Part A

1. e (If it has a negative charge, that means it already has an excess of electrons. Adding more electrons will just add to the excess of electrons. See page 37 of text.)

2. c (This is the same meaning of r in the universal law of gravitation. See top of page 39.)

3. e (The charge on the conducting hollow sphere migrates to the outside. Any small charge on the inside will feel no force because the other charge is spread out and pulls on the inside charge in all directions. See page 50 of text.)

4. e (Kinetic energy will increase when the object moves in the direction of the force exerted upon it. We can't tell which way the force is until we are given the charge on the object.)

5. d (Since the charge on each object is the same, the magnitude of the force will depend on how close the objects are to each other. Since B is closer to C than A, the force due to the C will be greater. Since they are all positively-charged, this means that the repulsion from C, toward the left, will be greater than the repulsion from A, toward the right.)

6. a (Nucleus A has a higher binding energy and thus is more stable. To release energy, we need to go from less stable to more stable, i.e., from nucleus B to nucleus A, in this case. Since nucleus A has more nucleons, this means that we must have fusion of two B's to one A.)

7. d (use the loop rule; in any loop, the entire potential drop/rise must be zero)

8. b (we certainly don't want to have current flow through the volunteer because the current would cause the person to heat up; thus, only option b is crucial; options c, d and e would do the opposite; as for option a, although it is convenient for the volunteer to be at the same height or gravitational potential, that isn't as crucial making sure the current doesn't flow through the volunteer)

9. c (since they are in series, the current in each must be the same)
10. e (although a resistance can be determined via the ratio of voltage and current, an object is ohmic only if that ratio is independent of the voltage applied; consequently, one cannot tell if the material is ohmic until other voltages/current measurements are made)
11. a (electrons, being negative, are forced from lower to higher potential)
12. b (of the units provided, only keV and kJ are units of energy; to obtain energy from potential difference, multiply the potential difference by the charge; in this case, the charge is the charge on one electron, which is a tiny fraction of a Coulomb)
13. a (10 W means that 10 J of energy are "dissipated" every second)
14. Your answer to this one depends on the circuit provided.

Part B

1. (a) Before starting this, try to predict whether the work should be positive or negative.

   It turns out that the total work would be zero. This is because the energy required to bring the +4 μC charge close to A (which is also positive and thus repels it) is equal to the energy obtained by bringing to near C (which is negative and thus attracts it).

   To show this mathematically, first obtain the amount of work to bring the +4 μC charge from infinity to a place 10 cm from object A. This would be:

   $$\Delta PE_e = k\frac{(+4\ \mu\text{C})(+2\ \mu\text{C})}{(10\ \text{cm})}$$

   Then obtain the amount of work to bring the +4μC charge from infinity to a place 10 cm from object C. This would be:

   $$\Delta PE_e = k\frac{(+4\ \text{muC})(-2\ \mu\text{C})}{(10\ \text{cm})}$$

   It is negative because work isn't required – rather, energy is released. In other words, you need to force it the other way just to keep it from accelerating.

The total amount of work is obtained by adding them together.

Clearly, these are equal and opposite. The total work required is the sum of the two.

(b) Now it should take more work to bring the +4 μC charge close to A (which is also positive and thus repels it) than the energy obtained by bringing to near C (which is negative and thus attracts it).

Mathematically, the amount of work needed to bring the +4 μC charge from infinity to a place 5 cm from object A is

$$\begin{aligned}\Delta PE_e &= k\frac{(+4\ \mu\text{C})(+2\ \mu\text{C})}{(5\text{ cm})}\\ &= 1.44\text{ J}\end{aligned}$$

Remember to convert μC to 10^{-6} C and convert cm to 10^{-2} m. The work needed to bring the +4μC charge from infinity to a place 15 cm from object C is

$$\begin{aligned}\Delta PE_e &= k\frac{(+4\ \mu\text{C})(-2\ \mu\text{C})}{(15\text{ cm})}\\ &= 0.48\text{ J}\end{aligned}$$

The total amount of work is obtained by adding them together (0.96 J).

2. Before you begin, think about what would cause the woman to be weightless. Gravity is pulling her downward. What would pull her upward? Why would putting charge on the woman and the earth produce an upward force?

   It turns out that you want to have the force of gravity balancing out the electric force. The force of gravity is:

$$F_g = (6.67\times10^{-11}\text{ Nm}^2/\text{kg}^2)\frac{(54.5\text{ kg})(5.98\times10^{24}\text{ kg})}{(6.37\times10^{6}\text{ m})^2}$$

   Plugging in we get 536 N. By the way, since the woman is near the surface of the earth, we'd get the same answer if we took the woman's mass (54.5 kg) and multiplied it by 9.8 N/kg.

For the electric force to balance the gravitational force, we need that

$$\begin{aligned} F_e &= k\frac{q_1 q_2}{r^2} \\ &= (9.00\times10^9\ \mathrm{Nm^2/C^2})\frac{q^2}{(6.37\times10^6\ \mathrm{m})^2} \end{aligned}$$

to equal 536 N. Note that I used q^2 because the charge on each object is the same. Solve for q to get 1554 C.

We could also solve this by first doing a bit of algebra, i.e., set F_g equal to F_e:

$$G\frac{m_1 m_2}{r^2} = k\frac{q_1 q_2}{r^2}$$

which simplifies to

$$Gm_1 m_2 = kq^2$$

or

$$\begin{aligned} q^2 &= \frac{Gm_1 m_2}{k} \\ &= \frac{(6.67\times10^{-11}\ \mathrm{Nm^2/kg^2})(54.5\ \mathrm{kg})(5.98\times10^{24}\ \mathrm{kg})}{(9.00\times10^9\ \mathrm{Nm^2/C^2})} \end{aligned}$$

3. (a) The force is 1.00×10^6 N:

$$1.00\times10^6\ \mathrm{N} = (9.00\times10^9\ \mathrm{Nm^2/C^2})\frac{q^2}{(5.00\times10^{-2}\ \mathrm{m})^2}$$

Here I used Coulomb's law and simply plugged in what I know, i.e. the force is 1.00×10^6 N and the separation distance is 5.00×10^{-2} m. I don't know the charges, so I used q for each charge since the charge is the same on each sphere. Solving for q, I get

$$q^2 = \frac{(1.00\times10^6\ \mathrm{N})(5.00\times10^{-2}\ \mathrm{m})^2}{(9.00\times10^9\ \mathrm{Nm^2/C^2})}$$

to get a charge of 527 μC.

(b) Before they touched, the charges are not the same. Let's use q_1 and q_2 for them. With no other differences (same separation distance), the force is three times greater. That means that $q_1 q_2$ must be three times greater than q^2. In addition, since it is attractive instead of repulsive q_1q_2 must be negative (i.e. opposite charges). Mathematically, this is written as $q_1q_2 = -3q^2$.

To solve for the charges, we need to relate q_1 and q_2. We can do this through conservation of charge, i.e. the total charge before touching $(q_1 + q_2)$ must equal the total charge after touching $(2q)$. That means that $q_1 = 2q - q_2$ and so

$$\begin{aligned} q_1q_2 &= -3q^2 \\ (2q - q_2)q_2 &= -3q^2 \\ 0 &= (-3q^2) + (-2q)q_2 + (1)q_2^2 \end{aligned}$$

which is quadratic. To solve, use the quadratic equation

$$\begin{aligned} q_2 &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \\ &= \frac{-(-2q) \pm \sqrt{(-2q)^2 - 4(1)(-3q^2)}}{2(1)} \\ &= q \pm \sqrt{q^2 + 3q^2} \\ &= q \pm q\sqrt{1+3} \\ &= q(1 \pm \sqrt{4}) \\ &= q(1 \pm 2) \end{aligned}$$

This means that q_2 is (527 μC) times either +3 or −1. The one it isn't is the value of q_1. So, one charge is 1581 μC and the other is −527 μC.

Part C

1. Since appliances are connected in parallel, the potential difference across each one is 120 V. From $\Delta V = IR$, the current through each appliance equals the voltage across each (120 V) divided by the resistance of each (55 Ω). Consequently, the current through each is (120/55) A or 2.2 A. Five such appliances will draw 11 A. The most we can use is four.
2. (a) With the switch open, the only two resistances are the internal resistance of 2 Ω and the resistor of 50 Ω. Since they are in series, the

total resistance is 52 Ω. The voltage across both together is 10.0 V and so the current through both together is (10.0 V)/(52 Ω) = 0.19 A.

(b) When the switch is closed, all of the current will go through the switch and by-pass the resistor. Consequently the only resistance is the internal resistance of 2 Ω. The voltage is still 10.0 V and so the total current is (10.0 V)/(2 Ω) = 5.0 A.

(c) There is no current through the 50-Ω resistor when the switch is closed.

(d) There is no potential difference across the switch because the switch is assumed to have zero resistance.

(e) There is no potential difference across the resistor. If there was, current would flow.

3. The unknowns in this circuit are the currents, which I'll label I_{left}, I_{middle} and I_{right}. For each, we need to choose a direction. I'll assume the direction is up for the outer wires and down for the inner wire. Based upon those directions, the potential is higher on the left side of the 5.0-Ω resistor, the right side of the upper 10.0-Ω resistor and the top side of the middle 10.0-Ω resistor.

   Now I create two loop equations. For the outer loop, moving clockwise from the upper-left corner, I get

$$-(5\ \Omega)(I_{\text{left}}) + (10\ \Omega)(I_{\text{right}}) - (15.0\ \text{V}) + (10.0\ \text{V}) = 0$$

   For the left loop, moving clockwise from the upper-left corner, I get

$$-(5\ \Omega)(I_{\text{left}}) - (10\ \Omega)(I_{\text{middle}}) - (2.0\ \text{V}) + (10.0\ \text{V}) = 0$$

   My third equation is obtained from the junction rule and gives (based upon the directions of the currents I've chosen)

$$I_{\text{left}} + I_{\text{right}} = I_{\text{middle}}$$

   Now we solve algebraically. One way to do this is to first replace I_{left} in each loop equation with $I_{\text{middle}} - I_{\text{right}}$ from the junction equation. This gives (after simplifying)

$$-(5\ \Omega)(I_{\text{middle}}) + (15\ \Omega)(I_{\text{right}}) - (5.0\ \text{V}) = 0$$

For the left loop, moving clockwise from the upper-left corner, I get

$$+(5\ \Omega)(I_{\text{right}}) - (15\ \Omega)(I_{\text{middle}}) + (8.0\ \text{V}) = 0$$

Now multiply the first by 3 and subtract it from the second to get

$$-(40\ \Omega)(I_{\text{right}}) + (23.0\ \text{V}) = 0$$

or $I_{\text{right}} = 0.575$ A. Since

$$+(5\ \Omega)(I_{\text{right}}) - (15\ \Omega)(I_{\text{middle}}) + (8.0\ \text{V}) = 0$$

we can plug in to get $I_{\text{middle}} = 0.725$ A. Plug this into the junction equation to get $I_{\text{left}} = 0.150$ A. Since these are all positive, my initial choices for the directions of the currents must be correct.