CHAPTER 19 | *ELECTRIC POTENTIAL ENERGY AND THE ELECTRIC POTENTIAL*

PROBLEMS

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

$$W_{AB} = \text{EPE}_A - \text{EPE}_B = q_0 (V_A - V_B) = (+1.6 \times 10^{-19} \text{ C})(0.070 \text{ V}) = \boxed{1.1 \times 10^{-20} \text{ J}}$$

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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 $W_{AB} = \text{EPE}_A - \text{EPE}_B$. 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, $\text{EPE}_A - \text{EPE}_B$ 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 $\mathbf{E} = \mathbf{F}/q_0$, where q_0 is the charge.

SOLUTION a. Using Equation 19.1 and the fact that $W_{AB} = +Fs$, we find

$$W_{AB} = +Fs = \text{EPE}_A - \text{EPE}_B$$

$$F = \frac{\text{EPE}_A - \text{EPE}_B}{s} = \frac{9.0 \times 10^{-4} \text{ J}}{0.20 \text{ m}} = \boxed{4.5 \times 10^{-3} \text{ N}}$$

As discussed in the reasoning, the direction of the force is $\boxed{\text{from } A \text{ toward } B}$.

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

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

The direction is the same as that of the force on the positive charge, namely $\boxed{\text{from } A \text{ toward } B}$.

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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 $e = 1.6 \times 10^{-19}$ 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 $V_B - V_A = 2.0 \times 10^4$ V.

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

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

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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

$$W_{AB} = -q(V_B - V_A) = -(-1.6 \times 10^{-19}\text{ C})(+125\,000\text{V}) = \boxed{+2.00 \times 10^{-14}\text{ J}}$$

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:

$$\underbrace{\tfrac{1}{2}mv_A^2 + \text{EPE}_A}_{\substack{\text{Total energy at}\\ \text{point } A}} = \underbrace{\tfrac{1}{2}mv_B^2 + \text{EPE}_B}_{\substack{\text{Total energy at}\\ \text{point } B}}$$

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

$$\begin{aligned}\tfrac{1}{2}mv_B^2 &= -\text{EPE}_B + \text{EPE}_A \\ &= -q(V_B - V_A) = -(-1.60 \times 10^{-19}\text{ C})(125\,000\text{ V}) = \boxed{2.00 \times 10^{-14}\text{ J}}\end{aligned}$$

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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

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

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

$$\left(5.20\times10^{4}\ \text{W}\right)\frac{1\ \text{hp}}{746\ \text{W}}=\boxed{7.0\times10^{1}\ \text{hp}}$$

11. **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

$$q = \frac{rV}{k} = \frac{(0.25\text{ m})(+130\text{ V})}{9.0\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2} = \boxed{+3.6\times10^{-9}\text{ C}}$$

13. ***REASONING*** The potential V at a distance r from a proton is $V = k(+e)/r$ (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.

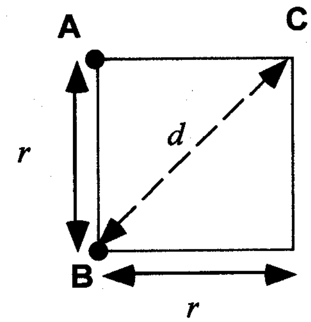
SOLUTION The difference in the electric potential energies when the electron and proton are separated by $r_{\text{final}} = 5.29 \times 10^{-11}$ m and when they are very far apart ($r_{\text{initial}} = \infty$) is

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

$$= -(8.99 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2$$

$$\times\left(\frac{1}{5.29 \times 10^{-11}\ \text{m}} - \frac{1}{\infty}\right) = \boxed{-4.35 \times 10^{-18}\ \text{J}}$$

15. SSM WWW ***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

$$W_{CA} = \frac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})^2}{0.500\ \text{m}}\left(\frac{1}{\sqrt{2}} - 1\right) = \boxed{-4.7\times10^{-2}\ \text{J}}$$

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

$$\boxed{Q = \frac{-q}{\sqrt{2}}}$$

23. SSM ***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 μC) 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-μC 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 m is the distance between corners 1 and 2, and q_1 = 8.00 μC. When the 20.0-μC charge is placed at corner 2, its electric potential energy EPE_2 is

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

$$= (20.0\times10^{-6}\ \text{C})\left[\frac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(8.00\times10^{-6}\ \text{C})}{5.00\ \text{m}}\right] = 0.288\ \text{J}$$

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 μC, r_{31} = 3.00 m, q_2 = 20.0 μC, and r_{32} = 4.00 m. When the third charge (q_3 = −15.0 μC) is placed at corner 3, its electric potential energy EPE_3 is

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

$$= (-15.0\times10^{-6}\ \text{C})(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\frac{8.00\times10^{-6}\ \text{C}}{3.00\ \text{m}} + \frac{20.0\times10^{-6}\ \text{C}}{4.00\ \text{m}}\right) = -1.034\ \text{J}$$

The electric potential energy of the entire array is given by

$$\text{EPE} = \text{EPE}_1 + \text{EPE}_2 + \text{EPE}_3 = 0 + 0.288\ \text{J} + (-1.034\ \text{J}) = \boxed{-0.746\ \text{J}}$$