satisfied.

2. Find the capacitance between the two concentric spheres of radii $r = b$, and $r = a$, such that $b>a$. If the potential $V = 0$ at $r = b$ and $V = V0$ at $r = a$ using Laplace's equation. [10] CO3 L2

$\int dx = x$

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dV}{dr}\right)=0$$

$$\text{or } \frac{d}{dr}\left(r^2\frac{dV}{dr}\right)=0$$

Integrating, $d\left(r^2\frac{dV}{dr}\right)=0$

$$\text{or } r^2\frac{dV}{dr}=c_1$$

$c_1 \rightarrow$ constant of integration.

Note: $V=0$ at $r=b$; $V=V_0$ at $r=a$

$$dV = c_1 \cdot \frac{dr}{r^2}$$

$$\int dV = c_1 \int \frac{dr}{r^2}$$

$$\text{or } \boxed{V = c_1\left[-\frac{1}{r}\right] + c_2}$$

$c_2 \rightarrow$ constant of integration.

$$0 = c_1\left(-\frac{1}{b}\right) + c_2 \quad \cdots (1)$$

$$V_0 = c_1\left(-\frac{1}{a}\right) + c_2 \quad \cdots (2)$$

Subtracting (1) from (2),

$$V_0 = c_1\left(-\frac{1}{a}\right) + \frac{c_1}{b}$$

$$\text{or } V_0 = c_1\left(\frac{1}{b} - \frac{1}{a}\right).$$

$$\therefore c_1 = \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)}.$$

$$c_2 = \frac{c_1}{b} = \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)} \cdot \frac{1}{b}$$

$$\text{i.e. } V = \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)}\left(-\frac{1}{r}\right) + \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)} \cdot \frac{1}{b}$$

$$\text{or } \boxed{V = \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)}\left[\frac{1}{b} - \frac{1}{r}\right]}$$

$\vec{E}$, $\vec{D}$, ρ_s, Q, C

$$\vec{E} = -\vec{\nabla}V = -\frac{\partial V}{\partial r}\hat{a}_r$$

$$= -\frac{\partial}{\partial r}\left[\frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)} \cdot \left(-\frac{1}{r}\right)\right]\hat{a}_r$$

$$= \frac{V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)} \cdot \left(-\frac{1}{r^2}\right)\hat{a}_r$$

$$\text{or } \vec{E} = \frac{V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)} \cdot \frac{1}{r^2}\hat{a}_r \text{ V/m}$$

$$\vec{D} = \epsilon\vec{E} = \frac{\epsilon V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)} \cdot \frac{1}{r^2}\hat{a}_r \text{ C/m}^2$$

$$\rho_s = |\vec{D_N}| = \frac{\epsilon V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)} \cdot \frac{1}{r^2} \text{ C/m}^2$$

$$Q = \rho_s \times 4\pi r^2 = \frac{\epsilon V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)} \cdot \cancel{\frac{1}{r^2}} \cdot 4\pi \cancel{r^2}$$

$$= \frac{4\pi\epsilon V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)} \text{ C}$$

$\therefore$ capacitance,

$$\boxed{C = \frac{Q}{V_0} = \frac{4\pi\epsilon}{\left(\frac{1}{a}-\frac{1}{b}\right)} \text{ Farad}}$$

3.a) Write the equations to compare electric circuit and magnetic circuit parameters. [06] CO4 L2

Electric Circuit	Magnetic Circuit
$\mathbf{E} = -\nabla V$	$\mathbf{H} = -\nabla V_m$
$V_{AB} = \int_A^B \mathbf{E} \cdot d\mathbf{L}$	$V_{mAB} = \int_A^B \mathbf{H} \cdot d\mathbf{L}$
$\mathbf{J} = \sigma \mathbf{E}$	$\mathbf{B} = \mu \mathbf{H}$
$I = \int_S \mathbf{J} \cdot d\mathbf{S}$	$\Phi = \int_S \mathbf{B} \cdot d\mathbf{S}$
$V = IR$	$V_m = \Phi \Re$
$R = \frac{d}{\sigma S}$	$\Re = \frac{d}{\mu S}$
$\oint \mathbf{E} \cdot d\mathbf{L} = 0$	$\oint \mathbf{H} \cdot d\mathbf{L} = I_{total}$ $\oint \mathbf{H} \cdot d\mathbf{L} = NI$

3.b) An air core toroid has 500 turns, mean radius of 15 cm, cross-sectional area of 6 cm^2. The magnetomotive force is 2000 A.t. Calculate total reluctance, flux, flux-density, magnetic field intensity inside the core. [04] CO4 L3

$V_m = NI = 500 \times 4 = 2000$ A.t

$V_m = \Phi \mathcal{R}$ [Note analogous to $V = IR$]

$\mathcal{R} = \frac{d}{\mu s}$ [note $\rightarrow$ analogy $R = \frac{d}{\sigma s}$]

$= \frac{2\pi \times 0.15}{4\pi \times 10^{-7} \times 6 \times 10^{-4}}$ [$\because \mu = \mu_0$]

$= 1.25 \times 10^{9}$ A.t/Wb.

$\Phi = \frac{V_m}{\mathcal{R}} = \frac{2000}{1.25 \times 10^{9}} = 1.6 \times 10^{-6}$ Wb

$B = \frac{\Phi}{s} = \frac{1.6 \times 10^{-6}}{6 \times 10^{-4}} = 2.67 \times 10^{-3}$ T

$H = \frac{B}{\mu_0} = \frac{2.67 \times 10^{-3}}{4\pi \times 10^{-7}} = 2120$ A.t/m.

4.a) Discuss the force on a differential current element and obtain the expression for force. [05] CO4 L2

Force on a moving charge

Q in presence of $\vec{E}$,

force on it, $\vec{F} = Q\vec{E}$.

charge Q in motion in magnetic field with flux density $\vec{B}$, and velocity of charge $\vec{v}$,

$$\vec{F} = Q\vec{v} \times \vec{B}$$

Force on a moving particle due to combined effect of $\vec{E}$ and $\vec{B}$,

$$\vec{F} = Q(\vec{E} + \vec{v} \times \vec{B})$$

Consider the case of current carrying conductor

Current density $\vec{J} = (\rho_v \vec{v})$.

then, also, ~~ρ_v~~ $dQ = \rho\, dv$.

$$\therefore \vec{dF} = dQ\, \vec{v} \times \vec{B} = (\rho_v\, dv)\, \vec{v} \times \vec{B}$$
$$= \rho_v\, \vec{v} \times \vec{B}\, dv$$

$$d\vec{F} = (\vec{J} \times \vec{B})\, dv$$

Now, $\vec{J}\, dv = \vec{K}\, ds = I\, \vec{dl}$

$$\left[\frac{I\,A}{m^2} \cdot m^3 = \frac{I\,A}{m} \cdot m^2 = I\,A \cdot m \right]$$

$$\therefore d\vec{F} = \vec{K} \times \vec{B}\, ds$$

$$d\vec{F} = I\, \vec{dl} \times \vec{B}$$

Integrating,

$$F = \oint I\, \vec{dl} \times \vec{B} = -I \oint \vec{B} \times \vec{dl}$$

$\therefore$ For a straight conductor in an uniform mag. field,

$$\boxed{\vec{F} = I\vec{L} \times \vec{B}}$$

4.b) Write a short note on magnetic materials [05] CO4 L2

We consider a simple atomic model, which assumes that there is a central positive nucleus surrounded by electrons in various circular orbits.

- An electron in an orbit is analogous to a small current loop. It is considered that orbiting electrons in the material would shift in such a way as to add their magnetic fields to the applied field
- A second moment, however, is attributed to electron spin.
- A third contribution to the moment of an atom is caused by nuclear spin.
- Each atom contains many different component moments, and their combination determines the magnetic characteristics of the material and provides its general magnetic classification.

We describe briefly six different types of material: (i) diamagnetic, (ii) paramagnetic,
(iii) ferromagnetic, (iv) antiferromagnetic, (v) ferrimagnetic, and (vi) superparamagnetic.

Diamagnetic: Let us first consider atoms in which the small magnetic fields produced by the motion of the electrons in their orbits and those produced by the electron spin combine to produce a net field of zero. The material in which the permanent magnetic moment of each atom is zero is termed diamagnetic. E.g. Metallic bismuth, hydrogen, helium, the other "inert" gases, sodium chloride, copper, gold, silicon, germanium, graphite, and sulfur.

Paramagnetic: an atom in which the effects of the electron spin and orbital motion do not quite cancel. The atom as a whole has a small magnetic moment, but the random orientation of the atoms in a larger sample produces an average magnetic moment of zero. The material shows no magnetic effects in the absence of an external field. E.g Potassium, oxygen, tungsten.

Ferromagnetic: Each atom has a relatively large dipole moment, caused primarily by uncompensated electron spin moments. Interatomic forces cause these moments to line up in a parallel fashion over regions containing a large number of atoms. These regions are called domains. The only elements that are ferromagnetic at room temperature are iron, nickel, and cobalt, and they lose all their ferromagnetic characteristics above a temperature called the Curie temperature, which is 1043 K (770◦C) for iron.

Antiferromagnetic: The forces between adjacent atoms cause the atomic moments to line up in an antiparallel fashion. The net magnetic moment is zero, and antiferromagnetic materials are affected only slightly by the presence of an external magnetic field. E.g. manganese oxide, nickel oxide (NiO), ferrous sulfide (FeS), and cobalt chloride (CoCl2). Antiferromagnetism is only present at relatively low temperatures, often well below room temperature.

Ferrimagnetic: The ferrimagnetic substances also show an antiparallel alignment of adjacent atomic moments, but the moments are not equal. A large response to an external magnetic field therefore occurs, although not as large as that in ferromagnetic materials. The iron oxide magnetite (Fe_3O_4) is an examples of this class of materials.

Superparamagnetic: materials are composed of an assembly of ferromagnetic particles in a nonferromagnetic matrix. Although domains exist within the individual particles, the domain walls cannot penetrate the intervening matrix material to the adjacent particle. An important example is the magnetic tape used in audiotape or videotape recorders.

5. Using Maxwell's equation derive an expression for uniform plane wave in free space. [10] CO5 L2

TEM Wave propagation in free space

For free space, medium is sourceless,

$\rho_v = 0, \quad J = 0$

$\therefore$ Maxwell's equations are,

$$\vec{\nabla} \times \vec{H} = \frac{\partial \vec{D}}{\partial t} = \epsilon_0 \frac{\partial \vec{E}}{\partial t} \quad \cdots (1)$$

$$\vec{\nabla} \times \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t} \quad \cdots (2)$$

$$\vec{\nabla} \cdot \vec{E} = 0 \quad \cdots (3)$$

$$\vec{\nabla} \cdot \vec{H} = 0 \quad \cdots (4)$$

Note
$\vec{\nabla} \cdot \vec{D} = 0$ [$\because \rho_v = 0$
$\therefore \epsilon \vec{\nabla} \cdot \vec{E} = 0$

From (1), if $\vec{E}$ is changing with time, then at ~~same~~ same point $\vec{H}$ has curl.

Uniform plane wave where, $\vec{E}$ and $\vec{H}$ fields ~~lie~~ lie in the transverse plane.

– Such a wave is called TEM wave.

We assume, $\vec{E} = E_x \hat{a}_x$ and $\vec{H} = H_y \hat{a}_y$

Then, $\vec{\nabla} \times \vec{E} = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_x & 0 & 0 \end{vmatrix} = \hat{a}_y \frac{\partial E_x}{\partial z} - \hat{a}_z \frac{\partial E_x}{\partial y}$

$\therefore$ From eqn. (2)

$$\vec{\nabla} \times \vec{E} = \frac{\partial E_x}{\partial z} \hat{a}_y = -\mu_0 \frac{\partial H}{\partial t}$$

or $$\frac{\partial E_x}{\partial z} \hat{a}_y = -\mu_0 \frac{\partial H_y}{\partial t} \hat{a}_y \quad \cdots (5)$$

Similarly from (1),

$$\vec{\nabla} \times \vec{H} = -\frac{\partial H_y}{\partial z} \hat{a}_x = \epsilon_0 \frac{\partial E_x}{\partial t} \hat{a}_x \quad \cdots (6)$$

Equations (5) and (6),

$$\frac{\partial E_x}{\partial z} = -\mu_0 \frac{\partial H_y}{\partial t} \quad \cdots (7)$$

$$\frac{\partial H_y}{\partial z} = -\epsilon_0 \frac{\partial E_x}{\partial t} \quad \cdots (8)$$

Differentiating (7) w.r.t z,

$$\frac{\partial^2 E_x}{\partial z^2} = -\mu_0 \left(\frac{\partial^2 H_y}{\partial z \partial t}\right) \quad \cdots (9)$$

Differenting (8) w.r.t t,

$$\left(\frac{\partial^2 H_y}{\partial z \partial t}\right) = -\epsilon_0 \frac{\partial^2 E_x}{\partial t^2} \quad \cdots (10)$$

Substituting (10) into (9)

$$\boxed{\frac{\partial^2 E_x}{\partial z^2} = \mu_0 \epsilon_0 \frac{\partial^2 E_x}{\partial t^2}} \quad \cdots (11)$$

– x-polarized TEM electric field in free space

Differentiating (7) w.r.t t,

$$\left(\frac{\partial^2 E_x}{\partial t \partial z}\right) = -\mu_0 \frac{\partial^2 H_y}{\partial t^2} \quad \cdots (12)$$

Differentiating (8) w.r.t z,

$$\frac{\partial^2 H_y}{\partial z^2} = -\epsilon_0 \left(\frac{\partial^2 E_x}{\partial t \partial z}\right) \quad \cdots (13)$$

$$\therefore \frac{\partial^2 H_y}{\partial z^2} = \epsilon_0 \mu_0 \left(\frac{\partial^2 H_y}{\partial t^2}\right)$$

$$\boxed{\frac{\partial^2 H_y}{\partial z^2} = \mu_0 \epsilon_0 \frac{\partial^2 H_y}{\partial t^2}} \quad \cdots (14)$$

Wave equation for the magnetic field.

6.a) What is the inconsistency of Ampere's law with the continuity of current equation? Derive a modified form of Ampere's law for time-varying fields. [07] CO5 L2

Module-5

Ampere's circuital law for time-varying magnetic field:-

According to Ampere's law,

$$\vec{\nabla} \times \vec{H} = \vec{J} \quad \cdots (1)$$

$$\therefore \vec{\nabla} \cdot (\vec{\nabla} \times \vec{H}) \equiv \vec{\nabla} \cdot \vec{J} = 0$$

$$[\because \vec{\nabla} \cdot (\vec{\nabla} \times \vec{H}) = 0 \text{ identically}]$$

But According to continuity of current eqn,

$$\vec{\nabla} \cdot \vec{J} = -\frac{\partial \rho_v}{\partial t} \quad (2)$$

For time varying fields we add an unknown term G to eqn. (1).

$$\vec{\nabla} \times \vec{H} = \vec{J} + \vec{G}$$

$$\text{or} \quad \vec{\nabla} \cdot (\vec{\nabla} \times \vec{H}) = \vec{\nabla} \cdot \vec{J} + \vec{\nabla} \cdot \vec{G}$$

$$\text{or} \quad 0 = \vec{\nabla} \cdot \vec{J} + \vec{\nabla} \cdot \vec{G}$$

$$\text{or} \quad \vec{\nabla} \cdot \vec{J} = -\vec{\nabla} \cdot \vec{G} = \frac{-\partial \rho_v}{\partial t}$$

$$\therefore \vec{\nabla} \cdot \vec{G} = \frac{\partial \rho_v}{\partial t} = \frac{\partial}{\partial t}(\vec{\nabla} \cdot \vec{D})$$

$$[\because \vec{\nabla} \cdot \vec{D} = \rho_v]$$

$$\text{or} \quad \vec{\nabla} \cdot \vec{G} = \vec{\nabla} \cdot \frac{\partial \vec{D}}{\partial t}$$

$$\text{or} \quad \boxed{\vec{G} = \frac{\partial \vec{D}}{\partial t}}$$

$$\therefore \boxed{\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}}$$

$$\frac{\partial \vec{D}}{\partial t} = \vec{J}_D$$ = Displacement current density

∴ Point form of Ampere's law,

$$\oint \vec{H} \cdot \vec{dl} = I + \iint \frac{\partial \vec{D}}{\partial t} \cdot \vec{ds}$$ → Integral form of Ampere's law

6.b) Find magnetization in magnetic material where: [03] CO4 L3

$\mu = 1.8\times10^{-5}$H/m, H = 120A/m

Soln.

(i) $\mu = 1.8\times10^{-5}$ H/m and $\vec{H} = 120$ A/m

$\vec{M} = \chi_m \vec{H}$

$\mu = \mu_0 \mu_r$ or $1.8\times10^{-5} = 4\pi\times10^{-7} \cdot \mu_r$

or $\mu_r = \frac{1.8\times10^{-5}}{4\pi\times10^{-7}} = 14.32$

$\mu_r = (1+\chi_m)$

or $\chi_m = \mu_r - 1 = 13.32$.

$\therefore \vec{M} = \chi_m \vec{H} = (13.32\times120)$ A/m $= 1598.8$ A/m

7.a) List the Maxwell equations in point form. [04] CO5 L2

Point form of Maxwell equations

$\vec{\nabla} \cdot \vec{D} = \rho_v$ → Gauss's law of electrostatics

$\vec{\nabla} \cdot \vec{B} = 0$ → Gauss's law of magnetostatics

$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ → Faraday's law

$\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$ → Ampere's law

$\vec{D}$ → Electric flux density

7.b) A 9.375 GHz uniform plane wave is propagating in polyethylene ε_r=2.26. If the amplitude of the E is 500 V/m and the material is assumed to be lossless, find [06] CO5 L3

(a) phase constant, (b) wavelength, (c) velocity of propagation, (d) intrinsic impedance, and (e) magnetic field intensity.

9.375 GHz uniform plane wave propagating in polyethylene. If the amplitude of electric field intensity is 500 V/m, and the material is assumed to be lossless, find.

(i) Phase constant
(ii) wavelength in polyethylene.
(iii) Velocity of propagation.
(iv) Intrinsic impedance.
(v) Amplitude of mag. field intensity

$\epsilon_r' = 2.26$
$\mu_r = 1$

Note
$\mu = \mu_0 \mu_r$
$\epsilon = \epsilon_0 \epsilon_r$

Solution: For lossless medium, $\epsilon'' = 0$

$jk = \alpha + j\beta$, $\epsilon = \epsilon' - j\epsilon''$

(i) $\beta = \omega\sqrt{\mu \epsilon'} = \omega\sqrt{\mu_0 \epsilon_0}\sqrt{\mu_r \epsilon_r'}$

$= \frac{2\pi f}{c}\sqrt{\mu_r \epsilon_r} = \frac{2\pi \times 9.375\times 10^9}{3\times 10^8}\sqrt{2.26}$ $\left[\because c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}\right]$

$= 295$ rad/m

(ii) $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{295} = 2.13$ cm

(iii) $v_p = \frac{\omega}{\beta} = 1.99\times 10^8$ m/s

(iv) $\eta = \eta_0 \frac{\sqrt{\mu_r'}}{\sqrt{\epsilon_r'}} = \frac{377\sqrt{1}}{\sqrt{2.26}} = 250.7\ \Omega$

Note
$\eta = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0 \mu_r}{\epsilon_0 \epsilon_r}} = \eta_0\sqrt{\frac{\mu_r}{\epsilon_r}}$

(v) $H_y = \frac{E_x}{\eta} = \frac{500}{250.7} = 1.99$ A/m

CI Signature　　CCI Signature　　HoD Signature