41. We choose the zero of electric potential to be at infinity. The initial electric potential energy $U_i$ of the system before the particles are brought together is therefore zero. After the system is set up the final potential energy is

$$U_f = \frac{q^2}{4\pi \varepsilon_0 a} \left( \frac{1}{a} + \frac{1}{\sqrt{2a}} - \frac{1}{a} + \frac{1}{\sqrt{2a}} \right) = \frac{2q^2}{4\pi \varepsilon_0 a} \left( \frac{1}{\sqrt{2}} - 2 \right).$$

Thus the amount of work required to set up the system is given by

$$W = \Delta U = U_f - U_i = U_f = \frac{2q^2}{4\pi \varepsilon_0 a} \left( \frac{1}{\sqrt{2}} - 2 \right) = \frac{2 \times 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \times (2.30 \times 10^{-12} \text{ C})^2}{0.640 \text{ m}} \left( \frac{1}{\sqrt{2}} - 2 \right) = -1.92 \times 10^{-13} \text{ J}.$$

42. The work done must equal the change in the electric potential energy. From Eq. 24-14 and Eq. 24-26, we find (with $r = 0.020 \text{ m}$)

$$W = \frac{(3e - 2e + 2e)(6e)}{4\pi \varepsilon_0 r} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(18 \times 10^{-19} \text{ C})^2}{0.020 \text{ m}} = 2.1 \times 10^{-25} \text{ J}.$$

43. We apply conservation of energy for the particle with $q = 7.5 \times 10^{-6} \text{ C}$ (which has zero initial kinetic energy):

$$U_0 = K_f + U_f,$$

where $U = \frac{qQ}{4\pi \varepsilon_0 r}$.

(a) The initial value of $r$ is 0.60 m and the final value is $(0.6 + 0.4) \text{ m} = 1.0 \text{ m}$ (since the particles repel each other). Conservation of energy, then, leads to $K_f = 0.90 \text{ J}$.

(b) Now the particles attract each other so that the final value of $r$ is $0.60 - 0.40 = 0.20 \text{ m}$. Use of energy conservation yields $K_f = 4.5 \text{ J}$ in this case.

49. The escape speed may be calculated from the requirement that the initial kinetic energy (of launch) be equal to the absolute value of the initial potential energy (compare with the gravitational case in chapter 14). Thus,

$$\frac{1}{2} m v^2 = \frac{qQ}{4\pi \varepsilon_0 r},$$

where $m = 9.11 \times 10^{-31} \text{ kg}$, $e = 1.60 \times 10^{-19} \text{ C}$, $q = 10000e$, and $r = 0.010 \text{ m}$. This yields $v = 22490 \text{ m/s} \approx 2.2 \times 10^4 \text{ m/s}$.

52. When particle 3 is at $x = 0.10 \text{ m}$, the total potential energy vanishes. Using Eq. 24-43 we have (with meters understood at the length unit)

$$0 = \frac{q_1 q_2}{4\pi \varepsilon_0 d} + \frac{q_1 q_3}{4\pi \varepsilon_0 (d + 0.10 \text{ m})} + \frac{q_1 q_2}{4\pi \varepsilon_0 (0.10 \text{ m})}$$

This leads to

$$q_1 \left( \frac{q_1}{d + 0.10 \text{ m}} + \frac{q_2}{0.10 \text{ m}} \right) = -\frac{q_1 q_2}{d}$$

which yields $q_3 = -5.7 \text{ µC}$.