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CHAPTER 1

Prob. 1.1

$$\begin{aligned}
 \text{(a)} \quad \nabla \times \nabla \Phi &= \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \frac{\partial \Phi}{\partial x} & \frac{\partial \Phi}{\partial y} & \frac{\partial \Phi}{\partial z} \end{bmatrix} \\
 &= \left(\frac{\partial^2 \Phi}{\partial y \partial z} - \frac{\partial^2 \Phi}{\partial z \partial y} \right) \mathbf{a}_x + \left(\frac{\partial^2 \Phi}{\partial x \partial z} - \frac{\partial^2 \Phi}{\partial z \partial x} \right) \mathbf{a}_y + \left(\frac{\partial^2 \Phi}{\partial x \partial y} - \frac{\partial^2 \Phi}{\partial y \partial x} \right) \mathbf{a}_z = 0
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad \nabla \nabla \times \mathbf{F} &= \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) \cdot \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ F_x & F_y & F_z \end{bmatrix} \\
 &= \frac{\partial}{\partial x} \left(\frac{\partial F_x}{\partial y} - \frac{\partial F_y}{\partial x} \right) - \frac{\partial}{\partial y} \left(\frac{\partial F_z}{\partial x} - \frac{\partial F_x}{\partial z} \right) + \frac{\partial}{\partial z} \left(\frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y} \right) \\
 &= \frac{\partial^2 F_z}{\partial x \partial y} - \frac{\partial^2 F_y}{\partial x \partial z} - \frac{\partial^2 F_z}{\partial y \partial x} + \frac{\partial^2 F_x}{\partial y \partial z} + \frac{\partial^2 F_y}{\partial z \partial x} - \frac{\partial^2 F_x}{\partial z \partial y} = 0
 \end{aligned}$$

$$\begin{aligned}
 \text{(c)} \quad \nabla (\nabla \cdot \mathbf{F}) - \nabla^2 \mathbf{F} &= \left[\frac{\partial}{\partial x} \left(\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z} \right) - \frac{\partial^2 F_x}{\partial x^2} - \frac{\partial^2 F_x}{\partial y^2} - \frac{\partial^2 F_x}{\partial z^2} \right] \mathbf{a}_x \\
 &+ \left[\frac{\partial}{\partial y} \left(\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z} \right) - \frac{\partial^2 F_y}{\partial x^2} - \frac{\partial^2 F_y}{\partial y^2} - \frac{\partial^2 F_y}{\partial z^2} \right] \mathbf{a}_y \\
 &+ \left[\frac{\partial}{\partial z} \left(\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z} \right) - \frac{\partial^2 F_z}{\partial x^2} - \frac{\partial^2 F_z}{\partial y^2} - \frac{\partial^2 F_z}{\partial z^2} \right] \mathbf{a}_z \\
 &= \left[\frac{\partial}{\partial y} \left(\frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y} \right) - \frac{\partial}{\partial z} \left(\frac{\partial F_x}{\partial z} - \frac{\partial F_z}{\partial x} \right) \right] \mathbf{a}_x \\
 &+ \left[\frac{\partial}{\partial z} \left(\frac{\partial F_x}{\partial y} - \frac{\partial F_y}{\partial z} \right) - \frac{\partial}{\partial x} \left(\frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y} \right) \right] \mathbf{a}_y \\
 &+ \left[\frac{\partial}{\partial x} \left(\frac{\partial F_x}{\partial z} - \frac{\partial F_z}{\partial x} \right) - \frac{\partial}{\partial y} \left(\frac{\partial F_z}{\partial y} - \frac{\partial F_y}{\partial z} \right) \right] \mathbf{a}_z \\
 &= \nabla \times \nabla \times \mathbf{F}
 \end{aligned}$$

Prob. 1.2 Let $\mathbf{A} = U \nabla V$ and apply Stokes' theorem.

$$\begin{aligned}
 \oint_L U \nabla V \cdot d\mathbf{l} &= \int_S \nabla \times (U \nabla V) \cdot d\mathbf{S} \\
 &= \int_S (\nabla U \times \nabla V) \cdot d\mathbf{S} + \int_S U (\nabla \times \nabla V) \cdot d\mathbf{S}
 \end{aligned}$$

Since $\nabla \times \nabla V = 0$,

$$\oint_L U \nabla V \cdot d\mathbf{l} = \int_S (\nabla U \times \nabla V) \cdot d\mathbf{S}$$

Similarly, we can show that

$$\oint_L V \nabla U \cdot d\mathbf{l} = \int_S (\nabla V \times \nabla U) \cdot d\mathbf{S} = - \int_S (\nabla U \times \nabla V) \cdot d\mathbf{S}$$

Thus,

$$\oint_L U \nabla V \cdot d\mathbf{l} = - \oint_L V \nabla U \cdot d\mathbf{l}$$

as required.

Prob. 1.3

Using divergence theorem,

$$\int_S (U \nabla V) \cdot d\mathbf{S} = \int_v \nabla \cdot (U \nabla V) dv$$

But $\nabla \cdot (UA) = U \nabla \cdot A + A \cdot \nabla U$, where $A = \nabla V$

$$\begin{aligned} \int_S (U \nabla V) \cdot d\mathbf{S} &= \int_v (U \nabla \cdot \nabla V + \nabla V \cdot \nabla U) dv \\ &= \int_v (U \nabla^2 V + \nabla U \cdot \nabla V) dv \end{aligned}$$

Prob. 1.4 If $\mathbf{J} = 0 = \rho_v$, then Maxwell's equations become

$$\nabla \cdot \mathbf{B} = 0 \quad (1)$$

$$\nabla \cdot \mathbf{D} = 0 \quad (2)$$

$$\nabla \times \mathbf{E} = - \frac{\partial \mathbf{B}}{\partial t} \quad (3)$$

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} \quad (4)$$

Since $\nabla \cdot \nabla \times \mathbf{A} = 0$ for any vector field \mathbf{A} ,

$$\nabla \cdot \nabla \times \mathbf{E} = - \frac{\partial \nabla \cdot \mathbf{B}}{\partial t} = 0$$

$$\nabla \cdot \nabla \times \mathbf{H} = \frac{\partial \nabla \cdot \mathbf{D}}{\partial t} = 0$$

Showing that (1) and (2) are incorporated in (3) and (4). Thus Maxwell's equations can be reduced to curl equations (3) and (4).

Prob. 1.5 If $\mathbf{J} \neq 0 \neq \rho_v$,

$$\nabla \cdot \epsilon \mathbf{E} = \rho_v$$

$$\nabla \cdot \mu \mathbf{H} = 0$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \epsilon \frac{\partial \mathbf{E}}{\partial t}$$

$$\nabla \times \nabla \times \mathbf{E} = -\mu \frac{\partial}{\partial t} \nabla \times \mathbf{H} = -\mu \frac{\partial \mathbf{J}}{\partial t} - \mu \epsilon \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E} = -\mu \frac{\partial \mathbf{J}}{\partial t} - \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\nabla^2 \mathbf{E} - \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2} = \nabla(\rho_v / \epsilon) + \mu \frac{\partial \mathbf{J}}{\partial t}$$

Similarly,

$$\nabla \times \nabla \times \mathbf{H} = \nabla \times \mathbf{J} + \epsilon \frac{\partial}{\partial t} \nabla \times \mathbf{E}$$

$$\nabla(\nabla \cdot \mathbf{H}) - \nabla^2 \mathbf{H} = \nabla \times \mathbf{J} - \mu \epsilon \frac{\partial^2 \mathbf{H}}{\partial t^2}$$

or

$$\nabla^2 \mathbf{H} - \frac{1}{c^2} \frac{\partial^2 \mathbf{H}}{\partial t^2} = -\nabla \times \mathbf{J}$$

It is assumed that the medium is free space so that the medium is homogeneous and

$$u = \frac{1}{\sqrt{\mu \epsilon}} = c.$$

Prob. 1.6

(a)

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\nabla \times \nabla \times \mathbf{H} = \nabla \times \mathbf{J} + \frac{\partial}{\partial t} (\nabla \times \mathbf{D}) = \nabla \times \mathbf{J} + \epsilon \frac{\partial}{\partial t} (\nabla \times \mathbf{E}) = \nabla \times \mathbf{J} - \frac{\partial}{\partial t} \left(\mu \frac{\partial \mathbf{H}}{\partial t} \right)$$

$$\nabla \times \nabla \times \mathbf{H} + \mu \epsilon \frac{\partial^2 \mathbf{H}}{\partial t^2} = \nabla \times \mathbf{J}$$

$$(b) \nabla \times \nabla \times \mathbf{E} = -\mu \frac{\partial}{\partial t} (\nabla \times \mathbf{H}) = -\mu \frac{\partial}{\partial t} \left(\mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \right) = -\mu \frac{\partial \mathbf{J}}{\partial t} - \mu \epsilon \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\nabla \times \nabla \times \mathbf{E} + \mu \epsilon \frac{\partial^2 \mathbf{E}}{\partial t^2} = -\mu \frac{\partial \mathbf{J}}{\partial t}$$

Prob. 1.7

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \quad (1)$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \quad (2)$$

Dotting both sides of (2) with \mathbf{E} gives

$$\mathbf{E} \cdot (\nabla \times \mathbf{H}) = \mathbf{E} \cdot \mathbf{J} + \mathbf{E} \cdot \frac{\partial \mathbf{D}}{\partial t} \quad (3)$$

But for any arbitrary vectors \mathbf{A} and \mathbf{B} ,

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

Applying this to the left-hand side of (3) by letting $\mathbf{A} \equiv \mathbf{H}$ and $\mathbf{B} \equiv \mathbf{E}$, we get

$$\mathbf{H} \cdot (\nabla \times \mathbf{E}) + \nabla \cdot (\mathbf{H} \times \mathbf{E}) = \mathbf{E} \cdot \mathbf{J} + \frac{1}{2} \frac{\partial}{\partial t} (\mathbf{D} \cdot \mathbf{E}) \quad (4)$$

From (1),

$$\mathbf{H} \cdot (\nabla \times \mathbf{E}) = \mathbf{H} \cdot \left(-\frac{\partial \mathbf{B}}{\partial t} \right) = -\frac{1}{2} \frac{\partial}{\partial t} (\mathbf{B} \cdot \mathbf{H})$$

Substituting this into (4) gives

$$-\frac{1}{2} \frac{\partial}{\partial t} (\mathbf{B} \cdot \mathbf{H}) - \nabla \cdot (\mathbf{E} \times \mathbf{H}) = \mathbf{J} \cdot \mathbf{E} + \frac{1}{2} \frac{\partial}{\partial t} (\mathbf{D} \cdot \mathbf{E})$$

Rearranging terms and then taking the volume integral of both sides,

$$\int_v \nabla \cdot (\mathbf{E} \times \mathbf{H}) dv = -\frac{1}{2} \frac{\partial}{\partial t} \int_v (\mathbf{E} \cdot \mathbf{D} + \mathbf{H} \cdot \mathbf{B}) dv - \int_v \mathbf{J} \cdot \mathbf{E} dv$$

Using the divergence theorem, we get

$$\oint_S (\mathbf{E} \times \mathbf{H}) \cdot d\mathbf{S} = -\frac{\partial W}{\partial t} - \int_v \mathbf{J} \cdot \mathbf{E} dv$$

Or

$$\frac{\partial W}{\partial t} = -\oint_S (\mathbf{E} \times \mathbf{H}) \cdot d\mathbf{S} - \int_v \mathbf{E} \cdot \mathbf{J} dv$$

as required.

Prob. 1.8

$$\nabla \cdot \mathbf{E} = 0, \quad \nabla \cdot \mathbf{H} = 0$$

$$\begin{aligned} \nabla \times \mathbf{E} &= \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_x & E_y & 0 \end{vmatrix} = -\frac{\partial E_y}{\partial z} \mathbf{a}_x + \frac{\partial E_x}{\partial z} \mathbf{a}_y \\ &= -10k \sin(\omega t + kz) \mathbf{a}_x - 20k \cos(\omega t - kz) \mathbf{a}_y \end{aligned}$$

$$\begin{aligned}\mathbf{H} &= -\frac{1}{\mu_o} \int \nabla \times \mathbf{E} dt \\ &= \frac{k}{\omega \mu_o} \left[-10 \cos(\omega t - kz) \mathbf{a}_x + 20 \sin(\omega t - kz) \mathbf{a}_y \right]\end{aligned}$$

which is the given \mathbf{H} . Since all of Maxwell's equations are satisfied by the fields, they are genuine EM fields.

Prob. 1.9

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \quad \rightarrow \quad \frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\mu_o \epsilon_o} \nabla \times \epsilon_o \mathbf{E}$$

$$\begin{aligned}\frac{\partial \mathbf{H}}{\partial t} &= -\frac{1}{\mu_o \epsilon_o} \nabla \times \mathbf{D} = -\frac{1}{\mu_o \epsilon_o} \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ D_x(z,t) & 0 & 0 \end{vmatrix} \\ &= -\frac{1}{\mu_o \epsilon_o} \frac{\partial D_x}{\partial z} \mathbf{a}_y = \frac{\beta}{\mu_o \epsilon_o} D_o \sin(\omega t + \beta z) \mathbf{a}_y \\ \mathbf{H} &= -\frac{D_o}{\beta} \cos(\omega t - \beta z) \mathbf{a}_y\end{aligned}$$

Prob. 1.10

$$\begin{aligned}\nabla \times \mathbf{H}_s &= j\omega \mathbf{E}_s = \frac{1}{\rho} \frac{d}{d\rho} (\rho H_\phi) \mathbf{a}_z \\ &= \frac{H_o}{\rho} \left(\frac{1}{\rho} \rho^{1/2} e^{-j\beta\rho} - j\beta \rho^{1/2} e^{-j\beta\rho} \right) \mathbf{a}_z \\ &= \frac{H_o}{\sqrt{\rho}} \left(\frac{1}{\rho^2} - j\beta \right) e^{-j\beta\rho} \mathbf{a}_z \\ \mathbf{E}_s &= \frac{\nabla \times \mathbf{H}_s}{j\omega \epsilon} = \frac{1}{j\omega \epsilon} \frac{H_o}{\sqrt{\rho}} \left(\frac{1}{\rho^2} - j\beta \right) e^{-j\beta\rho} \mathbf{a}_z\end{aligned}$$

Prob. 1.11

It is evident that $\nabla \cdot \mathbf{E} = 0$ and $\nabla \cdot \mathbf{H} = 0$ are satisfied.

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad \longrightarrow \quad \nabla \times \mathbf{E}_s = -j\omega \mu \mathbf{H}_s$$

$$\nabla \times \mathbf{E}_s = \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_o e^{-j\beta z} & 0 & 0 \end{vmatrix} = -j\beta E_o e^{-j\beta z} \mathbf{a}_y$$

$$\text{i.e.} \quad -j\omega \mu \frac{E_o}{\eta} e^{-j\beta z} \mathbf{a}_y = -j\beta E_o e^{-j\beta z} \mathbf{a}_y$$

$$\beta = \frac{\omega\mu}{\eta} \quad (1)$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \longrightarrow \nabla \times \mathbf{H}_s = (\sigma + j\omega\varepsilon)\mathbf{E}_s$$

$$\nabla \times \mathbf{H}_s = \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & \frac{E_o}{\eta} e^{-j\beta z} & 0 \end{vmatrix} = \frac{j\beta E_o}{\eta} e^{-j\beta z} \mathbf{a}_x$$

$$(\sigma + j\omega\varepsilon)E_o e^{-j\beta z} \mathbf{a}_x = \frac{j\beta E_o}{\eta} e^{-j\beta z} \mathbf{a}_x$$

$$\beta = -j\eta(\sigma + j\omega\varepsilon) \quad (2)$$

From (1) and (2),

$$\frac{\omega\mu}{\eta} = -j\eta(\sigma + j\omega\varepsilon) \longrightarrow \eta^2 = \frac{j\omega\mu}{\sigma + j\omega\varepsilon}$$

Thus,

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}, \quad \beta = \frac{\omega\mu}{\eta}$$

Prob. 1.12

The surface current density is

$$\mathbf{K} = \mathbf{a}_n \times \mathbf{H} = \mathbf{a}_n \times (H_x, 0, H_z)$$

At $x = 0$, $\mathbf{a}_n = \mathbf{a}_x$, $\mathbf{K} = H_z(0, y, z, t)\mathbf{a}_y$

i.e. $\mathbf{K} = H_o \cos(\omega t - \beta z)\mathbf{a}_y$

At $x = a$, $\mathbf{a}_n = -\mathbf{a}_x$

$$\mathbf{K} = -H_z(a, y, z, t)\mathbf{a}_y = -H_o \cos(\pi) \cos(\omega t - \beta z)\mathbf{a}_y$$

i.e. $\mathbf{K} = H_o \cos(\omega t - \beta z)\mathbf{a}_y$

At $y = 0$, $\mathbf{a}_n = \mathbf{a}_y$

$$\begin{aligned} \mathbf{K} &= -H_z(x, 0, z, t)\mathbf{a}_x + H_x(x, 0, z, t)\mathbf{a}_z \\ &= -H_o \cos(\pi x/a) \cos(\omega t - \beta z)\mathbf{a}_x - \frac{\beta a}{\pi} H_o \sin(\pi x/a) \sin(\omega t - \beta z)\mathbf{a}_z \end{aligned}$$

At $y = b$, $\mathbf{a}_n = -\mathbf{a}_y$

$$\begin{aligned} \mathbf{K} &= -\mathbf{a}_y \times (H_x, 0, H_z) = H_x(x, b, z, t)\mathbf{a}_z - H_z(x, b, z, t)\mathbf{a}_x \\ &= H_o \cos(\pi x/a) \cos(\omega t - \beta z)\mathbf{a}_x - \frac{\beta a}{\pi} H_o \sin(\pi x/a) \sin(\omega t - \beta z)\mathbf{a}_z \end{aligned}$$

Prob. 1.13

$$(a) \quad \nabla^2 \mathbf{E} = \mu_o \epsilon_o \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\text{For } \mathbf{E}, \quad \nabla^2 \mathbf{E} = \frac{\partial^2}{\partial z^2} \cos(\omega t - \beta z) \mathbf{a}_x = \frac{\partial}{\partial z} [\beta \sin(\omega t - \beta z) \mathbf{a}_x] = -\beta^2 \cos(\omega t - \beta z) \mathbf{a}_x$$

$$\mu_o \epsilon_o \frac{\partial^2 \mathbf{E}}{\partial t^2} = -\omega^2 \mu_o \epsilon_o \cos(\omega t - \beta z) \mathbf{a}_x$$

$$\text{Thus,} \quad -\beta^2 = -\omega^2 \mu_o \epsilon_o \quad \longrightarrow \quad \beta = \omega \sqrt{\mu_o \epsilon_o}$$

(b)

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \quad \longrightarrow \quad \mathbf{H} = -\mu_o \int \nabla \times \mathbf{E} dt$$

$$\nabla \times \mathbf{E} = \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \cos(\omega t - \beta z) & 0 & 0 \end{vmatrix} = \beta \sin(\omega t - \beta z) \mathbf{a}_y$$

$$\mathbf{H} = -\mu_o \int \beta \sin(\omega t - \beta z) dt \mathbf{a}_y = \frac{\mu_o \beta}{\omega} \cos(\omega t - \beta z) \mathbf{a}_y$$

Prob. 1.14

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} = \epsilon \frac{\partial \mathbf{E}}{\partial t} \quad \rightarrow \quad \nabla \times \mathbf{H}_s = j\omega \epsilon \mathbf{E}_s$$

$$\begin{aligned} \nabla \times \mathbf{H}_s &= \frac{1}{r \sin \theta} \frac{IL}{4\pi r} (2 \sin \theta \cos \theta) \left(\frac{1}{r} + j\beta \right) e^{j\beta r} \mathbf{a}_r \\ &\quad - \frac{IL \sin \theta}{4\pi r} \left[-j\beta \left(\frac{1}{r} + j\beta \right) e^{j\beta r} - \frac{1}{r^2} e^{j\beta r} \right] \mathbf{a}_\theta \end{aligned}$$

$$\mathbf{E}_s = \frac{IL}{4\pi r j\omega \epsilon} e^{j\beta r} \left[2 \cos \theta \left(\frac{1}{r^2} + \frac{j\beta}{r^2} \right) \mathbf{a}_r - \sin \theta \left(\beta^2 - \frac{j\beta}{r} - \frac{1}{r^2} \right) \mathbf{a}_\theta \right]$$

Prob. 1.15

$$\begin{aligned} E_s &= \frac{20(e^{jk_x x} - e^{-jk_x x})}{2j} \frac{(e^{jk_y y} - e^{-jk_y y})}{2j} \\ &= j5 \left[e^{j(k_x x + k_y y)} + e^{j(k_x x - k_y y)} - e^{j(k_x x - k_y y)} - e^{-j(k_x x + k_y y)} \right] \end{aligned}$$

which consists of four plane waves.

$$\nabla \times \mathbf{E}_s = -j\omega \mu_o \mathbf{H}_s$$

Or

$$\begin{aligned}\mathbf{H}_s &= \frac{j}{\omega\mu_o} \nabla \times \mathbf{E}_s = \frac{j}{\omega\mu_o} \begin{vmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & 0 & E_{sz}(x, y) \end{vmatrix} \\ &= \frac{j}{\omega\mu_o} \left(\frac{\partial E_{sz}}{\partial y} \mathbf{a}_x - \frac{\partial E_{sz}}{\partial x} \mathbf{a}_y \right) \\ &= -\frac{20}{\omega\mu_o} \left[k_y \sin(k_x x) \sin(k_y y) \mathbf{a}_x + k_x \cos(k_x x) \cos(k_y y) \mathbf{a}_y \right]\end{aligned}$$

Prob. 1.16

- (a) $I = \text{Re}(I_s e^{j\omega t}) = \sin \pi x \cos \pi y \cos(\omega t - z)$
 (b) $V = \text{Re}(20e^{-j2x} e^{-j90^\circ} e^{j\omega t} - 10e^{-j4x} e^{j\omega t})$
 $V_s = 20e^{-j2x} e^{-j90^\circ} - 10e^{-j4x} = -j20e^{-j2x} - 10e^{-j4x}$

Prob. 1.17

- (a) $\mathbf{A} = \text{Re}(A_s e^{j\omega t}) = \cos(\omega t - 2z) \mathbf{a}_x - \sin(\omega t - 2z) \mathbf{a}_y$
 (b) $\mathbf{B} = \text{Re}(B_s e^{j\omega t}) = -10 \sin x \sin \omega t \mathbf{a}_x - 5 \cos(\omega t - 12z - 45^\circ) \mathbf{a}_z$
 (c) $C = \text{Re}(C_s e^{j\omega t}) = 2 \cos 2x \sin(\omega t - 3x) + e^{3x} \cos(\omega t - 4x)$

Prob. 1.18 Assuming the time factor $e^{j\omega t}$, equation

$$\nabla^2 \mathbf{E} - \mu\epsilon \frac{\partial^2 \mathbf{E}}{\partial t^2} = \mu \frac{\partial \mathbf{J}}{\partial t}$$

becomes

$$\nabla^2 \mathbf{E}_s + \omega^2 \mu\epsilon \mathbf{E}_s = j\omega\mu\sigma \mathbf{E}_s$$

or

$$\nabla^2 \mathbf{E}_s - j\omega\mu(\sigma + j\omega\epsilon) \mathbf{E}_s = 0$$

For conducting medium, $\sigma \gg \omega\epsilon$ so that

$$\nabla^2 \mathbf{E}_s - j\omega\mu\sigma \mathbf{E}_s = 0$$

Prob. 1.19

Let $\mathbf{A} = \text{Re}(A_s e^{j\omega t})$, $V = \text{Re}(V_s e^{j\omega t})$, etc

$$\frac{\partial \mathbf{A}}{\partial t} \rightarrow j\omega \mathbf{A}_s$$

$$\frac{\partial^2 \mathbf{A}}{\partial t^2} \rightarrow -\omega^2 \mathbf{A}_s$$

Similarly,

$$\frac{\partial^2 V}{\partial t^2} \rightarrow -\omega^2 V_s$$

Substituting these into eqs. (1.42) and (1.43), we obtain

$$\nabla^2 V_s + \omega^2 \mu \epsilon V_s = -\frac{\rho_{vs}}{\epsilon}$$

$$\nabla^2 \mathbf{A}_s + \omega^2 \mu \epsilon \mathbf{A}_s = -\mu \mathbf{J}_s$$

But $k^2 = \omega^2 \mu \epsilon$. Thus,

$$\nabla^2 V_s + k^2 V_s = -\frac{\rho_{vs}}{\epsilon}$$

$$\nabla^2 \mathbf{A}_s + k^2 \mathbf{A}_s = -\mu \mathbf{J}_s$$

Prob. 1.20

$$(a) \quad a = 1, \quad b = 2, \quad c = 0, \quad b^2 - 4ac = -16$$

Hence, it is elliptic.

$$(b) \quad a = y^2 + 1, \quad b = 0, \quad c = x^2 + 1, \\ b^2 - 4ac = -4(x^2 + 1)(y^2 + 1) < 0$$

Hence it is elliptic.

$$(c) \quad a = 1, \quad b = -2 \cos x, \quad c = -(3 + \sin^2 x) \\ b^2 - 4ac = 4 \cos^2 x + 12 + 4 \sin^2 x = 16 > 0$$

Hence it is hyperbolic.

$$(d) \quad a = x^2, \quad b = -2xy, \quad c = y^2, \\ b^2 - 4ac = 4x^2 y^2 - 4x^2 y^2 = 0$$

Hence it is parabolic.

Prob. 1.21

$$(a) \quad a = \alpha, \quad b = 0, \quad c = 0, \quad b^2 - 4ac = 0; \text{ i.e. it is parabolic.}$$

$$(b) \quad a = 1, \quad b = 0, \quad c = 0, \quad b^2 - 4ac = -4; \text{ i.e. it is elliptic.}$$

$$(c) \quad \left(\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} \right)^2 = 0$$

$$a = 1, \quad b = 0, \quad c = 1, \quad b^2 - 4ac = -4; \text{ i.e. it is elliptic.}$$