FE Review Course

Electricity & Magnetism

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FERC

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Equivalent Units

A	= W/V	= N/T·m	
C	= J/V	= N·m/V	
F	= C/V	= C^2/J	= C^2/N·M
H	= V·s/A	= T·m^2/A	
J	= N·m	= V·C	= C^2/F
N	= J/m	= V·C/m	
T	= N·s/C·m	= N/A·m	
V	= W/A	= C/F	= J/C
W	= J/s	= V·A	= V^2/Ω
Wb	= V·s	= H·A	= T·m^2

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Basic Complex Algebra

Review FERM Ch. 43 and Mathematics 1.

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Electrostatics

Charges

1 Coulomb (C) = charge on 6.24 × 10^{18} electrons
Charge on 1 e^- = 1.6022 × 10^{-19} C (the inverse of 1 Coulomb)

Force on Charged Object

- General case: $\mathbf{F} = Q\mathbf{E}$ 43.17
- Specific for 2 point charges: $\mathbf{F}_2 = Q_2\mathbf{E}_1 = \frac{Q_1 Q_2}{4\pi\epsilon r^2}\mathbf{a}$ 43.18
  – **a** is a unit vector pointing from point charge 1 to point charge 2.

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Electrostatics

Permittivity

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = \frac{\phi_{\text{actual}}}{\phi_{\text{vacuum}}}$$

$$\varepsilon = \varepsilon_r \varepsilon_0$$

NOTE: On the FE exam, assume the permittivity is $\Sigma_0 = 8.85 \times 10^{-12}$ F/m unless another value is provided.

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Electrostatics

Electric Field Intensity

- Due to a point charge Q_1: $\mathbf{E} = \frac{Q_1}{4\pi\epsilon r^2}\mathbf{a}$ 43.20
- For a line charge ρ_L: $\mathbf{E}_L = \frac{\rho L}{2\pi\epsilon r}\mathbf{a}$ 43.21
  - **a** is a unit vector normal to the line.
- For a sheet charge ρ_s: $\mathbf{E}_S = \frac{\rho_S}{2\epsilon}\mathbf{a}$ 43.22
  - **a** is a unit vector normal to the sheet charge.

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Electrostatics

Example (FEIM):

A point charge of 0.001 C is placed 10 m from a sheet charge of –0.001 C/m^2, and a 10 m diameter sphere of charge 0.001 C is placed half-way in between on a straight line, all in a vacuum. What is the force on the point charge?

$$\mathbf{F} = \mathbf{F}_{\text{sheet}} + \mathbf{F}_{\text{sphere}} = \mathbf{Q}_{\text{point}}\left(\mathbf{E}_{\text{sheet}} + \mathbf{E}_{\text{sphere}}\right)$$

$$F = Q_{\text{point}}\left(\frac{\rho_{\text{sheet}}}{2\varepsilon} + \frac{Q_{\text{sphere}}}{4\pi\varepsilon r^2}\right) = \left(\frac{0.001\,\text{C}}{8.85\times10^{-12}\,\frac{\text{F}}{\text{m}}}\right)\left(-\frac{0.001\,\frac{\text{C}}{\text{m}^2}}{2} + \frac{0.001\,\text{C}}{4\pi(5\,\text{m})^2}\right)$$

$$= -5.61\times10^4\ \text{N}$$

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Electrostatics

Electric Flux – Gauss' Law

$$Q_{\text{encl}} = \oiint_S \epsilon \mathbf{E}\cdot d\mathbf{S} \qquad 43.24$$

If **E** is constant and parallel to $d\mathbf{S}$, then

$$Q_{\text{encl}} = \int_S \varepsilon \mathbf{E}\cdot d\mathbf{S} = \varepsilon E \int d\mathbf{S}$$

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Electrostatics

Work (W) done by moving a charge Q_1 radially from distance r_1 to r_2 in an electric field:

$$W = -Q_1 \int_{r_1}^{r_2} \mathbf{E} \cdot d\mathbf{L} \qquad 43.25$$

- For a uniform field, the work done by moving a charge Q a distance d parallel to the uniform field:

$$\begin{aligned} W &= -\mathbf{F} \cdot \mathbf{d} = -EQd \\ &= \frac{-V_{\text{plates}} Qd}{r} \\ &= -Q\Delta V \qquad 43.27 \end{aligned}$$

Note that Eq. 43.27 is always true, for all fields. (V may not be easy to compute.)

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Electrostatics

Voltage

- A scalar quantity that describes the electrical field.
- The field **E** is the gradient of the voltage, V.
- The voltage differential between two points is the work to bring a unit charge from one point to the other.
- The choice of zero potential is arbitrary.
- Electric field strength between two parallel plates:

$$E = \frac{V}{d} \qquad 43.28$$

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Electrostatics

Example (FEIM):
A source at zero potential emits electrons at negligible velocity. An open grid at 18 V is located 0.003 m from the source. At what velocity will the electrons pass through the grid?

(A) 490 m/s
(B) 16 000 m/s
(C) 8.3×10^5 m/s
(D) 2.5×10^6 m/s

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Electrostatics

The mass of an electron is 9.11×10^{-31} kg.

The work done by the grid on an electron is equal to the change in kinetic energy of the electron and is equal to the charge on the electron times the change in voltage potential.

$$W = \tfrac{1}{2} m\mathrm{v}^2 = q\Delta V$$

$$\mathrm{v} = \sqrt{\frac{2q\Delta V}{m}} = \sqrt{\frac{(2)(1.6022 \times 10^{-19}\ \mathrm{C})(18\ \mathrm{V})}{9.11 \times 10^{-31}\ \mathrm{kg}}}$$

$$= 2.516 \times 10^6\ \mathrm{m/s} \quad \left(2.5 \times 10^6\ \mathrm{m/s}\right)$$

Therefore, the answer is (D).

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Current

Change in charge per unit time

$$i(t) = \frac{dq(t)}{dt} \qquad 43.29$$

Current Density (ρ)

- The density of charge moving per unit time through a volume

Volume Current Density (**J**)

- The vector current density

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Magnetism

Magnetic field around a current-carrying wire

$$\mathbf{H} = \frac{\mathbf{B}}{\mu} = \frac{I}{2\pi r}\mathbf{a} \quad \text{[straight wire]} \qquad 43.35$$

Force on current-carrying conductor

$$\mathbf{F} = I\mathbf{L} \times \mathbf{B} \qquad 43.36$$

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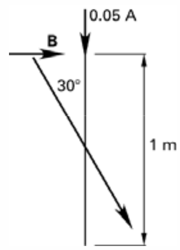
Magnetism

Example (FEIM):
A magnetic field of 0.0005 T makes a 30° angle with a 1 m wire carrying 0.05 A. What is the force on the wire?
(A) 1.25×10^{-5} N
(B) 5.00×10^{-4} N
(C) 1.25×10^{-3} N
(D) 2.50×10^{-3} N



$$|\mathbf{F}| = I|\mathbf{L} \times \mathbf{B}| = I|\mathbf{L}||\mathbf{B}|\sin\theta$$

$$= (0.05\text{ A})(1\text{ m})(0.0005\text{ T})(\sin 30°)$$

$$= 1.25 \times 10^{-5}\text{ N}$$

Therefore, the answer is (A).

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Induced Voltage

Also called *electromotive force* (emf)

For *N* loops:

$$v = \frac{-N\,d\phi}{dt} = -NBL\frac{ds}{dt} \qquad 43.40$$

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