Answer to Essential Question 18.7: The power provided to the circuit by the battery can be found from $P = \varepsilon I = (18\text{ V}) \times (2.0\text{ A}) = 36\text{ W}$. The equation $P = I^2 R$ gives the power dissipated in each resistor: $P_1 = I_1^2 R_1 = (1.5\text{ A})^2 (4.0\,\Omega) = 9.0\text{ W}$; $P_2 = I_2^2 R_2 = (0.5\text{ A})^2 (5.0\,\Omega) = 1.25\text{ W}$; $P_3 = I_2^2 R_3 = (0.5\text{ A})^2 (7.0\,\Omega) = 1.75\text{ W}$; and $P_4 = I^2 R_4 = (2.0\text{ A})^2 (6.0\,\Omega) = 24\text{ W}$, for a total of 36 W. Thus, the power input to the circuit by the battery equals the power dissipated in the resistors, which we expect because of conservation of energy.

18-8 An Example Problem; and Meters

Let's now explore a situation that involves many of the concepts from the last few sections, and allows us to discuss the role of a switch in a circuit.

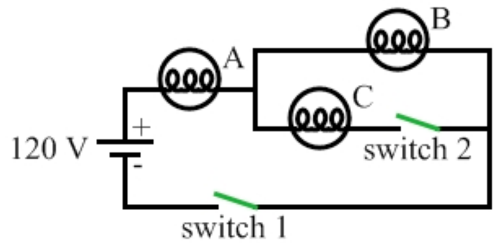

Figure 18.16: A circuit with one battery, two switches, and three identical light bulbs. The switches are initially open.

EXPLORATION 18.8 – Three bulbs and two switches

Three identical light bulbs, A, B, and C, are placed in the circuit shown in Figure 18.16 along with two switches, 1 and 2, and a battery with an emf of 120 V (like a standard electrical outlet).

Step 1 – ***Are any bulbs on when the switches are both open? If so, which bulbs are on? If not, explain why not.*** For a bulb to glow a current must pass through it. For there to be a current there must be a complete circuit, a conducting path for charges to flow through from one terminal of the battery to the other. With switch 1 open there is not a complete circuit, so all the bulbs are off.

Step 2 – ***Kirchoff's loop rule is true even when the switches are open. How is this possible?*** This is possible because the potential difference across switch 1 is equal to the battery emf. If we define the wire connecting the negative terminal of the battery to the left side of switch 1 to be at $V = 0$, all other parts of the circuit, including the right side of the switch, are at a potential of $V = +120\text{ V}$. There are no potential differences across the bulbs because there is no current.

Step 3 – ***Complete these sentences. An open switch has a resistance of _________. A closed switch has a resistance of ________.*** We generally treat an open switch as having a resistance of infinity. A closed switch acts like a wire, so we assume it has a resistance of zero.

Step 4 – ***Rank the bulbs based on their brightness when switch 1 is closed and switch 2 is open. What is the potential difference across each bulb?*** Bulb C is off – because switch 2 is open there is no current in that part of the circuit. Thus, the circuit has bulbs A and B in series with one another and the battery. Because bulbs A and B are identical, and have the same current through them, they are equally bright. The ranking is A=B>C. Bulbs A and B share the emf of the battery, with a potential difference of 60 V across each bulb. Bulb C has no potential difference across it.

Step 5 – ***What happens to the brightness of each bulb when switch 2 is closed (so both switches are closed)? What is the potential difference across each bulb?*** With switch 2 closed, charge flows through bulb C, so C comes on and is brighter than before. Bulbs B and C are in parallel, and have equal resistance, so half the current passes through B and half through C. Bulb B got all the current before switch 2 was closed, so you might think that bulb B is now obviously dimmer. However, closing switch 2 decreases the overall resistance of the circuit, increasing the current. So, bulb B only gets half the current, but the total current increases – which effect dominates?

Because all the current passes through bulb A, increasing the current in the circuit increases both the brightness of, and the potential difference across, bulb A. By the loop rule, increasing A's potential difference means B's potential difference decreases, so B's current and brightness must also be less. To summarize, A and C get brighter, while B gets dimmer. B and C are now equally bright, and A is the brightest of all. Assuming the bulbs have the same resistance, A has 80 V across it, while B and C each have 40 V across them, as shown in Figure 18.17.

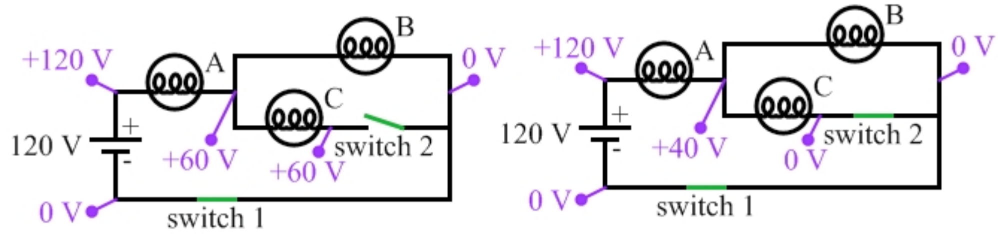

Figure 18.17: Labeling the potential at various points helps us understand what happens to the bulbs when switch 2 is closed.

Key Ideas for Switches: We can treat an open switch as having infinite resistance, and a closed switch as having no resistance. **Related End-of-Chapter Exercises**: **5 – 7.**

Ammeters Measure Current

A meter that measures current is known as an **ammeter**. Should an ammeter be wired in series or parallel? Should the ammeter have a small resistance or a large resistance? Does adding an ammeter to the circuit increase or decrease the current through the resistor of interest?

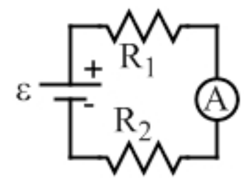

Figure 18.18: An ammeter, represented by an A inside a circle, is used to measure the current through whatever is in series with it. In this case, that's everything in the circuit.

Circuit elements that are in series have the same current passing through them. Thus, to measure the current through a resistor an ammeter should be placed in series with that resistor, as in Figure 18.18. Adding the ammeter, which has some resistance, increases the equivalent resistance of the circuit and thus reduces the current in the circuit. The resistance of the ammeter should be as small as possible to minimize the effect of adding the ammeter to the circuit.

Voltmeters Measure Potential Difference

A meter that measures potential difference is known as a **voltmeter**. Should a voltmeter be wired in series or parallel? Should it have a small or a large resistance? How does adding a voltmeter to a circuit affect the circuit?

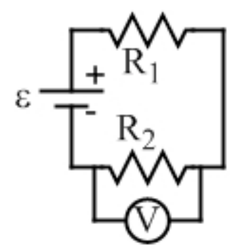

Figure 18.19: A voltmeter, represented by a V inside a circle, is used to measure the potential difference of whatever is in parallel with it. In this case, that's resistor R_2.

Circuit elements in parallel have the same potential difference across them. Thus, to measure the potential difference across a resistor a voltmeter should be placed in parallel with that resistor, as in Figure 18.19. Connecting the voltmeter, which has some resistance, in parallel decreases the resistance of the circuit, increasing the current. The resistance of the voltmeter should be as large as possible to minimize the effect of adding the voltmeter.

Related End-of-Chapter Exercises: 47, 60.

Essential Question 18.8: Can you add a 5.0 Ω resistor to the circuit in Figure 18.20 so that some current passes through it while the current through original resistors is unchanged? Explain.

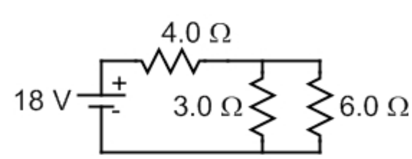

Figure 18.20: The circuit for Essential Question 18.8.