Three point charges sit in the $xy$ plane:

- Charge $A$ has a mass $m_A = 0.1\ \text{kg}$, charge $q_A = 0.1\ \text{C}$, and is at the position $(x_A, y_A) = (0\ \text{m}, 0\ \text{m})$.
- Charge $B$ has a mass $m_B = 0.2\ \text{kg}$, charge $q_B = 0.2\ \text{C}$, and is at the position $(x_B, y_B) = (0\ \text{m}, 0.3\ \text{m})$.
- Charge $C$ has a mass $m_C = 0.3\ \text{kg}$, charge $q_C = -0.3\ \text{C}$, and is at the position $(x_C, y_C) = (0.3\ \text{m}, 0\ \text{m})$.

(a) Find the electric field vector due to charges $A$ and $C$ at the location of charge $B$.

\[ \vec{E} = \text{________}_\hat{i} + \text{________}_\hat{j} \]

(b) If charge $B$ is released while charges $A$ and $C$ are held fixed, find the acceleration vector of charge $B$ at the instant immediately after it is released.

\[ \vec{a} = \text{________}_\hat{i} + \text{________}_\hat{j} \]
2 [10 points] Through the use of a power source, two oddly-shaped stationary conductors are kept so that conductor \( A \) has an electric potential 300 V higher than conductor \( B \). If a proton is released from rest at the surface of conductor \( A \) and spontaneously flies over to the surface of \( B \), what speed \( v \) will it have just before colliding with \( B \)? (Assume that there is no air resistance or other non-electric forces present.)

\[ v = \] 

3 [20 points] An infinitely long solid, nonconducting cylinder of radius \( a \) has a uniform charge per unit volume \( \rho \). In addition an infinitely long, infinitesimally thin straight wire carrying uniform charge per unit length \( \lambda \) lies along the axis of that cylinder. Find the electric field strength \( E \) at a distance \( r \) from the common axis for the cases \( r < a \) and \( r > a \).

\[ r < a : \quad E = \] 

\[ r > a : \quad E = \]
4 [20 points] A plastic rod with a uniform charge per unit length $\lambda$ has the shape of a $\pi / 3$ radian circular arc of radius $r$. Find the $\hat{i}$ and $\hat{j}$ components of the electric field $\vec{E}$ at the point $P$ in the coordinate system shown in the figure. Show all of your work.

Your answer should involve the symbols $\lambda$, $r$, and $k$ (or $\varepsilon_0$). In your answer you should use the following exact values: $\cos\left(\frac{\pi}{3}\right) = \frac{1}{2}$, $\sin\left(\frac{\pi}{3}\right) = \frac{\sqrt{3}}{2}$.

\[ \vec{E} = \text{______________} \hat{i} + \text{______________} \hat{j} \]
5 [15 points]

(a) Find the equivalent capacitance $C_{eq}$ of the combination of capacitors between the terminals of the battery.

\[ C_{eq} = \quad \]  

(b) Find the charge $Q_{2 \mu F}$ on the 2 $\mu$F capacitor.

\[ Q_{2 \mu F} = \quad \]

6 [15 points] A parallel plate capacitor is made of plates of area 0.01 m$^2$ separated by a distance 0.002 m.

(a) Initially the capacitor is filled with dry air, which has a dielectric constant of 1 and a “dielectric strength” (or “breakdown field strength”) of $3 \times 10^6$ V/m. What is the smallest potential difference $\Delta V_{\text{min}}$ that can be placed between the plates that will cause a spark to fly between the plates?

\[ \Delta V_{\text{min}} = \quad \]

(b) Later the capacitor is filled with polyvinyl chloride, which has a dielectric constant of 3.4 and a “dielectric strength” (or “breakdown field strength”) of $40 \times 10^6$ V/m. What is the smallest potential difference that can be placed between the plates that will cause a spark to fly between the plates?

\[ \Delta V_{\text{min}} = \quad \]
\[ d\tilde{E} = \frac{k \, dq}{r^2} \hat{r} \]

\[
\oint_{\text{any closed surface}} \mathbf{E} \cdot d\mathbf{A} = \frac{Q_m}{\varepsilon_0}
\]

\[ V_B - V_A = -\oint_A \mathbf{E} \cdot d\mathbf{\ell} \]

\[ \mathbf{E} = -\frac{\partial V}{\partial \mathbf{r}} = -\frac{\partial V}{\partial x} \hat{i} - \frac{\partial V}{\partial y} \hat{j} - \frac{\partial V}{\partial z} \hat{k} \]

\[ dV = \frac{k \, dq}{r} \]

\[ U = k \frac{q_1 q_2}{r_{12}} \]

\[ Q = C \Delta V \]

\[ U = \frac{1}{2} C (\Delta V)^2 \]

\[ u_k = \frac{1}{2} \varepsilon_0 E^2 \]

\[ \bar{E} = \frac{\bar{E}}{\kappa} \]

\[ C = \kappa C_0 \]

\[ e = 1.602 \times 10^{-19} \text{ C} \]

\[ m_{\text{proton}} = 1.672 \times 10^{-27} \text{ kg} \]

\[ k = \frac{1}{4 \pi \varepsilon_0} = 8.987 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \]