Chapter 19

DC Circuits

19.1 Electric current

OALG 19.1.1 Observe and explain

a. Watch the following experiment https://youtu.be/IA28ahpNdxk. Describe what you observed, and explain why both electroscopes got discharged. Explain what is happening inside the metal rod right when it touches the electroscopes and at the end of the experiment.
b. Read and interrogate Observational Experiment Table 19.1 in Chapter 19 in the textbook. What do you think is needed for continuous charge flow?

c. Read and interrogate section "Fluid flow and charge flow" on page 574 in the textbook. How does this section explain the experiments with electroscopes and experiments in Table 19.1?

OALG 19.1.2 Observe and explain

Equipment: 1 D or C 1.5 V battery, a small incandescent lightbulb, 2 connecting wires.

If you have a battery, two wires, and a small lightbulb, follow instructions below.

a. Try different arrangements of these four elements to make the lightbulb glow.

b. Then, remove one wire and try to light the bulb with just a battery and one wire.

c. Draw pictures of the arrangements where the bulb lights and several where it does not. Explain how this experiment is similar to Activity 19.1.1 and how it is different.

d. Think of how an incandescent lightbulb might be constructed.

If you do not have the materials, go to https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html

Note that the simulation also uses incandescent light bulbs. They are very different from the LED bulbs that you use at home.

a. With PhET drag one light bulb, two wires, and a battery to the center of the screen. Arrange these four elements to light the bulb.

b. Now use only one wire. Can you light the bulb? How is this circuit similar to the first one? How is it different?

OALG 19.1.3 Explain

Use your observations and explanations for the previous activities to answer the following questions.
a. Summarize the conditions that are necessary for the continuous flow of electric charge in an electric circuit.
b. What properties of the devices are necessary to maintain a continuous electric charge flow through the wire? Think of such devices in your everyday experience.

c. Construct an analogy to explain how an electric circuit works. Use the following table to help you create your analogy. *Note*: An analogy involves mapping between the target phenomenon (the one we are trying to understand) and some source phenomenon (that we understand and are using to compare to the target phenomenon). The source phenomenon should be some everyday experience that you are familiar with, and whose physical processes are similar to the workings of the electric circuit you're trying to explain (this is your target phenomenon).

Source phenomenon	**Target phenomenon (electric circuit)**
	Battery
	Connecting wires
	Lightbulb
	Electric charges

Explain how your analogy works. How are the elements of your source phenomenon similar to the battery, charge flow, lightbulb, and connecting wires?

d. Compare and contrast your analogy with the material discussed in sub-sections "Making the process continuous" and "Electric current" on page 575 in the textbook.

OALG 19.1.4 Read and interrogate

Read and interrogate the entire Section 19.1 in the textbook and answer Review Question 19.1.

19.2 Batteries and emf

19.2.1 Explain

In Activity 19.1.2 you found that without a battery there is no continuous flow of charge in an electric circuit. How can you explain this fact?

19.2.2 Observe and design

Go to https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html and use available materials to build the three circuits according to the descriptions below.

Experiment 1	Experiment 2	Experiment 3
One battery, one lighted lightbulb, and two wires.	Two batteries arranged so that the positive side of one touches the negative side of the other, forming a chain (in physics they are said to be *in series*); one lighted lightbulb; and wires.	Two batteries arranged so that their positive sides are together and negative sides are together, forming a ladder (*in parallel*); one lighted lightbulb; and wires.

a. Draw each circuit in your notes. Observe the brightness of the lightbulb in each experiment relative to the other experiments and record your findings.

b. Explain the difference in brightness using the analogy you developed in Activity 19.1.3, or modify your analogy to explain your new findings if necessary. Sometimes your analogy won't work to explain what you found here. In that case you may need to abandon your analogy and come up with a new one.

c. Explain the difference in brightness using the language of energy.

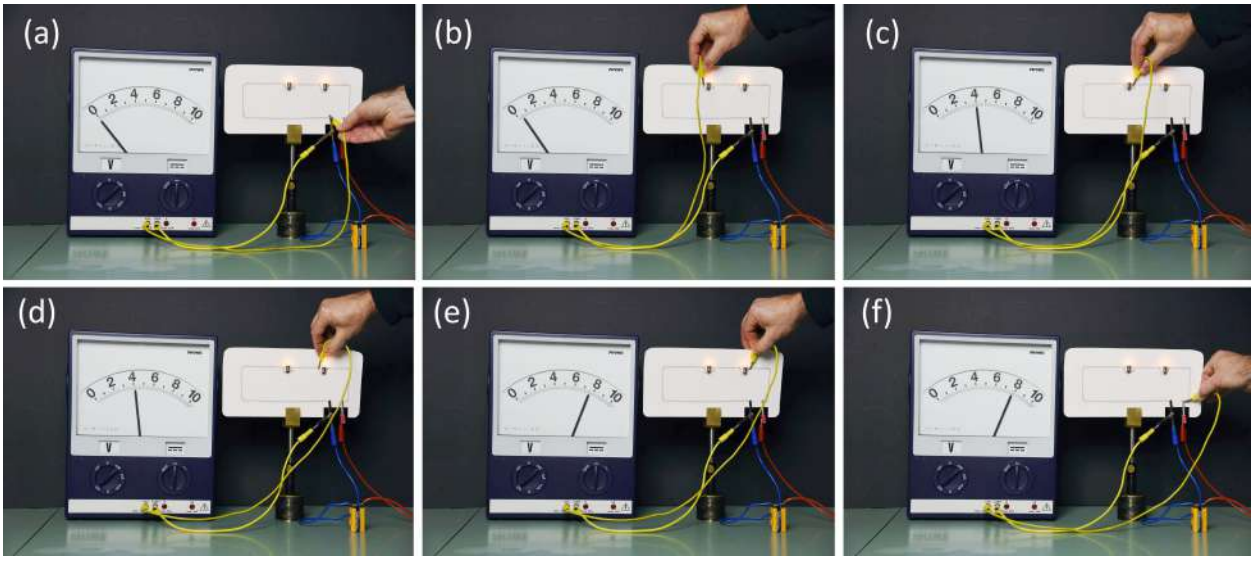
OALG 19.2.3 Observe and find a pattern

Read and interrogate Conceptual Exercise 19.2 on page 577 in the textbook. Then, read the "Try it yourself" question. The following photos show experimental steps to help you with the question. Here, we used 2 lightbulbs instead of two motors.

a. Draw a sketch of the electric circuit used in the experiment. Carefully follow all connections.

b. Find a pattern in the reading of the voltmeter. What can you say about the changes in electric potential through the circuit?

c. Draw a graph of potential-vs-location using the graph in Conceptual Exercise as a guide. How is your graph different from the graph in the exercise? Explain.



OALG 19.2.4 Read and interrogate

Read and interrogate Section 19.2 in the textbook and then:
a. Answer Review Question 19.2.

b. Compare and contrast the physical quantities emf and potential difference (voltage).

OALG 19.2.5 Practice

Answer Question 15 and solve Problems 1 - 4 on page 610 in the textbook.

19.3 Making and representing simple circuits

OALG 19.3.1 Observe and explain

You Observe the following experiment done with a 9-V battery and steel wool https://youtu.be/9ZUCXdjDAsA.

a. Use the analogy you developed in Activity 19.1.3 to explain what you saw. Modify your analogy to explain this phenomenon if necessary. Explain why steel wool keeps burning after the battery was removed.

b. Explain your observations using the language of energy, and compare and contrast steel wool burning with how the lightbulb works in the electric circuit. Do not forget that the steel wool, once it started burning, continued to burn even after you disconnected the battery.

OALG 19.3.2 Design an experiment

Your goal is to build an electric circuit in which the lightbulb glows, and an ammeter measures current *through* the bulb, and the voltmeter measures potential difference *across* different elements. You will do it using the circuit construction kit at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html.

a. Think of how to assemble the elements. Read the instructions about connecting ammeters and voltmeters in a circuit provided on your desk or on p. 580 of the textbook. Then examine the materials available for you in the simulation.

b. Draw the circuit you are going to make, including the ammeter so that it measures the current through the bulb. Mark points across which you will connect the voltmeter.

c. Make the circuit and check that the bulb only glows (and the ammeter is showing a non-zero reading) when the switch is closed.

d. Collect the current and potential difference data for different positions of the voltmeter (potential difference across the battery, across the bulb, across the wires, and across the closed and open switch).

e. Record the patterns that you find.

OALG 19.3.3 Reason

You learned that for a lightbulb to glow, the two poles of a battery must be connected to the lightbulb with conducting wires. You also observed experiments in which several batteries were connected to a lightbulb in series or in parallel. Use your knowledge of the internal structure of conductors and the understanding of the role of a battery to explain these observations using two analogies: one involving flowing water and the other involving a group of people running on a track. Remember that an analogy does not need to account for all aspects of a phenomenon. However, if you find similar aspects, make a note of them.

Parts of the electric circuit	**Parts of the water system**	**Parts of the running people system**
Moving electrons		
Battery		
Connecting wires	Pipes with water in them	
Lightbulb		Muddy patch on the track

Observed properties of the electric current	**Observed properties of the water system**	**Observed properties of the running people system**
When batteries are in series, the lightbulb is brighter than when only one battery is used.		
When identical batteries are in parallel, the lightbulb is the same brightness as when only one battery is used.		

Use the flowing water system and running-people system to find analogies for the quantities *potential difference* and *electric current*. Fill in the table that follows.

Electric circuit	**Water system**	**Running people**
Potential difference between two points ΔV		
Current I through a wire		

OALG 19.3.4 Read and interrogate

Read and interrogate Section 19.3 in the textbook and answer Review Question 19.3.

OALG 19.3.5 Practice

Solve Problems 5-9 on page 610 in the textbook.

19.4 Ohm's law

OALG 19.4.1 Design an experiment, find a pattern, and explain

Your goal is to find a relationship between the current through and potential difference across commercial resistors. Use the materials at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html

To make a variable power supply to vary the potential difference across a resistor you can place the battery in the circuit construction place, tap on it, and at the bottom of the screen you will see that you can change its emf from 0 to 120 V.

Please address the following points when you write up your report:

a. Describe the procedure for your investigation and describe your experimental design. Include a labeled circuit diagram.

b. What important physical quantities change during the experiment? What are the independent and dependent variables in your experiment?

c. Record your data in a table. Then calculate the ratio of potential difference across the resistor and the current through it for every potential difference reading. What can you say about the ratios if you take uncertainty into account?

d. The ratio of potential difference across the resistor and the current through it for each potential difference reading is called *resistance*. What can you say about the resistance of the resistor for different potential differences across it? Is the resistance of the resistor constant or is it changing?

e. Use the ohmmeter to measure the resistance of the resistor that is not connected to a circuit. Does it match your findings in part **c.**?

OALG19.4.2 Read and interrogate

Read the subsections "Ohmic and non-ohmic devices" and "Light-emitting diodes" in pages 582-584 in the textbook.

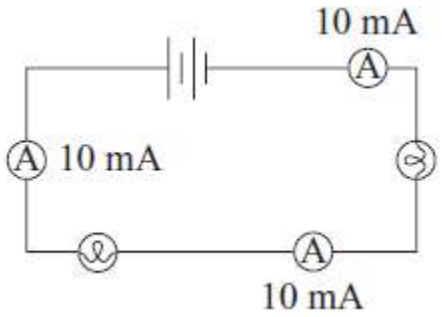
a. Devise a microscopic explanation for why the bulb didn't behave like the resistor in Activity 19.4.1 above. *Hint*: If you touch the glowing incandescent bulb, it is hot. What factor do you think temperature might play in this experiment?

b. Compare and contrast I-vs-ΔV graphs for the incandescent bulbs and LEDs. Why are both called non-ohmic elements?

OALG 19.4.3 Observe and explain

The readings of three ammeters are shown in the figure below.

a. What can you say about the magnitude of the current through each of the lightbulbs? Explain the pattern.



b. Build a circuit using a battery and two lightbulbs in series using the simulation at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html .

OALG 19.4.4 Test your ideas

Use materials at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html to build a circuit consisting of a battery (rated 9 V), a lightbulb, and a switch connected in series. Keep the switch open.

a. Draw the circuit diagram of your circuit.

b. Predict the potential difference across the battery, across the lightbulb, across a connecting wire, and across the switch. Now use a voltmeter to check your predictions. Write down the readings. Discuss any surprising results you found and reconcile them with your prediction.

c. Now close the switch and repeat the experiment. Write down the readings. Do they make sense?

d. Watch the following video https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-37. How do the readings of the voltmeters compare to the readings in your circuit?

e. Discuss whether Ohm's law in the form of $I = \frac{\Delta V}{R}$ applies to a battery and to a switch in an open circuit. Discuss whether Ohm's law applies to a battery, a switch, and a connecting wire in a closed circuit.

OALG 19.4.5 Read and interrogate

Read and interrogate Section 19.4 in the textbook and answer Review Question 19.4.

OALG 19.4.6 Practice

Answer Questions 10, 11, and 20, and solve Problems 10-14 on pages 609-611 and Problem 64 on page 613 in the textbook.

19.5 Qualitative analysis of circuits

To conduct the activities in this section, use materials at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html

OALG 19.5.1 Conduct an investigation

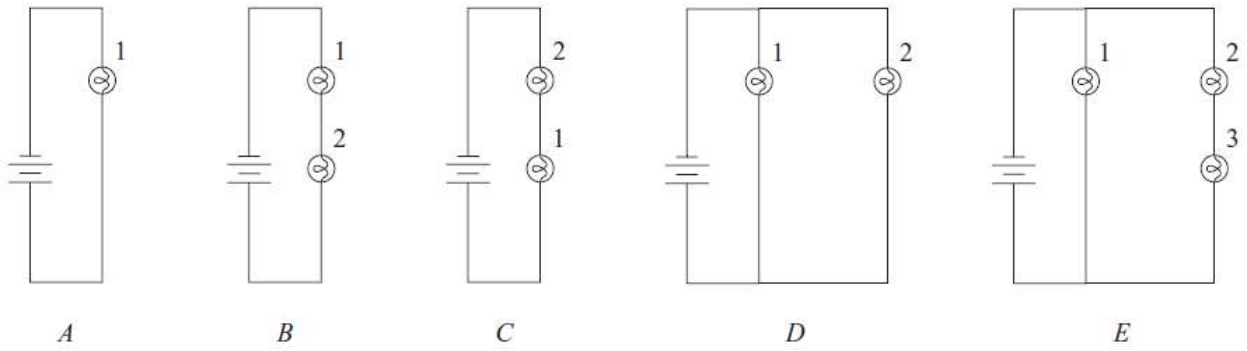
Equipment: battery, 2 identical lightbulbs, connecting wires.

a. Conduct experiments to see if can you connect both bulbs and the battery so that they both light when the circuit is completed but when one is disconnected, the other one does not shine. Draw a circuit diagram.

b. Use two lightbulbs, a battery, and sufficient number of connecting wires. Devise a way to connect the bulbs to the battery so that when they are both connected, they light up, but one is still shining when the other one is disconnected. Draw a circuit diagram of how you did this in your notes.

OALG 19.5.2 Observe and explain

Equipment: battery, 3 identical lightbulbs, connecting wires.



a. Build circuit *A* using a battery, wires, and a bulb (see the figure above). Observe and record the brightness of the bulb. Then build circuit *B* with a second identical bulb and notice the brightness of the two bulbs. Explain the differences in your observations using the concept of *V* field (potential difference) or any of the analogies you have developed.

b. Build circuit *C* and notice the brightness of the bulbs. Explain your observations using the concept of current and any analogies.

c. Build circuit *D* and notice the brightness of the bulbs. Now build circuit *E* with a third identical bulb and notice the brightness of the three bulbs. Explain the differences in your observations using the concepts of potential difference and current.

d. Can you say that a battery is a source of constant current? Explain your answer.

OALG 19.5.3 Test your ideas

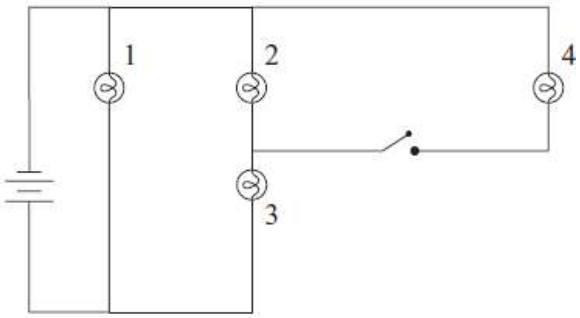
Equipment: battery, 4 identical lightbulbs in holders, connecting wires, switch.

a. Use the analogies you discussed in Activity 19.5.2 and the ideas of potential difference and current to rank the bulbs in the circuit shown below according to their brightness, listing the brightest bulb first. Indicate whether any bulbs are equally bright. Explain your rankings.

b. Now rank the bulbs according to their brightness in the circuit when the switch is closed. Explain your rankings.

c. Indicate how the brightness of the first three lightbulbs changes after the switch is closed. Explain.

d. Set up the circuit and conduct the experiment to see if the lightbulbs behave as you predicted.



OALG 19.5.4 Evaluate the reasoning

Equipment: optional: 2 different lightbulbs, two batteries, connecting wires.

a. Evaluate the following claim: Your friend says that when two lightbulbs are connected in series to each other and then to a battery, the lightbulb connected closest to the negative pole of the battery will be brighter. He explains this by claiming that the second bulb will get fewer electrons because the first bulb will use up some of the electrons. Do you agree or disagree? How can you convince your friend of your opinion? You can use theoretical arguments or design an experiment to test his suggestion.

b. Your friend says that when two identical lightbulbs are connected in series to each other and to the terminals of a battery, the lightbulb closest to the negative pole of the battery will have a greater potential difference across it. She explains it by saying that it will be harder for the electric field to push through to the second bulb after it has already pushed through the first. Do you agree or disagree? How can you convince your friend of your opinion? You can use theoretical arguments or perform an experiment to test her suggestion.

OALG19.5.5 Read and interrogate

Read and interrogate Section 19.5 in the textbook and answer Review Question 19.5.

OALG 19.5.6 Practice

Answer Questions 1-9 on page 609.

19.6 Joule's law

To conduct the activities in this section, use materials at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html

OALG 19.6.1 Observe and explain

Equipment: 2 different lightbulbs, battery, connecting wires, voltmeter, ammeter.

In this activity you will need to use different light bulbs. In the simulation, to make different light bulbs click on the lightbulb and change its resistance. After you have created two different lightbulbs, connect the two bulbs in series with each other and the battery, and compare their brightness.

a. Devise several explanations for why the brightness of the bulbs is different.

b. Design and implement experiments to test the explanations you came up with. Which explanation couldn't you rule out?

c. Use the explanation that you did not rule out to predict the relative brightness of the same bulbs when you connect them in parallel to the battery (if you have not done this experiment yet in part **b**.).

d. Explain why incandescent lightbulbs glow when there is current through them. Where does this light energy come from?

OALG 19.6.2 Derive

In the previous activity you found that both current through and potential difference across a bulb affect its brightness. Here you will derive the expression for the electric power using prior knowledge and check whether this expression explains your observations in Activity 19.6.1

a. Start with one definition of power P as the rate at which electric potential energy is converted into internal thermal energy $P = \frac{\Delta U_q}{\Delta t}$ and with the relationship for the electric potential energy change ΔU_q when a charge Δq moves through a potential difference ΔV, that is $\Delta U_q = \Delta q \Delta V$.

b. Combine these two ideas and any others that you need to complete the derivation.

c. What is the expression for power that you found? Do the units make sense? Is it consistent with the observations in Activity 19.6.1?

d. Read and interrogate the derivation on page 590 in the textbook. How does Equation 19.5 compare to the one you arrived at in part **b**?

OALG 19.6.3 Test your idea

Equipment: 2 different lightbulbs, battery, connecting wires, voltmeter, ammeter.

a. Connect the bulbs in parallel and observe that bulb A is brighter than bulb B. Use your knowledge of electric power to explain this observation, and then predict what you will observe if you connect the bulbs in series to the same battery.

b. Perform the experiment and record the outcome. Did it match your prediction? If not, revise your explanation to account for the outcome.

OALG 19.6.6 Read and interrogate

Read and interrogate the entire Section 19.6 in the textbook and answer Review Question 19.6.

OALG 19.6.7 Practice

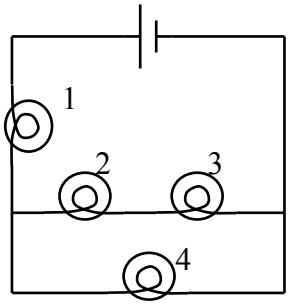
Solve Problems 21-24 on page 611 in the textbook.

19.7 Kirchhoff's rules

To conduct the activities in this section, use materials at https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html unless specified otherwise.

OALG 19.7.1 Design observational experiments

Equipment: variable power supply (battery with variable emf), 4 lightbulbs (preferably different from each other), connecting wires, ammeters, voltmeters.



a. Design an experiment to investigate the relationship between currents through bulbs 1, 2, 3, and 4, shown in the figure. Describe the experiment and record the results in any format you find appropriate. Identify any pattern you found.

b. Design an experiment to investigate the relationships between the potential differences across bulbs 1, 2, 3, 4 and the battery/power source. Describe the experiment and record the results in any format you find appropriate. Identify any pattern you found.

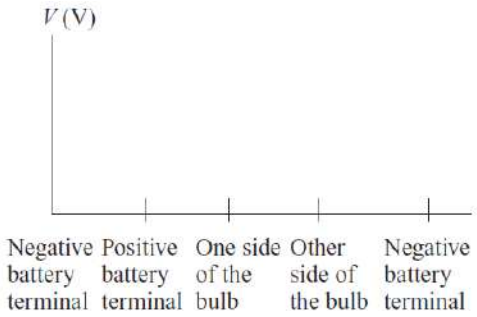
c. Read and interrogate sub-sections "Kirchhoff's loop rule" and "Kirchhoff's junction rule" in the textbook (pages 592-593 and 595 respectively). Design experiments to test both rules. Describe the experiments in your notes, conduct them, and record the results.

OALG 19.7.2 Represent and reason

Imagine that you have a 9-V battery connected by wires to a lightbulb. Consider that the negative terminal of the battery is at zero potential.

a. Draw the circuit.

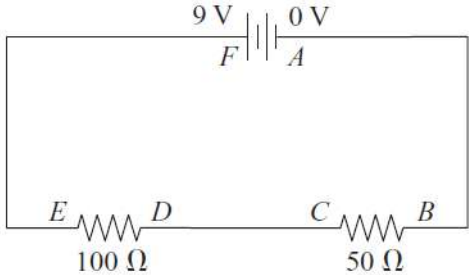
b. Draw a qualitative electric-potential-versus-position graph following the format shown in the figure below.



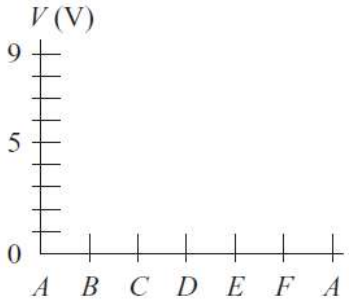
c. What assumptions did you make in drawing the electric potential-versus-position graph?

OALG 19.7.3 Represent and reason

Answer the questions that follow for the circuit in the illustration below.



a. Find the current in the circuit and then calculate the electric potential at each lettered position in the circuit.
b. Plot the electric-potential-versus-position for the circuit. Make the graph in your notes.



c. What assumptions did you make in drawing the electric potential-versus-position graph?

OALG 19.7.4 Represent and reason

The application of Kirchhoff's loop rule for a circuit is shown in the equation that follows.

$$-1.0\,\text{V} - I(2\Omega) + 4.0\,\text{V} - I(6\Omega) - I(4\Omega) = 0$$

Draw a circuit that is consistent with the equation and label the resistors and batteries in the circuit. Draw an arrow and label the electric current.

OALG 19.7.5 Electric circuit Jeopardy

You have a circuit consisting of a variety of elements including a 9-V battery (measured as 9 V when you put a voltmeter across it without an external circuit), a switch, and several resistors. You measure current through different circuit elements and the potential difference across them (each element has corresponding voltmeter and ammeter numbers). The results are in the table below. Draw a picture of the circuit for which these measurements could have been taken, determine the values of resistances if possible, and show where the voltmeters and ammeters could be located.

Element	Ammeter reading	Voltmeter reading
1	0.071 A	8.86 V
2	0.071 A	7.10 V
3	0.071 A	0 V
4	0.035 A	1.76 V
5	0.035 A	1.76 V

OALG 19.7.6 Electric circuit Jeopardy

You have a circuit with the same 9-V battery as in the previous activity, several resistors, and a switch. You measure current through different circuit elements and the potential difference across them (each element has corresponding voltmeter and ammeter numbers). The results are in the table below. Draw a picture of the circuit for which these measurements could have been taken, determine the values of resistances if possible, and show where the voltmeters and ammeters could be located.

Element	Ammeter reading	Voltmeter reading
1	0	9.0 V
2	0	9.0 V
3	0	0

OALG 19.7.7 Design an experiment

Equipment: Real battery, 3 different lightbulbs, connecting wires, ammeter, voltmeter, switch.

To make a real battery, go to https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html and make battery resistance 1 ohm.

Then design an experiment to investigate how potential difference across this battery changes as the current through the circuit changes. Make sure you start with the case when the current through the circuit is zero and finish with the maximum possible current (without short-circuiting the battery).

a. Draw the circuit for your experiment. Describe the data you plan to collect.

b. Make a table to record the data, and after you make the circuit put the data in the table.

c. Reduce the resistance of the battery to zero and repeat the experiments. Record the data the same way you did in part b.

d. Describe the differences in the patterns you found in parts b and c. How do the emf of the battery and its internal resistance explain the differences?

e. For help, read and interrogate sub-section "Internal resistance of a battery" on page 594 in the textbook.

OALG 19.7.8 Practice

Solve Problems 27-33 on page 611 in the textbook.

19.8 Resistor and capacitor circuits

OALG 19.8.1 Derive

Derive a mathematical expression for the resistance of a single resistor that can replace several resistors that are connected in series in a circuit.

a. Draw a sketch showing a circuit with several labeled resistors (you can choose four, for example, their resistances are $R_1, R_2, R_3, R_4)$ in series connected across the terminals of a battery.

b. Draw another sketch with a single "equivalent resistor" across an identical battery. The resistance of this single equivalent resistor is said to be the same as that of the series resistors if there is the same electric current through the battery in each circuit.

c. Apply the loop rule for each circuit and relate them in order to formulate a relationship between the total equivalent resistance of several resistors connected in series with the resistance of each individual resistor.

d. Compare your derivation to the derivation on page 596 in the textbook. Did you arrive at the same result? Explain.

OALG 19.8.2 Derive

Derive a mathematical expression for the resistance of a single resistor that can replace several resistors in parallel in a circuit.

a. Draw a sketch showing a circuit with several labeled resistors in parallel (you can choose four for example, their resistances are $R_1, R_2, R_3, R_4)$ connected across the terminals of a battery.

b. Draw another sketch with a single "equivalent resistor" across an identical battery. The resistance of this single resistor is said to be the same as that of the parallel resistors if there is the same electric current through the battery in each circuit. Label the currents in the parallel resistor circuit and apply the junction rule for one side of parallel circuit.

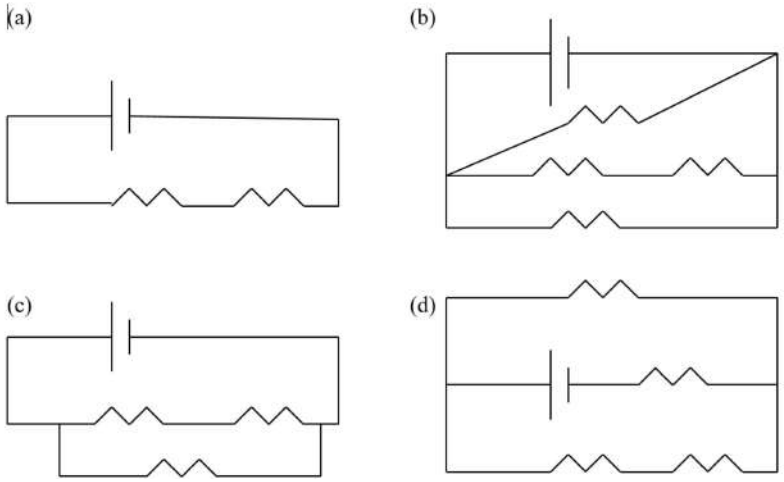
c. Then use the loop rule for the battery and one resistor branch to replace the expression for the current for that branch. Repeat for each parallel branch. Compare the expressions for the current through the battery for each circuit and relate them in order to formulate a general relationship

between the total equivalent resistance of several resistors connected in parallel with the resistance of each individual resistor.

d. Compare your derivation to the derivation on page 597 in the textbook. Did you arrive at the same result?

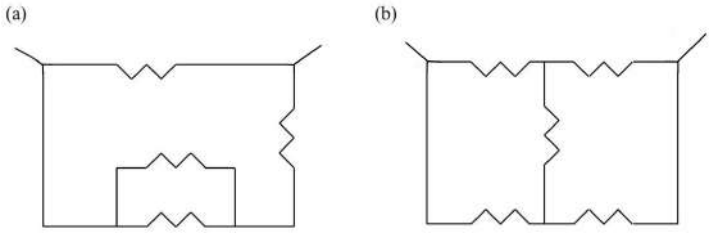
OALG 19.8.4 Represent and reason

Four circuits are shown below. For each of them, draw an equivalent simplified circuit and find the total resistance. Each resistor has resistance *R*.



OALG 19.8.5 Practice

Find an equivalent resistance of the resistor combinations below. Each resistor has resistance *R*. Show all the steps of your reasoning.



OALG 19.8.6 Practice

You have a box full of 50-Ω and 100-Ω resistors. For a circuit board that you are building, you need three 25-Ω resistors and two 125-Ω resistors. Decide how you can connect the 50-Ω and 100-Ω resistors together to make the required resistors for this circuit board. Draw your circuits.

OALG 19.8.7 Apply

You know from experience that when you turn on too many appliances in your house, you can lose electric power in the whole house. This happens because the wires connecting the house to the power line could overheat, and a safety device opens up the circuit, stopping the current. Why would the wires connecting the house to the power line overheat when you turn on many appliances? Include a circuit diagram to explain your reasoning.

OALG 19.8.8 Apply

You have two incandescent lightbulbs that were used some time ago to light up our houses. They are marked as a 40-W lightbulb and a 120-W lightbulb. Which one would be brighter if you put them in parallel? Which one would be brighter if you put them in series? Explain, and draw the circuits. Indicate any assumptions that you made.

OALG 19.8.9 Observe and explain

Equipment: battery, lightbulb, capacitor, switch, connecting wires.

For this activity you will need a different simulation. Go to https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac and download it on your device.

Connect the switch, the light bulb, the capacitor, and the power supply in series. Do not close the switch yet.

a. Close the switch. Describe what you observed. Note also when the bulb is brightest for each process.

b. Sketch qualitative graphs of brightness versus time.

c. Explain the changes in the brightness of the bulb.

Hints: Think about what is happening to the electric charge in the circuit. What is happening to the current in the circuit? What is happening to the potential difference across the capacitor? Try drawing charge diagrams at different points in time.

OALG 19.8.10 Read and interrogate

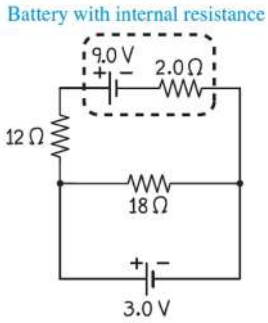
Read and interrogate Section 19.8 in the textbook and answer Review Question 19.8.

OALG 19.8.11 Practice

Solve Problems 37-41 on page 612 in the textbook.

19.9 Skills for solving circuit problems

OALG 19.9.1 Regular problem



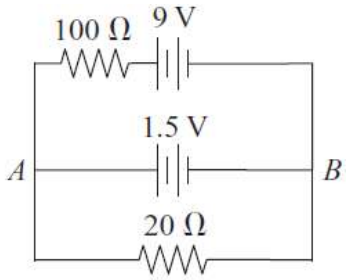
Follow the steps of the problem-solving procedure to solve the problem below. Then compare your solution to Example 19.8 in the textbook.

Determine the currents in each branch of the circuit shown in the figure on the right. Assume that the 9.0-V battery has a 2.0-Ω internal resistance and the 3.0-V battery has negligible internal resistance.

Sketch and translate • Draw the electric circuit described in the problem statement and label all the known quantities. • Decide which resistors are in series with each other and which are in parallel.	
Simplify and diagram • Decide whether you can neglect the internal resistance of the battery and/or the resistance of the connecting wires. • Draw an arrow representing the direction of the electric current in each branch of the circuit.	
Represent mathematically • If possible, replace combinations of resistors with equivalent resistors. • Apply the loop rule for the potential changes as you move around one or more different loops of the circuit. Each additional loop you choose must include at least one branch of the circuit that you have not yet included. • Once you have included branches, apply the junction rule for one or more junctions. In total, you will need the same number of independent equations as the number of unknown currents. • If necessary, use expressions for electric power.	
Solve and evaluate • Solve the equations for the unknown quantities. Check whether the directions of the current and the magnitude of the quantities make sense.	

OALG 19.9.2 Practice

Practice applying the loop and junction rules, following the steps below.



a. Redraw the circuit and identify currents with arrows and symbols.

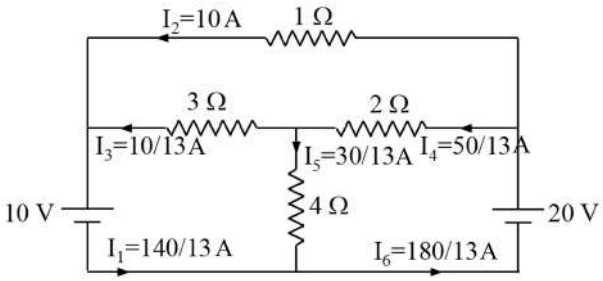
b. Apply the junction rule for junctions *A* and *B*.

c. Apply the loop rule for three different loops.

d. Determine the current through each branch. *Note:* A branch of a circuit is one part of the circuit where there is the same electric current through each element in that branch.

OALG 19.9.3 Evaluate the solution

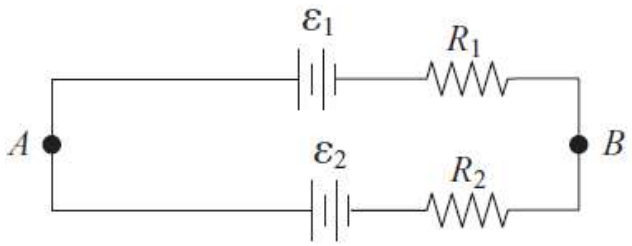
A classmate decides to work out all the currents in the circuit shown to the right. Her answers are marked on the circuit. She used the values of the resistors and potential differences across the batteries that are provided on the same diagram.



Come up with a minimum of two different ways to evaluate the classmate's solution. In each case, explain how you are evaluating her solution, if her solution is reasonable or not, and why it is reasonable or not. In addition, what is her mistake and can you fix it? (*Hint*: Only one current is wrong.)

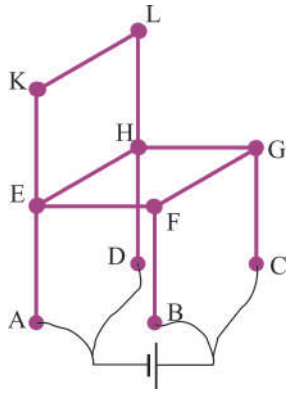
OALG 19.9.4 Regular application

What is the potential difference between the points *A* and *B* if the emfs of the batteries are $\varepsilon_1 = 4.0\ \text{V}$ and $\varepsilon_2 = 1.0\ \text{V}$, and the resistances of the resistors are $R_1 = 10.0\ \Omega$ and $R_2 = 5.0\ \Omega$?



OALG 19.9.5 Represent and reason

A "chair" shown in the figure on the right is made of 11 identical metal rods, each rod having a resistance of 10 Ω. The legs of the chair are connected to a 9-V battery of zero internal resistance with wires that have negligible resistance.



a. Compare the potential differences between different pairs of connected nodes that are labeled with the letters. Are there any pairs of connected nodes for which the potential difference is zero? Explain.

b. Your friend says: "When the potential difference between two nodes is zero, removing the wire between those two nodes from the circuit will not cause any changes in the currents in the remaining circuit." How can you convince others that your friend is correct?

c. Apply the rule invented by your friend to reduce the initial circuit by removing all rods across which the potential difference is zero. Draw an equivalent "flat" circuit diagram of the reduced circuit and determine the current through the battery.

OALG 19.9.6 Apply

You have an unknown electrical device and a variable power supply that also shows you the potential difference between its terminals. You observe that when the device is connected to the power supply it becomes warm. The device is sealed so you cannot open it but you can immerse it in water and measure the increase of water temperature after connecting the device to the power supply for a certain time. These measurements allowed your friend to estimate the power output of the device. She repeated the measurements at different voltages across the power supply terminals and obtained the following data:

ΔV (V)	P (W)
5	71
10	25
15	2
20	5
25	32
30	85

a. Describe in detail how your friend determined the power output values of the device.

Your friend has a hypothesis that the device consists of a battery and a heating element (a resistor) connected in series.

b. Draw a circuit diagram of the device according to your friend's idea when the device is connected to the power supply.

c. Do you agree or disagree with your friend? Explain.

d. If you agree, determine the emf of the battery and the resistance of the resistor. Assume that the battery has a negligible internal resistance.

e. If you disagree, propose a different hypothesis about the structure of the device. Explain how you came up with your idea. Determine as many physical parameters of the elements from your suggested device as you can.

OALG 19.9.7 Practice

Solve Problems 42, 43, 50 – 52, 65, 66, 69, and 78 on page 612-614 in the textbook.

19.10 Properties of resistors

OALG 19.10.1 Read and interrogate

Read and interrogate Section 19.10. Why is it important to understand the properties of different resistors? How is this knowledge connected to every day life?

OALG 19.10.2 Reason

You need to make two identical resistors with one of aluminum wire and the other of copper wire. The wires have equal diameters. Which resistor will need a longer wire? How much longer? Which one will have larger mass? How much larger?

OALG 19.10.3 Reason

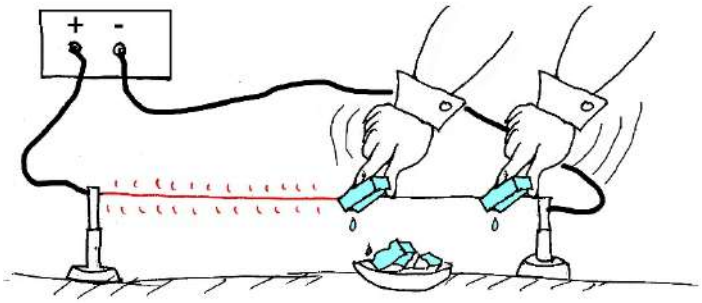
Determine the ratio of the resistances of two wires that are identical except that (a) wire A is twice as long as wire B; (b) wire A has twice the radius of wire B; and (c) wire A is made of copper and wire B is made of aluminum. Be sure to show clearly how you arrive at each answer.

OALG 19.10.4 Reason

Compare the current through two long pieces of wire when the potential difference across them is the same. The wires are made of the same material and are of the same length, but one is twice the diameter of the other.

OALG 19.10.5 Explain and test

At the end of the 18th century, Sir Humphry Davy performed the following famous experiment at the House of the Royal Institution. First, he connected a thin wire to a pile of batteries making the wire barely glow dark red. Then, he started rubbing one part of the wire with an ice cube. As a result, that part of the wire stopped glowing, but the remaining part of the wire started glowing red, much brighter than before (see the figure below).



Propose an explanation for Davy's experiment. Draw a circuit diagram, label the elements of the circuit, and refer to them in your explanation.

Predict outcomes of the following experiments based on your explanation. Account for as many details as you can.

1. Swap the battery poles and repeat Davy's experiment.

2. Take half the length of the original wire and connect it to the same battery (with no ice rubbing).

3. Use the original set-up but use a Bunsen burner to warm up one part of the wire.

OALG 19.10.6 Explain

A lightbulb has a resistance of 100 Ω when it is not plugged into a circuit and 240 Ω when it is bright. How can you explain this?

OALG 19.10.7 Practice

Solve Problems 52, 57-61 on page 613 in the textbook.