Activity 14, "Series and Parallel Circuits"

from

Science & Global Issues: Global Energy & Power

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14 Series and Parallel Circuits

LABORATORY • 2–3 CLASS SESSION

OVERVIEW

Students build and compare series and parallel circuits. They apply what they have discovered about Ohm's law to analyze current, voltage, and resistance in series and parallel connections.

Next Generation Science Standards (NGSS)
DISCIPLINARY CORE IDEAS
PS.3.A: Definitions of Energy
ETS.1.A: Defining and Delimiting Engineering problems
SCIENCE AND ENGINEERING PRACTICES
Analyzing and Interpreting Data
Obtaining, Evaluating, and Communicating Information
Planning and Carrying Out Investigations
Using Mathematics and Computational Thinking
CROSSCUTTING CONCEPTS
Cause and Effect
Energy and Matter
Scale, Proportion, and Quantity
Structure and Function

KEY CONTENT

1. The current through elements of a circuit connected in series is the same at all points in the circuit, regardless of the resistance of the elements.
2. The voltage across elements connected in parallel is the same, regardless of the resistance of the elements.
3. At any node or junction in a circuit, the sum of the currents flowing into the junction is equal to the sum of the currents flowing out of it (Kirchhoff's junction law).
4. The sum of the voltages around any closed loop in a circuit is zero (Kirchhoff's loop law).
5. For elements in a circuit that are connected in series, the cumulative resistance of all the elements is equal to the sum of the individual resistances.
6. For elements in a circuit that are connected in parallel, the cumulative resistance of all the elements is given as

$$\frac{1}{R_{total}} = \Sigma\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\cdots\right)$$

MATERIALS AND ADVANCE PREPARATION

For the teacher

Scoring Guide: DESIGNING INVESTIGATIONS (DI)
Scoring Guide: UNDERSTANDING CONCEPTS (UC)
Scoring Guide: ORGANIZING DATA (OD)
Student Sheet 14.1, "Sample Procedure: Series and Parallel Circuits *(optional)*
Science Skills Student Sheet 4, "Elements of Good Experimental Design" *(optional)*
Literacy Transparency 3, "Read, Think, and Take Note Guidelines" *(optional)*

For each group of four students

2 wires with clips
2 D cells in holder
2 Cir-Kit incandescent lightbulbs (2.5 V)
3 Cir-Kit component holders
2 82-Ω resistors
120-Ω resistor
8 Cir-Kit slides
14 Cir-Kit junctions
Cir-Kit switch
Cir-Kit ammeter
Cir-Kit voltmeter

For each student

graph paper*
3–5 sticky notes
Student Sheet 14.1, "Sample Procedure: Series and Parallel Circuits" *(optional)*
Scoring Guide: DESIGNING INVESTIGATIONS (DI) *(optional)*
Scoring Guide: UNDERSTANDING CONCEPTS (UC) *(optional)*
Scoring Guide: ORGANIZING DATA (OD) *(optional)*

**Not supplied in kit*

Masters for Scoring Guides are in Teacher Resources IV: Assessment. Masters for Literacy Transparencies are in Teacher Resources III: Literacy. Masters for Science Skills Sheets are in Teacher Resources II: Diverse Learners.

TEACHING SUMMARY

Getting Started

- Formally introduce the terms series and parallel

Doing the Activity

- Students conduct a qualitative investigation.
- (DI, OD ASSESSMENT) Students design and conduct a quantitative investigation.
- (LITERACY) Students read the Technology Connection.

Follow-up

- (UC ASSESSMENT)(LITERACY) Review the class results and how the total resistance is determined when resistors are connected in series and in parallel.

BACKGROUND INFORMATION

Series Circuits

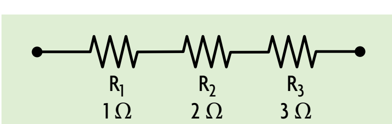
When circuit elements, such as lightbulbs, are connected in series, current from one side of a battery to the other must pass through all the elements in succession. The current is the same through each element, and through the battery. However, the voltages across each element can differ, depending on the resistance of the element. The sum of all the voltages across the elements will equal the voltage across the battery.

The equivalent resistance of all the circuit elements connected in series is given by

$$R_{eq.} = R_1 + R_2 + R_3 + \dots$$

For example, if there are three lightbulbs in series with unequal resistances as shown below, the equivalent resistance of all three combined will be:

$$R_{eq.} = R_1 + R_2 + R_3 = 1\,\Omega + 2\,\Omega + 3\,\Omega + = 6\,\Omega$$



Parallel Circuits

When circuit elements are connected in parallel, the current is allowed to split and travel through multiple circuit elements simultaneously before returning to the other side of the battery. The voltage across each pathway is the same and is equal to the voltage across the battery. However, the currents through each circuit element can differ, depending on the resistance of the element. The sum of all the currents through each circuit element will equal the current through the battery.

The equivalent resistance of all the circuit elements connected in parallel is given by

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

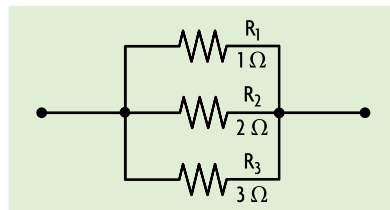
For example, if we have three lightbulbs in parallel, as shown below, the total resistance of all three combined will be:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

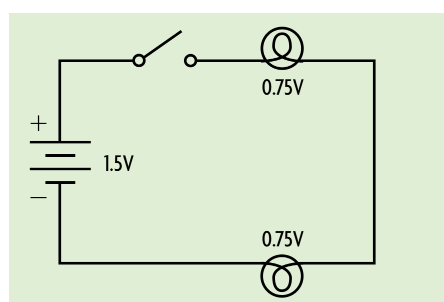
$$= 1\,\Omega + 1/2\,\Omega + 1/3\,\Omega$$

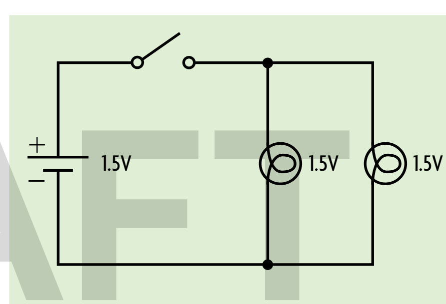
$$= 1.83\,\Omega^{-1}$$

$$R_{total} = 0.55\,\Omega$$



Kirchhoff's loop rule is true for both parallel and series circuits. For a series circuit, there is only one "loop" to follow. But for two lightbulbs connected in parallel, there are multiple loops or paths of current. The voltages across each path will follow the loop rule. For example, the series circuit at right contains two identical lightbulbs with 0.75 V going across, and the voltage across the battery is 1.5 V. The parallel circuit below also contains two identical lightbulbs. The voltage across each one is 1.5 V, and the voltage across the battery is also 1.5 V.





GETTING STARTED

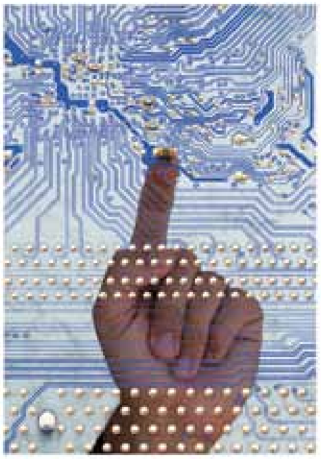
1 Point out to students that they already have experience with circuits that have components oriented in different ways. Sometimes they have connected components in a chain, and sometimes they have connected components side by side. If you have not already done so, introduce the terms *series* for the chain configuration and *parallel* for side-by-side connections. Present actual setups or schematics from previous activities to help students see the differences in these methods of connection.

Let students know they that in this activity they will investigate how Ohm's law applies to series and parallel circuits.

14 Series and Parallel Circuits

1 MANY MAJOR ADVANCEMENTS in the field of electrical engineering were propelled by relationships described by Ohm's law. For example, 50 years after Ohm's work, Thomas Edison rediscovered this relationship when developing the incandescent lightbulb. No one else had been able to get such a bulb to work reliably, but Edison had a breakthrough when he realized that the filament in the bulb should have a high resistance so that the current through the wires could be low. He calculated that for a 1–2 A current through copper, he would have to use a high-resistance bulb operating at a lower 110 V. Ultimately, his team of scientists determined that carbonized cardboard in the lightbulb provided the resistance and durability he sought.

Edison applied Ohm's law when he designed home circuits with bulbs in parallel instead of in series to lower the overall resistance. In a **parallel circuit,** the components are set up in the circuit so that the electrical energy has more than one conducting path from the battery. This is in contrast to a **series circuit,** where all the components in the circuit are connected in succession. There is only one path for the electrical energy to travel in a series circuit. In this activity you will investigate how connecting circuit components in series or parallel affects current and resistance.



Integrated circuit boards connect many tiny devices, such as resistors and capacitors, in series and parallel.

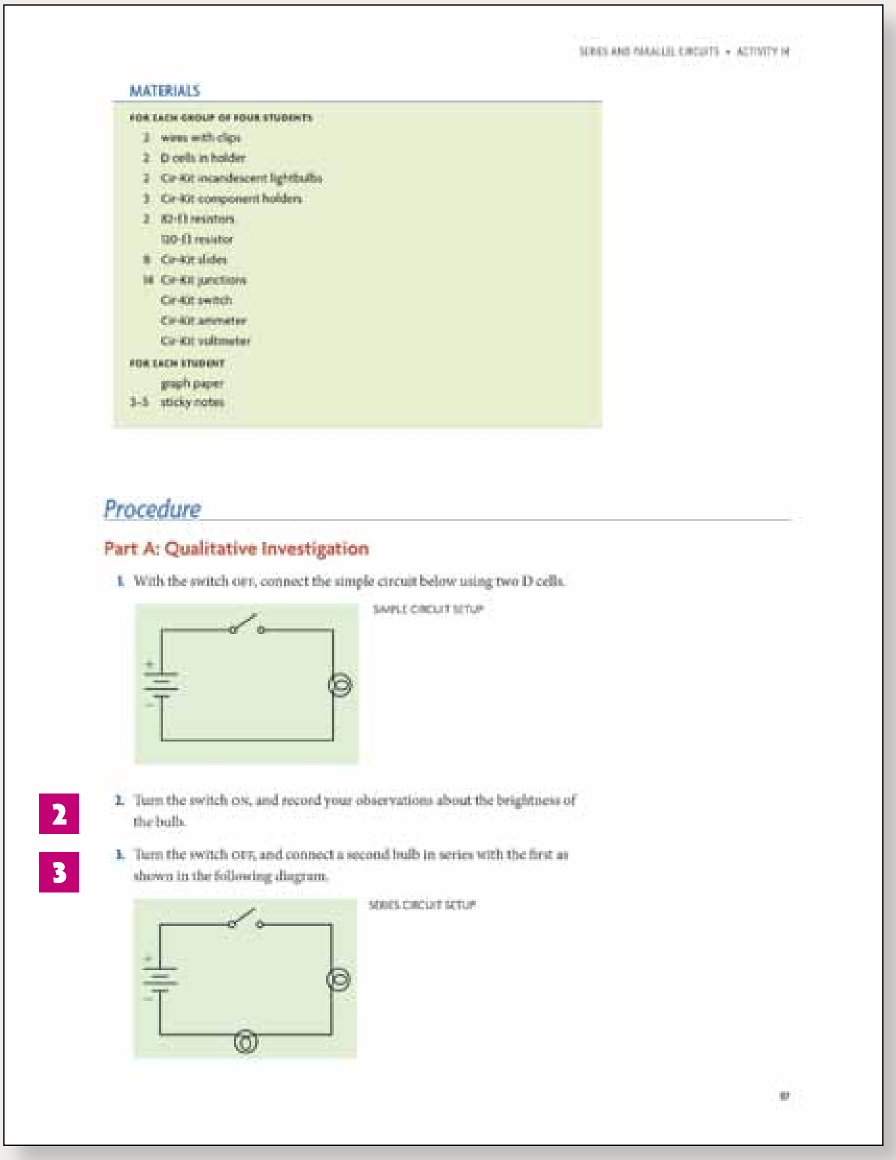
Challenge

► How do current and resistance change when components are connected in series or parallel circuits?

DOING THE ACTIVITY

2 Make sure that students understand that the brightness of the bulb at a constant voltage is an indication of the current flowing through it.

3 Students should notice that when a second bulb is connected in series both bulbs are dimmer than for the single-bulb circuit. This indicates that less current is now flowing through the bulbs compared to when there was only one bulb. Adding the bulb in series increased the resistance, thereby reducing the current. If the two identical bulbs are of equal brightness, it can be assumed that they are receiving the same current. The bulbs are also now sharing the voltage.


SERIES AND PARALLEL CIRCUITS • ACTIVITY 14

MATERIALS

FOR EACH GROUP OF FOUR STUDENTS
3 wires with clips
2 D cells in holder
2 Cir-Kit incandescent lightbulbs
3 Cir-Kit component holders
2 82-Ω resistors
120-Ω resistor
8 Cir-Kit slides
14 Cir-Kit junctions
Cir-Kit switch
Cir-Kit ammeter
Cir-Kit voltmeter

FOR EACH STUDENT
graph paper
3–5 sticky notes

Procedure

Part A: Qualitative Investigation

1. With the switch OFF, connect the simple circuit below using two D cells.

SIMPLE CIRCUIT SETUP

2. Turn the switch ON, and record your observations about the brightness of the bulb.

3. Turn the switch OFF, and connect a second bulb in series with the first as shown in the following diagram.

SERIES CIRCUIT SETUP

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4 When the two bulbs are connected in parallel they should be much brighter than when they were connected in series where each one was getting less current than with one bulb. In the parallel circuit the total resistance has decreased, and so the current in the circuit has increased compared to the circuit with the two bulbs connected in series. The bulbs should also be of equal brightness. Both bulbs are getting the same voltage in parallel.

5 (DI ASSESSMENT) The circuits that the students build are similar to those in Part A except that resistors will replace the bulbs and students connect a voltmeter and ammeter to measure voltage and current. They calculate the resistance using the values for voltage and current.

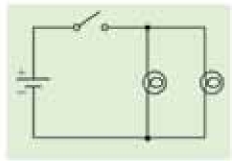
Groups should design an investigation to test series and parallel circuits using two and three resistors in each circuit. You may want to review with some groups Science Skills Student Sheet 4, "Elements of Good Experimental Design," to help students with their investigations.

Students' written work from the procedure may be scored with the DESIGNING INVESTIGATIONS (DI) Scoring Guide. Student Sheets 14.1, "Sample Procedure: Series and Parallel Circuits," show sample procedures that help guide the laboratory part of this activity for those groups who may have difficulty in designing their own experimental procedures. In combination with sample student results below, it may also serve as a sample Level-3 response.

6 (OD ASSESSMENT) Students' written work from Procedure Step 7 may be scored with the ORGANIZING DATA (OD) Scoring Guide. A complete and correct response is shown on the right.

4. Turn the switch on, and record your observations of the brightnesses of the two bulbs.

4 5. Remove one D cell and connect the parallel circuit shown in the following diagram. Turn the switch on, and record your observations of the brightnesses of the bulbs.



PARALLEL CIRCUIT SETUP

Part B: Quantitative Investigation

5 6. Working with your observations from Part A, design an investigation to test how the current and voltage differ in a parallel circuit compared to a series circuit. Make sure to consider the following as you design your investigation:

- You may use one D cell, an ammeter, a voltmeter, connectors, and up to three resistors.
- You may connect the resistors in different combinations.
- The ammeter and voltmeter are for measuring current and voltage in various parts of the circuits.

Discuss your experimental design with your teacher before connecting the circuit.

6 7. Conduct your investigation, and record all data in your science notebook.

7 8. In your science notebook write your conclusions from the investigation. Include how you think the resistance of a parallel circuit compares to that of a series circuit.

Hint: Refer to Activity 12, "Ohm's Law," for ways to determine resistance.

Part C: Technology Connection

8 9. Individually read the Technology Connection, "Electronics Power Consumption and Heat Production," on the following pages. As you read, follow the literacy strategy, "Read, Think, and Take Note."

10. Share your thinking with your group. Place your sticky notes on the table in front of you. Look for connections between your notes and those of others in your group.

11. Place your sticky notes in your science notebook. Below them write a short summary of your group discussion and any conclusions your group came to.

Sample Student Response: Procedure Step 7

A. Resistors in series

R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	I (mA)	V (V)	Calculated R (Ω)
82	82	None	9	167	88
85	120	None	7	200	127
82	82	120	5	280	175

B. Resistors in parallel

R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	I (mA)	V (V)	Calculated R (Ω)
82	82	None	31	1.3	42
82	120	None	26	1.3	50
82	82	120	41	1.3	32

Note: Although they should be close, the calculated resistance will likely not be an exact match with the actual resistance due to the combination of the tolerances of the resistors with the inaccuracies of the meter. Theoretical values for the combinations are provided in the table below. If appropriate, this would be a good time to discuss sources of error in experiments.

Title for this table?

R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	THEORETICAL RESISTANCE	
			SERIES (Ω)	PARALLEL (Ω)
82	82	None	164	41
82	120	None	202	49
82	82	120	284	31

7 The table below summarizes what students should be able to state, based on their investigations, about the relationships of V, I, and R in the circuits.

The relationship between individual resistance and total resistance in parallel circuits, however, is not as obvious as in series circuits. It is more challenging for students to discover this exact relationship, even with highly accurate meters. It is unlikely that students will be able to derive the exact relationship of resistors in parallel without some assistance. So that all students will grasp the quantitative relationship for resistance in parallel circuits, carefully guide students who may need help through this relationship. In a parallel circuit, the inverse of the total resistance is equal to the sum of the inverse of the individual resistances. For example, if a 120-Ω resistor is connected in parallel with an 82-Ω resistor, the total resistance is

$$\frac{1}{R_{total}} = \Sigma\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\cdots\right)$$

$$\frac{1}{R_{total}} = \frac{1}{120} + \frac{1}{82}$$

$$= 0.0205\ \Omega^{-1}$$

$$R_{total} = 49\ \Omega$$

Students previously discovered the loop law that states the voltages in any closed path in a circuit is zero. In this activity, students learn that the sum of the currents going into any junction in a closed circuit is also zero. Although not identified as such in the student book, this relationship is known as Kirchhoff's junction law. As students work with the circuits, introduce the convention of current direction: positive (+) for currents entering a junction and negative (–) for those leaving a junction. If direction is not accounted for correctly, the sums at the junction do not make sense. Another way to present the junction law for single-voltage-source circuits is that the total current going into a junction needs to be equal to the total current going out of a junction.

8 (LITERACY) If appropriate, project Literacy Transparency 3, "Read, Think, and Take Note Guidelines," to review with students. Begin the discussion of the Technology Connection by asking students to discuss with their partners or groups the main points of the text and their comments on their sticky notes.

Sample Student Response: Procedure Step 8
Summary Table: Series and Parallel Conclusions

Conclusions	*Series*	*Parallel*
Voltage	*The voltage across each resistor depended on the resistance of the resistor. Higher resistances had a greater voltage and vice versa. The voltages across all of the resistors in series equal the voltage supplied by the battery.*	*The voltage across each resistor was the same.*
Current	*The current is the same through all resistors.*	*The current through each resistor was not always the same. Higher resistance results in lower current and vice versa. The sum of the currents through each branch of the parallel circuit is equal to the current supplied by the battery.*
Resistance	*The total resistance increases.*	*The total resistance is less than when the same resistors are connected in series and less than the value of any of the individual resistances.*

FOLLOW-UP

(LITERACY) In the next activity, students will rely on the content from this and previous activities to complete a circuit design challenge. After completion of the analysis questions and revisiting the challenge, consider concluding the activity by summarizing the main ideas of electrical circuits by developing a concept map.

A concept map is a graphic organizer that shows the relationships among important ideas and allows students to negotiate their own meaning of a central idea or concept. Students write the main concept, in this case electrical circuits, in the center of a piece of paper with topics placed around it. They draw a connecting line between each topic and the central concept to show that there is a relationship between the two ideas. Then, on or near the lines, they write brief descriptions of the relationships. They may draw additional lines to connect topics and fill in associated descriptions. This is the first of several activities involving concept maps. For more information, see Teachers Resources III: Literacy.

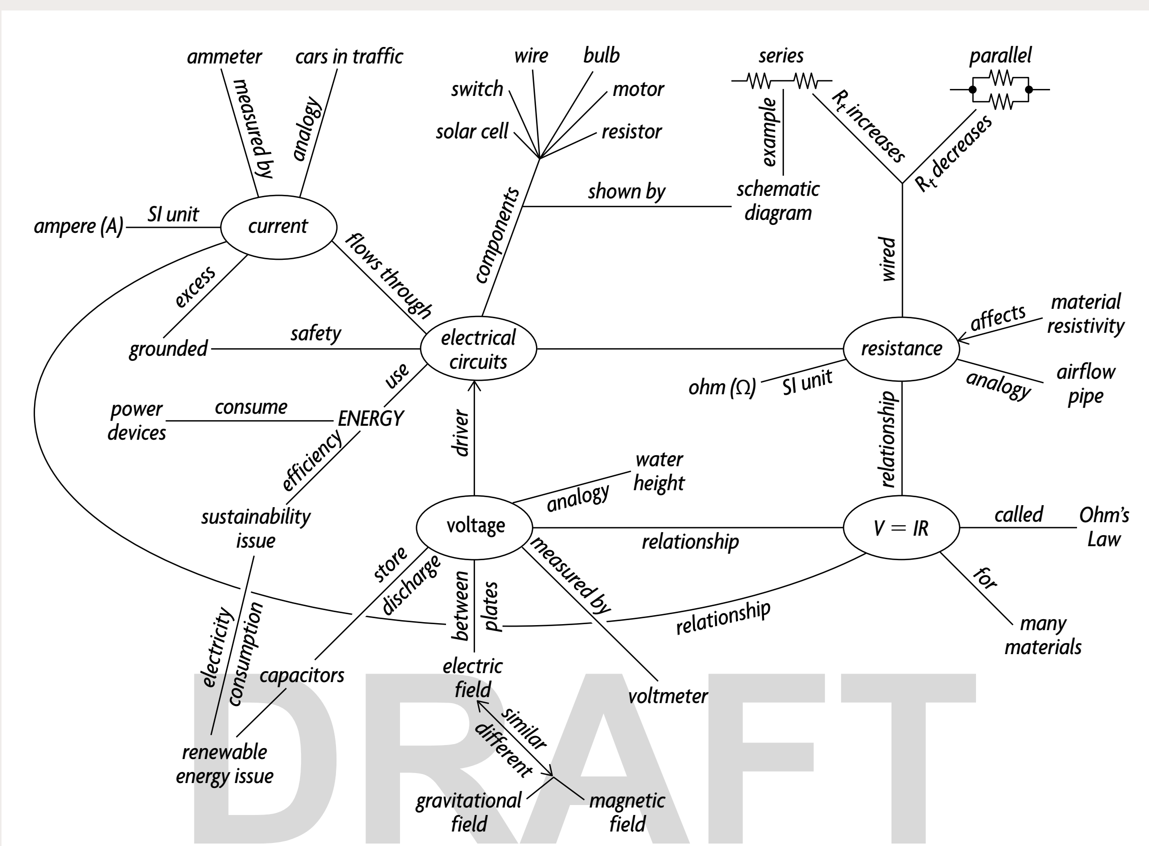
Because this activity introduces the concept-map strategy, construct this one on the board or an overhead with the whole class. Use the following list of terms from this unit to start the concept map electrical circuits:

Voltage	*Series*
Current	*Parallel*
Resistance	*Electric Field*
Ohm's law	

Follow these steps:

1. Write the words "electrical circuit" in the middle of your paper, and circle it.
2. Discuss with the class how the other words are related to the words electrical circuit. Sort your words into categories based on these relationships.
3. Decide on the first set of words you want to add to the concept map, and plan where to place these words on your paper. Then place the words, and circle them
4. Draw a line between the word electrical circuit and your first set of words. On the line write brief phrases to describe the relationship between the words.

A sample concept map is shown below.



SERIES AND PARALLEL CIRCUITS • ACTIVITY 14

Technology Connection: Electronics Power Consumption and Heat Production

All of the electronic items typically found in homes, such as TVs, game consoles, computers, and phones, rely on sophisticated components. They consume electricity whether or not they are always connected to the electrical circuit in your home or are just recharged from it. Because electronics are so widespread in the developed world, the total amount of electrical energy needed to power these devices is very high. Having efficient electronic components is important for sustainability. From an economic perspective, having more-energy-efficient components will waste less electricity and, therefore, will cost less to operate. Wasting less electricity also has environmental benefits because generating less electricity produces fewer pollutants and uses fewer natural resources.

When you make a purchase online or at a store, the odds are that your transaction will be processed by a remote computer, possibly thousands of miles away. In fact most large-scale technological applications rely on server "farms." Such places are referred to as data centers, and they can be huge. Google, for example, has data centers around the world, each with tens of thousands of servers. The number of servers in data centers around the world almost doubled to a little under 24 million in 2005 from just under 12 million in 2000. The number of servers in 2010 has been estimated at almost 32 million. Data centers need tremendous amounts of power. For example, in 2005, U.S. data centers consumed 56 billion kWh of electricity at an estimated cost of $2.7 billion, and as more data centers are built the power demands will likely rise for some time into the future. Recent trends at least show a slowing of the increase in power demands, considering that the 100% increase between 2000 and 2005 was followed by a 53% increase between 2005 and 2010. However, even such a slowing in the rate of increase will not lead to a reduction in total electricity use.

Racks of servers at a data center

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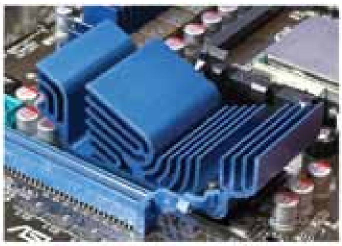
THE HEAT PROBLEM

Almost half the energy supplied to a data center is for cooling the servers. All electronic devices waste some energy by generating heat, and if the heat is allowed to build up it can cause the device to function less efficiently or even to fail. Heat is produced in various parts of electronic devices but especially in microprocessors. Microprocessors have integrated circuits containing transistors located on a silicon chip about the size of a postage stamp. The transistors are digital switches that are switched on and off millions of times per second to control the movement of electricity around the circuit. Just 40 years ago the number of transistors that could be placed on a single chip was in the thousands, but now that the size of transistors has been reduced the number that can fit on a chip is above 1 billion and is still increasing.

Even this tiny microchip consumes power and generates waste heat.

Each transistor, no matter how tiny, consumes power and generates waste heat, and with a billion of them on one small chip the total amount of heat generated is considerable. As new generations of transistors employ faster switching speeds they produce more heat, and as transistors are made smaller there is less area through which the heat can escape. A further problem occurs when transistor size shrinks too far. Below about the size of 45 nm the transistor is so inefficient that over two-thirds of the power supplied to a chip is lost through leakage. Current research is investigating alternatives to transistors as switches. One idea is to use electrons themselves as switches by controlling whether they spin clockwise or counterclockwise.

Microprocessors are cooled in various ways. A common method is to increase the surface area that releases heat by attaching a heat sink. The heat sink is a piece of metal with small fins. The metal conducts heat away from the chip, and the fins increase the area exposed to the air. The heat sink is often painted black because dark colors are more effective at radiating heat into the air. Fans may be installed in a device to circulate air around the chip. This may range from powerful airflow systems in a data center to a cooling fan on a graphics card in a desktop computer. Since air is not a good conductor of heat, some microprocessors instead circulate a liquid through narrow channels on the chip. The liquid absorbs some of the heat and moves it away from the chip. Using fans or liquids is not an option for mobile devices because incorporating such systems into small structures or supplying enough electricity to power them is not feasible. The cooling that does occur in a mobile device is limited to convection and radiation. The modest cooling ability of mobile devices limits its energy use and processing power.



The fins on a heat sink conduct heat away from the chips that are generating the heat.

9 If appropriate for your students, allow them to answer Analysis Questions 4 and 5 without identifying the exact ratios between quantities. Just indicating increasing or decreasing quantities is sufficient in some cases.

SAMPLE RESPONSES

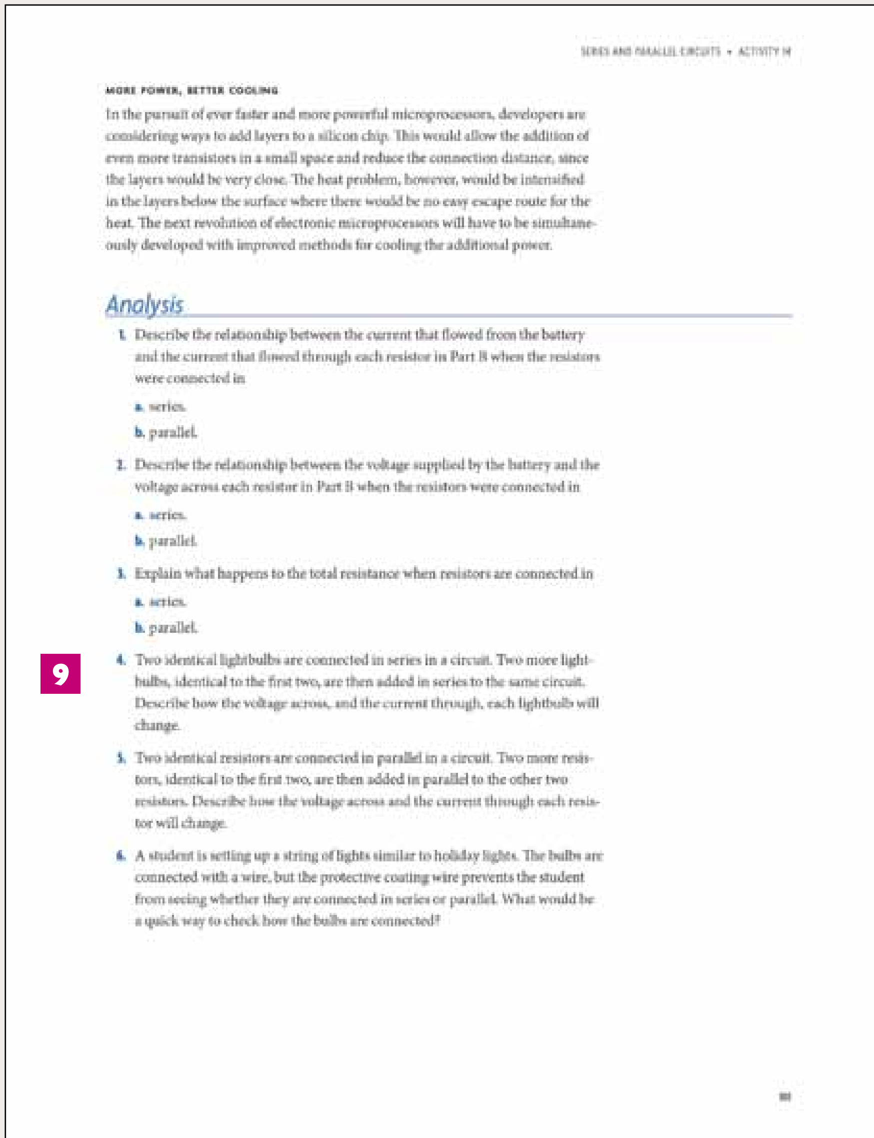
1 a. When resistors are connected in series, the current was the same through each resistor and equaled the current supplied by the battery.

b. When resistors were connected in parallel the current through each resistor was not always the same. The higher the resistance the lower the amount of current that flowed through it. We also found that if we added up the current through each branch of the parallel circuit it was equal to the current supplied by the battery.

2 a. When resistors are connected in series the voltage across each resistor depended on the resistance of the resistor. Higher resistances had a greater voltage across them. When we added up the voltages across all of the resistors in series the sum equaled the voltage supplied by the battery.

b. When resistors were connected in parallel the voltage across each one was the same.

3 a. The total resistance in a circuit increases when resistors are connected in series. We came to this conclusion because as each resistor was added the current in the circuit decreased although the voltage supplied to the circuit had not increased.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MORE POWER, BETTER COOLING

In the pursuit of ever faster and more powerful microprocessors, developers are considering ways to add layers to a silicon chip. This would allow the addition of even more transistors in a small space and reduce the connection distance, since the layers would be very close. The heat problem, however, would be intensified in the layers below the surface where there would be no easy escape route for the heat. The next revolution of electronic microprocessors will have to be simultaneously developed with improved methods for cooling the additional power.

Analysis

1. Describe the relationship between the current that flowed from the battery and the current that flowed through each resistor in Part B when the resistors were connected in
   a. series.
   b. parallel.
2. Describe the relationship between the voltage supplied by the battery and the voltage across each resistor in Part B when the resistors were connected in
   a. series.
   b. parallel.
3. Explain what happens to the total resistance when resistors are connected in
   a. series.
   b. parallel.

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4. Two identical lightbulbs are connected in series in a circuit. Two more lightbulbs, identical to the first two, are then added in series to the same circuit. Describe how the voltage across, and the current through, each lightbulb will change.
5. Two identical resistors are connected in parallel in a circuit. Two more resistors, identical to the first two, are then added in parallel to the other two resistors. Describe how the voltage across and the current through each resistor will change.
6. A student is setting up a string of lights similar to holiday lights. The bulbs are connected with a wire, but the protective coating wire prevents the student from seeing whether they are connected in series or parallel. What would be a quick way to check how the bulbs are connected?

b. The current increased in our circuit when resistors were connected in parallel. Since the voltage supplied to the circuit stayed the same (one D cell), the increased current must be due to reduced resistance.

4. In a series circuit the current is the same at all points, and if the lightbulbs are identical, they will have an identical voltage across each one. Doubling the number of lightbulbs will double the resistance in the circuit and will, therefore, halve the current; however all the bulbs will receive the same reduced current. Since the voltage of the supply is now shared across twice as many lightbulbs instead, the voltage across each bulb will be halved.

5. In a parallel circuit the voltage across each resistor is the same, and so if the resistors are identical they will each receive half of the total current. Adding two more identical resistors will halve the resistance in the circuit and will, therefore, double the total current. However, each individual resistor will still receive the same current and voltage.

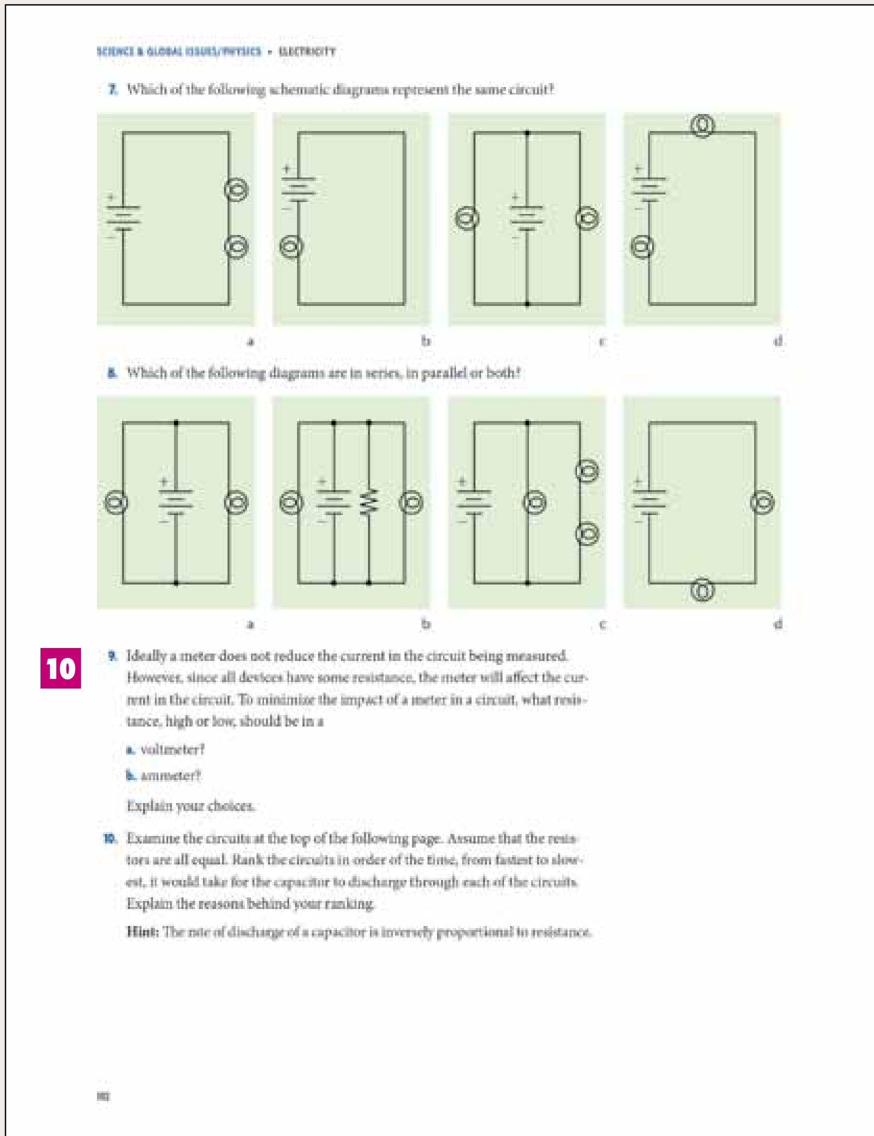
6. If you unscrew (or pull out) one of the bulbs and all of the bulbs go out, that means the bulbs are connected in series because the single current path through the bulbs was broken.

7. Circuits a and d are the same. Schematic diagrams don't show the actual placement of components in a circuit.
8. A and b are parallel, d is series, and c has both series and parallel.

10 (UC ASSESSMENT) Students' written work from Analysis Questions 9 and 10 may be scored with the UNDERSTANDING CONCEPTS (UC) Scoring Guide. A complete and correct response is shown in the Sample Responses below.

Students' written work from Analysis Questions 9 and 10 can be scored with the UNDERSTANDING CONCEPTS (UC) Scoring Guide. Provide all students with a UC Scoring Guide, and explain to the class how you will apply it to provide feedback on the quality of their work and to assess their understanding of the key concepts in the activity.

9. (UC ASSESSMENT) Students' responses will vary. A complete and correct response will show an understanding of how meters are connected in a circuit. See Background Information for Activity 7, "Discharging Capacitors," for more information on properly connecting meters.


SCIENCE & GLOBAL ISSUES/PHYSICS • ELECTRICITY

7. Which of the following schematic diagrams represent the same circuit?

a b c d

8. Which of the following diagrams are in series, in parallel or both?

a b c d

10

9. Ideally a meter does not reduce the current in the circuit being measured. However, since all devices have some resistance, the meter will affect the current in the circuit. To minimize the impact of a meter in a circuit, what resistance, high or low, should be in a
   a. voltmeter?
   b. ammeter?

   Explain your choices.

10. Examine the circuits at the top of the following page. Assume that the resistors are all equal. Rank the circuits in order of the time, from fastest to slowest, it would take for the capacitor to discharge through each of the circuits. Explain the reasons behind your ranking.

   Hint: The rate of discharge of a capacitor is inversely proportional to resistance.

Sample Level-3 Response

a. A voltmeter is always connected in parallel with the device whose voltage it is measuring. To draw as little current as possible from the circuit, the voltmeter should have as high a resistance as possible.

b. An ammeter is always connected in series in a circuit. To reduce the current in the circuit as little as possible the ammeter should have low resistance.

10. (UC ASSESSMENT) Students' responses will vary. A complete and correct response will show an understanding that current will increase through a lower resistance. Even if students cannot calculate that the resistance will be exactly halved, they should know that connecting resistors in parallel makes the total resistance less than any of the individual resistances.

Sample Level-3 Response

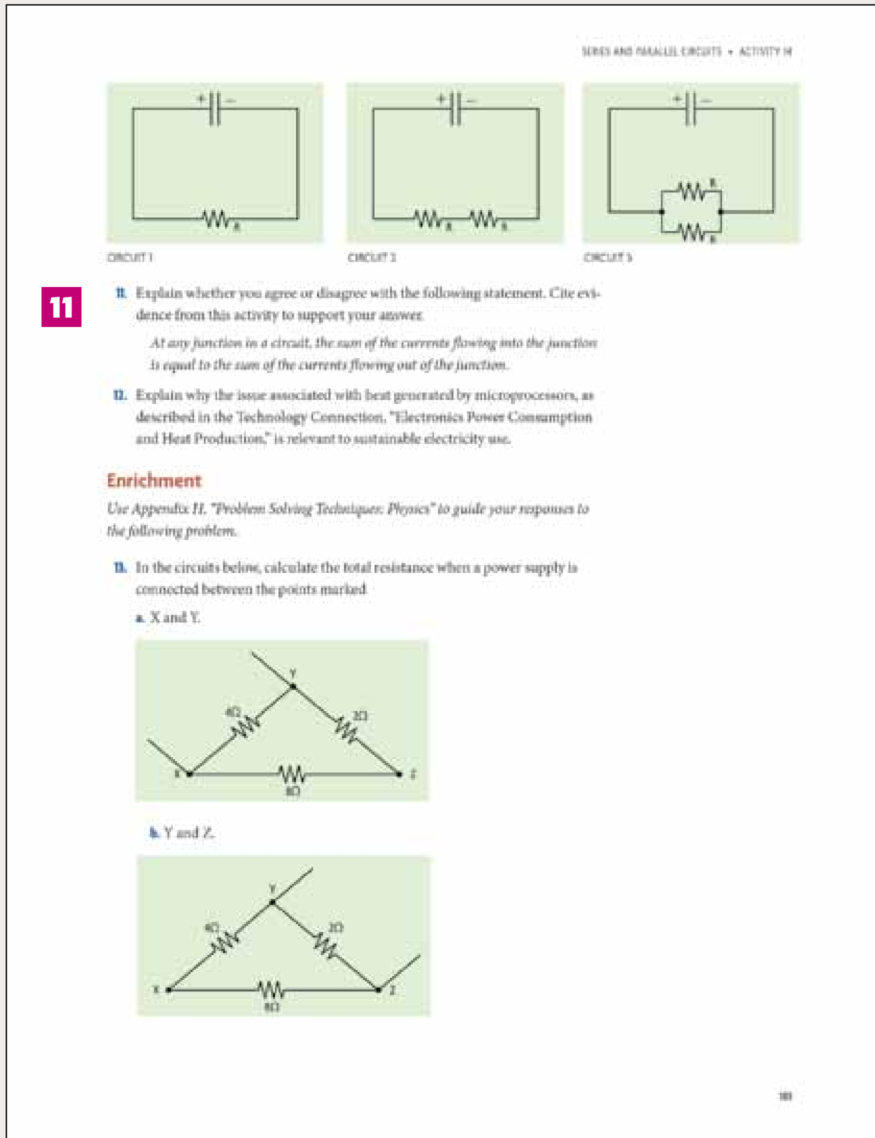
The capacitor will discharge quickest through the circuit with the lowest resistance.

Circuit 2 has the highest resistance because it has two resistors in series.

Circuit 3 has the lowest resistance because it has two resistors in parallel. Since the resistors are equal in value the total resistance will be half of the individual resistance. Circuit 1 has a resistance in between the other two. Therefore, the order of discharge will be:

Circuit 3 = fastest
Circuit 1 = medium
Circuit 2 = slowest.

11 ✓Analysis Question 11 serves as a Quick Check assessment to ensure that students can accurately identify the key content, which is a component of the UNDERSTANDING CONCEPTS Scoring Guide.


SERIES AND PARALLEL CIRCUITS • ACTIVITY 14

11. Explain whether you agree or disagree with the following statement. Cite evidence from this activity to support your answer.

At any junction in a circuit, the sum of the currents flowing into the junction is equal to the sum of the currents flowing out of the junction.

12. Explain why the issue associated with heat generated by microprocessors, as described in the Technology Connection, "Electronics Power Consumption and Heat Production," is relevant to sustainable electricity use.

Enrichment

Use Appendix H, "Problem Solving Techniques: Physics" to guide your responses to the following problem.

13. In the circuits below, calculate the total resistance when a power supply is connected between the points marked

a. X and Y.

b. Y and Z.

11. ✓Students should indicate that they agree. The current entering a junction is numerically equal to the current that leaves the junction. In our experiment we found that the sum of the current in the branches equaled the current being supplied from the batteries.

12. A device is efficient if the majority of the energy supplied to it is used by the device to do its job. For example, the purpose of a lightbulb is to produce light. Any electricity supplied to the bulb that is not used for light is wasted energy. A lightbulb that produces a lot of heat wastes a lot of energy. Similarly, when a microprocessor produces a lot of heat, it is wasting a lot of energy. In addition, the devices that keep microprocessors cool (and functioning correctly) consume a energy. It takes resources to produce this energy, which often produces pollutants. To increase sustainability we need to make devices that operate in a more efficient way so that less energy is wasted.

ENRICHMENT

13. a. The resistance is equivalent to the 4-Ω resistor being placed in parallel to a branch of the circuit that has the 8-Ω and 2-Ω resistors in series. The total resistance is

$$\frac{1}{R_{parallel}} = \frac{1}{4\,\Omega} + \frac{1}{(8\,\Omega + 2\,\Omega)}$$

$$= \frac{7}{20\,\Omega}$$

$$R_{parallel} = 2.9\,\Omega$$

b. The resistance is equivalent to the 2-Ω resistor being placed in parallel to a branch that has the 4-Ω and 8-Ω resistor in series.

$$\frac{1}{R_{parallel}} = \frac{1}{2\,\Omega} + \frac{1}{(4\,\Omega + 8\,\Omega)}$$

$$= \frac{7}{12\,\Omega}$$

$$R_{parallel} = 1.7\,\Omega$$

14. a. When both switches are open the circuit has two 10-Ω resistors connected in series. Therefore the total resistance is 20 Ω.

Applying Ohm's law,

$V = IR$

$20\text{ V} = I(20\,\Omega)$

$I = 1\text{ A}$

b. When S_1 is open, the resistance on the top is 10 Ω. When S_2 is closed, the 10-Ω resistor on the bottom is in parallel with the 8-Ω resistor next to it. So the resistance on the bottom is

$$\frac{1}{R_2} = \frac{1}{8\Omega} + \frac{1}{10\,\Omega}$$

$$= \frac{18}{80\Omega}$$

$$R_2 = 4.4\ \Omega$$

The total resistance of the circuit is

$$R_{total} = 10\ \Omega + 4.4\ \Omega = 14.4\ \Omega$$

In this case of S_1 open, the current would be

$$V = IR$$
$$20\ V = I\,(14.4\ \Omega)$$
$$I = 1.4\ A$$

When S_1 is closed, the 10-Ω resistor is in parallel with the 2-Ω resistor next to it. So the resistance on the top is

$$\frac{1}{R_1} = \frac{1}{10\,\Omega} + \frac{1}{2\,\Omega}$$

$$= 0.6\ \Omega^{-1}$$
$$R_1 = 1.7\ \Omega$$

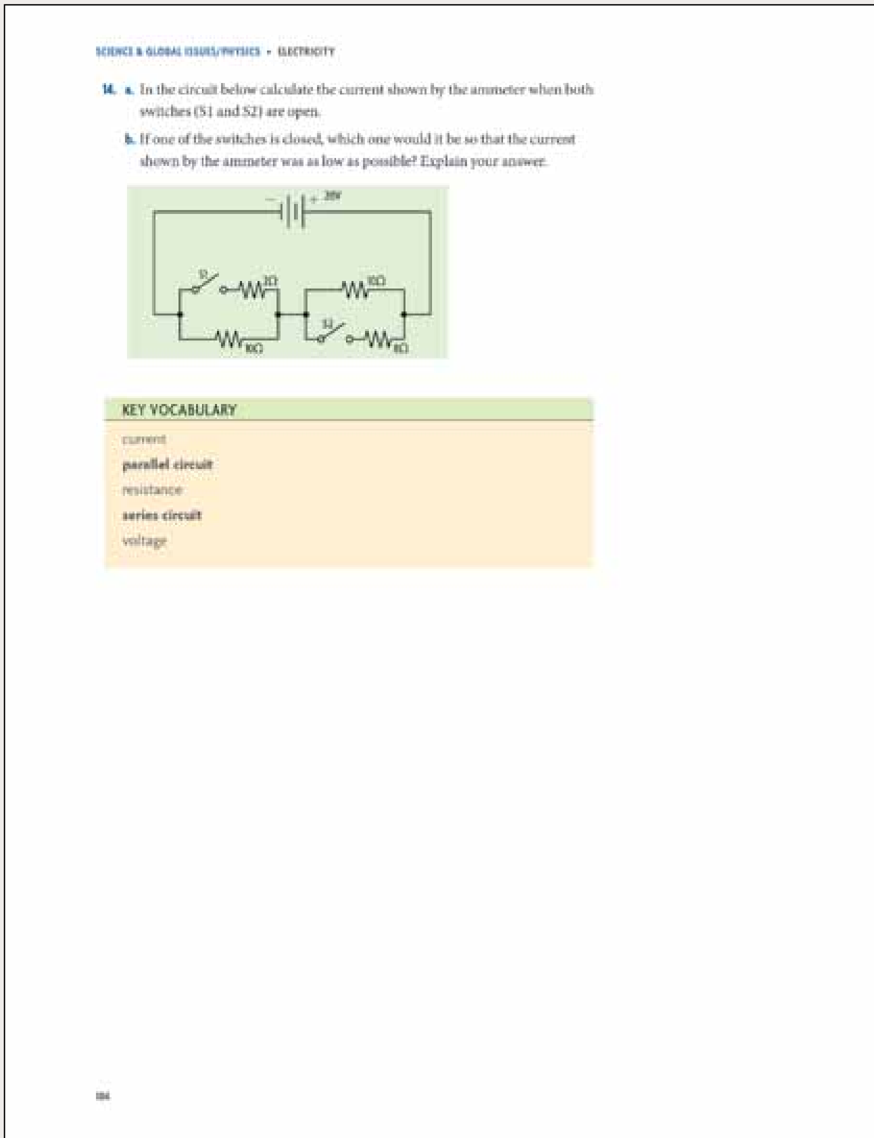
The total resistance of the circuit is

$$R_{total} = 10\ \Omega + 1.7\ \Omega = 11.7\ \Omega$$

In this case of S_1 closed, the current would be

$$V = IR$$
$$20\ V = I\,(11.7\ \Omega)$$
$$I = 1.7\ A$$

Since the current in the circuit is lower when the resistance is higher with S_1 closed, the first situation will produce a lower current.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14. a. In the circuit below calculate the current shown by the ammeter when both switches (S1 and S2) are open.

b. If one of the switches is closed, which one would it be so that the current shown by the ammeter was as low as possible? Explain your answer.

KEY VOCABULARY

current
parallel circuit
resistance
series circuit
voltage

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REVISIT THE CHALLENGE

Students should understand that total resistance increases when devices are connected in series and decreases when connected in parallel. Students should be able to express this mathematically for series circuits,

$$R_{total} = R_1 + R_2 + R_3 + \cdots$$

For parallel circuits, students should be able to express this mathematically only if they were guided to this relationship in the activity,

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$