Description: Students use the PhET simulation "Circuit Construction Kit (DC Only)" to understand the relationship between the voltage distribution and the current distribution in a variety of direct-current circuits containing resistors in series and in parallel.

Learning Goal:
To understand the relationship between the voltage distribution and the current distribution in a variety of direct-current circuits containing resistors in series and in parallel.

For this tutorial, use the PhET simulation *Circuit Construction Kit (DC Only)*. This simulation allows you to build circuits using wire, resistors, batteries, and other circuit components. The voltage across any two locations on the circuit can be measured using a voltmeter, and the current can be measured using an ammeter. In this tutorial, only direct current (DC) circuits are considered. Start the simulation. When you click the simulation link, a new window will load. Click on **Intro** to get started.

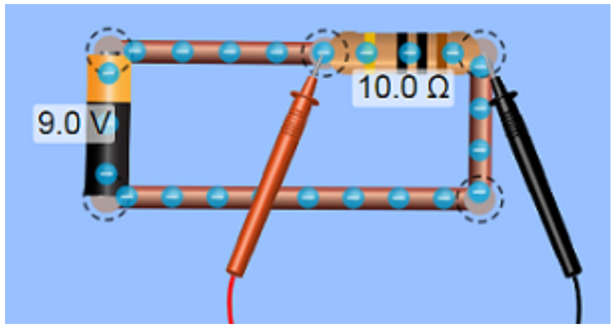
You should see a variety of circuit components (named and pictured) near the left edge of the blue panel. You can click and drag any of these components into the blue panel and construct a circuit. The components can be connected to each other by overlapping the red circles (the junction becomes a black circle). Each component can be rotated by dragging it by the red circle, and the wire can also be lengthened or shortened this way. To disconnect two components, click on the black circle of the junction and select the Scissors icon that appears. To change the resistance of a resistor or the emf of the battery, click the component and use the arrows or slidebar that appear at the bottom of the panel to make the adjustment. If you wish to remove any component, simply click it and select the trash can icon that appears at the bottom.

The two tools you will use in this tutorial are the voltmeter and the noncontact ammeter. The voltmeter gives you the voltage (potential difference) between the two locations of the probes. Simply drag the red and black probes and place the tips at any two locations on the circuit. The output of the voltmeter is the potential of the red probe minus the potential of the black probe. The noncontact ammeter allows you to measure the current simply by dragging the transparent circle (with cross hairs) over a wire.

Feel free to play around with the simulation. When you are done, click the **Reset** icon at the bottom-right corner of the panel before beginning Part A.

Part A

Let's start with a simple circuit that you will have seen in the Ohm's Law and Power PhET tutorial, if you completed that one. What is the voltage reading across the resistor, as shown in the figure below? You should see the blue electrons flowing through the circuit, whereas (conventional) current is the flow of positive charge. You can select which current to display in the panel in the upper-right corner.



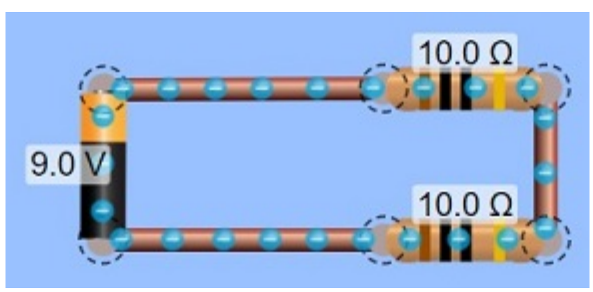
ANSWER:

- ○ 4.5 V
- ○ $-9.0\ \mathrm{V}$
- ○ $-4.5\ \mathrm{V}$
- ◉ 9.0 V

Since the resistance of the wire is essentially zero, the potential of the end of the resistor with the red probe is equal to the potential of the positive terminal (9 V if the negative terminal is defined to be the zero point of the potential), and the potential of the other end of the resistor is the same as the potential of the negative terminal of the battery. This means that the voltage across the battery, V, is equal to the magnitude of the voltage drop across the resistor, $\triangle V$.

Part B

Construct a circuit containing two 10-Ω resistors in series, as shown below.



Place the crosshairs of the noncontact ammeter just before each resistor to measure the current through the top and bottom resistors. How do these currents compare?

ANSWER:

- (selected) The currents are the same.
- There's less current through the top resistor than the bottom resistor.
- There's more current through the top resistor than the bottom resistor.

The current through all components connected in series is the same everywhere. Otherwise, since current is the flow of charge, there would be a buildup of either positive or negative charge somewhere, which is inconsistent with a steady state circuit. (A buildup of charge would produce an electric field, which would quickly cause the charges to disperse.)

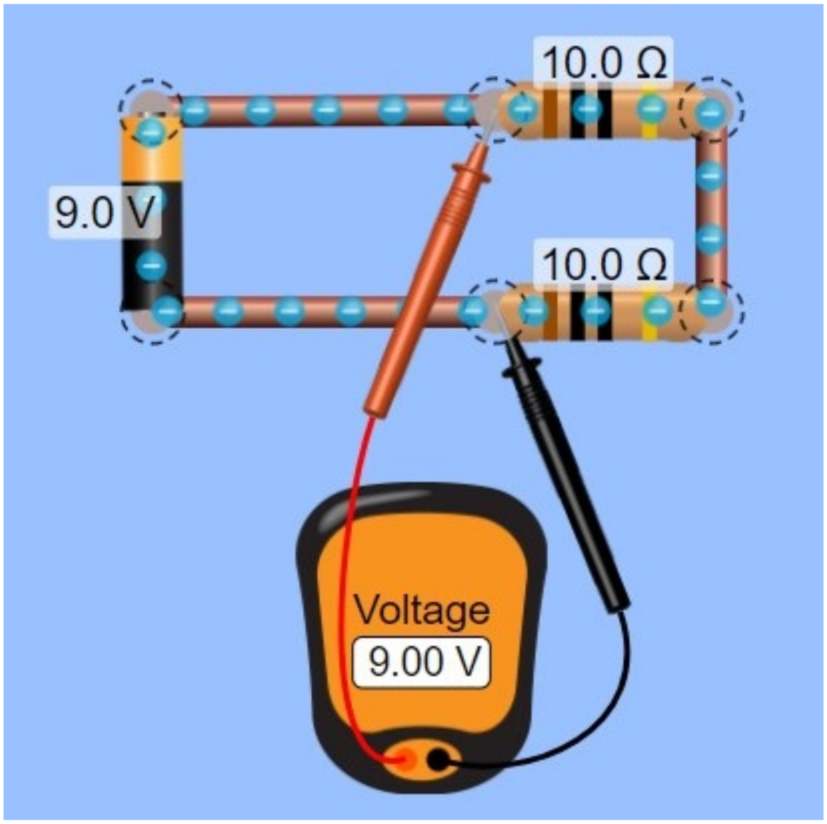
Part C

The current through each resistor in the two-resistor circuit is __________ the current through the resistor in the one-resistor circuit (the circuit in Part A). The voltage across each resistor in the two-resistor circuit is ____________ the voltage across the resistor in the one-resistor circuit.

ANSWER:

- half / the same as
- the same as / half
- twice / twice
- (selected) half / half
- twice / half
- half / twice

The voltage across each resistor is given by $\triangle V = IR$, where R is the resistance of each resistor. Since the current through each resistor is the same and the resistances of the two resistors are the same, the voltage across each resistor is the same. Additionally, the voltage across both resistors must be equal to the emf of the battery, so the voltage across each resistor must be half the emf of the battery (i.e., half the voltage across the resistor in the single-resistor circuit).



Part D

For the series circuit in the previous part, change the resistance of the bottom resistor to 20 Ω. What is the voltage across this 20-Ω resistor?

ANSWER:

- ○ 3.0 V
- ◉ 6.0 V
- ○ 4.5 V

Since $\triangle V = IR$, the voltage across the 20-Ω resistor must be twice that across the 10-Ω resistor, so the voltage across the 20 Ω resistor is 2/3 the emf of the battery (since the voltage across both resistors must equal the emf), or $\triangle V = 2/3$ x $9 \mathrm{~V} = 6 \mathrm{~V}$.

Part E

What must be the resistance of a single resistor connected to a 9-V battery for the current coming out of the battery to be the same as that of the circuit in Part D?

View Available Hint(s) (1)

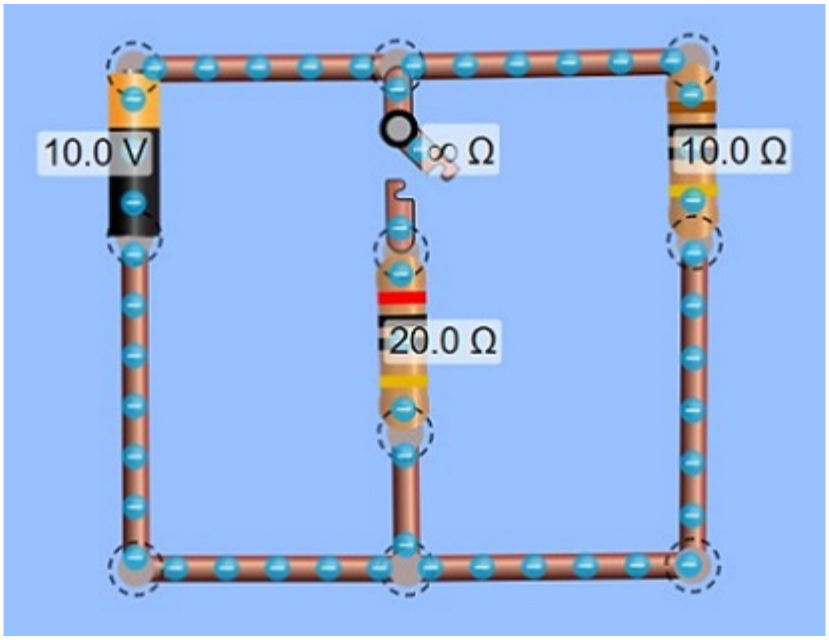
ANSWER:

- ○ 5 Ω
- ○ 15 Ω
- ○ 7 Ω
- ◉ 30 Ω

For resistors connected in series, the equivalent resistance is equal to the sum of the individual resistances.

Part F

Construct a circuit having two resistors connected in parallel, as shown in the figure below.



Change the value of the battery emf to 10.0 V, and make sure the middle resistor is set to 20 Ω. Use extra wire for each "leg" of the circuit so you can measure the current through all legs with the ammeter.

How does the current coming out of the battery change when the switch is closed?

ANSWER:

- ○ The current does not change.
- ○ The current decreases.
- ◉ The current increases.

Since the current is greater, the equivalent resistance ($R_{\rm eq} = V_{\rm emf}/I$) of the circuit with the switch closed (which contains two resistors in parallel) must be less than 10 Ω. This means that the equivalent resistance of two resistors in parallel is less than the resistance of either of the resistors!

Part G

With the switch closed, how does the voltage across the 20-Ω resistor compare to the voltage across the 10-Ω resistor?

ANSWER:

- (selected) The voltage across the 20-Ω resistor is equal to the voltage across the 10-Ω resistor.
- The voltage across the 20-Ω resistor is greater than that across the 10-Ω resistor.
- The voltage across the 20-Ω resistor is less than that across the 10-Ω resistor.

The potential everywhere along the *top* wire is equal to that of the *positive* terminal of the battery, and the potential everywhere along the *bottom* wire is equal to that of the *negative* terminal (which we chose to be zero) since the wires are assumed to have no resistance. This means that the voltage across each of the resistors is equal to the emf of the battery.

Part H

For the parallel circuit in the previous part (with the switch closed), the current through the 20-Ω resistor is __________ the current through 10-Ω resistor.

ANSWER:

- equal to
- greater than
- (selected) less than

Since the voltage across each resistor is the same, the resistor with the smaller resistance will have a higher current through it ($I = \triangle V/R$).

Part I

For the circuit in the previous part, what happens to the current flowing through the resistor on the right when the switch is closed (allowing current to flow through the resistor on the left)?

ANSWER:

- ○ The current flowing through the resistor on the right increases.
- ○ The current flowing through the resistor on the right decreases.
- ◉ The current flowing through the resistor on the right does not change.

The current doesn't change since the voltage across the resistor on the right is still equal to the voltage of the battery (this is independent of whether the switch is open or closed). Notice that since current begins flowing through the resistor on the left, more current must be coming out of the battery (even though the voltage of the battery doesn't change).

Part J

With the switch open, roughly what must be the resistance of the resistor on the right for the current out of the battery to be the same as when the switch is closed (and the resistances of the two resistors are 20 Ω and 10 Ω)?

View Available Hint(s) (1)

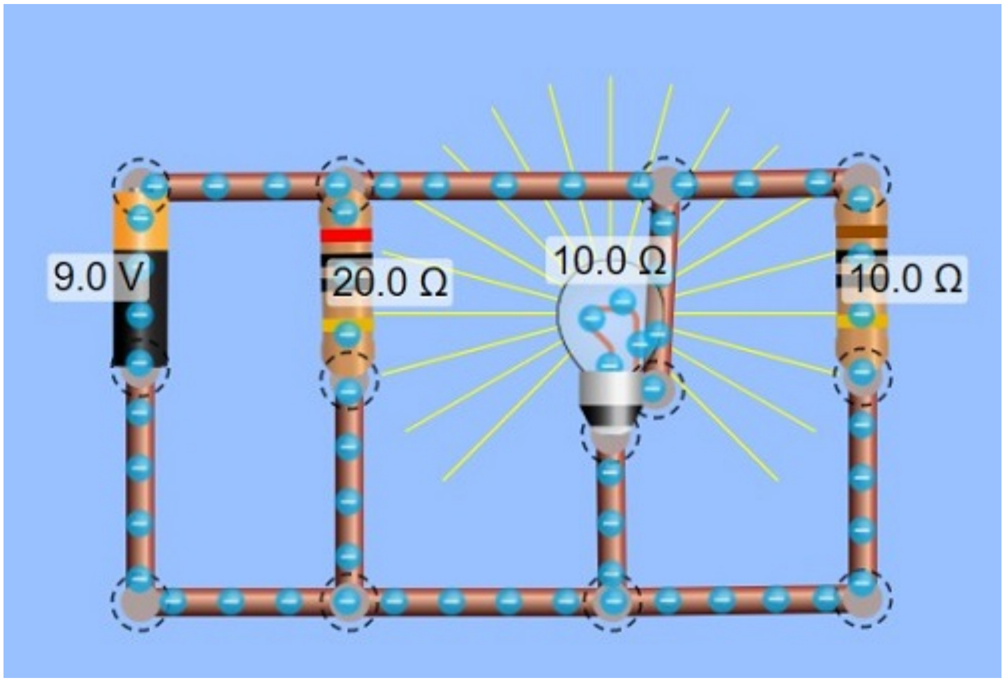
ANSWER:

- ○ 30 Ω
- ○ 5 Ω
- ◉ 7 Ω
- ○ 15 Ω

This is consistent with the way resistors add in parallel: $\frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2}$,where $R_1 = 10\ \Omega$ and $R_2 = 20\ \Omega$. The equivalent resistance of the circuit is $R_{\text{parallel}} = 20/3\ \Omega$. When the switch is open, the circuit is a single-resistor circuit, so when the resistance of this resistor is equal to the equivalent resistance of the two resistors in parallel, the current flowing out of the battery is the same.

Part K

The brightness of a light bulb having a specific resistance increases if the current through it increases. For the circuit shown in the figure below, how does the brightness of the light bulb change when the resistance of the 10-Ω resistor is decreased?



ANSWER:

- (selected) The brightness does not change.
- The brightness decreases.
- The brightness increases.

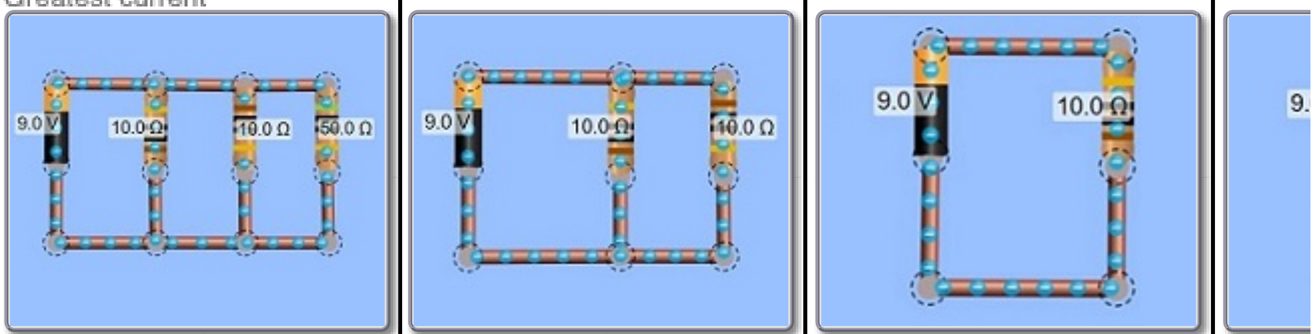
Just as you found in the previous part, for a circuit with resistors connected in parallel, the current through each resistor is independent of the properties of the other resistors. The current through the light bulb depends only on the emf of the battery and the resistance of the light bulb.

Part L

The figures below show four circuits, with the resistances of the resistors given. In all cases, the emf of the battery is 10 V. Rank the circuits in order of descending total current coming out of the battery. (You should be able to answer this question using what you have already learned, but if you want, feel free to build the four circuits and make measurements.)

ANSWER:

Greatest current



☐ The correct ranking cannot be determined.

PhET Interactive Simulations
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