

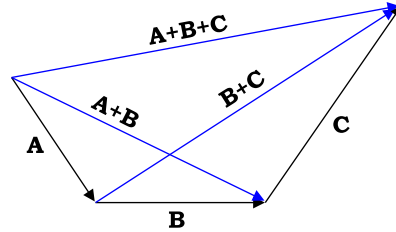
[연습문제 공개용 답안 이용 안내]

- 본 연습문제 답안의 저작권은 이연호와 한빛아카데미(주)에 있습니다.
- 이 자료를 무단으로 전제하거나 배포할 경우 저작권법 136조에 의거하여 최고 5년 이하의 징역 또는 5천만원 이하의 벌금에 처할 수 있고 이를 병과(併科)할 수도 있습니다.

Chapter 01 연습문제 답안

추상적 형태의 벡터연산 법칙들

1.1



- 1.2 (a) $\mathbf{A} + \mathbf{B}$, $\mathbf{A} - \mathbf{B}$
(b) $\mathbf{A} = \mathbf{B}$

- 1.3 (a) 0
(b) $-\cos(48^\circ)\mathbf{a}_x - \sin(48^\circ)\mathbf{a}_y$.

1.4 $\mathbf{A} \cdot (\mathbf{B} + \mathbf{C}) = \mathbf{A} \cdot \mathbf{B} + \mathbf{A} \cdot \mathbf{C}$

1.5 $\mathbf{A} \times (\mathbf{B} + \mathbf{C}) = \mathbf{A} \times \mathbf{B} + \mathbf{A} \times \mathbf{C}$

- 1.6 벡터가 3차원 공간에서 선형적으로 이동하더라도 벡터 평면 위 투영은 영향을 받지 않는다.

1.7 증명 생략

1.8 증명 생략

1.9 증명 생략

1.10 증명 생략

선과 면벡터연산 법칙들

$$1.11 \quad (\mathbf{A} \times \mathbf{B})(\mathbf{A} \cdot \mathbf{B}) = 16\mathbf{a}_x + 8\mathbf{a}_y - 28\mathbf{a}_z$$

1.12

$$(a) \quad \mathbf{a}_A = \frac{\mathbf{A}}{A} = \frac{2}{\sqrt{14}}\mathbf{a}_x + \frac{1}{\sqrt{14}}\mathbf{a}_y + \frac{3}{\sqrt{14}}\mathbf{a}_z$$

(b)

$$\begin{aligned} \mathbf{B} - \mathbf{A} &= (-1-2)\mathbf{a}_x + (2-1)\mathbf{a}_y + (1-3)\mathbf{a}_z \\ &= -3\mathbf{a}_x + \mathbf{a}_y - 2\mathbf{a}_z \end{aligned}$$

$$(c) \quad \mathbf{A} \cdot \mathbf{B} = (2)(-1) + (1)(2) + (3)(1) = 3$$

$$(d) \quad \mathbf{A} \times \mathbf{B} = \begin{vmatrix} \mathbf{a}_x & \mathbf{a}_y & \mathbf{a}_z \\ 2 & 1 & 3 \\ -1 & 2 & 1 \end{vmatrix} = -5\mathbf{a}_x - 5\mathbf{a}_y + 5\mathbf{a}_z$$

$$(e) \quad \theta_{AB} = \cos^{-1} \left(\frac{\mathbf{A} \cdot \mathbf{B}}{AB} \right) = \cos^{-1} \left(\frac{3}{\sqrt{14}\sqrt{6}} \right) = 70.9^\circ$$

$$(f) \quad \mathbf{B}_{\parallel} = (\mathbf{B} \cdot \mathbf{a}_A)\mathbf{a}_A = \frac{3}{14}(2\mathbf{a}_x + \mathbf{a}_y + 3\mathbf{a}_z)$$

(g)

$$\begin{aligned} \mathbf{B}_{\perp} &= \mathbf{B} - \mathbf{B}_{\parallel} = \left(-1 - \frac{6}{14}\right)\mathbf{a}_x + \left(2 - \frac{3}{14}\right)\mathbf{a}_y + \left(1 - \frac{9}{14}\right)\mathbf{a}_z \\ &= -\frac{20}{14}\mathbf{a}_x + \frac{25}{14}\mathbf{a}_y + \frac{5}{14}\mathbf{a}_z \end{aligned}$$

1.13

$$(a) \quad A = \sqrt{(2)^2 + (1)^2 + (1)^2} = \sqrt{6}$$

$$\mathbf{a}_A = \frac{\mathbf{A}}{A} = \frac{2}{\sqrt{6}}\mathbf{a}_R + \frac{1}{\sqrt{6}}\mathbf{a}_\theta + \frac{1}{\sqrt{6}}\mathbf{a}_\phi$$

(b)

$$\begin{aligned}\mathbf{B} - \mathbf{A} &= (3-2)\mathbf{a}_R + (2-1)\mathbf{a}_\theta + (-4-1)\mathbf{a}_\phi \\ &= \mathbf{a}_R + \mathbf{a}_\theta - 5\mathbf{a}_\phi\end{aligned}$$

(c) $\mathbf{A} \cdot \mathbf{B} = (2)(3) + (1)(2) + (1)(-4) = 4$

(d) $\mathbf{A} \times \mathbf{B} = \begin{vmatrix} \mathbf{a}_R & \mathbf{a}_\theta & \mathbf{a}_\phi \\ 2 & 1 & 1 \\ 3 & 2 & -4 \end{vmatrix} = -6\mathbf{a}_R + 11\mathbf{a}_\theta + \mathbf{a}_\phi$

(e) $\theta_{AB} = \cos^{-1}\left(\frac{\mathbf{A} \cdot \mathbf{B}}{AB}\right) = \cos^{-1}\left(\frac{4}{\sqrt{6}\sqrt{29}}\right) = 72.3^\circ$

(f) $\mathbf{B}_\parallel = (\mathbf{B} \cdot \mathbf{a}_A)\mathbf{a}_A = \frac{4}{3}\mathbf{a}_R + \frac{2}{3}\mathbf{a}_\theta + \frac{2}{3}\mathbf{a}_\phi$

(g)

$$\begin{aligned}\mathbf{B}_\perp &= \mathbf{B} - \mathbf{B}_\parallel = \left(3 - \frac{4}{3}\right)\mathbf{a}_R + \left(2 - \frac{2}{3}\right)\mathbf{a}_\theta + \left(-4 - \frac{2}{3}\right)\mathbf{a}_\phi \\ &= \frac{5}{3}\mathbf{a}_R + \frac{4}{3}\mathbf{a}_\theta - \frac{14}{3}\mathbf{a}_\phi\end{aligned}$$

1.14

(a) $\mathbf{A} + \mathbf{B} = 7\mathbf{a}_\rho + 2\mathbf{a}_\phi + 5\mathbf{a}_z$

(b) $\mathbf{A} \cdot \mathbf{B} = (3\mathbf{a}_\rho + 2\mathbf{a}_\phi) \cdot (4\mathbf{a}_\rho + 5\mathbf{a}_z) = 12$

(c) $\mathbf{A} \times \mathbf{B} = \begin{vmatrix} \mathbf{a}_\rho & \mathbf{a}_\phi & \mathbf{a}_z \\ 3 & 2 & 0 \\ 4 & 0 & 5 \end{vmatrix} = 10\mathbf{a}_\rho - 15\mathbf{a}_\phi - 8\mathbf{a}_z$

1.15

(a) $\mathbf{A} + \mathbf{B} = 6\mathbf{a}_R + 4\sqrt{2}\mathbf{a}_\phi$

(b) $\mathbf{A} \cdot \mathbf{B} = 9$

(c) $\mathbf{A} \times \mathbf{B} = -12\sqrt{2}\mathbf{a}_\theta$

벡터 성분

1.16

(a) $\mathbf{r} = 4\mathbf{a}_x + 3\mathbf{a}_y + 12\mathbf{a}_z$

(b) $\mathbf{r} = 5\mathbf{a}_\rho + 12\mathbf{a}_z$

(c) $\mathbf{r} = 13\mathbf{a}_R$

1.17

(a) $\mathbf{A}_\parallel = (\mathbf{A} \cdot \mathbf{a}_\parallel) \mathbf{a}_\parallel = (2\mathbf{a}_x - \mathbf{a}_y)$

(b) $\mathbf{A}_\perp = \mathbf{A} - \mathbf{A}_\parallel = (3\mathbf{a}_x + 6\mathbf{a}_y + 5\mathbf{a}_z)$

1.18

(a) $\mathbf{a}_A = -\frac{1}{2}\mathbf{a}_x + \frac{3}{4}\mathbf{a}_y + \frac{\sqrt{3}}{4}\mathbf{a}_z$

(b) $\mathbf{a}_\perp = \pm \left(\frac{1}{2}\mathbf{a}_y - \frac{\sqrt{3}}{2}\mathbf{a}_z \right)$

1.19

(a)

$$\cos \theta_x = \frac{\mathbf{A} \cdot \mathbf{a}_x}{A} = \frac{1}{3} \quad \rightarrow \quad \theta_x = 70.5^\circ$$

$$\cos \theta_y = \frac{\mathbf{A} \cdot \mathbf{a}_y}{A} = \frac{2}{3} \quad \rightarrow \quad \theta_y = 48.2^\circ$$

$$\cos \theta_z = \frac{\mathbf{A} \cdot \mathbf{a}_z}{A} = \frac{2}{3} \quad \rightarrow \quad \theta_z = 48.2^\circ$$

(b)

$$\cos \theta_x = \frac{\mathbf{r} \cdot \mathbf{a}_x}{r} = \frac{2}{4} \quad \rightarrow \quad \theta_x = 60^\circ$$

$$\cos \theta_y = \frac{\mathbf{r} \cdot \mathbf{a}_y}{r} = \frac{3}{4} \quad \rightarrow \quad \theta_y = 41.4^\circ$$

$$\cos \theta_z = \frac{\mathbf{r} \cdot \mathbf{a}_z}{r} = \frac{\sqrt{3}}{4} \quad \rightarrow \quad \theta_z = 64.3^\circ$$

$$1.20 \quad \pm \frac{1}{\sqrt{5}}(-\mathbf{a}_\rho + 2\mathbf{a}_\phi)$$

1.21

$$\begin{aligned} (\mathbf{A} \cdot \mathbf{a}_{\mathcal{R}}) \mathbf{a}_{\mathcal{R}} &= (2\sqrt{3} \mathbf{a}_x + 2\mathbf{a}_y) \cdot \left(-\frac{\sqrt{3}}{2} \mathbf{a}_x + \frac{1}{2} \mathbf{a}_y \right) \mathbf{a}_{\mathcal{R}} \\ &= \sqrt{3} \mathbf{a}_x - \mathbf{a}_y \end{aligned}$$

1.22

$$(a) \quad \mathbf{F}_\perp = \frac{1}{2} \mathbf{a}_R$$

$$(b) \quad \mathbf{F}_\parallel = \mathbf{F} - \mathbf{F}_\perp = \frac{3}{\sqrt{2}} \mathbf{a}_\theta - 2\mathbf{a}_\phi$$

$$1.23 \quad \mathbf{F}_\parallel = \mathbf{F} - \mathbf{F}_\perp = \frac{1}{2} \mathbf{a}_R - 2\mathbf{a}_\phi$$

위치벡터와 거리벡터

$$1.24 \quad \mathbf{r} = 3\mathbf{a}_x + 4\mathbf{a}_y + z \mathbf{a}_z$$

$$\begin{aligned} 1.25 \quad \mathcal{R} &= \mathbf{r} - \mathbf{r}' \\ &= -x \mathbf{a}_x - y \mathbf{a}_y + 4\mathbf{a}_z \end{aligned}$$

1.26

$$(a) \quad \mathbf{a}_n = \frac{2}{3} \mathbf{a}_x + \frac{1}{3} \mathbf{a}_y + \frac{2}{3} \mathbf{a}_z$$

$$(b) \quad \mathbf{r} = \mathbf{r}_1 + d \mathbf{a}_n = \left(1 + \frac{2}{3} d \right) \mathbf{a}_x + \left(1 + \frac{1}{3} d \right) \mathbf{a}_y + \left(\frac{2}{3} d \right) \mathbf{a}_z$$

1.27

$$(a) \overline{p_1 p_0} = |\mathbf{R}_{1-3} \cdot \mathbf{a}_{1-2}| = \left| (-\mathbf{a}_x - 2\mathbf{a}_y + 2\mathbf{a}_z) \cdot \left(\frac{2}{3}\mathbf{a}_x - \frac{2}{3}\mathbf{a}_y + \frac{1}{3}\mathbf{a}_z \right) \right| = \frac{4}{3}$$

$$(b) \overline{p_3 p_0} = |\mathbf{R}_{1-3} \times \mathbf{a}_{1-2}| = \frac{1}{3} \begin{vmatrix} \mathbf{a}_x & \mathbf{a}_y & \mathbf{a}_z \\ -1 & -2 & 2 \\ 2 & -2 & 1 \end{vmatrix} = \frac{1}{3} |(2\mathbf{a}_x + 5\mathbf{a}_y + 6\mathbf{a}_z)| = \frac{\sqrt{65}}{3}$$

1.28 $\mathbf{R}_{1-2} = (2 - \sqrt{3})\mathbf{a}_p + \mathbf{a}_\phi$

점곱 및 가위곱

1.29 증명 생략

1.30 증명 생략

1.31 $180^\circ - 94.10^\circ - 42.95^\circ = 42.95^\circ$

1.32 $\frac{1}{2} |\mathbf{R}_{2-1} \times \mathbf{R}_{3-1}| = \frac{1}{2} \sqrt{36 + 4 + 64} = 5.1$

1.33 $\frac{c}{a} = 1.55$

1.34 증명 생략

1.35 $\theta = 180^\circ - 84.3^\circ = 95.7^\circ$

1.36 $\mathbf{k}_r = -3\mathbf{a}_x + 4\mathbf{a}_y + 5\mathbf{a}_z$

선과 면

$$1.37 \quad \pm \frac{1}{5}(4\mathbf{a}_x + 3\mathbf{a}_y).$$

$$1.38 \quad (a) \quad \mathbf{r} \cdot \mathbf{a}_n = \frac{c}{\sqrt{a^2 + b^2}} = p$$

(b) $\mathbf{a}_n$ 는 평면상의 선에 수직인 단위벡터이다.
 p 는 원점에서 선까지의 수직 거리이다.

$$1.39 \quad 78.7^\circ.$$

$$1.40 \quad (a) \quad \mathbf{r} \cdot \mathbf{a}_n = \frac{d}{\sqrt{a^2 + b^2 + c^2}} = p$$

(b) $\mathbf{a}_n$ 는 평면에 수직인 단위벡터이다.
 p 는 원점에서 평면까지의 수직 거리이다.

$$1.41 \quad \theta = \cos^{-1} \frac{\mathbf{A} \cdot \mathbf{B}}{AB} = \cos^{-1} \frac{4}{3\sqrt{13}} = 68.3^\circ$$

$$1.42 \quad (a) \quad \frac{1}{2}x + y + z = 1$$

(b) $2\mathbf{a}_x \cdot \frac{1}{3}(\mathbf{a}_x + 2\mathbf{a}_y + 2\mathbf{a}_z) = \frac{2}{3}$

$$1.43 \quad x + 2y + 4z = 13$$

미분 면적벡터

- 1.44 (a) $d\mathbf{s} = 4d\phi dz \mathbf{a}_\rho$
 (b) $d\mathbf{s} = 2d\rho d\phi \mathbf{a}_z$
 (c) $d\mathbf{s} = d\rho dz \mathbf{a}_\phi$
 (d) $d\mathbf{s} = -d\rho dz \mathbf{a}_\phi$
- 1.45 (a) $d\mathbf{s} = 36 \sin 20^\circ d\theta d\phi \mathbf{a}_R = 12.3 d\theta d\phi \mathbf{a}_R$
 (b) $d\mathbf{s} = 4 \sin 30^\circ dR d\phi \mathbf{a}_\theta = 2 dR d\phi \mathbf{a}_\theta$
 (c) $d\mathbf{s} = -4 dR d\theta \mathbf{a}_\phi$
 (d) $d\mathbf{s} = 5 dR d\theta \mathbf{a}_\phi$
- 1.46 (a) $\pm dy dz \mathbf{a}_x$
 (b) $\pm dx dy \mathbf{a}_z$
 (c) $\pm \rho d\rho d\phi \mathbf{a}_z$
 (d) $\pm 2d\phi dz \mathbf{a}_\rho$
 (e) $\pm d\rho dz \mathbf{a}_\phi$
 (f) $\pm 9 \sin \theta d\theta d\phi \mathbf{a}_R$
 (g) $\pm R dR d\theta \mathbf{a}_\phi$
 (h) $\pm (R/2) dR d\phi \mathbf{a}_\theta$

좌표 변환

- 1.47 $\mathbf{H} = \frac{I}{(x-x_1)^2 + (y-y_1)^2} [-(y-y_1)\mathbf{a}_x + (x-x_1)\mathbf{a}_y]$
- 1.48 $\mathbf{E} = q \frac{[(x-x_1)\mathbf{a}_x + (y-y_1)\mathbf{a}_y + (z-z_1)\mathbf{a}_z]}{[(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2]^{3/2}}$
- 1.49 $\mathbf{A}' = \sqrt{3} [(\sqrt{3}+1)x' + (\sqrt{3}-1)y'] \mathbf{a}_{x'} - [(\sqrt{3}+1)x' + (\sqrt{3}-1)y'] \mathbf{a}_{y'}$
- 1.50 (a) $\phi = 180^\circ - 63.4^\circ = 116.6^\circ$, $z = 3$, (b) $\phi = 116.6^\circ$.

$$\begin{aligned}
1.51 \quad (a) \quad \mathbf{a}_x &= \frac{1}{\sqrt{14}} \mathbf{a}_R + \frac{3}{\sqrt{70}} \mathbf{a}_\theta + \frac{2}{\sqrt{5}} \mathbf{a}_\phi \\
(b) \quad \mathbf{a}_x &= \frac{1}{\sqrt{2}} \mathbf{a}_R + \frac{1}{2} \mathbf{a}_\theta - \frac{1}{2} \mathbf{a}_\phi \\
(c) \quad \mathbf{a}_x &= \frac{1}{2\sqrt{2}} \mathbf{a}_R + \frac{1}{2\sqrt{2}} \mathbf{a}_\theta - \frac{\sqrt{3}}{2} \mathbf{a}_\phi
\end{aligned}$$

$$\begin{aligned}
1.52 \quad (a) \quad \mathbf{A} &= \sqrt{2} \mathbf{a}_\rho + \frac{1}{2} \mathbf{a}_z \\
(b) \quad \mathbf{A} &= \frac{3}{2} \mathbf{a}_R
\end{aligned}$$

$$1.53 \quad \mathbf{H} = \frac{2}{x^2 + y^2} (x \mathbf{a}_x + y \mathbf{a}_y)$$

$$1.54 \quad \mathbf{H} = \frac{1}{(x^2 + y^2 + z^2)^{3/2}} \left[\frac{xz}{\sqrt{x^2 + y^2}} \mathbf{a}_x + \frac{yz}{\sqrt{x^2 + y^2}} \mathbf{a}_y - \sqrt{x^2 + y^2} \mathbf{a}_z \right]$$

$$1.55 \quad \mathbf{a}_{A'} = \frac{1}{3\sqrt{2}} (-\mathbf{a}_\rho + 3\mathbf{a}_\phi - 2\sqrt{2} \mathbf{a}_z)$$

$$1.56 \quad d\mathbf{l} = d\rho \mathbf{a}_\rho + \rho d\phi \mathbf{a}_\phi + dz \mathbf{a}_z$$

1.57 변환을 하려면 변환행렬 $\mathbf{T}$ 외에도 삼각법과 피타고라스 정리를 사용해야 한다.

$$1.58 \quad \begin{bmatrix} A_R \\ A_\theta \\ A_\phi \end{bmatrix} = \begin{bmatrix} \sin \theta \cos \phi & \sin \theta \sin \phi & \cos \theta \\ \cos \theta \cos \phi & \cos \theta \sin \phi & -\sin \theta \\ -\sin \phi & \cos \phi & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

1.59 증명 생략

Chapter 02 연습문제 답안

선 및 면

$$2.1 \quad \mathbf{a}_T = \frac{-2\sqrt{3}\mathbf{a}_x + \mathbf{a}_y}{\sqrt{13}}$$

2.2 x 가 증가함에 따라 타원에서 시계방향으로 움직인다.

$$2.3 \quad (a) \quad \mathbf{r}(\varphi) = (2 + 0.5 \cos \varphi) \mathbf{a}_x + (1 + 0.5 \sin \varphi) \mathbf{a}_y$$

$$(b) \quad d\mathbf{l} = \frac{d\mathbf{r}}{d\varphi} d\varphi = (-0.5 \sin \varphi) d\varphi \mathbf{a}_x + (0.5 \cos \varphi) d\varphi \mathbf{a}_y$$

2.4

$$(a) \quad \mathbf{r}(y) = x_1 \mathbf{a}_x + y \mathbf{a}_y + \left[\sqrt{a^2 - x_1^2 - y^2} + a \right] \mathbf{a}_z$$

(b)

$$d\mathbf{l}^1 = \left[\mathbf{a}_x - \frac{x_1}{\sqrt{a^2 - x_1^2 - y_1^2}} \mathbf{a}_z \right] dx$$

$$d\mathbf{l}^2 = \left[\mathbf{a}_y - \frac{y_1}{\sqrt{a^2 - x_1^2 - y_1^2}} \mathbf{a}_z \right] dy$$

(c)

$$\begin{aligned} d\mathbf{s} &= d\mathbf{l}^1 \times d\mathbf{l}^2 \\ &= \left[\frac{x}{\sqrt{a^2 - x^2 - y^2}} \mathbf{a}_x + \frac{y}{\sqrt{a^2 - x^2 - y^2}} \mathbf{a}_y + \mathbf{a}_z \right] dxdy \end{aligned}$$

$$2.5 \quad (a) \quad \mathbf{r} = x \mathbf{a}_x + y \mathbf{a}_y + \sqrt{a^2 - y^2} \mathbf{a}_z$$

$$(b) \quad d\mathbf{s} = d\mathbf{l}^1 \times d\mathbf{l}^2 = \left(\mathbf{a}_z + \frac{y}{\sqrt{a^2 - y^2}} \mathbf{a}_y \right) dxdy$$

2.6

$$(a) \mathbf{r}(\rho, \phi) = \rho \mathbf{a}_\rho + z \mathbf{a}_z = \rho \mathbf{a}_\rho + \frac{1}{2} \sqrt{16 - \rho^2} \mathbf{a}_z$$

$$(b) d\mathbf{s} = \left(\frac{\partial \mathbf{r}}{\partial \rho} \times \frac{\partial \mathbf{r}}{\partial \phi} \right) d\rho d\phi = \left(\frac{1}{2} \frac{\rho^2}{\sqrt{16 - \rho^2}} \mathbf{a}_\rho + \rho \mathbf{a}_z \right) d\rho d\phi$$

선적분

2.7 (a) 28/3
(b) 28/3

2.8 $\frac{\pi}{4}$

2.9 (a) $\mathbf{r} = x \mathbf{a}_x + y \mathbf{a}_y = x \mathbf{a}_x + \sqrt{1 - x^2} \mathbf{a}_y$
(b) $-\ln 2$

2.10

$$\begin{aligned} \int_C \mathbf{A} \cdot d\mathbf{l} &= \int_{R=2}^{R=3} R \sin 90^\circ \cos 30^\circ dR + \int_{\phi=30^\circ}^{\phi=60^\circ} (-\sin \phi) 3 \sin 90^\circ d\phi \\ &\quad + \int_{R=3}^{R=2} R \sin 90^\circ \cos 60^\circ dR + \int_{\phi=60^\circ}^{\phi=30^\circ} (-\sin \phi) 2 \sin 90^\circ d\phi \\ &= \frac{\sqrt{3}}{2} \frac{5}{2} + 3 \left(\frac{1}{2} - \frac{\sqrt{3}}{2} \right) + \frac{1}{2} \left(-\frac{5}{2} \right) + 2 \left(\frac{\sqrt{3}}{2} - \frac{1}{2} \right) \\ &= \frac{3}{4} (\sqrt{3} - 1) \end{aligned}$$

2.11 -2

면적분

2.12 10π

2.13

$$\begin{aligned}
 \int_S \mathbf{A} \cdot d\mathbf{s} &= \int_{\text{At } \rho=4} \mathbf{A} \cdot (\mathbf{a}_\rho \rho d\phi dz) \\
 &+ \int_{\text{At } \phi=30^\circ} \mathbf{A} \cdot (-\mathbf{a}_\phi d\rho dz) + \int_{\text{At } \phi=210^\circ} \mathbf{A} \cdot (\mathbf{a}_\phi d\rho dz) \\
 &+ \int_{\text{At } z=0} \mathbf{A} \cdot (-\mathbf{a}_z \rho d\rho d\phi) + \int_{\text{At } z=5} \mathbf{A} \cdot (\mathbf{a}_z \rho d\rho d\phi) \\
 &= \int_{z=0}^{z=5} \int_{\phi=\pi/6}^{\phi=7\pi/6} 4^2 d\phi dz \\
 &+ \int_{z=0}^{z=5} \int_{\rho=0}^{\rho=4} 3\rho \cos 30^\circ (d\rho dz) + \int_{z=0}^{z=5} \int_{\rho=0}^{\rho=4} -3\rho \cos 210^\circ (d\rho dz) \\
 &+ \int_{\phi=\pi/6}^{\phi=7\pi/6} \int_{\rho=0}^{\rho=4} 2(0)\rho d\rho d\phi + \int_{\phi=\pi/6}^{\phi=7\pi/6} \int_{\rho=0}^{\rho=4} -2(5)\rho d\rho d\phi \\
 &= 80\pi + 60\sqrt{3} + 60\sqrt{3} + 0 - 80\pi = 120\sqrt{3}
 \end{aligned}$$

2.14 -3π

선 및 면그래디언트

2.15

$$\begin{aligned}
 \text{(a)} \quad \nabla U &= 6ze^{2x+y} \mathbf{a}_x + 3ze^{2x+y} \mathbf{a}_y + 3e^{2x+y} \mathbf{a}_z \\
 \text{(b)} \quad \nabla V &= 5 \sin \phi \mathbf{a}_\rho + 5 \cos \phi \mathbf{a}_\phi - \frac{2z}{z^2+1} \mathbf{a}_z \\
 \text{(c)} \quad \nabla W &= -2 \frac{\sin \theta \cos \phi}{R^3} \mathbf{a}_R + \frac{\cos \theta \cos \phi}{R^3} \mathbf{a}_\theta - \frac{\sin \phi}{R^3} \mathbf{a}_\phi
 \end{aligned}$$

2.16 (a) 6
(b) $-\ln 5 - 10$
(c)

$$\begin{aligned}
 \int_{p_1}^{p_2} \nabla W \cdot d\mathbf{l} &= W(p_2) - W(p_1) = \left[\frac{\sin 0^\circ \cos 45^\circ}{2^2} \right] - \left[\frac{\sin 90^\circ \cos 45^\circ}{8} \right] \\
 &= -\frac{1}{8\sqrt{2}}
 \end{aligned}$$

2.17 (a) 예, (b) 예, (c) 예, (d) 예

2.18 증명 생략됨

- 2.19 (a) 5
(b) -8
(c) 6

2.20 $\nabla W = 4\sqrt{2} \mathbf{a}_x - 8\sqrt{2} \mathbf{a}_y - 2\sqrt{2} \mathbf{a}_z$

- 2.21 (a) p_o, p_4
(b) p_3
(c) p_1, p_2, p_3 에서 p_o 로 향한다.

- 2.22 (a) $\nabla V = 2\mathbf{a}_z$
(b)
$$\nabla V = \frac{\partial V}{\partial R} \mathbf{a}_R + \frac{1}{R} \frac{\partial V}{\partial \theta} \mathbf{a}_\theta + \frac{1}{R \sin \theta} \frac{\partial V}{\partial \phi} \mathbf{a}_\phi$$
$$= 2 \cos \theta \mathbf{a}_R - 2 \sin \theta \mathbf{a}_\theta$$

(c) $\nabla V = 2\mathbf{a}_z$

2.23 $\nabla V = \frac{\partial V}{\partial x'} \mathbf{a}_{x'} + \frac{\partial V}{\partial y'} \mathbf{a}_{y'} + \frac{\partial V}{\partial z'} \mathbf{a}_{z'}$

- 2.24 (a) $\nabla f = \nabla (k_x x + k_y y + k_z z) = \mathbf{k}$
(b) $\mathbf{k}$ 에 수직인 무한 평면
(c) $c_1 / |\mathbf{k}|$ 는 원점에서 평면까지의 수직 거리이다.

2.25 $\theta = \cos^{-1} \frac{\mathbf{A} \cdot \mathbf{B}}{AB} = \cos^{-1} \frac{-36 + 64}{6^2 + 8^2} = 73.7^\circ$

- 2.26 (a) $\mathbf{a}_n = \frac{1}{\sqrt{11}} (3\mathbf{a}_x + \mathbf{a}_y + \mathbf{a}_z)$
(b) $3x + y + z = 12$

2.27

$$\begin{aligned} d\mathbf{s} &= \frac{2\rho^2 d\rho d\phi}{8z} \mathbf{a}_\rho + \rho d\rho d\phi \mathbf{a}_z \\ &= \left(\frac{\rho^2}{2\sqrt{16-\rho^2}} \mathbf{a}_\rho + \rho \mathbf{a}_z \right) d\rho d\phi \end{aligned}$$

2.28 $\mathbf{r} = x\mathbf{a}_x + 3x\mathbf{a}_y + 2x^4\mathbf{a}_z$

선속 및 선속밀도

2.29 $\Phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \frac{\mathbf{a}_R}{a} \cdot \mathbf{a}_R a^2 \sin \theta d\theta d\phi = 4\pi a$

2.30 $\Phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \int_{R=0}^a \frac{e^{-2R}}{R^2} R^2 \sin \theta dR d\theta d\phi = 2\pi(1 - e^{-2a})$

다이버전스 및 다이버전스 정리

2.31 증명 생략

2.32 (a) $\nabla \cdot \mathbf{A} = -\frac{(x+y+z)}{(x^2+y^2+z^2)^{3/2}}$

(b) $\nabla \cdot \mathbf{B} = \frac{1}{\rho}(\ln \rho + 1) - \sin \phi + 3z^2$

(c) $\nabla \cdot \mathbf{C} = -\frac{1}{R^4} + 2e^{-R} \cos \theta - R \sin \theta \sin 2\phi$

2.33 (a) $\nabla \cdot \mathbf{D} = 1$, (b) 1

2.34 (a) 3, (b) 3

2.35 증명 생략

2.36 증명 생략

2.37 증명 생략

2.38 증명 생략

컬 및 스토크스 정리

2.39 (a)

$$\nabla \times \mathbf{A} = \begin{vmatrix} \mathbf{a}_x & \mathbf{a}_y & \mathbf{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & x^2 & -z \end{vmatrix} = 2x \mathbf{a}_z$$

(b) $\nabla \times \mathbf{A} = 2x \mathbf{a}_z$

2.40 증명 생략

2.41 증명 생략

2.42 증명 생략

2.43 증명 생략

2.44 증명 생략

2.45 증명 생략

2.46 증명 생략

라플라시안

- 2.47 (a) $\nabla^2 V = 2z + 2y$
(b) $\nabla^2 V = 3z \sin \phi$
(c) $\nabla^2 V = 3 \cos \phi$

헬름홀츠 정리

- 2.48 (a) 비회전장이지만, 솔레노이드는 아님
(b) 솔레노이드형이면서 비회전형임
(c) 솔레노이드형이지만, 비회전형은 아님
(d) 솔레노이드도 아니고 비회전장도 아님
(e) 비회전장이지만, 솔레노이드는 아님
(f) 솔레노이드형이면서 비회전형임

- 2.49 (a) $\mathbf{k} \cdot \mathbf{A} = 0$, (b) $\mathbf{k} \times \mathbf{A} = 0$.

2.50 $\mathbf{H} = \frac{A}{\rho} \mathbf{a}_\phi$

2.51 $\mathbf{E}(\mathbf{r}) = \frac{A}{R^2} \mathbf{a}_R$

Chapter 03 연습문제 답안

쿨롱 법칙

$$3.1 \quad q_2 = -Q [\text{C}]$$

$$3.2 \quad x = \sqrt{2}$$

$$3.3 \quad \mathbf{F}_1 + \mathbf{F}_2 = \frac{q^2}{4\pi\epsilon_0 a^2} (\mathbf{a}_x + \mathbf{a}_y + \mathbf{a}_z) \left(1 + \frac{1}{3\sqrt{3}} - \frac{1}{\sqrt{2}} \right)$$

3.4

$$\begin{aligned} \mathbf{F}_1 &= \left(-2.26 \times 15 \times 10^{-9} + \frac{15 \times 10 \times 10^{-18}}{4\pi \times 8.854 \times 10^{-12} \times 5^2} \right) \mathbf{a}_z \\ &= (-33.9 + 53.9) \times 10^{-9} \mathbf{a}_z \\ &= 20.0 \times 10^{-9} \mathbf{a}_z [\text{N}] \end{aligned}$$

The electric force on q_2 is

$$\begin{aligned} \mathbf{F}_2 &= (2.26 \times 10 \times 10^{-9} - 53.9 \times 10^{-9}) \mathbf{a}_z \\ &= -31.3 \times 10^{-9} \mathbf{a}_z [\text{N}] \end{aligned}$$

전기장 세기

$$3.5 \quad \mathbf{E} = -\frac{\rho_\ell}{10\pi\epsilon_0} (2\mathbf{a}_x + \mathbf{a}_z)$$

$$3.6 \quad \mathbf{E} = \frac{\rho_\ell \epsilon_0}{4\pi\epsilon_0 \rho} [(\cos \theta_2 + \cos \theta_1) \mathbf{a}_\rho + (\sin \theta_2 - \sin \theta_1) \mathbf{a}_z]$$

$$3.7 \quad \mathbf{E} = \mathbf{a}_x \frac{\rho_\ell}{2\pi\epsilon_0 \mathcal{R}} \left(2 \frac{\mathcal{R}_x}{\mathcal{R}} \right) = \mathbf{a}_x \frac{\rho_\ell}{\pi\epsilon_0} \frac{a(1 - \cos \phi_1)}{2a^2(1 - \cos \phi_1)} = \mathbf{a}_x \frac{\rho_\ell}{2\pi\epsilon_0 a}$$

$$3.8 \quad \mathbf{E} = \mathbf{a}_y \frac{\rho_s}{\pi \epsilon_0} \tan^{-1} \left(\frac{a}{b} \right)$$

3.9

$$\begin{aligned} \mathbf{E} &= \int_{z'=-b}^{z'=b} \frac{\rho_s dz'}{2\epsilon_0} \frac{a(z-z')\mathbf{a}_z}{[a^2 + (z-z')^2]^{3/2}} = \frac{\rho_s a \mathbf{a}_z}{2\epsilon_0} \frac{1}{[a^2 + (z-z')^2]^{1/2}} \bigg|_{z'=-b}^{z'=b} \\ &= \frac{\rho_s a \mathbf{a}_z}{2\epsilon_0} \left[\frac{1}{[a^2 + (z-b)^2]^{1/2}} - \frac{1}{[a^2 + (z+b)^2]^{1/2}} \right] \end{aligned}$$

$$3.10 \quad \mathbf{E} = \mathbf{a}_\rho \frac{\rho_s}{\epsilon_0}$$

$$3.11 \quad (a) \quad \mathbf{E} = \frac{Q}{2\pi\epsilon_0 a^2} \mathbf{a}_z \left(1 - \frac{1}{\sqrt{(a/b)^2 + 1}} \right)$$

$$(b) \quad b > 5a$$

$$(c) \quad b < 0.01a$$

$$3.12 \quad \mathbf{E} = \frac{\rho_s}{2\epsilon_0} (-\mathbf{a}_n) = -\frac{\rho_s}{14\epsilon_0} (6\mathbf{a}_x + 3\mathbf{a}_y + 2\mathbf{a}_z)$$

$$3.13 \quad \mathbf{E} = \frac{\rho_v}{4\epsilon_0} \mathbf{a}_y$$

$$3.14 \quad R = c \sin^2 \theta$$

전속

$$3.15 \quad 20 [\text{nC/m}] \times 0.2 [\text{m}] = 4 [\text{nC}]$$

$$3.16 \quad q/8[\text{C}]$$

$$3.17 \quad q/2$$

$$3.18 \quad 5[\mu\text{C}]$$

가우스 법칙

$$3.19 \quad (\text{a}) \quad \mathbf{E} = 0 \quad \text{Outside}$$

$$\mathbf{E} = -\frac{Q}{A\epsilon_0}\mathbf{a}_z \quad \text{Gap}$$

$$\mathbf{E} = -\frac{Q}{2A\epsilon_0}\mathbf{a}_z \quad \text{Interior of the conductor}$$

(b) 전하는 $\mathbf{E}$ 가 간격이 0이 되지 않도록 상판의 바닥과 아래판의 윗면에 위치해야 한다.

$$3.20 \quad \mathbf{D} = (1 - e^{-z})\mathbf{a}_z \quad (z > 0)$$

$$\mathbf{D} = -(1 - e^z)\mathbf{a}_z \quad (z < 0)$$

$$3.21 \quad \mathbf{D} = \frac{\rho_v(\rho^2 - a^2)}{2\rho}\mathbf{a}_\rho, \quad \mathbf{D} = \frac{\rho_v(b^2 - a^2)}{2\rho}\mathbf{a}_\rho$$

$$3.22 \quad \mathbf{D} = \frac{(a^2\rho_{s1} + b^2\rho_{s2})}{R^2}\mathbf{a}_R, \quad \mathbf{D} = \frac{a^2\rho_{s1}}{R^2}\mathbf{a}_R, \quad \mathbf{D} = 0$$

$$3.23 \quad \mathbf{D} = \mathbf{D}_s + \mathbf{D}_l = (7.7\mathbf{a}_y + 2.6\mathbf{a}_z)[\text{nC/m}^2]$$

$$3.24 \quad \rho_v = \frac{1}{4\pi\epsilon_0 R^2}$$

$$Q = \int_{\phi=0}^{\phi=2\pi} \int_{\theta=0}^{\theta=\pi} \int_{R=a}^{R=b} \frac{1}{4\pi\epsilon_0 R^2} R^2 \sin\theta dR d\theta d\phi = \frac{1}{\epsilon_0} (b-a)$$

전위

3.25 K 는 보존장이 아니다.

3.26 둘 다 아니다.

3.27 (a) 36, (b), 36

$$3.28 \quad V_{p-o} = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{\sqrt{5}} - \frac{1}{\sqrt{7}} - \frac{1}{4} + \frac{1}{6} \right]$$

$$3.29 \quad V = \sum_{n=1}^N \frac{Q/N}{4\pi\epsilon_0 \sqrt{a^2 + d^2 - 2ad \cos(2\pi n/N)}}$$

$$\begin{aligned} 3.30 \quad V &= \frac{1}{4\pi\epsilon_0} \int_{\mathcal{R}} \frac{\rho_{\ell o}}{r'} d\ell' \\ &= \frac{\rho_{\ell o}}{4\pi\epsilon_0} \left[\int_{\phi'=0}^{\pi} \frac{ad\phi'}{\sqrt{a^2 + b^2}} + \int_{x'=-a}^a \frac{1}{\sqrt{b^2 + x'^2}} dx' \right] \\ &= \frac{\rho_{\ell o}}{4\pi\epsilon_0} \left[\frac{a\pi}{\sqrt{a^2 + b^2}} + \ln \left(x' + \sqrt{b^2 + x'^2} \right) \right]_{x'=-a}^a \\ &= \frac{\rho_{\ell o}}{4\pi\epsilon_0} \left[\frac{a\pi}{\sqrt{a^2 + b^2}} + \ln \frac{a + \sqrt{a^2 + b^2}}{-a + \sqrt{a^2 + b^2}} \right] \end{aligned}$$

3.31 대칭성이 부족

$$3.32 \quad V = -6.78 \times 10^4 \times \ln(\rho / 0.4) [\text{V}] \quad (1)$$

$$V = -6.78 \times 10^4 \times \ln(0.2 / 0.4) = 4.70 \times 10^4 [\text{V}] \quad (2)$$

$$V = 0 \quad (3)$$

$$\begin{aligned} 3.33 \quad V_1 &= \frac{Q}{4\pi\epsilon_0 R} \\ V_2 &= V_1(R=b) - \int_{R=b}^{R=R_2} \mathbf{E}_2 \cdot d\mathbf{l} \\ &= \frac{Q}{4\pi\epsilon_0 b} + \frac{Q}{4\pi\epsilon} \left(\frac{1}{R} - \frac{1}{b} \right) \\ V_3 &= \frac{Q}{4\pi\epsilon_0 b} + \frac{Q}{4\pi\epsilon} \left(\frac{1}{a} - \frac{1}{b} \right) \end{aligned}$$

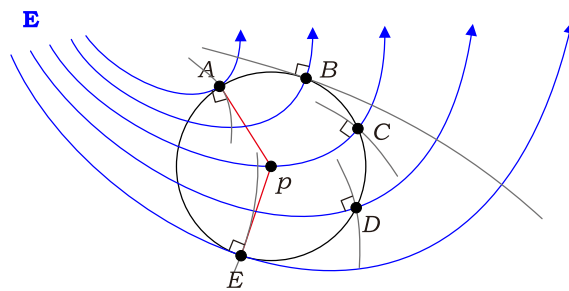
$$3.34 \quad V = V_a + V_{1-a} = \frac{\rho_v}{6\epsilon_0} [3a^2 - R_1^2]$$

$$3.35 \quad 2x + 3y = 0$$

$$3.36 \quad xy^2 = 2$$

$$3.37 \quad (y^2 + z^2)^{3/2} = \frac{z}{(4\pi\epsilon_0 / qd)V}$$

3.38



전기분극

$$3.39 \quad (a) \quad \mathbf{D} = \frac{q}{4\pi R^2} \mathbf{a}_R$$

$$\mathbf{E} = \frac{\mathbf{D}}{\epsilon_r \epsilon_0} = \frac{q}{4\pi\epsilon_0\epsilon_r R^2} \mathbf{a}_R$$

$$\mathbf{P} = \mathbf{D} - \epsilon_0 \mathbf{E} = \frac{\epsilon_r - 1}{\epsilon_r} \frac{q}{4\pi R^2} \mathbf{a}_R$$

$$(b) \rho_{pv} = -\nabla \cdot \mathbf{P} = -\nabla \cdot \left(\frac{\epsilon_r - 1}{\epsilon_r} \frac{q}{4\pi R^2} \mathbf{a}_R \right) = 0$$

(c) 증명 생략

3.40 증명 생략

$$\mathbf{3.41} \quad \rho_{ps} = \mathbf{P} \cdot \mathbf{a}_n = \frac{\epsilon_r - 1}{\epsilon_r} \frac{\rho_\ell}{2\pi c}$$

$$\mathbf{3.42} \quad (a) \mathbf{P} = \epsilon_0 (\epsilon_r - 1) \mathbf{E}_i = 7.5\epsilon_0 (\epsilon_r - 1) \mathbf{a}_z$$

$$(b) \rho_{ps} = \mathbf{P} \cdot \mathbf{a}_R = 7.5\epsilon_0 (\epsilon_r - 1) \cos \theta$$

$$(c) \mathbf{E}_p = -\frac{7.5\epsilon_0 (\epsilon_r - 1)}{3\epsilon_0} \mathbf{a}_z$$

$$(d) \epsilon_r = 2.$$

3.43

$$(a) \mathbf{E} = \frac{Q}{2\pi\epsilon_0 R^2 (\epsilon_r + 1)} \mathbf{a}_R$$

$$(b) S_{a2} : \rho_{ps}^a = \mathbf{P} \cdot (-\mathbf{a}_R) = \frac{-Q(\epsilon_r - 1)}{2\pi a^2 (\epsilon_r + 1)},$$

$$S_{b2} : \rho_{ps}^b = \mathbf{P} \cdot (\mathbf{a}_R) = \frac{Q(\epsilon_r - 1)}{2\pi b^2 (\epsilon_r + 1)}$$

$$(c) S_{a1} : \rho_s = \frac{Q}{2\pi a^2 (\epsilon_r + 1)}, \quad S_{a2} : \rho_s = \rho_{s, total} - \rho_{ps}^a = \frac{\epsilon_r Q}{2\pi a^2 (\epsilon_r + 1)}$$

(d) 유일해이다.

경계면 조건

3.44

$$(a) \mathbf{E}_2 = 3\mathbf{a}_x - 2\mathbf{a}_y + 4\mathbf{a}_z$$

$$(b) \rho_{ps} = \rho_{ps1} + \rho_{ps2} = 2\epsilon_0$$

$$(c) \mathbf{E}_{ps1} = \frac{\rho_{ps}}{2\epsilon_0} \mathbf{a}_z = \mathbf{a}_z \quad (z \geq 0)$$

$$\mathbf{E}_{ps2} = -\mathbf{a}_z \quad (z < 0)$$

$$(d) \mathbf{E}_1 - \mathbf{E}_{ps1} = \mathbf{E}_2 - \mathbf{E}_{ps2} = 3\mathbf{a}_x - 2\mathbf{a}_y + 5\mathbf{a}_z$$

3.45 $V_d = -y - z$

3.46 $E_z = \epsilon_r E_{iz} = \frac{\epsilon_r \rho_{ps}}{\epsilon_0 (\epsilon_r - 1)} = 338.8 [\text{V/m}]$

3.47 (a) $\mathbf{D} = 0 = \mathbf{E} \quad (z > 0.2 \text{ or } z < 0)$
 $\mathbf{D} = -4.5\mathbf{a}_z [\text{nC/m}^2] \quad (0 < z < 0.2)$

$$\mathbf{E} = \frac{\mathbf{D}}{\epsilon_0 \epsilon_r} = -\frac{3 \times 10^{-9}}{\epsilon_0} \mathbf{a}_z [\text{V/m}],$$

$$\mathbf{P} = \mathbf{D} - \epsilon_0 \mathbf{E} = -1.5\mathbf{a}_z [\text{nC/m}^2] \quad (0 < z < 0.1)$$

$$\mathbf{E} = -\frac{4.5}{\epsilon_0} \mathbf{a}_z [\text{nV/m}],$$

$$\mathbf{P} = 0 \quad (0.1 < z < 0.2)$$

$$\rho_{ps} = \mathbf{P} \cdot \mathbf{a}_n = -1.5 \times 10^{-9} \mathbf{a}_z \cdot (-\mathbf{a}_z) = 1.5 [\text{nC/m}^2] \quad (z = 0)$$

$$\rho_{ps} = \mathbf{P} \cdot \mathbf{a}_n = -1.5 \times 10^{-9} \mathbf{a}_z \cdot \mathbf{a}_z = -1.5 [\text{nC/m}^2] \quad (z = 0.1)$$

(b) $\rho_s + \rho_{ps} = -3.0 [\text{nC/m}^2] \quad (z = 0)$

$$-1.5 [\text{nC/m}^2] \quad (z = 0.1)$$

$$4.5 [\text{nC/m}^2] \quad (z = 0.2)$$

3.48 $\mathbf{E} = 7.5(2 \cos \theta \mathbf{a}_R - \sin \theta \mathbf{a}_\theta)$

- 3.49 (a) $3.66 \varepsilon_0 \text{ [C/m}^2\text{]} \quad (z = d), -3.66 \varepsilon_0 \text{ [C/m}^2\text{]} \quad (z = 0)$
 (b) $\mathbf{E}_1 = 5\mathbf{a}_x + 5\sqrt{3}\mathbf{a}_z$
 (c) 설명 생략

- 3.50 (a) $\mathbf{E}_i = (5\mathbf{a}_x + 5\sqrt{3}\mathbf{a}_z) - 5.77\mathbf{a}_z = 5\mathbf{a}_x + 2.89\mathbf{a}_z$
 (b) $\varepsilon_r = 3.0$

- 3.51 (a) $A = \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2}$, and $B = \frac{2\varepsilon_2}{\varepsilon_1 + \varepsilon_2}$
 (b) $\rho_{ps} = 2\varepsilon_0 A [\mathbf{E}_o|_{z=0} \cdot (-\mathbf{a}_z)]$

3.52 $\mathbf{F} = -\frac{q^2}{16\pi\varepsilon_0 d^2} \frac{\chi_e}{\chi_e + 2} \mathbf{a}_z$

정전기 포텐셜 에너지

3.53 $W_E = \frac{1}{2} 5 [\text{nC}] \times (V_1 + V_2 + V_3) = \frac{25 \times 10^{-18}}{8\pi \times 8.854 \times 10^{-12}} [4 + \sqrt{2}] = 0.61 [\mu\text{J}]$

3.54 (a) $\mathbf{E} = \frac{a^2 \rho_{so}}{\varepsilon_0 R^2} \mathbf{a}_R \quad (R > a), \mathbf{E} = 0 \quad (R < a)$

$$V = \frac{4\pi a^2 \rho_{so}}{4\pi \varepsilon_0 R} = \frac{a^2 \rho_{so}}{\varepsilon_0 R}$$

(b) $W_E = \frac{1}{2} \int_{v'} \mathbf{D} \cdot \mathbf{E} dv = \frac{(a^2 \rho_{so})^2}{2\varepsilon_0} \int_0^{2\pi} \int_0^\pi \int_a^\infty \frac{1}{R^4} R^2 \sin \theta dR d\theta d\phi = \frac{2\pi a^3 \rho_{so}^2}{\varepsilon_0}$

(c) $W_E = \frac{1}{2} \int_s \rho_{so} V(R=a) ds = \frac{1}{2} \int_{\phi=0}^{2\pi} \int_{\theta=0}^\pi \rho_{so} \frac{a \rho_{so}}{\varepsilon_0} a^2 \sin \theta d\theta d\phi = \frac{2\pi a^3 \rho_{so}^2}{\varepsilon_0}$

(d) $W = \int_0^{\rho_{so}} \frac{a^3 \rho_s}{\varepsilon_0} 4\pi d\rho_s = 2\pi \frac{a^3 \rho_{so}^2}{\varepsilon_0}$

3.55 $W_E = \rho_v^2 \frac{4\pi}{15\varepsilon_0} a^5$

경계값 문제

3.56 ①만 라플라스 방정식을 만족한다.

3.57 $Q = -4\pi\epsilon_0 V_o \text{ [C]}$

3.58 (a)

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

$$\frac{\partial V}{\partial R} = \frac{c_o}{R^2}$$

$$V = \frac{c_1}{R} + c_2$$

(b)

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

$$\frac{\partial V}{\partial \rho} = \frac{c_o}{\rho}$$

$$V = c_1 \ln \rho + c_2$$

3.59 $V = -\frac{5}{3}(2x + y + 3z) + 20$

3.60 $V = V_o \frac{\ln[\tan(\theta/2)]}{\ln[\tan(\theta_o/2)]}$

3.61 $V = V_1 + \frac{q}{4\pi\epsilon} \left(\frac{1}{R} - \frac{1}{a} \right) \quad (0 < R < a)$

영상법

3.62 $71.9 \mathbf{a}_z \text{ [V/m]}$

$$3.63 \quad \mathbf{E} = \frac{q}{4\pi\epsilon_0} \left(\mathbf{a}_y - \frac{\mathbf{a}_y + 2\mathbf{a}_z}{5\sqrt{5}} \right)$$

3.64

$$\rho_s = \mathbf{D}|_{y=0} \cdot \mathbf{a}_y = \frac{q}{2\pi} \left[\frac{-b}{\{(x-a)^2 + b^2 + z^2\}^{3/2}} + \frac{b}{\{(x+a)^2 + b^2 + z^2\}^{3/2}} \right]$$

($y=0$)

$$\rho_s = \mathbf{D}|_{x=0} \cdot \mathbf{a}_x = \frac{q}{2\pi} \left[\frac{-a}{\{a^2 + (y-b)^2 + z^2\}^{3/2}} + \frac{a}{\{a^2 + (y+b)^2 + z^2\}^{3/2}} \right]$$

($x=0$)

$$3.65 \quad 2.43 [\text{nC/m}]$$

정전용량

$$3.66 \quad C = \frac{Q}{V} = \frac{S}{\frac{d}{2} \left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_0} \right)}$$

$$3.67 \quad C = \frac{Q}{V_o} = \epsilon_1 \frac{S}{2d} + \epsilon_0 \frac{S}{2d}$$

$$3.68 \quad C = \left| \frac{Q}{V} \right| = \frac{S\epsilon_1}{(e^d - 1)}$$

가상변위 원리

$$3.69 \quad (a) \quad \mathbf{F} = \frac{V_o^2}{2} \frac{S}{wd} (\epsilon_2 - \epsilon_1) \mathbf{a}_x$$

$$(b) \quad V_2 = V_o \frac{\epsilon_2 x_o + \epsilon_1 (w - x_o)}{\epsilon_2 w}$$

- 3.70** (a) $0.243\text{ [}\mu\text{J]}$
(b) $dV = 89.03\,dx$
(c) $0.11\text{ [}\mu\text{N/m]} .$

Chapter 04 연습문제 답안

전류 및 전류밀도

4.1 2.4 [A]

4.2 3.83 [A]

4.3 1.77 [A]

4.4 10^{19}

전도도

4.5 (a) $2.96 \times 10^{-4} \text{ [S/m]}$
(b) $1.18 \text{ [}\mu\text{A]}$
(c) $4.24 \text{ [M}\Omega\text{]}$
(d) $5.90 \text{ [}\mu\text{W]}$

4.6 7.6% .

저항

4.7 $b = a \sqrt{\frac{\sigma_1 + \sigma_2}{\sigma_2}}$

4.8 $R = \frac{V_2 - V_1}{I} = \frac{|\ln(a/b)|}{\sigma 2\pi \ell} = 4.15 \text{ [}\mu\Omega\text{]}$

4.9 $4.15 \text{ [}\mu\Omega\text{]}$

$$4.10 \quad R = \frac{V_o}{I} = \frac{1}{2\pi\sigma} \left(\frac{1}{a} - \frac{1}{b} \right)$$

$$4.11 \quad \sigma = 1.48 \times 10^{-3} \text{ [S/m]}$$

$$4.12 \quad \begin{aligned} \text{(a)} \quad & 4.41 \text{ } [\Omega] \\ \text{(b)} \quad & 5.92 \text{ } [\Omega] \end{aligned}$$

$$4.13 \quad \text{(a)} \quad \mathbf{J}_1 = \sigma_1 \mathbf{E}_1 = \frac{\sigma_1 V_o}{\ln(b/a) + (\sigma_1 / \sigma_2) \ln(c/b)} \frac{1}{\rho} \mathbf{a}_\rho \quad (a \leq \rho \leq b)$$

$$\mathbf{J}_2 = \sigma_2 \mathbf{E}_2 = \frac{\sigma_1 V_o}{\ln(b/a) + (\sigma_1 / \sigma_2) \ln(c/b)} \frac{1}{\rho} \mathbf{a}_\rho \quad (b \leq \rho \leq c)$$

(b)

$$\begin{aligned} \rho_s = D_\rho(\rho = a) &= \frac{\varepsilon_1}{\sigma_1} J_1(\rho = a) \\ &= \frac{(\varepsilon_1 / a) V_o}{\ln(b/a) + (\sigma_1 / \sigma_2) \ln(c/b)} \quad (\rho = a) \end{aligned}$$

$$\begin{aligned} \rho_s = D_\rho(\rho = b^+) - D_\rho(\rho = b^-) \\ = \frac{\sigma_1 V_o / b}{\ln(b/a) + (\sigma_1 / \sigma_2) \ln(c/b)} \left[\frac{\varepsilon_2}{\sigma_2} - \frac{\varepsilon_1}{\sigma_1} \right] \quad (\rho = b) \end{aligned}$$

$$\begin{aligned} \rho_s = -D_\rho(\rho = c) &= -\frac{\varepsilon_2}{\sigma_2} J_2 \\ &= -\frac{(\varepsilon_2 / c)(\sigma_1 / \sigma_2) V_o}{\ln(b/a) + (\sigma_1 / \sigma_2) \ln(c/b)} \quad (\rho = c) \end{aligned}$$

(c)

$$R = \frac{V_o}{I} = \frac{\ln(b/a)}{2\pi\sigma_1 \ell} + \frac{\ln(c/b)}{2\pi\sigma_2 \ell}$$

$$4.14 \quad b = a \sqrt{\frac{(\sigma_1 + \sigma_2)}{\sigma_2}}$$

$$4.15 \quad R = \frac{V}{I} = \frac{\ell}{\sigma_1 \pi (b^2 - a^2) + \sigma_2 \pi (c^2 - b^2)}$$

4.16

$$\mathbf{J} = -\frac{\sigma_o V_o}{0.83d} \mathbf{a}_z$$

$$\mathbf{E} = \frac{\mathbf{J}}{\sigma} = -\frac{V_o}{0.83d \sqrt{1 + (z/d)^2}} \mathbf{a}_z$$

$$I = \int \mathbf{J} \cdot d\mathbf{s} = \frac{\sigma_o V_o S}{0.83d}$$

$$R = \frac{V_o}{I} = \frac{0.83d}{\sigma_o S}$$

4.17 (a)

$$R_1 = \frac{a}{\sin(\theta_o/2)} = \frac{a}{b-a} \sqrt{(b-a)^2 + c^2}$$

$$R_2 = \frac{b}{\sin(\theta_o/2)} = \frac{b}{b-a} \sqrt{(b-a)^2 + c^2}$$

(b)

$$R = \left| \frac{V}{I} \right| = \frac{(b-a)^2}{2\pi\sigma ab} \frac{1}{\sqrt{(b-a)^2 + c^2} - c}$$

경계면 조건

$$4.18 \quad (a) \quad \mathbf{J}_2 = 2 \frac{\sigma_2}{\sigma_1} \mathbf{a}_y + 3 \mathbf{a}_z$$

(b)

$$\mathbf{E}_1 = \frac{\mathbf{J}_1}{\sigma_1} = \frac{1}{\sigma_1} (2 \mathbf{a}_y + 3 \mathbf{a}_z)$$

$$\mathbf{E}_2 = \frac{\mathbf{J}_2}{\sigma_2} = \frac{2}{\sigma_1} \mathbf{a}_y + \frac{3}{\sigma_2} \mathbf{a}_z$$

(c)

$$\rho_s = D_{2n} - D_{1n} = 3 \left(\frac{\epsilon_2}{\sigma_2} - \frac{\epsilon_1}{\sigma_1} \right)$$

$$\begin{aligned}
4.19 \quad (a) \quad J_o &= \frac{V_o}{t_1 / \sigma_1 + t_2 / \sigma_2} \\
E_1 &= \frac{V_o / \sigma_1}{t_1 / \sigma_1 + t_2 / \sigma_2}, \quad E_2 = \frac{V_o / \sigma_2}{t_1 / \sigma_1 + t_2 / \sigma_2} \\
(b) \quad \rho_{s1} &= \frac{\epsilon_1 V_o / \sigma_1}{t_1 / \sigma_1 + t_2 / \sigma_2}, \quad \rho_{s2} = \frac{-\epsilon_2 V_o / \sigma_2}{t_1 / \sigma_1 + t_2 / \sigma_2} \\
\rho_{\infty} &= D_2 - D_1 = \frac{V_o}{t_1 / \sigma_1 + t_2 / \sigma_2} \left(\frac{\epsilon_2}{\sigma_2} - \frac{\epsilon_1}{\sigma_1} \right)
\end{aligned}$$

전하완화

$$4.20 \quad I = q\sigma / \epsilon$$

$$4.21 \quad \sigma = 0.41 [\text{S/m}]$$

4.22 증류수는 $\tau_1 > \tau_2$ 이기 때문에 더 나은 부도체이다.

$$4.23 \quad I = 4.73 \times 10^{11} e^{-4.73 \times 10^{11} t}$$

$$4.24 \quad \rho_{so} = \frac{(A+B-1)}{B} J_o \frac{\epsilon_2}{\sigma_2} = J_o \left(\frac{\epsilon_2}{\sigma_2} - \frac{\epsilon_1}{\sigma_1} \right)$$

$$4.25 \quad \rho_{s1} = \epsilon_1 \left(\frac{1}{\sigma_1} - \frac{1}{\sigma_o} \right) J_o$$

Chapter 05 연습문제 답안

로렌츠 힘의 식

$$5.1 \quad \mathbf{E} = B_o(-b \mathbf{a}_x + a \mathbf{a}_y)$$

$$5.2 \quad v_o = \frac{2\pi m \rho^2 \omega^2}{q \mu_0 I}$$

$$5.3 \quad \begin{aligned} \text{(a)} \quad \mathbf{v} &= \frac{I}{hwnq} \mathbf{a}_y \\ \text{(b)} \quad \mathbf{E}_H &= -\frac{\mathbf{F}_m}{q} = -\frac{IB_o}{hwnq} \mathbf{a}_x \end{aligned}$$

비오-사바르 법칙

$$5.4 \quad \mathbf{H} = \left(\frac{I}{2\pi} \right) \frac{-(y_1 - a) \mathbf{a}_x + x_1 \mathbf{a}_y}{x_1^2 + (y_1 - a)^2}$$

5.5

$$\text{(a)} \quad \mathbf{H} = \mathbf{a}_x \frac{I}{2\pi d}$$

$$\text{(b)} \quad \mathbf{H} = (|\mathbf{H}_1| + |\mathbf{H}_2|) 2 \cos \zeta \mathbf{a}_x = \mathbf{a}_x \frac{I}{2\pi \sqrt{a^2 + d^2}} \frac{2d}{\sqrt{a^2 + d^2}}$$

$$\text{(c)} \quad a = d$$

$$5.6 \quad \mathbf{H} = 3\mathbf{H}_1 = \frac{9I}{2\pi a} \mathbf{a}_z$$

$$5.7 \quad \mathbf{H}_1 = \frac{I}{2a} \left(\frac{\sqrt{2}}{\pi} + \frac{1}{2} \right) \mathbf{a}_z$$

$$5.8 \quad \mathbf{H} = \frac{I}{4\pi} \left(-\frac{1}{\sqrt{5}} + \frac{1}{\sqrt{2}} - \frac{2}{\sqrt{45}} \right) \mathbf{a}_z$$

$$5.9 \quad (a) \quad \mathbf{H} = \frac{2Ia^2}{\pi(a^2 + b^2)} \frac{1}{\sqrt{2a^2 + b^2}} \mathbf{a}_z$$

$$(b) \quad \mathbf{H} = \frac{2I}{4\pi a} \left[\frac{\sqrt{10}}{3} - \sqrt{2} \right] \mathbf{a}_z$$

$$5.10 \quad \mathbf{H} = \int d\mathbf{H} = \frac{Ia^2}{2(a^2 + b^2)^{3/2}} \mathbf{a}_z$$

$$5.11 \quad \mathbf{H} = \mathbf{a}_x \frac{J_o}{\pi} \tan^{-1} \frac{a}{b}$$

$$\int \frac{dx}{(x^2 + a^2)^{3/2}} = \frac{x/a^2}{\sqrt{x^2 + a^2}} \text{ and } \int \frac{dx}{x^2 + a^2} = \frac{1}{a} \tan^{-1} \frac{x}{a}$$

$$5.12 \quad \mathbf{H} = \int \Delta\mathbf{H} = \mathbf{a}_x \frac{J_o b}{\pi} \int_{x=0}^{x=a} \frac{1}{x^2 + b^2} dx = \mathbf{a}_x \frac{J_o}{\pi} \tan^{-1} \frac{a}{b}$$

$$5.13 \quad \mathbf{H} = \frac{I\mathbf{a}_z}{2} \left(\frac{b}{\sqrt{a^2 + b^2}} - \frac{b-c}{\sqrt{a^2 + (b-c)^2}} \right)$$

$$5.14 \quad (a) \quad \mathbf{J}_s = \rho \omega \rho_s \mathbf{a}_\phi.$$

$$(b) \quad \mathbf{H} = \frac{\omega \rho_s}{2} \mathbf{a}_z \left[\frac{b^2 + 2d^2}{\sqrt{b^2 + d^2}} - \frac{a^2 + 2d^2}{\sqrt{a^2 + d^2}} \right]$$

$$(c) \quad \mathbf{H} = \frac{\omega \rho_s}{2} \mathbf{a}_z \int_{\rho=a}^{\rho=b} \frac{\rho^3}{(d^2 + \rho^2)^{3/2}} d\rho$$

5.15 증명 생략

암페어 법칙

5.16 (a) 증명 생략

$$(b) \mathbf{H} = \frac{J_o}{2} \mathbf{a}_x \quad (z > 0)$$

$$\mathbf{H} = -\frac{J_o}{2} \mathbf{a}_x \quad (z < 0)$$

$$5.17 \quad \mathbf{H} = J_o d \mathbf{a}_x \quad (z > d)$$

$$\mathbf{H} = -J_o d \mathbf{a}_x \quad (z < -d)$$

$$\mathbf{H} = J_o z \mathbf{a}_x \quad (-d \leq z \leq d)$$

자기장, 자속밀도, 유일해

- 5.18 (a) 자유 공간에서의 자기장일 수 있다.
(b) 자유 공간에서는 자기장이 될 수 없다.
(c) 자유 공간에서는 자기장이 될 수 없다.
(d) 자유 공간에서의 자기장일 수 있다.

5.19 증명 생략

5.20 증명 생략

5.21 증명 생략, $\mathbf{H} = 0$

$$5.22 \quad (a) \mathbf{J}_{s1} = I \mathbf{a}_\rho / 2\pi\rho \text{ [A/m]}$$

$$\mathbf{J}_{s2} = -I \mathbf{a}_z / 2\pi a \text{ [A/m]}$$

$$\mathbf{J}_{s3} = -I \mathbf{a}_\rho / 2\pi\rho \text{ [A/m]}$$

(b) 증명 생략

(c) 증명 생략

벡터 자기포텐셜

5.23

$$\begin{aligned}\mathbf{A} &= \int_{C'} \frac{\mu_0 I d\mathbf{l}'}{4\pi \mathcal{R}} = \frac{\mu_0 I}{4\pi} \mathbf{a}_z \int_{z'=-a}^{z'=a} \frac{dz'}{\sqrt{\rho^2 + (z-z')^2}} \\ &= \frac{\mu_0 I}{4\pi} \mathbf{a}_z \ln \left[\frac{(z+a) + \sqrt{\rho^2 + (z+a)^2}}{(z-a) + \sqrt{\rho^2 + (z-a)^2}} \right] \\ \mathbf{H} &= \frac{I}{4\pi \rho} \mathbf{a}_\phi \left[\frac{a+z}{\sqrt{\rho^2 + (z+a)^2}} + \frac{a-z}{\sqrt{\rho^2 + (z-a)^2}} \right]\end{aligned}$$

5.24 $\mathbf{A} = \mathbf{a}_z \frac{\mu_0 I}{2\pi} \ln(a/\rho)$

5.25

$$A_z = -\frac{\mu_0 I}{2\pi} \ln \rho + c_1 \quad : c_1, \text{ a constant}$$

or

$$\mathbf{A} = \frac{\mu_0 I}{2\pi} \ln \frac{a}{\rho} \mathbf{a}_z \quad : a, \text{ a constant.}$$

5.26 (a) 증명 생략

$$(b) \mathbf{A} = \frac{1}{2} \mu_0 N I \rho \mathbf{a}_\phi \quad (\rho \leq a)$$

$$\mathbf{A} = \frac{\mu_0 N I a^2}{2\rho} \mathbf{a}_\phi \quad (\rho \geq a)$$

5.27 (a) $\mathbf{A}_1 = \mathbf{a}_\phi \frac{1}{3} (\mu_0 \rho_s \omega) a R \sin \theta \quad (R \leq a)$

$$\begin{aligned}\mathbf{B}_1 &= \frac{2}{3} (\mu_0 \rho_s \omega) a (\mathbf{a}_R \cos \theta - \mathbf{a}_\theta \sin \theta) \\ &= \frac{2}{3} (\mu_0 \rho_s \omega) a \mathbf{a}_z\end{aligned}$$

$$\mathbf{A}_2 = \mathbf{a}_\phi \frac{1}{3} (\mu_0 \rho_s \omega) a^4 \frac{\sin \theta}{R^2} \quad (R \geq a)$$

$$\mathbf{B}_2 = \frac{1}{3}(\mu_0 \rho_s \omega) a^4 \frac{(\mathbf{a}_R 2 \cos \theta + \mathbf{a}_\theta \sin \theta)}{R^3}$$

(b), (c) 증명 생략

자기화 및 투자율

5.28 (a) $9.51 \times 10^5 \text{ [A/m]}$
 (b) $1.04 \times 10^{-23} \text{ [A} \cdot \text{m}^2]$

5.29 $51\mu_0$

5.30 (a) $\mathbf{B} = \frac{I}{\pi \rho} \frac{\mu_1 \mu_2}{\mu_1 + \mu_2} \mathbf{a}_\phi$
 $\mathbf{H} = \frac{\mathbf{B}}{\mu_1} = \frac{I}{\pi \rho} \frac{\mu_2}{\mu_1 + \mu_2} \mathbf{a}_\phi \quad (0 < \phi < \pi)$
 $\mathbf{H} = \frac{\mathbf{B}}{\mu_2} = \frac{I}{\pi \rho} \frac{\mu_1}{\mu_1 + \mu_2} \mathbf{a}_\phi \quad (\pi < \phi < 2\pi)$

(b)
 $\mathbf{J}_{ms} = \mathbf{M}_1 \times \mathbf{a}_n = \left(\frac{\mu_1}{\mu_0} - 1 \right) \frac{I}{\pi a} \frac{\mu_2}{\mu_1 + \mu_2} \mathbf{a}_z \quad (0 < \phi < \pi)$
 $\mathbf{J}_{ms} = \mathbf{M}_1 \times \mathbf{a}_n = \left(\frac{\mu_2}{\mu_0} - 1 \right) \frac{I}{\pi a} \frac{\mu_1}{\mu_1 + \mu_2} \mathbf{a}_z \quad (\pi < \phi < 2\pi).$

(c) 증명 생략

자기 경계면 조건

5.31 $\mathbf{H}_2 = \frac{1}{6}(10\mathbf{a}_x + 82\mathbf{a}_y + 95\mathbf{a}_z)$

5.32 $\mathbf{H}_1 = \left(\frac{B_o}{\mu_0} - J_o \right) \mathbf{a}_y$ and $\mathbf{B}_1 = \mu_0 \left(\frac{B_o}{\mu_0} - J_o \right) \mathbf{a}_y$

$$\begin{aligned}
5.33 \quad \mathbf{B} &= \frac{\mu I}{2\pi\rho} \mathbf{a}_\phi && \text{(inside)} \\
\mathbf{B} &= \frac{\mu_0 I}{2\pi\rho} \mathbf{a}_\phi && \text{(outside)}
\end{aligned}$$

$$\begin{aligned}
5.34 \quad (a) \quad B_2 &= \sqrt{(B_1 \cos \theta_1)^2 + \left(\frac{\mu}{\mu_0} B_1 \sin \theta_1\right)^2} \\
\theta_2 &= \tan^{-1} \left(\frac{B_{2t}}{B_{2n}} \right) = \tan^{-1} \left(\frac{\mu}{\mu_0} \tan \theta_1 \right)
\end{aligned}$$

$$(b) \quad B_3 = B_1, \quad \theta_3 = \theta_1$$

$$\begin{aligned}
(c) \quad \mathbf{J}_{ms1} &= \mathbf{M} \times \mathbf{a}_n = \left(\frac{\mu}{\mu_0} - 1 \right) \frac{\mathbf{B}_2}{\mu} \times (-\mathbf{a}_z) = -\mathbf{a}_x \left(\frac{\mu}{\mu_0} - 1 \right) \frac{B_1}{\mu_0} \sin \theta_1 \\
\mathbf{J}_{ms2} &= \mathbf{M} \times \mathbf{a}_n = \left(\frac{\mu}{\mu_0} - 1 \right) \frac{\mathbf{B}_2}{\mu} \times (\mathbf{a}_z) = \mathbf{a}_x \left(\frac{\mu}{\mu_0} - 1 \right) \frac{B_1}{\mu_0} \sin \theta_1
\end{aligned}$$

유도용량과 자기 에너지

$$5.35 \quad L = \frac{\Lambda}{I} = \frac{N^2 \mu h}{2\pi} \ln \frac{b}{a} \quad [\text{H}]$$

$$5.36 \quad L = \frac{\Lambda}{I} = \frac{N^2 h}{4\pi} (\mu_1 + \mu_2) \ln \frac{b}{a}, \quad L = L_1 + L_2.$$

$$\begin{aligned}
5.37 \quad (a) \quad W_m &= \frac{1}{2} \int_V \mathbf{B} \cdot \mathbf{H} \, dv \\
&= \frac{h}{2\pi} \frac{\mu_1 \mu_2}{\mu_1 + \mu_2} (NI)^2 \ln \frac{b}{a} \\
(b) \quad L &= \frac{2W_m}{I^2} = \frac{h}{\pi} \frac{\mu_1 \mu_2}{\mu_1 + \mu_2} N^2 \ln \frac{b}{a}
\end{aligned}$$

$$\begin{aligned}
5.38 \quad (a) \quad \mathbf{B} &= \mu_1 \mathbf{H} = \mu_1 N I \mathbf{a}_z & (\rho < a) \\
\mathbf{B} &= \mu_2 \mathbf{H} = \mu_2 N I \mathbf{a}_z & (a < \rho < b) \\
(b) \quad L &= \frac{2W_m}{I^2} = \mu_1 N^2 \pi a^2 + \mu_2 N^2 \pi (b^2 - a^2) \\
(c) \quad L &= \frac{\Lambda}{I} = \mu_1 N^2 \pi a^2 + \mu_2 N^2 \pi (b^2 - a^2)
\end{aligned}$$

$$5.39 \quad L = \frac{1}{2\pi} \left[\mu_1 \ln \frac{b}{a} + \mu_2 \ln \frac{c}{b} \right]$$

5.40 증명 생략

$$\begin{aligned}
5.41 \quad (a) \quad W_{ma} &= \frac{W_m}{2} \\
(b) \quad W_{mb} &= 2W_m \\
(c) \quad W_{mc} &= 4W_m
\end{aligned}$$

$$5.42 \quad 16.4 [\text{nH/m}], 50 [\text{nH/m}]$$

$$\begin{aligned}
5.43 \quad (a) \quad W_m &= \frac{I^2 \mu_1 \mu_2}{2\pi(\mu_1 + \mu_2)} \ln \frac{b}{a} \\
(b) \quad L &= \frac{2W_m}{I^2} = \frac{\mu_1 \mu_2}{\pi(\mu_1 + \mu_2)} \ln \frac{b}{a}
\end{aligned}$$

자기력 및 토크

$$\begin{aligned}
5.44 \quad (a) \quad \mathbf{F}_m &= \frac{\mu_0 c I_1 I_2}{2\pi a} \mathbf{a}_\rho - \frac{\mu_0 c I_1 I_2}{2\pi(a+b)} \mathbf{a}_\rho \\
(b) \quad \mathbf{F}_m &= \frac{\mu_0 I_1 I_2}{2\pi} \left(\frac{b}{a} - \ln \frac{a+b}{a} \right) \mathbf{a}_\rho
\end{aligned}$$

$$5.45 \quad \mathbf{F}_m = -\nabla W_m = -\frac{dW_m}{dz} \mathbf{a}_z = -\frac{\mu^2 N^2 I^2 \pi a^2}{2\mu_0} \mathbf{a}_z$$

$$5.46 \quad (\text{a}) \quad \mathbf{F}_m = -6\pi A \frac{ab}{(a^2 + b^2)} \mathbf{a}_z \approx -\frac{3\pi\mu_0 a^4 I_1 I_2}{2b^4} \mathbf{a}_z$$

$$(\text{b}) \quad \mathbf{F}_m = I_1 I_2 \frac{3\pi\mu_0 a^4}{2b^4} \mathbf{a}_z$$

$$5.47 \quad \mathbf{T} = -B_2 \left(\frac{1}{2} I \pi a^2 + 2 I a^2 \right) \mathbf{a}_x$$

$$5.48 \quad \mathbf{m} = \mathbf{a}_z \frac{4}{3} \rho_s \omega \pi a^4$$

$$5.49 \quad \mathbf{T} = \sum \mathbf{m} \times \mathbf{B} = N I \pi a^2 \mathbf{a}_z \times B_o \mathbf{a}_x = B_o N I \pi a^2 \mathbf{a}_y$$

$$5.50 \quad \mathbf{T}_2 = \frac{3\mu_0 m_o^2}{128\pi} (-\sqrt{2} \mathbf{a}_x + \mathbf{a}_y)$$

$$5.51 \quad \mathbf{T} = \mathbf{m} \times \mathbf{B} = -\mathbf{a}_x \frac{\sqrt{3}}{4} a^2 I B_o .$$

Chapter 06 연습문제 답안

패러데이 법칙

6.1 $B_o = -V_o / a^2$

6.2

$$\mathbf{V}_{1-2} = \frac{\omega 2abB_o}{\pi} \mathbf{cc}$$
$$\mathbf{i} = \frac{\mathbf{V}_{1-2}}{R} = \frac{\omega 2abB_o}{\pi R} \mathbf{cc}$$

6.3 (a) $\mathbf{B} = \frac{\mu_0 m_o}{4\pi R^3} (2 \cos \theta \mathbf{a}_R + \sin \theta \mathbf{a}_\theta) \cos(\omega t)$

$$\mathbf{A} = \mathbf{a}_\phi \frac{\mu_0 m_o \sin \theta}{4\pi R^2} \cos(\omega t)$$

(b) $emf = -\frac{d\Phi}{dt} = \frac{\mu_0}{2} \frac{m_o a^2 \omega}{(a^2 + d^2)^{3/2}} \sin(\omega t)$

6.4 (a) $\mathbf{V} = \int \mathbf{E}_m \cdot d\mathbf{l} = -ab\omega_o B_o \cos(\omega_o t)$

(b) $\mathbf{V} = -\frac{d\Phi}{dt} = -ab\omega_o B_o \cos(\omega_o t)$

6.5 증명 생략

6.6 (a) $v_o x_o B_o$.

(b) $P_{el} = I v_o x_o B_o$.

(c) $\mathbf{F}_m = I x_o B_o \mathbf{a}_y$.

(d) $P_m = \mathbf{F}_m \cdot \mathbf{v} = I v_o x_o B_o$.

(e) $P_{el} = P_m$.

6.7 (a) $emf = \frac{\mu_0 I_1 h v_o}{2\pi} \left[\frac{1}{a} - \frac{1}{b} \right]$

$$\begin{aligned}
\text{(b)} \quad \dot{\mathbf{i}} &= \frac{emf}{R} = \frac{\mu_0 I_1 h v_o}{2\pi R} \left[\frac{1}{a} - \frac{1}{b} \right] \\
\text{(c)} \quad \mathbf{F}_m &= \mathbf{F}_{m,l} + \mathbf{F}_{m,r} = -\dot{\mathbf{i}} \frac{\mu_0 I_1 h}{2\pi} \left(\frac{1}{a} - \frac{1}{b} \right) \mathbf{a}_\rho \\
\text{(d)} \quad P_m &= -\mathbf{F}_m \cdot v_o \mathbf{a}_\rho = \dot{\mathbf{i}} v_o \frac{\mu_0 I_1 h}{2\pi} \left(\frac{1}{a} - \frac{1}{b} \right) \\
\text{(e)} \quad P_{el} &= \dot{\mathbf{i}} \times emf = \dot{\mathbf{i}} v_o \frac{\mu_0 I_1 h}{2\pi} \left[\frac{1}{a} - \frac{1}{b} \right]
\end{aligned}$$

$$6.8 \quad V_{1-2} = \frac{1}{2} \omega_o B_o a^2$$

$$\begin{aligned}
6.9 \quad \text{(a)} \quad emf &= \pi \rho^2 \omega B_o \sin(\omega t). \\
\text{(b)} \quad \langle P \rangle &= \frac{1}{16} \pi a^4 \omega^2 B_o^2 \sigma h
\end{aligned}$$

변위 전류

$$\begin{aligned}
6.10 \quad \text{(a)} \quad \mathbf{J}_c &= \sigma \mathbf{E} = \sigma E_o \mathbf{a}_x e^{-\alpha z} \cos(\omega t - kz) \\
\text{(b)} \quad \mathbf{J}_d &= \frac{\partial}{\partial t} (\epsilon \mathbf{E}) = -\omega \epsilon E_o \mathbf{a}_x e^{-\alpha z} \sin(\omega t - kz) \\
\text{(c)} \quad \frac{|\mathbf{J}_c|}{|\mathbf{J}_d|} &= \frac{\sigma}{\omega \epsilon}
\end{aligned}$$

$$6.11 \quad \cong 1.04 \times 10^8$$

$$\begin{aligned}
6.12 \quad \text{(a)} \quad \dot{\mathbf{i}}_c &= C \frac{dV}{dt} = -\frac{2\pi \epsilon \ell}{\ln(b/a)} \omega V_o \sin(\omega t) \\
\text{(b)} \quad \dot{\mathbf{i}}_d &= 2\pi \rho \ell J_D = -\frac{2\pi \ell \epsilon \omega V_o}{\ln(b/a)} \sin(\omega t)
\end{aligned}$$

6.13 (a) $\rho_s = \frac{CV_o}{\pi a^2} [1 - e^{-t/RC}]$

(b) $\mathbf{H}_2 = -\frac{V_o}{2\pi R} \frac{\rho}{a^2} e^{-t/RC} \mathbf{a}_\phi$

(c) $\mathbf{J}_s(\rho) = \left(1 - \frac{\rho^2}{a^2}\right) \frac{V_o}{2\pi \rho R} e^{-t/RC} \mathbf{a}_\rho$

(d)

$$\mathbf{H}_1 \cdot (-dl \mathbf{a}_\phi) + \mathbf{H}_2 \cdot (dl \mathbf{a}_\phi) = J_s dl$$

$$\mathbf{H}_2 = -\frac{V_o}{2\pi R} \frac{\rho}{a^2} e^{-t/RC} \mathbf{a}_\phi$$

(e) (b),(d)와 동일하다.

맥스웰 방정식

6.14 증명 생략

6.15 증명 생략

6.16 (a) $\nabla \times \mathbf{E} = -\mu_0 \frac{\partial \mathbf{H}}{\partial t} \quad (1) \qquad \nabla \times \mathbf{H} = \varepsilon \frac{\partial \mathbf{E}}{\partial t} \quad (2)$

$\nabla \cdot \mathbf{E} = 0 \quad (3) \qquad \nabla \cdot \mathbf{H} = 0 \quad (4)$

(b) $\mathbf{H} = (-E_2 \mathbf{a}_x + E_1 \mathbf{a}_y) \frac{k}{\mu_0 \omega} \cos(\omega t - kz)$

(c) $k = \pm \omega \sqrt{\mu_0 \varepsilon}$

6.17 $\frac{\partial \mathbf{E}_x}{\partial z^2} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}_x}{\partial t^2}$

전자기 경계면 조건

6.18 증명 생략

6.19 (a) $E_1 / E_2 = -1$

(b)

$$\begin{aligned} \mathcal{H} &= \frac{1}{\mu_0 \omega} (k_z \mathbf{a}_y - k_y \mathbf{a}_z) E_1 \cos(\omega t - k_y y - k_z z) \\ &\quad + \frac{1}{\mu_0 \omega} (k_z \mathbf{a}_y + k_y \mathbf{a}_z) E_1 \cos(\omega t - k_y y + k_z z). \end{aligned}$$

(c) $\mathbf{J}_s = -\frac{2}{\mu_0 \omega} (k_z \mathbf{a}_x) E_1 \cos(\omega t - k_y y)$

6.20 (a) $\mathcal{E} = \mathbf{a}_x \omega A_o \sin[\omega(t - z/c)]$

(b) $\mathcal{E} = \mathbf{a}_x \omega A_o \sin[\omega(t - z/c)]$.

6.21 증명 생략

Chapter 07 연습문제 답안

1차원 파

7.1 ①, ③

조화파

- 7.2 (a) e^2 [cm].
(b) $\lambda = 100$ [m]
(c) $f = 50$ [Hz]
(d) 5000 [m/s]
(e) $+z$ -direction.

7.3 $\psi = 5 \cos(0.1\pi x - 1.5\pi t + 1.1\pi)$ [V/m].

- 7.4 (a) $A'_o = -0.5A_o e^{-j0.4\pi}$
(b) $\psi_T(x_1) = A_o e^{-j1.4\pi} - 0.5A_o e^{-j0.4\pi + j1.4\pi} = 0.97A_o e^{j1.373}$
 $\psi_T(x_2) = A_o e^{-j\pi} - 0.5A_o e^{-j0.4\pi + j\pi} = 0.97A_o e^{-j2.629}$
(c) 4.00 radians

7.5 $\frac{A_r}{A_o} = \Gamma e^{-j2ka}$ and $\frac{A_t}{A_o} = \tau e^{j(k'-k)a}$

7.6

$$\begin{aligned} A_1 + A_2 &= A_3 + A'_3 \\ &= A_3 \left[1 + \frac{1}{3} e^{-j0.8\pi} \right] = A_3 (0.730 - j0.196) \\ -A_1 + A_2 &= -2A_3 + 2A'_3 \\ &= -2A_3 \left[1 - \frac{1}{3} e^{-j0.8\pi} \right] = -A_3 (2.539 + j0.392) \end{aligned}$$

$$\begin{aligned} A_2 &= -A_3 (0.905 + j0.294) \\ A_1 &= A_3 (1.635 + j0.098) \rightarrow A_3 = A_1 (0.609 - j0.037) \end{aligned}$$

$$\mathbf{A}_4 = \mathbf{A}_1(0.629 - j0.518)$$

$$\mathbf{A}'_3 = \mathbf{A}_1(-0.172 - j0.110)$$

$$\mathbf{A}_2 = \mathbf{A}_1(-0.562 - j0.146)$$

$$7.7 \quad (a) \quad \omega = \frac{2\pi}{2} = \pi \text{ [rad/s]}$$

$$(b) \quad k = \frac{\omega}{v_p} = 0.1\pi \text{ [rad/m]}$$

$$(c) \quad \psi = 5 \cos(0.1\pi x - \pi t + 0.8\pi) \text{ [V/m]}$$

$$7.8 \quad \mathbf{k} = 0.02\pi \times (3\mathbf{a}_x + 4\mathbf{a}_y + 2\mathbf{a}_z)$$

평면파

$$7.9 \quad (a) \quad v_p = 20\pi \text{ [m/s]}$$

$$(b) \quad v_{p,x} = 24\pi \text{ [m/s]}$$

$$7.10 \quad (a) \quad \lambda = \frac{\pi}{15} \text{ [m]}$$

$$(b) \quad \Delta x = 0.2\pi \text{ [m]}.$$

$$7.11 \quad (a) \quad \mathbf{k} = \frac{2\pi}{\lambda} \mathbf{a}_k = \frac{2\pi}{0.25\pi} \frac{1}{4} (2\mathbf{a}_x + \sqrt{3}\mathbf{a}_y + 3\mathbf{a}_z) = 2(2\mathbf{a}_x + \sqrt{3}\mathbf{a}_y + 3\mathbf{a}_z)$$

$$(b) \quad \mathbf{k} \cdot \mathbf{r} = 2(2\mathbf{a}_x + \sqrt{3}\mathbf{a}_y + 3\mathbf{a}_z) \cdot \frac{1}{2}\mathbf{a}_x = 2$$

$$7.12 \quad (a) \quad \mathbf{a}_k = -\frac{1}{4}(2\mathbf{a}_x + \sqrt{3}\mathbf{a}_y + 3\mathbf{a}_z)$$

$$(b) \quad v_p = \frac{1.5}{0.2} = 7.5 \text{ [m/s]}$$

$$7.13 \quad 3.5 \text{ [m]}$$

7.14 증명 생략

전자기 평면파

- 7.15 (a) 예
 (b) 아니오
 (c) 아니오
 (d) 아니오
 (e) 예
 (f) 아니오
 (g) 예

- 7.16 ①~④

- 7.17 (a) $\omega = ck = 1.5 \times 10^9$ [rad/s].
 (b) $\mathbf{E}_o = 12\mathbf{a}_x - 9\mathbf{a}_y + 10\mathbf{a}_z$

- 7.18 (a) $\mathcal{E} = \text{Re}[\mathbf{E}e^{-i\omega t}] = (3\mathbf{a}_x + 4\mathbf{a}_y)\cos(10^6 z - 3 \times 10^{14} t)$
 (b) $\mathcal{H} = \frac{1}{377}(-4\mathbf{a}_x + 3\mathbf{a}_y)\cos(10^6 z - 3 \times 10^{14} t)$

- 7.19 (a) $\omega = 2\pi f = 2\pi \frac{c}{\lambda} = 3 \times 10^{12}$ [rad/s]
 (b) $\mathcal{E} = \mathbf{a}_x \sqrt{5} \cos(10^4 z - 3 \times 10^{12} t + 0.31) + \mathbf{a}_y \cos(10^4 z - 3 \times 10^{12} t - 0.8)$.

$$\mathcal{H} = \mathbf{a}_y \frac{\sqrt{5}}{120\pi} \cos(10^4 z - 3 \times 10^{12} t + 0.31)$$

$$- \mathbf{a}_x \frac{1}{120\pi} \cos(10^4 z - 3 \times 10^{12} t - 0.8)$$

- 7.20 $\mathcal{E} = 2\mathbf{a}_z \cos[2\pi \times 10^7 t - 0.13x - 0.17y + 1.02]$

$$7.21 \quad \mathcal{E} = 20 \mathbf{a}_z \cos(24x + 18y - 9 \times 10^9 t) \text{ [V/m]}$$

$$\mathcal{H} = (1/90\pi)(9 \mathbf{a}_x - 12 \mathbf{a}_y) \cos(24x + 18y - 9 \times 10^9 t) \text{ [A/m]}$$

Chapter 08 연습문제 답안

균질 매질에서의 균일 평면파

8.1 (a) $\tilde{\mathbf{H}} = \mathbf{a}_y \frac{E_o}{\eta_o} e^{-\alpha z} e^{-j\beta z - j\pi/2}$

(b) $\tilde{\mathbf{H}} = (-\mathbf{a}_y) \frac{1}{\eta_o e^{-j\pi/4}} E_o e^{-\alpha z} e^{j\beta z + j\pi} = \mathbf{a}_y \frac{E_o}{\eta_o} e^{-\alpha z} e^{j\beta z + j\pi/4}$

(c) $\tilde{\mathbf{H}} = \mathbf{a}_x \frac{E_o}{2\eta_o} e^{jkz} - \mathbf{a}_x \frac{E_o}{2\eta_o} e^{-jkz}$

(d) $\tilde{\mathbf{H}} = (\mathbf{a}_z - 2\mathbf{a}_y) \frac{E_o}{\eta_o} e^{-jkx}$

(e) $\tilde{\mathbf{H}} = -\frac{1}{j\omega\mu_0} \nabla \times \tilde{\mathbf{E}} = \frac{E_o}{\omega\mu_0} [k_2 \sin(k_1 x) \mathbf{a}_x - jk_1 \cos(k_1 x) \mathbf{a}_y] e^{-jk_2 y}$

8.2 $\mathbf{E} = (4.01\mathbf{a}_x - 3.47\mathbf{a}_y) \cos \left[4.7 \times 10^8 t \pm \frac{\pi}{8} (\sqrt{3}x + 2y + 3z) + \phi \right]$

8.3 (a) $\beta = \frac{\omega}{c} \sqrt{\mu_r \epsilon_r} = \frac{2\pi \times 2 \times 10^8}{3 \times 10^8} \sqrt{60} = 32.4 \text{ [rad/m]}$

(b) $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{32.4} = 19.4 \text{ [cm]}$

(c) $v_p = \frac{c}{\sqrt{\mu_r \epsilon_r}} = \frac{3 \times 10^8}{\sqrt{60}} = 3.87 \times 10^7 \text{ [m/s]}$

(d) $\eta = \sqrt{\frac{\mu_0}{\epsilon_0}} \sqrt{\frac{\mu_r}{\epsilon_r}} = 377 \sqrt{\frac{5}{12}} = 243.4 \text{ [\Omega]}$

8.4

(a) $\mathbf{k} = 3\mathbf{a}_y + 4\mathbf{a}_z$

(b) $\lambda = \frac{2\pi}{5} \text{ [m]}$

(c) $1.5 \times 10^9 \text{ [rad/s]}$

(d) $\tilde{\mathbf{H}} = \frac{1}{\eta_o} (\mathbf{a}_k \times \tilde{\mathbf{E}}) = 10^{-3} (12.73\mathbf{a}_y - 9.55\mathbf{a}_z) e^{-j3y - j4z}$

8.5 $\tilde{\mathbf{E}} = (24.32e^{j1.37} \mathbf{a}_y - 14.59e^{-j0.20} \mathbf{a}_z)e^{-j20x} \text{ [KV/m]}$

- 8.6 (a) 313.0 [Ω]
 (b) 3.83
 (c) 2.64

8.7 증명 생략

8.8 증명 생략

포인팅 벡터

- 8.9 (a) $\langle \mathbf{S} \rangle = \mathbf{a}_z \frac{1}{2\sqrt{2}} \frac{E_o^2}{\eta_o} e^{-2\alpha z}$
 (b) $\langle \mathbf{S} \rangle = -\mathbf{a}_z \frac{1}{2\sqrt{2}} \frac{E_o^2}{\eta_o} e^{-2\alpha z}$
 (c) $\langle \mathbf{S} \rangle = 0$
 (d) $\langle \mathbf{S} \rangle = \frac{5E_o^2}{2\eta_o} \mathbf{a}_x$
 (e) $\langle \mathbf{S} \rangle = \frac{E_o^2}{2\omega\mu_o} k_2 \sin^2(k_1 x) \mathbf{a}_y$

- 8.10 (a) 6.25
 (b) 48π
 (c) $\langle \mathbf{S} \rangle = \frac{1}{24\pi} \mathbf{a}_z \text{ [W/m}^2\text{]}$
 (d) $\frac{1}{24} \text{ [W]}$

- 8.11 (a) $\eta = \frac{(4^2 + 2^2)}{2 \times 30.6 \times 10^{-3}} = 326.8 \text{ [Ω]}$
 (b) $\mu_r = 1.20$

$$(c) \quad \tilde{\mathbf{H}} = \frac{1}{326.8} (4\mathbf{a}_y + j2\mathbf{a}_z) e^{j15x} \text{ [A/m]}$$

$$8.12 \quad v_p = \frac{3 \times 10^8}{\sqrt{3}} = 1.73 \times 10^8 \text{ [m/s]}$$

$$8.13 \quad E = 490 \text{ [V/m]}$$

8.14 증명 생략

전자기파의 편광

8.15 (a) $\mathbf{a}_k = -\mathbf{a}_z$. Therefore, it propagates in the $-z$ -direction.

(b) 파동이 $-z$ -방향으로 전파될 때 오른손 원형 편광파가 나타난다.

$$8.16 \quad \tilde{\mathbf{E}} = \left[\frac{E_o}{2} e^{j\theta} (\mathbf{a}_x - j\mathbf{a}_y) + \frac{E_o}{2} e^{-j\theta} (\mathbf{a}_x + j\mathbf{a}_y) \right] e^{-jkz}$$

8.17 설명 생략

8.18 설명 생략

8.19 설명 생략

$$8.20 \quad \tilde{\mathbf{E}} = (3\mathbf{a}_x + 2e^{-j0.927} \mathbf{a}_y) e^{-jkz}$$

감폭 손실의 유전체

- 8.21 (a) 점 p_2 에서 $\mathcal{E}$ 의 진폭은 점 p_1 에서의 진폭에 비해 6.82×10^{-4} 배 감소한다.
 (b) 점 p_2 에서의 $\mathcal{E}$ 위상은 시공간에서 p_1 에서의 위상보다 0.23 [rad] 만큼 뒤쳐진다.

8.22 $\epsilon'_r = 8.20$, $\epsilon''_r = \epsilon'_r \tan \xi = 0.27$
 $\mathbf{H} = 0.018e^{-j0.017} \mathbf{a}_y e^{-0.1z} e^{-j6z}$

8.23 $\tilde{\mathbf{H}} = \frac{1}{125.67} (10 \mathbf{a}_y - j5 \mathbf{a}_x) e^{-3z-j4z-j0.644}$

8.24 $\frac{\beta}{\alpha} = \frac{\sqrt{\sec \xi + 1}}{\sqrt{\sec \xi - 1}} = 1.73$

8.25 (a) $\frac{0.2}{1.8} \neq 0.126$
 (b) $\frac{\alpha}{\beta} = \frac{9.8}{10} = 0.98$, and $\frac{\sqrt{\sec \xi - 1}}{\sqrt{\sec \xi + 1}} = 0.980$

8.26 $\mathcal{E}(z, t) = 410.1e^{-0.05z} \mathbf{a}_x \cos(2\pi \times 10^8 t - 3.33z - 0.30)$

8.27 $\eta = 377 \sqrt{\frac{\cos(0.44)e^{j0.44}}{2.41}} = 231.0e^{j0.22}$

저 전도도의 유전체

- 8.28 (a) $\beta_1 = 3.14 [\text{rad/m}]$, $\beta_2 = 140.4 [\text{rad/m}]$
(b) $\lambda_1 = 2.0 [\text{m}]$, $\lambda_2 = 4.5 [\text{cm}]$
(c) $v_{p1} = f\lambda_1 = 2.0 \times 10^8 [\text{m/s}]$, $v_{p2} = f\lambda_2 = 4.5 \times 10^6 [\text{m/s}]$

- 8.29 (a) $\eta = 6.71e^{j0.7194} [\Omega]$
(b) $\epsilon_r = 2.0$
(c) $\sigma = 0.20 [\text{S/m}]$
(d) $\alpha = 12.84 [\text{Np/m}]$
(e) $\beta = 14.66 [\text{rad/m}]$

- 8.30 (a) $\tan \xi = 1.44$
(b) $\epsilon_r = 2.5$
(c) $\eta = \eta_o \sqrt{\frac{\mu_r}{\epsilon_r}} \sqrt{(\cos \xi) e^{j\xi}} = 180.1 e^{j0.48}$

- 8.31 (a) $\tan \xi = 1.75 \times 10^4$
(b) $\sigma = 72.9 [\text{S/m}]$

- 8.32 (a) $\langle \mathbf{S} \rangle = \mathbf{a}_z (202.7) e^{-0.42z}$
(b) $-\nabla \cdot \langle \mathbf{S} \rangle \Big|_{z=0.5} = 69.0 [\text{W/m}^3]$
(c) (b)와 같음

양도체

- 8.33 (a) $\sigma = 4.98 \times 10^5 [\text{S/m}]$.
(b) $\eta = 15.4(1+j) [\text{m}\Omega]$

- 8.34 (a) $\delta = 15.9 [\mu\text{m}]$
 (b) $v_p = 10^4 [\text{m/s}]$
 (c) $\eta = 6.29(1 + j) [\text{m}\Omega]$

8.35 $\sigma = 3.1 \times 10^4 [\text{S/m}]$

8.36 $f = 6.2 [\text{GHz}]$

8.37 $\sigma = 1.56 \times 10^7 [\text{S/m}]$

8.38 $R_{ac} = 26.3 [\Omega]$

8.39 증명 생략

8.40 증명 생략

수직 입사

- 8.41 (a) $\Gamma = -0.2$
 (b) $S = 1.5$
 (c) $|\Gamma|^2 = 0.04$
 (d) $\mathcal{E}^r = -2\mathbf{a}_x \cos(3 \times 10^{15}t + 10^7z)$
 $\mathcal{E}^t = 8\mathbf{a}_x \cos(3 \times 10^{15}t - 1.5 \times 10^7z)$

8.42 $\eta = 202.4e^{j0.518}$.

- 8.43 (a) $\frac{\eta_2}{\eta_1} = 3 \pm 2\sqrt{2} = 5.83 \text{ or } 1/5.83$
 (b) $S = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{\sqrt{2}+1}{\sqrt{2}-1} = 5.83$

8.44 증명 생략

- 8.45** (a) $\Gamma = -0.6$
 (b) $\tau = \Gamma + 1 = 0.4$
 (c) $\eta_2 = 0.25\eta_o$
 (d) $\left| \langle \mathbf{S}^t \rangle \right| = 3.2 [\text{W/m}^2]$

- 8.46** (a) $\tilde{\mathbf{E}}^r = 0.852 \mathbf{a}_x e^{j4z + j2.55}$
 $\tilde{\mathbf{E}}^t = 1.374 \mathbf{a}_x e^{-4.0z - j6.93z + j0.35}$
 (b) Ignoring floating-point errors, $\langle \mathbf{S} \rangle^i = \langle \mathbf{S} \rangle^r + \langle \mathbf{S} \rangle^t$.

8.47 $|\Gamma|^2 + |\tau|^2 \operatorname{Re} \left[\frac{1}{\eta_2} \right] / \operatorname{Re} \left[\frac{1}{\eta_1} \right] = 1$

- 8.48** (a) $|\Gamma| = 0.968$.
 (b) $1 - |\Gamma|^2 = 0.063$

8.49 $T = 1 - R = 0.14$

8.50 $P = 0.64 \times 1.2 = 0.77 [\text{W}]$

8.51 증명 생략

- 8.52** (a) 증명 생략
 (b) $S = \frac{1 + |\Gamma_2|}{1 - |\Gamma_2|} = \frac{\eta_2}{\eta_1}$

8.53 $\frac{E_o^t}{E_o^i} = 0.040 e^{-j0.36}$

경사 입사

8.54 (a) 증명 생략

$$(b) d = \overline{p'p''} \cos \theta_t = [(t_1 + t_2) \tan \theta_i - (t_1 \tan \theta_1 + t_2 \tan \theta_2)] \cos \theta_t$$

$$8.55 \quad (a) \quad \theta_t = \sin^{-1} \left(\frac{n_1}{n_2} \sin \theta_i \right) = \sin^{-1} \left(\frac{1}{1.3} \sin 33.69^\circ \right) = 25.26^\circ.$$

$$(b) \quad |\mathbf{k}_i| = 2\pi / \lambda \quad \text{and} \quad |\mathbf{k}_t| = n 2\pi / \lambda.$$

$$(c) \quad \Gamma_{\perp} = -0.171, \quad \tau_{\perp} = 0.829$$

$$(d) \quad \tilde{\mathbf{E}}^r = 51.30 \mathbf{a}_y e^{-j(10x-15z)}$$

$$\tilde{\mathbf{E}}^t = -248.7 \mathbf{a}_y e^{-j(10x+21.2z)}$$

$$8.56 \quad (a) \quad \theta_t = \sin^{-1} \left(\frac{n_1}{n_2} \sin \theta_i \right) = \sin^{-1} \left(\frac{1}{1.3} \sin 36.87^\circ \right) = 27.49^\circ$$

$$(b) \quad \mathbf{k}_r = \sqrt{9^2 + 12^2} (\sin 36.87^\circ \mathbf{a}_x - \cos 36.87^\circ \mathbf{a}_z) = 9 \mathbf{a}_x - 12 \mathbf{a}_z$$

$$\mathbf{k}_t = 1.30 \sqrt{9^2 + 12^2} (\sin 27.49^\circ \mathbf{a}_x + \cos 27.49^\circ \mathbf{a}_z) = 9 \mathbf{a}_x + 17.30 \mathbf{a}_z$$

$$(c) \quad \mathbf{a}_{\parallel}^r = -\frac{4}{5} \mathbf{a}_x - \frac{3}{5} \mathbf{a}_z$$

$$\mathbf{a}_{\parallel}^t = -\frac{17.30}{19.5} \mathbf{a}_x + \frac{9}{19.5} \mathbf{a}_z$$

$$(d) \quad \Gamma_{\parallel} = -0.0793, \quad \tau_{\parallel} = 0.830$$

$$(e) \quad \tilde{\mathbf{E}}^r = \Gamma_{\parallel} 500 \left(-\frac{4}{5} \mathbf{a}_x - \frac{3}{5} \mathbf{a}_z \right) e^{-j(9x-12z)} = (31.72 \mathbf{a}_x + 23.79 \mathbf{a}_z) e^{-j(9x-12z)}$$

$$\tilde{\mathbf{E}}^t = (-368.18 \mathbf{a}_x + 191.54 \mathbf{a}_z) e^{-j(9x+17.30z)}$$

$$8.57 \quad \tilde{\mathbf{E}}^i = (1.2 \mathbf{a}_x + 2.4 \mathbf{a}_y - 4 \mathbf{a}_z) e^{-j(4x+8y+6z)} + (0.8 \mathbf{a}_x - 0.4 \mathbf{a}_y) e^{-j(4x+8y+6z)}$$

$$8.58 \quad \tilde{\mathbf{E}}^r = (-1.2 \mathbf{a}_x - 2.4 \mathbf{a}_y - 4 \mathbf{a}_z) e^{-j(4x+8y-6z)} + (-0.8 \mathbf{a}_x + 0.4 \mathbf{a}_y) e^{-j(4x+8y-6z)}$$

$$8.59 \quad (a) \quad \tilde{\mathbf{H}}^i = \frac{1}{\eta_o} (\mathbf{a}_{k_i} \times \tilde{\mathbf{E}}^i) = \mathbf{a}_y 0.40 e^{-j(10x+20z)}$$

$$\tilde{\mathbf{E}}^r = -\left(\frac{2}{\sqrt{5}}\mathbf{a}_x + \frac{1}{\sqrt{5}}\mathbf{a}_z\right)150e^{-j(10x-20z)}$$

$$\tilde{\mathbf{H}}^r = \mathbf{a}_y 0.40e^{-j(10x-20z)}$$

$$(b) \quad \tilde{\mathbf{E}}(z=0) = \tilde{\mathbf{E}}^i(z=0) + \tilde{\mathbf{E}}^r(z=0) = -\mathbf{a}_z 134.2 e^{-j10x} \text{ [V/m]}$$

$$\tilde{\mathbf{H}}(z=0) = \tilde{\mathbf{H}}^i(z=0) + \tilde{\mathbf{H}}^r(z=0) = \mathbf{a}_y 0.80e^{-j10x} \text{ [A/m]}$$

$$(c) \quad \tilde{\mathbf{J}}_s = \mathbf{a}_n \times \tilde{\mathbf{H}} = (-\mathbf{a}_z) \times \mathbf{a}_y 0.80e^{-j10x} = \mathbf{a}_x 0.80e^{-j10x} \text{ [A/m]}$$

$$8.60 \quad (a) \quad \tilde{\mathbf{E}}^i = \tilde{\mathbf{E}}_{\perp}^i + \tilde{\mathbf{E}}_{\parallel}^i = 3\mathbf{a}_y e^{-j(x+\sqrt{3}z)} + \sqrt{7}\left(\frac{\sqrt{3}}{2}\mathbf{a}_x - \frac{1}{2}\mathbf{a}_z\right)e^{-j(x+\sqrt{3}z)}$$

$$(b) \quad \tilde{\mathbf{E}}^r = \tilde{\mathbf{E}}_{\perp}^r + \tilde{\mathbf{E}}_{\parallel}^r = -(0.37\mathbf{a}_x + 0.72\mathbf{a}_y + 0.21\mathbf{a}_z)e^{-j(x-\sqrt{3}z)}$$

$$8.61 \quad (a) \quad \theta_B = 56.66^\circ$$

$$(b) \quad \Gamma_{\perp} = -0.40$$

$$8.62 \quad (a) \quad \mathbf{a}_{k_t} = \sin 34.4^\circ \mathbf{a}_x + \cos 34.4^\circ \mathbf{a}_z = 0.56\mathbf{a}_x + 0.83\mathbf{a}_z$$

$$(b) \quad \mathbf{a}_{E^i} = \mathbf{a}_y \times \mathbf{a}_{k_i} = 0.56\mathbf{a}_x - 0.83\mathbf{a}_z$$

$$\mathbf{a}_{E^t} = \mathbf{a}_y \times \mathbf{a}_{k_t} = 0.83\mathbf{a}_x - 0.56\mathbf{a}_z$$

8.63 설명 생략

8.64 증명 생략

전반사

$$8.65 \quad -90^\circ \leq \theta_i \leq 5.87^\circ$$

8.66 증명 생략

$$\mathbf{8.67} \quad (\text{a}) \quad \tilde{\mathbf{H}}^t = \mathbf{a}_z \frac{E_o^t}{\eta_o} e^{-\alpha_e z} e^{-j\beta_e x}$$

(b) 증명 생략

$$\mathbf{8.68} \quad (\text{a}) \quad v_p = \sqrt{\frac{2\omega}{\mu_0 \sigma}}$$

$$(\text{b}) \quad v_g = \sqrt{\frac{8\omega}{\mu_0 \sigma}}$$

Chapter 09 연습문제 답안

전송선로 파라미터

9.1 (a) $C = 114.4 \text{ [pF/m]}$
 $L = 0.22 \text{ [}\mu\text{H/m]}$
 $R = 0.88 \text{ [}\Omega/\text{m]}$
 $G = 17.2 \text{ [}\mu\text{S/m]}$

(b) $\gamma = 0.01 + j31.5 \text{ [m}^{-1}\text{]}$
 $\alpha = 0.01 \text{ [Np/m]}$ and $\beta = 31.5 \text{ [rad/m]}$
 $Z_o = 43.9 - j0.013 \text{ [}\Omega\text{]}$

9.2 $L = 0.16 \text{ [}\mu\text{H/m]}$
 $G = 0.8 \text{ [mS/m]}$
 $R = 0.33 \text{ [}\Omega/\text{m]}$

9.3 $\alpha = 1.33 \times 10^{-3} \text{ [Np/m]}$

9.4 $a = 1.8 \text{ [mm]}$

9.5 $Z_o = 275 \text{ [}\Omega\text{]}$
 $Z'_o = 188 \text{ [}\Omega\text{]}$
 $\frac{275 - 188}{275} \times 100 = 32\%$
 $\beta = \omega\sqrt{LC} = \omega\sqrt{\mu\epsilon}$

9.6 (a) $\frac{\alpha_1}{\alpha_2} = 1.17$
(b) $\frac{\alpha_1}{\alpha_2} = 1.05$

9.7

$$\gamma = 0.032 + j44.6 \\ \equiv \alpha + j\beta$$

$$Z_o = 19.7 - j0.0036 [\Omega]$$

9.8 $L = 1.26 [\mu\text{H/m}]$, $C = 223 [\text{pF/m}]$

9.9 $\frac{R}{L} = 2.1 \times 10^6$, $\frac{G}{C} = 2.1 \times 10^6$

9.10 $C = 185 [\text{pF/m}]$

$$L = 167 [\text{nH/m}]$$

$$R = 1.41 [\Omega/\text{m}]$$

$$G = 1.56 [\text{mS/m}]$$

9.11 $\epsilon_r = 1.66$.

$$\sigma = 7.22 \times 10^{-5} [\text{S}].$$

9.12 증명 생략

9.13 (a) $\mathcal{H} = \frac{I_o \mathbf{a}_\phi}{2\pi\rho} \cos(\omega t - kz)$

$$\mathcal{E} = \sqrt{\frac{\mu_0}{\epsilon_0}} \frac{I_o \mathbf{a}_\rho}{2\pi\rho} \cos(\omega t - kz)$$

(b) $\mathbf{V} = \sqrt{\frac{\mu_0}{\epsilon_0}} \frac{I_o}{2\pi} \ln(b/a) \cos(\omega t - kz)$

(c) $\frac{V_o}{I_o} = Z_o$

반사계수

$$9.14 \quad |\Gamma| = \frac{3-1}{3+1} = 0.5$$

$$9.15 \quad \Gamma = 0.46e^{j1.6\pi}$$

$$9.16 \quad \Gamma = 0.2e^{-j0.33\pi}$$

$$9.17 \quad \Gamma = 0.11e^{j0.86\pi}$$

$$9.18 \quad f = 984 \text{ [MHz]}$$

$$9.19 \quad (a) \quad \Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} = 0.23e^{-j2.06}$$

(b)

$$\begin{aligned} \ell'_{\max} &= \frac{1}{2 \times 4.19} (-2.06 + 2m\pi) \\ &= 0.50 \text{ [m]}, 1.25 \text{ [m]}, 2.00 \text{ [m]}, \dots \end{aligned}$$

$$9.20 \quad (a) \quad \Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} = 0.70e^{j0.58}$$

$$(b) \quad \tilde{V}(z) = 10e^{-j1.2\pi z} \left[1 + 0.70e^{j0.58}e^{-j2.4\pi\ell'} \right]$$

$$(c) \quad \ell' = \frac{0.58}{2.4\pi} = 7.7 \text{ [cm]}$$

$$9.21 \quad (a) \quad \Gamma = 0.524e^{j0.6\pi} = -0.162 + j0.498$$

$$(b) \quad Z_L = 90.8 + j124.6 \text{ [\Omega]}$$

$$9.22 \quad R_o = 100 \text{ [\Omega]}.$$

$$9.23 \quad \tilde{V}(z) = (19.46 + j39.68) \left[1 + (0.12 + j0.16)e^{-j0.8\pi} \right] = 44.94e^{j0.92} \text{ [V]}$$

9.24 (a) $\tilde{I}(\ell) = 1000e^{-j1.5711} [\text{A}]$

(b) $\tilde{I}(\ell) = 1.0e^{-j1.571} [\text{A}]$

입력 임피던스

9.25 $Z_{in} = 153.86 + j87.25 [\Omega]$

9.26 $Z_L = 35.4 + j42.7 [\Omega]$

9.27 $\ell' = \frac{\lambda}{4\pi}(\pi + \phi) = 0.15\lambda$

9.28 $Z_{in}(\ell') = 422.4 + j76.4 [\Omega]$

9.29 (a) $\ell' = 0.076\lambda$
 (b) $z_{in}(\ell') = 1 + j1.155$

9.30 $Z_{in} = 142.5 - j36.4 [\Omega]$

9.31 (a) $Z_{in} = 40 - j30 [\Omega]$
 (b) $\tilde{V}_{in} = 11.18e^{-j0.18} [\text{V}]$
 (c) $\tilde{I}_L = -0.20 - j0.099 [\text{A}]$

9.32 $S_2 = \frac{1+1/3}{1-1/3} = 2, \quad S_1 = \frac{1+0.40}{1-0.40} = 2.33$

임피던스 매칭

$$9.33 \quad \frac{\lambda}{4} = 14.6 [\text{cm}]$$

$$9.34 \quad R_1 = \frac{R_o}{2} \frac{1+|\Gamma|}{|\Gamma|}$$

$$9.35 \quad R_1 = 122.4 [\Omega], \quad \ell_1 = 0.11\lambda$$

닫힌 선로 및 열린 선로

$$9.36 \quad \ell = 3.6 [\text{cm}]$$

$$9.37 \quad \begin{aligned} \text{(a)} \quad R_o &= \sqrt{Z_{in}^o Z_{in}^s} = \sqrt{(-j68.8)(j36.3)} = 50.0 [\Omega] \\ \text{(b)} \quad \epsilon_r &= 2.25 \end{aligned}$$

$$9.38 \quad d_1 = \frac{\lambda}{4}.$$

전력 전달

$$\begin{aligned} 9.39 \quad \text{(a)} \quad \tilde{I}_{in} &= 0.300 + j0.076 \\ \tilde{V}_{in} &= Z_{in} \tilde{I}_{in} = 8.981 - j1.515 \\ \text{(b)} \quad \tilde{V}_L &= -6.389 + j14.735 \\ \tilde{I}_L &= \frac{\tilde{V}_L}{Z_L} = -0.064 + j0.147 \\ \text{(c)} \quad \langle P_{in} \rangle &= 1.29 [\text{W}] \\ \text{(d)} \quad \langle P_L \rangle &= 1.29 [\text{W}] \\ \text{(e)} \quad \langle P_t \rangle &= 2.25 [\text{W}] \end{aligned}$$

$$\begin{aligned}
9.40 \quad (a) \quad \langle P_1 \rangle &= \frac{1}{2} \operatorname{Re} \left[\frac{1}{Z_o} V_o^{+*} V_o^+ \right] = 1.30 [\text{W}] \\
(b) \quad \langle P_2 \rangle &= \frac{1}{2} \operatorname{Re} \left[\frac{1}{Z_L} \tilde{V}_L^* \tilde{V}_L \right] = 1.18 [\text{W}] \\
(c) \quad \langle P_3 \rangle &= \frac{1}{2} \operatorname{Re} \left[V_o^{-*} \frac{V_o^-}{Z_o} \right] = 0.12 [\text{W}]
\end{aligned}$$

$$\begin{aligned}
9.41 \quad (a) \quad Z_{in} &= Z_L = 20 - j15 [\Omega] \\
(b) \quad \langle P_{in} \rangle &= 0.63 [\text{W}]
\end{aligned}$$

$$\begin{aligned}
9.42 \quad (a) \quad \langle P \rangle &= 320 [\text{mW}] \\
(b) \quad Z_A &= 24.6 - j20.5 \\
\langle P_L \rangle &= 156 [\text{mW}]
\end{aligned}$$

$$9.43 \quad 25\%$$

$$9.44 \quad 4(1 - |\Gamma'|^2) = 3.2 [\text{W}]$$

$$\begin{aligned}
9.45 \quad (a) \quad V_2(z) &= V_{o2}^+ e^{-j\beta z'} \left[1 + \Gamma e^{-j2\beta(\ell_2 - z')} \right] = V_{o2}^+ e^{-j\pi z'} \left[1 + 0.2 e^{-j0.5\pi} e^{j2\pi z'} \right] \\
V_1(z) &= V_{o1}^+ e^{-j\beta z} \left[1 + \Gamma' e^{-j2\beta(\ell_1 - z)} \right] = V_{o1}^+ e^{-j\pi z} \left[1 + 0.388 e^{-j2.668} e^{j2\pi z} \right] \\
(b) \quad \langle P_L \rangle &= 0.92 [\text{W}] \\
(c) \quad &\text{(b)와 동일함}
\end{aligned}$$

스미스 차트

$$9.46 \quad \phi = \tan^{-1} \left(\frac{x'}{r' - 1} \right) - \tan^{-1} \left(\frac{x'}{r' + 1} \right)$$

$$\begin{aligned}
9.47 \quad (a) \quad \Gamma &= 0.41 e^{j2.10} \\
(b) \quad S &= 2.4 \\
(c) \quad Z_{in} &= 144 - j136 [\Omega]
\end{aligned}$$

- 9.48 (a) $\Gamma = 0.60e^{j(0.25-0.071)\times 4\pi} = 0.60e^{j2.25}$
 (b) $S = 4$.
 (c) 첫 번째 전압 최대값은 부하에서 발생한다.
 (d) $Z_{in} = 35 - j60 [\Omega]$
 (e) $Y_{in} = 7.2 + j12.5 [\text{mS}]$

9.49 $Z_L = 120 + j114 [\Omega]$.

9.50 $R_L = 0.42 \times 150 = 63 [\Omega]$.

9.51 $z_{in} = 1.25 - j0.75$.

9.52 $Z_{in} = 120 \times (1.4 + j1.3) = 168 + j156 [\Omega]$

9.53 (a) $Z_L = 15 + j27.5 [\Omega]$

(b) $\Gamma = 0.63e^{j2.07}$

9.54 $Z_L = 200 \times (1.6 - j1.8) = 320 - j360 [\Omega]$

9.55 $z_{in} = -120 \times j1.15 = -j138 [\Omega]$

9.56 (a) $Z_{in}^s = 120 \times j1.5 = j180 [\Omega]$

(b) $Z_{in}^s = 120 \times (-j1.5) = -j180 [\Omega]$

9.57 증명 생략

9.58 $a = -\frac{1}{2} \ln 0.5 = 0.35$, $b = \frac{1}{2} (\pi - 0.968) = 1.09$

9.59 $Z_L = 50 \times (0.4 + j0.3) = 20 + j15 [\Omega]$

9.60 $Z_L = 100(0.4 + j1.7) = 40 + j170 [\Omega]$

9.61 (a) $y_{in} = 0.6 - j0.8$., (b) $y_{in} = 1.70 + j0.94$.

9.62 $Y_m = 10 \times 10^{-3} \times (0.26 + j0.18) = 2.6 + j1.8 [\text{mS}]$

9.63 (a) $\ell_1 = 0.401\lambda$
(b) $R_1 = 200 [\Omega]$
(c) $\ell_2 = 0.081\lambda$

9.64 $Z_{in} = 100 \times (0.8 - j0.6) = 80 - j60 [\Omega]$.

9.65 (a) 0.148λ .
(b) $d = (0.408 - 0.25)\lambda = 0.158\lambda$

9.66 (a) $d = 0.0935\lambda$.
(b) $\ell' = 0.396\lambda$.

9.67 $Z_L = 70 - j122 [\Omega]$.

Chapter 10 연습문제 답안

Herizian 쌍극자

$$\begin{aligned} 10.1 \quad P_{\text{rad}} &= 0.16 \text{ [W]} \\ R_{\text{rad}} &= 0.08 \text{ } [\Omega] \end{aligned}$$

$$\begin{aligned} 10.2 \quad |E|_{\text{max}} &= 42.4 \text{ [mV/m]} \\ R^2 \left\langle \mathbf{S} \right\rangle_{\text{max}} &= 0.24 \text{ [kW/sr]} \end{aligned}$$

$$10.3 \quad \frac{P_{\text{b.w.}}}{P_{\text{rad}}} = \frac{3 \left(\sqrt{2} - \frac{1}{3\sqrt{2}} \right)}{4} = 88.4\%$$

10.4 증명 생략

10.5 증명 생략

$$\begin{aligned} 10.6 \quad (a) \quad \zeta &= 37.4\% \\ (b) \quad G_p &= \zeta D = 0.56 = -2.5 \text{ [dB]} \end{aligned}$$

안테나 특성

$$\begin{aligned} 10.7 \quad (a) \quad G_d(\theta, \phi) &= \frac{U(\theta, \phi)}{P_{\text{rad}} / 4\pi} = 4\pi \frac{30 \sin^2 \theta \cos \phi}{80} = (1.5\pi) \sin^2 \theta \cos \phi \\ (b) \quad \Omega &= \int_{\phi=-\pi/2}^{\pi/2} \int_{\theta=0}^{\pi} \sin^3 \theta \cos \phi d\theta d\phi = 2.67 \text{ [sr]} \\ (c) \quad &120^\circ, 90^\circ. \end{aligned}$$

$$10.8 \quad \Omega_p = \frac{P_{\text{rad}}}{|\langle \mathbf{S} \rangle|_{\text{max}} R^2} = \frac{72}{60 \times 10^{-6} \times 10^6} = 1.2 [\text{sr}] \quad (1)$$

$$D = \frac{U_{\text{max}}(\theta, \phi)}{P_{\text{rad}} / 4\pi} = \frac{|\langle \mathbf{S} \rangle|_{\text{max}} R^2}{P_{\text{rad}} / 4\pi} \quad (2)$$

$$D = \frac{4\pi}{\Omega_p} = \frac{4\pi}{1.2} = 10.5$$

$$10.9 \quad G_p = \zeta D = 5.99 = 7.78 [\text{dB}]$$

10.10 증명 생략

선형 안테나

$$10.11 \quad I_o = 11.4 [\text{A}]$$

$$10.12 \quad \theta = 0^\circ, 70.5^\circ, 109.5^\circ, 180^\circ.$$

$$10.13 \quad 47.8^\circ.$$

$$10.14 \quad R_{\text{rad}} = 39.5 [\text{m}\Omega] \\ \zeta = 81.1\%$$

$$10.15 \quad I_o = 0.55 [\text{A}]$$

$$10.16 \quad U(\theta, \phi) = \frac{\eta_o}{2} \left(\frac{k^2 I_o S}{4\pi} \right)^2 \sin^2 \theta [\text{W/sr}]$$

$$G_d(\theta, \phi) = \frac{U(\theta, \phi)}{P_{\text{rad}} / 4\pi} = \frac{3}{2} \sin^2 \theta$$

10.17 (a) $n \left| \tilde{E}_\phi \right|_{\max} = 4.1 \text{ [mV/m]}$
 (b) $P_{\text{rad}} = 4.74 \text{ [\mu W]}$

10.18 (a) $R_{\text{rad}} = 30.8 \text{ [\Omega]}$
 (b) $P_{\text{rad}} = 15.4 \text{ [W]}$
 (c) $\zeta = 98.6\%$

반파 쌍극자

10.19 (a) $P_{\text{rad}} = 146 \text{ [W]}$
 (b) $E_{\max} = 12.0 \text{ [mV/m]}$

10.20 $P_{\text{rad}} = 9.87 \times 10^{-3} I_o^2 \text{ [W]}$
 $P_{\text{rad}} = 36.6 I_o^2 \text{ [W]}$

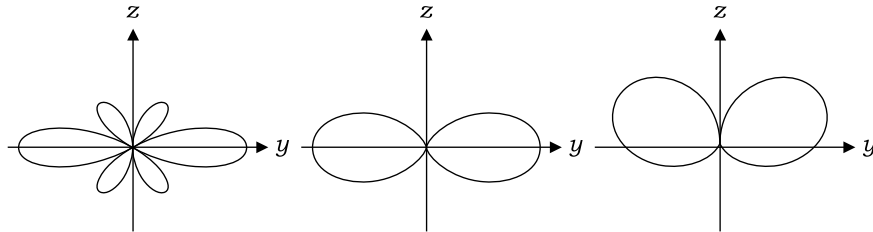
10.21 $\rho = \frac{k}{j\omega} I_o \sin kz = -j \frac{I_o}{c} \sin kz$ c , speed of light in free space.

안테나 배열

10.22 (a) $|A(\theta, \phi)| = \left| 2 \cos \left(\frac{\Psi}{2} \right) \right| = |2 \cos(\pi \cos \phi + \xi/2)|$
 (b) $\xi = 105.4^\circ$

10.23 0 to 60° .

10.24



10.25 $d = \frac{2}{3}\lambda$ and $\xi = -\frac{4\pi}{3}$

10.26 $\xi = -\frac{\pi}{2}$.

10.27 (a) $|\bar{A}(\theta = \pi/2, \phi)| = \left| \cos\left(\frac{\pi}{2} \cos \phi\right) \right|^3$
 (b) 35° .
 (c) 26.4° .

10.28 $|A(\theta, \phi)| = \frac{1}{8} \left| 2 \cos(\pi \sin \theta \cos \phi) + 3 \cos\left(\frac{\pi}{2} \sin \theta \cos \phi\right) + 3 \right|$

10.29 $d = n \frac{\lambda}{N}$

10.30 $d = \frac{\lambda}{4}$ and $\xi = -\frac{\pi}{4}$

10.31 $\xi = -\frac{\pi}{12}$ and $d = \frac{\lambda}{12}$

$$10.32 \quad (a) \quad \Delta\phi = \frac{2\lambda}{Nd}$$

$$(b) \quad \Delta\phi = 0.84 \frac{\lambda}{Nd}$$

실효면적과 프리스 전송공식

$$10.33 \quad A_e = 1.68 [\text{m}^2]$$

$$10.34 \quad A_e(\theta, \phi) = 0.25 [\text{m}^2]$$

$$10.35 \quad (a) \quad A_e(\theta, \phi)|_{\max} = 1.64 \times \frac{\lambda^2}{4\pi}$$

$$(b) \quad P_{L, \max} = |\langle \mathbf{S} \rangle| A_{e, \max} = \frac{E_o^2}{2\eta_o} \times 1.64 \times \frac{\lambda^2}{4\pi} = \frac{1.64}{960} \left(\frac{E_o \lambda}{\pi} \right)^2$$

(c) 증명 생략

$$10.36 \quad \ell_e = \frac{\lambda}{\pi}$$

$$10.37 \quad (a) \quad P_L = \frac{E_o^2}{2\eta_o} \times 1.5 \times \frac{\lambda^2}{4\pi} = \frac{1}{640} \left(\frac{E_o \lambda}{\pi} \right)^2$$

$$(b) \quad P_L = \frac{1}{8} \frac{|V_{oc}|^2}{R_{rad}} = \frac{1}{8} \frac{|E_o d \ell|^2}{80\pi^2} \left(\frac{\lambda}{d \ell} \right)^2 = \frac{1}{640} \left(\frac{E_o \lambda}{\pi} \right)^2$$

$$10.38 \quad P_L = 0.19 [\text{mW}]$$

$$10.39 \quad P_{rad} = 1.0 [\text{kW}]$$

$$10.40 \quad P_{rad} = 0.44 [\text{W}]$$

- 10.41** (a) $|\langle \mathbf{S}_i \rangle| = 20.0 [\text{mW/m}^2]$
(b) $\sigma |\langle \mathbf{S}_i \rangle| = 15 \times 0.02 = 0.3 [\text{W}]$
(c) $P_L = 19.1 [\text{pW}]$