1) (10 points) In my intricate solution to Problem P26 of Chapter 15, I asked whether (in my solution) I could have neglected $x^2$ compared to $(L/2)^2$ from the beginning (and answered “yes”). Do as I suggested in the solution: start with $F = \frac{2 \lambda q}{4 \pi \varepsilon_0} \left[ \frac{1}{x-s} - \frac{1}{x+s} \right]$ and show that in the limit that $s \ll x$, $F \approx \frac{2 \lambda q}{4 \pi \varepsilon_0 x^2}$.

$$F = \frac{2 \lambda q}{4 \pi \varepsilon_0} \left[ \frac{(x+s)-(x-s)}{x^2-s^2} \right]$$

$$= \frac{2 \lambda q}{4 \pi \varepsilon_0} \left[ \frac{2s}{x^2-s^2} \right]$$

$$= \frac{2 \lambda p}{4 \pi \varepsilon_0} \cdot \frac{1}{x^2-s^2}$$

$$\approx \frac{2 \lambda p}{4 \pi \varepsilon_0 x^2}$$
2) (20 points) In the solution to problem P48 of Chap. 15, I charged you with repeating the calculation for the pen oriented horizontally above the foil.

A) Start by writing an expression for the electric field produced by the pen near the paper. Explain the physical meaning of each symbol. (HINT: There's nothing to calculate here.)

\[ E = \frac{1}{4\pi \varepsilon_0} \frac{q}{r \sqrt{r^2 + (\frac{L}{2})^2}} \]

B) Estimate unknown quantities and calculate a numerical value for the electric field near the foil.

\[ q \sim 10^{-8} \text{C} \]
\[ r \sim 10^{-2} \text{m} \]
\[ L \sim 0.15 \text{m} \]

\[ E = 9 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \times \frac{10^{-8} \text{C}}{(0.01)(0.075) \text{m}^2} \]

\[ = 120 \frac{\text{N}}{\text{C}} \]

\[ = 120 \frac{\text{V}}{\text{m}} \]
3) (20 points) Given an electric field of \( \vec{E} = (1, 0.2, -0.5) \, N/C \) and a change in position of \( \Delta \vec{l} = (3, -1, 5) \, cm \):

A) Calculate the change in voltage of such a change in position.

\[
\Delta V = -\vec{E} \cdot \Delta \vec{l} = - \left[ 1.3 + (0.2)(-1) + (-0.5)(5) \right] \text{N cm}/C
\]

\[
= - \left[ 0.3 \, \text{N cm}/C \right] = -0.003 \, V
\]

B) Find the angle between the electric field and the position change.

\[
\Delta V = -\vec{E} \cdot \Delta \vec{l} = - |\vec{E}| |\Delta \vec{l}| \cos \theta
\]

\[
\cos \theta = - \frac{\Delta V}{|\vec{E}| |\Delta \vec{l}|}
\]

\[
= \frac{-0.003 \, V}{1.136 \, \text{N cm}/C \times 0.059 \, \text{m}} = 0.045
\]

\[
\theta = 87.4^\circ
\]
4) **(10 points)** In the solution to problem P54 of Chap. 16, I ignored the voltage changes $\Delta V_{BA}$ and $\Delta V_{DC}$. That is, I did not include the voltage change between points B and A, and the voltage change between points C and D. How can this be justified?

Inside a metal at equilibrium, the electric field is zero, so the voltage is constant. So $\Delta V_{BA} = \Delta V_{DC} = 0$
5) **(20 points)** Nuclear fission is called "nuclear power", but it's actually electrical power. To show this, start with a plutonium-239 nucleus, initially at rest. It consists of 94 protons and 145 neutrons. When it "fissions", suppose it breaks into two identical pieces, spherical in shape, a distance d apart.

A) Write an algebraic expression for the speed of each of the two parts when they are "far apart". [HINT: Since they are spherical (they really are) they can be treated as point charges. OTHER HINT: The two nuclei exert equal and opposite forces upon one another, so the center of mass momentum stays zero throughout.]

\[ \Delta E = -\Delta U \]

\[ 2 \times \left( \frac{1}{2} m v^2 \right) = - \left( 0 - \frac{0}{\frac{92}{m}} \right) \]

\[ v^2 = \frac{q^2}{4\pi \varepsilon_0 m r} \]

B) Suppose they start 10 fm apart. Calculate a numerical value for the speed (in m/s). [You can assume the speed is low enough to be nonrelativistic.]

\[ v^2 = \frac{9.1 \times 10^{45} \text{eV}}{4\pi \times \frac{q^2}{m_r}} \cdot \frac{(47.16 \times 10^{-19}^2)}{2 \times (239 \times 1.7 \times 10^{-27}^2)} \times (10^{-14} \text{m})^2 \]

\[ v = 2.5 \times 10^{14} \text{ m/s} \]

\[ v = 16 \times 10^6 \text{ m/s} \left( \approx 0.05c \right) \]
(20 points) According to the magnetic field calculator on the NOAA website (I love the internet), near Hammond, the Earth's magnetic field has a value of \((24, -0.034, 41) \mu T\) where the x-axis is positive North, the y-axis is positive East and the z-axis is positive down. Calculate the force on an electron moving UP in a wire at a speed of \(10^{-3} \text{ m/s}\). [HINT: Recall that the force on a charge moving in a magnetic field is given by \(\vec{F} = q \vec{v} \times \vec{B}\).]

\[
\vec{F} = q \vec{v} \times \vec{B} = (-1.6 \times 10^{-19} \text{ C}) \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -10^{-3} \\ 2.4 & -0.034 & 41 \end{vmatrix} \vec{m} = (2.4 \times 10^{-3}) + \hat{z} (0) \text{ N} \\
= (-1.6 \times 10^{-19}) \begin{vmatrix} \hat{i} & \hat{j} \\ 3.4 \times 10^{-5} & 2.4 \times 10^{-3} \end{vmatrix} \mu N = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 0 & -10^{-3} \end{vmatrix} \mu N \\
\approx 3.84 \times 10^{-27} \text{ N}
\]