energy. **Kirchhoff's first rule** or **junction rule** is based on the conservation of electric charge, and we already used it in deriving the rule for parallel resistors. It states that

> **at any junction point, the sum of all currents entering the junction must equal the sum of all currents leaving the junction.**

Junction rule (conservation of charge)

That is, whatever charge goes in must come out. For example, at the junction point a in Fig. 19–11, I_3 is entering whereas I_1 and I_2 are leaving. Thus Kirchhoff's junction rule states that $I_3 = I_1 + I_2$. We already saw an instance of this in the NOTE at the end of Example 19–5.

Kirchhoff's second rule or **loop rule** is based on the conservation of energy. It states that

> **the sum of the changes in potential around any closed path of a circuit must be zero.**

Loop rule (conservation of energy)

To see why this rule should hold, consider a rough analogy with the potential energy of a roller coaster on its track. When the roller coaster starts from the station, it has a particular potential energy. As it climbs the first hill, its potential energy increases and reaches a maximum at the top. As it descends the other side, its potential energy decreases and reaches a local minimum at the bottom of the hill. As the roller coaster continues on its path, its potential energy goes through more changes. But when it arrives back at the starting point, it has exactly as much potential energy as it had when it started at this point. Another way of saying this is that there was as much uphill as there was downhill.

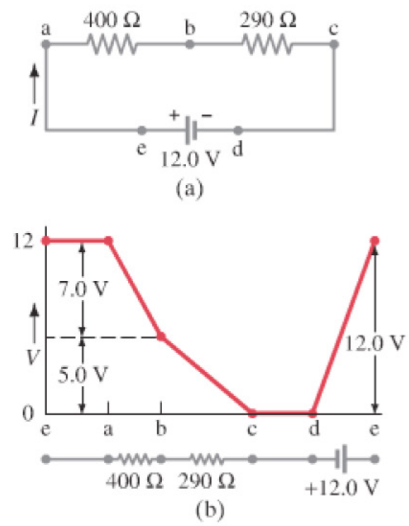

FIGURE 19–12 Changes in potential around the circuit in (a) are plotted in (b).

Similar reasoning can be applied to an electric circuit. We will do the circuit of Fig. 19–11 shortly but first we consider the simpler circuit in Fig. 19–12. We have chosen it to be the same as the equivalent circuit of Fig. 19–8b already discussed. The current in this circuit is $I = (12.0\text{ V})/(690\,\Omega) = 0.0174\text{ A}$, as we calculated in Example 19–4. (We keep an extra digit in I to reduce rounding errors.) The positive side of the battery, point e in Fig. 19–12a, is at a high potential compared to point d at the negative side of the battery. That is, point e is like the top of a hill for a roller coaster. We follow the current around the circuit starting at any point. We choose to start at point e and follow a positive test charge completely around this circuit. As we go, we note all changes in potential. When the test charge returns to point e, the potential will be the same as when we started (total change in potential around the circuit is zero). We plot the changes in potential around the circuit in Fig. 19–12b; point d is arbitrarily taken as zero.

As our positive test charge goes from point e to point a, there is no change in potential since there is no source of emf and we assume negligible resistance in the connecting wires. Next, as the charge passes through the 400-Ω resistor to get to point b, there is a decrease in potential of $V = IR = (0.0174\text{ A})(400\,\Omega) = 7.0\text{ V}$. The positive test charge is flowing "downhill" since it is heading toward the negative terminal of the battery, as indicated in the graph of Fig. 19–12b. Because this is a *decrease* in potential, we use a *negative* sign:

PROBLEM SOLVING
Be consistent with signs when applying the loop rule

$$V_{\text{ba}} = V_{\text{b}} - V_{\text{a}} = -7.0\text{ V}.$$

As the charge proceeds from b to c there is another potential decrease (a "voltage drop") of $(0.0174\text{ A}) \times (290\,\Omega) = 5.0\text{ V}$, and this too is a decrease in potential:

$$V_{\text{cb}} = -5.0\text{ V}.$$

There is no change in potential as our test charge moves from c to d as we assume negligible resistance in the wires. But when it moves from d, which is the negative or low potential side of the battery, to point e, which is the positive terminal (high potential side) of the battery, the potential *increases* by 12.0 V. That is,

$$V_{\text{ed}} = +12.0\text{ V}.$$

The sum of all the changes in potential around the circuit of Fig. 19–12 is

$$-7.0\text{ V} - 5.0\text{ V} + 12.0\text{ V} = 0.$$

This is exactly what Kirchhoff's loop rule said it would be.