CBCS SCHEME

USN | | | | | | | | | | |

18EC55

Fifth Semester B.E. Degree Examination, Jan./Feb. 2023
Electromagnetic Waves

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Module-1

1 a. The three vertices of a triangle are located at $A(6, -1, 2)$, $B(-2, 3, -4)$ and $C(-3, 1, 5)$. Find (i) $R_{AB} \times R_{AC}$ (ii) Area of triangle **(04 Marks)**

b. Define Electric field intensity. Derive the expression for electric field intensity due to infinite line charge. **(10 Marks)**

c. Given the electric flux density $\overline{D} = 0.3r^2 \bar{a}_r nC/m^2$ in free space.
   (i) Find E at point $P(r = 2, \theta = 25^\circ, \phi = 90^\circ)$.
   (ii) Find total charge within the sphere r = 3.
   (iii) Find total electric flux learing the sphere r = 4. **(06 Marks)**

OR

2 a. Four identical 3nC (nano Coulomb) charges are located at $P_1(1, 1, 0)$, $P_2(-1, 1, 0)$, $P_3(-1, -1, 0)$ and $P_4(1, -1, 0)$. Find the electric field intensity $\overline{E}$ at $P(1, 1, 1)$. **(10 Marks)**

b. Infinite uniform line charges of 5 nC/m lie along the (positive and negative) x and y axes in free space. Find $\overline{E}$ at $P_A(0, 0, 4)$. **(04 Marks)**

c. Define Coulomb's law. Make use of this to find the force on Q_1. Given that the point charges $Q_1 = 50\,\mu C$ and $Q_2 = 10\,\mu C$ are located at $(-1, 1, -3)$m and $(3, 1, 0)$m respectively. **(06 Marks)**

Module-2

3 a. Explain Gauss law applicable to the case of infinite line charge and derive the relation used. **(08 Marks)**

b. Evaluate both sides of the divergence theorem for the field $\overline{D} = 2xy\overline{a_x} + x^2\overline{a_y}$ C/m^2 and the rectangular parallelepiped formed by the places x = 0 and 1, y = 0 and 2 and z = 0 and 3. **(08 Marks)**

c. Given the potential field $V = 2x^2y - 5z$ and point $P(-4 \quad 3 \quad 6)$. (i) Find potential V at P. (ii) Field intensity $\overline{E}$, (iii) Volume charge density ρ_V. **(04 Marks)**

OR

4 a. Compute the numerical value for $\text{div}\overline{D}$ at the point specified below:
$\overline{D} = (2xyz - y^2)\bar{a}_x + (x^2z - 2xy)\bar{a}_y + x^2y\bar{a}_z\, C/m^2$ at $P_A(2, 3, -1)$ **(04 Marks)**

b. Show that Electric field is a negative gradient of potential. **(08 Marks)**

c. Let $E = y\bar{a}_x$ V/m at a certain instant of time and calculate the work required to move a 3c charge from $(1, 3, 5)$ to $(2, 0, 3)$ along the straight line segment joining
   (i) $(1, 3, 5)$ to $(2, 3, 5)$ to $(2, 0, 5)$ to $(2, 0, 3)$
   (ii) $(1, 3, 5)$ to $(1, 3, 3)$ to $(1, 0, 3)$ to $(2, 0, 3)$ **(08 Marks)**

Module-3

5 a. Solve the Laplace's equation for the potential field in the homogenous region between the two concentric conducting spheres with radii 'a' and 'b' such that b>a, if potential V = 0 at r = b and $V = V_0$ at r = a. Also find the capacitance between two concentric spheres. **(10 Marks)**

b. State and explain Biot-Savart law applicable to magnetic field. **(06 Marks)**

c. Calculate the value of vector current density in a rectangular coordinates at $P_A(2, 3, 4)$ if $\overline{H} = x^2 z \overline{a}_y - y^2 x \overline{a}_z$. **(04 Marks)**

OR

6 a. State and illustrate uniqueness theorem. **(08 Marks)**

b. Define Stoke's theorem. Use this theorem to evaluate both sides of the theorem for the field $\overline{H} = 6xy\overline{a}_x - 3y^2\overline{a}_y$ A/M and the rectangular path around the region, $2 \le x \le 5$, $-1 \le y \le 1$ $z = 0$. Let the positive direction of ds be $\overline{a}_z$. **(12 Marks)**

Module-4

7 a. Obtain the expression for magnetic force between differential current elements. **(06 Marks)**

b. Derive the boundary conditions to apply to $\overline{B}$ and $\overline{H}$ at the interface between two different magnetic materials. **(08 Marks)**

c. The point charge $\theta = 18\text{nC}$ has a velocity of 5×10^6 m/s in the direction. $\overline{a}_v = 0.60\overline{a}_x + 0.75\overline{a}_y + 0.30\overline{a}_z$

Calculate the magnitude of the force exerted on the charge by the field,

(i) $\overline{B} = -3\overline{a}_x + 4\overline{a}_y + 6\overline{a}_z$ mT

(ii) $\overline{E} = -3\overline{a}_x + 4\overline{a}_y + 6\overline{a}_z$ kV/m

(iii) B and $\overline{E}$ acting together **(06 Marks)**

OR

8 a. Find the magnetization in a magnetic material, where

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

(ii) $\mu_r = 22$, there are 8.3×10^{28} atoms/m^3, and each atom has a dipole moment of 4.5×10^{-27} A.m^2

(iii) $B = 300\,\mu T$ and $\chi_m = 15$. **(06 Marks)**

b. Let permittivity be 5 μH/m in region A where x < 0 and 20 μH/m in region B, where x > 0. If there is a surface current density $\overline{K} = 150\overline{a}_y - 200\overline{a}_z$ A/m at x = 0, and if $H_A = 300\overline{a}_x - 400\overline{a}_y + 500\overline{a}_z$ A/m. Compute

(i) $|H_{tA}|$ (ii) $|H_{NA}|$ (iii) $|H_{tB}|$ (iv) $|H_{NB}|$ **(08 Marks)**

c. State and explain Faraday's law of electromagnetic induction. **(06 Marks)**

Module-5

9 a. List and explain Maxwell's equations in point and integral form. **(08 Marks)**

b. The time domain expression for the magnetic field of a uniform plane wave travelling in free space is given by,

$H(z,t) = \bar{a}_y 2.5\cos(1.257\times10^9 t - K_0 z)$ mA/m.

Compute

(i) The direction of wave propagation.

(ii) Operating frequency

(iii) Phase constant.

(iv) The time domain expression for electric field E(z,t) starting from the Maxwell's equations.

(v) The phasor form of both the electric and magnetic field. **(10 Marks)**

c. For silver the conductivity is $\sigma = 3\times10^6$ S/m. At what frequency will the depth of penetration be 1 mm. **(02 Marks)**

OR

10 a. State and explain Poynting theorem and write the equation both in point and integral form. **(08 Marks)**

b. Simplify the value of K to satisfy the Maxwell's equations for region $\sigma = 0$ and $\rho_v = 0$ if $\bar{D} = 10x\bar{a}_x - 4y\bar{a}_y + kz\bar{a}_z\ \mu C/m^2$ and $B = 2\bar{a}_y$ mT. **(06 Marks)**

c. A plane wave of 16 GHz frequency and E = 10 V/m propagates through the body of salt water having constant $\varepsilon_r = 100$, $\mu_r = 1$ and $\sigma = 100$ s/m. Determine attenuation constant, phase constant, phase velocity and intrinsic impedance and depth and penetration. **(06 Marks)**

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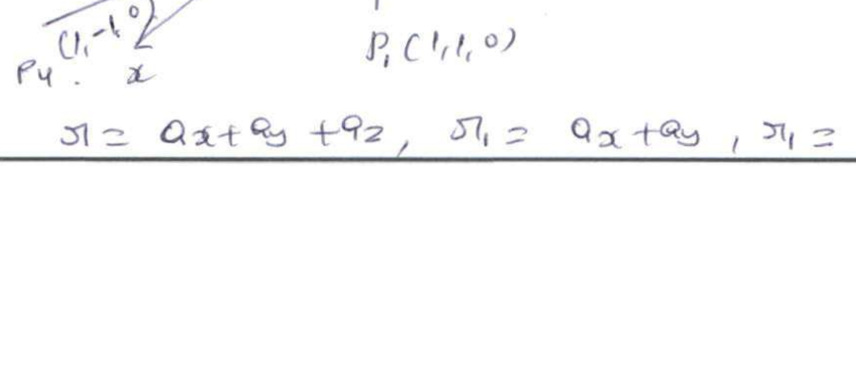
Question Number	Solution	Marks Allocated
1a)	$R_{AB} = R_B - R_A = -8a_x + 4a_y - 6a_z$	1
	$R_{AC} = R_C - R_A = -9a_x + 2a_y + 3a_z$	1
	(i) $R_{AB} \times R_{AC} = 24a_x + 78a_y + 20a_z.$	1
	(ii) Area of triangle $= \frac{1}{2} \lvert R_{AB} \times R_{AC} \rvert = 42$ Sq.units	1 (04)
1b)	The force exerted per unit charge is called electric field intensity $\bar{E} = \frac{F}{Q}$. V/M	02.
	Expression for line charge Fig –	02
	intermediate steps	06
	Final expression $\overline{E_p} = \frac{\rho_L}{2\pi\epsilon_0 r} \overline{a_r}\ \overline{a_y}$ V/M	02
1c)	(i) $D = \epsilon E$, $E = D/\epsilon$ at $r=2$ we get $E = 135.2$ V/M	02
	(ii) $D = \frac{Q}{4\pi r^2} \Rightarrow Q = 305.208\,nC$	02
	(iii) WKT $Q = \phi$. at $r = 4$ $D = \frac{Q}{4\pi r^2} \Rightarrow Q \doteq 964.608\,nC$, $\phi = 965\,nC$	02
2a)		02
	$r = a_x + a_y + a_z$, $r_1 = a_x + a_y$, $r_1 = a_z$	

(29)

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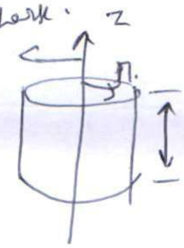
Question Number	Solution	Marks Allocated
	$\lvert r-r_1\rvert = 1$, $\lvert r-r_2\rvert = \sqrt{5}$, $\lvert r-r_3\rvert = 3$ and $\lvert r-r_4\rvert = \sqrt{5}$,	04
	$E = 26.96\left[\frac{a_z}{1}\frac{1}{1^2} + \frac{2a_x+a_z}{\sqrt{5}}\frac{1}{(\sqrt{5})^2} + \frac{2a_x+2a_y+a_z}{3}\frac{1}{3^2} + \frac{2a_y+a_z}{\sqrt{5}}\frac{1}{(\sqrt{5})^2}\right]$	04
	$\boxed{E = 6.82\overline{a_x} + 6.82\overline{a_y} + 32.8\overline{a_z}\ V/m}$	
2b)	$E = \frac{\rho_L}{2\pi\varepsilon\rho}a_\rho = \frac{5\times10^{-9}}{2\pi\varepsilon(4)}\frac{4a_z}{4} + \frac{5\times10^{-9}}{2\pi\varepsilon(4)}\frac{4a_z}{4}$	2 2
	$= 45 a_z\ V/m$	
2c)	Defination — — —	02
	$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}\overline{a_r}$, $\overline{a_r} = \frac{\bar{r}}{\lvert\bar{r}\rvert} = \frac{-4a_x-3a_z}{5}$	02 02.
	$\bar{F} = -0.144\overline{a_x} - 0.108\overline{a_z}\ N$	
3a)	line charge.  Consider line charge along z axis: $Q = \oint \vec{D}\cdot d\vec{s}$ $Q = \oint_{side}\vec{D}\cdot ds + \int_{top}\vec{D}\,ds + \int_{bottom}\vec{D}\cdot ds$	04
	$\bar{D}$ has only radial component and no component along a_z & $-a_z$. $Q = \oint_{side}\vec{D}\,ds = \oint D_r r\,d\phi\,dz$. $D_r = \frac{Q}{2\pi rL}\overline{a_r}$ $\rho_L = Q/L$ $\underline{\bar{D} = \frac{\rho_L}{2\pi r}\overline{a_r}\ C/m^2}$ $E = \frac{D}{\varepsilon_0} = \frac{\rho_L}{2\pi\varepsilon_0 r}\overline{a_r}\ V/m$	04

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Question Number	Solution	Marks Allocated
3b)	$\oint \vec{D}\cdot d\vec{s} = \int \nabla\cdot D\, dv$ $\oint \vec{D}\cdot ds = 12, \quad \int \nabla\cdot D\, dv = 12.$	04+04 = 08
3c)	$V_P = 2(-4)^2(3) - 5(6) = 66V$	01
	$E = -\nabla V = -4xy\bar{a_x} - 2x^2\bar{a_y} + 5\bar{a_z}$ V/m	01
	$D = \varepsilon_0 E = -35.4xy\bar{a_x} - 17.71x^2 a_y + 44.3\bar{a_z}$	pC/m³
	$\rho_v = \nabla\cdot D = -35.4y$ pC/m³.	02
4a)	$\nabla\cdot D = \frac{\partial}{\partial x}D_x + \frac{\partial}{\partial y}D_y + \frac{\partial}{\partial z}D_z.$ $= 2yz - 2x = 2(3)(-1) - 2(2) = -10$	04
4b)	$E = -\nabla V.$	
	$dV = \frac{\partial V}{\partial x}dx + \frac{\partial V}{\partial y}dy + \frac{\partial V}{\partial z}dz$	01
	$dV = -E\cdot dL = -E_x dx - E_y dy - E_z dz.$	01
	$E = -\left(\frac{\partial V}{\partial x}\bar{a_x} + \frac{\partial V}{\partial y}a_y + \frac{\partial V}{\partial z}a_z\right)$	03
	$E = -\nabla V$ Since $\nabla = \frac{\partial}{\partial x}\bar{a_x} + \frac{\partial}{\partial y}\bar{a_y} + \frac{\partial}{\partial z}\bar{a_z}$	03
4c)	(i) $W = -Q\int E\cdot dL.$ $W = W_1 + W_2 + W_3.$ $W_1 = -3\int_1^2 (y a_x + 0a_y + 0a_z)\, dx a_x$ $W_1 = -9J$ $W_2 = -3\int_3^0 (y a_x + 0a_y + 0a_z)(dy\, a_y)$ $= 0J$ $W_3 = -3\int_5^3 (y a_x + 0a_y + 0a_z)\, dz a_z$	04

$= 0J$

$W = -9J$

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Question Number	Solution	Marks Allocated

(ii) $W = -Q\int \bar{E}\cdot d\bar{L}$

$W = W_1 + W_2 + W_3$

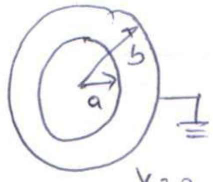
$W_1 = -3\int_1^1 y\,dx = -3x = 0J$

$W_2 = 0J$

$W_3 = 0J$ 04.

$W = 0+0+0 = \underline{0J}$

5a)



$V=0,\ r=b$

$\nabla^2 V = 0$

$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial V}{\partial r}\right) = 0$

Solving V 03.

$V = -\frac{C_1}{r} + C_2$

Apply boundary condition

$V=0,\ r=b \quad V=V_0$ at $r=a$

$C_1 = \frac{V_0}{\frac{1}{b}-\frac{1}{a}} \qquad C_2 = \frac{V_0}{b\left[\frac{1}{b}-\frac{1}{a}\right]}$ 03

$V = \frac{-V_0}{r\left[\frac{1}{b}-\frac{1}{a}\right]} + \frac{V_0}{b\left[\frac{1}{b}-\frac{1}{a}\right]}\ V$

$\bar{E} = -\nabla V \Rightarrow \frac{-V_0}{\left(\frac{1}{b}-\frac{1}{a}\right)r^2}\ \bar{a_r}\ V/m.$

$D = \frac{\varepsilon V_0}{\left(\frac{1}{a}-\frac{1}{b}\right)r^2}\ C/m^2.$ 04

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

$Q = \rho_s \times A.$

$C = \frac{Q}{V},\ V = V_0 = \frac{4\pi\varepsilon_0 V_0}{\frac{\frac{1}{a}-\frac{1}{b}}{V_0}} = \frac{4\pi\varepsilon}{\frac{1}{a}-\frac{1}{b}}\ F$

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Question Number	Solution	Marks Allocated
5b)	The magnetic field intensity $d\bar{H}$ produced at a point P due to a differential current element IdL is proportional to the product of current I and differential length dL, sine of the angle b/n the element and line joining point P to the element and inversely proportional to the square of the distance R b/n point P and the element.	02
	$d\bar{H} = \frac{IdL\sin\theta}{4\pi R^2}$ explanation -	04
5c)	Given $\bar{H} = x^2z\,a_y - y^2x\,\bar{a_z}$	
	$J = \nabla\times H = \begin{vmatrix} a_x & a_y & a_z \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ 0 & x^2z & -y^2x \end{vmatrix}$	03
	$\bar{J} = -16\bar{a_x} + 9\bar{a_y} + 16\bar{a_z}\ A/m^2$	01
6a)	Statement: Under the given boundary condition the Laplace equation has a unique solution.	02
	$V_1 = V_2$. Illustration —	06
6b)	Defination of Stockes theorem —	02
	$\oint \bar{H}\cdot d\bar{L} = \int_s (\nabla\times H)\cdot ds$ —	
	LHS, $\oint_{ab} H\cdot dl = \int_2^5 (6xya_x - 3y^2a_y)\,(dx\,a_x)$ $= 63y = 63(-1) = -63$	04
	$\int_{bc} H\cdot dl = -2$, $\int_{cd} H\cdot dL = -63$, $\int_{da} H\cdot dL = 2$	

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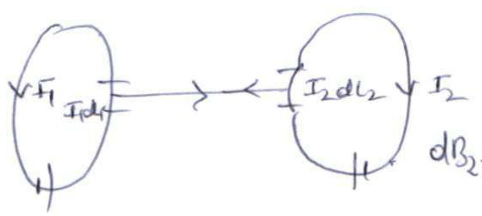
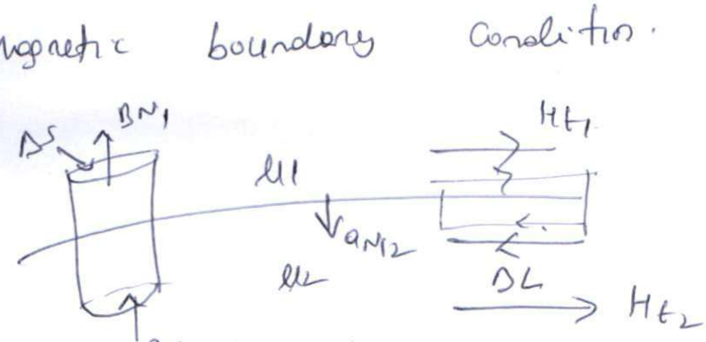
Question Number	Solution	Marks Allocated
	$\oint H \cdot dL = 63 - 2 - 63 + 2 = \underline{-126A}$	01
	RHS. $\nabla \times H = -6xa_z$	01
	$\int(\nabla \times H) \cdot ds = \int_{-1}^{1}\int_{2}^{5} -6x\,a_z\,(dz\,dy\,dz)$	04
	$= \underline{-126A}$	
	$\underline{RHS = LHS}$ $\underline{-126 = 126A}$	
7a)	Force b/n differential current element	
		
	$d(dF_1) = I_1 d\bar{L}_1 \times dB_2$	
	$dB_2 = \mu_0 d\bar{H}_2 = \mu_0 \left[\frac{I_2 d\bar{L}_2 \times a_{R21}}{4\pi R_{21}^2}\right]$	
	$d(dF_1) = \frac{\mu_0 I_1 dL_1 \times (I_2 d\bar{L}_2 \times a_{R21})}{4\pi R_{21}^2}$	
	$F_1 = \frac{\mu_0 I_1 I_2}{4\pi} \oint_{L1}\oint_{L2} dL_1 \frac{\times (dL_2 \times a_{R21})}{R_{21}^2}$	03
	$F_2 = \frac{\mu_0 I_2 I_1}{4\pi} \oint_{L2}\oint_{L1} \frac{dL_2 \times (d\bar{L}_1 \times a_{R12})}{R_{12}^2}$.	03
7b)	Magnetic boundary condition.	
		04
	$\oint B \cdot ds = 0$ we get $B_{N1}\Delta s - B_{N2}\Delta s = 0$	
	$B_{N1} = B_{N2}$	

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Question Number	Solution	Marks Allocated
	$H_{N_2} = \frac{\mu_1}{\mu_2} H_{N_1}$	04.
	$\oint H \cdot dL = I$. $H_{t_1}\Delta L - H_{t_2}\Delta L = K\Delta L$. $H_{t_1} - H_{t_2} = K$. $(H_1 - H_2) \times a_{N12} = K$ $H_{t_1} - H_{t_2} = a_{N12} \times K$. $\frac{B_{t_1}}{\mu_1} - \frac{B_{t_2}}{\mu_2} = K$.	04.
7c)	(i) $F = Qv \times B$. $= (297 a_x - 405 a_y + 418 a_z) \times 10^{-6}$ N	02
	$\lvert F_M \rvert = \underline{660 \mu N}$	
	(ii) $F = QE = 18 \times 10^{-9}(-3 a_x + 4 a_y + 6 a_z) \times 10^{-3}$ $= (-54 a_x + 72 a_y + 108 a_z) \mu N$	02
	$\lvert F \rvert = 140.6 \mu N$	
	(iii) $F = Q(E + v \times B)$. $[(-54 a_x + 72 a_y + 108 a_z) + (297 a_x - 405 a_y + 418 a_z)] \times 10^{-6}$	02.
	$\lvert F \rvert = \underline{668.7 \mu N}$	
8a)	(i) $\mu = \mu_r \cdot \mu_0$ $\mu_r = 14.32$ H/m $\chi_m = \mu_r - 1 = 14.3 - 1 = 13.3$	02
	$M = \chi_m \times H = 13.3 \times 120 = 1599$ A/m	
	(ii) $M = n \cdot m \Rightarrow 8.3 \times 10^{28} \times 4.5 \times 10^{-27}$ $= 374$ A/m	02
	(iii) $\mu_r = \chi_m + 1 = 16$, $H = \frac{B}{\mu_r \mu_0} = 14.92$	

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Q.No.		Marks
	$M = \chi_m H = 15 \times 14.92$ $= 224 A/m$	02.
8b)	Since $x=0$ plane (ii) H_{NA} has only x component. $H_{NA} = 300 \bar{a_x}$ A/m. To find H_{NB}, $\frac{H_{NA}}{H_{NB}} = \frac{\mu_2}{\mu_1}$ $\frac{300 a_x}{H_{NB}} = \frac{20}{5} \Rightarrow H_{NB} = 75 \bar{a_x}$ A/m. To find $H_A = H_{tanA} + H_{NB}$. $= 300\bar{a_x} - 400\bar{a_y} + 500\bar{a_z}$ $H_{tA} + 300\bar{a_x}$ $H_{tA} = \sqrt{(400)^2 + (500)^2}$ $H_{tA} = 640 A$ $H_B = H_{tanB} + H_{NB}$. $H_{tB} = 695 A/m$ $\lvert H_{tA} \rvert = 640 A/m$, $\lvert H_{NA} \rvert = 300 A/m$, $\lvert H_{tB} \rvert = 695 A/m$ $\lvert H_{NB} \rvert = 75 A/m$.	2×4=8
8c)	The electromotive force (e.m.f) induced in a closed path is proportional to rate of change of magnetic flux enclosed by the closed path. $e = -N\frac{d\phi}{dt}$ volts.	02
	$emf = \oint E \cdot dl = -\frac{d}{dt}\int B \cdot ds$. $= -\int \frac{\partial B}{\partial t} \cdot ds$.	04.

$\int_s \nabla \times E \, ds = -\int_s \frac{\partial B}{\partial t} ds$.

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Q.No.		Marks
9a)	point form — integral form $\nabla \times E = -\frac{\partial B}{\partial t}$ — $\oint E \cdot dl = -\int_s \frac{\partial B}{\partial t} \cdot ds$ $\nabla \times H = J + \frac{\partial D}{\partial t}$ — $\oint H \cdot dl = I + \int \frac{\partial}{\partial t} D ds$. $\nabla \cdot D = \rho_v$ — $\oint \vec{B} \cdot ds = \int \rho_v dv$ $\nabla \cdot B = 0$ — $\oint \vec{B} \cdot \vec{ds} = 0$	4+4 = 8.
9b)	(i) The wave propagate along +Z. direction (ii) operating frequency = 200 MHz. (iii) phase Const = 4.19 rad/m (iv) $E(z,t) = a_x 0.94 \cos(1.257 \times 10^9 t - 4.19z)$ V/m v) $E_s(z) = a_x 0.94 e^{-j4.19z}$ V/m $H_s(z) = a_y 2.5 e^{-j4.19z}$ mA/m.	2x5 = 10.
9c)	$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \Rightarrow f = 84.4$ KHZ	2.
10a)	poynthing theorem definition —	02
	explanation —	04
	point form + integral form $\oint (E \times H) \cdot ds = \int_{vol} J \cdot E dv + \frac{d}{dt} \int_{vol} \frac{1}{2} D \cdot E dv + \frac{d}{dt} \int_{vol} \frac{1}{2} B \cdot H dv$ $-\nabla \cdot (E \times H) = J \cdot E + \frac{\partial}{\partial t} (\frac{1}{2} D \cdot E) + \frac{\partial}{\partial t} (\frac{1}{2} B \cdot H)$.	02
10b)	$\nabla \cdot D = \rho_v$, $\rho_v = 0$	02
	$\frac{\partial}{\partial x} D_x + \frac{\partial}{\partial y} D_y + \frac{\partial}{\partial y} D_z = 0$. $10 - 4 + K = 0 \Rightarrow K = -6$ nC/m^2	04.
10c)	$\frac{\sigma}{\omega \epsilon} > 1$ hence it is a good Conductor	01
	$\alpha = \beta = \sqrt{\frac{\omega \mu \sigma}{2}} = 2513$	02
		01
	$\eta = \sqrt{\frac{\omega \mu}{\sigma}} \angle 45 = 35.5 \angle 45°$	01+01.
	$v = \frac{\omega}{\beta} = 4 \times 10^7$ m/s, $\delta = \frac{1}{\sqrt{\pi f \mu_0 \mu_r \sigma}} = 2513$ m	