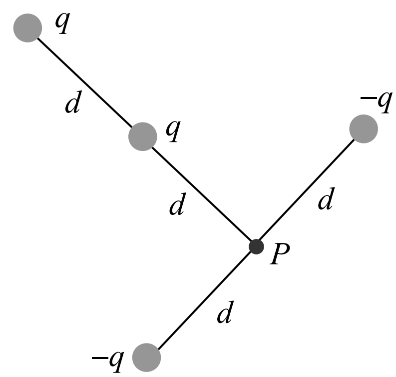
18. ***REASONING*** The electric potential at a distance r from a point charge q is given by Equation 19.6 as $V = kq/r$. The total electric potential at location P due to the four point charges is the algebraic sum of the individual potentials.



SOLUTION The total electric potential at P is (see the drawing)

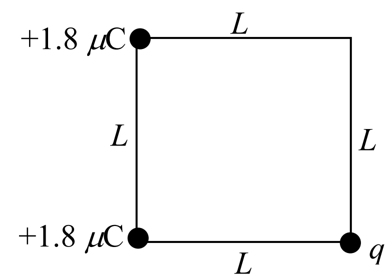
$$V = \frac{k(-q)}{d} + \frac{k(+q)}{2d} + \frac{k(+q)}{d} + \frac{k(-q)}{d} = \frac{-kq}{2d}$$

Substituting in the numbers gives

$$V = \frac{-kq}{2d} = \frac{-\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(2.0\times10^{-6}\ \text{C}\right)}{2(0.96\ \text{m})} = \boxed{-9.4\times10^{3}\ \text{V}}$$

. ***REASONING*** The potential V created by a point charge q at a spot that is located at a distance r is given by Equation 19.6 as $V = \frac{kq}{r}$, where q can be either a positive or negative quantity, depending on the nature of the charge. We will apply this expression to obtain the potential created at the empty corner by each of the three charges fixed to the square. The total potential at the empty corner is the sum of these three contributions. Setting this sum equal to zero will allow us to obtain the unknown charge.

SOLUTION The drawing at the right shows the three charges fixed to the corners of the square. The length of each side of the square is denoted by L. Note that the distance between the unknown charge q and the empty corner is L. Note also that the distance between one of the 1.8-μC charges and the empty corner is $r = L$, but that the distance between the other 1.8-μC charge and the empty corner is $r = \sqrt{L^2 + L^2} = \sqrt{2}L$, according to the Pythagorean theorem.



Using Equation 19.6 to express the potential created by the unknown charge q and by each of the 1.8-μC charges, we find that the total potential at the empty corner is

$$V_{\text{total}} = \frac{kq}{L} + \frac{k\left(+1.8\times10^{-6}\ \text{C}\right)}{L} + \frac{k\left(+1.8\times10^{-6}\ \text{C}\right)}{\sqrt{2}L} = 0$$

In this result the constant k and the length L can be eliminated algebraically, leading to the following result for q:

$$q + 1.8\times10^{-6}\text{ C} + \frac{1.8\times10^{-6}\text{ C}}{\sqrt{2}} = 0 \quad \text{or} \quad q = \left(-1.8\times10^{-6}\text{ C}\right)\left(1+\frac{1}{\sqrt{2}}\right) = \boxed{-3.1\times10^{-6}\text{ C}}$$

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36. ***REASONING*** The net work W_{AB} done by the electric force on the point charge q_0 as it moves from A to B is proportional to the potential difference $V_B - V_A$ between those positions, according to $V_B - V_A = \frac{-W_{AB}}{q_0}$ (Equation 19.4). Positions A and B are on different equipotential surfaces, so we will read the potentials V_B and V_A from the drawing. We will employ the same procedure to solve part (b).

SOLUTION

a. Solving $V_B - V_A = \frac{-W_{AB}}{q_0}$ (Equation 19.4) for W_{AB}, we obtain

$$W_{AB} = -q_0\left(V_B - V_A\right) \qquad (1)$$

From the drawing, we see that $V_A = +350.0\text{ V}$ and $V_B = +550.0\text{ V}$. Therefore, from Equation (1),

$$W_{AB} = -\left(+2.8\times10^{-7}\text{ C}\right)\left(550.0\text{ V} - 350.0\text{ V}\right) = \boxed{-5.6\times10^{-5}\text{ J}}$$

b. Positions A and C are both on the +350.0-V equipotential surface. Adapting Equation (1), then, we obtain

$$W_{AC} = -q_0\left(V_C - V_A\right) = -\left(+2.8\times10^{-7}\text{ C}\right)\left(350.0\text{ V} - 350.0\text{ V}\right) = \boxed{0\text{ J}}$$

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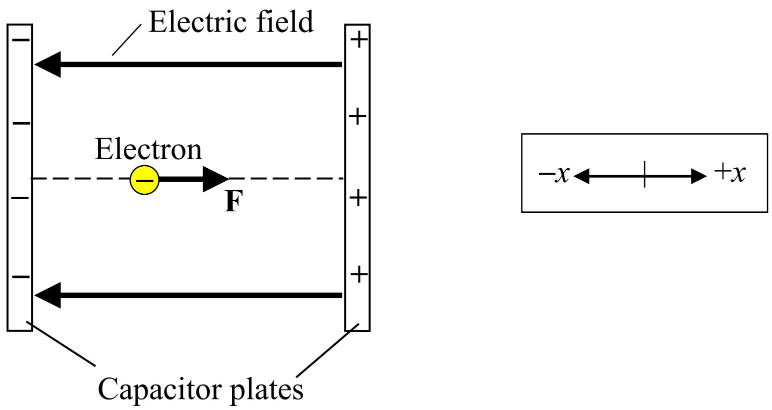
38. ***REASONING*** The electric force **F** is a conservative force, so the total energy (kinetic energy plus electric potential energy) remains constant as the electron moves across the capacitor. Thus, as the electron accelerates and its kinetic energy increases, its electric potential energy decreases. According to Equation 19.4, the change in the electron's electric potential energy is equal to the charge on the electron ($-e$) times the potential difference between the plates, or

$$\text{EPE}_{\text{positive}} - \text{EPE}_{\text{negative}} = (-e)(V_{\text{positive}} - V_{\text{negative}}) \qquad (19.4)$$

The electric field E is related to the potential difference between the plates and the displacement Δs by $E = -\frac{(V_{\text{positive}} - V_{\text{negative}})}{\Delta s}$ (Equation 19.7a). Note that Δs and $(V_{\text{positive}} - V_{\text{negative}})$ are positive numbers, so the electric field is a negative number, denoting that it points to the left in the drawing:



SOLUTION The total energy of the electron is conserved, so its total energy at the positive plate is equal to its total energy at the negative plate:

$$\underbrace{\text{KE}_{\text{positive}} + \text{EPE}_{\text{positive}}}_{\text{Total energy at positive plate}} = \underbrace{\text{KE}_{\text{negative}} + \text{EPE}_{\text{negative}}}_{\text{Total energy at negative plate}}$$

Since the electron starts from rest at the negative plate, $\text{KE}_{\text{negative}} = 0$ J. Thus, the kinetic energy of the electron at the positive plate is $\text{KE}_{\text{positive}} = -(\text{EPE}_{\text{positive}} - \text{EPE}_{\text{negative}})$. We know from Equation 19.4 in the ***REASONING*** section that $\text{EPE}_{\text{positive}} - \text{EPE}_{\text{negative}} = (-e)(V_{\text{positive}} - V_{\text{negative}})$, so the kinetic energy can be written as

$$\text{KE}_{\text{positive}} = -(\text{EPE}_{\text{positive}} - \text{EPE}_{\text{negative}}) = e\,(V_{\text{positive}} - V_{\text{negative}})$$

Since the potential difference is related to the electric field E and the displacement Δs by $V_{\text{positive}} - V_{\text{negative}} = -E\Delta s$ (Equation 19.7a), we have that

$$\begin{aligned}\text{KE}_{\text{positive}} &= e\left(V_{\text{positive}} - V_{\text{negative}}\right) = e(-E\ \Delta \text{s}) \\ &= \left(1.60 \times 10^{-19}\ \text{C}\right)\left[-\left(-2.1\times10^{6}\ \text{V/m}\right)\left(+0.012\ \text{m}\right)\right] = \boxed{4.0\times10^{-15}\ \text{J}}\end{aligned}$$

In arriving at this result, we have used the fact that the electric field is negative, since it points to the left in the drawing.

46. ***REASONING*** Equation 19.10 gives the capacitance as $C = \kappa\varepsilon_0 A/d$, where κ is the dielectric constant, and A and d are, respectively, the plate area and separation. Other things being equal, the capacitor with the larger plate area has the greater capacitance. The diameter of the circle equals the length of a side of the square, so the circle fits within the square. The square, therefore, has the larger area, and the capacitor with the square plates would have the greater capacitance.

To make the capacitors have equal capacitances, the dielectric constant must compensate for the larger area of the square plates. Therefore, since capacitance is proportional to the dielectric constant, the capacitor with square plates must contain a dielectric material with a smaller dielectric constant. Thus, the capacitor with circular plates contains the material with the greater dielectric constant.

SOLUTION The area of the circular plates is $A_{\text{circle}} = \pi\left(\frac{1}{2}L\right)^2$, while the area of the square plates is $A_{\text{square}} = L^2$. Using these areas and applying Equation 19.10 to each capacitor gives

$$C = \frac{\kappa_{\text{circle}}\varepsilon_0\pi\left(\frac{1}{2}L\right)^2}{d} \qquad \text{and} \qquad C = \frac{\kappa_{\text{square}}\varepsilon_0 L^2}{d}$$

Since the values for C are the same, we have

$$\frac{\kappa_{\text{circle}}\varepsilon_0\pi\left(\frac{1}{2}L\right)^2}{d} = \frac{\kappa_{\text{square}}\varepsilon_0 L^2}{d} \qquad \text{or} \qquad \kappa_{\text{circle}} = \frac{4\kappa_{\text{square}}}{\pi}$$

$$\kappa_{\text{circle}} = \frac{4\kappa_{\text{square}}}{\pi} = \frac{4(3.00)}{\pi} = \boxed{3.82}$$

48. ***REASONING*** The energy stored in a capacitor is given by $\text{Energy} = \frac{1}{2}CV^2$ (Equation 19.11b), where C is the capacitance of the capacitor and V is the potential difference across its plates. The only difference between the two capacitors is the dielectric material (dielectric constant $\kappa = 4.50$) inside the filled capacitor. Therefore, the filled capacitor's capacitance C_2 is greater than the capacitance C_1 of the empty capacitor by a factor of κ:

$$C_2 = \kappa C_1 \tag{1}$$

Because both capacitors store the same amount of energy, from $\text{Energy} = \frac{1}{2}CV^2$ (Equation 19.11b), we have that

$$\tfrac{1}{2}C_2V_2^2 = \tfrac{1}{2}C_1V_1^2 \qquad (2)$$

where V_2 is the potential difference across the plates of the filled capacitor, and V_1 = 12.0 V is the potential difference across the plates of the empty capacitor.

SOLUTION Solving Equation (2) for V_2, we obtain

$$V_2^2 = \frac{C_1V_1^2}{C_2} \qquad \text{or} \qquad V_2 = \sqrt{\frac{C_1V_1^2}{C_2}} \qquad (3)$$

Substituting Equation (1) into Equation (3) yields

$$V_2 = \sqrt{\frac{C_1V_1^2}{C_2}} = \sqrt{\frac{\cancel{C_1}V_1^2}{\kappa\,\cancel{C_1}}} = \sqrt{\frac{V_1^2}{\kappa}} = \frac{V_1}{\sqrt{\kappa}} = \frac{12.0\text{ V}}{\sqrt{4.50}} = \boxed{5.66\text{ V}}$$

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54. ***REASONING*** The charge q stored on the plates of a capacitor connected to a battery of voltage V is $q = CV$ (Equation 19.8). The capacitance C is $C = \frac{\kappa\varepsilon_0 A}{d}$ (Equation 19.10), where κ is the dielectric constant of the material between the plates, ε_0 is the permittivity of free space, A is the area of each plate, and d is the distance between the plates. Once the capacitor is charged and disconnected from the battery, there is no way for the charge on the plates to change. Therefore, as the distance between the plates is doubled, the charge q must remain constant. However, Equation 19.10 indicates that the capacitance is inversely proportional to the distance d, so the capacitance decreases as the distance increases. In Equation 19.8, as C decreases, the voltage V must increase in order that q remains constant. The voltage increases as a result of the work done in moving the plates farther apart. In solving this problem, we will apply Equations 19.8 and 19.10 to the capacitor twice, once with the smaller and once with the larger value of the distance between the plates.

SOLUTION Using $q = CV$ (Equation 19.8) and $C = \frac{\kappa\varepsilon_0 A}{d}$ (Equation 19.10), we can express the charge on the capacitor as follows:

$$q = CV = \left(\frac{\kappa\varepsilon_0 A}{d}\right)V = \frac{\varepsilon_0 AV}{d}$$

where we have made use of the fact that $\kappa = 1$, since the capacitor is empty. Applying this result to the capacitor with smaller and larger values of the distance *d*, we have

$$q = \frac{\varepsilon_0 A V_{\text{smaller}}}{d_{\text{smaller}}} \quad \text{and} \quad q = \frac{\varepsilon_0 A V_{\text{larger}}}{d_{\text{larger}}}$$

Since *q* is the same in each of these expressions, it follows that

$$\frac{\varepsilon_0 A V_{\text{smaller}}}{d_{\text{smaller}}} = \frac{\varepsilon_0 A V_{\text{larger}}}{d_{\text{larger}}} \quad \text{or} \quad \frac{V_{\text{smaller}}}{d_{\text{smaller}}} = \frac{V_{\text{larger}}}{d_{\text{larger}}}$$

Thus, we find that the voltage increases to a value of

$$V_{\text{larger}} = V_{\text{smaller}} \left(\frac{d_{\text{larger}}}{d_{\text{smaller}}} \right) = (9.0 \text{ V}) \left(\frac{2 d_{\text{smaller}}}{d_{\text{smaller}}} \right) = \boxed{18 \text{ V}}$$