# THE CITADEL
# THE MILITARY COLLEGE OF SOUTH CAROLINA

## Department of Electrical and Computer Engineering

**ELEC 318 Electromagnetic Fields** **Exam #2 equation sheets**

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$$A = \left|\mathbf{A}\right| = \sqrt{A_x{}^2 + A_y{}^2 + A_z{}^2}$$

$$\mathbf{a} = \mathbf{A}\big/\left|\mathbf{A}\right| = \mathbf{A}\big/A$$

$$\mathbf{r}_{PQ} = \left(x_2 - x_1\right)\hat{\mathbf{x}} + \left(y_2 - y_1\right)\hat{\mathbf{y}} + \left(y_2 - y_1\right)\hat{\mathbf{z}}$$

$$\mathbf{A}_B = \left(\mathbf{A}\cdot\hat{\mathbf{b}}\right)\hat{\mathbf{b}} = A_B\,\hat{\mathbf{b}}$$

$$\mathbf{A}\cdot\mathbf{B} = \begin{cases} \left|\mathbf{A}\right|\left|\mathbf{B}\right|\cos\theta \\ A\;B\;\cos\theta \end{cases} = \begin{matrix} \left(A_x B_x\right) + \left(A_y B_y\right) \\ + \left(A_z B_z\right) \end{matrix}$$

$$\mathbf{A}\times\mathbf{B} = \begin{cases} \left|\mathbf{A}\right|\left|\mathbf{B}\right|\sin\theta\;\hat{\mathbf{n}} \\ A\;B\;\sin\theta\;\hat{\mathbf{n}} \end{cases} = \begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

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$$x = r\cos\phi,\quad y = r\sin\phi,\quad z = z$$

$$r = \sqrt{x^2 + y^2},\quad \phi = \tan^{-1}\frac{y}{x},\quad z = z$$

$$\hat{\mathbf{x}} = \cos\phi\;\hat{\mathbf{r}} - \sin\phi\;\hat{\boldsymbol{\phi}} \qquad \hat{\mathbf{z}} = \hat{\mathbf{z}}$$

$$\hat{\mathbf{y}} = \sin\phi\;\hat{\mathbf{r}} + \cos\phi\;\hat{\boldsymbol{\phi}}$$

$$\hat{\mathbf{r}} = \cos\phi\;\hat{\mathbf{x}} + \sin\phi\;\hat{\mathbf{y}} \qquad \hat{\mathbf{z}} = \hat{\mathbf{z}}$$

$$\hat{\boldsymbol{\phi}} = -\sin\phi\;\hat{\mathbf{x}} + \cos\phi\;\hat{\mathbf{y}}$$

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$$x = R\sin\theta\cos\phi,\quad z = R\cos\theta$$

$$y = R\sin\theta\sin\phi$$

$$R = \sqrt{x^2 + y^2 + z^2},\quad \theta = \tan^{-1}\sqrt{x^2 + y^2}\big/x,$$

$$\phi = \tan^{-1}\left(y\big/x\right)$$

$$\hat{\mathbf{x}} = \sin\theta\cos\phi\;\hat{\mathbf{R}} + \cos\theta\cos\phi\;\hat{\boldsymbol{\theta}} - \sin\phi\;\hat{\boldsymbol{\phi}}$$

$$\hat{\mathbf{y}} = \sin\theta\sin\phi\;\hat{\mathbf{R}} + \cos\theta\sin\phi\;\hat{\boldsymbol{\theta}} + \cos\phi\;\hat{\boldsymbol{\phi}}$$

$$\hat{\mathbf{z}} = \cos\theta\;\hat{\mathbf{R}} - \sin\theta\;\hat{\boldsymbol{\theta}}$$

$$\hat{\mathbf{R}} = \sin\theta\cos\phi\;\hat{\mathbf{x}} + \sin\theta\sin\phi\;\hat{\mathbf{y}} + \cos\theta\;\hat{\mathbf{z}}$$

$$\hat{\boldsymbol{\theta}} = \cos\theta\cos\phi\;\hat{\mathbf{x}} + \cos\theta\sin\phi\;\hat{\mathbf{y}} - \sin\theta\;\hat{\mathbf{z}}$$

$$\hat{\boldsymbol{\phi}} = -\sin\phi\;\hat{\mathbf{x}} + \cos\phi\;\hat{\mathbf{y}}$$

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$$d\mathbf{l} = dx\;\hat{\mathbf{x}} + dy\;\hat{\mathbf{y}} + dz\;\hat{\mathbf{z}}$$

$$d\mathbf{l} = dr\;\hat{\mathbf{r}} + r\;d\phi\;\hat{\boldsymbol{\phi}} + dz\;\hat{\mathbf{z}}$$

$$d\mathbf{l} = dr\;\hat{\mathbf{R}} + R\;d\theta\;\hat{\boldsymbol{\theta}} + R\sin\theta\;d\phi\;\hat{\boldsymbol{\phi}}$$

$$d\mathbf{S} = dy\;dz\;\hat{\mathbf{x}}$$

$$d\mathbf{S} = dz\;dx\;\hat{\mathbf{y}}$$

$$d\mathbf{S} = dx\;dy\;\hat{\mathbf{z}}$$

$$d\mathbf{S} = r\;d\phi\;dz\;\hat{\mathbf{r}}$$

$$d\mathbf{S} = dr\;dz\;\hat{\boldsymbol{\phi}}$$

$$d\mathbf{S} = r\;dr\;d\phi\;\hat{\mathbf{z}}$$

$$d\mathbf{S} = R^2\sin\theta\;d\theta\;d\phi\;\hat{\mathbf{R}}$$

$$d\mathbf{S} = R\sin\theta\;dR\;d\phi\;\hat{\boldsymbol{\theta}}$$

$$d\mathbf{S} = R\;dR\;d\theta\;\hat{\boldsymbol{\phi}}$$

$$dv = dx\;dy\;dz$$

$$dv = r\;dr\;d\phi\;dz$$

$$dv = R^2\sin\theta\;dR\;d\theta\;d\phi$$

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

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

$$\nabla \cdot \mathbf{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} = \frac{1}{r}\frac{\partial}{\partial r}\left(rA_r\right) + \frac{1}{r}\frac{\partial}{\partial \phi}A_\phi + \frac{\partial}{\partial z}A_z$$

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

$$\nabla \times \mathbf{A} = \begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix} = \frac{1}{r}\begin{vmatrix} \hat{\mathbf{r}} & r\hat{\boldsymbol{\phi}} & \hat{\mathbf{z}} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ A_r & rA_\phi & A_z \end{vmatrix} = \frac{1}{R^2\sin\theta}\begin{vmatrix} \hat{\mathbf{R}} & R\,\hat{\boldsymbol{\theta}} & R\sin\theta\,\hat{\boldsymbol{\phi}} \\ \frac{\partial}{\partial R} & \frac{\partial}{\partial \theta} & \frac{\partial}{\partial \phi} \\ A_R & RA_\theta & R\sin\theta\, A_\phi \end{vmatrix}$$

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

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

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

$$\frac{\partial^2 V}{\partial x^2} = 0 \quad \Rightarrow \quad V = V_1 x + V_2$$

$$\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right) = 0 \quad \Rightarrow \quad V = V_1 \ln\left(r\right) + V_2$$

$$\frac{\partial}{\partial R}\left(R^2\frac{\partial V}{\partial R}\right) = 0 \quad \Rightarrow \quad V = \frac{V_1}{R} + V_2$$

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$$\oint_S \mathbf{A}\cdot d\mathbf{S} = \int_v \nabla\cdot\mathbf{A}\; dv \qquad \oint_L \mathbf{A}\cdot d\mathbf{l} = \int_S \left(\nabla\times\mathbf{A}\right)\cdot d\mathbf{S} \qquad d\mathbf{S} = dS\;\hat{\mathbf{n}} \qquad \Psi = \int_S \mathbf{A}\cdot d\mathbf{S}$$

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$$\mathbf{F} = \frac{q_1 q_2}{4\pi\varepsilon_0}\cdot\frac{\mathbf{R}-\mathbf{R}'}{\left|\mathbf{R}-\mathbf{R}'\right|^3} \qquad \mathbf{E} = \frac{\mathbf{F}}{q} \qquad dq = \rho_l dl \qquad dq = \rho_v dv \qquad dq = \rho_s dS$$

$$\mathbf{E} = \frac{q}{4\pi\varepsilon_0}\cdot\frac{\mathbf{R}-\mathbf{R}'}{\left|\mathbf{R}-\mathbf{R}'\right|^3} \qquad d\mathbf{E} = \frac{dq}{4\pi\varepsilon_0}\cdot\frac{\mathbf{R}-\mathbf{R}'}{\left|\mathbf{R}-\mathbf{R}'\right|^3} \qquad \mathbf{E} = \frac{1}{4\pi\varepsilon_0}\int dq\,\frac{\mathbf{R}-\mathbf{R}'}{\left|\mathbf{R}-\mathbf{R}'\right|^3}$$

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$$\nabla^2 V = -\frac{\rho_v}{\varepsilon} \qquad \mathbf{E} = -\nabla V \qquad V_{AB} = \frac{W}{q} = -\int_A^B \mathbf{E}\cdot d\mathbf{l}$$

$$\nabla\times\mathbf{E} = 0 \qquad \oint_L \mathbf{E}\cdot d\mathbf{l} = 0 \qquad V_{\substack{\text{point}\\\text{charge}}} = \frac{q}{4\pi\varepsilon_0\left|\mathbf{R}-\mathbf{R}'\right|} \qquad dV = \frac{dq}{4\pi\varepsilon_0\left|\mathbf{R}-\mathbf{R}'\right|}$$

$$\mathbf{E}_{\substack{\text{point}\\\text{charge}}} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{\mathbf{R}}$$

$$\mathbf{E}_{\text{dipole}} \approx \frac{q\cdot d\cdot\cos\theta}{2\pi\varepsilon_0 r^3}\hat{\mathbf{r}} + \frac{q\cdot d\cdot\sin\theta}{4\pi\varepsilon_0 r^3}\hat{\boldsymbol{\theta}}$$

$$\mathbf{E}_{\substack{\text{infinite}\\\text{line charge}}} = \frac{\rho_l}{2\pi\varepsilon_0 r}\hat{\mathbf{r}}$$

$$\mathbf{E}_{\substack{\text{infinite}\\\text{surf charge}}} = \frac{\rho_s}{2\varepsilon_0}\hat{\mathbf{n}}$$

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$$\nabla\cdot\mathbf{D} = \rho_v$$

$$Q = \oint_S \mathbf{D}\cdot d\mathbf{S}$$

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

$$\mathbf{D} = \varepsilon_0\mathbf{E} + \mathbf{P} = \left(1+\chi_e\right)\varepsilon_0\mathbf{E}$$

$$\varepsilon = \varepsilon_r\varepsilon_0$$

$$E_{1t} = E_{2t}$$

$$D_{1n} - D_{2n} = \rho_s$$

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$$\mathbf{J} = \sigma\mathbf{E}$$

$$\mathbf{J} = \rho_v\cdot\mathbf{u}$$

$$I = \frac{dQ}{dt}$$

$$\mathbf{J} = \frac{dI}{dS}\hat{\mathbf{n}}$$

$$I = \int_S \mathbf{J}\cdot d\mathbf{S}$$

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$$R = \frac{V}{I} = \frac{\int_L \mathbf{E}\cdot d\mathbf{l}}{\int_S \sigma\mathbf{E}\cdot d\mathbf{S}}$$

$$C = \frac{Q}{V} = \frac{\varepsilon\oint_S \mathbf{E}\cdot d\mathbf{S}}{\int_L \mathbf{E}\cdot d\mathbf{l}}$$

$$C_{\substack{\text{parallel}\\\text{plates}}} = \varepsilon\frac{A}{d}$$

$$R_{\substack{\text{uniform}\\\text{cross sec}}} = \frac{L}{\sigma A}$$

$$C_{\substack{\text{coaxial}\\\text{line}}} = \frac{2\pi\varepsilon L}{\ln\left(b/a\right)}$$

$$C_{\substack{\text{two}\\\text{spheres}}} = \frac{4\pi\varepsilon}{\frac{1}{a}-\frac{1}{b}}$$

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$$W_E = \frac{1}{2}\sum_{k=1}^{N} q_k V_k$$

$$W_E = \frac{1}{2}\int_v \varepsilon\left|\mathbf{E}\right|^2 dv$$

$$W_E = \frac{1}{2}CV^2$$

$$\varepsilon_0 = 8.854\times10^{-12}\ \mathrm{F/m}$$

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$$S_{\text{cylinder}} = 2\pi r^2 + 2\pi r h$$

$$v_{\text{cylinder}} = \pi r^2 h$$

$$S_{\text{sphere}} = 4\pi r^2$$

$$v_{\text{sphere}} = \frac{4}{3}\pi r^3$$