CHAPTER 17: Electric Potential

Answers to Questions

1. If two points are at the same potential, then no NET work was done in moving a test charge from one point to the other. Along some segments of the path, some positive work might have been done, but along other segments of the path, negative work would then have been done. And if the object was moved along an equipotential line, then no work would have been done along any segment of the path.

   Along any segment of the path where positive or negative work was done, a force would have to be exerted. If the object was moved along an equipotential line, then no force would have been exerted along any segment of the path.

   This is analogous to climbing up and then back down a flight of stairs to get from one point to another point on the same floor of a building. Gravitational potential increased while going up the stairs, and decreased while going down the stairs. A force was required both to go up the stairs and down the stairs. If instead you walked on the level from one point to another, then the gravitational potential was constant, and no force was need to change gravitational potential.

2. A negative charge will move toward a region of higher potential. A positive charge will move toward a region of lower potential. The potential energy of each will decrease.

3. (*a*) Electric potential, a scalar, is the electric potential energy per unit charge at a point in space. Electric field, a vector, is the electric force per unit charge at a point in space.
   (*b*) Electric potential energy is the work done against the electric force in moving a charge from a specified location of zero potential energy to some other location. Electric potential is the electric potential energy per unit charge.

4. The potential energy of the electron is proportional to the voltage used to accelerate it. Thus, if the voltage is multiplied by a factor of 4, then the potential energy is increased by a factor of 4 also. Then, by energy conservation, we assume that all of the potential energy is converted to kinetic energy during the acceleration process. Thus the kinetic energy has increased by a factor of 4 also. Finally, since the speed is proportional to the square root of kinetic energy, the speed must increase by a factor of 2.

5. The electric field is zero at the midpoint of the line segment joining the two equal positive charges. The electric field due to each charge is of the same magnitude at that location, because the location is equidistant from both charges, but the two fields are in the opposite direction. Thus the net electric field is zero there. The electric potential is never zero along that line, except at infinity. The electric potential due to each charge is positive, and so the total potential, which is the algebraic sum of the two potentials, is always positive.

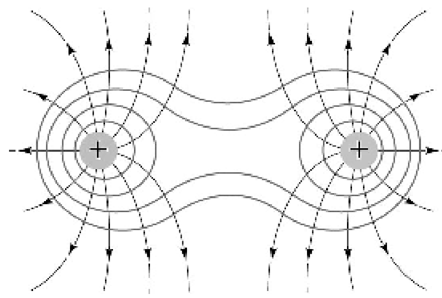
6. A negative particle will have its electric potential energy decrease if it moves from a region of low electric potential to one of high potential. By Eq. 17-3, if the charge is negative and the potential difference is positive, the change in potential energy will be negative, and so decrease.

7. The proton would gain half the kinetic energy as compared to the alpha particle. The alpha particle has twice the charge of the proton, and so has twice the potential energy for the same voltage. Thus the alpha will have twice the kinetic energy of the proton after acceleration.

8. There is no general relationship between the value of V and the value of $\vec{\mathbf{E}}$. Instead, the magnitude of $\vec{\mathbf{E}}$ is equal to the rate at which V decreases over a short distance. Consider the point midway between two positive charges. $\vec{\mathbf{E}}$ is 0 there, but V is high. Or, consider the point midway between two negative charges. $\vec{\mathbf{E}}$ is also 0 there, but V is low, because it is negative. Finally, consider the point midway between positive and negative charges of equal magnitude. There $\vec{\mathbf{E}}$ is not 0, because it points towards the negative charge, but V is zero.

9. Two equipotential lines cannot cross. That would indicate that a region in space had two different values for the potential. For example, if a 40-V line and a 50-V line crossed, then the potential at the point of crossing would be both 40 V and 50 V, which is impossible. Likewise, the electric field is perpendicular to the equipotential lines. If two lines crossed, the electric field at that point would point in two different directions simultaneously, which is not possible.

10. The equipotential lines are drawn so that they are perpendicular to the electric field lines where they cross.



11. The electric field would be zero in a region of space that has the same potential throughout. The electric field is related to the change in potential as you move from place to place. If the potential does not change, then the electric field is zero.

12. The orbit must be a circle. The gravitational potential (or potential energy) depends on the distance from the center of the Earth. If the potential is constant (equipotential line), then the distance from the center of the Earth must be constant, and so the orbit is a circle.

13. (*a*) V would decrease by 10 V at every location.
    (b) E is related to the change in electric potential. Decreasing the potential by 10 V everywhere would not affect the changes in potential from one location to another, and so would not affect E.

14. Any imbalance of charge that might exist would quickly be resolved. Suppose the positive plate, connected to the positive terminal of the battery, had more charge than the negative plate. Then negative charges from the negative battery terminal would be attracted to the negative plate by the more charged positive plate. This would only continue until the negative plate was as charged as the positive plate. If the negative plate became "over charged", then the opposite transfer of charge would take place, again until equilibrium was reached. Another way to explain the balance of charge is that neither the battery nor the capacitor can create or destroy charge. Since they were neutral before they were connected, they must be neutral after they are connected. The charge removed from one plate appears as excess on the other plate. This is true regardless of the conductor size or shape.

15. We meant that the capacitance did not depend on the amount of charge stored or on the potential difference between the capacitor plates. Changing the amount of charge stored or the potential difference will not change the capacitance.

Solutions to Problems

1. The work done by the electric field can be found from Eq. 17-2b.

$$V_{ba} = -\frac{W_{ba}}{q} \rightarrow W_{ba} = -qV_{ba} = -\left(-7.7\times10^{-6}\,\text{C}\right)\left(+55\text{ V}\right) = \boxed{4.2\times10^{-4}\,\text{J}}$$

2. The work done by the electric field can be found from Eq. 17-2b.

$$V_{ba} = -\frac{W_{ba}}{q} \rightarrow W_{ba} = -qV_{ba} = -\left(1.60\times10^{-19}\,\text{C}\right)\left(-1.80\times10^{2}\,\text{V}\right) = \boxed{2.88\times10^{-17}\,\text{J}}$$

$$= -\left(1\,e\right)\left(-180\text{ V}\right) = \boxed{1.80\times10^{2}\,\text{eV}}$$

3. The kinetic energy gained is equal to the work done on the electron by the electric field. The potential difference must be positive for the electron to gain potential energy. Use Eq. 17-2b.

$$V_{ba} = -\frac{W_{ba}}{q} \rightarrow W_{ba} = -qV_{ba} = -\left(-1.60\times10^{-19}\,\text{C}\right)\left(2.3\times10^{4}\,\text{V}\right) = \boxed{3.7\times10^{-15}\,\text{J}}$$

$$= -\left(-1\,e\right)\left(2.3\times10^{4}\,\text{V}\right) = \boxed{2.3\times10^{4}\,\text{eV}}$$

4. The kinetic energy gained by the electron is the work done by the electric force. Use Eq. 17-2b to calculate the potential difference.

$$V_{ba} = -\frac{W_{ba}}{q} = -\frac{7.45\times10^{-17}\,\text{J}}{\left(-1.60\times10^{-19}\,\text{C}\right)} = \boxed{466\,\text{V}}$$

The electron moves from low potential to high potential, so $\boxed{\text{plate B}}$ is at the higher potential.

5. The magnitude of the electric field can be found from Eq. 17-4b.

$$E = \frac{V_{ba}}{d} = \frac{220\text{ V}}{5.8\times10^{-3}\,\text{m}} = \boxed{3.8\times10^{4}\text{ V/m}}$$

6. The magnitude of the voltage can be found from Eq. 17-4b.

$$E = \frac{V_{ba}}{d} \rightarrow V_{ba} = Ed = \left(640\,\text{V/m}\right)\left(11.0\times10^{-3}\,\text{m}\right) = \boxed{7.0\,\text{V}}$$

7. The distance between the plates can be found from Eq. 17-4b.

$$E = \frac{V_{ba}}{d} \rightarrow d = \frac{V_{ba}}{E} = \frac{45\text{ V}}{1500\,\text{V/m}} = \boxed{3.0\times10^{-2}\,\text{m}}$$

8. The gain of kinetic energy comes from a loss of potential energy due to conservation of energy, and the magnitude of the potential difference is the energy per unit charge.

$$\Delta V = \frac{\Delta\text{PE}}{q} = -\frac{\Delta\text{KE}}{q} = \frac{65.0\times10^{3}\,\text{eV}}{2e} = \boxed{-3.25\times10^{4}\,\text{V}}$$

The negative sign indicates that the helium nucleus had to go from a higher potential to a lower potential.

9. Find the distance corresponding to the maximum electric field, using Eq. 17-4b.

$$E = \frac{V_{ba}}{d} \rightarrow d = \frac{V_{ba}}{E} = \frac{200\text{ V}}{3\times10^{6}\text{ V/m}} = 6.67\times10^{-5}\text{ m} \approx \boxed{7\times10^{-5}\text{ m}}$$

10. By the work energy theorem, the total work done, by the external force and the electric field together, is the change in kinetic energy. The work done by the electric field is given by Eq. 17-2b.

$$W_{\text{external}} + W_{\text{electric}} = \text{KE}_{\text{final}} - \text{KE}_{\text{initial}} \rightarrow W_{\text{external}} - q\left(V_b - V_a\right) = \text{KE}_{\text{final}} \rightarrow$$

$$\left(V_b - V_a\right) = \frac{W_{\text{external}} - \text{KE}_{\text{final}}}{q} = \frac{15.0\times10^{-4}\text{ J} - 4.82\times10^{-4}\text{ J}}{-8.50\times10^{-6}\text{C}} = \boxed{-1.20\times10^{2}\text{ V}}$$

11. The kinetic energy of the electron is given in each case. Use the kinetic energy to find the speed.

(*a*) $\frac{1}{2}mv^2 = \text{KE} \rightarrow v = \sqrt{\frac{2\text{KE}}{m}} = \sqrt{\frac{2\left(750\text{ eV}\right)\left(1.60\times10^{-19}\text{ J/eV}\right)}{9.11\times10^{-31}\text{kg}}} = \boxed{1.6\times10^{7}\text{ m/s}}$

(*b*) $\frac{1}{2}mv^2 = \text{KE} \rightarrow v = \sqrt{\frac{2\text{KE}}{m}} = \sqrt{\frac{2\left(3.2\times10^{3}\text{eV}\right)\left(1.60\times10^{-19}\text{ J/eV}\right)}{9.11\times10^{-31}\text{kg}}} = \boxed{3.4\times10^{7}\text{ m/s}}$

12. The kinetic energy of the proton is given. Use the kinetic energy to find the speed.

$$\frac{1}{2}mv^2 = \text{KE} \rightarrow v = \sqrt{\frac{2\text{KE}}{m}} = \sqrt{\frac{2\left(3.2\times10^{3}\text{eV}\right)\left(1.60\times10^{-19}\text{ J/eV}\right)}{1.67\times10^{-27}\text{ kg}}} = \boxed{7.8\times10^{5}\text{ m/s}}$$

13. The kinetic energy of the alpha particle is given. Use the kinetic energy to find the speed.

$$\frac{1}{2}mv^2 = \text{KE} \rightarrow v = \sqrt{\frac{2\text{KE}}{m}} = \sqrt{\frac{2\left(5.53\times10^{6}\text{eV}\right)\left(1.60\times10^{-19}\text{ J/eV}\right)}{6.64\times10^{-27}\text{ kg}}} = \boxed{1.63\times10^{7}\text{ m/s}}$$

14. Use Eq. 17-5 to find the potential.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \left(8.99\times10^{9}\text{ N}\bullet\text{m}^2/\text{C}^2\right)\frac{4.00\times10^{-6}\text{C}}{1.50\times10^{-1}\text{m}} = \boxed{2.40\times10^{5}\text{V}}$$

15. Use Eq. 17-5 to find the charge.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} \rightarrow Q = \left(4\pi\varepsilon_0\right)rV = \left(\frac{1}{8.99\times10^{9}\text{ N}\bullet\text{m}^2/\text{C}^2}\right)\left(0.15\text{ m}\right)\left(125\text{ V}\right) = \boxed{2.1\times10^{-9}\text{C}}$$

16. The work required is the difference in potential energy between the two locations. The test charge has potential energy due to each of the other charges, given in Conceptual Example 17-7 as $\text{PE} = k\frac{Q_1Q_2}{r}$. So to find the work, calculate the difference in potential energy between the two locations. Let *Q* represent the $35\mu\text{C}$ charge, let *q* represent the $0.50\mu\text{C}$ test charge, and let *d* represent the 32 cm distance.

$$\text{PE}_{\text{initial}} = \frac{kQq}{d/2} + \frac{kQq}{d/2} \qquad \text{PE}_{\text{final}} = \frac{kQq}{\left[d/2 - 0.12\text{ m}\right]} + \frac{kQq}{\left[d/2 + 0.12\text{ m}\right]}$$

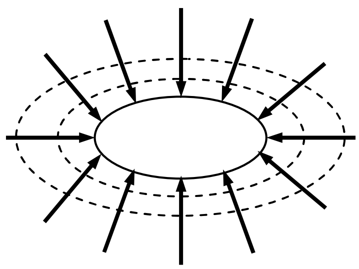
$$\text{Work} = \text{PE}_{\text{final}} - \text{PE}_{\text{initial}} = \frac{kQq}{[d/2 - 0.12\text{ m}]} + \frac{kQq}{[d/2 + 0.12\text{ m}]} - 2\left(\frac{kQq}{d/2}\right)$$

$$= kQq\left[\frac{1}{[0.16\,\text{m} - 0.12\,\text{m}]} + \frac{1}{[0.16\,\text{m} + 0.12\,\text{m}]} - \frac{2}{0.16\,\text{m}}\right]$$

$$= \left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(35\times10^{-6}\,\text{C}\right)\left(0.50\times10^{-6}\,\text{C}\right)\left(16.07\,\text{m}^{-1}\right) = \boxed{2.5\,\text{J}}$$

An external force needs to do positive work to move the charge.

17.



18. (*a*) The electric potential is given by Eq. 17-5.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\frac{1.60\times10^{-19}\,\text{C}}{2.5\times10^{-15}\,\text{m}} = 5.754\times10^{5}\,\text{V} \approx \boxed{5.8\times10^{5}\,\text{V}}$$

(*b*) The potential energy of a pair of charges is derived in Conceptual Example 17.7.

$$\text{PE} = k\frac{Q_1Q_2}{r} = \left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\frac{\left(1.60\times10^{-19}\,\text{C}\right)^2}{2.5\times10^{-15}\,\text{m}} = \boxed{9.2\times10^{-14}\,\text{J}}$$

19. The potential at the corner is the sum of the potentials due to each of the charges, using Eq. 17-5.

$$V = \frac{k(3Q)}{L} + \frac{kQ}{\sqrt{2}L} + \frac{k(-2Q)}{L} = \frac{kQ}{L}\left(1 + \frac{1}{\sqrt{2}}\right) = \boxed{\frac{\sqrt{2}kQ}{2L}\left(\sqrt{2}+1\right)}$$

20. By energy conservation, all of the initial potential energy will change to kinetic energy of the electron when the electron is far away. The other charge is fixed, and so has no kinetic energy. When the electron is far away, there is no potential energy.

$$E_{\text{initial}} = E_{\text{final}} \ \rightarrow\ \text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \ \rightarrow\ \frac{k(-e)(Q)}{r} = \tfrac{1}{2}mv^2 \ \rightarrow$$

$$v = \sqrt{\frac{2k(-e)(Q)}{mr}} = \sqrt{\frac{2\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(-1.60\times10^{-19}\,\text{C}\right)\left(-1.25\times10^{-7}\,\text{C}\right)}{\left(9.11\times10^{-31}\,\text{kg}\right)\left(0.325\,\text{m}\right)}}$$

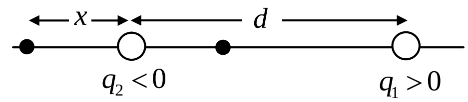
$$= \boxed{3.49\times10^{7}\ \text{m/s}}$$

21. By energy conservation, all of the initial potential energy of the charges will change to kinetic energy when the charges are very far away from each other. By momentum conservation, since the initial momentum is zero and the charges have identical masses, the charges will have equal speeds in opposite directions from each other as they move. Thus each charge will have the same kinetic energy.

$$E_{\text{initial}} = E_{\text{final}} \rightarrow \text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \rightarrow \frac{kQ^2}{r} = 2\left(\tfrac{1}{2}mv^2\right) \rightarrow$$

$$v = \sqrt{\frac{kQ^2}{mr}} = \sqrt{\frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(9.5\times10^{-6}\,\text{C}\right)^2}{\left(1.0\times10^{-6}\,\text{kg}\right)\left(0.035\,\text{m}\right)}} = \boxed{4.8\times10^3\ \text{m/s}}$$

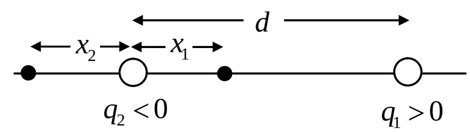
22. (*a*) Because of the inverse square nature of the electric field, any location where the field is zero must be closer to the weaker charge (q_2). Also, in between the two charges, the fields due to the two charges are parallel to each other (both to the left) and cannot cancel. Thus the only places where the field can be zero are closer to the weaker charge, but not between them. In the diagram, this is the point labeled as "*x*". Take to the right as the positive direction.



$$E = k\frac{|q_2|}{x^2} - k\frac{q_1}{(d+x)^2} = 0 \rightarrow |q_2|(d+x)^2 = q_1x^2 \rightarrow$$

$$x = \frac{\sqrt{|q_2|}}{\sqrt{q_1}-\sqrt{|q_2|}}d = \frac{\sqrt{2.0\times10^{-6}\,\text{C}}}{\sqrt{3.0\times10^{-6}\,\text{C}}-\sqrt{2.0\times10^{-6}\,\text{C}}}(5.0\,\text{cm}) = \boxed{22\,\text{cm left of } q_2}$$

(*b*) The potential due to the positive charge is positive everywhere, and the potential due to the negative charge is negative everywhere. Since the negative charge is smaller in magnitude than the positive charge, any point where the potential is zero must be closer to the negative charge. So consider locations between the charges (position x_1) and to the left of the negative charge (position x_2) as shown in the diagram.

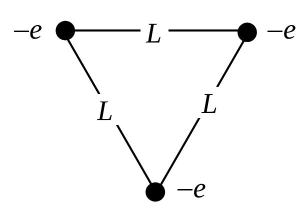


$$V_{\text{location 1}} = \frac{kq_1}{(d-x_1)} + \frac{kq_2}{x_1} = 0 \rightarrow x_1 = \frac{q_2d}{(q_2-q_1)} = \frac{\left(-2.0\times10^{-6}\,\text{C}\right)(5.0\,\text{cm})}{\left(-5.0\times10^{-6}\,\text{C}\right)} = 2.0\,\text{cm}$$

$$V_{\text{location 2}} = \frac{kq_1}{(d+x_2)} + \frac{kq_2}{x_2} = 0 \rightarrow x_2 = -\frac{q_2d}{(q_1+q_2)} = -\frac{\left(-2.0\times10^{-6}\,\text{C}\right)(5.0\,\text{cm})}{\left(1.0\times10^{-6}\,\text{C}\right)} = 10.0\,\text{cm}$$

So the two locations where the potential is zero are 2.0 cm from the negative charge towards the positive charge, and 10.0 cm from the negative charge away from the positive charge.

23. Let the side length of the equilateral triangle be *L*. Imagine bringing the electrons in from infinity one at a time. It takes no work to bring the first electron to its final location, because there are no other charges present. Thus $W_1 = 0$. The work done in bringing in the second electron to its final location is equal to the charge on the electron times the potential (due to the first electron) at the final location of the second electron.



Thus $W_2 = (-e)\left(-\frac{ke}{L}\right) = \frac{ke^2}{L}$. The work done in bringing the third electron to its final location is equal to the charge on the electron times the potential (due to the first two electrons). Thus $W_3 = (-e)\left(-\frac{ke}{L}-\frac{ke}{L}\right) = \frac{2ke^2}{L}$. The total work done is the sum $W_1 + W_2 + W_3$.

$$W = W_1 + W_2 + W_3 = 0 + \frac{ke^2}{L} + \frac{2ke^2}{L} = \frac{3ke^2}{L} = \frac{3\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\,\text{C}\right)^2}{\left(1.0\times10^{-10}\,\text{m}\right)}$$

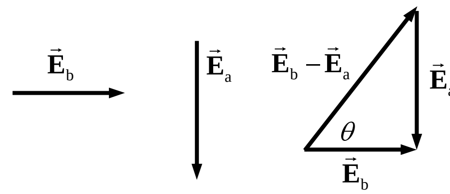
$$= \boxed{6.9\times10^{-18}\,\text{J}}$$

24. (*a*) The potential due to a point charge is given by Eq. 17.5

$$V_{\text{ba}} = V_{\text{b}} - V_{\text{a}} = \frac{kq}{r_{\text{b}}} - \frac{kq}{r_{\text{a}}} = kq\left(\frac{1}{r_{\text{b}}} - \frac{1}{r_{\text{a}}}\right)$$

$$= \left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(-3.8\times10^{-6}\,\text{C}\right)\left(\frac{1}{0.88\,\text{m}} - \frac{1}{0.72\,\text{m}}\right) = \boxed{8.6\times10^3\,\text{V}}$$

(*b*) The magnitude of the electric field due to a point charge is given by Eq. 16-4a. The direction of the electric field due to a negative charge is towards the charge, so the field at point a will point downward, and the field at point b will point to the right. See the vector diagram.



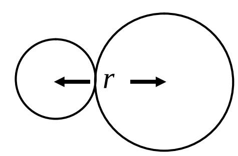
$$\vec{\mathbf{E}}_{\text{b}} = \frac{k|q|}{r_{\text{b}}^2}\ \text{right} = \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(3.8\times10^{-6}\,\text{C}\right)}{\left(0.88\,\text{m}\right)^2}\ \text{right} = 4.4114\times10^4\ \text{V/m, right}$$

$$\vec{\mathbf{E}}_{\text{a}} = \frac{k|q|}{r_{\text{a}}^2}\ \text{down} = \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(3.8\times10^{-6}\,\text{C}\right)}{\left(0.72\,\text{m}\right)^2}\ \text{down} = 6.5899\times10^4\ \text{V/m, down}$$

$$\left|\vec{\mathbf{E}}_{\text{b}} - \vec{\mathbf{E}}_{\text{a}}\right| = \sqrt{E_{\text{a}}^2 + E_{\text{b}}^2} - \sqrt{\left(4.4114\times10^4\ \text{V/m}\right)^2 + \left(6.5899\times10^4\ \text{V/m}\right)^2} = \boxed{7.9\times10^4\ \text{V/m}}$$

$$\theta = \tan^{-1}\frac{E_{\text{a}}}{E_{\text{b}}} = \tan^{-1}\frac{65899}{44114} = \boxed{56^{\text{o}}}$$

25. We assume that all of the energy the proton gains in being accelerated by the voltage is changed to potential energy just as the proton's outer edge reaches the outer radius of the silicon nucleus.



$$\text{PE}_{\text{initial}} = \text{PE}_{\text{final}} \quad\rightarrow\quad eV_{\text{initial}} = k\frac{e(14e)}{r} \quad\rightarrow$$

$$V_{\text{initial}} = k\frac{14e}{r} = \left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\frac{(14)\left(1.60\times10^{-19}\,\text{C}\right)}{(1.2+3.6)\times10^{-15}\text{m}} = \boxed{4.2\times10^6\,\text{V}}$$

26. Use Eq. 17-2b and Eq. 17-5.

$$V_{\text{BA}} = V_{\text{B}} - V_{\text{A}} = \left(\frac{kq}{d-b} + \frac{k(-q)}{b}\right) - \left(\frac{kq}{b} + \frac{k(-q)}{d-b}\right) = kq\left(\frac{1}{d-b} - \frac{1}{b} - \frac{1}{b} + \frac{1}{d-b}\right)$$

$$= 2kq\left(\frac{1}{d-b} - \frac{1}{b}\right) = \boxed{\frac{2kq(2b-d)}{b(d-b)}}$$

27. (*a*) The electric potential is found from Eq. 17-5.

$$V_{\text{initial}} = k\frac{q_{\text{p}}}{r_{\text{atom}}} = \left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\frac{\left(1.60\times10^{-19}\,\text{C}\right)}{0.53\times10^{-10}\text{m}} \approx \boxed{27\,\text{V}}$$

(*b*) The kinetic energy can be found from the fact that the magnitude of the net force on the electron, which is the attraction by the proton, is causing circular motion.

$$\left|F_{\text{net}}\right| = \frac{m_{\text{e}}v^2}{r_{\text{atom}}} = k\frac{q_{\text{p}}\left|q_{\text{e}}\right|}{r_{\text{atom}}^2} \rightarrow m_{\text{e}}v^2 = k\frac{e^2}{r_{\text{atom}}} \rightarrow \text{KE} = \tfrac{1}{2}m_{\text{e}}v^2 = \tfrac{1}{2}k\frac{e^2}{r_{\text{atom}}}$$

$$= \tfrac{1}{2}\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\frac{\left(1.60\times10^{-19}\,\text{C}\right)^2}{\left(0.53\times10^{-10}\text{m}\right)} = 2.171\times10^{-18}\,\text{J} \approx \boxed{2.2\times10^{-18}\,\text{J}}$$

$$= 2.171\times10^{-18}\,\text{J}\times\frac{1\text{eV}}{1.60\times10^{-19}\text{J}} = 13.57\,\text{eV} \approx \boxed{14\,\text{eV}}$$

(*c*) The total energy of the electron is the sum of its KE and PE. The PE is found from Eq. 17-2a, and is negative since the electron's charge is negative.

$$E_{\text{total}} = \text{PE} + \text{KE} = -eV + \tfrac{1}{2}m_{\text{e}}v^2 = -k\frac{e^2}{r_{\text{atom}}} + \tfrac{1}{2}k\frac{e^2}{r_{\text{atom}}} = -\tfrac{1}{2}k\frac{e^2}{r_{\text{atom}}}$$

$$= -2.171\times10^{-18}\,\text{J} \approx \boxed{-2.2\times10^{-18}\,\text{J}} \approx \boxed{-14\,\text{eV}}$$

(*d*) If the electron is taken to infinity at rest, both its PE and KE would be 0. The amount of energy needed by the electron to have a total energy of 0 is just the opposite of the answer to part (c), $\boxed{2.2\times10^{-18}\text{J}}$ or $\boxed{14\,\text{eV}}$.

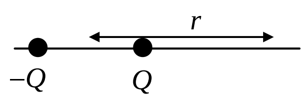
28. The dipole moment is the product of the magnitude of one of the charges times the separation distance.

$$p = Ql = \left(1.60\times10^{-19}\,\text{C}\right)\left(0.53\times10^{-10}\,\text{m}\right) = \boxed{8.5\times10^{-30}\,\text{C}\bullet\text{m}}$$

29. The potential due to the dipole is given by Eq. 17-6b.

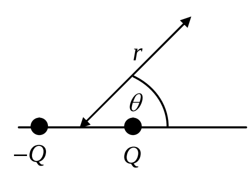
(*a*) $$V = \frac{kp\cos\theta}{r^2} = \frac{\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(4.8\times10^{-30}\,\text{C}\bullet\text{m}\right)\cos 0}{\left(1.1\times10^{-9}\text{m}\right)^2}$$

$$= \boxed{3.6\times10^{-2}\,\text{V}}$$



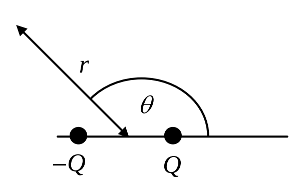
(*b*) $$V = \frac{kp\cos\theta}{r^2} = \frac{\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(4.8\times10^{-30}\,\text{C}\bullet\text{m}\right)\cos 45^\circ}{\left(1.1\times10^{-9}\text{m}\right)^2}$$

$$= \boxed{2.5\times10^{-2}\,\text{V}}$$



(*c*) $$V = \frac{kp\cos\theta}{r^2} = \frac{\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(4.8\times10^{-30}\,\text{C}\bullet\text{m}\right)\cos 135^\circ}{\left(1.1\times10^{-9}\text{m}\right)^2}$$

$$= \boxed{-2.5\times10^{-2}\,\text{V}}$$



30. We assume that $\vec{\mathbf{p}}_1$ and $\vec{\mathbf{p}}_2$ are equal in magnitude, and that each makes a 52° angle with $\vec{\mathbf{p}}$. The magnitude of $\vec{\mathbf{p}}_1$ is also given by $p_1 = qd$, where q is the charge on the hydrogen atom, and d is the distance between the H and the O.

$$p = 2p_1\cos 52^\circ \quad \rightarrow \quad p_1 = \frac{p}{2\cos 52^\circ} = qd \quad \rightarrow$$

$$q = \frac{p}{2d\cos 52^\circ} = \frac{6.1\times10^{-30}\,\mathrm{C\bullet m}}{2\left(0.96\times10^{-10}\,\mathrm{m}\right)\cos 52^\circ} = \boxed{5.2\times10^{-20}\,\mathrm{C}}$$

This is about 0.32 times the charge on an electron.

31. The capacitance is found from Eq. 17-7.

$$Q = CV \quad \rightarrow \quad C = \frac{Q}{V} = \frac{2.5\times10^{-3}\,\mathrm{C}}{850\,\mathrm{V}} = \boxed{2.9\times10^{-6}\,\mathrm{F}}$$

32. The voltage is found from Eq. 17-7.

$$Q = CV \quad \rightarrow \quad V = \frac{Q}{C} = \frac{16.5\times10^{-8}\,\mathrm{C}}{9.5\times10^{-9}\,\mathrm{F}} = \boxed{17.4\,\mathrm{V}}$$

33. The capacitance is found from Eq. 17-7.

$$Q = CV \quad \rightarrow \quad C = \frac{Q}{V} = \frac{95\times10^{-12}\,\mathrm{C}}{120\,\mathrm{V}} = \boxed{7.9\times10^{-13}\,\mathrm{F}}$$

34. We assume the capacitor is fully charged, according to Eq. 17-7.

$$Q = CV = \left(7.00\times10^{-6}\,\mathrm{F}\right)\left(12.0\,\mathrm{V}\right) = \boxed{8.4\times10^{-5}\,\mathrm{C}}$$

35. The area can be found from Eq. 17-8.

$$C = \frac{\varepsilon_0 A}{d} \quad \rightarrow \quad A = \frac{Cd}{\varepsilon_0} = \frac{\left(0.20\,\mathrm{F}\right)\left(2.2\times10^{-3}\,\mathrm{m}\right)}{\left(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2}\right)} = \boxed{5.0\times10^{7}\,\mathrm{m^2}}$$

36. Let Q_1 and V_1 be the initial charge and voltage on the capacitor, and let Q_2 and V_2 be the final charge and voltage on the capacitor. Use Eq. 17-7 to relate the charges and voltages to the capacitance.

$$Q_1 = CV_1 \qquad Q_2 = CV_2 \qquad Q_2 - Q_1 = CV_2 - CV_1 = C\left(V_2 - V_1\right) \quad \rightarrow$$

$$C = \frac{Q_2 - Q_1}{V_2 - V_1} = \frac{18\times10^{-6}\,\mathrm{C}}{24\,\mathrm{V}} = \boxed{7.5\times10^{-7}\,\mathrm{F}}$$

37. The desired electric field is the value of V/d for the capacitor. Combine Eq. 17-7 and Eq. 17-8 to find the charge.

$$Q = CV = \frac{\varepsilon_0 AV}{d} = \varepsilon_0 AE = \left(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2}\right)\left(35.0\times10^{-4}\,\mathrm{m^2}\right)\left(8.50\times10^{5}\,\mathrm{V/m}\right)$$

$$= \boxed{2.63\times10^{-8}\,\mathrm{C}}$$

38. Combine Eq. 17-7 and Eq. 17-8 to find the area.

$$Q = CV = \frac{\varepsilon_0 AV}{d} = \varepsilon_0 AE \quad \rightarrow \quad A = \frac{Q}{\varepsilon_0 E} = \frac{\left(5.2\times10^{-6}\,\mathrm{C}\right)}{\left(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2}\right)\left(\dfrac{2000\,\mathrm{V}}{10^{-3}\mathrm{m}}\right)} = \boxed{0.29\ \mathrm{m^2}}$$

39. From Eq. 17-4a, the voltage across the capacitor is the magnitude of the electric field times the separation distance of the plates. Use that with Eq. 17-7.

$$Q = CV = CEd \quad \rightarrow \quad E = \frac{Q}{Cd} = \frac{\left(72\times10^{-6}\,\mathrm{C}\right)}{\left(0.80\times10^{-6}\,\mathrm{F}\right)\left(2.0\times10^{-3}\,\mathrm{m}\right)} = \boxed{4.5\times10^{4}\ \mathrm{V/m}}$$

40. After the first capacitor is disconnected from the battery, the total charge must remain constant. The voltage across each capacitor must be the same when they are connected together, since each capacitor plate is connected to a corresponding plate on the other capacitor by a constant-potential connecting wire. Use the total charge and the final potential difference to find the value of the second capacitor.

$$Q_{\text{Total}} = C_1 V_{1\,\text{initial}} \qquad Q_{1\,\text{final}} = C_1 V_{\text{final}} \qquad Q_{2\,\text{final}} = C_2 V_{\text{final}}$$

$$Q_{\text{Total}} = Q_{1\,\text{final}} + Q_{2\,\text{final}} = \left(C_1 + C_2\right)V_{\text{final}} \quad \rightarrow \quad C_1 V_{1\,\text{initial}} = \left(C_1 + C_2\right)V_{\text{final}} \quad \rightarrow$$

$$C_2 = C_1\left(\frac{V_{1\,\text{initial}}}{V_{\text{final}}} - 1\right) = \left(7.7\times10^{-6}\,\mathrm{F}\right)\left(\frac{125\,\mathrm{V}}{15\,\mathrm{V}} - 1\right) = \boxed{5.6\times10^{-5}\,\mathrm{F}}$$

41. The total charge on the combination of capacitors is the sum of the charges on the two individual capacitors, since there is no battery connected to them to supply additional charge. The voltage across each capacitor must be the same after they are connected, since each capacitor plate is connected to a corresponding plate on the other capacitor by a constant-potential connecting wire. Use the total charge and the fact of equal potentials to find the charge on each capacitor and the common potential difference.

$$Q_{1\,\text{initial}} = C_1 V_{1\,\text{initial}} \qquad Q_{2\,\text{initial}} = C_2 V_{2\,\text{initial}} \qquad Q_{1\,\text{final}} = C_1 V_{\text{final}} \qquad Q_{2\,\text{final}} = C_2 V_{\text{final}}$$

$$Q_{\text{Total}} = Q_{1\,\text{initial}} + Q_{2\,\text{initial}} = Q_{1\,\text{final}} + Q_{2\,\text{final}} = C_1 V_{1\,\text{initial}} + C_2 V_{2\,\text{initial}} = C_1 V_{\text{final}} + C_2 V_{\text{final}} \quad \rightarrow$$

$$V_{\text{final}} = \frac{C_1 V_{1\,\text{initial}} + C_2 V_{2\,\text{initial}}}{C_1 + C_2} = \frac{\left(2.50\times10^{-6}\,\mathrm{F}\right)\left(875\,\mathrm{V}\right) + \left(6.80\times10^{-6}\,\mathrm{F}\right)\left(652\,\mathrm{V}\right)}{\left(9.30\times10^{-6}\,\mathrm{F}\right)}$$

$$= 711.95\,\mathrm{V} \approx \boxed{712\,\mathrm{V}} = V_1 = V_2$$

$$Q_{1\,\text{final}} = C_1 V_{\text{final}} = \left(2.50\times10^{-6}\,\mathrm{F}\right)\left(711.95\right) = \boxed{1.78\times10^{-3}\,\mathrm{C}}$$

$$Q_{2\,\text{final}} = C_2 V_{\text{final}} = \left(6.80\times10^{-6}\,\mathrm{F}\right)\left(711.95\right) = \boxed{4.84\times10^{-3}\,\mathrm{C}}$$

42. Use Eq. 17-9 to calculate the capacitance with a dielectric.

$$C = K\varepsilon_0 \frac{A}{d} = (2.2)\left(8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)\frac{\left(5.5\times10^{-2}\,\mathrm{m}\right)^2}{\left(1.8\times10^{-3}\,\mathrm{m}\right)} = \boxed{3.3\times10^{-11}\,\mathrm{F}}$$

43. Use Eq. 17-9 to calculate the capacitance with a dielectric.

$$C = K\varepsilon_0 \frac{A}{d} = (7)\left(8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)\frac{\pi\left(5.0\times10^{-2}\,\mathrm{m}\right)^2}{\left(3.2\times10^{-3}\,\mathrm{m}\right)} = \boxed{1.5\times10^{-10}\,\mathrm{F}}$$

44. The initial charge on the capacitor is $Q_{\text{initial}} = C_{\text{initial}}V$. When the mica is inserted, the capacitance changes to $C_{\text{final}} = KC_{\text{initial}}$, and the voltage is unchanged since the capacitor is connected to the same battery. The final charge on the capacitor is $Q_{\text{final}} = C_{\text{final}}V$.

$$\Delta Q = Q_{\text{final}} - Q_{\text{initial}} = C_{\text{final}}V - C_{\text{initial}}V = (K-1)C_{\text{initial}}V = (7-1)\left(3.5\times10^{-9}\,\mathrm{F}\right)(22\,\mathrm{V})$$
$$= \boxed{4.6\times10^{-7}\,\mathrm{C}}$$

45. The capacitance is found from Eq. 17-7, with the voltage given by Eq. 17-4 (ignoring the sign).

$$Q = CV = C(Ed) \quad\rightarrow\quad C = \frac{Q}{Ed} = \frac{0.775\times10^{-6}\,\mathrm{C}}{\left(8.24\times10^{4}\ \mathrm{V/m}\right)\left(1.95\times10^{-3}\,\mathrm{m}\right)} = \boxed{4.82\times10^{-9}\,\mathrm{F}}$$

The plate area is found from Eq. 17-9.

$$C = K\varepsilon_0 \frac{A}{d} \quad\rightarrow\quad A = \frac{Cd}{K\varepsilon_0} = \frac{\left(4.82\times10^{-9}\,\mathrm{F}\right)\left(1.95\times10^{-3}\,\mathrm{m}\right)}{(3.75)\left(8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)} = \boxed{0.283\,\mathrm{m^2}}$$

46. The stored energy is given by Eq. 17-10.

$$\mathrm{PE} = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\left(2.2\times10^{-9}\,\mathrm{F}\right)(650\,\mathrm{V})^2 = \boxed{4.6\times10^{-4}\,\mathrm{J}}$$

47. The capacitance can be found from the stored energy using Eq. 17-10.

$$\mathrm{PE} = \tfrac{1}{2}CV^2 \quad\rightarrow\quad C = \frac{2(\mathrm{PE})}{V^2} = \frac{2(1200\,\mathrm{J})}{\left(5.0\times10^{3}\,\mathrm{V}\right)^2} = \boxed{9.6\times10^{-5}\,\mathrm{F}}$$

48. The two charged plates form a capacitor. Use Eq. 17-8 to calculate the capacitance, and Eq. 17-10 for the energy stored in the capacitor.

$$C = \frac{\varepsilon_0 A}{d} \qquad \mathrm{PE} = \tfrac{1}{2}\frac{Q^2}{C} = \tfrac{1}{2}\frac{Q^2 d}{\varepsilon_0 A} = \tfrac{1}{2}\frac{\left(4.2\times10^{-4}\,\mathrm{C}\right)^2\left(1.5\times10^{-3}\,\mathrm{m}\right)}{\left(8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)\left(8.0\times10^{-2}\,\mathrm{m}\right)^2} = \boxed{2.3\times10^{3}\,\mathrm{J}}$$

49. (*a*) Use Eq. 17-8 to estimate the capacitance.

$$C = \frac{\varepsilon_0 A}{d} = \frac{\left(8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)\pi\left(4.5\,\mathrm{in}\times.0254\,\mathrm{m/in}\right)^2}{\left(5.0\times10^{-2}\,\mathrm{m}\right)} = 7.265\times10^{-12}\,\mathrm{F} \approx \boxed{7\times10^{-12}\,\mathrm{F}}$$

(*b*) Use Eq. 17-7 to estimate the charge on each plate.

$$Q = CV = \left(7.265\times10^{-12}\,\text{F}\right)\left(9\,\text{V}\right) = 6.54\times10^{-11}\,\text{C} \approx \boxed{7\times10^{-11}\,\text{C}}$$

(*c*) Use Eq. 17-4b to estimate the (assumed uniform) electric field between the plates. The actual location of the field measurement is not critical in this approximation.

$$E = \frac{V}{d} = \frac{9\,\text{V}}{5.0\times10^{-2}\,\text{m}} = 180\,\text{V/m} \approx \boxed{200\,\text{V/m}}$$

(*d*) By energy conservation, the work done by the battery to charge the plates is the potential energy stored in the capacitor, given by Eq. 17-10.

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}\left(6.54\times10^{-11}\,\text{C}\right)\left(9\,\text{V}\right) = 2.94\times10^{-10}\,\text{J} \approx \boxed{3\times10^{-10}\,\text{J}}$$

(*e*) If a dielectric is inserted, the $\boxed{\text{capacitance}}$ changes, and so the $\boxed{\text{charge}}$ on the capacitor and the $\boxed{\text{energy}}$ stored also change. The electric field does not change because it only depends on the battery voltage and the plate separation.

50. (*a*) From Eq. 17-8 for the capacitance, $C = \varepsilon_0 \dfrac{A}{d}$, since the separation of the plates is doubled, the capacitance is reduced to half its original value. Then from Eq. 17-10 for the energy, $\text{PE} = \tfrac{1}{2}\dfrac{Q^2}{C}$, since the charge is constant and the capacitance is halved, the energy is doubled. So the energy stored changes by a factor of $\boxed{2}$.

(*b*) The work done to separate the plates is the source of the increase of stored energy. So the work is the change in the stored energy.

$$\text{PE}_{\text{final}} - \text{PE}_{\text{initial}} = 2\text{PE}_{\text{initial}} - \text{PE}_{\text{initial}} = \text{PE}_{\text{initial}} = \tfrac{1}{2}\frac{Q^2}{C} = \tfrac{1}{2}\frac{Q^2}{\varepsilon_0 \frac{A}{d}} = \boxed{\frac{Q^2 d}{2\varepsilon_0 A}}$$

51. (*a*) The energy stored in the capacitor is given by Eq. 17-10, $\text{PE} = \tfrac{1}{2}CV^2$. Assuming the capacitance is constant, then if the potential difference is doubled, the stored energy is $\boxed{\text{multiplied by 4}}$.

(*b*) Now we assume the potential difference is constant, since the capacitor remains connected to a battery. Then the energy stored in the capacitor is given by $\text{PE} = \tfrac{1}{2}QV$, and so the stored energy is $\boxed{\text{multiplied by 2}}$.

52. (*a*) Before the two capacitors are connected, all of the stored energy is in the first capacitor. Use Eq. 17-10.

$$\text{PE} = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\left(2.70\times10^{-6}\,\text{F}\right)\left(12.0\,\text{V}\right)^2 = 1.944\times10^{-4}\,\text{J} \approx \boxed{1.94\times10^{-4}\,\text{J}}$$

(*b*) After the first capacitor is disconnected from the battery, the total charge must remain constant, and the voltage across each capacitor must be the same, since each capacitor plate is connected to a corresponding plate on the other capacitor by a connecting wire which always has a constant potential. Use the total charge and the fact of equal potentials to find the charge on each capacitor, and then calculate the stored energy.

$$Q_{\text{total}} = C_1 V_{\text{initial}} = \left(2.70\times10^{-6}\,\text{F}\right)\left(12.0\,\text{V}\right) = 3.24\times10^{-5}\,\text{C}$$

$$Q_1 = C_1 V \quad Q_2 = C_2 V \quad \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_{\text{total}} - Q_1}{C_2} \rightarrow$$

$$Q_1 = Q_{\text{total}}\frac{C_1}{C_1 + C_2} = \left(3.24\times10^{-5}\,\text{C}\right)\frac{\left(2.70\times10^{-6}\,\text{F}\right)}{\left(6.70\times10^{-6}\,\text{F}\right)} = 1.3057\times10^{-5}\,\text{C}$$

$$\text{Q}_2 = Q_{\text{total}} - Q_1 = 3.24\times10^{-5}\,\text{C} - 1.3057\times10^{-5}\,\text{C} = 1.9343\times10^{-5}\,\text{C}$$

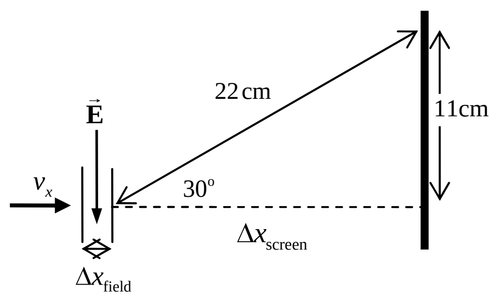
$$\text{PE}_{\text{total}} = \text{PE}_1 + \text{PE}_2 = \tfrac{1}{2}\frac{Q_1^2}{C_1} + \tfrac{1}{2}\frac{Q_2^2}{C_2} = \tfrac{1}{2}\left[\frac{\left(1.3057\times10^{-5}\,\text{C}\right)^2}{\left(2.70\times10^{-6}\,\text{F}\right)} + \frac{\left(1.9343\times10^{-5}\,\text{C}\right)^2}{\left(4.00\times10^{-6}\,\text{F}\right)}\right]$$

$$= \tfrac{1}{2}\left[\frac{\left(1.3057\times10^{-5}\,\text{C}\right)^2}{\left(2.70\times10^{-6}\,\text{F}\right)} + \frac{\left(1.9343\times10^{-5}\,\text{C}\right)^2}{\left(4.00\times10^{-6}\,\text{F}\right)}\right] = \boxed{7.83\times10^{-5}\,\text{J}}$$

(*c*) Subtract the two energies to find the change.

$$\Delta\text{PE} = \text{PE}_{\text{final}} - \text{PE}_{\text{initial}} = 7.83\times10^{-5}\,\text{J} - 1.944\times10^{-4}\,\text{J} = \boxed{-1.16\times10^{-4}\,\text{J}}$$

53. Consider three parts to the electron's motion. First, during the horizontal acceleration phase, energy will be conserved and so the horizontal speed of the electron v_x can be found from the accelerating potential V. Secondly, during the deflection phase, a vertical force will be applied by the uniform electric field which gives the electron an upward velocity, v_y. We assume that there is very little upward displacement during this time. Finally, after the electron leaves the region of electric field, it travels in a straight line to the top of the screen, moving at an angle of approximately 30°.



Acceleration:

$$\text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \rightarrow eV = \tfrac{1}{2}mv_x^2 \rightarrow v_x = \sqrt{\frac{2eV}{m}}$$

Deflection:

$$\text{time in field: } \Delta x_{\text{field}} = v_x t_{\text{field}} \rightarrow t_{\text{field}} = \frac{\Delta x_{\text{field}}}{v_x}$$

$$F_y = eE = ma_y \rightarrow a_y = \frac{eE}{m} \qquad v_y = v_0 + a_y t_{\text{field}} = 0 + \frac{eE\Delta x_{\text{field}}}{mv_x}$$

Screen:

$$\Delta x_{\text{screen}} = v_x t_{\text{screen}} \rightarrow t_{\text{screen}} = \frac{\Delta x_{\text{screen}}}{v_x} \qquad \Delta y_{\text{screen}} = v_y t_{\text{screen}} = v_y\frac{\Delta x_{\text{screen}}}{v_x}$$

$$\frac{\Delta y_{\text{screen}}}{\Delta x_{\text{screen}}} = \frac{v_y}{v_x} = \frac{\dfrac{eE\Delta x_{\text{field}}}{mv_x}}{v_x} = \frac{eE\Delta x_{\text{field}}}{mv_x^2} \rightarrow$$

$$E=\frac{\Delta y_{\text{screen}} m v_x^2}{\Delta x_{\text{screen}} e \Delta x_{\text{field}}}=\frac{\Delta y_{\text{screen}} m \dfrac{2eV}{m}}{\Delta x_{\text{screen}} e \Delta x_{\text{field}}}=\frac{2V\Delta y_{\text{screen}}}{\Delta x_{\text{screen}}\Delta x_{\text{field}}}=\frac{2\left(7.0\times10^3\,\text{V}\right)\left(0.11\,\text{m}\right)}{\left[\left(0.22\text{ m}\right)\cos 30^\circ\right]\left(0.028\,\text{m}\right)}$$

$$=2.89\times10^5\ \text{V/m}\approx\boxed{2.9\times10^5\ \text{V/m}}$$

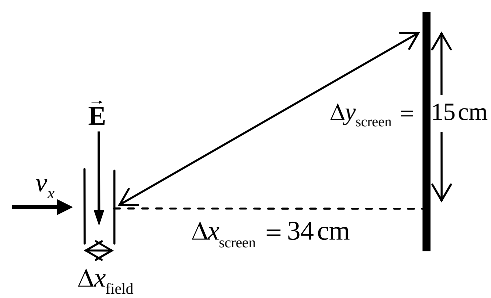
As a check on our assumptions, we calculate the upward distance that the electron would move while in the electric field.

$$\Delta y=v_0 t_{\text{field}}+\tfrac{1}{2}a_y t_{\text{field}}^2=0+\tfrac{1}{2}\left(\frac{eE}{m}\right)\left(\frac{\Delta x_{\text{field}}}{v_x}\right)^2=\frac{eE\left(\Delta x_{\text{field}}\right)^2}{2m\left(\dfrac{2eV}{m}\right)}=\frac{E\left(\Delta x_{\text{field}}\right)^2}{4V}$$

$$=\frac{\left(2.89\times10^5\ \text{V/m}\right)\left(2.8\times10^{-2}\,\text{m}\right)^2}{4\left(7000\,\text{V}\right)}=8\times10^{-3}\,\text{m}$$

This is about 7% of the total 11 cm vertical deflection, and so for an estimation, our approximation is acceptable.

54. If there were no deflecting field, the electrons would hit the center of the screen. If an electric field of a certain direction moves the electrons towards one extreme of the screen, then the opposite field will move the electrons to the opposite extreme of the screen. So we solve for the field to move the electrons to one extreme of the screen. Consider three parts to the electron's motion, and see the diagram, which is a top view. First, during the horizontal acceleration phase, energy will be conserved and so the horizontal speed of the electron v_x can be found from the accelerating potential V. Secondly, during the deflection phase, a vertical force will be applied by the uniform electric field which gives the electron a leftward velocity, v_y. We assume that there is very little leftward displacement during this time. Finally, after the electron leaves the region of electric field, it travels in a straight line to the left edge of the screen.



Acceleration:

$$\text{PE}_{\text{initial}}=\text{KE}_{\text{final}}\ \rightarrow\ eV=\tfrac{1}{2}mv_x^2\ \rightarrow\ v_x=\sqrt{\frac{2eV}{m}}$$

Deflection:

$$\text{time in field: }\Delta x_{\text{field}}=v_x t_{\text{field}}\ \rightarrow\ t_{\text{field}}=\frac{\Delta x_{\text{field}}}{v_x}$$

$$F_y=eE=ma_y\ \rightarrow\ a_y=\frac{eE}{m}\qquad v_y=v_0+a_y t_{\text{field}}=0+\frac{eE\Delta x_{\text{field}}}{mv_x}$$

Screen:

$$\Delta x_{\text{screen}}=v_x t_{\text{screen}}\ \rightarrow\ t_{\text{screen}}=\frac{\Delta x_{\text{screen}}}{v_x}\qquad \Delta y_{\text{screen}}=v_y t_{\text{screen}}=v_y\frac{\Delta x_{\text{screen}}}{v_x}$$

$$\frac{\Delta y_{\text{screen}}}{\Delta x_{\text{screen}}}=\frac{v_y}{v_x}=\frac{\dfrac{eE\Delta x_{\text{field}}}{mv_x}}{v_x}=\frac{eE\Delta x_{\text{field}}}{mv_x^2}\ \rightarrow$$

$$E=\frac{\Delta y_{\text{screen}} m v_x^2}{\Delta x_{\text{screen}} e \Delta x_{\text{field}}}=\frac{\Delta y_{\text{screen}} m \frac{2eV}{m}}{\Delta x_{\text{screen}} e \Delta x_{\text{field}}}=\frac{2V\Delta y_{\text{screen}}}{\Delta x_{\text{screen}}\Delta x_{\text{field}}}=\frac{2\left(6.0\times10^3\,\text{V}\right)\left(0.15\,\text{m}\right)}{\left(0.34\text{ m}\right)\left(0.026\,\text{m}\right)}$$

$$=2.04\times10^5\ \text{V/m}\approx2.0\times10^5\ \text{V/m}$$

As a check on our assumptions, we calculate the upward distance that the electron would move while in the electric field.

$$\Delta y=v_0 t_{\text{field}}+\tfrac{1}{2}a_y t_{\text{field}}^2=0+\tfrac{1}{2}\left(\frac{eE}{m}\right)\left(\frac{\Delta x_{\text{field}}}{v_x}\right)^2=\frac{eE\left(\Delta x_{\text{field}}\right)^2}{2m\left(\frac{2eV}{m}\right)}=\frac{E\left(\Delta x_{\text{field}}\right)^2}{4V}$$

$$=\frac{\left(2.04\times10^5\ \text{V/m}\right)\left(2.6\times10^{-2}\,\text{m}\right)^2}{4\left(6000\,\text{V}\right)}=6\times10^{-3}\,\text{m}$$

This is about 4% of the total 15 cm vertical deflection, and so for an estimation, our approximation is acceptable. And so the field must vary from $\boxed{+2.0\times10^5\ \text{V/m to }-2.0\times10^5\ \text{V/m}}$

55. (*a*) The electron was accelerated through a potential difference –6.3 kV in gaining 6.3 keV of KE. The proton is accelerated through the opposite potential difference as the electron, and has the exact opposite charge. Thus the proton gains the same KE, $\boxed{6.3\text{ keV}}$.

(*b*) Both the proton and the electron have the same KE. Use that to find the ratio of the speeds.

$$\tfrac{1}{2}m_p v_p^2=\tfrac{1}{2}m_e v_e^2\quad\rightarrow\quad\frac{v_e}{v_p}=\sqrt{\frac{m_p}{m_e}}=\sqrt{\frac{1.67\times10^{-27}\,\text{kg}}{9.11\times10^{-31}\,\text{kg}}}=\boxed{42.8}$$

56. (*a*) The energy is related to the charge and the potential difference by Eq. 17-3.

$$\Delta\text{PE}=q\Delta V\quad\rightarrow\quad\Delta V=\frac{\Delta\text{PE}}{q}=\frac{4.2\times10^6\,\text{J}}{4.0\,\text{C}}=1.05\times10^6\,\text{V}\approx\boxed{1.1\times10^6\,\text{V}}$$

(*b*) The energy (as heat energy) is used to raise the temperature of the water and boil it. Assume that room temperature is 20°C.

$$Q=mc\Delta T+mL_f\quad\rightarrow$$

$$m=\frac{Q}{c\Delta T+L_f}=\frac{4.2\times10^6\,\text{J}}{\left(4186\frac{\text{J}}{\text{kg}\bullet{}^\circ\text{C}}\right)\left(80\,\text{C}^\circ\right)+\left(22.6\times10^5\,\frac{\text{J}}{\text{kg}}\right)}=\boxed{1.6\,\text{kg}}$$

57. The energy density is given by Eq. 17-11.

$$\text{Energy density}=\tfrac{1}{2}\varepsilon_0 E^2=\tfrac{1}{2}\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(150\,\text{V/m}\right)^2=\boxed{1.0\times10^{-7}\ \text{J/m}^3}$$

58. The electric force on the electron must be the same magnitude as the weight of the electron. The magnitude of the electric force is the charge on the electron times the magnitude of the electric field. The electric field is the potential difference per meter: $E=V/d$.

$$F_E=mg\quad\rightarrow\quad eV/d=mg\quad\rightarrow$$

$$V=\frac{mgd}{e}=\frac{\left(9.11\times10^{-31}\text{kg}\right)\left(9.80\,\text{m/s}^2\right)\left(3.0\times10^{-2}\,\text{m}\right)}{1.60\times10^{-19}\text{C}}=\boxed{1.7\times10^{-12}\,\text{V}}$$

Since it takes such a tiny voltage to balance gravity, the thousands of volts in a television set are more than enough (by many orders of magnitude) to move electrons upward against the force of gravity.

59. The energy in the capacitor, given by Eq. 17-10, is the heat energy absorbed by the water, given by Eq. 14-2.

$$\mathrm{PE} = Q_{\text{heat}} \quad \rightarrow \quad \tfrac{1}{2}CV^2 = mc\Delta T \quad \rightarrow$$

$$V = \sqrt{\frac{2mc\Delta T}{C}} = \sqrt{\frac{2(2.5\,\text{kg})\left(4186\,\frac{\text{J}}{\text{kg}\bullet{}^\circ\text{C}}\right)(95^\circ\text{C} - 21\text{C}^\circ)}{4.0\,\text{F}}} = 622\,\text{V} \approx \boxed{620\,\text{V}}$$

60. Since the capacitor is disconnected from the battery, the charge on it cannot change. The capacitance of the capacitor is increased by a factor of *K*, the dielectric constant.

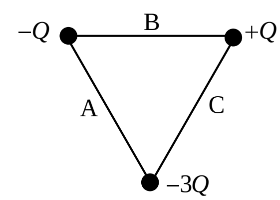
$$Q = C_{\text{initial}}V_{\text{initial}} = C_{\text{final}}V_{\text{final}} \quad \rightarrow \quad V_{\text{final}} = V_{\text{initial}}\frac{C_{\text{initial}}}{C_{\text{final}}} = V_{\text{initial}}\frac{C_{\text{initial}}}{KC_{\text{initial}}} = (24.0\,\text{V})\frac{1}{2.2} = \boxed{11\,\text{V}}$$

61. Combine Eq. 17-7 with Eq. 17-8 and Eq. 17-4.

$$Q = CV = \frac{\varepsilon_0 A}{d}V = \varepsilon_0 A\frac{V}{d} = \varepsilon_0 AE = \left(8.85\times10^{-12}\,\text{C}^2/\text{N}\cdot\text{m}^2\right)\left(56\times10^{-4}\,\text{m}^2\right)\left(3.0\times10^6\,\text{V/m}\right)$$

$$= \boxed{1.5\times10^{-7}\,\text{C}}$$

62. Use Eq. 17-5 to find the potential due to each charge. Since the triangle is equilateral, the 30-60-90 triangle relationship says that the distance from a corner to the midpoint of the opposite side is $\sqrt{3}L/2$.

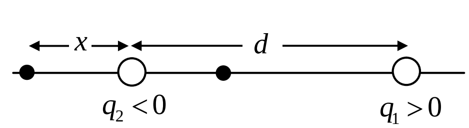


$$V_{\text{A}} = \frac{k(-Q)}{L/2} + \frac{k(-3Q)}{L/2} + \frac{k(Q)}{\sqrt{3}L/2} = \frac{2kQ}{L}\left(-4 + \frac{1}{\sqrt{3}}\right) = \boxed{-6.85\frac{kQ}{L}}$$

$$V_{\text{B}} = \frac{k(-Q)}{L/2} + \frac{k(Q)}{L/2} + \frac{k(-3Q)}{\sqrt{3}L/2} = -\frac{6kQ}{\sqrt{3}L} = \boxed{-3.46\frac{kQ}{L}}$$

$$V_{\text{C}} = \frac{k(Q)}{L/2} + \frac{k(-3Q)}{L/2} + \frac{k(-Q)}{\sqrt{3}L/2} = -\frac{2kQ}{L}\left(2 + \frac{1}{\sqrt{3}}\right) = \boxed{-5.15\frac{kQ}{L}}$$

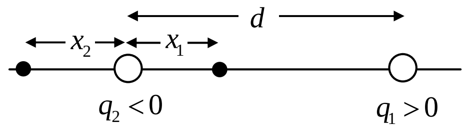
63. (*a*) Because of the inverse square nature of the electric field, any location where the field is zero must be closer to the weaker charge (q_2). Also, in between the two charges, the fields due to the two charges are parallel to each other (both to the left) and cannot cancel. Thus the only places where the field can be zero are closer to the weaker charge, but not between them. In the diagram, this is the point labeled as "*x*". Take to the right as the positive direction.



$$E = k\frac{|q_2|}{x^2} - k\frac{q_1}{(d+x)^2} = 0 \quad \rightarrow \quad |q_2|(d+x)^2 = q_1x^2 \quad \rightarrow$$

$$x = \frac{\sqrt{|q_2|}}{\sqrt{q_1} - \sqrt{|q_2|}} d = \frac{\sqrt{2.6\times10^{-6}\,\mathrm{C}}}{\sqrt{3.4\times10^{-6}\,\mathrm{C}} - \sqrt{2.6\times10^{-6}\,\mathrm{C}}}(1.6\,\mathrm{cm}) = \boxed{11.1\,\mathrm{cm\ left\ of}\ q_2}$$

(*b*) The potential due to the positive charge is positive everywhere, and the potential due to the negative charge is negative everywhere. Since the negative charge is smaller in magnitude than the positive charge, any point where the potential is zero must be closer to the negative charge. So consider locations between the charges (position x_1) and to the left of the negative charge (position x_2) as shown in the diagram.



$$V_{\text{location 1}} = \frac{kq_1}{(d-x_1)} + \frac{kq_2}{x_1} = 0 \;\rightarrow\; x_1 = \frac{q_2 d}{(q_2 - q_1)} = \frac{(-2.6\times10^{-6}\,\mathrm{C})(1.6\,\mathrm{cm})}{(-6.0\times10^{-6}\,\mathrm{C})} = 0.69\,\mathrm{cm}$$

$$V_{\text{location 2}} = \frac{kq_1}{(d+x_2)} + \frac{kq_2}{x_2} = 0 \;\rightarrow\; x_2 = -\frac{q_2 d}{(q_1 + q_2)} = -\frac{(-2.6\times10^{-6}\,\mathrm{C})(1.6\,\mathrm{cm})}{(0.8\times10^{-6}\,\mathrm{C})} = 5.2\,\mathrm{cm}$$

So the two locations where the potential is zero are **0.7 cm from the negative charge towards the positive charge, and 5.2 cm from the negative charge away from the positive charge.**

64. The voltage across the capacitor stays constant since the capacitor remains connected to the battery. The capacitance changes according to Eq. 17-9.

$$C_{\text{initial}} = \frac{\varepsilon_0 A}{d} = 2600\times10^{-12}\,\mathrm{F} \qquad C_{\text{final}} = K\frac{\varepsilon_0 A}{d} = KC_{\text{initial}} = 5C_{\text{initial}}$$

$$Q_{\text{final}} - Q_{\text{initial}} = C_{\text{final}}V - C_{\text{initial}}V = (5C_{\text{intial}} - C_{\text{initial}})V = 4C_{\text{initial}}V = 4(2600\times10^{-12}\,\mathrm{F})(9.0\,\mathrm{V})$$

$$= \boxed{9.4\times10^{-8}\,\mathrm{C}}$$

65. To find the angle, the horizontal and vertical components of the velocity are needed. The horizontal component can be found using conservation of energy for the initial acceleration of the electron. That component is not changed as the electron passes through the plates. The vertical component can be found using the vertical acceleration due to the potential difference of the plates, and the time the electron spends between the plates.

Horizontal:

$$\mathrm{PE}_{\text{inital}} = \mathrm{KE}_{\text{final}} \;\rightarrow\; qV = \tfrac{1}{2}mv_x^2 \qquad t = \frac{\Delta x}{v_x}$$

Vertical:

$$F_{\mathrm{E}} = qE_y = ma = m\frac{(v_y - v_{y0})}{t} \;\rightarrow\; v_y = \frac{qE_y t}{m} = \frac{qE_y \Delta x}{mv_x}$$

Combined:

$$\tan\theta = \frac{v_y}{v_x} = \frac{\dfrac{qE_y\Delta x}{mv_x}}{v_x} = \frac{qE_y\Delta x}{mv_x^2} = \frac{qE_y\Delta x}{2qV} = \frac{E_y\Delta x}{2V} = \frac{\left(\dfrac{250\,\mathrm{V}}{0.013\,\mathrm{m}}\right)(0.065\,\mathrm{m})}{2(5{,}500\,\mathrm{V})} = 0.1136$$

$$\theta = \tan^{-1} 0.1136 = \boxed{6.5^\circ}$$

66. There is no other source of charge except for the original capacitor. Thus the total charge must remain at Q_0. Also, since the plates of the one capacitor are connected via equipotential wires to the plate of the other capacitor, the two capacitors must have the same voltage across their plates. Use the total charge and fact of equal potentials to find the charge on each capacitor and the common potential difference.

$$Q_0 = Q_1 + Q_2 \quad Q_1 = C_1V \quad Q_2 = C_2V \quad Q_0 = C_1V + C_2V = (C_1 + C_2)V \quad \rightarrow \quad V = \boxed{\frac{Q_0}{C_1 + C_2}}$$

$$Q_1 = C_1V = \boxed{Q_0 \frac{C_1}{C_1 + C_2}} \qquad Q_2 = C_2V = \boxed{Q_0 \frac{C_2}{C_1 + C_2}}$$

67. Use Eq. 17-8 for the capacitance.

$$C = \frac{\varepsilon_0 A}{d} \quad \rightarrow \quad d = \frac{\varepsilon_0 A}{C} = \frac{(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)(1.0\times10^{-4}\ \text{m}^2)}{(1\text{F})} = \boxed{9\times10^{-16}\ \text{m}}$$

$\boxed{\text{No}}$, this is not practically achievable. The gap would have to be smaller than the radius of a proton.

68. Since the E-field points downward, the surface of the Earth is a lower potential than points above the surface. Call the surface of the Earth 0 volts. Then a height of 2.00 m has a potential of 300 V. We also call the surface of the Earth the 0 location for gravitational PE. Write conservation of energy relating the charged spheres at 2.00 m (where their speed is 0) and at ground level (where their electrical and gravitational potential energies are 0).

$$E_{\text{initial}} = E_{\text{final}} \quad \rightarrow \quad mgh + qV = \tfrac{1}{2}mv^2 \quad \rightarrow \quad v = \sqrt{2\left(gh + \frac{qV}{m}\right)}$$

$$v_+ = \sqrt{2\left[(9.80\ \text{m/s}^2)(2.00\ \text{m}) + \frac{(6.5\times10^{-4}\ \text{C})(300\ \text{V})}{(0.540\ \text{kg})}\right]} = 6.3184\ \text{m/s}$$

$$v_- = \sqrt{2\left[(9.80\ \text{m/s}^2)(2.00\ \text{m}) + \frac{(-6.5\times10^{-4}\ \text{C})(300\ \text{V})}{(0.540\ \text{kg})}\right]} = 6.2030\ \text{m/s}$$

$$v_+ - v_- = 6.3184\ \text{m/s} - 6.2030\ \text{m/s} = \boxed{0.12\ \text{m/s}}$$

69. (*a*) Use Eq. 17-10 to calculate the stored energy.

$$\text{PE} = \tfrac{1}{2}CV^2 = \tfrac{1}{2}(5.0\times10^{-8}\ \text{F})(3.0\times10^4\ \text{V})^2 = 22.5\ \text{J} \sim \boxed{23\ \text{J}}$$

(*b*) The power is the energy converted per unit time.

$$P = \frac{\text{Energy}}{\text{time}} = \frac{0.12(22.5\ \text{J})}{8.0\times10^{-6}\ \text{s}} = \boxed{3.4\times10^5\ \text{W}}$$

70. (*a*) Use Eq. 17-8.

$$C = \frac{\varepsilon_0 A}{d} = \frac{(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)(110\times10^6\ \text{m}^2)}{(1500\ \text{m})} = 6.49\times10^{-7}\ \text{F} \approx \boxed{6.5\times10^{-7}\ \text{F}}$$

(*b*) Use Eq. 17-7.

$$Q = CV = \left(6.49\times10^{-7}\,\text{F}\right)\left(3.5\times10^{7}\,\text{V}\right) = 22.715\,\text{C} \approx \boxed{23\,\text{C}}$$

(*c*) Use Eq. 17-10.

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}\left(22.715\,\text{C}\right)\left(3.5\times10^{7}\,\text{V}\right) = \boxed{4.0\times10^{8}\,\text{J}}$$

71. The kinetic energy of the electrons (provided by the UV light) is converted completely to potential energy at the plate since they are stopped. Use energy conservation to find the emitted speed, taking the 0 of PE to be at the surface of the barium.

$$\text{KE}_{\text{initial}} = \text{PE}_{\text{final}} \quad\rightarrow\quad \tfrac{1}{2}mv^2 = qV \quad\rightarrow$$

$$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2\left(-1.60\times10^{-19}\,\text{C}\right)\left(-3.02\,\text{V}\right)}{9.11\times10^{-31}\,\text{kg}}} = \boxed{1.03\times10^{6}\,\text{m/s}}$$

72. Let d_1 represent the distance from the left charge to point b, and let d_2 represent the distance from the right charge to point b. Let Q represent the positive charges, and let q represent the negative charge that moves. The change in potential energy is given by Eq. 17-3, $\text{PE}_\text{b} - \text{PE}_\text{a} = qV_{\text{ba}} = q\left(V_\text{b} - V_\text{a}\right)$.

$$d_1 = \sqrt{12^2 + 14^2}\,\text{cm} = 18.44\ \text{cm} \qquad d_2 = \sqrt{14^2 + 24^2}\,\text{cm} = 27.78\ \text{cm}$$

$$\text{PE}_\text{b} - \text{PE}_\text{a} = q\left(V_\text{b} - V_\text{a}\right) = q\left[\left(\frac{kQ}{0.1844\,\text{m}} + \frac{kQ}{0.2778\,\text{m}}\right) - \left(\frac{kQ}{0.12\,\text{m}} + \frac{kQ}{0.24\,\text{m}}\right)\right]$$

$$= kQq\left[\left(\frac{1}{0.1844\,\text{m}} + \frac{1}{0.2778\,\text{m}}\right) - \left(\frac{1}{0.12\,\text{m}} + \frac{1}{0.24\,\text{m}}\right)\right]$$

$$= \left(8.99\times10^{9}\right)\left(-1.5\times10^{-6}\,\text{C}\right)\left(33\times10^{-6}\,\text{C}\right)\left(-3.477\,\text{m}^{-1}\right) = 1.547\,\text{J} \approx \boxed{1.5\,\text{J}}$$

73. Use Eq. 17-7 with Eq. 17-9 to find the charge.

$$Q = CV = K\varepsilon_0\frac{A}{d}V = (3.7)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\cdot\text{m}^2\right)\frac{\pi\left(0.55\times10^{-2}\,\text{m}\right)^2}{\left(0.15\times10^{-3}\,\text{m}\right)}\left(12\,\text{V}\right) = \boxed{2.5\times10^{-10}\,\text{C}}$$

74. (*a*) Use Eq. 17-5 to calculate the potential due to the charges. Let the distance between the charges be *d*.

$$V_{\text{mid}} = \frac{kQ_1}{(d/2)} + \frac{kQ_2}{(d/2)} = \frac{2k}{d}\left(Q_1 + Q_2\right) = \frac{2\left(8.99\times10^{9}\,\text{N}\bullet\text{m}^2/\text{C}^2\right)}{\left(0.23\,\text{m}\right)}\left(4.5\times10^{-6}\,\text{C} - 8.2\times10^{-6}\,\text{C}\right)$$

$$= \boxed{-2.9\times10^{5}\,\text{V}}$$

(*b*) Use Eq. 16-4b to calculate the electric field. Note that the field due to each of the two charges will point to the left, away from the positive charge and towards the negative charge. Find the magnitude of the field using the absolute value of the charges.

$$E_{\text{mid}} = \frac{kQ_1}{(d/2)^2} + \frac{k\left|Q_2\right|}{(d/2)^2} = \frac{4k}{d^2}\left(Q_1 + \left|Q_2\right|\right)$$

$$= \frac{4\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)}{\left(0.23\,\text{m}\right)^2}\left(4.5\times10^{-6}\,\text{C}+8.2\times10^{-6}\,\text{C}\right) = \boxed{8.6\times10^{6}\ \text{V/m, left}}$$

75. (*a*) Use Eq. 17-7 and Eq. 17-8 to calculate the charge.

$$Q = CV = \frac{\varepsilon_0 A}{d}V = \frac{\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(2.0\times10^{-4}\,\text{m}^2\right)}{\left(5.0\times10^{-4}\,\text{m}\right)}\left(12\,\text{V}\right) = 4.248\times10^{-11}\,\text{C}$$

$$\approx \boxed{4.2\times10^{-11}\text{C}}$$

(*b*) The charge does not change. Since the capacitor is not connected to a battery, no charge can flow to it or from it. Thus $Q = 4.248\times10^{-11}\,\text{C} \approx \boxed{4.2\times10^{-11}\text{C}}$.

(*c*) The separation distance was multiplied by a factor of 1.5. The capacitance is inversely proportional to the separation distance, so the capacitance was divided by a factor of 1.5. Since $Q = CV$, if the charge does not change and the capacitance is divided by a factor of 1.5, then the voltage must have increased by a factor of 1.5.

$$V_{\text{final}} = 1.5V_{\text{initial}} = 1.5\left(12\,\text{V}\right) = \boxed{18\,\text{V}}$$

(*d*) The work done is the change in energy stored in the capacitor.

$$W = PE_{\text{final}} - PE_{\text{initial}} = \tfrac{1}{2}QV_{\text{final}} - \tfrac{1}{2}QV_{\text{initial}} = \tfrac{1}{2}Q\left(V_{\text{final}} - V_{\text{initial}}\right)$$

$$= \tfrac{1}{2}\left(4.248\times10^{-11}\text{C}\right)\left(18\,\text{V} - 12\,\text{V}\right) = \boxed{1.3\times10^{-10}\,\text{J}}$$

76. The energy stored in the capacitor is given by Eq. 17-10. The final energy is half the initial energy. Find the final charge, and then subtract the final charge from the initial charge to find the charge lost.

$$E_{\text{final}} = \tfrac{1}{2}E_{\text{initial}} \;\rightarrow\; \tfrac{1}{2}\frac{Q_{\text{final}}^2}{C} = \tfrac{1}{2}\tfrac{1}{2}\frac{Q_{\text{initial}}^2}{C} \;\rightarrow\; Q_{\text{final}} = \frac{1}{\sqrt{2}}Q_{\text{initial}}$$

$$Q_{\text{lost}} = Q_{\text{initial}} - Q_{\text{final}} = Q_{\text{initial}}\left(1-\frac{1}{\sqrt{2}}\right) = CV\left(1-\frac{1}{\sqrt{2}}\right) = \left(2.5\times10^{-6}\,\text{F}\right)\left(6.0\,\text{V}\right)\left(0.2929\right)$$

$$= \boxed{4.4\times10^{-6}\,\text{C}}$$

77. (*a*) We assume that Q_2 is held at rest. The energy of the system will then be conserved, with the initial potential energy of the system all being changed to kinetic energy after a very long time.

$$E_{\text{initial}} = E_{\text{final}} \;\rightarrow\; \text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \;\rightarrow\; \frac{kQ_1Q_2}{r} = \tfrac{1}{2}m_1v_1^2 \;\rightarrow$$

$$v_1 = \sqrt{\frac{2kQ_1Q_2}{m_1 r}} = \sqrt{\frac{2\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(5.0\times10^{-6}\,\text{C}\right)^2}{\left(1.5\times10^{-6}\,\text{kg}\right)\left(4.0\times10^{-2}\,\text{m}\right)}} = \boxed{2.7\times10^{3}\ \text{m/s}}$$

(*b*) In this case, both the energy and the momentum of the system will be conserved. Since the initial momentum is zero, the magnitudes of the momenta of the two charges will be equal.

$$p_{\text{initial}} = p_{\text{final}} \;\rightarrow\; 0 = m_1v_1 + m_2v_2 \;\rightarrow\; v_2 = -v_1\frac{m_1}{m_2}$$

$$E_{\text{initial}} = E_{\text{final}} \;\rightarrow\; \text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \;\rightarrow$$

$$\frac{kQ_1Q_2}{r} = \tfrac{1}{2}m_1v_1^2 + \tfrac{1}{2}m_2v_2^2 = \tfrac{1}{2}\left[m_1v_1^2 + m_2\left(-v_1\frac{m_1}{m_2}\right)^2\right] = \tfrac{1}{2}\frac{m_1}{m_2}\left(m_1 + m_2\right)v_1^2$$

$$v_1 = \sqrt{\frac{2kQ_1Q_2m_2}{m_1\left(m_1+m_2\right)r}} = \sqrt{\frac{2\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(5.0\times10^{-6}\,\text{C}\right)^2\left(2.5\times10^{-6}\,\text{kg}\right)}{\left(1.5\times10^{-6}\,\text{kg}\right)\left(4.0\times10^{-2}\,\text{m}\right)\left(4.0\times10^{-6}\,\text{kg}\right)}}$$

$$= \boxed{2.2\times10^3\ \text{m/s}}$$

78. Calculate $V_{AB} = V_A - V_B$. Represent the 0.10 m distance by the variable *d*.

$$V_{AB} = V_A - V_B = \left(\frac{kq_1}{d} + \frac{kq_2}{\sqrt{2}d}\right) - \left(\frac{kq_2}{d} + \frac{kq_1}{\sqrt{2}d}\right) = \frac{k}{d}\left(q_1 - q_2\right)\left(1 - \frac{1}{\sqrt{2}}\right)$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)}{0.1\,\text{m}}\left(4.8\times10^{-6}\,\text{C}\right)\left(1 - \frac{1}{\sqrt{2}}\right) = \boxed{1.3\times10^5\,\text{V}}$$