A parallel-plate capacitor is charged and then disconnected from the battery, so that the charge \( Q \) on its plates cannot change. Originally the separation between the plates of the capacitor is \( d \) and the electrical field between the plates of the capacitor is \( E = 6.0 \times 10^4 \text{ N/C} \). If the plates are moved closer together, so that their separation is halved and becomes \( d/2 \), what then is the electrical field between the plates of the capacitor? What if the battery is left connected?

Knowns:
\[ E = 6 \times 10^4 \text{ N/C} \]

Unknowns:
Final \( E \)

Equation:
\[ C = \varepsilon_0 \frac{A}{d} = \frac{Q}{V} \]
\[ E = \frac{\sigma}{\varepsilon_0} \]

Algebra and PnP:
\[ E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} \]
\[ \varepsilon_0 \frac{A}{d} = \frac{Q}{V} \Rightarrow Q = \frac{\varepsilon_0 AV}{d} \]
\[ E = \frac{\varepsilon_0 AV}{Ad\varepsilon_0} = \frac{V}{d} \]
\[ E = \frac{Q}{Ad\varepsilon_0} \text{ No change} \]
\[ E_f = 6 \times 10^4 \text{ N/C} \]
\[ E = \frac{V}{d} \text{ Double} \]
\[ E_f = 1.2 \times 10^5 \text{ N/C} \]

A parallel-plate capacitor is charged and then disconnected from the battery, so that the charge \( Q \) on its plates cannot change. Originally the separation between the plates of the capacitor is \( d \) and the electrical energy stored in the capacitor is 8J. If the plates are moved farther apart, so that their separation is doubled and becomes \( 2d \), what then is the energy stored in the capacitor? Repeat with the battery still attached.

Knowns:
\[ U_0 = 8.0 \text{J} \]

Unknowns:
Final stored energy, \( U_f \)

Equations:
\[ U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 \]

Algebra and PnP:
\[ C = \varepsilon_0 \frac{A}{d} = \frac{Q}{V} \]
\[ U_1f = \frac{Q^2}{2C} = \frac{Q^2}{2\varepsilon_0 A} \text{ Double} \]
\[ U_2f = \frac{1}{2} CV^2 = \frac{1}{2} \frac{\varepsilon_0 AV^2}{d} \text{ Half} \]
\[ U_1f = 16.0 \text{J} \]
\[ U_2f = 4.0 \text{J} \]
Sketch potential for a parallel-plate capacitor inside and outside the capacitor along the axis passing through the center of the plates. Assume that potential at infinity is zero.

The positive plate must be the higher potential with the negative plate at the lower potential. The potential must be continuous over all space. The easiest way to get a curve from one potential to the other is with a straight line. Outside the capacitor, the potential dies off from the value given on the plate to zero at infinity.

Two non-conducting balls, 1m apart, and radius 0.1m each are oppositely charged: \( Q_l \) is +3nC, while \( Q_r \) is -3nC. On each of the balls, charge is distributed homogeneously. Let the axis of symmetry be the y-axis. A proton is located 2m away from the centers of the balls. Its initial speed is negligible. What is the ultimate fate of the proton? Will it escape? What is its final speed? What if it is 3m away from the centers? What if in place of the proton, it will be alpha-particle?

The proton cannot escape. The yz-plane defines zero potential between the balls. That is where the particle starts and it cannot cross it. It is stuck in the positive x region. The
ball will initially move to the right, because the electric field on the y-axis is always pointing
to the right on that axis. The particle will then swing up at the negative charge begins to
dominate its motion. It may circle around and hit the y-axis somewhere else, but it will
eventually lose all energy and crash into the negative charge. I have no reason to require it
crash into the particle at full energy other than Dr. Fienklestien said so. Special relativity
says that accelerating particles lose energy, so I know it will eventually hit the ball, but I
don’t know when or with how much energy will be left. I’ll just assume that it does what
has been drawn and the particle will always hit the ball on the inside surface on the x-axis.

Knowns:
\[ Q_l = 3 \times 10^{-9} C \]
\[ Q_r = -3 \times 10^{-9} C \]
\[ d = 1 m \]
\[ r = .1 m \]
\[ m_p = 1.672622 \times 10^{-27} kg \]
\[ m_\alpha = 4m_p \]
\[ q_p = 1.602 \times 10^{-19} C \]
\[ q_\alpha = 2q_p \]
\[ v_i = 0 \frac{m}{s} \]

Unknowns:
\[ U_i, U_f, K_f \]
\[ V_i, V_f, v_f \]

Equations:
\[ U = qV \]
\[ V = \frac{1}{4 \pi \epsilon_0} \frac{q}{r} \]
\[ \Delta E = 0 J \]
\[ E = U + K \]
\[ K = \frac{1}{2}mv^2 \]

Algebra and PnP:
\[ V_i = \frac{1}{4 \pi \epsilon_0} \left( \frac{q}{r} - \frac{q}{r} \right) = 0 V \]
\[ V_f = \frac{1}{4 \pi \epsilon_0} \left( \frac{3 \times 10^{-9} C}{.9m} - \frac{3 \times 10^{-9} C}{.1m} \right) = -60 V \]
\[ U_f = -9.6 \times 10^{-18} J \]
\[ U_i + K_i = 0 J = U_f + K_f \]
\[ K_f = -U_f = 9.6 \times 10^{-18} J \]
\[ v_f = \sqrt{\frac{2K_f}{m_p}} = 107000 \frac{m}{s} = .0003574 c \]

Changing the proton out for the alpha particle doubles the energy and quadruples the
mass of the particle. The end result is that
the alpha particle is slower by a factor by \( \sqrt{2} \)
or \[ v_f = 75800 \frac{m}{s} \]