UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

EEE 276 – ELECTROMAGNETIC THEORY
[TEORI ELEKTROMAGNET]

Duration 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of **FIFTEEN (15)** pages and Appendices **THIRTEEN (13)** pages of printed material before you begin the examination. This examination paper consist of two versions, The English version and Malay version. The English version from page **TWO (2)** to page **EIGHT (8)** and Malay version from page **NINE (9)** to page **FIFTEEN (15).**

*Sila pastikan bahawa kertas peperiksaan ini mengandungi **LIMA BELAS (15)** muka surat dan Lampiran **TIGA BELAS (13)** muka surat bercetak sebelum anda memulakan peperiksaan ini. Kertas peperiksaan ini mengandungi dua versi, versi Bahasa Inggeris dan Bahasa Melayu. Versi Bahasa Inggeris daripada muka surat **DUA (2)** sehingga muka surat **LAPAN (8)** dan versi Bahasa Melayu daripada muka surat **SEMBILAN (9)** sehingga muka surat **LIMA BELAS (15)**.*

Instructions: This question paper consists **SIX (6)** questions. Answer **FIVE (5)** questions. All questions carry the same marks.

*[**Arahan:** Kertas soalan ini mengandungi **ENAM (6)** soalan. Jawab **LIMA (5)** soalan. Semua soalan membawa jumlah markah yang sama]*

Begin your answer to each question on a new page.
[Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru]

"In the event of any discrepancies, the English version shall be used".
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai]

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ENGLISH VERSION

1. (a) What is Coulomb's Law? State its properties. (20 marks)

(b) A transverse harmonic wave on a string is described by

– where *x* and *y* are in cm and *t* in second. The positive direction of *x* is from left to right.

(i) Is this a travelling or a stationary wave? Explain the reason for such wave.

(10 marks)

(ii) Find the speed and direction of its propagation? (10 marks)

(iii) What are its amplitude and its frequency? (10 marks)

(iv) What is the initial phase at the origin? (10 marks)

(v) What is the least distance between two successive crests in the wave?

(10 marks)

(c) The voltage source of the circuit shown in Figure 1 is given by

–

Obtain expression for , the current flowing through the inductor.

(30 marks)

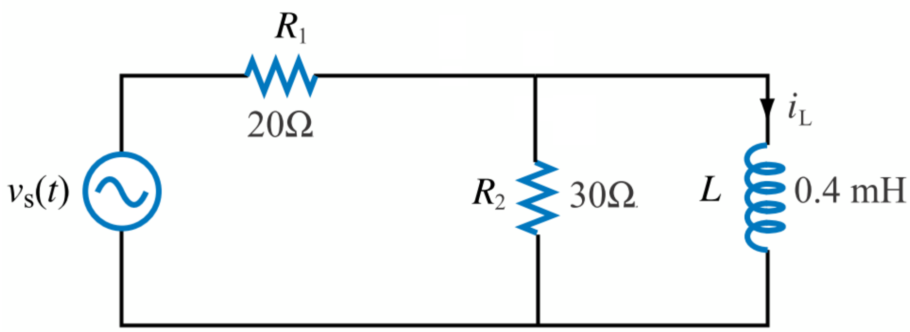

Figure 1

2. (a) Two vectors **A** and **B** are given at a point P (r, θ, ϕ) in space as

and

Determine the following:

(i) 2**A** – 5**B** (10 marks)

(ii) (10 marks)

(iii) (10 marks)

(iv) the scalar component of **A** in the direction of **B** (10 marks)

(v) the vector projection of **A** in the direction of **B** (10 marks)

(vi) a unit vector perpendicular to both **A** and **B** (10 marks)

(b) A vector is given at a point P (3, 4, 12) in the rectangular coordinate system. Express this vector in the spherical coordinate system.

(20 marks)

(c) Verify the divergence theorem for a vector field in the region bounded by the cylinder and the planes x = 0, y = 0, z = 0 and z = 2.

(i) Hint: See Figure 2 below (20 marks)

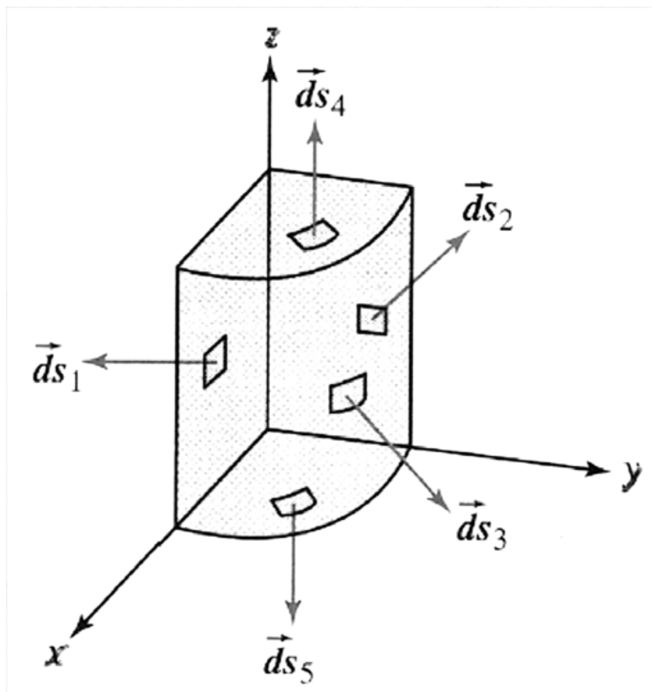

Figure 2

3. (a) Three equal charges of 200 nC are placed in free space at (0, 0, 0), (2, 0, 0), and (0, 2, 0). Determine the total force acting on a charge of 500 nC at (2, 2, 0).

(30 marks)

(b) A semi-infinite line extending from -∞ to 0 along the *z* axis carries a uniform charge distribution of 100 *n*C/m. Find the electric field, **E** at point P (0, 0, 2). Then, if a charge of 1 μC is placed at P, calculate the force acting on it.

(30 marks)

(c) A hollow conductor in the form of a matchbox is placed in a static electric field. What is the electric fied inside the conductor. Sketch the charge distribution on the inner and the outer surfaces of the conductor.

(10 marks)

(d) The plane z = 0 marks the boundary between the free space and a dielectric medium with a dielectric constant of 40. The **E** field next to the interface in free space is V/m. Determine the **E** field on the other side of the interface.

(30 marks)

4. (a) State the Bio-Savart Law and explain how it can be applied to determine the total magnetic field **H**.

(30 marks)

(b) A wire bent as shown in Figure 3 below lies in the *xy* plane and carries a current *I*. If the magnetic flux density in the region is , determine the magnetic force acting on the wire,

(Hint: Apply Ampere's Law,)

(40 marks)

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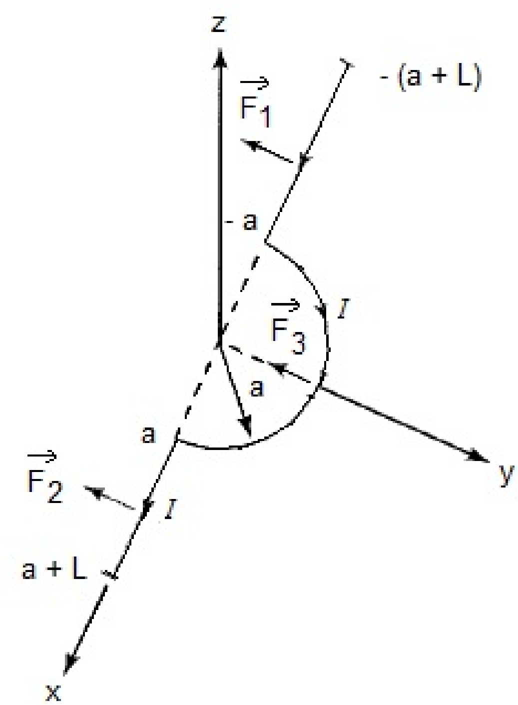

Figure 3 : Bent Wire

(c) A circular coil of 200 turns has a mean area of 10 cm^2, and the plane of the coil makes an angle of 30^0 with the uniform magnetic flux density of 1.2 T, as in Figure 4(a). Figure 4(b) shows the side view of the coil. Determine the torque experienced by the coil if it carries a current of 50 A.

(30 marks)

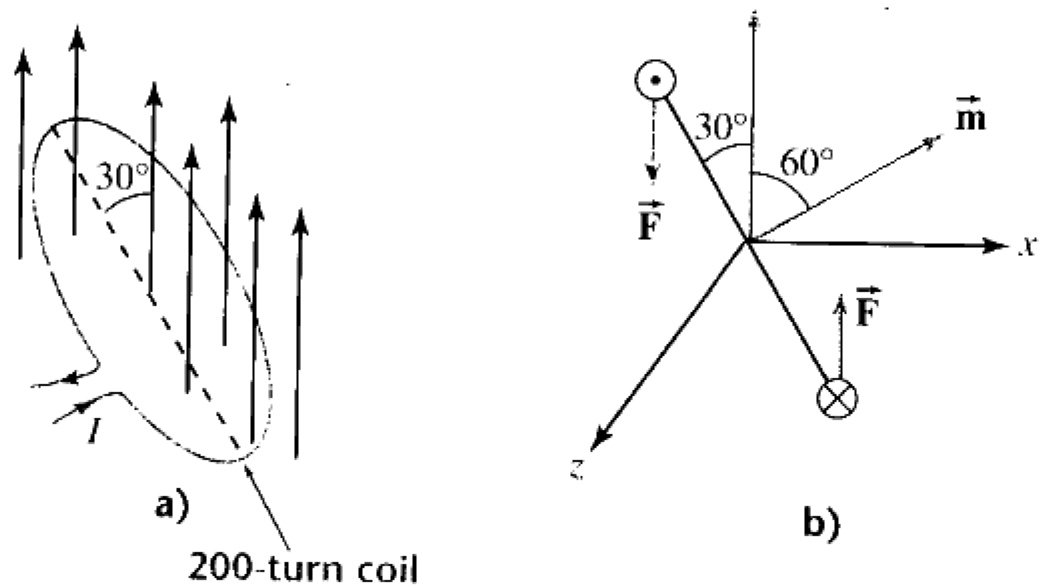

Figure 4

5. (a) State Faraday' Law of induction. Hence, explain why is the induced Electric field is not a conservative field.

(30 marks)

(b) A circular conducting loop of radius 40 cm lies in the *xy* plane and has a resistance of 20 Ω. If the magnetic flux density in the region is given as:

(T)

Determine the effective value of the induced current in the loop.
(Hint: Faraday's Law (Transformer/Loop): _))

(30 marks)

(c) The magnetic field, H in free space is given by A/m where $\theta = \omega t - \beta z$, and β is a constant quantity. Determine the following

(i) the displacement current density (20 marks)

(ii) the electrical field, **E** (20 marks)

6. (a) Explain the differences between a plane wave and a uniform plane wave by giving suitable example.

(20 marks)

(b) Determine the polarization of the wave if the electric field intensity in a region is given by V/m.

(20 marks)

(c) The phasor electric field of a 1 GHz electromagnetic wave propagating through a lossless medium with is given by

—

Determine:

(i) The direction of wave propagation (10 marks)
(ii) The relative permittivity of the medium (10 marks)
(iii) The velocity of the propagation for the wave (10 marks)
(iv) The wavelength (10 marks)
(v) The intrinsic wave impedance of the medium (10 marks)
(vi) The instantaneous vector magnetic field (10 marks)

VERSI BAHASA MELAYU

1. (a) Apakah itu Peraturan Coulomb? Nyatakan sifat-sifatnya.

(20 markah)

(b) Satu gelombang lintang harmonik di atas sebuah tali digambarkan oleh − di mana *x* dan *y* adalah dalam cm dan *t* dalam saat. Arah positif bagi *x* adalah dari kiri ke kanan.

(i) Adakah ini gelombang mengembara atau pegun? Terangkan sebab bagi gelombang yang dinyatakan.

(10 markah)

(ii) Dapatkan kelajuan dan arah bagi perambatannya?

(10 markah)

(iii) Apakah amplitud dan frekuensinya? (10 markah)

(iv) Apakah fasa awal pada titik asal? (10 markah)

(v) Apakah jarak terkurang di antara dua puncak berturutan dalam gelombang tersebut?

(10 markah)

(c) Sumber voltan bagi litar yang ditunjukkan pada Rajah 1 di bawah adalah diberikan oleh

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Dapatkan ekspresi bagi , arus yang mengalir melalui induktor.

(30 markah)

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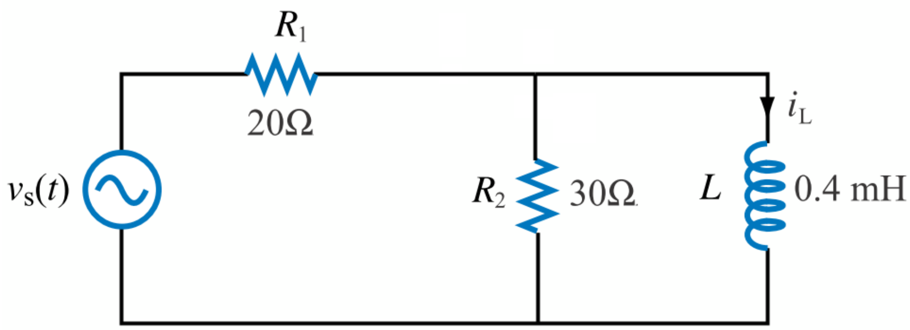


Rajah 1

2. (a) Dua vektor **A** dan **B** adalah diberikan pada satu titik point P (r, θ, ϕ) dalam ruang sebagai

dan

Dapatkan yang berikut:

(i) 2**A** – 5**B** (10 markah)

(ii) (10 markah)

(iii) (10 markah)

(iv) Komponen skalar bagi **A** dalam arah **B** (10 markah)

(v) Unjuran vektor **A** dalam arah **B** (10 markah)

(vi) Vektor unit serenjang pada kedua-dua **A** dan **B** (10 markah)

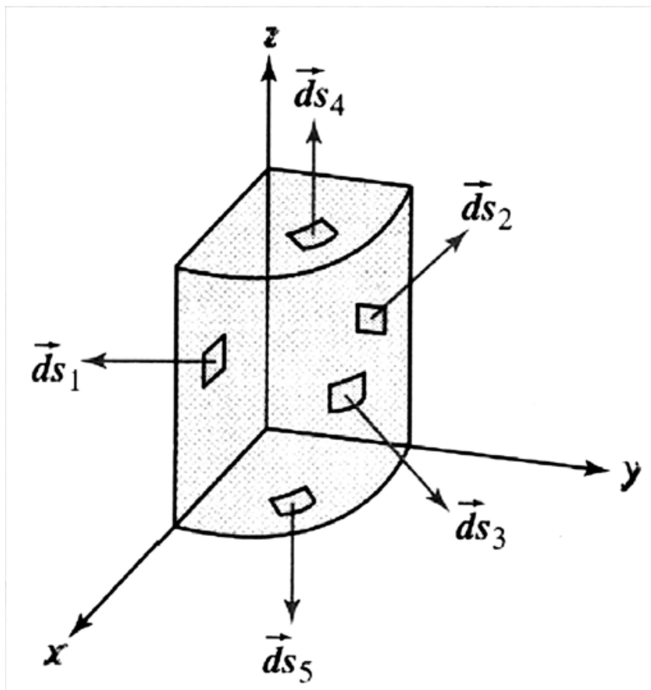
(b) Satu vektor adalah diberikan pada titik P (3, 4, 12) dalam sistem koordinat segiempat tepat. Nyatakan vektor ini dalam sistem koordinat sfera.

(20 markah)

(c) Sahkan teorem "Divergence" bagi satu medan vektor dalam kawasan disempadani oleh silinder dan satah $x = 0$, $y = 0$, $z = 0$ dan $z = 2$.

Petunjuk: Lihat Rajah 2 di bawah.

(20 markah)



Rajah 2

3. (a) Tiga cas yang sama bernilai 200 *n*C adalah diletakkan dalam ruang bebas pada (0, 0, 0), (2, 0, 0) dan (0, 2, 0). Hitungkan jumlah kuasa yang bertindak ke atas cas sebanyak 500 *n*C pada (2, 2, 0).

(30 markah)

(b) Sebuah garis separuh tanpa had melanjut dari -∞ ke 0 sepanjang paksi z membawa satu taburan cas seragam sebanyak 100 *n*C/m. Cari medan elektrik **E** pada titik P (0, 0, 2). Kemudian, sekiranya satu cas sebanyak 1 μC diletakkan pada titik P, kirakan kuasa yang bertindak keatasnya.

(30 markah)

(c) Satu konduktor berongga yang berbentuk seperti kotak mancis adalah diletakkan dalam suatu medan elektrik yang statik. Apakah medan elektrik di dalam konduktor tersebut? Lakarkan taburan cas di atas permukaan dalam dan luar bagi konduktor tersebut.

(10 markah)

(d) Satah *z* = 0 menandakan sempadan di antara ruang bebas dan satu medium dielektrik yang mempunyai pemalar dielektrik sebanyak 40. Medan **E** disebelah antara muka ruang bebas adalah V/m. Dapatkan medan **E** pada antara muka yang sebelah lainnya.

(30 markah)

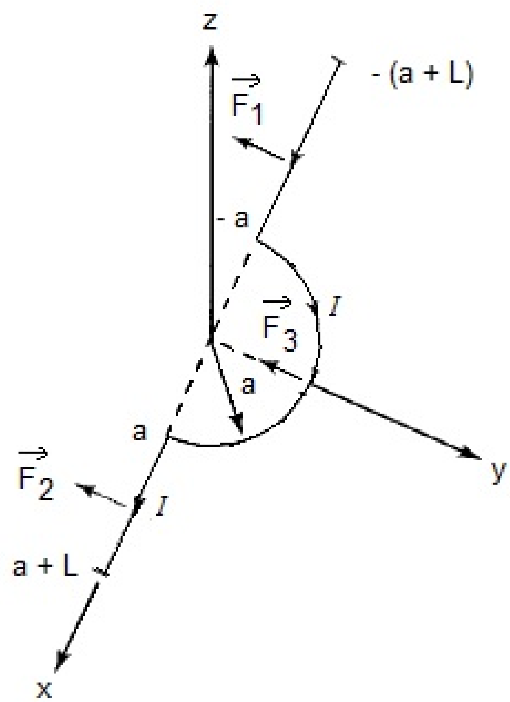
4. (a) Nyatakan Peraturan Bio-Savart dan terangkan bagaimana ianya boleh diaplikasikan untuk mendapatkan jumlah medan magnet **H**.

(30 markah)

(b) Satu wayar bengkok seperti yang ditunjukkan oleh Rajah 3 di bawah terletak dalam satah *xy* dan membawa arus *I*. Sekiranya, ketumpatan fluk magnet di dalam kawasan tersebut adalah , dapatkan kuasa magnet yang bertindak di atas wayar tersebut.

(Petunjuk: Aplikasikan Peraturan Ampere,)

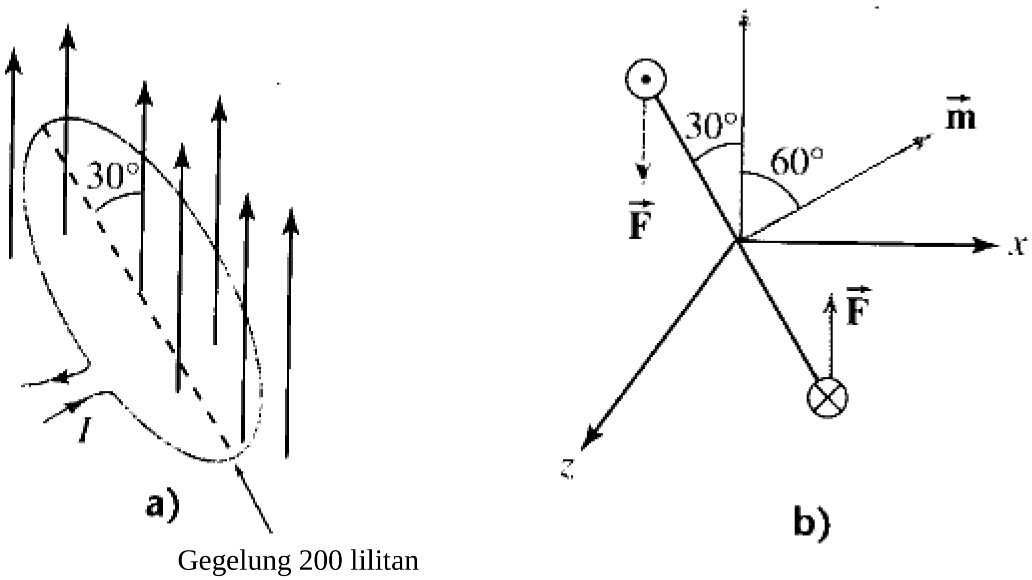
(40 markah)



Rajah 3 : Dawai Bengkok

(c) Satu gegelung bulat berlilitan sebanyak 200 mempunyai luas purata sebanyak 10 cm^2, dan satah pada gegelung tersebut membuat satu sudut sebanyak 30^0 dengan ketumpatan fluk magnet seragam sebanyak 1.2 T, seperti di dalam Rajah 4(a). Rajah 4(b) menunjukkan pandangan sisi gegelung tersebut. Dapatkan tork yang dialami oleh gegelung tersebut sekiranya ia membawa arus sebanyak 50 A.

(30 markah)



Rajah 4

5. (a) Nyatakan induksi bagi Peraturan Faraday. Kemudian, terangkan mengapa medan elektrik induksi adalah bukan medan yang konservatif.

(30 markah)

(b) Sebuah koduktor gelung bulat dengan jejari 40 cm terletak dalam satah *xy* dan mempunyai rintangan sebanyak 20Ω. Sekiranya ketumpatan fluk magnet di dalam kawasan tersebut diberikan sebagai:

(T)

Dapatkan nilai keberkesanan bagi induksi arau di dalam gelung tersebut.

(Petunjuk: Peraturan Faraday (Transformer/gelung): —)

(30 markah)

(c) Medan magnet, H dalam ruang bebas diberikan oleh A/m di mana $\theta = \omega t - \beta z$, dan β adalah kuantiti konstan. Dapatkan yang berikut:

(i) ketumpatan arus anjakan (20 markah)

(ii) medan elektrik, **E** (20 markah)

6\. (a) Nyatakan perbezaan di antara gelombang satah dan gelombang satah seragam dengan memberikan contoh yang sesuai.

(20 markah)

(b) Dapatkan polarisasi bagi gelombang tersebut sekiranya kekuatan medan elektrik di dalam kawasan tersebut diberikan oleh V/m.

(20 markah)

(c) Medan elekrik berfasa bagi satu gelombang electromagnet merambat melalui satu medium tanpa kehilangan dengan adalah diberikan sebagai

—

Dapatkan:

(i) arah perambatan gelombang (10 markah)

(ii) ketelusan relatif medium (10 markah)

(iii) halaju perambatan bagi gelombang tersebut (10 markah)

(iv) panjang gelombang (10 markah)

(v) galangan intrinsik gelombang bagi medium tersebut (10 markah)

(vi) vektor medan magnet serta merta (10 markah)

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LIST OF APPENDIXES

FIRST PART

$$\mathbf{F}_{e21} = \hat{\mathbf{R}}_{12} \frac{q_1 q_2}{4\pi \varepsilon_0 R_{12}^2} \quad \text{(N)} \quad \text{(in free space)},$$

$$\mathbf{E} = \hat{\mathbf{R}} \frac{q}{4\pi \varepsilon_0 R^2} \quad \text{(V/m)} \quad \text{(in free space)},$$, $$\mathbf{D} = \varepsilon \mathbf{E} \quad (\text{C/m}^2)$$

Table 1-4: Constitutive parameters of materials.

Parameter	Units	Free-space Value
Electrical permittivity ε	F/m	$\varepsilon_0 = 8.854 \times 10^{-12}$ (F/m) $\simeq \frac{1}{36\pi} \times 10^{-9}$ (F/m)
Magnetic permeability μ	H/m	$\mu_0 = 4\pi \times 10^{-7}$ (H/m)
Conductivity σ	S/m	0

Euler's Identity: $e^{j\theta} = \cos\theta + j\sin\theta$

$\sin\theta = \dfrac{e^{j\theta} - e^{-j\theta}}{2j}$	$\cos\theta = \dfrac{e^{j\theta} + e^{-j\theta}}{2}$
$\mathbf{z} = x + jy = \lvert\mathbf{z}\rvert e^{j\theta}$	$\mathbf{z}^* = x - jy = \lvert\mathbf{z}\rvert e^{-j\theta}$
$x = \mathfrak{Re}(\mathbf{z}) = \lvert\mathbf{z}\rvert\cos\theta$	$\lvert\mathbf{z}\rvert = \sqrt[+]{\mathbf{z}\mathbf{z}^*} = \sqrt[+]{x^2 + y^2}$
$y = \mathfrak{Im}(\mathbf{z}) = \lvert\mathbf{z}\rvert\sin\theta$	$\theta = \tan^{-1}(y/x)$
$\mathbf{z}^n = \lvert\mathbf{z}\rvert^n e^{jn\theta}$	$\mathbf{z}^{1/2} = \pm\lvert\mathbf{z}\rvert^{1/2} e^{j\theta/2}$
$\mathbf{z}_1 = x_1 + jy_1$	$\mathbf{z}_2 = x_2 + jy_2$
$\mathbf{z}_1 = \mathbf{z}_2$ iff $x_1 = x_2$ and $y_1 = y_2$	$\mathbf{z}_1 + \mathbf{z}_2 = (x_1 + x_2) + j(y_1 + y_2)$
$\mathbf{z}_1\mathbf{z}_2 = \lvert\mathbf{z}_1\rvert\lvert\mathbf{z}_2\rvert e^{j(\theta_1+\theta_2)}$	$\dfrac{\mathbf{z}_1}{\mathbf{z}_2} = \dfrac{\lvert\mathbf{z}_1\rvert}{\lvert\mathbf{z}_2\rvert} e^{j(\theta_1-\theta_2)}$
$-1 = e^{j\pi} = e^{-j\pi} = 1\angle\pm180^\circ$	
$j = e^{j\pi/2} = 1\angle 90^\circ$	$-j = e^{-j\pi/2} = 1\angle -90^\circ$
$\sqrt{j} = \pm e^{j\pi/4} = \pm\dfrac{(1 + j)}{\sqrt{2}}$	$\sqrt{-j} = \pm e^{-j\pi/4} = \pm\dfrac{(1 - j)}{\sqrt{2}}$

Time & Phasor Domain:

$x(t)$		$\mathbf{X}$
$A\cos\omega t$	$\leftrightarrow$	A
$A\cos(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j\phi}$
$-A\cos(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi\pm\pi)}$
$A\sin\omega t$	$\leftrightarrow$	$Ae^{-j\pi/2}=-jA$
$A\sin(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi-\pi/2)}$
$-A\sin(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi+\pi/2)}$
$\frac{d}{dt}(x(t))$	$\leftrightarrow$	$j\omega\mathbf{X}$
$\frac{d}{dt}[A\cos(\omega t+\phi)]$	$\leftrightarrow$	$j\omega Ae^{j\phi}$
$\int x(t)\,dt$	$\leftrightarrow$	$\frac{1}{j\omega}\mathbf{X}$
$\int A\cos(\omega t+\phi)\,dt$	$\leftrightarrow$	$\frac{1}{j\omega}Ae^{j\phi}$

Table 1-5: Time-domain sinusoidal functions $z(t)$ and their cosine-reference phasor-domain counterparts $\widetilde{Z}$, where $z(t) = \mathfrak{Re}\ [\widetilde{Z}e^{j\omega t}]$.

$z(t)$		$\widetilde{Z}$
$A\cos\omega t$	⟷	A
$A\cos(\omega t + \phi_0)$	⟷	$Ae^{j\phi_0}$
$A\cos(\omega t + \beta x + \phi_0)$	⟷	$Ae^{j(\beta x + \phi_0)}$
$Ae^{-\alpha x}\cos(\omega t + \beta x + \phi_0)$	⟷	$Ae^{-\alpha x}e^{j(\beta x + \phi_0)}$
$A\sin\omega t$	⟷	$Ae^{-j\pi/2}$
$A\sin(\omega t + \phi_0)$	⟷	$Ae^{j(\phi_0 - \pi/2)}$
$\frac{d}{dt}(z(t))$	⟷	$j\omega\widetilde{Z}$
$\frac{d}{dt}[A\cos(\omega t + \phi_0)]$	⟷	$j\omega Ae^{j\phi_0}$
$\int z(t)\,dt$	⟷	$\frac{1}{j\omega}\widetilde{Z}$
$\int A\sin(\omega t + \phi_0)\,dt$	⟷	$\frac{1}{j\omega}Ae^{j(\phi_0 - \pi/2)}$

Chapter 1 Relationships

Electric field due to charge q in free space

$$\mathbf{E} = \hat{\mathbf{R}}\frac{q}{4\pi\varepsilon_0 R^2}$$

Magnetic field due to current I in free space

$$\mathbf{B} = \hat{\boldsymbol{\phi}}\frac{\mu_0 I}{2\pi r}$$

Plane wave $y(x,t) = Ae^{-\alpha x}\cos(\omega t - \beta x + \phi_0)$

- $\alpha = 0$ in lossless medium
- phase velocity $u_p = f\lambda = \frac{\omega}{\beta}$
- $\omega = 2\pi f;\ \beta = 2\pi/\lambda$
- ϕ_0 = phase reference

Complex numbers

- Euler's identity

  $e^{j\theta} = \cos\theta + j\sin\theta$
- Rectangular-polar relations

  $x = |z|\cos\theta, \quad y = |z|\sin\theta,$

  $|z| = \sqrt[+]{x^2 + y^2}, \quad \theta = \tan^{-1}(y/x)$

Phasor-domain equivalents

Table 1-5

APPENDIX
LAMPIRAN

Table 3-1: Summary of vector relations.

	Cartesian Coordinates	Cylindrical Coordinates	Spherical Coordinates
Coordinate variables	x, y, z	r, ϕ, z	R, θ, ϕ
Vector representation $\mathbf{A} =$	$\hat{\mathbf{x}}A_x + \hat{\mathbf{y}}A_y + \hat{\mathbf{z}}A_z$	$\hat{\mathbf{r}}A_r + \hat{\boldsymbol{\phi}}A_\phi + \hat{\mathbf{z}}A_z$	$\hat{\mathbf{R}}A_R + \hat{\boldsymbol{\theta}}A_\theta + \hat{\boldsymbol{\phi}}A_\phi$
Magnitude of A $\quad |\mathbf{A}| =$	$\sqrt[+]{A_x^2 + A_y^2 + A_z^2}$	$\sqrt[+]{A_r^2 + A_\phi^2 + A_z^2}$	$\sqrt[+]{A_R^2 + A_\theta^2 + A_\phi^2}$
Position vector $\overrightarrow{OP_1} =$	$\hat{\mathbf{x}}x_1 + \hat{\mathbf{y}}y_1 + \hat{\mathbf{z}}z_1$, for $P = (x_1, y_1, z_1)$	$\hat{\mathbf{r}}r_1 + \hat{\mathbf{z}}z_1$, for $P = (r_1, \phi_1, z_1)$	$\hat{\mathbf{R}}R_1$, for $P = (R_1, \theta_1, \phi_1)$
Base vectors properties	$\hat{\mathbf{x}}\cdot\hat{\mathbf{x}} = \hat{\mathbf{y}}\cdot\hat{\mathbf{y}} = \hat{\mathbf{z}}\cdot\hat{\mathbf{z}} = 1$ $\hat{\mathbf{x}}\cdot\hat{\mathbf{y}} = \hat{\mathbf{y}}\cdot\hat{\mathbf{z}} = \hat{\mathbf{z}}\cdot\hat{\mathbf{x}} = 0$ $\hat{\mathbf{x}}\times\hat{\mathbf{y}} = \hat{\mathbf{z}}$ $\hat{\mathbf{y}}\times\hat{\mathbf{z}} = \hat{\mathbf{x}}$ $\hat{\mathbf{z}}\times\hat{\mathbf{x}} = \hat{\mathbf{y}}$	$\hat{\mathbf{r}}\cdot\hat{\mathbf{r}} = \hat{\boldsymbol{\phi}}\cdot\hat{\boldsymbol{\phi}} = \hat{\mathbf{z}}\cdot\hat{\mathbf{z}} = 1$ $\hat{\mathbf{r}}\cdot\hat{\boldsymbol{\phi}} = \hat{\boldsymbol{\phi}}\cdot\hat{\mathbf{z}} = \hat{\mathbf{z}}\cdot\hat{\mathbf{r}} = 0$ $\hat{\mathbf{r}}\times\hat{\boldsymbol{\phi}} = \hat{\mathbf{z}}$ $\hat{\boldsymbol{\phi}}\times\hat{\mathbf{z}} = \hat{\mathbf{r}}$ $\hat{\mathbf{z}}\times\hat{\mathbf{r}} = \hat{\boldsymbol{\phi}}$	$\hat{\mathbf{R}}\cdot\hat{\mathbf{R}} = \hat{\boldsymbol{\theta}}\cdot\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\phi}}\cdot\hat{\boldsymbol{\phi}} = 1$ $\hat{\mathbf{R}}\cdot\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\theta}}\cdot\hat{\boldsymbol{\phi}} = \hat{\boldsymbol{\phi}}\cdot\hat{\mathbf{R}} = 0$ $\hat{\mathbf{R}}\times\hat{\boldsymbol{\theta}} = \hat{\boldsymbol{\phi}}$ $\hat{\boldsymbol{\theta}}\times\hat{\boldsymbol{\phi}} = \hat{\mathbf{R}}$ $\hat{\boldsymbol{\phi}}\times\hat{\mathbf{R}} = \hat{\boldsymbol{\theta}}$
Dot product $\quad \mathbf{A}\cdot\mathbf{B} =$	$A_xB_x + A_yB_y + A_zB_z$	$A_rB_r + A_\phi B_\phi + A_zB_z$	$A_RB_R + A_\theta B_\theta + A_\phi B_\phi$
Cross product $\quad \mathbf{A}\times\mathbf{B} =$	$\begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$	$\begin{vmatrix} \hat{\mathbf{r}} & \hat{\boldsymbol{\phi}} & \hat{\mathbf{z}} \\ A_r & A_\phi & A_z \\ B_r & B_\phi & B_z \end{vmatrix}$	$\begin{vmatrix} \hat{\mathbf{R}} & \hat{\boldsymbol{\theta}} & \hat{\boldsymbol{\phi}} \\ A_R & A_\theta & A_\phi \\ B_R & B_\theta & B_\phi \end{vmatrix}$
Differential length $\quad d\mathbf{l} =$	$\hat{\mathbf{x}}\,dx + \hat{\mathbf{y}}\,dy + \hat{\mathbf{z}}\,dz$	$\hat{\mathbf{r}}\,dr + \hat{\boldsymbol{\phi}}r\,d\phi + \hat{\mathbf{z}}\,dz$	$\hat{\mathbf{R}}\,dR + \hat{\boldsymbol{\theta}}R\,d\theta + \hat{\boldsymbol{\phi}}R\sin\theta\,d\phi$
Differential surface areas	$ds_x = \hat{\mathbf{x}}\,dy\,dz$ $ds_y = \hat{\mathbf{y}}\,dx\,dz$ $ds_z = \hat{\mathbf{z}}\,dx\,dy$	$ds_r = \hat{\mathbf{r}}r\,d\phi\,dz$ $ds_\phi = \hat{\boldsymbol{\phi}}\,dr\,dz$ $ds_z = \hat{\mathbf{z}}r\,dr\,d\phi$	$ds_R = \hat{\mathbf{R}}R^2\sin\theta\,d\theta\,d\phi$ $ds_\theta = \hat{\boldsymbol{\theta}}R\sin\theta\,dR\,d\phi$ $ds_\phi = \hat{\boldsymbol{\phi}}R\,dR\,d\theta$
Differential volume $dV =$	$dx\,dy\,dz$	$r\,dr\,d\phi\,dz$	$R^2\sin\theta\,dR\,d\theta\,d\phi$

Table 3-2: Coordinate transformation relations.

Transformation	Coordinate Variables	Unit Vectors	Vector Components
Cartesian to cylindrical	$r = \sqrt[+]{x^2 + y^2}$ $\phi = \tan^{-1}(y/x)$ $z = z$	$\hat{\mathbf{r}} = \hat{\mathbf{x}} \cos\phi + \hat{\mathbf{y}} \sin\phi$ $\hat{\boldsymbol{\phi}} = -\hat{\mathbf{x}} \sin\phi + \hat{\mathbf{y}} \cos\phi$ $\hat{\mathbf{z}} = \hat{\mathbf{z}}$	$A_r = A_x \cos\phi + A_y \sin\phi$ $A_\phi = -A_x \sin\phi + A_y \cos\phi$ $A_z = A_z$
Cylindrical to Cartesian	$x = r\cos\phi$ $y = r\sin\phi$ $z = z$	$\hat{\mathbf{x}} = \hat{\mathbf{r}} \cos\phi - \hat{\boldsymbol{\phi}} \sin\phi$ $\hat{\mathbf{y}} = \hat{\mathbf{r}} \sin\phi + \hat{\boldsymbol{\phi}} \cos\phi$ $\hat{\mathbf{z}} = \hat{\mathbf{z}}$	$A_x = A_r \cos\phi - A_\phi \sin\phi$ $A_y = A_r \sin\phi + A_\phi \cos\phi$ $A_z = A_z$
Cartesian to spherical	$R = \sqrt[+]{x^2 + y^2 + z^2}$ $\theta = \tan^{-1}[\sqrt[+]{x^2 + y^2}/z]$ $\phi = \tan^{-1}(y/x)$	$\hat{\mathbf{R}} = \hat{\mathbf{x}} \sin\theta\cos\phi + \hat{\mathbf{y}} \sin\theta\sin\phi + \hat{\mathbf{z}} \cos\theta$ $\hat{\boldsymbol{\theta}} = \hat{\mathbf{x}} \cos\theta\cos\phi + \hat{\mathbf{y}} \cos\theta\sin\phi - \hat{\mathbf{z}} \sin\theta$ $\hat{\boldsymbol{\phi}} = -\hat{\mathbf{x}} \sin\phi + \hat{\mathbf{y}} \cos\phi$	$A_R = A_x \sin\theta\cos\phi + A_y \sin\theta\sin\phi + A_z \cos\theta$ $A_\theta = A_x \cos\theta\cos\phi + A_y \cos\theta\sin\phi - A_z \sin\theta$ $A_\phi = -A_x \sin\phi + A_y \cos\phi$
Spherical to Cartesian	$x = R\sin\theta\cos\phi$ $y = R\sin\theta\sin\phi$ $z = R\cos\theta$	$\hat{\mathbf{x}} = \hat{\mathbf{R}} \sin\theta\cos\phi + \hat{\boldsymbol{\theta}} \cos\theta\cos\phi - \hat{\boldsymbol{\phi}} \sin\phi$ $\hat{\mathbf{y}} = \hat{\mathbf{R}} \sin\theta\sin\phi + \hat{\boldsymbol{\theta}} \cos\theta\sin\phi + \hat{\boldsymbol{\phi}} \cos\phi$ $\hat{\mathbf{z}} = \hat{\mathbf{R}} \cos\theta - \hat{\boldsymbol{\theta}} \sin\theta$	$A_x = A_R \sin\theta\cos\phi + A_\theta \cos\theta\cos\phi - A_\phi \sin\phi$ $A_y = A_R \sin\theta\sin\phi + A_\theta \cos\theta\sin\phi + A_\phi \cos\phi$ $A_z = A_R \cos\theta - A_\theta \sin\theta$
Cylindrical to spherical	$R = \sqrt[+]{r^2 + z^2}$ $\theta = \tan^{-1}(r/z)$ $\phi = \phi$	$\hat{\mathbf{R}} = \hat{\mathbf{r}} \sin\theta + \hat{\mathbf{z}} \cos\theta$ $\hat{\boldsymbol{\theta}} = \hat{\mathbf{r}} \cos\theta - \hat{\mathbf{z}} \sin\theta$ $\hat{\boldsymbol{\phi}} = \hat{\boldsymbol{\phi}}$	$A_R = A_r \sin\theta + A_z \cos\theta$ $A_\theta = A_r \cos\theta - A_z \sin\theta$ $A_\phi = A_\phi$
Spherical to cylindrical	$r = R\sin\theta$ $\phi = \phi$ $z = R\cos\theta$	$\hat{\mathbf{r}} = \hat{\mathbf{R}} \sin\theta + \hat{\boldsymbol{\theta}} \cos\theta$ $\hat{\boldsymbol{\phi}} = \hat{\boldsymbol{\phi}}$ $\hat{\mathbf{z}} = \hat{\mathbf{R}} \cos\theta - \hat{\boldsymbol{\theta}} \sin\theta$	$A_r = A_R \sin\theta + A_\theta \cos\theta$ $A_\phi = A_\phi$ $A_z = A_R \cos\theta - A_\theta \sin\theta$

Chapter 3 Relationships

Distance Between Two Points

$$d = [(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]^{1/2}$$

$$d = \left[r_2^2 + r_1^2 - 2r_1 r_2 \cos(\phi_2 - \phi_1) + (z_2 - z_1)^2\right]^{1/2}$$

$$d = \left\{R_2^2 + R_1^2 - 2R_1 R_2[\cos\theta_2 \cos\theta_1 + \sin\theta_1 \sin\theta_2 \cos(\phi_2 - \phi_1)]\right\}^{1/2}$$

Coordinate Systems Table 3-1

Coordinate Transformations Table 3-2

Vector Products

$$\mathbf{A} \cdot \mathbf{B} = AB \cos\theta_{AB}$$

$$\mathbf{A} \times \mathbf{B} = \hat{\mathbf{n}}\, AB \sin\theta_{AB}$$

$$\mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = \mathbf{B} \cdot (\mathbf{C} \times \mathbf{A}) = \mathbf{C} \cdot (\mathbf{A} \times \mathbf{B})$$

$$\mathbf{A} \times (\mathbf{B} \times \mathbf{C}) = \mathbf{B}(\mathbf{A} \cdot \mathbf{C}) - \mathbf{C}(\mathbf{A} \cdot \mathbf{B})$$

Divergence Theorem

$$\int_V \nabla \cdot \mathbf{E}\, dV = \oint_S \mathbf{E} \cdot d\mathbf{s}$$

Vector Operators

$$\nabla T = \hat{\mathbf{x}}\frac{\partial T}{\partial x} + \hat{\mathbf{y}}\frac{\partial T}{\partial y} + \hat{\mathbf{z}}\frac{\partial T}{\partial z}$$

$$\nabla \cdot \mathbf{E} = \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z}$$

$$\nabla \times \mathbf{B} = \hat{\mathbf{x}}\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z}\right) + \hat{\mathbf{y}}\left(\frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x}\right) + \hat{\mathbf{z}}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$$

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

(see back cover for cylindrical and spherical coordinates)

Stokes's Theorem

$$\int_S (\nabla \times \mathbf{B}) \cdot d\mathbf{s} = \oint_C \mathbf{B} \cdot d\mathbf{l}$$

Chapter 4 Relationships

Maxwell's Equations for Electrostatics

Name	Differential Form	Integral Form
Gauss's law	$\nabla \cdot \mathbf{D} = \rho_v$	$\oint_S \mathbf{D} \cdot d\mathbf{s} = Q$
Kirchhoff's law	$\nabla \times \mathbf{E} = 0$	$\oint_C \mathbf{E} \cdot d\mathbf{l} = 0$

		Electric Field	
Current density	$\mathbf{J} = \rho_v \mathbf{u}$	Point charge	$\mathbf{E} = \hat{\mathbf{R}} \dfrac{q}{4\pi\varepsilon R^2}$
Poisson's equation	$\nabla^2 V = -\dfrac{\rho_v}{\varepsilon}$	Many point charges	$\mathbf{E} = \dfrac{1}{4\pi\varepsilon} \sum_{i=1}^{N} \dfrac{q_i (\mathbf{R} - \mathbf{R}_i)}{\lvert\mathbf{R} - \mathbf{R}_i\rvert^3}$
Laplace's equation	$\nabla^2 V = 0$	Volume distribution	$\mathbf{E} = \dfrac{1}{4\pi\varepsilon} \int_{V'} \hat{\mathbf{R}}' \dfrac{\rho_v \, dV'}{R'^2}$
Resistance	$R = \dfrac{-\int_l \mathbf{E} \cdot d\mathbf{l}}{\int_S \sigma \mathbf{E} \cdot d\mathbf{s}}$	Surface distribution	$\mathbf{E} = \dfrac{1}{4\pi\varepsilon} \int_{S'} \hat{\mathbf{R}}' \dfrac{\rho_s \, ds'}{R'^2}$
Boundary conditions	Table 4-3	Line distribution	$\mathbf{E} = \dfrac{1}{4\pi\varepsilon} \int_{l'} \hat{\mathbf{R}}' \dfrac{\rho_\ell \, dl'}{R'^2}$
Capacitance	$C = \dfrac{\int_S \varepsilon \mathbf{E} \cdot d\mathbf{s}}{-\int_l \mathbf{E} \cdot d\mathbf{l}}$	Infinite sheet of charge	$\mathbf{E} = \hat{\mathbf{z}} \dfrac{\rho_s}{2\varepsilon_0}$
RC relation	$RC = \dfrac{\varepsilon}{\sigma}$	Infinite line of charge	$\mathbf{E} = \dfrac{\mathbf{D}}{\varepsilon_0} = \hat{\mathbf{r}} \dfrac{D_r}{\varepsilon_0} = \hat{\mathbf{r}} \dfrac{\rho_\ell}{2\pi\varepsilon_0 r}$
Energy density	$w_e = \frac{1}{2}\varepsilon E^2$	Dipole	$\mathbf{E} = \dfrac{qd}{4\pi\varepsilon_0 R^3} (\hat{\mathbf{R}}\, 2\cos\theta + \hat{\boldsymbol{\theta}} \sin\theta)$
		Relation to V	$\mathbf{E} = -\nabla V$

SECOND PART

(i)

(ii)

(iii) Moment,

(iv) For Toroidal coil: (for a≤r≤b), Φ=

(v) Magnetic Energy Density: (J/)

(vi) Faraday's Law (Motional):

(vii) Faraday's Law (Transformer/Loop):

(viii) Lossless Medium:

(ix) , (, (m/s),

(x) Power Density, (W/m^2)