

Answers

Chapter 1

1. (a) $A_x = 5, A_y = -3, A_z = -1$. (b) $A_x = 1, A_y = 0, A_z = 1$. (c) $\sqrt{35}$.
2. (a) $\mathbf{v} = \hat{\mathbf{E}} 35.36 + \hat{\mathbf{N}} 35.36$ km/h. (b) 84 h 51 min. (c) 4,242.64 km.
3. (a) $82^\circ.49'$ from north. (b) 220.48 m/s. (c) 22,678 s (6h, 13 m).
4. (a) 5.916. (b) $\hat{\mathbf{x}} 2 + \hat{\mathbf{y}} 8 - \hat{\mathbf{z}} 3$. (c) $\hat{\mathbf{x}} 8 - \hat{\mathbf{y}} 2 + \hat{\mathbf{z}}$. (d) $-\hat{\mathbf{x}} 8 + \hat{\mathbf{y}} 2 - \hat{\mathbf{z}}$. (e) $(-\hat{\mathbf{x}} 8 + \hat{\mathbf{y}} 2 - \hat{\mathbf{z}})/\sqrt{69}$.
5. (b) $\hat{\mathbf{x}} + \hat{\mathbf{y}} 2 + \hat{\mathbf{z}} 8, -\hat{\mathbf{x}} + \hat{\mathbf{y}} 6 + \hat{\mathbf{z}} 4, \hat{\mathbf{x}} 5 - \hat{\mathbf{z}} 2, \hat{\mathbf{x}} 7 - \hat{\mathbf{y}} 4 + \hat{\mathbf{z}} 2, -\hat{\mathbf{x}} + \hat{\mathbf{y}} 6 + \hat{\mathbf{z}} 4, -\hat{\mathbf{x}} + \hat{\mathbf{y}} 6 + \hat{\mathbf{z}}$.
6. (a) $\hat{\mathbf{E}} 16,000$ km/h (before), $\hat{\mathbf{E}} 15,000$ km/h (after). (b) $k = 0.9375$ m/s.
7. (a) $\hat{\mathbf{v}} = (\hat{\mathbf{x}} 150 + \hat{\mathbf{y}} 25 - \hat{\mathbf{z}} 50)/160.08$ m/s. (b) 160.08 m/s.
8. $(-\hat{\mathbf{x}} 3 - \hat{\mathbf{y}} 4 - \hat{\mathbf{z}} 1)/\sqrt{26}$.
9. (a) $102^\circ 51'$. (b) $\mathbf{v}_{1g} = -\hat{\mathbf{x}} 2 + \hat{\mathbf{y}} 1, \mathbf{v}_{2g} = -\hat{\mathbf{x}} 2 + \hat{\mathbf{y}} 3$. (c) $105^\circ 31'$.
10. (a) $(-\hat{\mathbf{x}} - \hat{\mathbf{y}} - \hat{\mathbf{z}})/\sqrt{3}$. (b) $\hat{\mathbf{x}} 0.784 - \hat{\mathbf{y}} 0.588 + \hat{\mathbf{z}} 0.196$. (c) $(\hat{\mathbf{x}} a + \hat{\mathbf{y}} b - \hat{\mathbf{z}})/\sqrt{a^2 + b^2 + 1}$.
11. $(\hat{\mathbf{x}} 9 + \hat{\mathbf{y}} 3 - \hat{\mathbf{z}} 3)/11r$.
14. (a) 57.688° . (b) $\hat{\mathbf{x}} - \hat{\mathbf{y}} 3$.
15. (a) $15/\sqrt{17}$ N.
16. (a) 27.04.
17. $7x - 7y - 7z = 0$.
22. (a) 3.13. (b) 0.911. (c) 0.738.
23. (b) (1,2) and (0,2).
26. (a) $P_1(\sqrt{2}, 45^\circ, 1), P_2(\sqrt{2}, 45^\circ, 0), P_3(1, 90^\circ, 1), P_1(\sqrt{3}, 54.736^\circ, 45^\circ), P_2(\sqrt{2}, 90^\circ, 45^\circ), P_3(\sqrt{2}, 45^\circ, 90^\circ)$. (b) $y = 1$.
(c) $r \sin \phi = 1$. (d) $R \sin(\theta) \sin(\phi) = 1$.
27. (a) $x^2 + y^2 + z^2 = a^2$. (b) $r^2 + z^2 = a^2$. (c) $R = a$.
28. (a) $P(a \sin \theta \cos \phi, \sin \theta \sin \phi, a \cos \theta)$. (b) $P(a, \theta, \phi)$.
29. $\mathbf{A} = -\hat{\mathbf{R}} 4.276 - \hat{\theta} 4.229 + \hat{\phi} 1.1094$.
30. (a) $\mathbf{A} = \hat{\mathbf{x}} (3 \cos^2 \phi + 2\sqrt{r} \sin \phi) + \hat{\mathbf{y}} (3 \cos \phi \sin \phi - 2\sqrt{r} \cos \phi) + \hat{\mathbf{z}} r \phi$. (b) $A_R = 3 \cos \phi \sin \theta + r \phi \cos \theta, A_\theta = 3 \cos \phi \cos \theta - r \phi \sin \theta, A_\phi = -2\sqrt{r}$.
31. (a) $\mathbf{r}_1 = \hat{\mathbf{x}} a + \hat{\mathbf{y}} b + \hat{\mathbf{z}} c$. (b) $\mathbf{r}_2 = \hat{\mathbf{x}} a' + \hat{\mathbf{y}} b' + \hat{\mathbf{z}} c'$. (c) $\mathbf{R} = \hat{\mathbf{x}} (a' - a) + \hat{\mathbf{y}} (b' - b) + \hat{\mathbf{z}} (c' - c)$.
32. (a) $\mathbf{r}_1 = \hat{\mathbf{z}} 3, \mathbf{r}_2 = \hat{\mathbf{x}} 1.5 + \hat{\mathbf{y}} 1.5 + \hat{\mathbf{z}} 3\sqrt{2}/2$. (b) $\hat{\mathbf{x}} 1.5 + \hat{\mathbf{y}} 1.5 + \hat{\mathbf{z}} (3\sqrt{2} - 6)/2$.
33. $(A_y B_z - A_z B_y)x + (A_z B_x - A_x B_z)y + (A_x B_y - A_y B_x)z = 0$.

Chapter 2

1. (a) $\tan^{-1}(b/a)$. (b) $\tan^{-1}(b/a)$.
3. (a) 12. (b) 12.
4. π .

5. $\pi^2/12 - \pi(\sqrt{3} - 2)$.
 6. 3.
 7. $3\pi a^2$.
 8. (a) $7\pi a^4 d/6 + \pi d^3 a^2/12$. (b) $4.98a^5$.
 9. $(100\pi h_0^9)(600a^5 + 600ba^4 + a^3h_0^2 + 600a^3b^2 + 3a^2bh_0^2 + 600a^2b^3 + 6ah_0^2b^2 + 600ab^4 + 10h_0^2b^3 + 600b^5)$.
 10. (a) $\hat{z} 8/3$. (b) $\hat{x} 16 + \hat{y} 8 + \hat{z} 32/3$.
 11. $\hat{x} 50/3 + \hat{y} 75/2$ m/s.
 12. $\hat{x} 10/3 + \hat{y} 10$.
 13. Zero.
 14. (a) $|\nabla P| = 2\sqrt{(x-2)^2 + (y-2)^2 + (z+1)^2}$, $\widehat{\nabla P} = (\hat{x}(x-2) + \hat{y}(y-2) + \hat{z}(z+1))/|\nabla P|$. (b) $2(z+1)$. (c) $\sqrt{2}(x+y-4)$.
 15. (a) $\hat{r} \cos^2\phi + \hat{\phi}(-2r\cos\phi \sin\phi + z\cos\phi)/r + \hat{z} \sin\phi$. (b) $\hat{x}(x^3 + 2xy^2 - xyz)/(x^2 + y^2)^{3/2} + \hat{y}(-x^2y + x^2z)/(x^2 + y^2)^{3/2} + \hat{z}y/(x^2 + y^2)^{1/2}$. (c) $\hat{R}(\cos^2\phi \sin\theta + \cos\theta \sin\phi) + \hat{\theta}(\cos^2\phi \cos\theta - \sin\theta \sin\phi) - \hat{\phi}(2\cos^2\phi \sin\phi - \cos\theta \cos\phi/\sin\theta)$.
 16. (a) $\hat{x} 5/\sqrt{35} + \hat{y} 3/\sqrt{35} + \hat{z} 1/\sqrt{35}$. (b) $\hat{x} 4/\sqrt{26} - \hat{y} 3/\sqrt{26} + \hat{z} 1/\sqrt{26}$. (c) $(\hat{x}a + \hat{y}b - \hat{z}1)/\sqrt{a^2 + b^2 + 1}$.
 17. (a) $\frac{\hat{x}3y + \hat{y}(3x+z) + \hat{z}(y+1)}{\sqrt{9y^2 + (3x+z)^2 + (y+1)^2}}$. (b) $\frac{\hat{x}1 - \hat{y}2y - \hat{z}2z}{\sqrt{1 + 4y^2 + 4z^2}}$. (c) $\frac{\hat{x}x + \hat{y}y + \hat{z}z}{\sqrt{x^2 + y^2 + z^2}}$.
 18. (a) $2x$. (b) $2z^2/r$. (c) $x/\sqrt{x^2 + z^2} + y/\sqrt{x^2 + y^2}$.
 19. 4.
 20. 4.
 21. 3.6.
 24. (a) 3. (b) 3.
 25. (a) $-\hat{x}2y$. (b) $\hat{\phi}(4z + 6r) + \hat{z}10$. (c) $\hat{y}z/\sqrt{x^2 + z^2} + \hat{z}x/\sqrt{x^2 + y^2}$.
 26. (a) Zero.
 27. (a) $\hat{x}150x \sin(\omega t + 50z) + \hat{z}3 \cos(\omega t + 50z)$.
 28. (a) $-\hat{x}2(x+1)y + \hat{y}z^2 + \hat{z}(2yz - 2y)$. (b) $-\hat{z}6 \sin\phi$.
 30. (a) $2z$. (b) $-\hat{z}5$. (c) -20π .
 31. $\pm(ba + ca + bc)/2$.
 33. (a) $2(y-2)^2(z+1)^2 + 2(x-2)^2(z+1)^2 + 2(x-2)^2(y-2)^2$. (b) $12z$.
 34. (a) $\nabla^2 \mathbf{A} = \hat{z}2$. (b) $\nabla^2 \mathbf{A} = \hat{r}(6/r) \cos^2\phi$.
 36. (a) $\hat{x}4x + \hat{y}1$. (b) $10x^2 + 4y$. (c) 4. (d) $\nabla^2 \mathbf{R} = 0$. (e) $\hat{x}z - \hat{y}4xz + \hat{z}(4xy - x)$.
 39. (a) 3. (b) 1 and 5.

Chapter 3

1. (a) 8.615×10^{13} C.
 2. 2.3×10^{12} N.
 3. (a) 0.0957 m. (b) 0.1354 m.
 4. 15.4 mm.
 5. (a) 1.168×10^{-11} C.
 6. (a) $\mathbf{a}_x = -\hat{x}4qQx/\pi m\epsilon_0(4x^2 + d^2)^{3/2}$, a_{max} occurs at $x = \pm d/2\sqrt{2}$.
 7. (a) to $x = 0.414d$ [m] from Q_1 .
 8. (b) 0.1 m to the right of negative charge.
 10. (a) $\mathbf{E} = \frac{q}{4\pi\epsilon_0} \left(\frac{2\mathbf{R}}{|\mathbf{R}|^3} - \frac{\mathbf{R} - \mathbf{d}/2}{|\mathbf{R} - \mathbf{d}/2|^3} - \frac{\mathbf{R} + \mathbf{d}/2}{|\mathbf{R} + \mathbf{d}/2|^3} \right)$ [N/C]. (b) $\mathbf{E} = \frac{3pd}{8\pi\epsilon_0 R^4} (\hat{\mathbf{R}} \cos^2\theta - \hat{\boldsymbol{\theta}} \sin\theta \cos\theta)$ [N/C].
 11. (a) ∞ . (b) $\mathbf{E} = \hat{z}Q/12\pi\epsilon_0 a^2$ [N/C]. (c) zero.
 12. (a) 0.303 m.
 13. (a) 0.303 m.
 15. $3.82 \cdot 10^{-13}$ C/h/m².
 16. (a) 0.289L or 0.125L from centers of sides of the triangle and at infinity.

17. (a) 6.131×10^{10} N/C. (b) 3.066×10^{10} N/C.
 18. (a) 438.15 m/s.
 19. (a) 9.81×10^{-7} C. (b) 9.81 m/s². (c) 1.53×10^7 s.
 20. $\mathbf{E}_1 = \hat{\mathbf{y}} \sqrt{2} \rho_l / 2\pi\epsilon_0 L$, $\mathbf{E}_2 = \hat{\mathbf{x}} \rho_l (\sqrt{5} - 1) / 2\pi\epsilon_0 L \sqrt{5} + \hat{\mathbf{y}} \rho_l / \pi\epsilon_0 L \sqrt{5}$, $\mathbf{E}_3 = \hat{\mathbf{x}} \rho_l / 3\pi\epsilon_0 L$ [N/C].
 21. (a) $E = \rho_l a h / 2\epsilon_0 (h^2 + a^2)^{3/2}$ [N/C].
 22. 1.797×10^{-5} N.
 23. 1.78×10^{-4} N (attraction).
 24. $F = \frac{Q_1 Q_2}{4\pi\epsilon L_1 L_2} \ln \frac{(a + L_2)(a + L_1)}{a(L_1 + a + L_2)}$ [N].
 25. $\mathbf{E} = \hat{\mathbf{z}} \frac{\rho_0 h}{2\epsilon_0} \left[\frac{1}{h} - \frac{1}{\sqrt{h^2 + a^2}} \right]$ [N/C].
 26. $\mathbf{E} = \hat{\mathbf{z}} \frac{\rho_0 h}{2\epsilon_0} \left[\ln \frac{a + \sqrt{h^2 + a^2}}{h} - \frac{a}{\sqrt{h^2 + a^2}} \right]$ [N/C].
 27. $\mathbf{E} = \hat{\mathbf{z}} \rho_s / 2\epsilon_0$ [N/C].
 28. $\mathbf{E} = \hat{\mathbf{z}} \frac{\rho_s}{2\epsilon} \left[\frac{L^2}{a\sqrt{L^2 + a^2}} + \frac{\sqrt{L^2 + a^2}}{a} - 1 \right]$ [N/C].
 29. $\mathbf{E}_1 = 0$, $\mathbf{E}_2 = \hat{\mathbf{z}} \rho_v L (5 - \sqrt{17}) / 8\epsilon_0$, $\mathbf{E}_3 = \hat{\mathbf{z}} \rho_v L (4 + \sqrt{5} - \sqrt{37}) / 8\epsilon_0$ [N/C].
 30. (a) $\mathbf{E}(R) = -\hat{\mathbf{R}} 1.44 \times 10^{-9} / R^2$ [N/C]. (b) $\mathbf{E}(R) = -\hat{\mathbf{R}} 1.44 \times 10^{-9} / R^2$ [N/C].
 32. $\mathbf{E} = -\hat{\mathbf{R}} \rho_0 a^4 / 20\epsilon_0 R^2$ [N/C].
 33. (a) $8.988 \times 10^{-7} / d^2$ [N], repulsion. (b) $1.11 \times 10^{-8} / d^2$ [N], repulsion.
 34. (a) $\mathbf{D} = \hat{\mathbf{R}} q / 4\pi R^2$ [C/m²]. (b) $\mathbf{E} = \hat{\mathbf{R}} q / 4\pi\epsilon_0 R^2$ [N/C] for $R < d_1/2$ and $R > d_2/2$, $\mathbf{E} = \hat{\mathbf{R}} q / 4\pi\epsilon R^2$ [N/C] for $d_1/2 < R < d_2/2$. (c) $\Phi = q$ [C]. (d) $\Phi = q$ [C]. (e) $\Phi = q$ [C].

Chapter 4

1. (a) $\rho(x) = 3k\epsilon x^2$ [C/m³].
 2. (a) 8.854×10^{-26} C/m³.
 4. (a) $\mathbf{E} = \hat{\mathbf{z}} \rho_0 / 2\epsilon$ [N/C], $z > 0$, $\mathbf{E} = -\hat{\mathbf{z}} \rho_0 / 2\epsilon$ [N/C], $z < 0$. (b) $\mathbf{E} = \hat{\mathbf{z}} \rho_0 / 2\epsilon_0$ [N/C], $z > 0$, $\mathbf{E} = -\hat{\mathbf{z}} \rho_0 / 2\epsilon_0$ [N/C], $z < 0$.
 5. $\mathbf{E} = -\hat{\mathbf{y}} \rho_v a / \epsilon_0$ [N/C], $y < -b$. $\mathbf{E} = -\hat{\mathbf{y}} (\rho_s + \rho_v a) / \epsilon_0$ [N/C], $-b < y < -a$. $\mathbf{E} = \hat{\mathbf{y}} \rho_v |y| / \epsilon_0$ [N/C], $-a < y < 0$. $\mathbf{E} = \hat{\mathbf{y}} \rho_v y / \epsilon_0$ [N/C], $0 < y < a$. $\mathbf{E} = \hat{\mathbf{y}} (-\rho_s + \rho_v a) / \epsilon_0$ [N/C], $a < y < b$. $\mathbf{E} = \hat{\mathbf{y}} \rho_v a / \epsilon_0$ [N/C], $b < y$.
 6. (a) $\mathbf{E}_1 = \hat{\mathbf{x}} \rho_s / 2\epsilon_1 + \hat{\mathbf{y}} \rho_s / 2\epsilon_1$, $\mathbf{E}_2 = -\hat{\mathbf{x}} \rho_s / 2\epsilon_0 + \hat{\mathbf{y}} \rho_s / 2\epsilon_0$, $\mathbf{E}_3 = -\hat{\mathbf{x}} \rho_s / 2\epsilon_2 - \hat{\mathbf{y}} \rho_s / 2\epsilon_2$, $\mathbf{E}_4 = \hat{\mathbf{x}} \rho_s / 2\epsilon_3 - \hat{\mathbf{y}} \rho_s / 2\epsilon_3$ [N/C].
 (b) $\mathbf{F}_2 = -\hat{\mathbf{x}} q \rho_s / 2\epsilon_0 + \hat{\mathbf{y}} q \rho_s / 2\epsilon_0$ [N] (in second quadrant).
 7. (a) $\mathbf{E} = \hat{\mathbf{R}} R / 6\epsilon_0$ [N/C]. (b) $\mathbf{E} = \hat{\mathbf{R}} 4 \times 10^{-9} / 3\epsilon_0 R^2$ [N/C]. (c) $\mathbf{E} = -\hat{\mathbf{R}} (-68 \times 10^{-9} + R^3) / 3\epsilon_0 R^2$ [N/C]. (d) $\mathbf{E} = -\hat{\mathbf{R}} 148 \times 10^{-9} / 3\epsilon_0 R^2$ [N/C].
 8. Zero.
 9. $\mathbf{E} = \hat{\mathbf{x}} \rho_0 x^2 / 2\epsilon_0$ [N/C], $0 < x < d/2$, $\mathbf{E} = -\hat{\mathbf{x}} \rho_0 x^2 / 2\epsilon_0$ [N/C], $-d/2 < x < 0$, $\mathbf{E} = \hat{\mathbf{x}} \rho_0 d^2 / 8\epsilon_0$ [N/C], $x \geq d/2$, $\mathbf{E} = -\hat{\mathbf{x}} \rho_0 d^2 / 8\epsilon_0$ [N/C], $x \leq -d/2$.
 10. (a) $\mathbf{E} = \hat{\mathbf{y}} \frac{\rho_l y}{2\pi\epsilon_0(y^2 + z^2)} + \hat{\mathbf{z}} \left[\frac{\rho_l z}{2\pi\epsilon_0(y^2 + z^2)} + \frac{\rho_s}{2\epsilon_0} \right]$ [N/C], $z > z_0$, $\mathbf{E} = \hat{\mathbf{y}} \frac{\rho_l y}{2\pi\epsilon_0(y^2 + z^2)} + \hat{\mathbf{z}} \left[\frac{\rho_l z}{2\pi\epsilon_0(y^2 + z^2)} - \frac{\rho_s}{2\epsilon_0} \right]$ [N/C], $z > z_0$. (b) $\mathbf{D}(0, 0, 1) = \hat{\mathbf{z}} (\rho_l / 2\pi \pm \rho_s / 2)$ [C/m²].
 11. (a) $\mathbf{E} = 0$, $0 < r < a$, $\mathbf{E} = \hat{\mathbf{r}} \frac{a\rho_s}{r\epsilon_0}$ [N/C], $a < r < b$, $\mathbf{E} = \hat{\mathbf{r}} \frac{\rho_s}{r\epsilon_0} (a - b)$ [N/C], $r > b$. (c) $\rho_l = 2\pi\rho_s (b - a)$ [C/m].
 12. (a) Zero. (b) 4,493.87 N/C.
 13. (a) $\mathbf{E} = \hat{\mathbf{R}} \frac{Q}{4\pi\epsilon_0 R^2}$ [N/C], $R < a$, $\mathbf{E} = \hat{\mathbf{R}} \left(\frac{a^2 \rho_s}{\epsilon_0 R^2} + \frac{Q}{4\pi\epsilon_0 R^2} \right)$ [N/C], $R > a$. (b) $\rho_s = -\frac{Q}{4\pi a^2}$ [C/m²].
 14. (a) $\rho_v = \epsilon |y|$ [C/m³]. (b) $E = \epsilon d^2 / 8\epsilon_0$ [N/C].
 15. (a) $\rho_v = 4\epsilon b$ [C/m³]. (b) $\mathbf{E} = \hat{\mathbf{R}} b^2 / 4$ [V/m]. (c) $\Phi = \epsilon b^4 \pi$ [C].
 16. 2.65×10^{-5} C/m².
 17. 8 V.

18. (a) $V = 498.15 \text{ V}$, $E = 0$. (b) $V = 481.18 \text{ V}$, $E = 234.8 \text{ V/m}$.
19. (a) $V(R) = -R^2\rho_v/6\epsilon_0 + Q/4\pi\epsilon_0R + a^2\rho_v/2\epsilon_0 \text{ [V]}$, $R \leq a$.
20. (a) $\mathbf{E} = -\hat{\mathbf{x}}\rho_s/\epsilon_0 \text{ [V/m]}$ between plates, $\mathbf{E} = 0$ outside. (b) $V = \rho_s d/\epsilon_0 \text{ [V]}$ between plates. $V = 0$ to the left of the left plate, $V = \rho_s d/\epsilon_0 \text{ [V]}$ to the right of the right plate.
21. (a) $\rho_{sb} = V\epsilon_0/b \ln(b/a) \text{ [C/m}^2\text{]}$. (b) $\rho_{sa} = V\epsilon_0/a \ln(a/b) \text{ [C/m}^2\text{]}$.
22. $V = \rho_0(\sqrt{a^2 + d^2} - d)/2\epsilon_0 \text{ [V]}$.
23. (a) $\mathbf{E} = \hat{\mathbf{y}}\rho_l/4\sqrt{5}\pi\epsilon_0 \text{ [V/m]}$. (b) $V = \frac{\rho_l}{4\pi\epsilon_0} \ln\left(\frac{\sqrt{2}-1}{\sqrt{10}-3}\right) \text{ [V]}$.
24. $\mathbf{E} = \hat{\mathbf{x}}\rho_l/\pi\epsilon_0 d \text{ [V/m]}$, $V = 0$.
25. (a) $\mathbf{E} = \hat{\mathbf{x}}\rho_v x/\epsilon \text{ [V/m]}$ for $-a < x < a$ (the $x = 0$ plane is midway between the plates), $\mathbf{E} = \hat{\mathbf{x}}\rho_v a/\epsilon_0 \text{ [V/m]}$, $x > a$, $\mathbf{E} = -\hat{\mathbf{x}}\rho_v a/\epsilon_0 \text{ [V/m]}$, $x < -a$. (b) $V = \rho_v(a^2 - x^2)/2\epsilon \text{ [V]}$, $-a < x < a$, $V = \rho_v a(a - |x|)/\epsilon_0 \text{ [V]}$, $x < -a$, $x > a$.
26. $\mathbf{E} = \hat{\mathbf{x}}50x \text{ [V/m]}$.
27. (a) $\rho_v = -6\epsilon \text{ [C/m}^3\text{]}$. (b) $\mathbf{E} = -\hat{\mathbf{R}}2R \text{ [V/m]}$, $R < b$, $\mathbf{E} = -\hat{\mathbf{R}}2\epsilon b^3/\epsilon_0 R^2 \text{ [V/m]}$, $R > b$.
28. (a) $\mathbf{E} = \hat{\mathbf{x}}2 - \hat{\mathbf{y}}2 + \hat{\mathbf{z}}4 \text{ [V/m]}$. (b) Zero. (c) 4.9 V/m . (d) $W = -20 \times 10^{-6} \text{ J}$.
29. (a) $Vy/2b \text{ [V]}$ (y is the distance from lower plate). (b) $Vy/(2b - 2c) \text{ [V]}$, $0 < y \leq d$ and $Vd/(2b - 2c) + V(y - (d + 2c))/(2b - 2c) \text{ [V]}$, $d + 2c < y \leq 2b$.
30. $V = Q/4\pi\epsilon_0 R \text{ [V]}$.
31. $\rho_{sc} = \frac{V_0}{c^2(1/a\epsilon_1 - 1/b\epsilon_1 + 1/b\epsilon_2 - 1/c\epsilon_2)}$, $\rho_{sa} = -\frac{V_0}{a^2(1/a\epsilon_1 - 1/b\epsilon_1 + 1/b\epsilon_2 - 1/c\epsilon_2)} \text{ [C/m}^2\text{]}$.
32. (a) In 4.68a: $\mathbf{E} = -\hat{\mathbf{R}}\frac{Q}{4\pi\epsilon_0 R^2} \text{ [V/m]}$, $V = -\frac{Q}{4\pi\epsilon_0 R} + \frac{\rho_s a}{\epsilon_0} - \frac{\rho_s b}{\epsilon_0} \text{ [V]}$, $0 < R < a$, $\mathbf{E} = -\hat{\mathbf{R}}\frac{Q}{4\pi\epsilon_0 R^2} + \hat{\mathbf{R}}\frac{\rho_s a^2}{\epsilon_0 R^2} \text{ [V/m]}$,
 $V = -\frac{Q}{4\pi\epsilon_0 R} + \frac{\rho_s a^2}{\epsilon_0 R} - \frac{\rho_s b}{\epsilon_0} \text{ [V]}$, $a < R < b$, $\mathbf{E} = -\hat{\mathbf{R}}\frac{Q}{4\pi\epsilon_0 R^2} + \hat{\mathbf{R}}\frac{\rho_s a^2}{\epsilon_0 R^2} - \hat{\mathbf{R}}\frac{\rho_s b^2}{\epsilon_0 R^2} \text{ [V/m]}$, $V = -\frac{Q}{4\pi\epsilon_0 R} + \frac{\rho_s a^2}{\epsilon_0 R} - \frac{\rho_s b^2}{\epsilon_0 R} \text{ [V]}$, $R > b$; in 4.68b: $\mathbf{E} = -\hat{\mathbf{R}}\frac{Q}{4\pi\epsilon_0 R^2} \text{ [V/m]}$, $V = -\frac{Q}{4\pi\epsilon_0 R} + \frac{Q}{4\pi\epsilon_0 R} + \frac{Q}{4\pi\epsilon_0 a} - \frac{Q}{4\pi\epsilon_0 b} \text{ [V]}$, $0 < R < a$, $\mathbf{E} = 0$,
 $V = -\frac{Q}{4\pi\epsilon_0 b} \text{ [V]}$, $a < R < b$, $\mathbf{E} = -\hat{\mathbf{R}}\frac{Q}{4\pi\epsilon_0 R^2} \text{ [V/m]}$, $V = -\frac{Q}{4\pi\epsilon_0 R} \text{ [V]}$, $R > b$.
33. $\mathbf{E} = -\hat{\mathbf{R}}q/4\pi\epsilon_0 R_4^2 \text{ [V/m]}$, $V = -q/4\pi\epsilon_0 R_4 \text{ [V]}$.
34. $\mathbf{P} = \hat{\mathbf{r}}\rho_l(\epsilon_1 - \epsilon_0)/2\pi\epsilon_1 r \text{ [C/m}^2\text{]}$, $a < r < b$, $\mathbf{P} = \hat{\mathbf{r}}\rho_l(\epsilon_2 - \epsilon_0)/2\pi\epsilon_2 r \text{ [C/m}^2\text{]}$, $b < r < c$.
35. (a) $E = 120 \text{ kV/m}$. (b) $P = 3.187 \times 10^{-6} \text{ C/m}^2$.
36. (a) $\mathbf{D} = \hat{\mathbf{x}}\left[\frac{\rho_l x}{2\pi(x^2 + y^2)} + \frac{\rho_s}{2}\right] + \hat{\mathbf{y}}\frac{\rho_l y}{2\pi(x^2 + y^2)} \text{ [C/m}^2\text{]}$, $x > 1$, $\mathbf{D} = \hat{\mathbf{x}}\left[\frac{\rho_l x}{2\pi(x^2 + y^2)} - \frac{\rho_s}{2}\right] + \hat{\mathbf{y}}\frac{\rho_l y}{2\pi(x^2 + y^2)} \text{ [C/m}^2\text{]}$,
 $x < 1$. (b) $\mathbf{D} = \hat{\mathbf{x}}6.367 \times 10^{-7} \text{ C/m}^2$. (c) $\mathbf{P} = \hat{\mathbf{x}}\left[\frac{3\rho_l x}{8\pi(x^2 + y^2)} + \frac{3\rho_s}{8}\right] + \hat{\mathbf{y}}\frac{3\rho_l y}{8\pi(x^2 + y^2)} \text{ [C/m}^2\text{]}$, $x > 1$,
 $\mathbf{P} = \hat{\mathbf{x}}\left[\frac{3\rho_l x}{8\pi(x^2 + y^2)} - \frac{3\rho_s}{8}\right] + \hat{\mathbf{y}}\frac{3\rho_l y}{8\pi(x^2 + y^2)} \text{ [C/m}^2\text{]}$, $x < 1$.
37. (a) $E = 120 \text{ V/m}$ in air. (b) $V = 15,093.75 \text{ V}$.
38. (a) $\rho_s = 26.55 \times 10^{-6} \text{ C/m}^2$. (b) $V = 3 \times 10^6 a \text{ [V]}$.
39. $Q = 1.397 \times 10^{10} \text{ C}$.
40. (a) $V = 4.577 \times 10^5 \text{ V}$. (b) $5.024 \times 10^5 \text{ V}$.
41. $\mathbf{D}_2 = \hat{\mathbf{x}}5\epsilon_0 + \hat{\mathbf{y}}6\epsilon_0 \text{ [C/m}^2\text{]}$.
42. (a) $\mathbf{E}_2 = -\hat{\mathbf{x}}\epsilon_0 E/\epsilon_1$, $\mathbf{E}_3 = 0$, $\mathbf{E}_4 = -\hat{\mathbf{x}}\epsilon_0 E/\epsilon_1$, $\mathbf{E}_5 = -\hat{\mathbf{x}}E \text{ [V/m]}$. (b) $V = 2\epsilon_0 E d/\epsilon_1 \text{ [V]}$.
43. (a) $E = 21.76 \text{ V/m}$. (b) $E = 50 \text{ V/m}$.
44. (a) $\mathbf{E}_2 = -\hat{\mathbf{y}}E_1 \sin\theta - \hat{\mathbf{x}}(\epsilon_0/\epsilon_1)E_1 \cos\theta$, $\hat{\mathbf{E}}_3 = -\hat{\mathbf{y}}E_1 \sin\theta - \hat{\mathbf{x}}(\epsilon_0/\epsilon_2)E_1 \cos\theta$, $\hat{\mathbf{E}}_4 = \mathbf{E}_1 = -\hat{\mathbf{y}}E_1 \sin\theta - \hat{\mathbf{x}}E_1 \cos\theta \text{ [V/m]}$.
 (b) $V = E_1 a \epsilon_0 \cos\theta((\epsilon_2 + \epsilon_1)/\epsilon_1 \epsilon_2) \text{ [V]}$.
45. (a) $P_{1t}/(\epsilon_1 - \epsilon_0) = P_{2t}/(\epsilon_2 - \epsilon_0)$, $\epsilon_1 P_{1n}/(\epsilon_1 - \epsilon_0) = \epsilon_2 P_{2n}/(\epsilon_2 - \epsilon_0)$ for $\rho_s = 0$, $P_{1t}/(\epsilon_1 - \epsilon_0) = P_{2t}/(\epsilon_2 - \epsilon_0)$, $\epsilon_1 P_{1n}/(\epsilon_1 - \epsilon_0) - \epsilon_2 P_{2n}/(\epsilon_2 - \epsilon_0) = \rho_s$ for $\rho_s \neq 0$. (b) $P_{1t}/P_{2t} = (\epsilon_1 - \epsilon_0)/(\epsilon_2 - \epsilon_0)$, $P_{1n}/P_{2n} = \epsilon_2(\epsilon_1 - \epsilon_0)/\epsilon_1(\epsilon_2 - \epsilon_0)$.
46. $C_{\text{total}} = 60\epsilon_0/(20d_2 + 3d_1) \text{ [F]}$.
47. $C = \frac{2\pi\epsilon_0}{\ln(a/b)} \text{ [F/m]}$.
48. $C = 73.43 \text{ pF}$.

49. (a) $x = 0.02$ m. (b) $x = 0.0385$ m.
50. $C = 4\pi\epsilon_1\epsilon_2bc/a(\epsilon_1a(c-b) + \epsilon_2c(b-a))$ [F].
51. $W = \frac{Q^2}{4\pi\epsilon_0} \left[\frac{2}{a} - \frac{1}{a+b} - \frac{2}{b} \right]$ [J].
52. (a) $W_{in} = 2\pi\rho_v^2 a^5/45\epsilon_0$ [J]. (b) $W_{out} = 4\pi\rho_v^2 a^5/18\epsilon_0$ [J]. (c) $W_{total} = 4\pi\rho_v^2 a^5/15\epsilon_0$ [J].
53. $W = 2\pi\epsilon_0 aV^2$ [J].
54. (a) $\Delta W = \epsilon V^2 a/2d(d-a)$. (b) $\Delta W = \epsilon V^2 a/200d(d-a)$ [J].
55. $\Delta W = \frac{Q^2(\epsilon_r - 1)}{8\pi\epsilon_0\epsilon_r} \left[\frac{1}{a} - \frac{1}{b} \right]$ [J].
56. (a) $w = q^2/32\pi^2\epsilon_0 R^4$, $0 < R < a$, $w = (q + 4\pi a^2\rho_0)^2/32\pi^2\epsilon_0 R^4$, $a < R < b$, $w = (q + 4\pi a^2\rho_0 - 4\pi b^2\rho_0)^2/32\pi^2\epsilon_0 R^4$, $R > b$ [J/m³]. (b) $W = \frac{(q + 4\pi a^2\rho_0)^2}{8\pi\epsilon_0} \left[\frac{1}{a} - \frac{1}{b} \right]$ [J].
57. $\Delta W = \epsilon_0 V^2 b^2(1 - \epsilon_r)/2d$ [J].
58. $W = \rho_l^2 \ln(b/a)/4\pi\epsilon$ [J/m].
59. $p = \epsilon_0 V^2/d^2$ [Pa].
60. $V = (d/b)\sqrt{2P/\epsilon}$ [V].
61. $F = -\epsilon_0\epsilon_r V^2 b/2d$ [N] in the direction opposite the displacement.
62. $F = V_0^2 b(\epsilon - \epsilon_0)/2d$ [N].
63. (a) $P = \rho_0^2/2\epsilon_0$ [Pa]. (b) $\rho_s = 4.2 \times 10^{-3}$ C/m². (c) $P = 4.427 \times 10^6$ Pa.

Chapter 5

2. $k = -0.2yz$.
3. $V(x) = 2,500x$ [V].
4. $V(x) = -\rho_0 x^2/2\epsilon_0 + (V_0/d + \rho_0 d/2\epsilon_0)x$ [V].
5. $V(x) = -9,411.94x^4 + 37.64777x^3 + (50,000 - 7.52955 \times 10^{-5})x$ [V].
6. (a) $V(r) = -23.083 \ln r - 127.45$ V. (b) $\mathbf{E} = \hat{\mathbf{r}} 23.083/r$ [V].
7. $V(x, y) = -(2V_0/\pi) \tan^{-1}(y/x) + V_0$ [V].
8. (a) $V(R) = 25.25/R - 5,000$ V. (b) $\mathbf{E} = \hat{\mathbf{R}} 25.25/R^2$ [V/m].
9. (a) $\rho_s = -1.99 \times 10^{-10}$ C/m². (b) $\rho_s = -1.424 \times 10^{-10}$ C/m².
10. (b) $\mathbf{E} = \hat{\mathbf{z}} \frac{q}{4\pi\epsilon_0} \left[\frac{4a}{(x^2 + y^2 + 4a^2)^{3/2}} - \frac{2a}{(x^2 + y^2 + a^2)^{3/2}} \right]$ [V/m].
11. (a) $\rho_s = -\rho_l h/\pi(x^2 + h^2)$ [C/m²].
12. $\mathbf{E} = -\hat{\mathbf{y}} \rho_s/\epsilon_0$ [V], between sheet and conductor. $\mathbf{E} = 0$ elsewhere.
13. (a) $V(2d, y) = \frac{\rho_l}{2\pi\epsilon_0} \ln \frac{\sqrt{4d^2 + (y+d)^2}}{\sqrt{4d^2 + (y-d)^2}}$ [V]. (b) $\mathbf{E}(2d, y) = \hat{\mathbf{x}} \frac{4d\rho_l}{2\pi\epsilon_0} \left(\frac{1}{4d^2 + (y-d)^2} - \frac{1}{4d^2 + (y+d)^2} \right)$ [V/m].
14. (b) $\rho_s = \pm \frac{q\sqrt{2}}{4\pi} \left[\frac{b-a}{((x-a)^2 + (x-b)^2)^{3/2}} + \frac{b+a}{((x-a)^2 + (x+b)^2)^{3/2}} - \frac{b+a}{((x+a)^2 + (x-b)^2)^{3/2}} - \frac{b-a}{((x+a)^2 + (x+b)^2)^{3/2}} \right]$ [C/m²], where $b = 0.3827d$, $a = 0.9239d$.
15. (a) $\mathbf{E} = -\hat{\mathbf{x}} \frac{q}{4\pi\epsilon_0} \sum_{i=1}^{12} \frac{(-1)^{i+1}(x - a \cos(15^\circ + (i-1)30^\circ))}{[(x - a \cos(15^\circ + (i-1)30^\circ))^2 + (y - a \sin(15^\circ + (i-1)30^\circ))^2]^{3/2}}$
 $-\hat{\mathbf{y}} \frac{q}{4\pi\epsilon_0} \sum_{i=1}^{12} \frac{(-1)^{i+1}(y - a \sin(15^\circ + (i-1)30^\circ))}{[(x - a \cos(15^\circ + (i-1)30^\circ))^2 + (y - a \sin(15^\circ + (i-1)30^\circ))^2]^{3/2}}$ [V/m].
16. (b) $V(d/2, 0) = 2.2112q/4\pi\epsilon_0 d$ [V].

$$17. \text{(a)} V(x, y) = \frac{q}{4\pi\epsilon_0} \sum_{i=1, 5, 9, 13, \dots}^N \frac{1}{\sqrt{(x - (i-1)d/2 - 3d/4)^2 + y^2}} - \sum_{i=2, 6, 10, 14, \dots}^N \frac{1}{\sqrt{(x - id/2 - d/4)^2 + y^2}} - \sum_{i=3, 7, 11, 15, \dots}^N \frac{1}{\sqrt{(x + (i-3)d/2 + 3d/4)^2 + y^2}} + \sum_{i=4, 8, 12, 16, \dots}^N \frac{1}{\sqrt{(x + (i-2)d/2 + d/4)^2 + y^2}} \text{ [V].}$$

$$22. \mathbf{E}(0, 0) = \hat{\mathbf{x}} 16.178 \text{ V/m (down).}$$

$$23. \mathbf{E} = \hat{\mathbf{x}} \frac{\rho_l}{2\pi\epsilon_0} \left(\frac{(x-2r)}{((x-2r)^2 + y^2)} - \frac{(x-r/2)}{((x-r/2)^2 + y^2)} + \frac{(x+r/2)}{((x+r/2)^2 + y^2)} - \frac{(x+2r)}{((x+2r)^2 + y^2)} \right) + \hat{\mathbf{y}} \frac{\rho_l y}{2\pi\epsilon_0} \left(\frac{1}{((x-2r)^2 + y^2)} - \frac{1}{((x-r/2)^2 + y^2)} + \frac{1}{((x+r/2)^2 + y^2)} - \frac{1}{((x+2r)^2 + y^2)} \right) \text{ [V/m].}$$

$$24. \text{(a)} \mathbf{E}(a, 0, 0) = -\hat{\mathbf{x}} 7q/8\pi\epsilon_0 a^2 \text{ [V/m]. (b) zero.}$$

$$25. \text{(b)} E_R(r, \theta) = \frac{q}{4\pi\epsilon_0 r} \frac{-a^2 - 2ar}{(r^2 + (a+r)^2 - 2r(a+r)\cos\theta)^{3/2}} \text{ [V/m].}$$

$$\text{(c)} \rho_s(r, \theta) = -\frac{q}{4\pi r} \frac{a^2 + 2ar}{(r^2 + (a+r)^2 - 2r(a+r)\cos\theta)^{3/2}} \text{ [C/m}^2\text{].}$$

$$26. \text{(b)} \mathbf{E} = \hat{\mathbf{R}} aV_0/R^2 \text{ [V/m], } R \geq a.$$

$$27. \text{(b)} \mathbf{E}(r, \theta) = \hat{\mathbf{R}} \left(\frac{\rho_s}{\epsilon_0} - \frac{q}{4\pi\epsilon_0 r} \frac{(a^2 + 2ar)}{(r^2 + (a+r)^2 - 2r(a+r)\cos\theta)^{3/2}} \right) \text{ [V/m].}$$

$$29. V(x, y) = \frac{4V_0}{\pi} \sum_{m=1, 3, 5, \dots}^{\infty} \frac{1}{m} \sin \frac{m\pi y}{b} e^{-m\pi x/b} \text{ [V].}$$

$$30. \text{(a)} V(x, y) = \frac{4V_0}{\pi} \sum_{m=1, 3, 5, \dots}^{\infty} \frac{1}{m} \sin \frac{m\pi x}{a} \frac{\sinh\left(\frac{m\pi y}{a}\right)}{\sinh\left(\frac{m\pi b}{a}\right)} \text{ [V].}$$

$$31. V(x, y) = \frac{V_0}{\sinh \frac{\pi b}{a}} \sinh\left(\frac{\pi y}{a}\right) \sin\left(\frac{\pi x}{a}\right) \text{ [V].}$$

$$32. V(x, y) = \frac{4}{\pi} \left[V_2 \sum_{m=1, 3, 5, \dots}^{\infty} \frac{1}{m} \sin \frac{m\pi y}{b} \frac{\sinh\left(\frac{m\pi x}{b}\right)}{\sinh\left(\frac{m\pi a}{b}\right)} + V_1 \sum_{m=1, 3, 5, \dots}^{\infty} \frac{1}{m} \sin \frac{m\pi y}{b} \frac{\sinh\left(\frac{m\pi(a-x)}{b}\right)}{\sinh\left(\frac{m\pi a}{b}\right)} \right] \text{ [V].}$$

$$33. V(x, y, z) = \frac{16V_0}{\pi^2} \sum_{m=1, 3, 5}^{\infty} \sum_{n=1, 3, 5}^{\infty} \frac{\sin\left(\frac{n\pi y}{a}\right)}{m n \sinh(\pi\sqrt{m^2 + n^2})} \left[\sin \frac{m\pi x}{a} \sinh\left(\pi z \sqrt{\frac{m^2}{a^2} + \frac{n^2}{a^2}}\right) + \sin \frac{m\pi z}{a} \sinh\left(\pi x \sqrt{\frac{m^2}{a^2} + \frac{n^2}{a^2}}\right) \right] \text{ [V].}$$

$$34. \text{(a)} V(r, \phi) = \frac{2V_0}{\pi} \sum_{k=1, 3, 5, \dots}^{\infty} \frac{1}{k} \left(\frac{r}{a}\right)^k \sin k\phi \text{ [V], } r < a, V(r, \phi) = \frac{2V_0}{\pi} \sum_{k=1, 3, 5, \dots}^{\infty} \frac{1}{k} \left(\frac{a}{r}\right)^k \sin k\phi \text{ [V], } r > a.$$

$$\text{(b)} \mathbf{E} = -\frac{2V_0}{a\pi} \sum_{k=1, 3, 5, \dots}^{\infty} \frac{1}{k} \left(\frac{r}{a}\right)^{k-1} [\hat{\mathbf{r}} \sin k\phi - \hat{\boldsymbol{\phi}} \cos k\phi] \text{ [V/m], } r < a,$$

$$\mathbf{E} = \frac{2V_0}{a\pi} \sum_{k=1, 3, 5, \dots}^{\infty} \frac{1}{k} \left(\frac{a}{r}\right)^{k-1} [\hat{\mathbf{r}} \sin k\phi - \hat{\boldsymbol{\phi}} \cos k\phi] \text{ [V/m], } r > a.$$

$$35. \text{(a)} V(r, \phi) = \frac{4 \times 10^5}{\pi} \sum_{k=1,3,5,\dots}^{\infty} \frac{1}{k} \left(\frac{r}{a}\right)^k \left[\sin k\phi + \sin k\left(\phi + \frac{\pi}{2}\right) \right] \text{ [V], } r < a, V(r, \phi) = \frac{4 \times 10^5}{\pi} \sum_{k=1,3,5,\dots}^{\infty} \frac{1}{k} \left(\frac{a}{r}\right)^k$$

$$\times \left\{ \sin k\phi + \sin k\left(\phi + \frac{\pi}{2}\right) \right\} \text{ [V], } r > a. \text{(b) } \mathbf{E} = -\frac{4 \times 10^5}{a\pi} \sum_{k=1,3,5,\dots}^{\infty} \frac{1}{k} \left(\frac{r}{a}\right)^{k-1} [\hat{\mathbf{r}} \sin k\phi + \hat{\boldsymbol{\phi}} \cos k(\phi + \pi/2)] \text{ [V/m],}$$

$$r < a, \mathbf{E} = -\frac{4 \times 10^5}{a\pi} \sum_{k=1,3,5,\dots}^{\infty} \frac{1}{k} \left(\frac{a}{r}\right)^{k-1} [\hat{\mathbf{r}} \sin k\phi - \hat{\boldsymbol{\phi}} \cos k(\phi + \pi/2)] \text{ [V/m], } r > a.$$

Chapter 6

1. (a) $V_1 = 0, V_2 = 3 \text{ V}, V_3 = 6 \text{ V}, V_4 = 9 \text{ V}, V_5 = 12 \text{ V}$. (b) $V_1 = 0, V_2 = 1.5 \text{ V}, V_3 = 3 \text{ V}, V_4 = 4.5 \text{ V}, V_5 = 6 \text{ V}, V_6 = 7.5 \text{ V}, V_7 = 9 \text{ V}, V_8 = 10.5 \text{ V}, V_9 = 12 \text{ V}$. (c) $V(x) = 12x \text{ [V]}$.
2. (a) $V_1 = 0, V_2 = 3.09375 \text{ V}, V_3 = 6.125 \text{ V}, V_4 = 9.09375 \text{ V}$.
3. (b) $V(x) = 1.4118 \times 10^4(x - x^2) \text{ [V]}, E = -1.4118 \times 10^4(1 - 2x) \text{ [V/m]}$.
7. 1.343 to 5.59 pF.
8. 3.54 pF (8 patches), 3.99 pF (16 patches).
9. (a) 2.5116 pF. (b) 1.5547 pF.
10. (a) $\approx 3 \text{ pF}$.
11. (a) $4.913 \times 10^{-17} \text{ F}$. (b) $4.395 \times 10^{-17} \text{ F}$.
12. (a) 2.1943 pF (2×2 subdomains on each plate). (b) $V_P = 0 \text{ V}, \mathbf{E}_P = \hat{\mathbf{y}} 1.574 - \hat{\mathbf{z}} 1.574 \text{ [V/m]}$. (c) 1,024 subdomains.
13. (a) $N_1 = (x_2 - x)/(x_2 - x_1), N_2 = (x - x_1)/(x_2 - x_1)$. (b) $\phi(x) = (x_2 - x)\phi_1/(x_2 - x_1) + (x - x_1)\phi_2/(x_2 - x_1)$.
14. (c) $V(x) = -\rho_0 x^4/12\epsilon + \rho_0 x^3 d/6\epsilon + 10x/d - \rho_0 x d^3/12\epsilon \text{ [V]}$.
15. (c) $\mathbf{E} = -\hat{\mathbf{x}}(-\rho_0 x^3/\epsilon + 10/d + \rho_0 d/2\epsilon) \text{ [V/m]}$.
17. (a) 1.425 V. (b) 3.914 μm .
18. (a) 3,240 V. (b) 1,480 V.

Chapter 7

1. (a) 360,000 C. (b) 8,470 km^2 .
2. (a) $10.294 \times 10^6 \text{ A}$. (b) $205.88 \times 10^6 \text{ A}$.
3. $0.33 \times 10^{-3} \text{ m/s}$.
4. (a) $5.584 \times 10^{-2} \text{ V/m}$. (b) $2.487 \times 10^{-4} \text{ m/s}$.
5. Inside beam: $\mathbf{E} = -\hat{\mathbf{r}} 7.19 \times 10^7 r \text{ [V/m]}$, outside beam: $\mathbf{E} = -\hat{\mathbf{r}} 17.97/r \text{ [V/m]}$.
6. (a) 1,667 S/m. (b) 3.125×10^{21} carriers.
7. (a) $\mathbf{E} = -\hat{\mathbf{r}} V/r \ln(b/a) \text{ [V/m]}$. (b) $\mathbf{J} = -\hat{\mathbf{r}} \sigma V/r \ln(b/a) \text{ [A/m}^2\text{]}$. (c) $I = 2\pi L \sigma V / \ln(b/a) \text{ [A]}$. (d) $R = \ln(b/a)/2\pi L \sigma \text{ [\Omega]}$.
8. $7.368 \times 10^5 \text{ S/m}$.
9. (a) $5.1473 \times 10^{-5} \text{ }\Omega$. (b) -0.198% .
10. (a) $1.7243 \times 10^{-5} \text{ }\Omega$. (b) $1.5936 \times 10^{-5} \text{ }\Omega$.
11. $R_{\min} = 17.98 \text{ }\Omega, R_{\max} = 29.3 \text{ }\Omega$.
12. (a) $\sigma = 1.273 \times 10^3/V \text{ [S/m]}$.
13. $\sigma = \frac{\sigma_0(b^2 - a^2)}{a^2} \left[\frac{(b^2 - a^2)(L - p) + pb^2}{9pb^2 - (L - p)(b^2 - a^2)} \right] \text{ [S/m]}$.
14. (a) $V_{BA} = 2.944V/(\sigma\pi aR + 2.944) \text{ [V]}$.
15. $V = I l_1/\sigma_1\pi r_1^2 + I l_2/\sigma_2\pi r_2^2 + I l_3/\sigma_3\pi r_3^2 \text{ [V]}$.
16. $R = \frac{1}{b^2\sqrt{a\sigma_0}} \tan^{-1}\left(\sqrt{\frac{a}{\sigma_0}}d\right) \text{ [\Omega]}, |V| = \frac{I}{b^2\sqrt{a\sigma_0}} \tan^{-1}\left(\sqrt{\frac{a}{\sigma_0}}d\right) \text{ [V]}$.
17. (a) $V_{AB} = 2.944Ja/\sigma \text{ [V]}$.
18. 15.92 Ω .
19. $\sigma = I(a + b)/2\pi abV \text{ [S/m]}$.

20. (a) 1.628 mm for series connection, 7.28 mm for parallel connection. (b) 33.30 kg for series connection, 666 kg for parallel connection.
21. (a) $2.76 \times 10^{-6} \Omega$. (b) $8.354 \times 10^{10} \text{ W}$.
22. (a) $J_{\text{iron}} = V\sigma/a$ [A/m²], $J_{\text{copper}} = 5V\sigma/a$ [A/m²]. (b) $P_{\text{iron}} = V^2\sigma bc/a$ [W], $P_{\text{copper}} = V^2 5\sigma bc/a$ [W].
23. (a) $\Delta R = 0.0357 \Omega$. (b) $\Delta R = 2.589 \times 10^{-4} \Omega$.
24. (a) $R = 0.02076 \Omega$. (b) $R = 8.275 \times 10^{-4} \Omega$.
25. (a) 16 A.
26. (b) $I = 1.2e^{-100r}$ C/s.
27. $Q_1 = -\epsilon_1 V \sigma_2 \pi b^2 / (d_1 \sigma_2 + d_2 \sigma_1)$ [C], $Q_2 = V \pi b^2 (\epsilon_1 \sigma_2 - \epsilon_2 \sigma_1) / (d_1 \sigma_2 + d_2 \sigma_1)$ [C], $Q_3 = \epsilon_2 V \sigma_1 \pi b^2 / (d_1 \sigma_2 + d_2 \sigma_1)$ [C].
28. (a) $E_{\text{copper}} = 0.0223 \text{ V/m}$, $E_{\text{aluminum}} = 0.03536 \text{ V/m}$. (b) $w_{\text{copper}} = 28,440 \text{ W/m}^3$, $w_{\text{aluminum}} = 45,030 \text{ W/m}^3$.
29. (a) $V = 6.324 \text{ mV}$, $I = 2,483.4 \text{ A}$. (b) $1.754 \times 10^7 \text{ W/m}^3$.

Chapter 8

- $B = 9\mu_0 I / 2\pi a$ [T], (into the page).
- (a) $B = 12 \times 10^{-7} I / L$ [T], (out of page). (b) zero.
- $H = \rho_s \omega (b - a) / 2$ [A/m], (out of page).
- $\mathbf{B}_1 = -\hat{y} \frac{\mu I}{2\pi a} \left(\frac{1}{\sqrt{2}} - 1 \right)$ [T], $\mathbf{B}_2 = -\hat{y} \frac{\mu I}{4\pi d}$ [T].
- $B = \frac{2\sqrt{2}\mu_0 I a^2}{\pi(4h^2 + a^2)(2h^2 + a^2)^{1/2}}$ [T], (up).
- $B = \sum_{i=1}^N \frac{\mu_0 I a^2 i^2}{2N^2 (h^2 + i^2(a/N)^2)^{3/2}}$ [T], (up).
- $\mathbf{B} = \hat{x} \frac{\mu_0 I z}{2\pi a^2} - \hat{y} \frac{\mu_0 I}{2\pi d}$ [T], $0 < z < a$. $\mathbf{B} = \hat{x} \frac{\mu_0 I}{2\pi z} - \hat{y} \frac{\mu_0 I}{2\pi d}$ [T], $z > a$. $\mathbf{B} = -\hat{x} \frac{\mu_0 I z}{2\pi a^2} - \hat{y} \frac{\mu_0 I}{2\pi d}$ [T], $-a < z < 0$.
 $\mathbf{B} = -\hat{x} \frac{\mu_0 I}{2\pi|z|} - \hat{y} \frac{\mu_0 I}{2\pi d}$ [T], $z < -a$.
- $\mathbf{B} = \hat{x} \left[\frac{\mu_0 J a^2 z}{2(z^2 + (x-d)^2)} - \frac{\mu_0 J b^2 (y-d)}{2(x^2 + (y-d)^2)} \right] + \hat{y} \frac{\mu_0 J b^2 x}{2(x^2 + (y-d)^2)} - \hat{z} \frac{\mu_0 J a^2 (x-d)}{2(x^2 + (x-d)^2)}$ [T].
- (a) $\mathbf{B} = \hat{x} \frac{\mu_0 I h}{2\pi} \left(\frac{1}{(x-a)^2 + h^2} - \frac{1}{(x+a)^2 + h^2} \right) + \hat{y} \frac{\mu_0 I}{2\pi} \left(\frac{x-a}{(x-a)^2 + b^2} - \frac{x+a}{(x+a)^2 + h^2} \right)$ [T].
 (b) $\mathbf{B} = -\hat{y} 5.87 \times 10^{-6} \text{ T}$.
- (b) $-\hat{x} 3.0186 \times 10^{-4} + \hat{y} 3.0186 \times 10^{-4} \text{ T}$.
- $\mathbf{B} = -\hat{y} \mu_0 N I / 2$ [T], $x < 0$. $\mathbf{B} = \hat{y} \mu_0 N I / 2$ [T], $x > 0$.
- (a) $B = 0$, $0 < r < r_1$. $\mathbf{B} = \hat{\phi} J \mu_0 (\pi r^2 - \pi r_1^2) / 2\pi r$ [T], $r_1 < r < r_2$. $\mathbf{B} = \hat{\phi} J \mu_0 (\pi r_2^2 - \pi r_1^2) / 2\pi r$ [T], $r > r_2$. (b) $\mathbf{B} = \hat{\phi} \mu_0 I / 2\pi r$ [T], $0 < r < r_1$. $\mathbf{B} = \hat{\phi} \mu_0 (I + (\pi r^2 - \pi r_1^2) J) / 2\pi r$ [T], $r_1 < r < r_2$. $\mathbf{B} = \hat{\phi} \mu_0 (I + (\pi r_2^2 - \pi r_1^2) J) / 2\pi r$ [T], $r > r_2$. (c) $\mathbf{B} = -\hat{\phi} \mu_0 I / 2\pi r$ [T], $0 < r < r_1$. $\mathbf{B} = \hat{\phi} \mu_0 ((\pi r^2 - \pi r_1^2) J - I) / 2\pi r$ [T], $r_1 < r < r_2$. $\mathbf{B} = \hat{\phi} \mu_0 ((\pi r_2^2 - \pi r_1^2) J - I) / 2\pi r$ [T], $r > r_2$.
- $\mathbf{B} = \hat{z} \mu_0 \omega b \rho_s$ [T], $r \leq b$. $\mathbf{B} = 0$, $r > b$.
- $\mathbf{B} = \hat{x} \left(-\frac{\mu_0 y_0 J (b^2 - a^2)}{2(x_0^2 + y_0^2)} + \frac{\mu_0 y_0 J c^2}{2((x_0 - d)^2 + y_0^2)} \right) + \hat{y} \left(\frac{\mu_0 x_0 J (b^2 - a^2)}{2(x_0^2 + y_0^2)} - \frac{\mu_0 (x_0 - d) J c^2}{2((x_0 - d)^2 + y_0^2)} \right)$ [T].
- (a) $\mathbf{B} = -\hat{\phi} \mu_0 I_1 / 2\pi r$ [T]. (b) $\mathbf{B} = \hat{\phi} \mu_0 (\pi (r_2^2 - r_1^2) J_1 - I_1) / 2\pi r$ [T].
- (a) $\mathbf{B} = 0$, $0 < r < r_1$. $\mathbf{B} = -\hat{z} \mu_0 n I$ [T], $r_1 < r < r_2$. $\mathbf{B} = 0$, $r > r_2$. (b) $\mathbf{B} = -\hat{z} 2\mu_0 n I$ [T], $0 < r < r_1$. $\mathbf{B} = -\hat{z} \mu_0 n I$ [T], $r_1 < r < r_2$. $\mathbf{B} = 0$, $r > r_2$.

18. $H = \frac{J}{2} \left(\frac{b^2}{a} - \frac{c^2}{a-d} \right)$ [A/m].
19. $\mathbf{H} = -\hat{x}J/2 + \hat{z}J/2$ [A/m] (above upper plate), $\mathbf{H} = -\hat{x}J/2 - \hat{z}J/2$ [A/m] (between plates), $\mathbf{H} = \hat{x}J/2 - \hat{z}J/2$ [A/m] below lower plate.
20. (a) $\mathbf{A}(\mathbf{r}) = \hat{z} \frac{\mu_0 I}{2\pi} \ln \frac{2L}{a}$ [Wb/m]. (b) ∞ .
21. (a) $B_c/B_s = \pi/4\sqrt{2}$. (b) Zero.
22. (a) $\Phi = \mu_0 I a (\ln 3)/2\pi$ [Wb]. (b) $\Phi = \mu_0 I a (\ln 3)/2\pi$ [Wb].
23. (a) Zero. (b) $\Phi = \mu_0 I a$ [Wb].
24. $\psi_{NS} = 7.958 \times 10^3$ A.
25. $H = 1,000$ A/m, (down).

Chapter 9

1. (a) $m = \pi a^2 I$ [A · m²]. (c) $\mathbf{B} = \frac{\mu_0 m}{4\pi R^3} (\hat{\mathbf{R}} 2 \cos\theta + \hat{\boldsymbol{\theta}} \sin\theta)$ [T], $m = \pi a^2 I$ [A · m²] for circular loop, $m = a^2 I$ [A · m²] for square loop.
2. (a) $\Phi = \mu_0 I \pi a^2 b^2 / 2h^3$ [Wb]. (b) $\Phi = \mu_0 I \pi a^2 b^2 / 4h^3$ [Wb].
3. $I = M/n$ [A].
4. $\mathbf{H} = \mathbf{M}$ [A/m].
6. $\mathbf{B}_2 = \hat{x} \mu_1 H \cos\alpha_1 - \hat{y} \mu_2 H \sin\alpha_1$ [T], $\mathbf{B}_3 = \hat{x} \mu_1 H \cos\alpha_1 - \hat{y} \mu_3 H \sin\alpha_1$ [T].
7. 89°40' to the surface.
8. $B_{2n} = 0.00866$ T, $B_{2t} = 1.0$ T, $\theta_2 = 89^\circ 30'$. $B_{3n} = 0.00866$ T, $B_{3t} = 0.25$ T, $\theta_3 = 88^\circ$, $B_{4n} = 0.00866$ T, $B_{4t} = 0.005$ T, $\theta_4 = 30^\circ$.
9. (a) $L_{11} = \frac{\mu_1 N^2 c}{2\pi} \ln \frac{d}{b}$ [H]. (b) $L_{22} = \mu_0 n^2 \pi a^2$ [H/m].
10. (a) $L_{11} = \mu N_1^2 c^2 / 2(a+c)$ [H], $L_{22} = \mu N_2^2 c^2 / 2(a+c)$ [H], $L_{33} = \mu N_3^2 c^2 / 2(a+c)$ [H].
(b) $L_{21} = L_{12} = \mu N_1 N_2 c^2 / 2(a+c)$ [H], $L_{31} = L_{13} = \mu N_1 N_3 c^2 / 2(a+c)$ [H], $L_{32} = L_{23} = \mu N_2 N_3 c^2 / 2(a+c)$ [H].
11. $L_{11} = \mu_0 n^2 \pi b^2 + \mu_1 n^2 \pi (a^2 - b^2)$ [H/m].
12. $L_{11} = \mu_0 \pi (b^2 - a^2)$ [H/m].
13. $L_{12} = L_{21} = \mu_0 n \pi b^2$ [H].
14. (a) $L_{12} = 2\pi a^2 \mu_0 N$ [H]. (b) $L_{12} = 2\pi a^2 \mu_0 N$ [H].
15. (a) $L_{12} = L_{21} = \mu_0 \pi a^2 b^2 / 2h^3$ [H]. (b) $L_{12} = L_{21} = \mu_0 \pi a^2 b^2 / 4h^3$ [H].
16. (a) $3L$ [H]. (b) $L/3$ [H]. (c) $1.5L$ [H].
17. $L_{11} = \mu_0 \ln(a/b) / 2\pi$ [H/m].
18. (a) $\mu_0 / 8\pi$ [H/m]. (b) $\frac{\mu_0}{2\pi} \left(\frac{c^2}{c^2 - a^2} \right)^2 \ln \frac{c}{a} - \frac{\mu_0}{2\pi} \left(\frac{c^2}{c^2 - a^2} \right) + \frac{\mu_0}{8\pi} \left(\frac{c^2 + a^2}{c^2 - a^2} \right)$ [H/m]. (c) $\mu_0 \ln(a/b) / 2\pi$ [H/m].
(d) $L = \frac{\mu_0}{8\pi} + \frac{\mu_0}{2\pi} \ln \frac{a}{b} + \frac{\mu_0}{2\pi} \left[\left(\frac{c^2}{c^2 - a^2} \right)^2 \ln \frac{c}{a} - \left(\frac{c^2}{c^2 - a^2} \right) + \frac{1}{4} \left(\frac{c^2 + a^2}{c^2 - a^2} \right) \right]$ [H/m].
19. (a) $\frac{\mu_0}{2\pi} \ln \frac{(2a-d)^2}{d^2}$ [H/m]. (b) $\frac{\mu_0}{2\pi} \ln \frac{(4a-d)(4a+d)}{(2a+d)(6a-d)}$ [H/m].
20. (a) 1.271 μ H/m. (b) 1.371 μ H/m. (c) 3.39 nH.
21. $\Delta W = \mu_0 n N \pi a^2 I^2$ [J].
22. $\Delta W = (\mu_1 - \mu_0) \frac{N^2 I^2 c}{4\pi} \ln \frac{r_2}{r_1}$ [J].
23. $\Delta W = \frac{\mu_1 N^2 I^2 (r_2 - r_1) c}{2} \left[\frac{1}{\pi(r_2 + r_1)} - \frac{\mu_0}{\mu_0 \pi(r_2 + r_1) + l_g(\mu_1 - \mu_0)} \right]$ [J].
24. (a) $W_{total} = \frac{\mu N_1^2 c^2}{a+c} \left(\frac{I_1^2}{4} + \frac{I_2^2}{4} + I_3^2 + \frac{I_1 I_2}{2} + I_1 I_3 + I_2 I_3 \right)$ [J]. (b) $W_{min} = 0$, $L_{eq} = 0$. (c) $W_{max} = 4\mu N_1^2 c^2 I^2 / (a+c)$ [J].
 $L_{eq} = 8\mu N_1^2 c^2 / (a+c)$ [H].

25. $w = \mu_0 M^2/2$ [J/m³].
26. $\Delta W = n^2 I^2 \pi b^2 (\mu_0 - \mu)/2$ [J/m].
27. $\Delta W = -\mu_0 N a^2 I^2/d$ [J].
28. (a) $\Phi = \mu I c \ln(d/b)/2\pi$ [Wb]. (b) $\Phi = \frac{\mu \mu_0 I c (d - b)}{\mu_0 \pi (d + b) + l_g (\mu - \mu_0)}$ [Wb].
30. $L_{12} = \frac{\pi a^2 \mu \mu_0 N}{(2\pi r_0 - l_g) \mu_0 + l_g \mu} \approx \frac{\pi a^2 \mu \mu_0 N}{2\pi r_0 \mu_0 + l_g \mu}$ [H].
31. $H = \frac{\mu_1 \mu_2 [N_1 I_1 + N_2 I_2]}{\mu_0 \mu_2 [d + a - 2b] + \mu_0 \mu_1 [d + a - 2b] + \mu_1 \mu_2 l_g}$ [A/m].
32. $B = \frac{2\mu_0 \mu_1 \mu_2 N I}{\mu_0 [\pi (r_1 + r_2) - 4d] (\mu_2 + \mu_1) + 8\mu_1 \mu_2 d}$ [T].
33. (a) $W = \frac{(N_1 I_1 + N_2 I_2)^2 \mu_0 \mu_1 \mu_2 b c}{2[\mu_0 (d + a - 2b - l_g) (\mu_1 + \mu_2) + 2\mu_1 \mu_2 l_g]}$ [J]. (b) $I_2 = -N_1 I_1/N_2$ [A].
34. $W = \frac{\mu_0 b c (N_1 I_1 - N_2 I_2)^2}{2(e_1 + e_2)}$ [J].
35. $L_{12} = 0.8377$ mH.
36. $F_m = 0.0005$ N (perpendicular to **B**).
37. (a) $\mathbf{F} = \hat{\mathbf{r}} \frac{\mu_0 I_2 I_1 c}{2\pi} \left(\frac{b-a}{ab} \right)$ [N]. (b) $\mathbf{F} = -\hat{\mathbf{r}} \frac{\mu_0 I_2 I_1 c}{2\pi} \left(\frac{b-a}{ab} \right)$ [N].
38. (c) $F = 0.883$ N/m.
39. (c) $F = 4.37 \times 10^{-7}$ N.
40. (a) $241.274I$ [N/A]. (b) $I = 6.375$ A.
41. $F = -\frac{\mu_0 \mu^2 c d}{2} \left[\frac{N_1 I_1 - N_2 I_2}{\mu_0 (a + 3b - 2g) + 2\mu g} \right]^2$ [N].
42. Zero.
43. (a) Zero. (b) $\mathbf{T} = \hat{\mathbf{z}} B_0 I a^2/8$ [N · m].
44. (a) Zero. (b) Zero. (c) $\mathbf{T} = \hat{\phi} \frac{\mu_0 \sqrt{2} \pi I_s I a^2 b^2}{8h^3}$ [N · m]. (d) $\mathbf{T} = -\hat{\phi} \frac{\mu_0 \pi I I_s a^2 b^2 \sqrt{2}}{8R^3}$ [N · m].
45. (b) $\mathbf{T} = \hat{\mathbf{y}} \mu_0 I_s I_c \pi a^4/2\pi d^3$ [N · m]. (c) $\mathbf{T} = -\hat{\mathbf{y}} \mu_0 N I_s I_c \pi a^4/4\pi d^3$ [N · m]. (d) $\mathbf{T} = -\hat{\mathbf{y}} \mu_0 N^2 I_s I_c \pi a^4/4\pi d^3$ [N · m].

Chapter 10

1. (a) $I = 3.056 \times 10^{-3}$ A. (b) $I(t) = \frac{(v_2 + v_1) B_0 d}{2r [P - (v_2 + v_1)t]}$ [A].
2. (a) $v = V/B_0 d$ [m/s]. (c) $D = V/2Ir$ [m].
3. (a) $\mathbf{F} = -\hat{\mathbf{x}} \omega d^3 B_0^2 \cos(\omega t) \sin(\omega t)/R$ [N]. (b) Zero.
4. $|\text{emf}| = v_0 \mu_0 J r_1^2/2r$ [V].
5. $V_{ab} = B_0 v d \sqrt{2} \cos(\omega t)/2$ [V].
6. $V = 20\pi r_1 B d \sin(20\pi t)$ [V].
7. $\text{emf}_{\text{round}}/\text{emf}_{\text{square}} = \pi$.
8. $I = 157,080$ A.
9. $\text{emf} = 2\pi f B c d \sin(2\pi f t)$ [V].
10. (a) $\text{emf} = \omega B_0 l^2/2$ [V]. (b) $\text{emf} = \omega B_0 (1 - (l + 1)e^{-l})$ [V].
11. (a) $V = -\omega d^2 \mu_0 10^6 \cos(\omega t)/8$ [V].
12. $\text{emf}_{AB} = -0.1\pi \sin(800\pi t)$ [V].
13. $\text{emf} = -2f N \mu_0 S d I_0/(d^2 + h^2)$ [V (rms)]
14. $T = 0.1$ N · m.
15. (a) $V = 11$ V, $I = 13.64$ A. (b) $I = 1.364$ A. (c) $Z_p = 80.7 \Omega$, $Z_s = 0.807 \Omega$, $Z_p/Z_s = 100$.
16. $V = 1.0053 \times 10^{-2} \sin \omega t$ [V].
17. (a) $N_1/N_2 = 0.024$, $I_1 = 40,000$ A, $I_2 = 960$ A. (b) $N_1/N_2 = 0.024$. (c) $I_2 = 950.4$ A, $\Phi = 0.25$ Wb.

18. (a) 17.68 turns. (b) 5.3 turns.
 19. (a) $V_1 = 4.11\sin(314t)$ [V], $V_2 = 0.41\sin(314t)$ [V]. (b) $V_3 = 49.32\sin(314t)$ [V].
 20. (a) $\text{emf}_1 = 2,000\pi\cos(2\pi \times 10^5 t)$ [V], $\text{emf}_2 = 200\pi\cos(2\pi \times 10^5 t)$ [V]. (b) $\text{emf}_1 = 1,990\pi\cos(2\pi \times 10^5 t)$ [V],
 $\text{emf}_2 = 100\pi\cos(2\pi \times 10^5 t)$ [V].
 21. $\text{emf} = -\frac{\mu_0\omega c I_0}{2\pi} \ln \frac{a+b}{a} \cos\omega t$ [V].
 22. $\text{emf} = -\frac{N\mu_0 c I_0 \omega}{2\pi} \ln \frac{a+b}{a} \cos\omega t$ [V].
 23. (a) 156 turns. (b) 19.23 W.
 24. (a) 50,661 turns. (b) 25 turns.
 25. (a) $V = 40$ V. (b) $R = 0.02 \Omega$. (c) $P = 20$ kW.

Chapter 11

1. $\mathbf{J}_d = \hat{\mathbf{x}}(0.5/\mu)(\cos 100t) \sin 5z$ [A/m²].
 2. $I_d = 4\pi\epsilon_0 ab\omega V_0 \cos\omega t / (b-a)$ [A].
 3. (a) $\mathbf{J}_d = \hat{\mathbf{r}}\omega\epsilon_r\epsilon_0 V_0 \cos\omega t / r \ln(b/a)$ [A/m²]. (b) $I_d = 2\pi\epsilon_r\epsilon_0 \omega L V_0 \cos\omega t / \ln(b/a)$ [A].
 5. $f = 7.992$ GHz.
 6. $|J_{\text{cond}}|/|J_{\text{dissip}}| = \sigma/\omega\epsilon$.
 7. $t_c = 35.416 \times 10^{-9}$ s.
 8. $I = 49.43$ [mA rms]
 9. $A = 0.3185$, $\beta = 0.0419$.
 15. (a) $\mathbf{E} = \hat{\mathbf{y}} 1.997 \times 10^9 e^{j(10^4 t + 10^{-4} z)}$ [V/m]. (b) $\mathbf{D} = \hat{\mathbf{y}} 0.159 e^{j(10^4 t + 10^{-4} z)}$ [C/m²], $\mathbf{H} = \hat{\mathbf{x}} 0.159 \times 10^7 e^{j(10^4 t + 10^{-4} z)}$ [A/m].
 16. $\mathbf{H}(t) = \hat{\mathbf{y}} 1250 \cos(10^6 t - 50z)$ [A/m], $\mathbf{B}(t) = \hat{\mathbf{y}} 5 \times 10^{-4} \pi \cos(10^6 t - 50z)$ [T].
 17. $\nabla^2 \mathbf{J}_e - \mu\epsilon \frac{\partial^2 \mathbf{J}_e}{\partial t^2} = \mu\sigma \frac{\partial \mathbf{J}_e}{\partial t}$.
 18. $\nabla^2 \psi = 0$.
 19. (a) $-\nabla^2 \mathbf{A} + \nabla(\nabla \cdot \mathbf{A}) = \mu \mathbf{J}$. (b) $\mathbf{E} = -\partial \mathbf{A} / \partial t$. (c) $\nabla^2 \mathbf{A} = -\mu \mathbf{J}$.
 20. (a) $\mathbf{H} = -\nabla \psi$ [A/m]. (b) $-\nabla^2 \mathbf{F} + \nabla(\nabla \cdot \mathbf{F}) = -\epsilon\mu \frac{\partial^2 \mathbf{F}}{\partial t^2} - \epsilon\mu \frac{\partial}{\partial t}(\nabla \psi)$. (c) $\nabla \cdot \mathbf{F} = -\mu \frac{\partial}{\partial t}(\nabla \psi)z$.
 21. (b) $\nabla^2 \mathbf{F} = \mu \mathbf{J} + \mu\epsilon \frac{\partial^2 \mathbf{F}}{\partial t^2}$.
 22. $J_{d\text{max}} = 0.885$ A/m².
 23. $\mathbf{E} = \omega^2 \mu \epsilon \boldsymbol{\pi} + \nabla(\nabla \cdot \boldsymbol{\pi})$ [V/m], $\mathbf{H} = j\omega\epsilon \nabla \times \boldsymbol{\pi}$ [A/m].
 24. $\nabla^2 \boldsymbol{\pi}_m + \omega^2 \mu \epsilon \boldsymbol{\pi}_m = 0$, gauge: $\nabla \cdot \boldsymbol{\pi}_m = -\phi$, ϕ is the magnetic scalar potential.
 25. $|\mathbf{E}_1| = 5$ V/m, $|\mathbf{D}_1| = 10\epsilon_0$ C/m², $|\mathbf{E}_2| = 3.81$ V/m, $|\mathbf{D}_2| = 11.456\epsilon_0$ C/m².
 26. $\mathbf{B}_2 = 4\pi \times 10^{-7}(\hat{\mathbf{x}}24 + \hat{\mathbf{y}}5 - \hat{\mathbf{z}}10)$ [T].
 27. $H_{1t} = H_{2t} = 0$.
 28. (a) $\mathbf{J} = -\hat{\mathbf{x}}10^6/8\pi + \hat{\mathbf{y}}10^6/16\pi$ [A/m]. (b) $\mathbf{B}_2 = \hat{\mathbf{z}}0.1$ T.
 29. (a) $\mathbf{H}_1 = \mathbf{H}_2 = \hat{\mathbf{x}}10^5 + \hat{\mathbf{y}}2 \times 10^5 + \hat{\mathbf{z}}10^4$ A/m. (b) $\mathbf{H}_1 = \hat{\mathbf{x}}(10^5 + 100\sqrt{2}) + \hat{\mathbf{y}}(2 \times 10^5 - 100\sqrt{2}) + \hat{\mathbf{z}}10^4$ A/m,
 $\mathbf{H}_2 = \hat{\mathbf{x}}(10^5 - 100\sqrt{2}) + \hat{\mathbf{y}}(2 \times 10^5 + 100\sqrt{2}) + \hat{\mathbf{z}}10^4$ A/m.
 30. (a) $\mathbf{H}_2 = \hat{\mathbf{x}}(10^5 - 100\sqrt{2}) + \hat{\mathbf{y}}(2 \times 10^5 + 100/\sqrt{2}) + \hat{\mathbf{z}}10^4$ A/m.
 31. (a) $\mathbf{A} \cdot \mathbf{A} = a^2 - b^2 + j2\mathbf{a} \cdot \mathbf{b}$. (b) $\mathbf{A} \cdot \mathbf{A}^* = a^2 + b^2$. (c) $\mathbf{A} \cdot \mathbf{B} = (\mathbf{a} \cdot \mathbf{c} - \mathbf{b} \cdot \mathbf{d}) + j(\mathbf{b} \cdot \mathbf{c} + \mathbf{a} \cdot \mathbf{d})$. (d) $\mathbf{A} \cdot \mathbf{B}^* = (\mathbf{a} \cdot \mathbf{c} + \mathbf{b} \cdot \mathbf{d}) + j(\mathbf{b} \cdot \mathbf{c} - \mathbf{a} \cdot \mathbf{d})$. (e) $\mathbf{A} \times \mathbf{A} = 0$. (f) $\mathbf{A} \times \mathbf{A}^* = -j2(\mathbf{a} \times \mathbf{b})$. (g) $\mathbf{A} \times \mathbf{B} = (\mathbf{a} \times \mathbf{c} - \mathbf{b} \times \mathbf{d}) + j(\mathbf{b} \times \mathbf{c} + \mathbf{a} \times \mathbf{d})$. (h) $\mathbf{A} \times \mathbf{B}^* = (\mathbf{a} \times \mathbf{c} + \mathbf{b} \times \mathbf{d}) + j(\mathbf{b} \times \mathbf{c} - \mathbf{a} \times \mathbf{d})$.
 32. $\mathbf{H}(z, t) = \hat{\mathbf{y}}5 \cos(\omega t - \beta z)$ [A/m].
 33. $H(x, y, z) = H_0 \sin \frac{m\pi x}{a} \cos \frac{n\pi y}{b} [\cos(kz) - j \sin(kz)]$ [A/m], $H(x, y, z) = H_0 \sin \frac{m\pi x}{a} \cos \frac{n\pi y}{b} \angle -kz$ [A/m], $H(x, y, z) = H_0 \sin \frac{m\pi x}{a} \cos \frac{n\pi y}{b} e^{-jkz}$ [A/m].
 34. $E(z) = E_1 \angle (-kz + \psi) + E_2 \angle (kz + \psi)$ [V/m], $E(z) = E_1 e^{j(-kz + \psi)} + E_2 e^{j(kz + \psi)}$ [V/m].

35. $E(x, z, t) = E_0 \cos(\omega t - \beta_0(x \sin \theta_i + z \cos \theta_i))$ [V/m].
36. (a) $E_x(z) = E_0 e^{-j(kz - \phi)}$. (b) $\dot{E}_x(z) = j\omega E_0 e^{-j(kz - \phi)}$.
37. (a) $\mathbf{H} = -\hat{x} 1250 \cos(10^6 t - 50z) + \hat{y} 1250 \cos(10^6 t - 50z)$ [A/m]. (b) $\mathbf{H} = -\hat{x} 1250 e^{-j50z} + \hat{y} 1250 e^{-j50z}$ [A/m].
38. (a) $\mathbf{H}(x, y, z, t) = (\hat{x} h_x + \hat{y} h_y + \hat{z} h_z) \cos(\omega t + \beta z + \phi) - (\hat{x} g_x + \hat{y} g_y + \hat{z} g_z) \sin(\omega t + \beta z + \phi)$ [A/m]. (b) $\mathbf{H}(x, y, z) = |\hat{x} h_x + \hat{y} h_y + \hat{z} h_z| \angle(\beta z + \phi) + |\hat{x} g_x + \hat{y} g_y + \hat{z} g_z| \angle(\beta z + \phi + \pi/2)$ [A/m].
39. (a) $\mathbf{E}_1(t) = \hat{x} [20 \cos(\omega t + 0.3\pi z) - 20 \sin(\omega t + 0.3\pi z)] + \hat{y} [10 \cos(\omega t + 0.3\pi z) + 20 \sin(\omega t + 0.3\pi z)]$ [V/m], $\mathbf{E}_2(t) = \hat{x} [-20 \cos(\omega t + 0.3\pi z) - 10 \sin(\omega t + 0.3\pi z)] + \hat{y} [20 \cos(\omega t + 0.3\pi z) - 20 \sin(\omega t + 0.3\pi z)]$ [V/m]. (b) $\mathbf{E}_1 + \mathbf{E}_2 = \hat{x} j30 e^{j0.3\pi z} + \hat{y} 30 e^{j0.3\pi z}$ [V/m], $\mathbf{E}(t) = \mathbf{E}_1(t) + \mathbf{E}_2(t) = -\hat{x} 30 \sin(\omega t + 0.3\pi z) + \hat{y} 20 \cos(\omega t + 0.3\pi z)$ [V/m]. (c) $\mathbf{E} = \mathbf{E}_1 - \mathbf{E}_2 = \hat{x} (40 + j10) e^{j0.3\pi z} - \hat{y} (10 + j40) e^{j0.3\pi z}$ [V/m], $\mathbf{E}(t) = \mathbf{E}_1(t) - \mathbf{E}_2(t) = \hat{x} [40 \cos(\omega t + 0.3\pi z) - 10 \sin(\omega t + 0.3\pi z)] - \hat{y} [10 \cos(\omega t + 0.3\pi z) - 40 \sin(\omega t + 0.3\pi z)]$ [V/m]. (d) $\mathbf{E}_1 \times \mathbf{E}_2 = \hat{z} 300 e^{j(0.6\pi z + \pi/2)}$ [V²/m²], $\mathbf{E}_1(t) \times \mathbf{E}_2(t) = \hat{z} 300 \cos(2\omega t + 0.6\pi z + \pi/2)$ [V²/m²]. (e) $\mathbf{E}_1 \cdot \mathbf{E}_2 = 400 e^{j(0.6\pi z - \pi/2)}$ [V²/m²], $\mathbf{E}_1(t) \cdot \mathbf{E}_2(t) = 400 \cos(2\omega t + 0.6\pi z - \pi/2)$ [V²/m²].

Chapter 12

1. (a) $\nabla^2 \mathbf{E} - \nabla \left(\frac{\rho}{\epsilon} \right) - \mu \frac{\partial \mathbf{J}}{\partial t} = 0$. (b) $\nabla^2 \mathbf{E} - \epsilon \mu \frac{\partial^2 \mathbf{E}}{\partial t^2} = 0$.
2. $\nabla^2 \mathbf{B} - \mu \epsilon \frac{\partial^2 \mathbf{B}}{\partial t^2} = 0$.
3. $\nabla^2 \mathbf{A} + \omega^2 \mu \epsilon \mathbf{A} = 0$.
4. $\nabla^2 \mathbf{D} + \omega^2 \mu \epsilon \mathbf{D} = 0$.
5. $\nabla^2 \mathbf{B} + \omega^2 \mu \epsilon \mathbf{B} = 0$.
6. (a) $\mathbf{E} = \omega^2 \mu \epsilon \mathbf{\Pi}_e - \nabla V$. (b) $\nabla^2 \mathbf{\Pi}_e + \omega^2 \mu \epsilon \mathbf{\Pi}_e = 0$, Gauge: $\nabla \cdot \mathbf{\Pi}_e = -V$.
7. $\mathbf{E}(20) = \hat{z} 5 \cos(10^9 \pi t - 200\pi/3)$ [V/m].
8. (b) $v_p = 3 \times 10^8$ m/s, $f = 10.5$ GHz.
9. $\mathbf{E} = -\hat{z} H_0 \eta_0 e^{j\beta y} + \hat{x} H_1 \eta_0 e^{j\beta y}$ [V/m].
10. 663.13 W.
11. (a) 68 min, 37 s. (b) 34 min, 18 s. (c) 9.15 cents.
12. $P_{diss.} = I_0^2 / 2\pi R^2 \sigma$ [W/m].
13. (a) $\mathbf{H} = \hat{\phi} \frac{12\pi}{\eta R} e^{-j2\pi R} \sin \theta$ [A/m]. (b) $\mathcal{P}_{av} = \hat{\mathbf{R}} \frac{72\pi^2}{\eta R^2} \sin^2 \theta$ [W/m²]. (c) $P_{rad} = 15.79$ W.
14. (a) $E = 1,027$ V/m, $H = 2.72$ A/m. (b) $E = 275$ V/m, $H = 0.73$ A/m.
15. 2.4×10^{-9} J.
17. (b) $\eta(100 \text{ Hz}) = 9.934 \times 10^{-3} + j9.934 \times 10^{-3} \Omega$, $\eta(100 \text{ MHz}) = 9.934 + j9.934 \Omega$, $\eta(10 \text{ GHz}) = 74.47 + j10.92 \Omega$.
18. $\mathbf{E}(x = 1 \text{ m}) = -\hat{z} 3.2 \times 10^{-16} e^{-j41.3}$ [V/m], $\mathbf{H}(x = 1 \text{ m}) = \hat{y} 2.3 \times 10^{-17} e^{-j42.03}$ [A/m].
19. (a) $\mathcal{P}_{av} = 2,097.1$ W. (b) $\mathcal{P}_{av} = 0.012$ W.
20. (b) $\mathcal{P}(t) = \hat{y} 2(E_0^2/\eta) e^{-2\alpha y} \cos^2(\omega t - \beta y)$ [W/m²]. (c) $|\mathbf{H}| = 0.057$ A/m.
21. (a) 0.266 W.
22. (a) $P_1 = 1.0 \times 10^{-3}$ W, $P_2 = 1.026 \times 10^{-11}$ W. (b) $v_{p1} = 2.268 \times 10^8$ m/s, $\lambda_1 = 604.75$ nm, $\eta_1 = 284.98 \Omega$, $v_{p2} = 1.896 \times 10^8$ m/s, $\lambda_2 = 506$ nm, $\eta_2 = 238.4 \Omega$. (c) $\phi_2 - \phi_1 = 2.04 \times 10^{10}$ rad.
23. (a) $\eta = 367.9 \Omega$, $\beta = 2.146$ rad/m, $v_p = 2.928 \times 10^8$ m/s, -2.4% . (b) $\eta_0 = 377 \Omega$, $\beta_0 = 2.094$ rad/m, $v_{p0} = 3 \times 10^8$ m/s.
24. $\alpha = 1.21 \times 10^{-6}$ Np/m.
25. (a) $\eta = 2.63 \times 10^{-3} + j2.63 \times 10^{-3} \Omega$. (b) $\eta = 2.63 \times 10^{-3} + j2.63 \times 10^{-3} \Omega$.
26. $E_1 = 1.035 \times 10^{-2}$ V/m.
27. (a) $z_1/z_2 = 10^{-4}$. (b) $v_{p1}/v_{p2} = 10^{-4}$.
28. $\sigma = 3.36 \times 10^7$ S/m, $\alpha = 230.26$ Np/m.
29. (a) 2.198 m. (b) 695.295 m.
30. (a) $\delta_{cu} = 6.61 \times 10^{-7}$ m. (b) $\delta_{hg} = 5.03 \times 10^{-6}$ m.
31. (a) In copper: $\eta_{60\text{Hz}} = 2.04 \times 10^{-6} + j2.04 \times 10^{-6} \Omega$, $\eta_{10\text{GHz}} = 2.63 \times 10^{-2} + j2.63 \times 10^{-2} \Omega$.
In iron: $\eta_{60\text{Hz}} = 1.54 \times 10^{-4} + j1.54 \times 10^{-4} \Omega$, $\eta_{10\text{GHz}} = 0.198 + j0.198 \Omega$.

34. 0.0987 m.
 35. $\delta = 2.98 \times 10^{-9}$ m.
 36. (a) $f \ll 8.88 \times 10^8$ Hz. (b) $f \gg 8.88 \times 10^8$ Hz.
 37. $J = 62 \mu\text{A}/\text{m}^2$.
 38. (a) 790 A. (b) 2,317 A. (c) 12,566 A.
 39. (a) $d_{cu} = 2.9123 \times 10^{-4}$ m, $d_{al} = 3.665 \times 10^{-4}$ m, $d_{mu} = 3.1 \times 10^{-6}$ m, $d_{po} = 90.676$ m. (b) cost: *aluminum*. weight: *mumetal*. volume: *mumetal*.
 40. (b) $v_p = \frac{1}{\sqrt{\mu\epsilon}\sqrt{1 - \omega_c^2/\omega^2}}$ [m/s], $v_g = \frac{\sqrt{\omega^2 - \omega_c^2}}{\omega\sqrt{\mu\epsilon}}$ [m/s]. (c) $v_p = \infty$, $v_g = 0$.
 41. (b) $v_g = \frac{\sqrt{\omega^2\mu\epsilon - \pi^2/a}}{\omega\mu\epsilon}$ [m/s], $v_p = \frac{\omega}{\sqrt{\omega^2\mu\epsilon - \pi^2/a}}$ [m/s].
 43. (b) $v_p(f = 100) = 0.316$ m/s, $v_p(f = 10^8) = 316.23$ m/s, $v_g(f = 100) = 0.632$ m/s, $v_g(f = 10^8) = 632.45$ m/s.
 44. (a) $v_p = 1.498 \times 10^8$ m/s. (b) $v_g = 1.503 \times 10^8$ m/s. (c) $v_e = 1.4979 \times 10^8$ m/s.
 45. (a) $v_g = \frac{1}{\sqrt{\mu\epsilon} - \frac{\sigma^2\sqrt{\mu/\epsilon}}{8\epsilon\omega^2}}$ [m/s].

Chapter 13

1. $\mathbf{E}_r(z) = -\hat{\mathbf{x}}0.789E_i e^{i2.089z}$, $\mathbf{E}_t(z) = \hat{\mathbf{x}}0.211E_i e^{-2.22 \times 10^{-8}z} e^{-j17.77z}$ [V/m].
 2. (a) $E_{1\max} = 11.716$ V/m. (b) $H_{1\max} = 0.031$ A/m.
 3. $\frac{E_{\max}}{E_{\min}} = \frac{1 + |(\eta_2 - \eta_0)/(\eta_2 + \eta_0)|}{1 - |(\eta_2 - \eta_0)/(\eta_2 + \eta_0)|}$.
 4. (a) $P_{\text{converted}} = 343.24$ W/m², $\text{eff} = 24.5\%$. (b) $P_{\text{converted}} = 350$ W/m², $\text{eff} = 25\%$.
 5. (a) $E_{\text{glass}} = 7.414$ V/m, $H_{\text{glass}} = 0.0264$ A/m, (b) $P_{\text{glass}} = 7.686 \times 10^{-10}$ W.
 7. 731.89 W.
 8. $P = 84.9$ W, $W = 509.4$ W · h.
 9. (a) 3.25 λ . (b) 192.8 V/m.
 10. $E/H = -j\eta_0 \tan \beta z$.
 11. (a) $\mathbf{J}_s = -\hat{\mathbf{y}}2E_i/\eta_0$ [A/m].
 12. (a) $E_{1t} = E_{2t}$, $H_{1t} - H_{2t} = J_s$. (b) $\eta_2 = (1 + j)\frac{1}{\delta_2\sigma_2}$ [Ω], $\delta_2 = \frac{1}{\sqrt{\pi f\mu_2\sigma_2}}$ [m].
 13. $\alpha \leq 45^\circ$.
 14. (a) $\mathbf{H}_i = 0.265(\hat{\mathbf{y}}\cos\alpha - \hat{\mathbf{z}}\sin\alpha)e^{-j2094.4(\text{y}\sin\alpha + z\cos\alpha)}$ [A/m]. (b) $\mathbf{E}_r = -\hat{\mathbf{x}}100e^{-j2094.4(\text{y}\sin\alpha - z\cos\alpha)}$ [V/m], $\mathbf{H}_r = 0.265(\hat{\mathbf{y}}\cos\alpha + \hat{\mathbf{z}}\sin\alpha)e^{-j2094.4(\text{y}\sin\alpha + z\cos\alpha)}$ [A/m]. (c) $\mathbf{J}_x = \hat{\mathbf{x}}0.530\cos\alpha e^{-j2094.4\text{y}\sin\alpha}$ [A/m].
 15. (a) $E_{1t} = E_{2t}$, $H_{1t} - H_{2t} = J_s$.
 16. (a) $\mathbf{E}_i = 37,700(-\hat{\mathbf{y}}\cos\alpha + \hat{\mathbf{z}}\sin\alpha)e^{-j2094.4(\text{y}\sin\alpha + z\cos\alpha)}$ [V/m]. (b) $\mathbf{E}_r = 37,700(\hat{\mathbf{y}}\cos\alpha + \hat{\mathbf{z}}\sin\alpha)e^{-j2094.4(\text{y}\sin\alpha - z\cos\alpha)}$ [V/m], $\mathbf{H}_r = \hat{\mathbf{x}}100e^{-j2094.4(\text{y}\sin\alpha - z\cos\alpha)}$ [A/m]. (c) $\mathbf{J}_s = -\hat{\mathbf{y}}200$ A/m.
 18. (a) $\mathbf{E}_1(x, y, z) = \hat{\mathbf{y}}j9794.46\sin(173.2z)e^{-j100y}$ [V/m], $\mathbf{H}_1(x, y, z) = \hat{\mathbf{x}}30\cos 173.2ze^{-j100y}$ [A/m]. (b) $E_{\text{peak}} = \pm 9,794.46$ V/m at $z = n\pi/346.4$ m, $n = 1, 3, 5, 7, \dots$, $H_{\text{peak}} = \pm 30$ A/m at $z = n\pi/173.2$, $n = 0, 1, 2, 3, 4, \dots$
 (c) $\mathcal{P}_{\text{av}}(x, z) = \hat{\mathbf{y}}84,825\cos^2(173.2z)$.
 19. (a) $v_{px} = c/\sin\theta_i$. (b) $v_{px} = 3 \times 10^8$ m/s.
 20. (a) $\mathbf{J} = \hat{\mathbf{y}}0.0459$ A/m. (b) $\mathbf{J} = \hat{\mathbf{x}}0.053$ A/m.
 21. (a) $\mathcal{P}_{\text{av}} = \hat{\mathbf{y}}\frac{E_{i1}^2 \cos\theta_i}{2\eta_0}(1 + \Gamma_{\perp}^2 + \Gamma_{\perp}2\cos(2\beta_0z\cos\theta_i)) + \hat{\mathbf{z}}\frac{E_{i1}^2 \sin\theta_i}{2\eta_0}(1 - \Gamma_{\perp}^2)$ [W/m²]. (b) $\mathcal{P}_{\text{av}} = \frac{E_{i1}^2 T_{\perp}^2}{2\eta_2}(\hat{\mathbf{z}}\cos\theta_t + \hat{\mathbf{y}}\sin\theta_t)$ [W/m²].
 22. (a) $\theta_i = 63^\circ 26'$, $\theta_t = 46^\circ 55'$. (c) $\Gamma_{\parallel} = 0.11$, $T_{\parallel} = 0.726$. (d) $E_{tx} = 5.93$, $E_{ty} = 5.55$ V/m, $E_{rx} = -1.1$, $E_{ry} = 0.55$ V/m.
 23. (a) $\phi_{T_{\perp}} = \tan^{-1}\frac{\eta_0\cos\theta_t}{2\sqrt{\frac{\omega\mu_2}{2\sigma_2}}\cos\theta_i + \eta_0\cos\theta_t}$. (b) $\phi_{T_{\perp}} = \tan^{-1}\frac{2\eta_0\sqrt{\frac{\omega\mu_2}{2\sigma_2}}\cos\theta_i\cos\theta_t}{\frac{\omega\mu_2}{\sigma_2}\cos^2\theta_i - \eta_0^2\cos^2\theta_t}$.

25. $\Gamma_{\perp} = \frac{\cos\theta - \sqrt{2.1 - \sin^2\theta}}{\cos\theta + \sqrt{2.1 - \sin^2\theta}}, \Gamma_{\parallel} = \frac{\sqrt{2.1 - \sin^2\theta} - 2.1 \cos\theta}{\sqrt{2.1 - \sin^2\theta} + 2.1 \cos\theta}$.
26. $\Gamma_{\parallel} = (\eta_2 - \eta_1)/(\eta_2 + \eta_1), T_{\parallel} = 2\eta_2/(\eta_2 + \eta_1), \theta_i = 0, \Gamma_{\perp} = 1, T_{\perp} = 0, \theta_t = 90^\circ$.
27. $d = (d_2/2d_1)\sqrt{0.0016 + 3d_1^2}$ m.
28. (a) $\theta_b = 78^\circ 28'$. (b) $\theta_b = 63^\circ 26'$. (c) $\theta_b = 56^\circ 18'$.
29. $\epsilon_2 = 3.537\epsilon_0$.
30. (a) $\theta_c = 11^\circ 47'$. (b) $\theta_c = 41^\circ 25'$. (c) $\theta_c = 41^\circ 49'$.
31. $\epsilon_r = 2.894$.
32. (a) $\Gamma_{\parallel} = -0.12388, T_{\parallel} = 2.2478$. (b) $\theta_c = 30^\circ$.
33. (a) $\epsilon_r = 2$. (b) $\theta_c = 70^\circ 32'$. (c) $\theta_c = 45^\circ$.
35. (a) $\eta_1 = \eta_3 = 377 \Omega, \eta_2 = 188.5 \Omega$
- (b) $E_1 = E_{i0} \left(e^{-j20\pi z/3} + 3 \frac{-1 + e^{-j80\pi d/3}}{9 - e^{-j80\pi d/3}} e^{j20\pi z/3} \right)$ [V/m], $z < 0$,
- $H_1 = \frac{E_{i0}}{377} \left(e^{-j20\pi z/3} + 3 \frac{-1 + e^{-j80\pi d/3}}{9 - e^{-j80\pi d/3}} e^{j20\pi z/3} \right)$ [A/m], $z < 0$
- $E_2 = E_{i0} \left(\frac{6e^{-j40\pi z/3} + 2e^{-j80\pi d/3} e^{j40\pi z/3}}{9 - e^{-j80\pi d/3}} \right)$ [V/m], $0 < z < d$,
- $H_2 = \frac{E_{i0}}{188.5} \left(\frac{6e^{-j40\pi z/3} + 2e^{-j80\pi d/3} e^{j40\pi z/3}}{9 - e^{-j80\pi d/3}} \right)$ [A/m], $0 < z < d$
- $E_3 = E_{i0} \left(\frac{8e^{-j20\pi d/3}}{9 - e^{-j80\pi d/3}} e^{-j20\pi z/3} \right)$ [V/m], $z > d$, $H_3 = \frac{E_{i0}}{377} \left(\frac{8e^{-j20\pi d/3}}{9 - e^{-j80\pi d/3}} e^{-j20\pi z/3} \right)$ [A/m], $z > d$
- (c) $E_1(z=0) = 0.8581 - j0.255$ [V/m], $H_1(z=0) = 3.03 \times 10^{-3} + j6.76 \times 10^{-4}$ [A/m],
- $E_2(z=0.005m) = 0.866 - j0.368$ [V/m],
- $H_2(z=0.005m) = 2.68 \times 10^{-3} - j2.85 \times 10^{-4}$ [A/m],
- $E_3(z=0.01m) = 0.914 - j0.281$ [V/m], $H_3(z=0.01m) = 2.42 \times 10^{-3} - j7.46 \times 10^{-4}$ [A/m]
36. (a) $d = 0.075n$ [m], $n = 0, 1, 2, \dots$
37. $d = \tan^{-1}((\eta_0/\eta_2)e^{-j\pi/2})/\omega\sqrt{\mu_2\epsilon_2}$ [m].
38. $d = 7.5$ mm.
39. $d = 31.4$ mm.
40. (a) $\eta_1 = \eta_3 = 377 \Omega, \eta_2 = 188.37 - j0.42 \Omega$.
41. (a) $\mathbf{E}_1 = \hat{\mathbf{x}} [1e^{-j\pi z} + (-0.46693 - j0.12261)e^{j\pi z}]$ [V/m], $z < 0$, $\mathbf{H}_1 = \hat{\mathbf{y}} [1e^{-j\pi z} + (0.46693 + j0.12261)e^{j\pi z}]/377$ [A/m], $z < 0$, $\mathbf{E}_2 = \hat{\mathbf{x}} [(0.75552 - j0.020435)e^{-j1.5\pi z} - (0.22246 + j0.10218)e^{j1.5\pi z}]$ [V/m], $0 < z < 0.1$ m, $\mathbf{H}_2 = \hat{\mathbf{y}} [(0.75552 - j0.020435)e^{-j1.5\pi z} + (0.22246 + j0.10218)e^{j1.5\pi z}]/251.34$ [A/m], $0 < z < 0.1$ m, $\mathbf{E}_3 = \hat{\mathbf{x}} [(0.65441 + j0.055284)e^{-j2\pi z} - (0.16564 + j0.14313)e^{j2\pi z}]$ [V/m], 0.1 m $< z < 0.2$ m, $\mathbf{H}_3 = \hat{\mathbf{y}} [(0.65441 + j0.055284)e^{-j2\pi z} - (0.16564 + j0.14313)e^{j2\pi z}]/188.5$ [A/m], 0.1 m $< z < 0.2$ m, $\mathbf{E}_4 = \hat{\mathbf{x}} [(0.74918 + j0.45302)e^{-j\pi z}]$ [V/m], $z > 0.2$ m, $\mathbf{H}_4 = \hat{\mathbf{y}} [(0.74918 - j0.45302)e^{-j\pi z}]/377$ [A/m], $z > 0.2$ m. (b) $\Gamma_{slab} = -0.46693 - j0.12261, T_{slab} = 0.74918 - j0.45302$.
42. $\mathcal{P}_{av} = 4.93$ W/m².
43. (a) $\Gamma_{slab} = -0.9226 + j0.3858$. (b) $d = 0.0745n, n = 0, 1, 2, \dots$

Chapter 14

1. $C_1 = 80.26 \text{ pF/m}$, $L_1 = 0.1386 \text{ } \mu\text{H/m}$, $C_2 = 722.34 \text{ pF/m}$, $L_2 = 0.1386 \text{ } \mu\text{H/m}$.
2. (b) $C = 5.6 \times 10^{-12} \text{ F/m}$, $L = 1.98 \times 10^{-6} \text{ H/m}$. (c) $L = 0.2634 \text{ } \mu\text{H/m}$, $C = 42.24 \text{ pF/m}$.
3. $C = 66.67 \text{ pF/m}$, $L = 0.375 \text{ } \mu\text{H/m}$.
4. (a) $Z_0 = 415.9 \text{ } \Omega$, $v_p = 1 \times 10^7 \text{ m/s}$. (b) 9.97 ns .
5. (a) $v_p = c$. (b) $Z_0 = 3.77 \text{ } \Omega$.
6. (a) 299.79 m . (b) $L = 0.497 \text{ } \mu\text{H}$, $C = 22.388 \text{ pF}$, 300 sections (other solutions are possible).
7. (a) 14 mm (or 1.05 mm). (b) $Z_0 \approx 21.4 \text{ } \Omega$ (or $Z_0 \approx 176.65 \text{ } \Omega$), $\alpha = 0.00376 \text{ Np/m}$. (c) 307.8 m .
8. (a) $d = 0.0117 \text{ m}$. (b) $Z_0 \approx 44.1 \text{ } \Omega$, $\alpha = 3.77 \times 10^{-3} \text{ Np/m}$. (c) $d = 2,289 \text{ m}$.
9. (a) $\gamma = 4.86 \times 10^{-5} + j4.86 \times 10^{-5}$. (b) $Z_0 = 8.85 + j8.85 \text{ } \Omega$, $\gamma = 4.86 \times 10^{-5} + j4.86 \times 10^{-5}$.
10. (a) $Z_L = Z_0 = 635.68 - j19.9 \text{ } \Omega$. (b) $P = 0.0104 \text{ W}$.
11. (a) $C = 16.67 \times 10^{-12} \text{ F/m}$, $L = 1.499 \times 10^{-6} \text{ H/m}$, $R = 0.0628 \text{ } \Omega/\text{m}$. (b) $\gamma = 1.047 \times 10^{-4} + j3.14 \times 10^{-3}$.
12. (a) $\mathbf{E} = \hat{\mathbf{r}}(24.15/r)e^{-j\beta z} \text{ [A/m]}$, $\mathbf{H} = \hat{\boldsymbol{\phi}}(0.127/r)e^{-j\beta z} \text{ [A/m]}$. (b) $P = 24 \text{ W}$.
13. (a) $P = 282 \text{ kW}$. (b) $P = 902 \text{ kW}$. (c) $H_{\max} = 0.796 \text{ A/m}$, $E_{\max} = 300 \text{ V/m}$.
14. (a) $V^+ = 11.197 \angle 13.84^\circ \text{ V}$, $V^- = 15.382 \angle -69.81^\circ \text{ V}$. (b) $I^+ = 0.112 \angle 13.84^\circ \text{ A}$, $I^- = 0.154 \angle -69.81^\circ$. (c) $Z_L = 90 \angle 108^\circ \text{ } \Omega$.
15. (a) $V_i = 50 \text{ V (rms)}$, $I_i = 0.2 \text{ A (rms)}$. (b) 12 W .
16. (a) $d = n\lambda/2$, $n = 0, 1, 2, \dots$. (b) Same.
17. $d = \lambda/4$.
18. $\Gamma_a = \frac{Z_2(1 + \Gamma_L e^{-j2\beta_2 d}) - Z_1(1 - \Gamma_L e^{-j2\beta_2 d})}{Z_2(1 + \Gamma_L e^{-j2\beta_2 d}) + Z_1(1 - \Gamma_L e^{-j2\beta_2 d})} e^{-j2\beta_1 a}$.
19. $Z_{in}(r) = 18.84 \frac{e^{(0.0105 + j20.96)r} + 0.598e^{-(0.0105 + j20.96)r}}{e^{(0.0105 + j20.96)r} - 0.598e^{-(0.0105 + j20.96)r}} \text{ } [\Omega]$.
20. $45.23 + j14.69 \text{ } [\Omega]$.
21. (b) $Z_{in1} = 9Z_0/10$.
22. $Z_{in} = 50 + j153.9 \text{ } \Omega$.
23. $Z_{L1} = 200 \text{ } \Omega$, $Z_{L2} = 12.5 \text{ } \Omega$.
25. (a) zero. (b) $I = 0.24 \text{ A}$. (c) Time averaged power: zero, reactive power: 2.88 VAR .
26. (a) $d = 0.1762 + 0.5n$, $n = 0, 1, 2, \dots$ [m]. (b) $d = 0.8976 + 0.5n$, $n = 0, 1, 2, \dots$ [m]. (c) $d = 0.8238 + 0.5n$, for (a) and $d = 0.1024 + 0.5n$ for (b), $n = 0, 1, 2, \dots$ [m].
27. $d = v_{p0}/4(f_2 - f_1)$.
28. (b) $d_{\max} = v_{p0}(2f_1 - f_2)/4f_1f_2$.
29. (a) $Z_0 = 100 \text{ } \Omega$, $\alpha = 1.02 \times 10^{-4} \text{ Np/m}$, $\beta = 5.88 \times 10^{-5} \text{ rad/m}$. (b) 0.435 W .
30. (a) $83.69 \text{ } \Omega$. (b) $Z_{\min} = 31.25 \text{ } \Omega$, $Z_{\max} = 80 \text{ } \Omega$. Minima at: $z = 0, \lambda/2, \lambda, 1.5\lambda, \dots$, Maxima at: $z = \lambda/4, 3\lambda/4, 5\lambda/4, \dots$
33. (a) $Z_L = 10 \text{ } \Omega$. (b) 300 V and -200 V . (c) 6 A and 4 A .
34. (a) $\text{SWR} = 4.4$. (b) $V_{\max} = 100 \text{ V}$, $V_{\min} = 22.73 \text{ V}$. (c) V_{\max} at $z = n\lambda/2$, $n = 0, 1, 2, \dots$, V_{\min} at $z = (2n + 1)\lambda/4$, $n = 0, 1, 2, \dots$.
35. (a) 2.0 . (b) $V_{\min} = 100 \text{ V}$, $V_{\max} = 200 \text{ V}$. (c) V_{\min} at $z = n\lambda/2$, $n = 0, 1, 2, \dots$, V_{\max} at $z = (2n + 1)\lambda/4$, $n = 0, 1, 2, \dots$.
36. (a) $Z(z) = j50 \frac{-1 + \tan(20\pi z)}{1 + \tan(20\pi z)} \text{ } [\Omega]$.
37. (a) $Z(z) = j50 \frac{1 + \tan(20\pi z)}{1 - \tan(20\pi z)} \text{ } [\Omega]$.
38. (a) $\Gamma(z) = 0.2997e^{-j(0.042z - 1.267)}$. (b) 1.856 . (c) $z = 105.45 \text{ m}$. (d) $\text{SWR} = \frac{2.5\omega^2 + 10^{15} + |2.5\omega^2 + j5 \times 10^7 \omega|}{2.5\omega^2 + 10^{15} - |2.5\omega^2 + j5 \times 10^7 \omega|}$.
39. (a) $\Gamma(z) = 0.3033e^{-j(0.042z + 1.263)}$. (b) 1.87 . (c) $z = 109.93 \text{ m}$. (d) $\text{SWR} = \frac{2.5\omega^2 + 10^{13} + |10^{13} + j5 \times 10^6 \omega|}{2.5\omega^2 + 10^{13} - |10^{13} + j5 \times 10^6 \omega|}$.
41. (a) $V_L = 9.98 \angle 111.55^\circ \text{ V}$. (b) 0.003 W .
42. $d = 0.0413\lambda$.
43. (b) $f = 100, 200, 300, 400 \text{ MHz}$.
44. (b) $f = 78.75 \text{ MHz}$. (c) $f = 171, 328.75 \text{ MHz}$.
45. (a) $f = 200 \text{ MHz}$. (b) $f = 113.6, 129.2, 153.4 \text{ MHz}$.

Chapter 15

1. (a) $\Gamma = 0.598 \angle 21.8^\circ$. (b) $\Gamma = 0.598 \angle -98.2^\circ$. (c) 3.98. (d) $42 - j77 \Omega$. (e) V_{max} at 0.03λ , V_{min} at 0.28λ .
2. (a) $V_{max} = 80.5 \text{ V}$. (b) $V_{min} = 30.7 \text{ V}$. (c) Minima: $0.088\lambda + n(0.5\lambda)$, $n = 0, 1, 2, \dots$, maxima: $0.338\lambda + n(0.5\lambda)$, $n = 0, 1, 2, \dots$.
3. $Z = 48 + j44 \Omega$.
4. (a) $Z_{in} = 210 - j648 \Omega$. (b) SWR = 9. (c) $P_{in} = 17.5 \text{ W}$.
5. (a) $Z_L = 71 - j21 \Omega$. (b) Maxima: $0.45\lambda, 0.95\lambda, 1.45\lambda, 1.95\lambda, 2.45\lambda, 2.95\lambda, 3.45\lambda, 3.95\lambda, 4.45\lambda, 4.95\lambda, 5.45\lambda, 5.95\lambda, 6.45\lambda, 6.95\lambda, 7.45\lambda, 7.95\lambda$, and 8.45λ . Minima: $0.2\lambda, 0.7\lambda, 1.2\lambda, 1.7\lambda, 2.2\lambda, 2.7\lambda, 3.2\lambda, 3.7\lambda, 4.2\lambda, 4.7\lambda, 5.2\lambda, 5.7\lambda, 6.2\lambda, 6.7\lambda, 7.2\lambda, 7.7\lambda$, and 8.2λ . (c) $\Gamma_L = 0.244 \angle -36^\circ$, SWR = 1.75.
6. (a) $l = 0.058\lambda$, $R = 125 \Omega$.
7. (a) $Z_L = 97.5 - j78 \Omega$. (b) $\Gamma = 0.431 \angle -50^\circ$.
8. (a) $\text{SWR} = \frac{\sqrt{4Z_0^2 + (X_L + Z_1 \tan(\beta_1 d))^2 + |X_L + Z_1 \tan(\beta_1 d)|}}{\sqrt{4Z_0^2 + (X_L + Z_1 \tan(\beta_1 d))^2 - |X_L + Z_1 \tan(\beta_1 d)|}}$. (b) $d = (\lambda/2\pi) \tan^{-1}(-X_L/Z_1)$.
10. ($d_{1a} = 0.462\lambda$, $d_{2a} = 0.102\lambda$) or ($d_{1b} = 0.12\lambda$, $d_{2b} = 0.397\lambda$).
11. Position: 0.224λ (1.12 m), length: 0.153λ (0.765 m) or: position 0.422λ (2.11 m), length: 0.347λ (1.735 m).
12. $d_{1a} = 0.029\lambda$, $d_{2a} = 0.105\lambda$ or: $d_{1b} = 0.188\lambda$, $d_{2b} = 0.396\lambda$.
13. (a) $\Gamma = 1/3 \angle -180^\circ$. (b) 2.0. (c) location: 0.403λ (0.959 m), length: 0.153λ (0.364 m) or: location: 0.098λ (0.233 m), length: 0.347λ (0.826 m). (d) $\Gamma_L = 0.22 \angle 58^\circ$ or $\Gamma_L = 0.14 \angle 110^\circ$.
14. $d_{21} = 0.375\lambda$, $d_{11} = 0.177\lambda$ or: $d_{22} = 0.125\lambda$, $d_{12} = 0.094\lambda$.
15. $d_{11} = 0.199\lambda$, $d_{21} = 0.081\lambda$ or: $d_{12} = 0.346\lambda$, $d_{22} = 0.384\lambda$.
16. $Z_t = \sqrt{Z_1 Z_2} [\Omega]$.
17. $d = \lambda/4$, $Z_c = Z_0 \sqrt{(1 - |\Gamma_L|)/(1 + |\Gamma_L|)} [\Omega]$, if $Z_L < Z_0$, $Z_c = Z_0 \sqrt{(1 + |\Gamma_L|)/(1 - |\Gamma_L|)} [\Omega]$ if $Z_L > Z_0$.
18. $d = 0.1611\lambda$, $Z_t = 114 \Omega$ or: $d = 0.4111\lambda$, $Z_t = 43.85 \Omega$.
19. (a) $d_{min} = 2.75\lambda$. (b) $Z_t = 367.42 \Omega$. (c) 1.5 and 1.0.

Chapter 16

3. (a) Zero. (b) $> 3 \mu\text{s}$.
6. (a) 9.26 V. (b) 10 V.
8. (a) 33.34 V. (b) 0.667 A. (c) 0.1 ms. (d) 0.2 ms.
9. (a) $V(10\mu\text{s}) = -0.02232 \text{ V}$, $I(10\mu\text{s}) = -50 \mu\text{A}$.
10. $V(10.5 \mu\text{s}) = -3.3807 \text{ V}$, $I(10.5 \mu\text{s}) = -0.0676 \text{ A}$.
11. (a) $V_g = 7.11 \text{ V}$, $V_L = 6.912 \text{ V}$, $V_{a-} = 7.373 \text{ V}$, $V_{a+} = 7.4 \text{ V}$, $V_{b-} = 7.465 \text{ V}$, $V_{b+} = 7.465 \text{ V}$. (b) $V_g = 7.1424 \text{ V}$, $V_L = 6.912 \text{ V}$, $V_{a-} = 7.1424 \text{ V}$, $V_{a+} = 7.1424 \text{ V}$, $V_{b-} = 7.189 \text{ V}$, $V_{b+} = 7.1885 \text{ V}$.
12. $V_g = 5.952 \text{ V}$, $V_L = 0 \text{ V}$, $V_{a-} = 5.952 \text{ V}$, $V_{a+} = 5.952 \text{ V}$, $V_{b-} = 1.3824 \text{ V}$, $V_{b+} = 1.659 \text{ V}$. $I_g = 0.08064 \text{ A}$, $I_L = 0.1536 \text{ A}$, $I_{a-} = 0.08064 \text{ A}$, $I_{a+} = 0.05376 \text{ A}$, $I_{b-} = 0.11008 \text{ A}$, $I_{b+} = 0.16589 \text{ A}$.
13. (a) $v_L(t) = 100 \left(1 - e^{-(t-10^{-6})/50 \times 10^{-6}}\right) [\text{V}]$, $t \geq \Delta t$, $i_L(t) = 2e^{-(t-10^{-6})/50 \times 10^{-6}} [\text{A}]$, $t \geq \Delta t$.
14. (a) $v_L(t) = 100e^{-(t-10^{-4})50/1 \times 10^{-6}} [\text{V}]$, $t \geq \Delta t$, $i_L(t) = 2 \left(1 - e^{-(t-10^{-4})50/1 \times 10^{-6}}\right) [\text{A}]$, $t \geq 10^{-4} \text{ s}$. (b) $V(t) = 100e^{-(t-10^{-4})50/1 \times 10^{-6}} [\text{V}]$, $I(t) = 2 \left(1 - e^{-(t-10^{-4})50/1 \times 10^{-6}}\right) [\text{A}]$.
17. (a) 3,000 m.
18. (a) 1,500 m. (b) $Z = 16.7 \Omega$.
19. (a) 3,000 m. (b) $Z = 150 \Omega$.
20. (a) 1,500 m.

Chapter 17

1. (a) $v_g = 5.43 \times 10^8$ m/s, $\lambda_g = 0.003$ m, $Z_{TM} = 208.4 \Omega$. (b) $\mathbf{E}(x, z) = \hat{\mathbf{x}} 1.1134 \cos(1000\pi x) e^{-j2094.4z} + \hat{\mathbf{z}} j 1.67 \sin(1000\pi x) e^{-j2094.4z}$ [V/m]. (c) $\mathbf{H}(x, z) = \hat{\mathbf{y}} 0.0053 \cos(1000\pi x) e^{-j2094.4z}$ [A/m]. (d) $\mathcal{P} = \hat{\mathbf{z}} 0.0059 \cos^2(1000\pi x) e^{-j4188.8z} - \hat{\mathbf{x}} j 0.0088 \sin(1000\pi x) \cos(1000\pi x) e^{-j4148.8z}$ [W/m²].
2. (a) 160 GHz. (b) 160 GHz. (c) $Z_{TE} = 232.7 \Omega$, $Z_{TM} = 174.5 \Omega$, $Z_{TEM} = 201.5 \Omega$.
3. (a) 31.84×10^{-12} W. (b) 31.84×10^{-12} W. (c) $\mathcal{P}_{av_{TEM}} = 106 \times 10^{-12}$ W.
4. 3.75 GHz.
5. (a) $\Gamma = -0.268$, $T = 0.732$. (b) SWR = 1.732 (left), SWR = 1 (right).
6. $\mathbf{E} = -\hat{\mathbf{x}} (\eta\lambda/\lambda_z) 2H_0 \cos(\pi x/a) \cos(\omega t) \sin(2\pi z/\lambda_z) + \hat{\mathbf{z}} (\eta\lambda/\lambda_c) 2H_0 \sin(\pi x/a) \sin(\omega t) \sin(2\pi z/\lambda_z)$ [V/m], $\mathbf{H} = \hat{\mathbf{y}} 2H_0 \cos(\pi x/a) \sin(\omega t) \cos(2\pi z/\lambda_z)$ [A/m].
7. (a) TM₁. (b) 619.06×10^{-9} m.
8. $\mathbf{E}(z) = \hat{\mathbf{y}} E_0 e^{-j\omega\sqrt{\mu_0\epsilon_0}z}$ [V/m], $\mathbf{H}(z) = -\hat{\mathbf{x}} (E_0/\eta_0) e^{-j\omega\sqrt{\mu_0\epsilon_0}z}$ [A/m].
9. $\mathbf{E}(x, z) = \hat{\mathbf{y}} jE_0 \sin(m\pi x/d) e^{-j2\pi z/\lambda_g}$ [V/m], $\mathbf{H}(x, z) = -\hat{\mathbf{x}} j(E_0/\eta_0)(\lambda/\lambda_g) \sin(m\pi x/d) e^{-j2\pi z/\lambda_g} - \hat{\mathbf{z}} (E_0/\eta_0)(\lambda/\lambda_{cm}) \cos(m\pi x/d) e^{-j2\pi z/\lambda_g}$ [A/m].
10. $\mathbf{E} = \hat{\mathbf{x}} H_0 \eta_0 (\lambda/\lambda_g) \cos(m\pi x/d) e^{-j2\pi z/\lambda_g} + \hat{\mathbf{z}} jH_0 \eta_0 (\lambda/\lambda_{cm}) \sin(m\pi x/d) e^{-j2\pi z/\lambda_g}$ [V/m], $\mathbf{H} = \hat{\mathbf{y}} H_0 \cos(m\pi x/d) e^{-j2\pi z/\lambda_g}$ [A/m].
11. (a) $b = 1.5$ m. (b) 8.
12. (a) 2.0793 GHz. (b) 1.1865 GHz.
13. TE₁₀ (5.263 GHz), TE₀₁ (11.886 GHz), TE₁₁ = TM₁₁ (12.999 GHz), TE₂₀ (10.526 GHz).
14. (a) $E = 2.48 \times 10^6$ V/m, $H = 4318.13$ A/m.
15. (a) > 30 MHz. (b) 30 MHz.
16. (a) $f_{c0} = c \sqrt{\left(\frac{1}{2a}\right)^2 + \left(\frac{1}{2b}\right)^2}$ [Hz]. (b) $t = d \left[\sqrt{\mu_0\epsilon_0} \sqrt{1 - \left(\frac{f_{c0}}{f}\right)^2} + \sqrt{\mu_1\epsilon_1} \sqrt{1 - \left(\frac{f_{c1}}{f}\right)^2} \right]$ [s].
17. (a) $E_y(x, y, z) = -j20,040 \sin(66.1x) e^{-j67.2z}$, $E_z = 0$ [V/m] (b) $H_x(x, y, z) = j37.265 \sin(66.1x) e^{-j67.2z}$ [A/m], $H_z(x, y, z) = 37.265 \sin(66.1x) e^{-j67.2z}$ [A/m].
18. (a) TE₁₀ (15 GHz). (b) $P = 0.0149$ W. (c) $P = 0.00995$ W.
19. $P_{max} = 1.163 \times 10^6$ W.
20. (b) 5.3×10^{13} Hz (infrared). (c) 8.12×10^{-4} W.
26. (a) $\alpha_{dTE_{10}} = 0.0179$ Np/m. (b) 3%.
27. (a) 2.98 mW/m. (b) $\alpha_w = 0.00943$ Np/m.
28. (a) $\alpha = 0.0266$ Np/m. (b) 5.78 mW/m.
29. (a) 4.5 GHz. (b) TE₀₁₁ (5.59 GHz), TE₂₀₁ (7.9 GHz), TE₁₀₃ (8.38 GHz).
30. TE₁₀₁ (2.1 GHz), TE₁₀₂ (2.164 GHz), TE₁₀₃ (2.266 GHz), TE₁₀₄ (2.4 GHz), TE₁₀₅ (2.564 GHz), TE₁₀₆ (2.75 GHz), TE₁₀₇ (2.955 GHz), TE₁₀₈ (3.175 GHz), TE₁₀₉ (3.408 GHz), TE_{1,0,10} (3.65 GHz).
31. (a) $d = 0.0204$ m. (b) TE₁₀₁ (8 GHz).
32. $f = n/2d\sqrt{\mu_1\epsilon_1}$ [Hz], $n = 1, 2, 3 \dots$

Chapter 18

2. (a) $\mathbf{E} \approx \hat{\mathbf{R}} (1.53/jR^3) \cos\theta + \hat{\boldsymbol{\theta}} (0.763/jR^3) \sin\theta$ [V/m], $\mathbf{H} \approx \hat{\boldsymbol{\phi}} (6.37 \times 10^{-3}/R^2) \sin\theta$ [A/m]. (b) $\mathbf{E} = \hat{\boldsymbol{\theta}} (j7.54/R) \sin\theta e^{-j\pi R}$ [V/m], $\mathbf{H} = \hat{\boldsymbol{\phi}} (j0.02/R) \sin\theta e^{-j\pi R}$ [A/m]. (c) $R_{rad} = 0.316 \Omega$, $P_{rad} = 0.632$ W. (d) 27.5 km.
3. (a) $\mathcal{P}_{av} = \hat{\mathbf{R}} (V_0^2/2\eta_0 R^2) \sin^2\theta$ [W/m²]. (b) $P_{rad} = 4\pi V_0^2/3\eta_0$ [W].
4. (a) $P_{rad} = 5.12$ mW. (b) $P_{rad} = 44.92$ mW.
5. (a) 0.0318λ .
6. (a) $P_{rad} = 25\omega^2\mu^2\beta^2\pi a^2 I_0^2/3\eta$ [W]. (b) $R_{rad} = 50\omega^2\mu^2\beta^2\pi a^4/3\eta$ [Ω].
7. (a) $\mathbf{E} = \hat{\boldsymbol{\theta}} (j\beta\eta I_0 L/8\pi R) \sin\theta e^{-j\beta R}$ [V/m], $\mathbf{H} = \hat{\boldsymbol{\phi}} (j\beta I_0 L/8\pi R) \sin\theta e^{-j\beta R}$ [A/m], $\mathcal{P}_{av} = \hat{\mathbf{R}} (\beta^2\eta I_0^2 L^2/128\pi^2 R^2) \sin^2\theta$ [W/m²]. (b) $R_{rad} = 20\pi^2(L/\lambda)^2$ [Ω].
8. $\mathcal{P}_{av} = 7.54 \times 10^{-10}$ W/m².

9. (a) $R_{rad} = 73.08 \Omega$, $eff = 99.43\%$. (b) $eff = 99.86\%$.
10. (b) $eff = 96.8\%$.
11. $P_{rad} = 20.773 \text{ W}$.
12. (a) $\mathcal{P}_{av} = 1.464 \times 10^{-7} \text{ W/m}^2$. (b) $G = 1.618$.
13. (a) $\text{SWR} = 1.4615$. (b) $\text{SWR} = 1.4857$. (c) $\text{SWR} = 159$.
14. (a) $I(z) = I_0 \cos(\pi z'/L)$ [A]. (b) $I(z) = I_0 \sin(2\pi z'/L)$ [A]. (c) $I(z) = -I_0 \cos(3\pi z'/L)$ [A].
(d) $I(z) = I_0 \cos(\pi/4 - 3\pi z'/2L)$ [A]. (e) $I(z) = -I_0 \sin(4\pi z'/L)$ [A]. (f) $I(z) = -I_0 \sin(\pi/4 - 5\pi z'/2L)$ [A].
15. (a) $|f_e(\theta)| = |(\cos((3\pi/4)\cos\theta) + 1/\sqrt{2})/\sin\theta|$. (b) $|f_e(\theta)| = |(\cos(\pi)\cos\theta + 1)/\sin\theta|$.
(c) $|f_e(\theta)| = |\cos((3\pi/2)\cos\theta)/\sin\theta|$. (d) $|f_e(\theta)| = |(\cos((2\pi)\cos\theta) - 1)/\sin\theta|$. (e) $|f_e(\theta)| = |\cos((5\pi/2)\cos\theta)/\sin\theta|$.
16. $R_{rad} = 105.48 \Omega$, $D(\theta) = 1.1376(\cos((1.5\pi)\cos\theta))^2$, $P_{rad} = 2.1 \text{ W}$.
17. (a) $R_{rad} = 111 \Omega$. (b) $R_{rad} = 108.162 \Omega$. (c) $D(\theta) \approx 1.08(\cos((1.25\pi)\cos\theta + 0.707))^2$, $D(\theta) = 1.1094(\cos((1.25\pi)\cos\theta + 0.707))^2$.
18. (a) 1.5 m. (b) $R_{rad} = 99.54 \Omega$. (c) $49.77I_0^2$ [W]. (d) $D = 2.41$.
19. (a) $I = 2.433 \text{ A}$. (b) 23.2 km.
20. (b) 99.46% and 99.94%. (c) 0.995.
21. (a) 0.00439 Ω . (b) $0.002195I_0^2$ [W]. (c) $d = 1.5$.
22. (a) 0.75 m. (b) 36.54 Ω . (c) $18.271I_0^2$ [W]. (d) 1.642.
23. (a) $\mathbf{E} = \hat{\theta} \frac{\beta\eta I_0 d e^{-j\beta R}}{2\pi R} \sin\theta \sin(\beta h \sin\theta \cos^2\phi)$ [V/m], $\mathbf{H} = \hat{\phi} \frac{\beta I_0 d e^{-j\beta R}}{2\pi R} \sin\theta \sin(\beta h \sin\theta \cos^2\phi)$ [A/m].
(b) $|f_e(\theta, \phi)| = |\sin\theta \sin(\beta h \sin\theta \cos\phi)|$, $0 \leq \theta \leq \pi/2$, $0 \leq \phi \leq 2\pi$.
24. (a) $|f_e(\theta)| = |(\cos(2\pi\cos\theta) - 1)/\sin\theta|$. (b) 64.9 W. (c) $|f_e(\theta)| = |(\cos(3\pi\cos\theta) + 1)/\sin\theta|$, 73.9 W.
25. (a) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta)/\sin\theta|$. (b) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((\pi/2)\sin\theta \cos\phi)/\sin\theta|$. (c) $|f_a(\theta, \phi, \varphi)| = |-\cos((\pi/2)\cos\theta) \sin((\pi/2)\sin\theta \cos\phi)/\sin\theta|$. (d) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((\pi/2)\sin\theta \cos\phi + \pi/4)/\sin\theta|$.
(e) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((\pi/2)\sin\theta \cos\phi) + \pi/8)/\sin\theta|$. (f) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos(\pi \sin\theta \cos\phi)/\sin\theta|$. (g) $|f_a(\theta, \phi, \varphi)| = |-\cos((\pi/2)\cos\theta) \sin((\pi \sin\theta \cos\phi)/\sin\theta)|$. (h) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos(\pi \sin\theta \cos\phi + \pi/4)/\sin\theta|$. (i) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos(\pi \sin\theta \cos\phi + \pi/8)/\sin\theta|$. (j) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((3\pi/2)\sin\theta \cos\phi)/\sin\theta|$. (k) $|f_a(\theta, \phi, \varphi)| = |-\cos((\pi/2)\cos\theta) \sin((3\pi/2)\sin\theta \cos\phi)/\sin\theta|$. (l) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((3\pi/2)\sin\theta \cos\phi + \pi/4)/\sin\theta|$. (m) $|f_a(\theta, \phi, \varphi)| = |\cos((\pi/2)\cos\theta) \cos((3\pi/2)\sin\theta \cos\phi + \pi/8)/\sin\theta|$.
26. (a) $|f_a(\theta, \phi, \varphi)| = \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \cos(10\pi \sin\theta \cos\phi) \right|$.
(b) $|f_a(\theta, \phi, \varphi)| = \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \cos\left(10\pi \sin\theta \cos\phi + \frac{\pi}{4}\right) \right|$.
27. (a) $\mathbf{E} = \frac{0.0167e^{-j2.084R}}{R} \sin\theta (\hat{\theta} j11.31 + \hat{\phi} 55.81)$ [V/m], $\mathbf{H} = \frac{0.0167e^{-j2.084R}}{R} \sin\theta (\hat{\theta} j0.03 - \hat{\phi} 0.148)$ [A/m].
(b) $\mathbf{E} = \frac{0.0167e^{-j2.084R}}{R} \sin\theta (\hat{\theta} j11.31 - \hat{\phi} 55.81)$ [V/m], $\mathbf{H} = \frac{0.0167e^{-j2.084R}}{R} \sin\theta (\hat{\theta} j0.03 + \hat{\phi} 0.148)$ [A/m].
29. (a) $|f_e(\theta, \phi, \varphi)| = \frac{1}{6} \left| \frac{\sin(3\pi \sin\theta \cos\phi)}{\sin((\pi/2)\sin\theta \cos\phi)} \right| \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right|$.
(b) $|f_p(\theta, \phi, \varphi)| = \left(\frac{1}{6} \left| \frac{\sin(3\pi \sin\theta \cos\phi)}{\sin((\pi/2)\sin\theta \cos\phi)} \right| \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \right)^2$. (c) $\theta = 90^\circ$.
(d) $\phi = 60^\circ$, $\phi = 90^\circ$, $\phi = 120^\circ$, $\phi = 240^\circ$, $\phi = 270^\circ$ and $\phi = 300^\circ$.
30. (a) $|f_a(\theta, \phi, \varphi)| = \frac{1}{5} \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \frac{\sin(3\pi(\sin\theta \cos\phi - 1)/2)}{\sin(0.6\pi(\sin\theta \cos\phi - 1)/2)} \right|$.
(b) $|f_a(\theta, \phi, \varphi)| = \frac{1}{6} \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \frac{\sin(6\pi(0.6\sin\theta \cos\phi - 1)/2)}{\sin(\pi(0.6\sin\theta \cos\phi - 1)/2)} \right|$.
(c) $|f_a(\theta, \phi, \varphi)| = \frac{1}{10} \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \frac{\sin(10\pi(0.7\sin\theta \cos\phi - 0.75)/2)}{\sin(\pi(0.7\sin\theta \cos\phi - 0.75)/2)} \right|$.

- (d) $|f_a(\theta, \phi, \varphi)| = \frac{1}{5} \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \frac{\sin(5\pi(0.7\sin\theta\cos\phi - 1)/2)}{\sin(\pi(0.7\sin\theta\cos\phi - 1)/2)} \right|$.
31. $|f_a(\theta, \phi, 0)| = \frac{1}{5} |\sin\theta| \left| \frac{\sin((5\pi/4)\sin\theta\cos\phi)}{\sin((\pi/4)\sin\theta\cos\phi)} \right|$.
32. (a) $|f_a(\theta, \phi)| = \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \cos^2\left(\frac{\pi\sin\theta\cos\phi}{4}\right) \right|$.
33. (a) $|f_a(\theta, \phi)| = \left| \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right| \left| \frac{\sin((n\pi/2)\sin\theta\cos\phi)}{n\sin((\pi/2)\sin\theta\cos\phi)} \right|$, $0 \leq \theta \leq \pi/2$
- (b) $\mathbf{E} = \hat{\theta} \frac{j\eta I_0}{2\pi R} e^{-j\beta R} e^{j(n-1)(\pi/2)\sin\theta\cos\phi} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \frac{\sin((n\pi/2)\sin\theta\cos\phi)}{\sin((\pi/2)\sin\theta\cos\phi)} [\text{V/m}]$,
- $\mathbf{H} = \hat{\phi} \frac{jI_0}{2\pi R} e^{-j\beta R} e^{j(n-1)(\pi/2)\sin\theta\cos\phi} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \frac{\sin((n\pi/2)\sin\theta\cos\phi)}{\sin((\pi/2)\sin\theta\cos\phi)} [\text{A/m}]$, $0 \leq \theta \leq \pi/2$.
34. (a) $\mathbf{E} = \hat{\phi} \frac{\omega\mu\beta I \pi d^2/4}{4\pi R} e^{-j\beta R} \sin\theta e^{j(n-1)\psi/2} \frac{\sin(n\psi/2)}{\sin(\psi/2)} [\text{V/m}]$,
- $\mathbf{H} = -\hat{\theta} \frac{\omega\mu\beta I \pi d^2/4}{4\pi\eta R} e^{-j\beta R} \sin\theta e^{j(n-1)\psi/2} \frac{\sin(n\psi/2)}{\sin(\psi/2)} [\text{A/m}]$, $\psi = 0.08 \pi \sin\theta \cos\phi + \varphi$
- (b) $F_n(\theta, \phi, \varphi) = \frac{\sin(0.04n\pi \sin\theta \cos\phi)}{\sin(0.04\pi \sin\theta \cos\phi)}$, $|f_n(\theta, \phi, \varphi)| = \frac{1}{n} \left| \frac{\sin(0.04n\pi \sin\theta \cos\phi)}{\sin(0.04\pi \sin\theta \cos\phi)} \right|$.
35. (a) $\mathbf{E} = \hat{\theta} \frac{j\eta I_0}{2\pi} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \frac{e^{-j\beta R}}{R} (1 + 2\cos(2\pi\cos\theta) + 2\cos(4\pi\cos\theta)) [\text{V/m}]$,
- $\mathbf{H} = \hat{\phi} \frac{jI_0}{2\pi} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \frac{e^{-j\beta R}}{R} (1 + 2\cos(2\pi\cos\theta) + 2\cos(4\pi\cos\theta)) [\text{A/m}]$.
- (b) $\mathcal{P}_{av} = \frac{1}{2} \text{Re}\{\mathbf{E} \times \mathbf{H}^*\} = \hat{\mathbf{R}} \frac{\eta I_0^2}{8\pi^2 R^2} \left(\frac{\cos((\pi/2)\cos\theta)}{\sin\theta} \right)^2 [1 + 2\cos(2\pi\cos\theta) + 2\cos(4\pi\cos\theta)]^2 [\text{W/m}^2]$.
36. (a) $\mathbf{E} = \hat{\theta} \frac{j\eta I_0}{2\pi R} e^{-j\beta R} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} [1 + 2\cos(2\pi\cos\theta) + 2\cos(4\pi\cos\theta)] [\text{V/m}]$,
- $\mathbf{H} = \hat{\phi} \frac{jI_0}{2\pi R} e^{-j\beta R} \frac{\cos((\pi/2)\cos\theta)}{\sin\theta} [1 + 2\cos(2\pi\cos\theta) + 2\cos(4\pi\cos\theta)] [\text{A/m}]$,
- (b) $\mathcal{P}_{av} = \hat{\mathbf{R}} \frac{\beta^2 \eta I_0^2 \Delta l^2}{8\pi^2 R^2} [\sin\theta (\cos(\pi \sin\theta \sin\phi) - \cos(\pi \sin\theta \cos\phi))]^2 [\text{W/m}^2]$.
37. $\mathcal{P}_{av} = \hat{\mathbf{R}} \frac{I_0^2 \eta}{2\pi^2 R^2} \frac{\cos^2((\pi/2)\cos\theta)}{\sin^2\theta} (2 + \cos(\pi \sin\theta \cos^2\phi) - \cos((\pi/2)\sin\theta \cos^2\phi) - \cos((3\pi/2)\sin\theta \cos^2\phi))^2 [\text{W/m}^2]$.
38. At 520 kHz: $A_e = 39,726.7 \sin^2 \theta$, at 1.6 MHz: $A_e = 4,196.5 \sin^2 \theta$.
39. (a) $P_{receivedmax} = 3c^2 P / 32\pi^2 f^2 R^2 [\text{W}]$. (b) $I_{peak} = \frac{3c^3}{8f^3 R a^2 \pi^3} \sqrt{\frac{P}{2\pi\eta_0}} [\text{A}]$.
40. (a) $I = 4.969 \times 10^{-4} \text{ A}$. (b) $I = 1.633 \times 10^{-5} \text{ A}$.
41. (a) 125.66. (b) 10 m^2 .
42. (a) $12.8 \mu\text{A}$. (b) $32.44 \mu\text{A}$ (antennas are tilted 45° to the left of the normal).
43. 7,955 m.
44. $\sigma = 198.44 \text{ m}^2$.
45. $P_j = \frac{P_0 \sigma G_0}{4\pi R^2 G_a} [\text{W}]$.

Appendix: Summary of Vector Relations and Physical Constants

Gradient, divergence, curl, and the Laplacian in various coordinates:

Cartesian coordinates:

$$\begin{aligned}\nabla U &= \hat{\mathbf{x}} \frac{\partial U}{\partial x} + \hat{\mathbf{y}} \frac{\partial U}{\partial y} + \hat{\mathbf{z}} \frac{\partial U}{\partial z}, \\ \nabla \cdot \mathbf{A} &= \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}, \\ \nabla \times \mathbf{A} &= \hat{\mathbf{x}} \left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right) + \hat{\mathbf{y}} \left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right) + \hat{\mathbf{z}} \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right), \\ \nabla^2 U &= \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2}\end{aligned}$$

Cylindrical coordinates:

$$\begin{aligned}\nabla U &= \hat{\mathbf{r}} \frac{\partial U}{\partial r} + \hat{\boldsymbol{\phi}} \frac{1}{r} \frac{\partial U}{\partial \phi} + \hat{\mathbf{z}} \frac{\partial U}{\partial z}, \\ \nabla \cdot \mathbf{A} &= \frac{1}{r} \frac{\partial (rA_r)}{\partial r} + \frac{1}{r} \frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z}, \\ \nabla \times \mathbf{A} &= \hat{\mathbf{r}} \left(\frac{1}{r} \frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z} \right) + \hat{\boldsymbol{\phi}} \left(\frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r} \right) + \hat{\mathbf{z}} \frac{1}{r} \left(\frac{\partial (rA_\phi)}{\partial r} - \frac{\partial A_r}{\partial \phi} \right), \\ \nabla^2 U &= \frac{\partial^2 U}{\partial r^2} + \frac{1}{r} \frac{\partial U}{\partial r} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \phi^2} + \frac{\partial^2 U}{\partial z^2}\end{aligned}$$

Spherical coordinates:

$$\begin{aligned}\nabla U &= \hat{\mathbf{R}} \frac{\partial U}{\partial R} + \hat{\boldsymbol{\theta}} \frac{1}{R} \frac{\partial U}{\partial \theta} + \hat{\boldsymbol{\phi}} \frac{1}{R \sin \theta} \frac{\partial U}{\partial \phi}, \\ \nabla \cdot \mathbf{A} &= \frac{1}{R^2} \frac{\partial}{\partial R} (R^2 A_R) + \frac{1}{R \sin \theta} \frac{\partial}{\partial \theta} (A_\theta \sin \theta) + \frac{1}{R \sin \theta} \frac{\partial A_\phi}{\partial \phi}, \\ \nabla \times \mathbf{A} &= \hat{\mathbf{R}} \frac{1}{R \sin \theta} \left(\frac{\partial (A_\phi \sin \theta)}{\partial \theta} - \frac{\partial A_\theta}{\partial \phi} \right) + \hat{\boldsymbol{\theta}} \frac{1}{R} \left(\frac{1}{\sin \theta} \frac{\partial A_R}{\partial \phi} - \frac{\partial (R A_\phi)}{\partial R} \right) + \hat{\boldsymbol{\phi}} \frac{1}{R} \left(\frac{\partial (R A_\theta)}{\partial R} - \frac{\partial A_R}{\partial \theta} \right), \\ \nabla^2 U &= \frac{1}{R^2} \frac{\partial}{\partial R} \left(R^2 \frac{\partial U}{\partial R} \right) + \frac{1}{R^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial U}{\partial \theta} \right) + \frac{1}{R^2 \sin^2 \theta} \frac{\partial^2 U}{\partial \phi^2}\end{aligned}$$

The divergence theorem:

$$\int_v (\nabla \cdot \mathbf{A}) dv = \oint_s \mathbf{A} \cdot d\mathbf{s}$$

Stokes's theorem:

$$\int_s (\nabla \times \mathbf{A}) \cdot d\mathbf{s} = \oint_L \mathbf{A} \cdot d\mathbf{l}$$

Some useful vector identities:

$$\begin{aligned}\nabla \times (\nabla U) &= \mathbf{0}, \\ \nabla \cdot (\nabla \times \mathbf{A}) &= \mathbf{0}, \\ \nabla^2 \mathbf{A} &= \nabla(\nabla \cdot \mathbf{A}) - \nabla \times (\nabla \times \mathbf{A}), \\ \nabla(UQ) &= U(\nabla Q) + Q(\nabla U), \\ \nabla \cdot (U\mathbf{A}) &= U(\nabla \cdot \mathbf{A}) + (\nabla U) \cdot \mathbf{A}, \\ \nabla \cdot (\mathbf{A} \times \mathbf{B}) &= -\mathbf{A} \cdot (\nabla \times \mathbf{B}) + (\nabla \times \mathbf{A}) \cdot \mathbf{B}, \\ \nabla \times (U\mathbf{A}) &= U(\nabla \times \mathbf{A}) + (\nabla U) \times \mathbf{A}, \\ \nabla \cdot \nabla U &= \nabla^2 U, \\ \nabla^2 \mathbf{A} &= \hat{\mathbf{x}} \nabla^2 A_x + \hat{\mathbf{y}} \nabla^2 A_y + \hat{\mathbf{z}} \nabla^2 A_z\end{aligned}$$

Some physical constants:

Charge of the electron (q_e)	$-1.602129 \times 10^{-19}$ C
Rest mass of the electron (m_e)	$9.1093897 \times 10^{-31}$ kg
Speed of light in vacuum (c)	2.997992×10^8 m/s
Permittivity of free space (ϵ_0)	8.854187×10^{-12} F/m
Permeability of free space (μ_0)	$4\pi \times 10^{-7}$ H/m
Planck's constant (h)	6.62620×10^{-34} J · s
Intrinsic impedance in free space (η_0)	376.7304 Ω

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