

Table B-1 RELATIVE PERMITTIVITY ϵ_r OF COMMON MATERIALS^a

$$\epsilon = \epsilon_r \epsilon_0 \text{ and } \epsilon_0 = 8.854 \times 10^{-12} \text{ F/m.}$$

Material	Relative Permittivity, ϵ_r	Material	Relative Permittivity, ϵ_r
Vacuum	1	Dry soil	2.5–3.5
Air (at sea level)	1.0006	Plexiglass	3.4
Styrofoam	1.03	Glass	4.5–10
Teflon	2.1	Quartz	3.8–5
Petroleum oil	2.1	Bakelite	5
Wood (dry)	1.5–4	Porcelain	5.7
Paraffin	2.2	Formica	6
Polyethylene	2.25	Mica	5.4–6
Polystyrene	2.6	Ammonia	22
Paper	2–4	Seawater	72–80
Rubber	2.2–4.1	Distilled water	81

^aThese are low-frequency values at room temperature (20° C).

Note: For most metals, $\epsilon_r \simeq 1$.

Table B-2 CONDUCTIVITY σ OF SOME COMMON MATERIALS^a

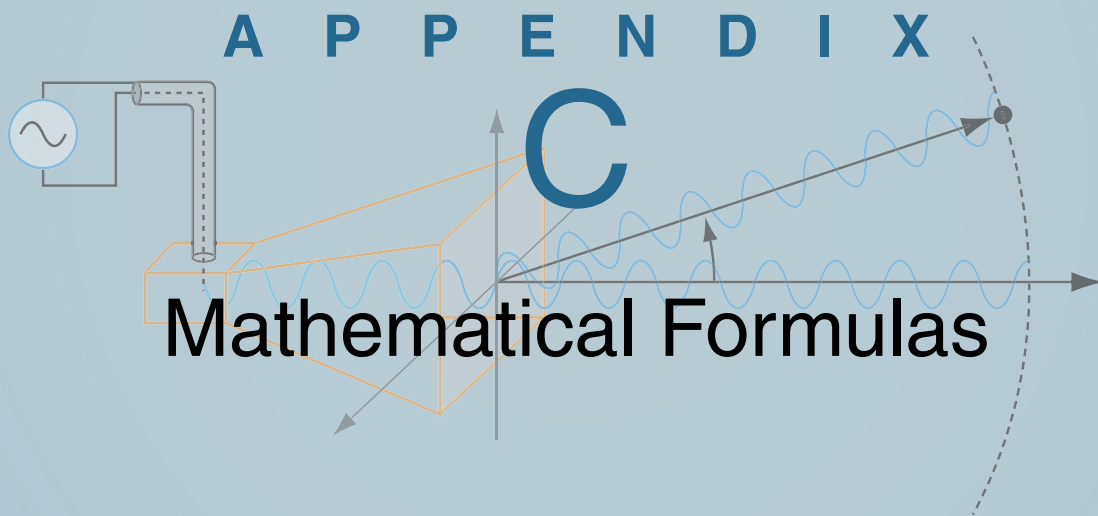
Material	Conductivity, σ (S/m)	Material	Conductivity, σ (S/m)
Conductors		Semiconductors	
Silver	6.2×10^7	Pure germanium	2.2
Copper	5.8×10^7	Pure silicon	4.4×10^{-4}
Gold	4.1×10^7	Insulators	
Aluminum	3.5×10^7	Wet soil	$\sim 10^{-2}$
Tungsten	1.8×10^7	Fresh water	$\sim 10^{-3}$
Zinc	1.7×10^7	Distilled water	$\sim 10^{-4}$
Brass	1.5×10^7	Dry soil	$\sim 10^{-4}$
Iron	10^7	Glass	10^{-12}
Bronze	10^7	Hard rubber	10^{-15}
Tin	9×10^6	Paraffin	10^{-15}
Lead	5×10^6	Mica	10^{-15}
Mercury	10^6	Fused quartz	10^{-17}
Carbon	3×10^4	Wax	10^{-17}
Seawater	4		
Animal body (average)	0.3 (poor cond.)		
^a These are low-frequency values at room temperature (20° C).			

Table B-3 RELATIVE PERMEABILITY μ_r OF SOME COMMON MATERIALS^a

$$\mu = \mu_r \mu_0 \text{ and } \mu_0 = 4\pi \times 10^{-7} \text{ H/m.}$$

Material	Relative Permeability, μ_r
Diamagnetic	
Bismuth	$0.99983 \simeq 1$
Gold	$0.99996 \simeq 1$
Mercury	$0.99997 \simeq 1$
Silver	$0.99998 \simeq 1$
Copper	$0.99999 \simeq 1$
Water	$0.99999 \simeq 1$
Paramagnetic	
Air	$1.000004 \simeq 1$
Aluminum	$1.00002 \simeq 1$
Tungsten	$1.00008 \simeq 1$
Titanium	$1.0002 \simeq 1$
Platinum	$1.0003 \simeq 1$
Ferromagnetic (nonlinear)	
Cobalt	250
Nickel	600
Mild steel	2,000
Iron (pure)	4,000–5,000
Silicon iron	7,000
Mumetal	$\sim 100,000$
Purified iron	$\sim 200,000$
^a These are typical values; actual values depend on material variety.	

Note: Except for ferromagnetic materials, $\mu_r \simeq 1$ for all dielectrics and conductors.



Trigonometric Relations

$$\sin(x \pm y) = \sin x \cos y \pm \cos x \sin y$$

$$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y$$

$$2 \sin x \sin y = \cos(x - y) - \cos(x + y)$$

$$2 \sin x \cos y = \sin(x + y) + \sin(x - y)$$

$$2 \cos x \cos y = \cos(x + y) + \cos(x - y)$$

$$\sin 2x = 2 \sin x \cos x$$

$$\cos 2x = 1 - 2 \sin^2 x$$

$$\sin x + \sin y = 2 \sin \left(\frac{x + y}{2} \right) \cos \left(\frac{x - y}{2} \right)$$

$$\sin x - \sin y = 2 \cos \left(\frac{x + y}{2} \right) \sin \left(\frac{x - y}{2} \right)$$

$$\cos x + \cos y = 2 \cos \left(\frac{x + y}{2} \right) \cos \left(\frac{x - y}{2} \right)$$

$$\cos x - \cos y = -2 \sin \left(\frac{x + y}{2} \right) \sin \left(\frac{x - y}{2} \right)$$

$$\cos(x \pm 90^\circ) = \mp \sin x$$

$$\cos(-x) = \cos x$$

$$\sin(x \pm 90^\circ) = \pm \cos x$$

$$\sin(-x) = -\sin x$$

$$e^{jx} = \cos x + j \sin x \quad (\text{Euler's identity})$$

$$\sin x = \frac{e^{jx} - e^{-jx}}{2j}$$

$$\cos x = \frac{e^{jx} + e^{-jx}}{2}$$

Approximations for Small Quantities

For $|x| \ll 1$,

$$(1 \pm x)^n \simeq 1 \pm nx$$

$$(1 \pm x)^2 \simeq 1 \pm 2x$$

$$\sqrt{1 \pm x} \simeq 1 \pm \frac{x}{2}$$

$$\frac{1}{\sqrt{1 \pm x}} \simeq 1 \mp \frac{x}{2}$$

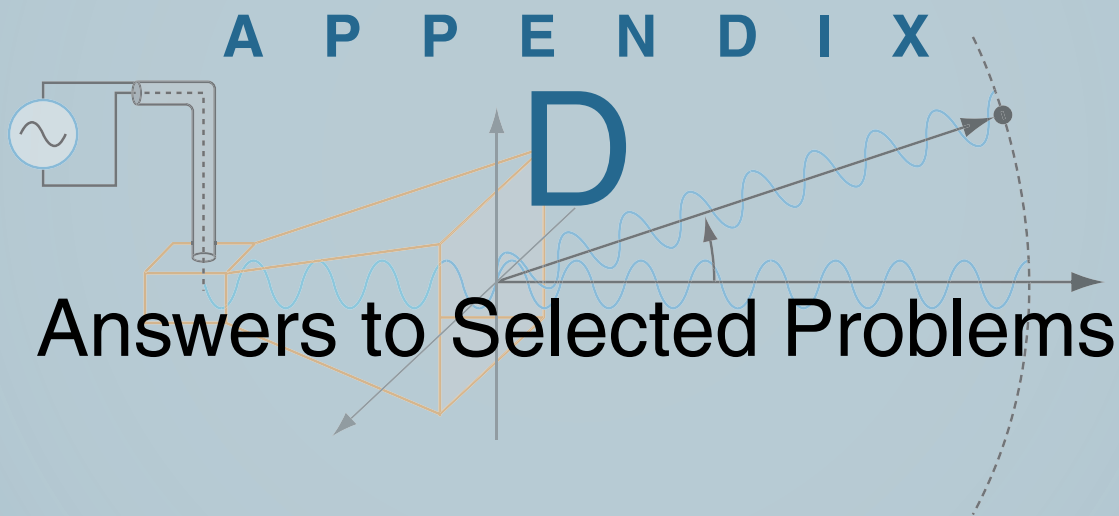
$$e^x = 1 + x + \frac{x^2}{2!} + \cdots \simeq 1 + x$$

$$\ln(1 + x) \simeq x$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \cdots \simeq x$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} + \cdots \simeq 1 - \frac{x^2}{2}$$

$$\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$$



Chapter 1

- 1.1** 5 cm
- 1.3** $p(x, t) = 51.04 \cos(4\pi \times 10^3 t - 12.12\pi x + 36^\circ)$ (N/m²)
- 1.6** $u_p = 0.83$ (m/s); $\lambda = 10.47$ m
- 1.8** (a) $y_1(x, t)$ is traveling in positive x direction. $y_2(x, t)$ is traveling in negative x direction.
- 1.10** $y_2(t)$ lags $y_1(t)$ by 54° .
- 1.12** $T = 1.25$ s; $u_p = 0.28$ m/s; $\lambda = 0.35$ m
- 1.14** $\alpha = 2 \times 10^{-3}$ (Np/m)
- 1.16** (c) $z_1 z_2 = 18e^{j109.4^\circ}$
- 1.17** (b) $z_2 = \sqrt{3} e^{j3\pi/4}$
- 1.19** (c) $|z|^2$,

- 1.20** (d) $t = 0$; $s = 6e^{j30^\circ}$
- 1.22** $\ln(z) = 1.76 + j1.03$
- 1.25** $v_c(t) = 15.57 \cos(2\pi \times 10^3 t - 81.5^\circ)$ V
- 1.26** (d) $i(t) = 3.61 \cos(\omega t + 146.31^\circ)$ A
- 1.27** (d) $\tilde{I} = 2e^{j\pi/4}$ A

Chapter 2

- 2.2** (a) $l/\lambda = 2 \times 10^{-5}$; transmission line may be ignored.
(c) $l/\lambda = 0.6$; transmission line effects should be included.
- 2.4** $R' = 0.69$ (Ω /m), $L' = 1.57 \times 10^{-7}$ (H/m), $G' = 0$, $C' = 1.84 \times 10^{-10}$ (F/m)
- 2.7** $\alpha = 0.109$ Np/m; $\beta = 44.5$ rad/m;
 $Z_0 = (19.6 + j0.030) \Omega$; $u_p = 1.41 \times 10^8$ m/s
- 2.10** $w = 0.613$ mm, $\lambda = 0.044$ m

2.14 $R' = 0.5 \text{ } (\Omega/\text{m})$; $L' = 200 \text{ (nH/m)}$; $G' = 200 \text{ } (\mu\text{S/m})$;
 $C' = 80 \text{ (pF/m)}$; $\lambda = 2.5 \text{ m}$

2.16 $R' = 0.4 \text{ } (\Omega/\text{m})$, $L' = 38.2 \text{ nH/m}$, $G' = 0.25 \text{ mS/m}$,
 $C' = 23.9 \text{ pF/m}$

2.17 (a) $b = 4.2 \text{ mm}$
 (b) $u_p = 2 \times 10^8 \text{ m/s}$

2.22 $Z_L = (120.5 - j89.3) \text{ } \Omega$

2.23 $Z_0 = 70.7 \text{ } \Omega$

2.29 $Z_{\text{in}} = (40 + j20) \text{ } \Omega$

2.31 (b) $\Gamma = 0.16 e^{-j80.54^\circ}$

2.32 (a) $\Gamma = 0.62 e^{-j29.7^\circ}$

2.33 (a) $Z_{\text{in}1} = (35.20 - j8.62) \text{ } \Omega$

2.35 $L = 8.3 \times 10^{-9} \text{ H}$

2.36 $l = \lambda/4 + n\lambda/2$

2.39 $Z_{\text{in}} = \frac{100^2}{33.33} = 300 \text{ } \Omega$

2.41 (b) $i_L(t) = 3 \cos(6\pi \times 10^8 t - 135^\circ) \quad (\text{A})$

2.42 (a) $Z_{\text{in}} = (41.25 - j16.35) \text{ } \Omega$

2.44 $P_{\text{av}}^i = 10.0 \text{ mW}$; $P_{\text{av}}^r = -1.1 \text{ mW}$; $P_{\text{av}}^t = 8.9 \text{ mW}$

2.45 (a) $P_{\text{av}} = 0.29 \text{ W}$

2.48 (b) $\Gamma = 0.62 \exp -29.7^\circ$

2.50 $Z_{\text{in}} = (66 - j125) \text{ } \Omega$

2.52 (b) $S = 1.64$

2.53 $Z_{01} = 40 \text{ } \Omega$; $Z_{02} = 250 \text{ } \Omega$

2.55 (a) $Z_{\text{in}} = -j154 \text{ } \Omega$
 (b) $0.074\lambda + (n\lambda/2)$, $n = 0, 1, 2, \dots$

2.57 The reciprocal of point Z is at point Y , which is at
 $0.55 + j0.26$.

2.61 $Z_L = (41 - j19.5) \text{ } \Omega$

2.63 $Z_{\text{in}} = (95 - j70) \text{ } \Omega$

2.69 First solution: Stub at $d = 0.199\lambda$ from antenna and stub
 length $l = 0.125\lambda$. Second solution: $d = 0.375\lambda$ from
 antenna and stub length $l = 0.375\lambda$.

2.73 $Z_{\text{in}} = 100 \text{ } \Omega$

2.78 $V_g = 19.2 \text{ V}$; $R_g = 30 \text{ } \Omega$; $l = 700 \text{ m}$

2.80 (a) $l = 600 \text{ m}$

(b) $Z_L = 0$

(c) $R_g = \left(\frac{1 + \Gamma_g}{1 - \Gamma_g} \right) Z_0 = \left(\frac{1 + 0.25}{1 - 0.25} \right) 50 = 83.3 \text{ } \Omega$

(d) $V_g = 32 \text{ V}$

Chapter 3

3.2 $\hat{\mathbf{a}} = \hat{\mathbf{x}}0.32 - \hat{\mathbf{z}}0.95$

3.3 Area = 36

3.5 (a) $A = \sqrt{14}$; $\hat{\mathbf{a}}_A = (\hat{\mathbf{x}} + \hat{\mathbf{y}}2 - \hat{\mathbf{z}}3)/\sqrt{14}$

(e) $\mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = 20$

(h) $(\mathbf{A} \times \hat{\mathbf{y}}) \cdot \hat{\mathbf{z}} = 1$

3.9 $\hat{\mathbf{a}} = \frac{\mathbf{A}}{|\mathbf{A}|} = \frac{-\hat{\mathbf{x}} - \hat{\mathbf{y}}y - \hat{\mathbf{z}}2}{\sqrt{5 + y^2}}$

3.10 $\hat{\mathbf{a}} = (\hat{\mathbf{x}}3 - \hat{\mathbf{z}}6)/\sqrt{45}$

3.12 $\mathbf{A} = \hat{\mathbf{x}}0.8 + \hat{\mathbf{y}}1.6$

3.15 $\hat{\mathbf{c}} = \hat{\mathbf{x}}0.37 + \hat{\mathbf{y}}0.56 + \hat{\mathbf{z}}0.74$

3.17 $\mathbf{G} = \pm (-\hat{\mathbf{x}}\frac{8}{3} + \hat{\mathbf{y}}\frac{8}{3} + \hat{\mathbf{z}}\frac{4}{3})$

3.23 (a) $P_1 = (2.24, 63.4^\circ, 0)$ in cylindrical;
 $P_1 = (2.24, 90^\circ, 63.4^\circ)$ in spherical

(d) $P_4 = (2.83, 135^\circ, -2)$ in cylindrical;
 $P_4 = (3.46, 125.3^\circ, 135^\circ)$ in spherical

3.24 (a) $P_1 = (0, 0, 5)$

3.25 (c) $A = 12$

3.27 (a) $V = 21\pi/2$

3.30 (a) $\theta_{AB} = 90^\circ$

(b) $\pm(\hat{\mathbf{r}}0.487 + \hat{\boldsymbol{\phi}}0.228 + \hat{\mathbf{z}}0.843)$

3.31 (a) $d = \sqrt{3}$

3.34 (c) $\mathbf{C}(P_3) = \hat{\mathbf{r}}0.707 + \hat{\mathbf{z}}4$

(e) $\mathbf{E}(P_5) = -\hat{\mathbf{r}} + \hat{\boldsymbol{\phi}}$

3.35 (c) $\mathbf{C}(P_3) = \hat{\mathbf{R}}0.854 + \hat{\boldsymbol{\theta}}0.146 - \hat{\boldsymbol{\phi}}0.707$

3.36 (e) $\nabla S = \hat{\mathbf{x}}8xe^{-z} + \hat{\mathbf{y}}3y^2 - \hat{\mathbf{z}}4x^2e^{-z}$

3.37 (b) $\nabla T = \hat{\mathbf{x}}2x$

(g) $\nabla T = -\hat{\mathbf{x}} \frac{2\pi}{6} \sin\left(\frac{\pi x}{3}\right)$

3.38 $T(z) = 10 + (1 - e^{-4z})/4$

3.39 $\left(\frac{dV}{dl}\right)\big|_{(1,-1,2)} = 1.34$

3.42 $dU/dl = -0.02$

3.46 $\mathbf{E} = \hat{\mathbf{R}}2R$

3.48 (a) $\oint \mathbf{D} \cdot d\mathbf{s} = 150\pi$

(b) $\iiint \nabla \cdot \mathbf{D} dV = 150\pi$

3.56 (a) \mathbf{A} is solenoidal, but not conservative.

(d) \mathbf{D} is conservative, but not solenoidal.

(h) \mathbf{H} is conservative, but not solenoidal.

3.58 (c) $\nabla^2 \left(\frac{3}{x^2 + y^2} \right) = \frac{12}{(x^2 + y^2)^2}$

Chapter 4

4.2 $Q = 2.62 \text{ (mC)}$

4.3 $Q = 260 \text{ (mC)}$

4.7 $I = 314.2 \text{ A}$

4.8 (a) $\rho_l = -\frac{\pi ca^4}{2} \text{ (C/m)}$

4.11 $\mathbf{E} = \hat{\mathbf{z}}51.2 \text{ kV/m}$

4.12 $q_2 \approx -94.69 \text{ (}\mu\text{C)}$

4.15 (a) $\mathbf{E} = -\hat{\mathbf{x}}1.6 - \hat{\mathbf{y}}0.66 \text{ (MV/m)}$

4.17 $\mathbf{E} = \hat{\mathbf{z}}(\rho_{s0}h/2\epsilon_0) \left[\sqrt{a^2 + h^2} + h^2/\sqrt{a^2 + h^2} - 2h \right]$

4.20 $\mathbf{E} = -\hat{\mathbf{y}} \frac{\rho_l}{\pi\epsilon_0 R_1} \frac{R_1}{R_2} + \hat{\mathbf{y}} \frac{\rho_l}{\pi\epsilon_0 R_2} = 0$

4.23 (a) $\rho_v = y^3 z^3$

(b) $Q = 32 \text{ (C)}$

(c) $Q = 32 \text{ (C)}$

4.25 $Q = 4\pi\rho_0 a^3 \text{ (C)}$

4.26 $\mathbf{D} = \hat{\mathbf{r}} \frac{\rho_{v0}(r^2 - 1)}{2r}, \quad 1 \leq r \leq 2 \text{ m}$

$\mathbf{D} = \hat{\mathbf{r}} D_r = \hat{\mathbf{r}} \frac{3\rho_{v0}}{2r}, \quad r \geq 2 \text{ m}$

4.30 $R_1 = \frac{a}{2}, R_3 = \frac{a\sqrt{5}}{2}, V = \frac{0.55Q}{\pi\epsilon_0 a}$

4.33 (b) $\mathbf{E} = \hat{\mathbf{z}}(\rho_l a/2\epsilon_0)[z/(a^2 + z^2)^{3/2}] \text{ (V/m)}$

4.34 $V(b) = (\rho_l/4\pi\epsilon) \times \ln \left[\frac{l + \sqrt{l^2 + 4b^2}}{-l + \sqrt{l^2 + 4b^2}} \right] \text{ (V)}$

4.37 $V = \frac{\rho_l}{2\pi\epsilon_0} \left[\ln \left(\frac{a}{\sqrt{(x-a)^2 + y^2}} \right) - \ln \left(\frac{a}{\sqrt{(x+a)^2 + y^2}} \right) \right]$

4.40 $V_{AB} = -234.18 \text{ V}$

4.41 (c) $\mathbf{u}_e = -8.125\mathbf{E}/|\mathbf{E}| \text{ (m/s)}; \mathbf{u}_h = 3.125\mathbf{E}/|\mathbf{E}| \text{ (m/s)}$

4.45 $R = 4.2 \text{ (m}\Omega\text{)}$

4.48 $\theta = 61^\circ$

4.50 $Q = 3\pi\epsilon_0 \text{ (C)}$

4.52 (a) $|E|$ is maximum at $r = a$.

4.56 $W_e = 4.62 \times 10^{-9} \text{ (J)}$

4.57 (a) $C = 3.1 \text{ pF}$

4.60 (b) $C = 6.07 \text{ pF}$

4.63 $C' = \frac{\pi\epsilon_0}{\ln[(2d/a) - 1]} \text{ (C/m)}$

Chapter 5

$$5.1 \quad \mathbf{a} = -\hat{\mathbf{y}}8.44 \times 10^{18} \text{ (m/s}^2\text{)}$$

$$5.4 \quad \mathbf{T} = -\hat{\mathbf{z}}1.66 \text{ (N}\cdot\text{m)}; \text{ clockwise}$$

$$5.5 \quad (\mathbf{a}) \quad \mathbf{F} = 0$$

$$5.9 \quad \mathbf{H} = \hat{\mathbf{z}} \frac{I\theta(b-a)}{4\pi ab}$$

$$5.10 \quad \mathbf{B} = -\hat{\mathbf{z}}0.6 \text{ (mT)}$$

$$5.11 \quad I_2 = \frac{2aI_1}{2\pi Nd} = \frac{1 \times 50}{\pi \times 20 \times 2} = 0.4 \text{ A}$$

$$5.14 \quad I = 100 \text{ A}$$

$$5.16 \quad \mathbf{F} = -\hat{\mathbf{x}}0.8 \text{ (mN)}$$

$$5.18 \quad (\mathbf{a}) \quad \mathbf{H}(0, 0, h) = -\hat{\mathbf{x}} \frac{I}{\pi w} \tan^{-1} \left(\frac{w}{2h} \right) \text{ (A/m)}$$

$$5.20 \quad \mathbf{F} = \hat{\mathbf{y}}8 \times 10^{-5} \text{ N}$$

$$5.24 \quad \mathbf{J} = \hat{\mathbf{z}}9e^{-3r} \text{ A/m}^2$$

$$5.26 \quad (\mathbf{a}) \quad \mathbf{A} = \hat{\mathbf{z}} \frac{\mu_0 I}{4\pi} \ln \left(\frac{\ell + \sqrt{\ell^2 + 4r^2}}{-\ell + \sqrt{\ell^2 + 4r^2}} \right)$$

$$5.28 \quad (\mathbf{a}) \quad \mathbf{B} = \hat{\mathbf{z}}5\pi \sin \pi y - \hat{\mathbf{y}}\pi \cos \pi x \text{ (T)}$$

$$5.29 \quad (\mathbf{a}) \quad \mathbf{A} = \hat{\mathbf{z}}\mu_0 IL/(4/\pi R)$$

$$(\mathbf{b}) \quad \mathbf{H} = (IL/4\pi)[(-\hat{\mathbf{x}}\mathbf{y} + \hat{\mathbf{y}}\mathbf{x})/(x^2 + y^2 + z^2)^{3/2}]$$

$$5.30 \quad n_e = 1.5 \text{ electrons/atom}$$

$$5.33 \quad \mathbf{H}_2 = \hat{\mathbf{z}}7$$

$$5.35 \quad \vec{B}_2 = \hat{\mathbf{x}}20000 - \hat{\mathbf{y}}30000 + \hat{\mathbf{z}}12$$

$$5.37 \quad L' = (\mu/\pi) \ln[(d-a)/a] \text{ (H)}$$

$$5.40 \quad \Phi = 1.66 \times 10^{-6} \text{ (Wb)}$$

Chapter 6

6.1 At $t = 0$, current in top loop is momentarily clockwise.
At $t = t_1$, current in top loop is momentarily counterclockwise.

$$6.4 \quad (\mathbf{a}) \quad V_{\text{emf}} = 750e^{-3t} \text{ (V)}$$

$$6.7 \quad I_{\text{ind}} = 18.85 \sin(200\pi t) \text{ mA}$$

$$6.9 \quad B_0 = 0.4 \text{ (nA/m)}$$

$$6.10 \quad V_{12} = -236 \text{ (}\mu\text{V)}$$

$$6.12 \quad I = 0.3 \text{ (A)}$$

$$6.14 \quad I = 0.82 \cos(120\pi t) \text{ (}\mu\text{A)}$$

$$6.17 \quad (\mathbf{b}) \quad 888$$

$$6.18 \quad f = 5 \text{ MHz}$$

6.20 $\rho_v = (8y/\omega) \sin \omega t + C_0$, where C_0 is a constant of integration.

$$6.24 \quad k = (4\pi/30) \text{ rad/m};$$

$$\mathbf{E} = -\hat{\mathbf{z}}941 \cos(2\pi \times 10^7 t + 4\pi y/30) \text{ (V/m)}$$

$$6.26 \quad \mathbf{H}(R, \theta; t) = \hat{\boldsymbol{\phi}} (53/R) \sin \theta \cos(6\pi \times 10^8 t - 2\pi R) \text{ (}\mu\text{A/m)}$$

$$6.28 \quad (\mathbf{a}) \quad k = 20 \text{ (rad/m)}$$

Chapter 7

7.2 (a) Positive y-direction

$$(\mathbf{c}) \quad \lambda = 12.6 \text{ m}$$

$$7.3 \quad (\mathbf{a}) \quad \lambda = 31.42 \text{ m}$$

$$7.5 \quad \epsilon_r = 16$$

$$7.6 \quad (\mathbf{a}) \quad \lambda = 10 \text{ m}$$

7.14 (a) $\gamma = 73.5^\circ$ and $\chi = -8.73^\circ$

(b) Right-hand elliptically polarized

7.17 (a) Low-loss dielectric. $\alpha = 8.42 \times 10^{-11}$ Np/m,
 $\beta = 468.3$ rad/m, $\lambda = 1.34$ cm, $u_p = 1.34 \times 10^8$
 m/s, $\eta_c \approx 168.5 \Omega$

7.19 \mathbf{H} lags \mathbf{E} by 31.72°

7.21 $z = 287.82$ m

7.23 $u_p = 6.28 \times 10^4$ (m/s)

7.25 $\mathbf{H} = -\hat{\mathbf{y}}0.16 e^{-30x} \cos(2\pi \times 10^9 t - 40x - 36.85^\circ)$
 (A/m)

7.29 $(R_{ac}/R_{dc}) = 287.1$

7.34 $\mathbf{S}_{av} = \hat{\mathbf{y}}0.48$ (W/m²)

7.35 (c) $z = 23.03$ m

7.36 $u_p = 1 \times 10^8$ (m/s)

7.39 (b) $P_{av} = 0$

7.42 (a) $(w_e)_{av} = \frac{\epsilon E_0^2}{4}$

Chapter 8

8.2 (a) $\Gamma = -0.67$; $\tau = 0.33$

(b) $S = 5$

(c) $S_{av}^i = 0.52$ (W/m²); $S_{av}^r = 0.24$ (W/m²);
 $S_{av}^t = 0.28$ (W/m²)

8.3 (b) $\mathbf{S}_{av}^i = \hat{\mathbf{y}}251.34$, $\mathbf{S}_{av}^r = \hat{\mathbf{y}}10.05$,
 $\mathbf{S}_{av}^t = \hat{\mathbf{y}}241.29$ (W/m²)

8.6 (a) $\Gamma = -0.71$

8.8 $|\tilde{\mathbf{E}}_1|_{\max} = 85.5$ (V/m); $l_{\max} = 1.5$ m

8.9 $\epsilon_{r2} = \sqrt{\epsilon_{r1}\epsilon_{r3}}$; $d = c/[4f(\epsilon_{r1}\epsilon_{r3})^{1/4}]$

8.11 $Z_{in}(-d) = 0.43\eta_0 \angle -51.7^\circ$
 $|\Gamma|^2 = 0.24$

8.12 $f = 50$ MHz

8.15 $P' = (3.3 \times 10^{-3})^2 \frac{10^2}{2} \times 1.14 [1 - e^{-2 \times 44.43 \times 2 \times 10^{-3}}] =$
 1.01×10^{-4} (W/m²)

8.17 $\theta_{\min} = 35.57^\circ$

8.20 $\frac{S^t}{S^i} = 0.85$

8.22 $d = 15$ cm

8.25 $d = 68.42$ cm

8.26 $f_p = 166.33$ (Mb/s)

8.27 (b) $\theta_i = 36.87^\circ$

8.29 (a) $\theta_i = 33.7^\circ$

8.30 $\theta_t = 18.44^\circ$

8.37 (a) 9.4%

8.39 $a = 2$ cm; $b = 1.6$ cm

8.41 Any one of the first four modes.

8.43 570 Ω (empty); 290 Ω (filled)

8.45 $\theta'_{20} = 43.16^\circ$

8.46 (a) $Q = 8367$

Chapter 9

9.2 $S_{\max} = 47.5$ (μ W/m²)

9.4 (a) Direction of maximum radiation is a circular cone
 120° wide, centered around the +z axis.

(b) $D = 4 = 6$ dB

(c) $\Omega_p = \pi$ (sr) = 3.14 (sr)

(d) $\beta = 120^\circ$

9.6 (b) $G = -3.5$ dB

9.9 $S_{\max} = 6 \times 10^{-5}$ (W/m²)

9.12 $D = 40.11$ dB

9.14 $S = 1.46$

9.15 (a) $\tilde{\mathbf{E}}(R, \theta, \phi) = \hat{\boldsymbol{\theta}} \tilde{E}_\theta = \hat{\boldsymbol{\theta}} j \frac{I_0 l k \eta_0}{8\pi} \left(\frac{e^{-jkR}}{R} \right) \sin \theta$
(V/m)

9.17 (a) $\theta_{\max_1} = 42.6^\circ, \quad \theta_{\max_2} = 137.4^\circ$

9.20 (a) $\theta_{\max_1} = 90^\circ, \quad \theta_{\max_2} = 270^\circ$

(b) $S_{\max} = \frac{60 I_0^2}{\pi R^2}$

(c) $F(\theta) = \frac{1}{4} \left[\frac{\cos(\pi \cos \theta) + 1}{\sin \theta} \right]^2$

9.23 $P_t = 25.9 \text{ (mW)}$

9.27 (a) $P_{\text{rec}} = 3.6 \times 10^{-6} \text{ W}$

9.31 $\beta_{\text{null}} = 5.73^\circ$

9.32 $D = 39.96 \text{ dB}$

9.34 (a) $\beta_e = 1.8^\circ; \quad \beta_a = 0.18^\circ$

(b) $\Delta y = \beta_a R = 0.96 \text{ m}$

9.37 (a) $F_a(\theta) = 4 \cos^2 \left[\frac{\pi}{8} (4 \cos \theta + 1) \right]$

9.39 $d/\lambda = 1.414$

9.44 $F_a(\theta) = [6 + 8 \cos(\pi \cos \theta) + 2 \cos(2\pi \cos \theta)]^2$

9.47 $\delta = -2.72 \text{ (rad)} = -155.9^\circ$

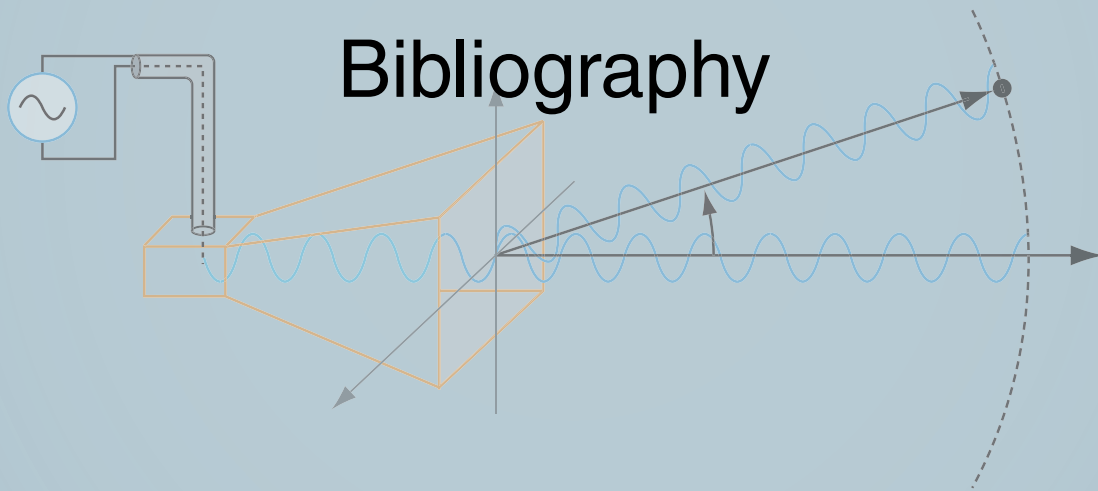
Chapter 10

10.1 $T = 89.72 \text{ minutes}$

10.3 $133.3 \approx 133 \text{ channels}$

10.6 $(f_p)_{\max} = 150 \text{ kHz}$

10.7 $R_{\max} = 4.84 \text{ km}$



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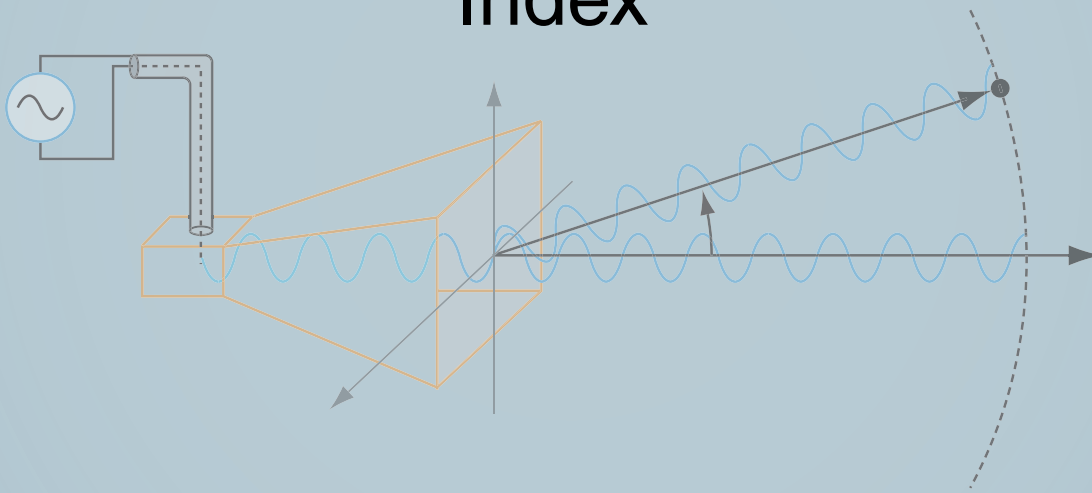
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FUNDAMENTAL PHYSICAL CONSTANTS

CONSTANT	SYMBOL	VALUE
speed of light in vacuum	c	$2.998 \times 10^8 \approx 3 \times 10^8$ m/s
gravitational constant	G	6.67×10^{-11} N·m ² /kg ²
Boltzmann's constant	K	1.38×10^{-23} J/K
elementary charge	e	1.60×10^{-19} C
permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \approx \frac{1}{36\pi} \times 10^{-9}$ F/m
permeability of free space	μ_0	$4\pi \times 10^{-7}$ H/m
electron mass	m_e	9.11×10^{-31} kg
proton mass	m_p	1.67×10^{-27} kg
Planck's constant	h	6.63×10^{-34} J·s
intrinsic impedance of free space	η_0	$376.7 \approx 120\pi$ Ω

FUNDAMENTAL SI UNITS

DIMENSION	UNIT	SYMBOL
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous Intensity	candela	cd

MULTIPLE & SUBMULTIPLE PREFIXES

PREFIX	SYMBOL	MAGNITUDE	PREFIX	SYMBOL	MAGNITUDE
exa	E	10^{18}	milli	m	10^{-3}
peta	P	10^{15}	micro	μ	10^{-6}
tera	T	10^{12}	nano	n	10^{-9}
giga	G	10^9	pico	p	10^{-12}
mega	M	10^6	femto	f	10^{-15}
kilo	k	10^3	atto	a	10^{-18}

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GRADIENT, DIVERGENCE, CURL, & LAPLACIAN OPERATORS

CARTESIAN (RECTANGULAR) COORDINATES (x, y, z)

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

$$\nabla \cdot \mathbf{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

$$\nabla \times \mathbf{A} = \begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix} = \hat{\mathbf{x}} \left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right) + \hat{\mathbf{y}} \left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right) + \hat{\mathbf{z}} \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right)$$

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

CYLINDRICAL COORDINATES (r, ϕ, z)

$$\nabla V = \hat{\mathbf{r}} \frac{\partial V}{\partial r} + \hat{\boldsymbol{\phi}} \frac{1}{r} \frac{\partial V}{\partial \phi} + \hat{\mathbf{z}} \frac{\partial V}{\partial z}$$

$$\nabla \cdot \mathbf{A} = \frac{1}{r} \frac{\partial}{\partial r} (r A_r) + \frac{1}{r} \frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z}$$

$$\nabla \times \mathbf{A} = \frac{1}{r} \begin{vmatrix} \hat{\mathbf{r}} & \hat{\boldsymbol{\phi}} r & \hat{\mathbf{z}} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ A_r & r A_\phi & A_z \end{vmatrix} = \hat{\mathbf{r}} \left(\frac{1}{r} \frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z} \right) + \hat{\boldsymbol{\phi}} \left(\frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r} \right) + \hat{\mathbf{z}} \frac{1}{r} \left[\frac{\partial}{\partial r} (r A_\phi) - \frac{\partial A_r}{\partial \phi} \right]$$

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

SPHERICAL COORDINATES (R, θ, ϕ)

$$\nabla V = \hat{\mathbf{R}} \frac{\partial V}{\partial R} + \hat{\boldsymbol{\theta}} \frac{1}{R} \frac{\partial V}{\partial \theta} + \hat{\boldsymbol{\phi}} \frac{1}{R \sin \theta} \frac{\partial V}{\partial \phi}$$

$$\nabla \cdot \mathbf{A} = \frac{1}{R^2} \frac{\partial}{\partial R} (R^2 A_R) + \frac{1}{R \sin \theta} \frac{\partial}{\partial \theta} (A_\theta \sin \theta) + \frac{1}{R \sin \theta} \frac{\partial A_\phi}{\partial \phi}$$

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

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

SOME USEFUL VECTOR IDENTITIES

$$\mathbf{A} \cdot \mathbf{B} = AB \cos \theta_{AB} \quad \text{Scalar (or dot) product}$$

$$\mathbf{A} \times \mathbf{B} = \hat{\mathbf{n}} AB \sin \theta_{AB} \quad \text{Vector (or cross) product, } \hat{\mathbf{n}} \text{ normal to plane containing } \mathbf{A} \text{ and } \mathbf{B}$$

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

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

$$\nabla(U + V) = \nabla U + \nabla V$$

$$\nabla(UV) = U\nabla V + V\nabla U$$

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

$$\nabla \cdot (U\mathbf{A}) = U\nabla \cdot \mathbf{A} + \mathbf{A} \cdot \nabla U$$

$$\nabla \times (U\mathbf{A}) = U\nabla \times \mathbf{A} + \nabla U \times \mathbf{A}$$

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

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

$$\nabla \cdot (\nabla \times \mathbf{A}) = 0$$

$$\nabla \times \nabla V = 0$$

$$\nabla \cdot \nabla V = \nabla^2 V$$

$$\nabla \times \nabla \times \mathbf{A} = \nabla(\nabla \cdot \mathbf{A}) - \nabla^2 \mathbf{A}$$

$$\int_{\mathcal{V}} (\nabla \cdot \mathbf{A}) d\mathcal{V} = \oint_S \mathbf{A} \cdot d\mathbf{s} \quad \text{Divergence theorem (} S \text{ encloses } \mathcal{V} \text{)}$$

$$\int_S (\nabla \times \mathbf{A}) \cdot d\mathbf{s} = \oint_C \mathbf{A} \cdot d\mathbf{l} \quad \text{Stokes's theorem (} S \text{ bounded by } C \text{)}$$