Cartesian		*Cylindrical*		*Spherical*
x	=	$\mathrm{r}\cos\phi$	=	$r\sin\theta\cos\phi$
y	=	$\mathrm{r}\sin\phi$	=	$r\sin\theta\sin\phi$
z	=	z	=	$r\cos\theta$
$\mathbf{i}_x$	=	$\cos\phi\mathbf{i}_{\mathrm{r}}-\sin\phi\mathbf{i}_\phi$	=	$\sin\theta\cos\phi\mathbf{i}_r+\cos\theta\cos\phi\mathbf{i}_\theta$ $-\sin\phi\mathbf{i}_\phi$
$\mathbf{i}_y$	=	$\sin\phi\mathbf{i}_{\mathrm{r}}+\cos\phi\mathbf{i}_\phi$	=	$\sin\theta\sin\phi\mathbf{i}_r+\cos\theta\sin\phi\mathbf{i}_\theta$ $+\cos\phi\mathbf{i}_\phi$
$\mathbf{i}_z$	=	$\mathbf{i}_z$	=	$\cos\theta\mathbf{i}_r-\sin\theta\mathbf{i}_\theta$

Cylindrical		*Cartesian*		*Spherical*
r	=	$\sqrt{x^2+y^2}$	=	$r\sin\theta$
ϕ	=	$\tan^{-1}y/x$	=	ϕ
z	=	z	=	$r\cos\theta$
$\mathbf{i}_{\mathrm{r}}$	=	$\cos\phi\mathbf{i}_x+\sin\phi\mathbf{i}_y$	=	$\sin\theta\mathbf{i}_r+\cos\theta\mathbf{i}_\theta$
$\mathbf{i}_\phi$	=	$-\sin\phi\mathbf{i}_x+\cos\phi\mathbf{i}_y$	=	$\mathbf{i}_\phi$
$\mathbf{i}_z$	=	$\mathbf{i}_z$	=	$\cos\theta\mathbf{i}_r-\sin\theta\mathbf{i}_\theta$

Spherical		*Cartesian*		*Cylindrical*
r	=	$\sqrt{x^2+y^2+z^2}$	=	$\sqrt{\mathrm{r}^2+z^2}$
θ	=	$\cos^{-1}\frac{z}{\sqrt{x^2+y^2+z^2}}$	=	$\cos^{-1}\frac{z}{\sqrt{\mathrm{r}^2+z^2}}$
ϕ	=	$\cot^{-1}x/y$	=	ϕ
$\mathbf{i}_r$	=	$\sin\theta\cos\phi\mathbf{i}_x+\sin\theta\sin\phi\mathbf{i}_y$ $+\cos\theta\mathbf{i}_z$	=	$\sin\theta\mathbf{i}_{\mathrm{r}}+\cos\theta\mathbf{i}_z$
$\mathbf{i}_\theta$	=	$\cos\theta\cos\phi\mathbf{i}_x+\cos\theta\sin\phi\mathbf{i}_y$ $-\sin\theta\mathbf{i}_z$	=	$\cos\theta\mathbf{i}_{\mathrm{r}}-\sin\theta\mathbf{i}_z$
$\mathbf{i}_\phi$	=	$-\sin\phi\mathbf{i}_x+\cos\phi\mathbf{i}_y$	=	$\mathbf{i}_\phi$

Geometric relations between coordinates and unit vectors for Cartesian, cylindrical, and spherical coordinate systems.

Cartesian Coordinates (x, y, z)

$$\nabla f = \frac{\partial f}{\partial x}\mathbf{i}_x + \frac{\partial f}{\partial y}\mathbf{i}_y + \frac{\partial f}{\partial z}\mathbf{i}_z$$

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

$$\nabla \times \mathbf{A} = \mathbf{i}_x\left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z}\right) + \mathbf{i}_y\left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}\right) + \mathbf{i}_z\left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y}\right)$$

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

Cylindrical Coordinates $(\mathrm{r}, \phi, \mathrm{z})$

$$\nabla f = \frac{\partial f}{\partial \mathrm{r}}\mathbf{i}_\mathrm{r} + \frac{1}{\mathrm{r}}\frac{\partial f}{\partial \phi}\mathbf{i}_\phi + \frac{\partial f}{\partial \mathrm{z}}\mathbf{i}_\mathrm{z}$$

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

$$\nabla \times \mathbf{A} = \mathbf{i}_\mathrm{r}\left(\frac{1}{\mathrm{r}}\frac{\partial A_\mathrm{z}}{\partial \phi} - \frac{\partial A_\phi}{\partial \mathrm{z}}\right) + \mathbf{i}_\phi\left(\frac{\partial A_\mathrm{r}}{\partial \mathrm{z}} - \frac{\partial A_\mathrm{z}}{\partial \mathrm{r}}\right) + \mathbf{i}_\mathrm{z}\frac{1}{\mathrm{r}}\left[\frac{\partial(\mathrm{r}A_\phi)}{\partial \mathrm{r}} - \frac{\partial A_\mathrm{r}}{\partial \phi}\right]$$

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

Spherical Coordinates (r, θ, ϕ)

$$\nabla f = \frac{\partial f}{\partial r}\mathbf{i}_r + \frac{1}{r}\frac{\partial f}{\partial \theta}\mathbf{i}_\theta + \frac{1}{r\sin\theta}\frac{\partial f}{\partial \phi}\mathbf{i}_\phi$$

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

$$\nabla \times \mathbf{A} = \mathbf{i}_r\frac{1}{r\sin\theta}\left[\frac{\partial(\sin\theta A_\phi)}{\partial \theta} - \frac{\partial A_\theta}{\partial \phi}\right] + \mathbf{i}_\theta\frac{1}{r}\left[\frac{1}{\sin\theta}\frac{\partial A_r}{\partial \phi} - \frac{\partial(rA_\phi)}{\partial r}\right] + \mathbf{i}_\phi\frac{1}{r}\left[\frac{\partial(rA_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta}\right]$$

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

MAXWELL'S EQUATIONS

	Integral	*Differential*	*Boundary Conditions*
Faraday's Law	$\oint_L \mathbf{E}' \cdot \mathbf{dl} = -\frac{d}{dt}\int_S \mathbf{B} \cdot \mathbf{dS}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\mathbf{n} \times (\mathbf{E}_2' - \mathbf{E}_1') = 0.$
Ampere's Law with Maxwell's Displacement Current Correction	$\oint_L \mathbf{H} \cdot \mathbf{dl} = \int_S \mathbf{J}_f \cdot \mathbf{dS} + \frac{d}{dt}\int_S \mathbf{D} \cdot \mathbf{dS}$	$\nabla \times \mathbf{H} = \mathbf{J}_f + \frac{\partial \mathbf{D}}{\partial t}$	$\mathbf{n} \times (\mathbf{H}_2 - \mathbf{H}_1) = \mathbf{K}_f$
Gauss's Law	$\oint_S \mathbf{D} \cdot \mathbf{dS} = \int_V \rho_f dV$	$\nabla \cdot \mathbf{D} = \rho_f$	$\mathbf{n} \cdot (\mathbf{D}_2 - \mathbf{D}_1) = \sigma_f$
	$\oint_S \mathbf{B} \cdot \mathbf{dS} = 0$	$\nabla \cdot \mathbf{B} = 0$	$\mathbf{n} \cdot (\mathbf{B}_2 - \mathbf{B}_1) = 0$
Conservation of Charge	$\oint_S \mathbf{J}_f \cdot \mathbf{dS} + \frac{d}{dt}\int_V \rho_f dV = 0$	$\nabla \cdot \mathbf{J}_f + \frac{\partial \rho_f}{\partial t} = 0$	$\mathbf{n} \cdot (\mathbf{J}_2 - \mathbf{J}_1) + \frac{\partial \sigma_f}{\partial t} = 0$

Usual Linear Constitutive Laws

$\mathbf{D} = \varepsilon \mathbf{E}$

$\mathbf{B} = \mu \mathbf{H}$

$\mathbf{J}_f = \sigma(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = \sigma \mathbf{E}'$ [Ohm's law for moving media with velocity **v**]

PHYSICAL CONSTANTS

Constant	Symbol	Value	units
Speed of light in vacuum	c	$2.9979 \times 10^8 \approx 3 \times 10^8$	m/sec
Elementary electron charge	e	1.602×10^{-19}	coul
Electron rest mass	m_e	9.11×10^{-31}	kg
Electron charge to mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	coul/kg
Proton rest mass	m_p	1.67×10^{-27}	kg
Boltzmann constant	k	1.38×10^{-23}	joule/°K
Gravitation constant	G	6.67×10^{-11}	nt-m^2/(kg)^2
Acceleration of gravity	g	9.807	m/(sec)^2
Permittivity of free space	ε_0	$8.854 \times 10^{-12} \approx \frac{10^{-9}}{36\pi}$	farad/m
Permeability of free space	μ_0	$4\pi \times 10^{-7}$	henry/m
Planck's constant	h	6.6256×10^{-34}	joule-sec
Impedance of free space	$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$	$376.73 \approx 120\pi$	ohms
Avogadro's number	N	6.023×10^{23}	atoms/mole