CHAPTER 19 | ELECTRIC POTENTIAL ENERGY AND THE ELECTRIC POTENTIAL

PROBLEMS

1. **REASONING AND SOLUTION** Combining Equations 19.1 and 19.3, we have

\[ W_{AB} = EPE_A - EPE_B = q_0 \left( V_A - V_B \right) = (+1.6 \times 10^{-19} \text{ C})(0.070 \text{ V}) = 1.1 \times 10^{-20} \text{ J} \]

2. **REASONING** Equation 19.1 indicates that the work done by the electric force as the particle moves from point A to point B is \( W_{AB} = EPE_A - EPE_B \). For motion through a distance \( s \) along the line of action of a constant force of magnitude \( F \), the work is given by Equation 6.1 as either \( +Fs \) (if the force and the displacement have the same direction) or \( -Fs \) (if the force and the displacement have opposite directions). Here, \( EPE_A - EPE_B \) is given to be positive, so we can conclude that the work is \( W_{AB} = +Fs \) and that the force points in the direction of the motion from point A to point B. The electric field is given by Equation 18.2 as \( E = F/q_0 \), where \( q_0 \) is the charge.

**SOLUTION**

a. Using Equation 19.1 and the fact that \( W_{AB} = +Fs \), we find

\[ W_{AB} = +Fs = EPE_A - EPE_B \]

\[ F = \frac{EPE_A - EPE_B}{s} = \frac{9.0 \times 10^{-4} \text{ J}}{0.20 \text{ m}} = 4.5 \times 10^{-3} \text{ N} \]

As discussed in the reasoning, the direction of the force is **from A toward B**.

b. From Equation 18.2, we find that the electric field has a magnitude of

\[ E = \frac{F}{q_0} = \frac{4.5 \times 10^{-3} \text{ N}}{1.5 \times 10^{-6} \text{ C}} = 3.0 \times 10^{3} \text{ N/C} \]

The direction is the same as that of the force on the positive charge, namely **from A toward B**.

3. **REASONING** The number \( N \) of electrons that jump from your hand (point A) to the door knob (point B) is equal to the total charge \( q \) that jumps divided by the charge \( -e \) of one electron: \( N = q/(-e) \), where \( e = 1.6 \times 10^{-19} \text{ C} \). We can determine \( q \) by using Equation 19.4,
which relates the work $W_{AB}$ done by the electric force to the difference in electric potentials, $V_B - V_A$, and the charge. The difference in potentials is given as $V_B - V_A = 2.0 \times 10^4 \text{ V}$.

**SOLUTION** The number of electrons that jumps from your hand to the door knob is

$$N = \frac{-W_{AB}}{-e} = \frac{\frac{-1.5 \times 10^{-7} \text{ J}}{2.0 \times 10^4 \text{ V}}}{-1.6 \times 10^{-19} \text{ C}} = 4.7 \times 10^7$$

4. **REASONING AND SOLUTION**

a. According to Equation 19.4, the work done by the electric force as the electron goes from point $A$ (the cathode) to point $B$ (the anode) is

$$W_{AB} = -q(V_B - V_A) = -(-1.6 \times 10^{-19} \text{ C})(+125000 \text{ V}) = +2.00 \times 10^{-14} \text{ J}$$

b. The only force that acts on the electron is the conservative electric force. Therefore, the total energy of the electron is conserved as it moves from point $A$ to point $B$:

$$\frac{1}{2}mv_A^2 + \text{EPE}_A = \frac{1}{2}mv_B^2 + \text{EPE}_B$$

Since the electron starts from rest, $v_A = 0$. The electric potential $V$ is related to the electric potential energy EPE by $V = \text{EPE}/q$ (see Equation 19.3). With these changes, the equation above gives the kinetic energy of the electron at point $B$ (the anode) to be

$$\frac{1}{2}mv_B^2 = -\text{EPE}_B + \text{EPE}_A$$

$$= -q(V_B - V_A) = -(1.60 \times 10^{-19} \text{ C})(125000 \text{ V}) = 2.00 \times 10^{-14} \text{ J}$$
7. **REASONING AND SOLUTION** The power rating $P$ is defined as the work $W_{AB}$ done by the battery divided by the time $t$,

$$ P = \frac{W_{AB}}{t} $$

The work done by the electric force as the charge moves from point $A$ (the positive terminal), through the electric motor, and to point $B$ (the negative terminal) is

$$ W_{AB} = q(V_A - V_B) = (1300 \text{ C})(320 \text{ V}) = 4.2 \times 10^5 \text{ J} \quad (19.4) $$

The power rating is

$$ P = \frac{W_{AB}}{t} = \frac{4.2 \times 10^5 \text{ J}}{8.0 \text{ s}} = 5.2 \times 10^4 \text{ W} $$
Since 746 W = 1 hp, the minimum horsepower rating of the car is

\[
(5.20 \times 10^4 \text{ W}) \frac{1 \text{ hp}}{746 \text{ W}} = 7.0 \times 10^1 \text{ hp}
\]
SSM REASONING AND SOLUTION The electric potential $V$ at a distance $r$ from a point charge $q$ is given by Equation 19.6, $V = kq/r$. Solving this expression for $q$, we find that

$$q = \frac{rV}{k} = \frac{(0.25 \text{ m})(+130 \text{ V})}{9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2} = +3.6 \times 10^{-9} \text{ C}$$
13. **REASONING** The potential $V$ at a distance $r$ from a proton is $V = \frac{k(+e)}{r}$ (see Equation 19.6), where $+e$ is the charge of the proton. When an electron ($q = -e$) is placed at a distance $r$ from the proton, the electric potential energy is $EPE = -eV$, as per Equation 19.3.

**SOLUTION** The difference in the electric potential energies when the electron and proton are separated by $r_{\text{final}} = 5.29 \times 10^{-11}$ m and when they are very far apart ($r_{\text{initial}} = \infty$) is

$$EPE_{\text{final}} - EPE_{\text{initial}} = \frac{(-e)ke}{r_{\text{final}}} - \frac{(-e)ke}{r_{\text{initial}}}$$

$$= -(8.99 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2)(1.60 \times 10^{-19} \text{ C})^2 \times \left(\frac{1}{5.29 \times 10^{-11} \text{ m}} - \frac{1}{\infty}\right) = -4.35 \times 10^{-18} \text{ J}$$
REASONING Initially, suppose that one charge is at C and the other charge is held fixed at B. The charge at C is then moved to position A. According to Equation 19.4, the work \( W_{CA} \) done by the electric force as the charge moves from C to A is \( W_{CA} = q(V_C - V_A) \), where, from Equation 19.6, \( V_C = kq/d \) and \( V_A = kq/r \). From the figure at the right we see that \( d = \sqrt{r^2 + r^2} = \sqrt{2}r \). Therefore, we find that

\[
W_{CA} = q \left( \frac{kq}{\sqrt{2}r} - \frac{kq}{r} \right) = \frac{kq^2}{r} \left( \frac{1}{\sqrt{2}} - 1 \right)
\]

SOLUTION Substituting values, we obtain

\[
W_{CA} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2)(3.0 \times 10^{-6} \text{ C})^2}{0.500 \text{ m}} \left( \frac{1}{\sqrt{2}} - 1 \right) = -4.7 \times 10^{-2} \text{ J}
\]
17. REASONING AND SOLUTION Let $s$ be the length of the side of the square and $Q$ be the value of the unknown charge. The potential at either of the vacant corners is

$$V = 0 = \frac{k(9q)}{s} + \frac{k(-8q)}{s} + \frac{kQ}{s/\sqrt{2}}$$

so

$$Q = \frac{-q}{\sqrt{2}}$$
REASONING Initially, the three charges are infinitely far apart. We will proceed as in Example 8 by adding charges to the triangle, one at a time, and determining the electric potential energy at each step. According to Equation 19.3, the electric potential energy EPE is the product of the charge \( q \) and the electric potential \( V \) at the spot where the charge is placed, \( EPE = qV \). The total electric potential energy of the group is the sum of the energies of each step in assembling the group.
**SOLUTION**  Let the corners of the triangle be numbered clockwise as 1, 2 and 3, starting with the top corner. When the first charge \( q_1 = 8.00 \, \mu\text{C} \) is placed at a corner 1, the charge has no electric potential energy, \( \text{EPE}_1 = 0 \). This is because the electric potential \( V_1 \) produced by the other two charges at corner 1 is zero, since they are infinitely far away.

Once the 8.00-\( \mu\text{C} \) charge is in place, the electric potential \( V_2 \) that it creates at corner 2 is

\[
V_2 = \frac{kq_1}{r_{21}}
\]

where \( r_{21} = 5.00 \, \text{m} \) is the distance between corners 1 and 2, and \( q_1 = 8.00 \, \mu\text{C} \). When the 20.0-\( \mu\text{C} \) charge is placed at corner 2, its electric potential energy \( \text{EPE}_2 \) is

\[
\text{EPE}_2 = q_2 V_2 = q_2 \left( \frac{kq_1}{r_{21}} \right)
\]

\[
= \left( 20.0 \times 10^{-6} \, \text{C} \right) \left[ \frac{(8.99 \times 10^9 \, \text{N} \cdot \text{m}^2 / \text{C}^2)(8.00 \times 10^{-6} \, \text{C})}{5.00 \, \text{m}} \right] = 0.288 \, \text{J}
\]

The electric potential \( V_3 \) at the remaining empty corner is the sum of the potentials due to the two charges that are already in place on corners 1 and 2:

\[
V_3 = \frac{kq_1}{r_{31}} + \frac{kq_2}{r_{32}}
\]

where \( q_1 = 8.00 \, \mu\text{C}, \, r_{31} = 3.00 \, \text{m}, \, q_2 = 20.0 \, \mu\text{C}, \) and \( r_{32} = 4.00 \, \text{m} \). When the third charge \( q_3 = -15.0 \, \mu\text{C} \) is placed at corner 3, its electric potential energy \( \text{EPE}_3 \) is

\[
\text{EPE}_3 = q_3 V_3 = q_3 \left( \frac{kq_1}{r_{31}} + \frac{kq_2}{r_{32}} \right) = q_3 k \left( \frac{q_1}{r_{31}} + \frac{q_2}{r_{32}} \right)
\]

\[
= (-15.0 \times 10^{-6} \, \text{C})(8.99 \times 10^9 \, \text{N} \cdot \text{m}^2 / \text{C}^2) \left( \frac{8.00 \times 10^{-6} \, \text{C}}{3.00 \, \text{m}} + \frac{20.0 \times 10^{-6} \, \text{C}}{4.00 \, \text{m}} \right) = -1.034 \, \text{J}
\]

The electric potential energy of the entire array is given by

\[
\text{EPE} = \text{EPE}_1 + \text{EPE}_2 + \text{EPE}_3 = 0 + 0.288 \, \text{J} + (-1.034 \, \text{J}) = -0.746 \, \text{J}
\]