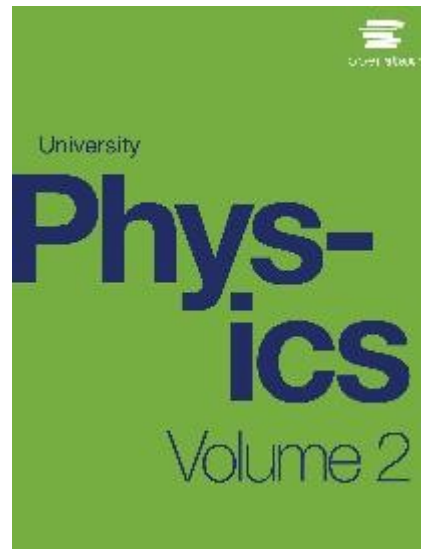


UNIVERSITY PHYSICS

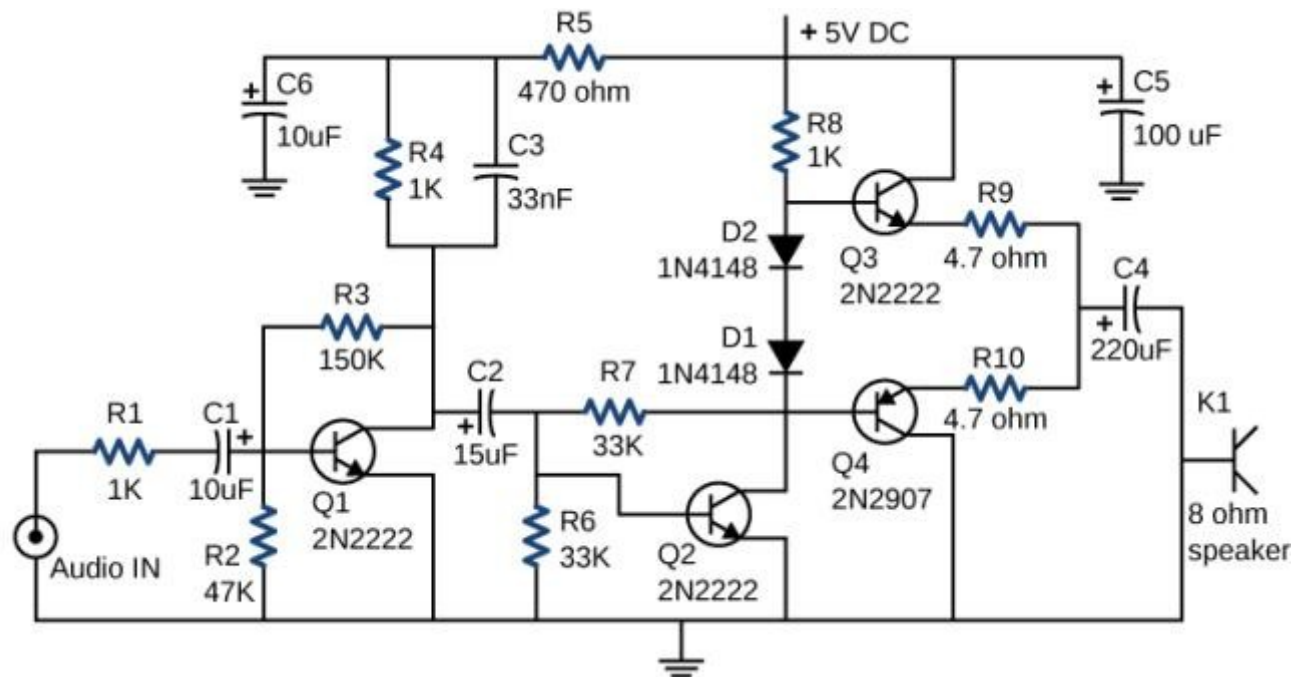
Chapter 10 DIRECT-CURRENT CIRCUITS

PowerPoint Image Slideshow



Circuits - introduction

FIGURE 10.1



This circuit shown is used to amplify small signals and power the earbud speakers attached to a cellular phone. This circuit's components include resistors, capacitors, and diodes, all of which have been covered in previous chapters, as well as transistors, which are semi-conducting devices covered in **Condensed Matter Physics** (<http://cnx.org/content/m58591/latest/>). Circuits using similar components are found in all types of equipment and appliances you encounter in everyday life, such as alarm clocks, televisions, computers, and refrigerators. (credit: Jane Whitney)

FIGURE 10.2



(a)



(b)



(c)

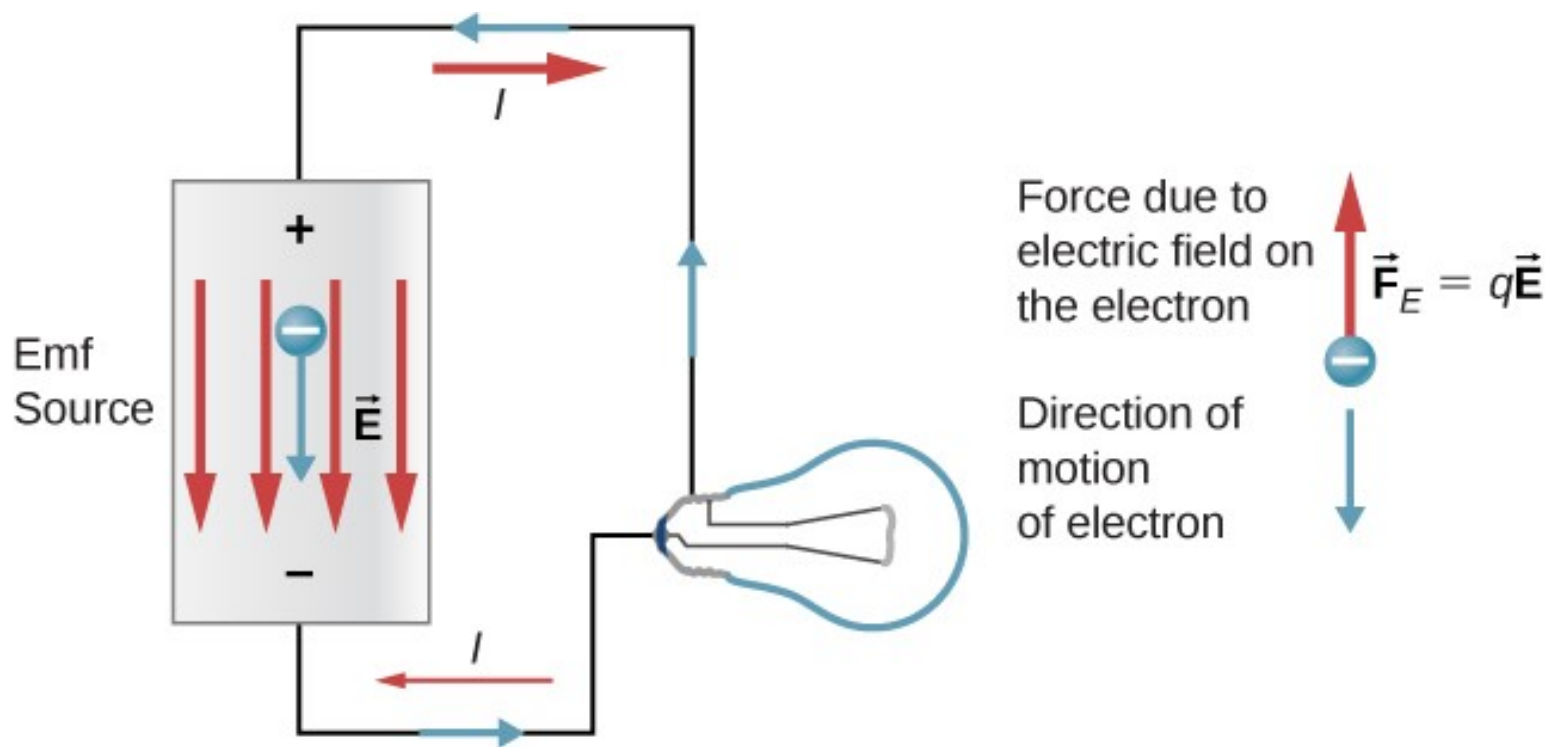


(d)

A variety of voltage sources. (a) The Brazos Wind Farm in Fluvanna, Texas; (b) the Krasnoyarsk Dam in Russia; (c) a solar farm; (d) a group of nickel metal hydride batteries. The voltage output of each device depends on its construction and load. The voltage output equals emf only if there is no load. (credit a: modification of work by “Leaflet”/Wikimedia Commons; credit b: modification of work by Alex Polezhaev; credit c: modification of work by US Department of Energy; credit d: modification of work by Tiaa Monto)

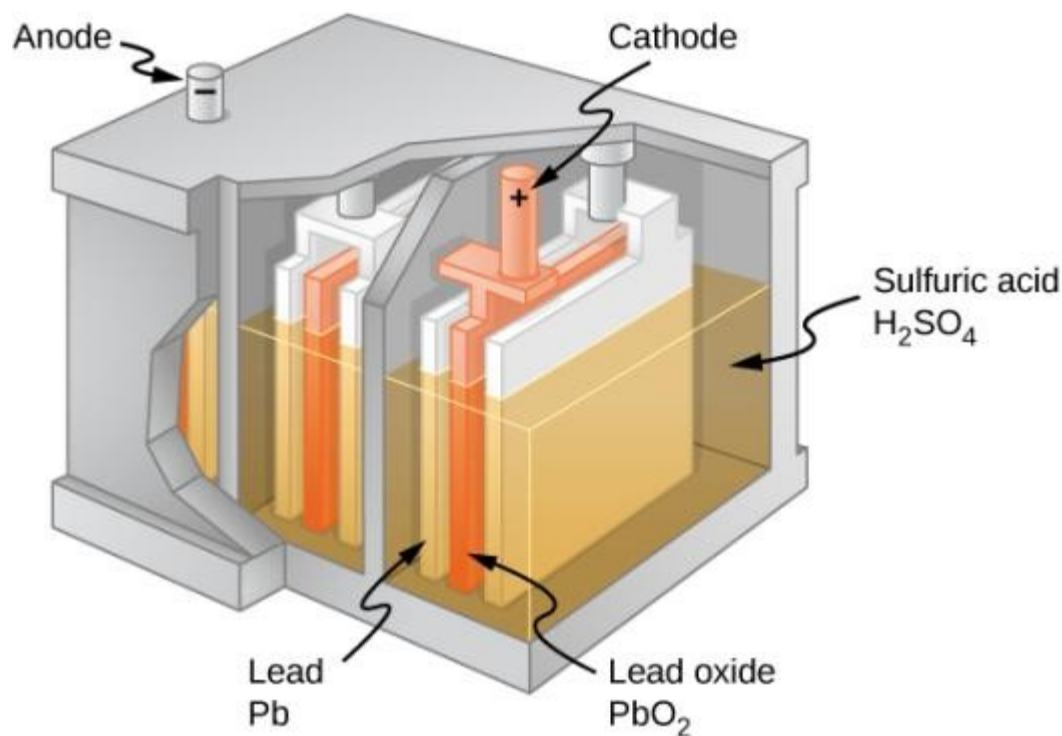
Basic circuits

FIGURE 10.3



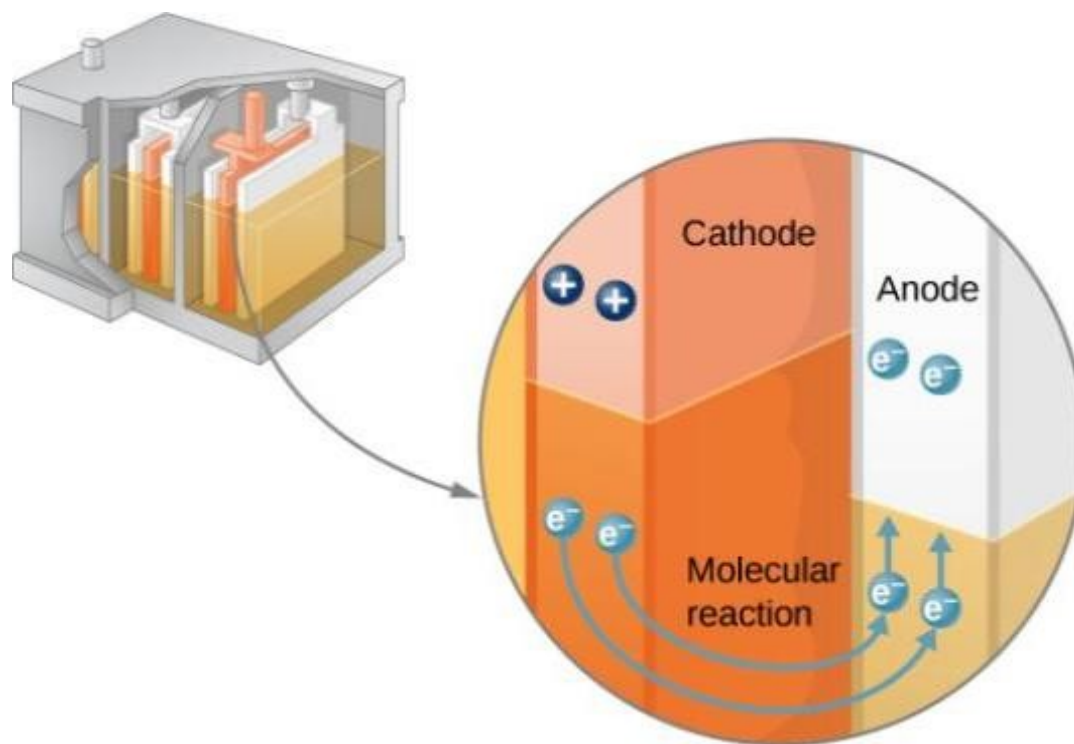
A source of emf maintains one terminal at a higher electric potential than the other terminal, acting as a source of current in a circuit.

FIGURE 10.4



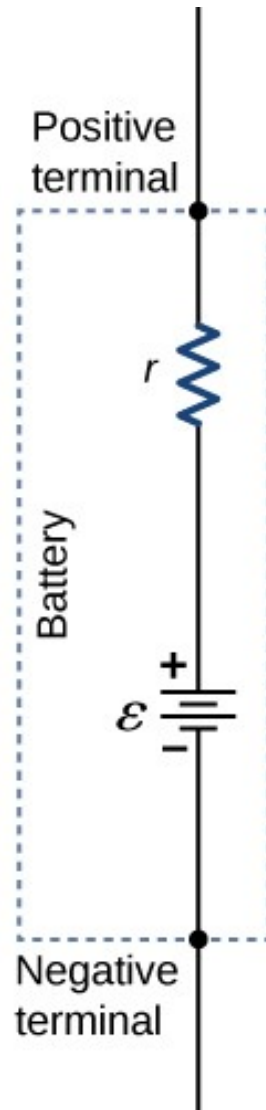
Chemical reactions in a lead-acid cell separate charge, sending negative charge to the anode, which is connected to the lead plates. The lead oxide plates are connected to the positive or cathode terminal of the cell. Sulfuric acid conducts the charge, as well as participates in the chemical reaction.

FIGURE 10.5



In a lead-acid battery, two electrons are forced onto the anode of a cell, and two electrons are removed from the cathode of the cell. The chemical reaction in a lead-acid battery places two electrons on the anode and removes two from the cathode. It requires a closed circuit to proceed, since the two electrons must be supplied to the cathode.

FIGURE 10.6



A battery can be modeled as an idealized emf (ε) with an internal resistance (r). The terminal voltage of the battery is $V_{\text{terminal}} = \varepsilon - Ir$.

Schematic of a voltage source and its load resistor R . Since the internal resistance r is in series with the load, it can significantly affect the terminal voltage and the current delivered to the load.

FIGURE 10.7

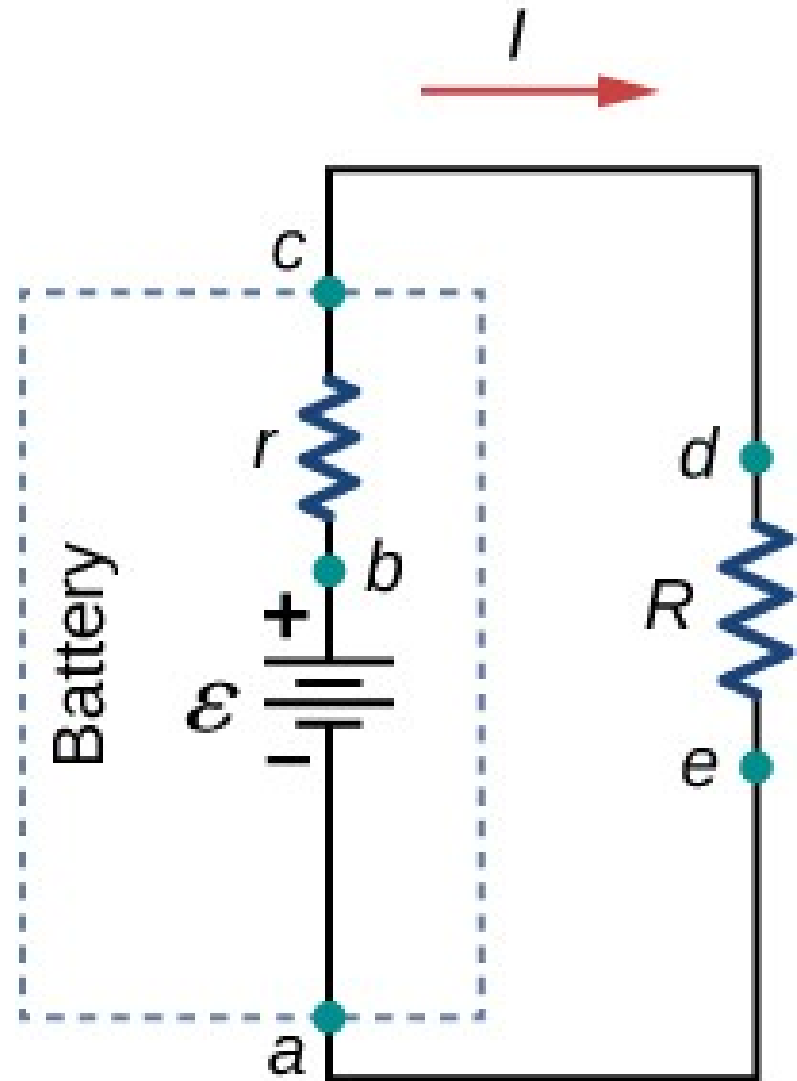
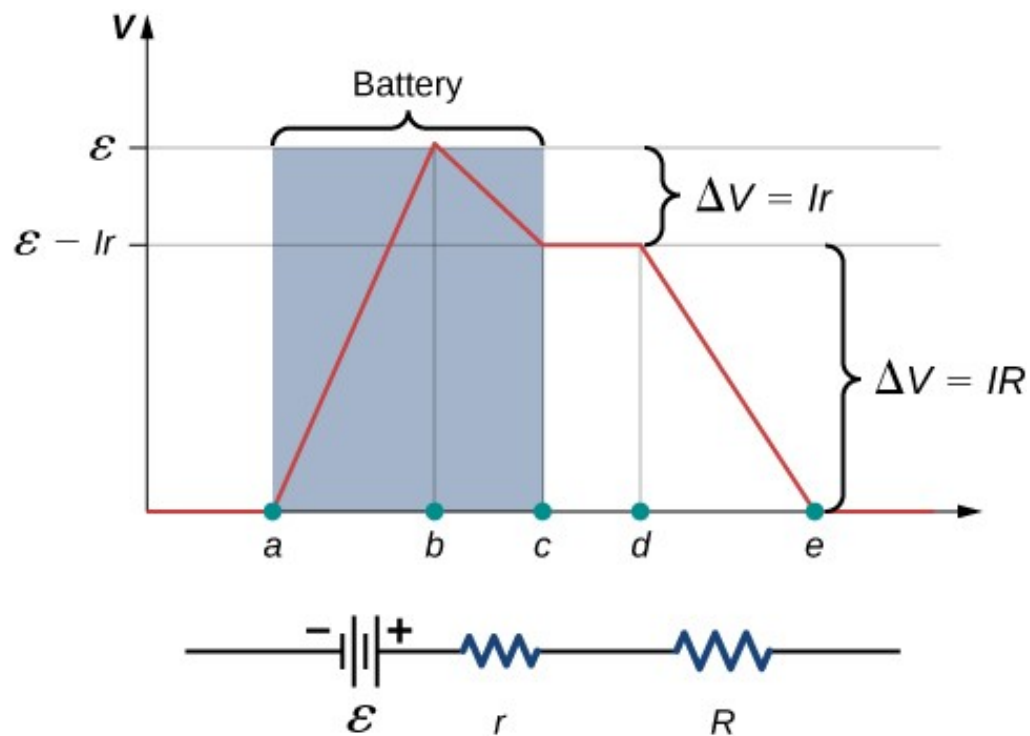


FIGURE 10.8



A graph of the voltage through the circuit of a battery and a load resistance. The electric potential increases the emf of the battery due to the chemical reactions doing work on the charges. There is a decrease in the electric potential in the battery due to the internal resistance. The potential decreases due to the internal resistance ($-Ir$) making the terminal voltage of the battery equal to $(\epsilon - Ir)$. The voltage then decreases by (IR) . The current is equal to I .

FIGURE 10.9



(a)

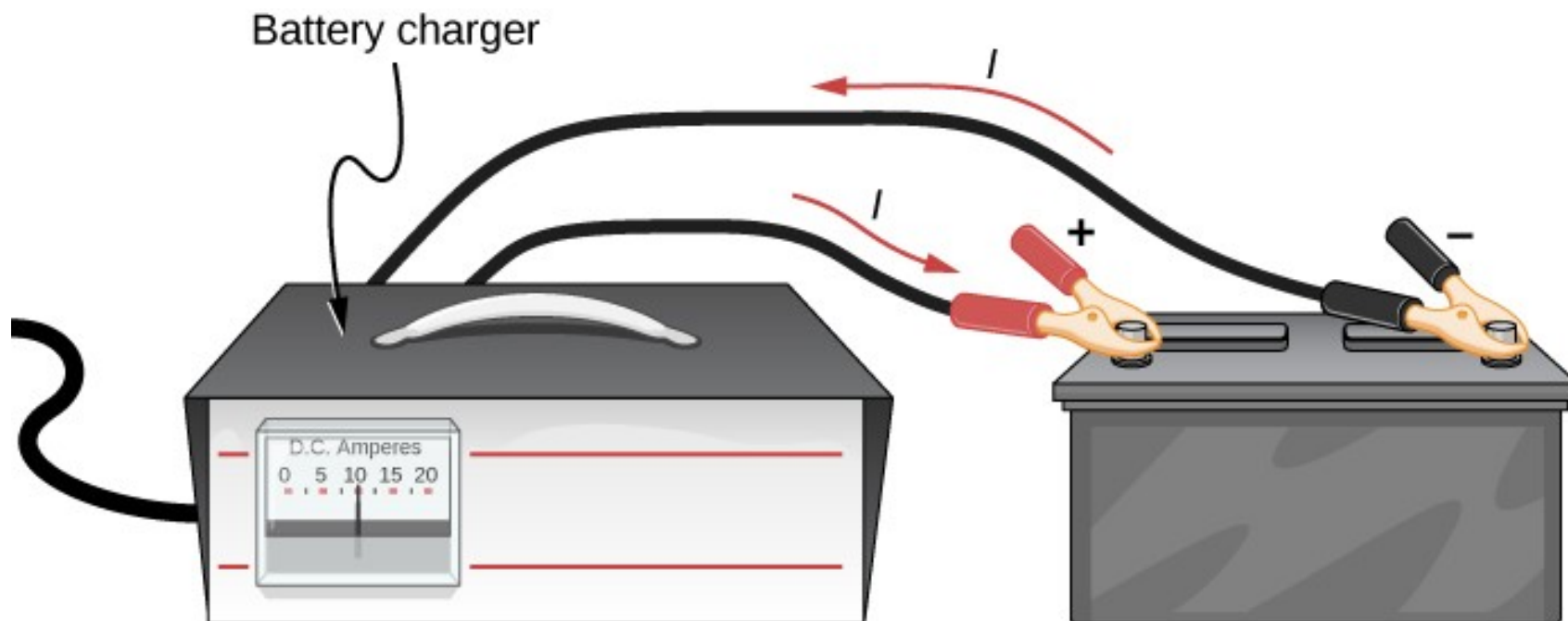


(b)

Battery testers measure terminal voltage under a load to determine the condition of a battery.

- a) A US Navy electronics technician uses a battery tester to test large batteries aboard the aircraft carrier USS *Nimitz*. The battery tester she uses has a small resistance that can dissipate large amounts of power.
- b) The small device shown is used on small batteries and has a digital display to indicate the acceptability of the terminal voltage. (credit a: modification of work by Jason A. Johnston; credit b: modification of work by Keith Williamson)

FIGURE 10.10



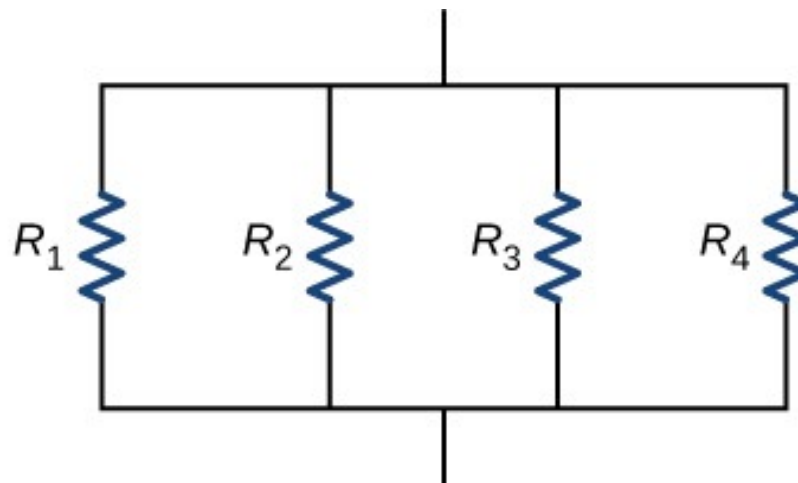
A car battery charger reverses the normal direction of current through a battery, reversing its chemical reaction and replenishing its chemical potential.

Calculating equivalent circuits - examples

FIGURE 10.11



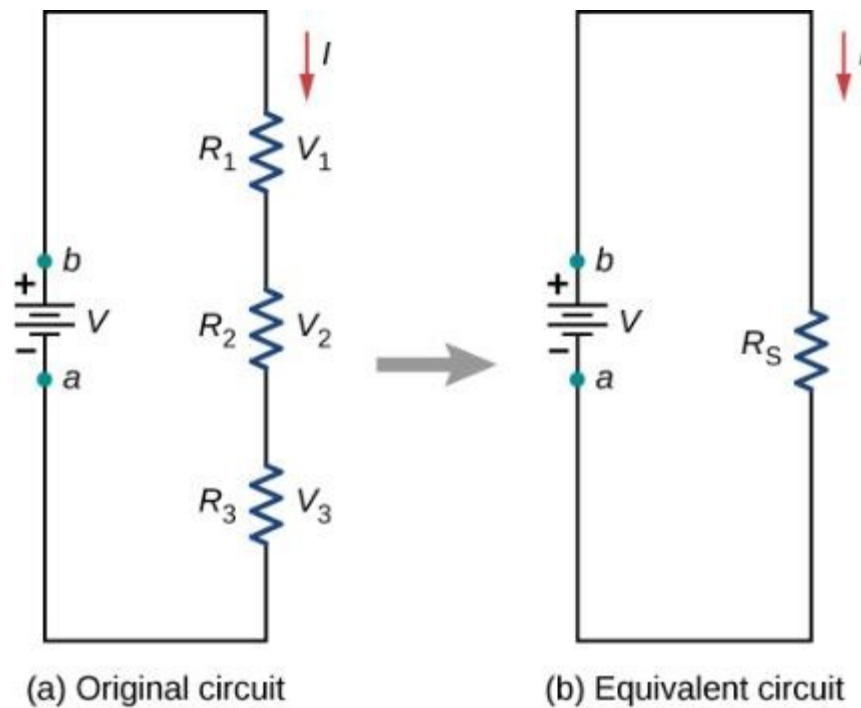
(a) Resistors connected in series



(b) Resistors connected in parallel

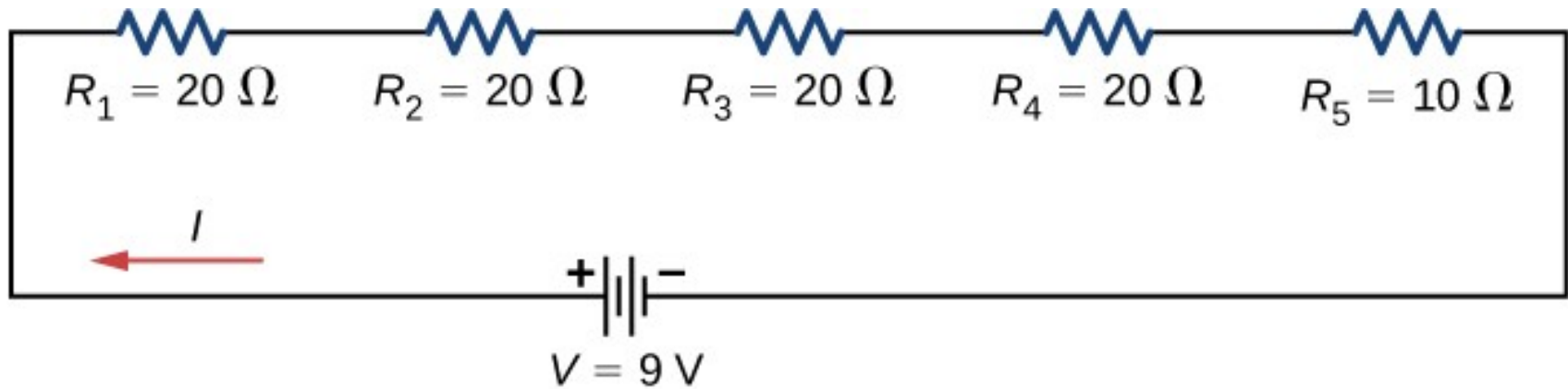
- a) For a series connection of resistors, the current is the same in each resistor.
- b) For a parallel connection of resistors, the voltage is the same across each resistor.

FIGURE 10.12



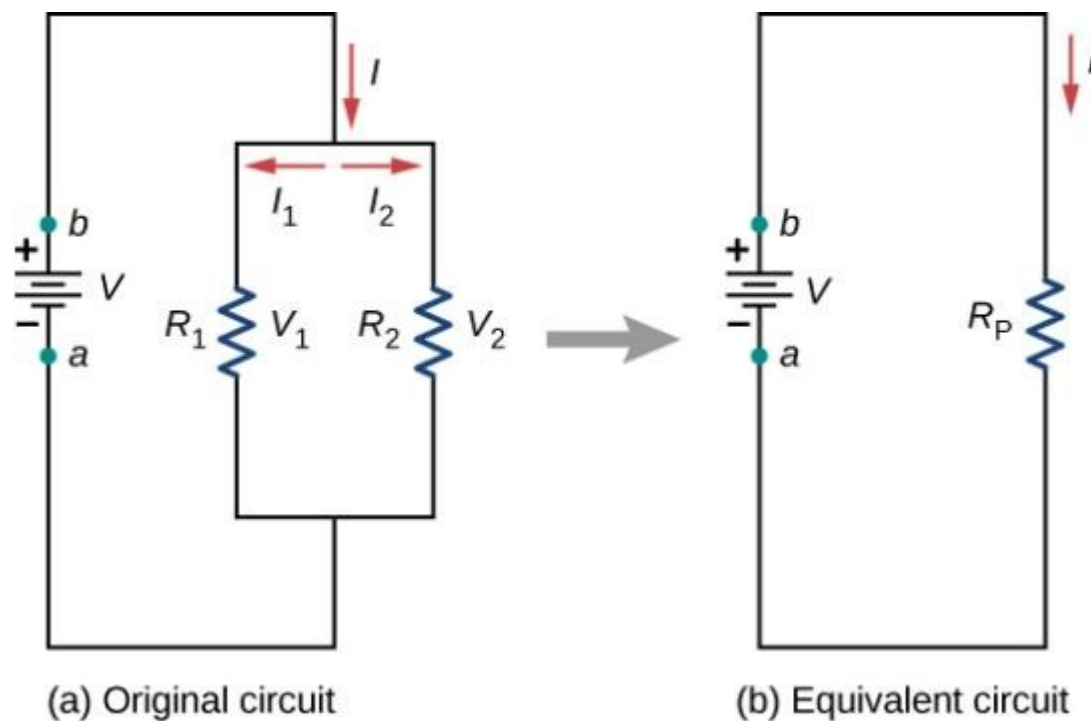
- a) Three resistors connected in series to a voltage source.
- b) The original circuit is reduced to an equivalent resistance and a voltage source.

FIGURE 10.13



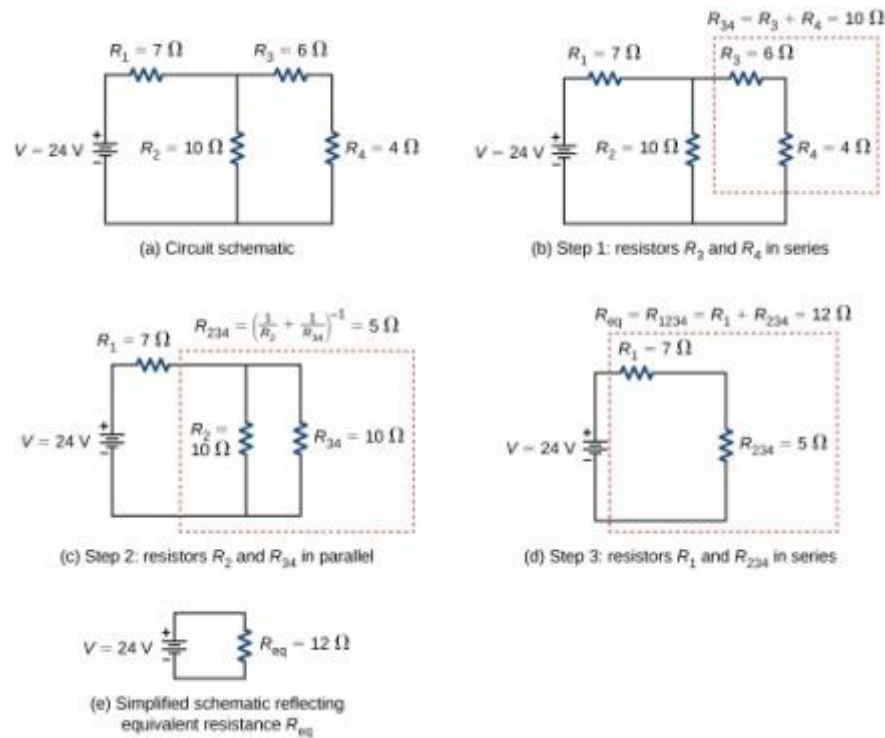
A simple series circuit with five resistors.

FIGURE 10.14



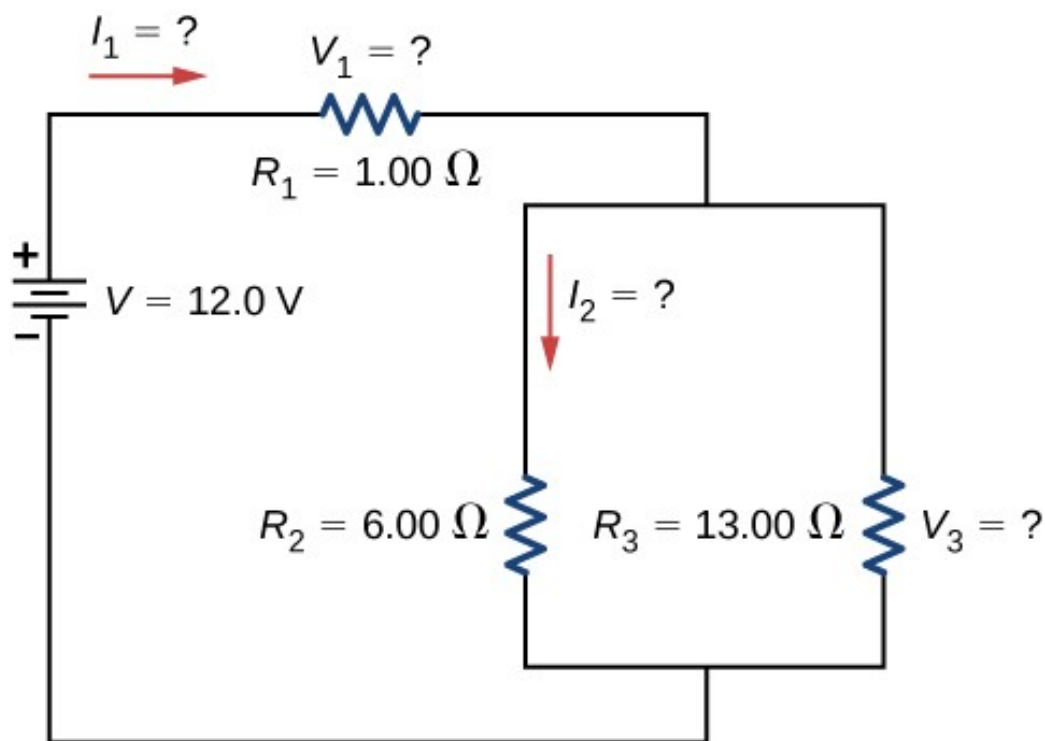
- a) Two resistors connected in parallel to a voltage source.
- b) The original circuit is reduced to an equivalent resistance and a voltage source.

FIGURE 10.15



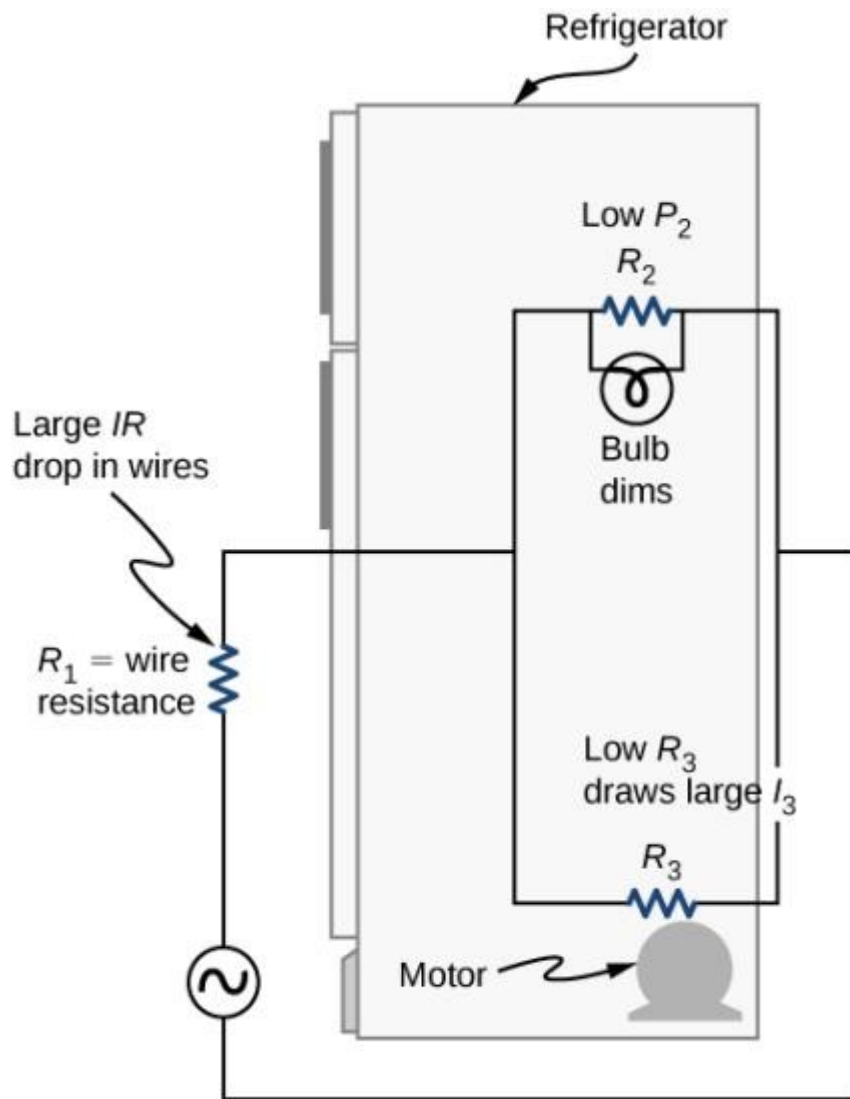
- The original circuit of four resistors.
- Step 1: The resistors R_3 and R_4 are in series and the equivalent resistance is $R_{34} = 10 \Omega$.
- Step 2: The reduced circuit shows resistors R_2 and R_{34} are in parallel, with an equivalent resistance of $R_{234} = 5 \Omega$.
- Step 3: The reduced circuit shows that R_1 and R_{234} are in series with an equivalent resistance of $R_{1234} = 12 \Omega$, which is the equivalent resistance R_{eq} .
- The reduced circuit with a voltage source of $V = 24 \text{ V}$ with an equivalent resistance of $R_{eq} = 12 \Omega$. This results in a current of $I = 2 \text{ A}$ from the voltage source.

FIGURE 10.16



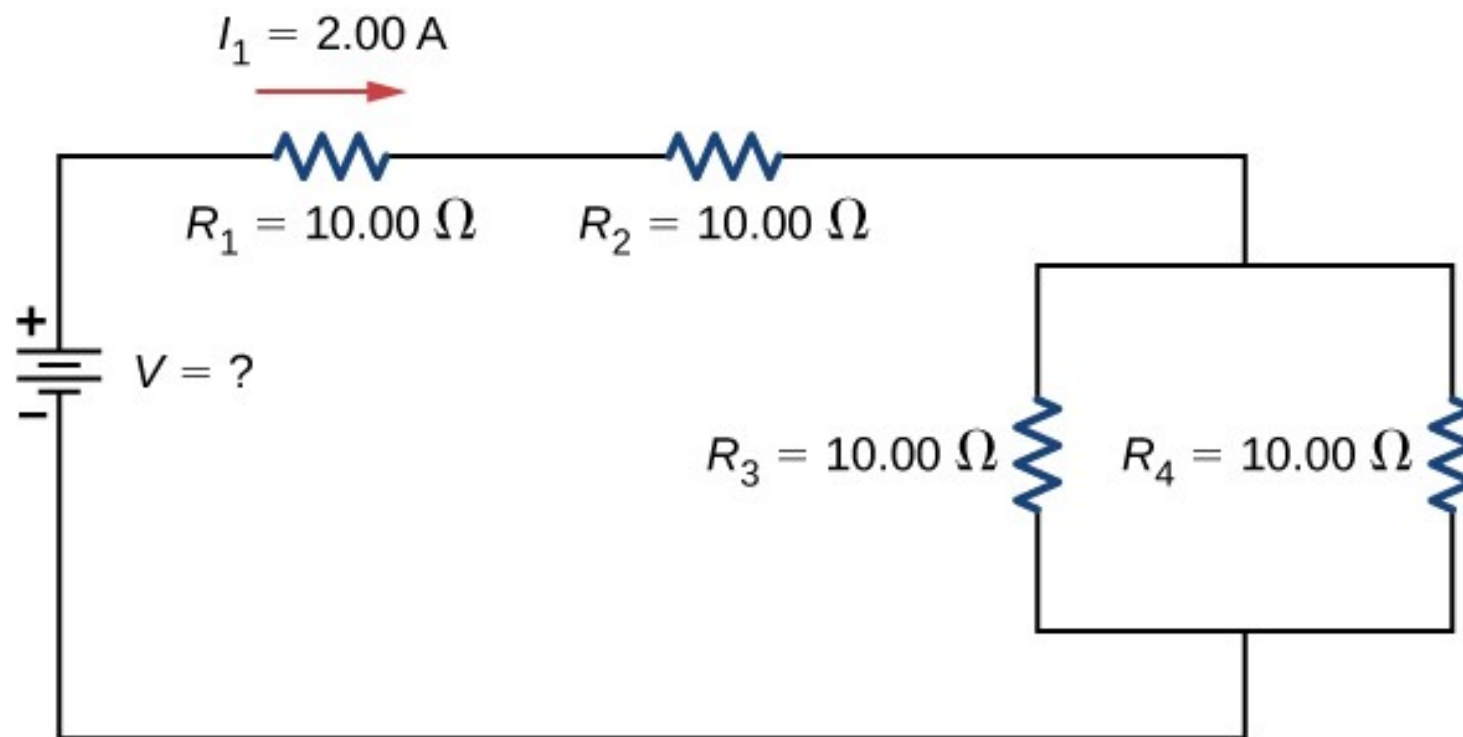
These three resistors are connected to a voltage source so that R_2 and R_3 are in parallel with one another and that combination is in series with R_1 .

FIGURE 10.17



Why do lights dim when a large appliance is switched on? The answer is that the large current the appliance motor draws causes a significant IR drop in the wires and reduces the voltage across the light.

FIGURE 10.18



To find the unknown voltage, we must first find the equivalent resistance of the circuit.

Kirchoff's rules

FIGURE 10.19

This circuit cannot be reduced to a combination of series and parallel connections. However, we can use Kirchhoff's rules to analyze it.

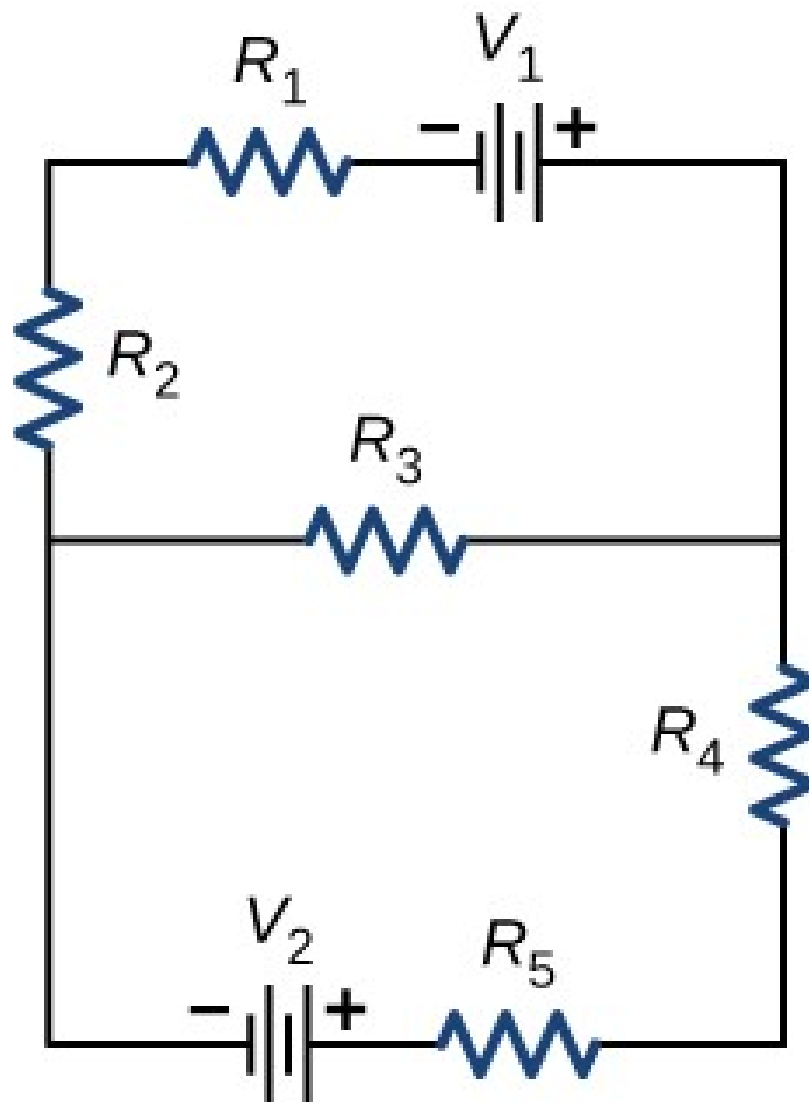
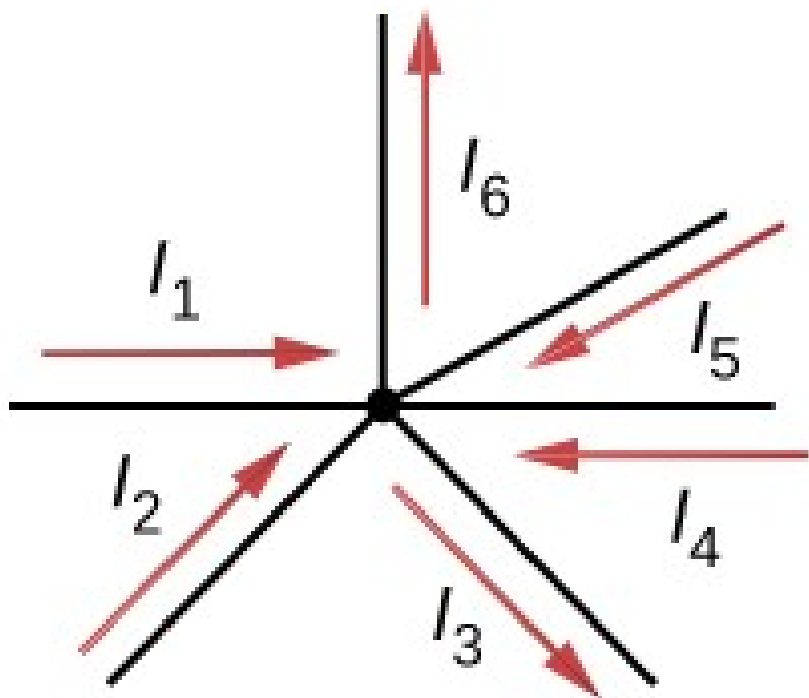


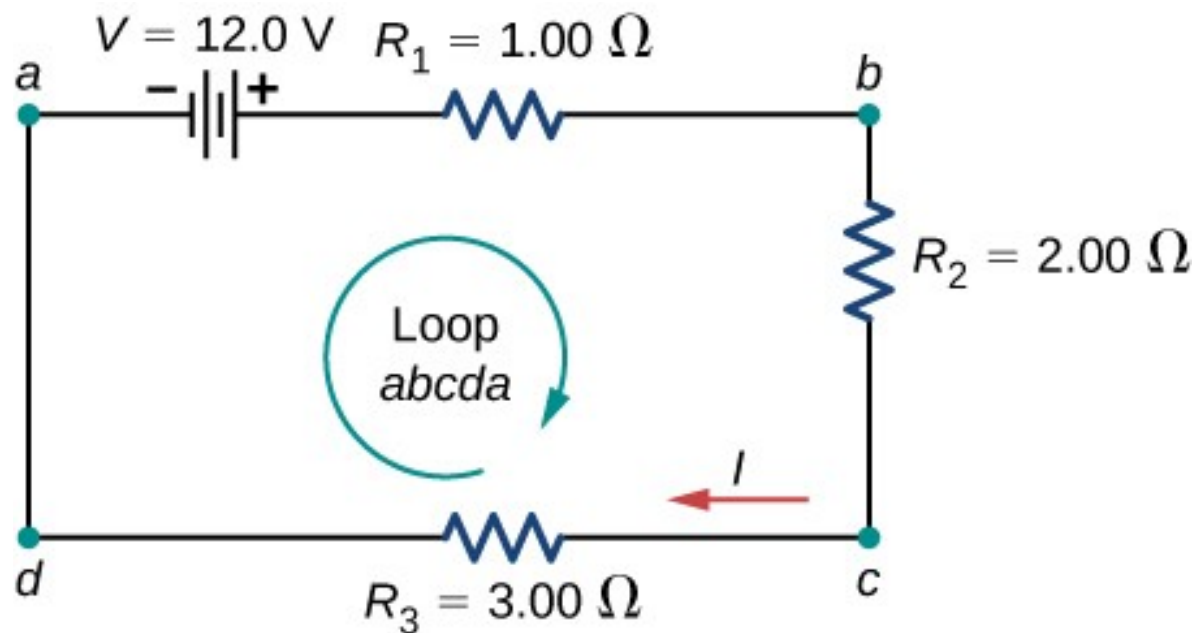
FIGURE 10.20

Charge must be conserved, so the sum of currents into a junction must be equal to the sum of currents out of the junction.



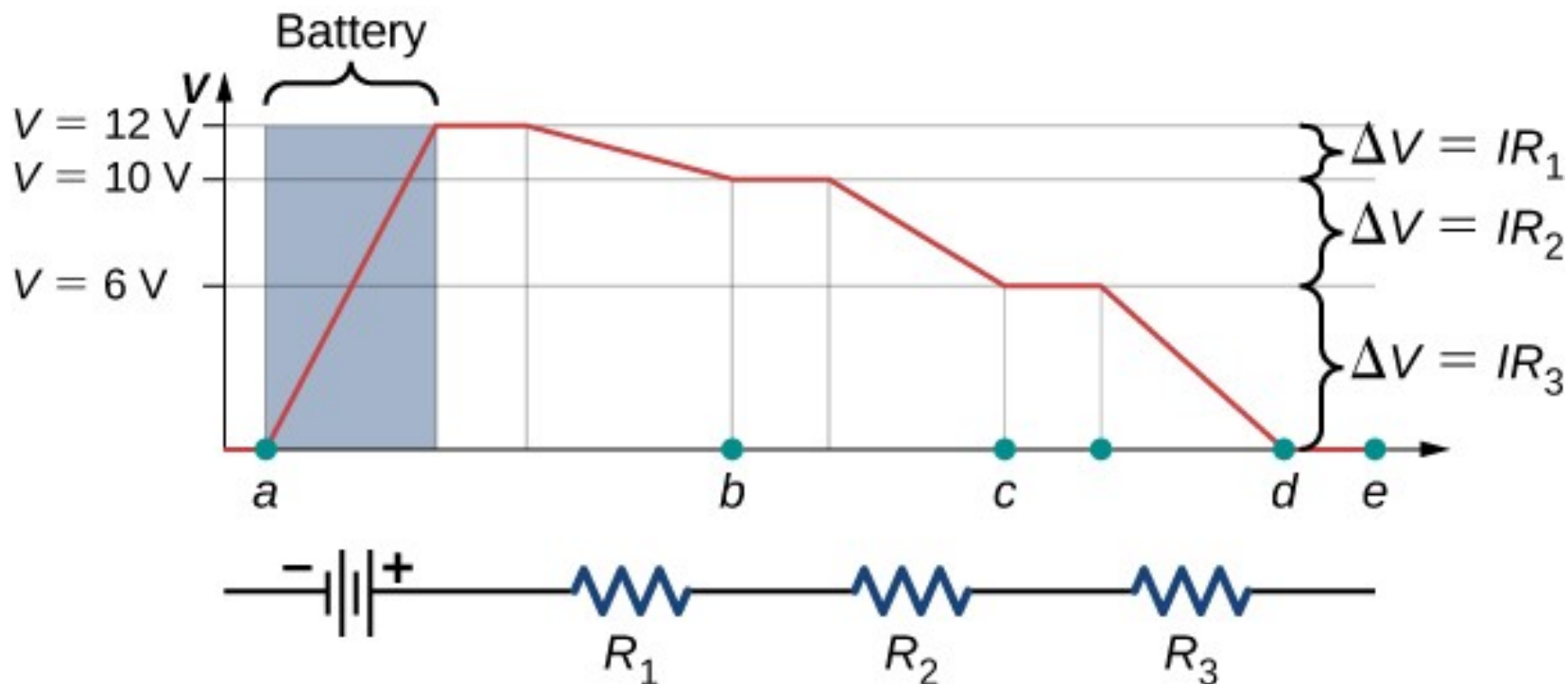
$$\sum I_{\text{in}} = \sum I_{\text{out}}$$
$$I_1 + I_2 + I_4 + I_5 = I_3 + I_6$$

FIGURE 10.21



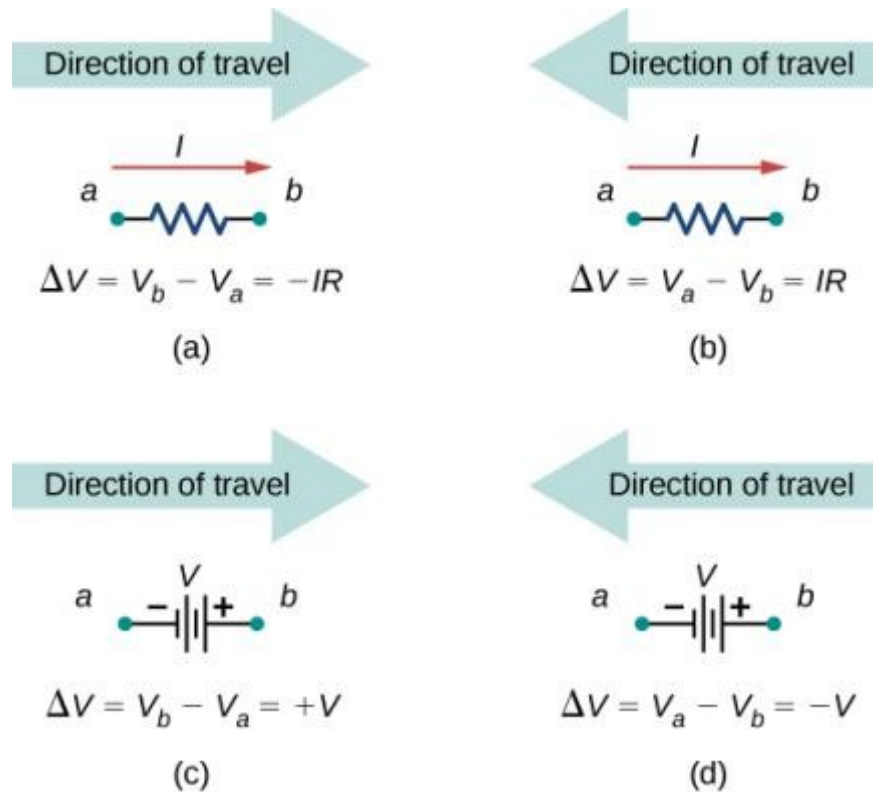
A simple loop with no junctions. Kirchhoff's loop rule states that the algebraic sum of the voltage differences is equal to zero.

FIGURE 10.22



A voltage graph as we travel around the circuit. The voltage increases as we cross the battery and decreases as we cross each resistor. Since the resistance of the wire is quite small, we assume that the voltage remains constant as we cross the wires connecting the components.

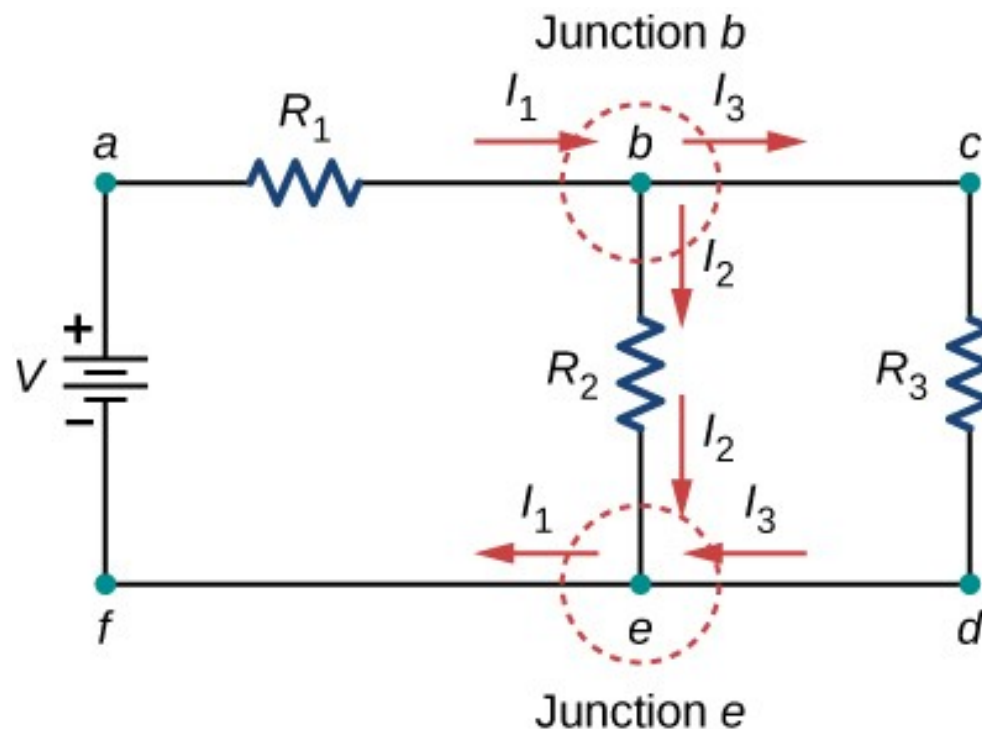
FIGURE 10.23



Each of these resistors and voltage sources is traversed from a to b .

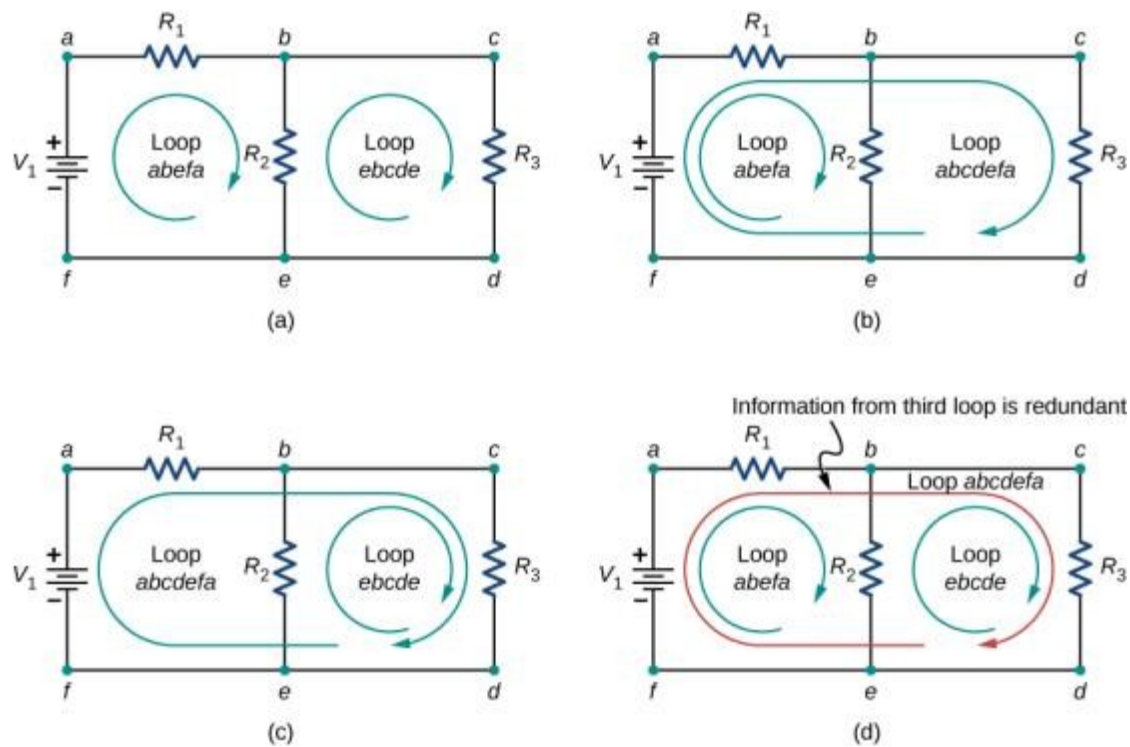
- When moving across a resistor in the same direction as the current flow, subtract the potential drop.
- When moving across a resistor in the opposite direction as the current flow, add the potential drop.
- When moving across a voltage source from the negative terminal to the positive terminal, add the potential drop.
- When moving across a voltage source from the positive terminal to the negative terminal, subtract the potential drop.

FIGURE 10.24



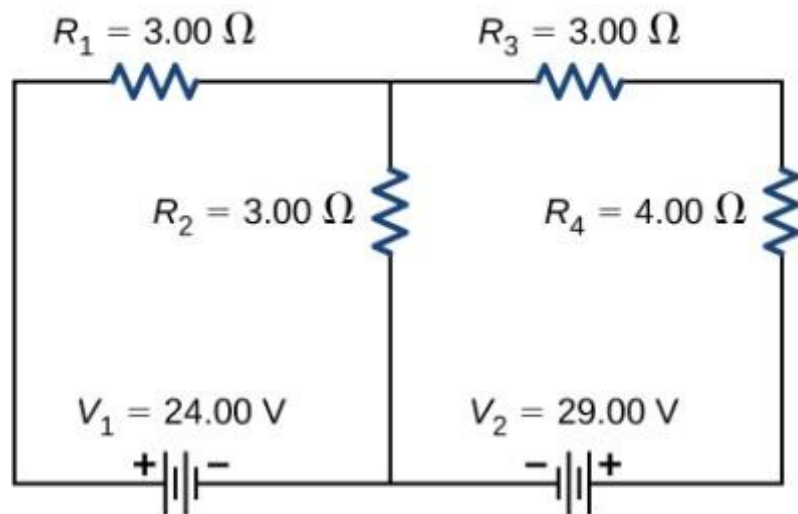
At first glance, this circuit contains two junctions, Junction b and Junction e , but only one should be considered because their junction equations are equivalent.

FIGURE 10.25

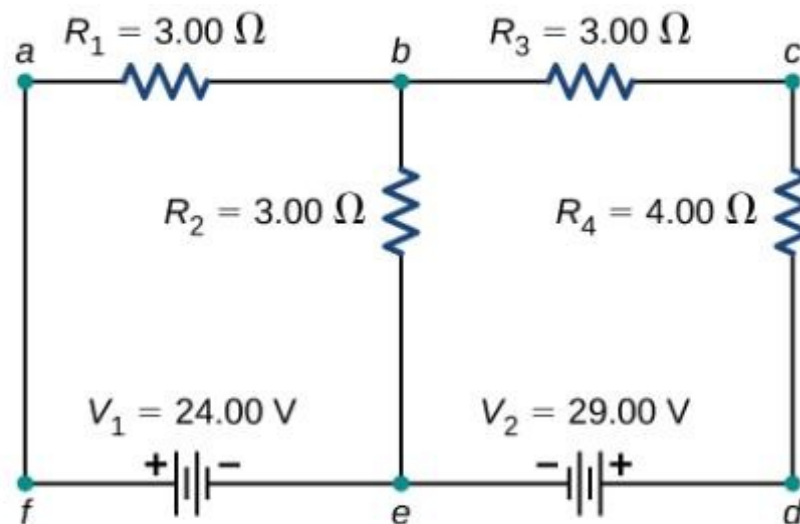


Panels (a)–(c) are sufficient for the analysis of the circuit. In each case, the two loops shown contain all the circuit elements necessary to solve the circuit completely. Panel (d) shows three loops used, which is more than necessary. Any two loops in the system will contain all information needed to solve the circuit. Adding the third loop provides redundant information.

FIGURE 10.26



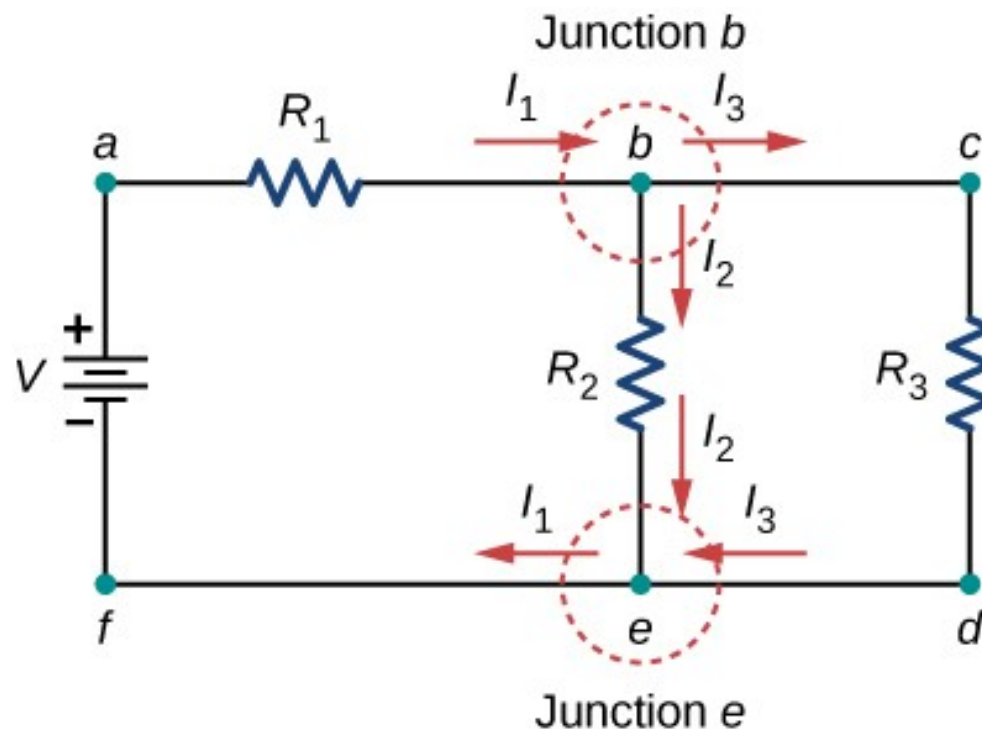
(a)



(b)

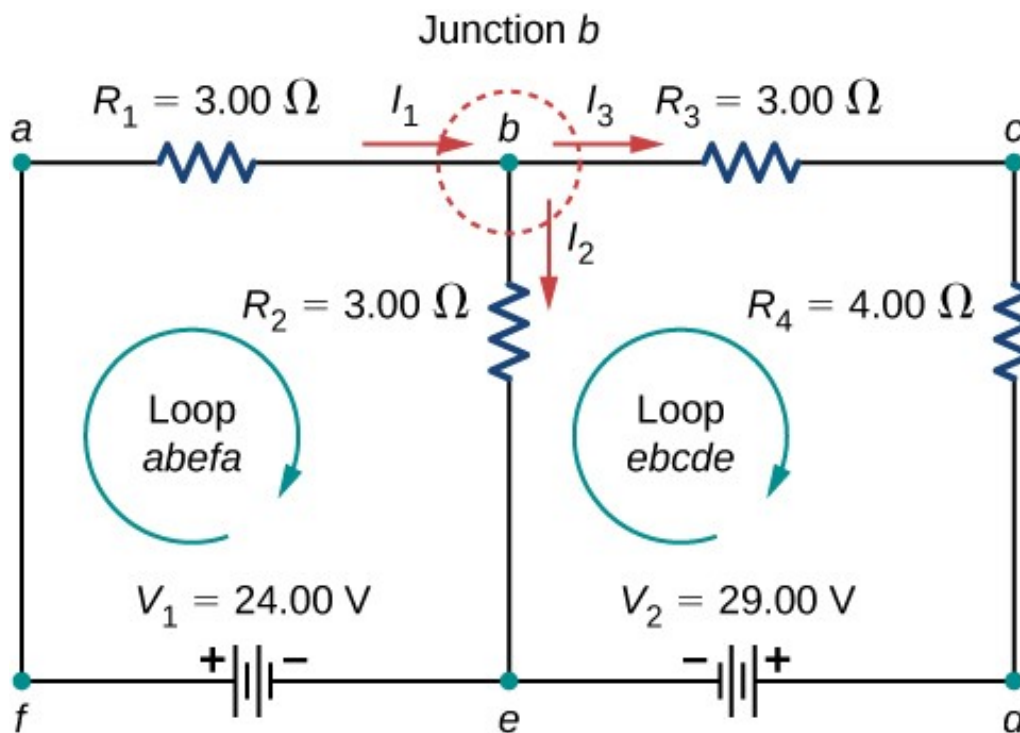
- a) A multi-loop circuit.
- b) Label the circuit to help with orientation.

FIGURE 10.27



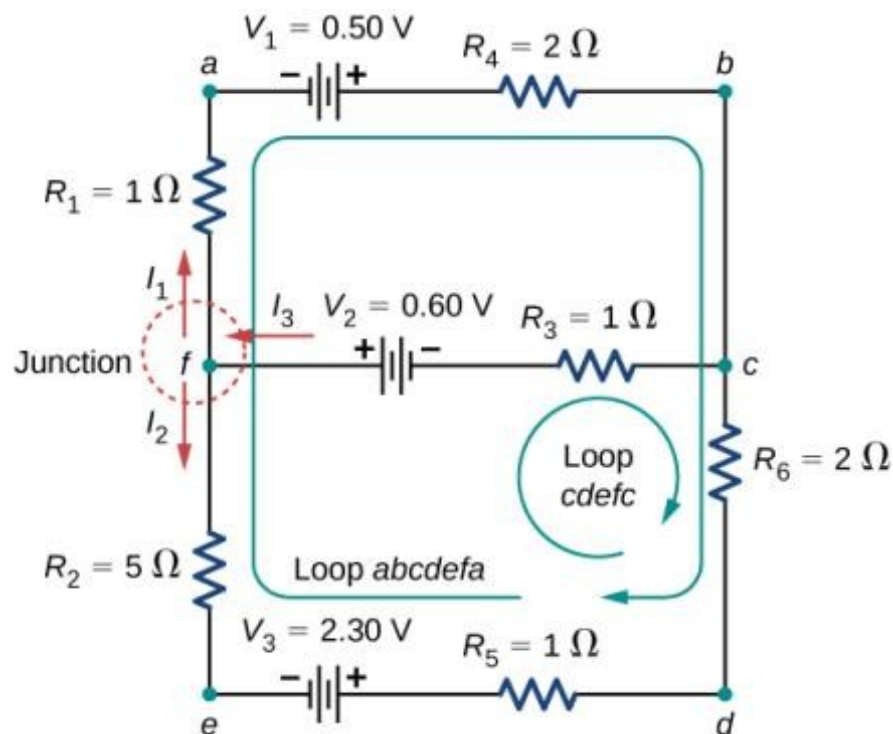
- a) This circuit has two junctions, labeled b and e , but only node b is used in the analysis.
- b) Labeled arrows represent the currents into and out of the junctions.

FIGURE 10.28



Choose the loops in the circuit.

FIGURE 10.29



This circuit is combination of series and parallel configurations of resistors and voltage sources. This circuit cannot be analyzed using the techniques discussed in **Electromotive Force** but can be analyzed using Kirchhoff's rules.

EXERCISE 10.6

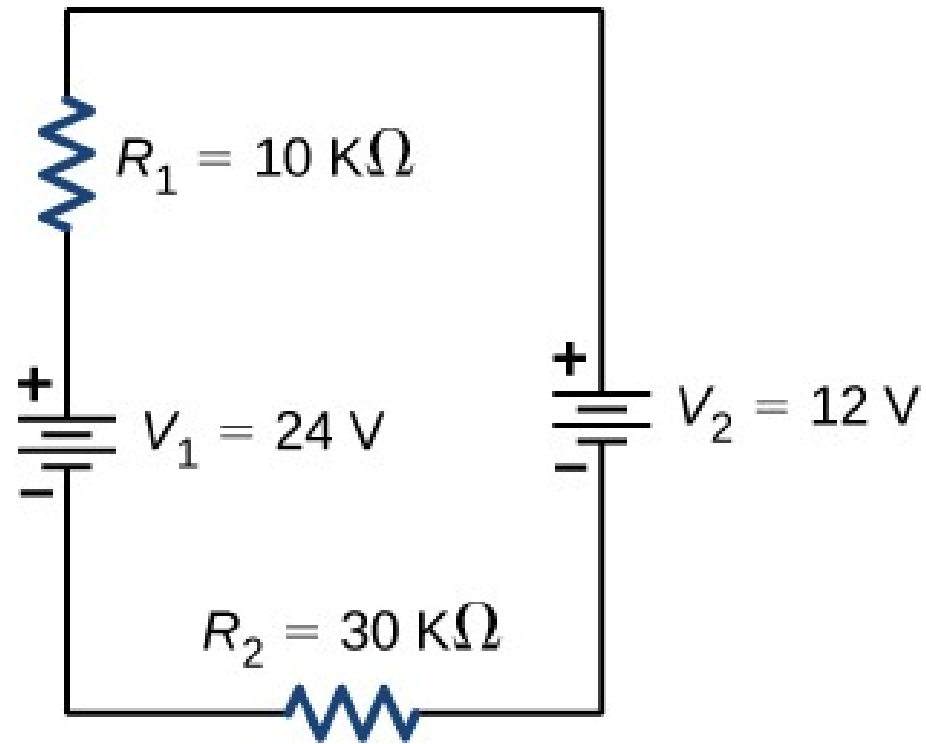
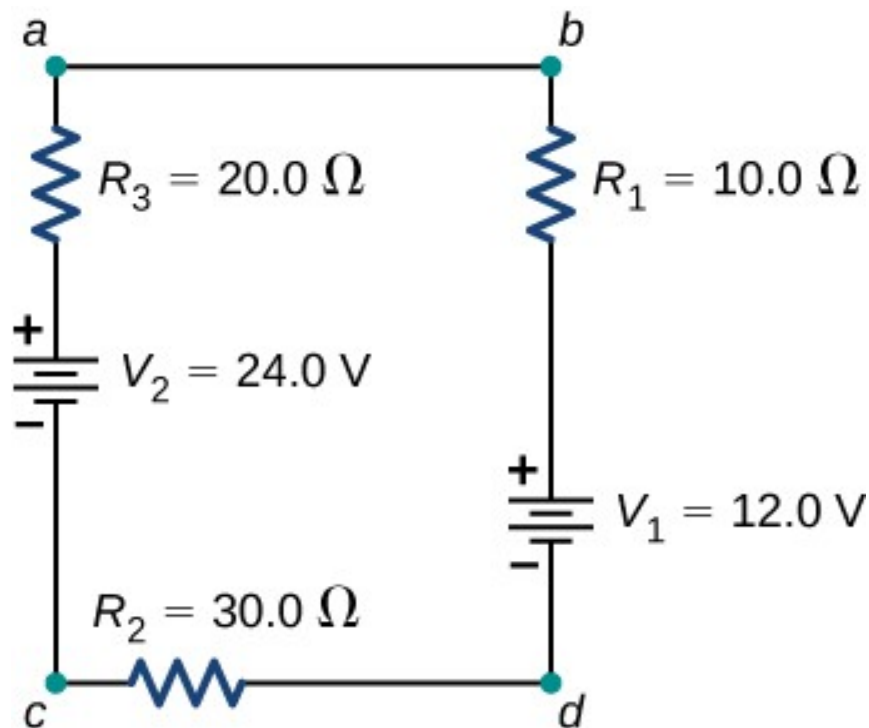
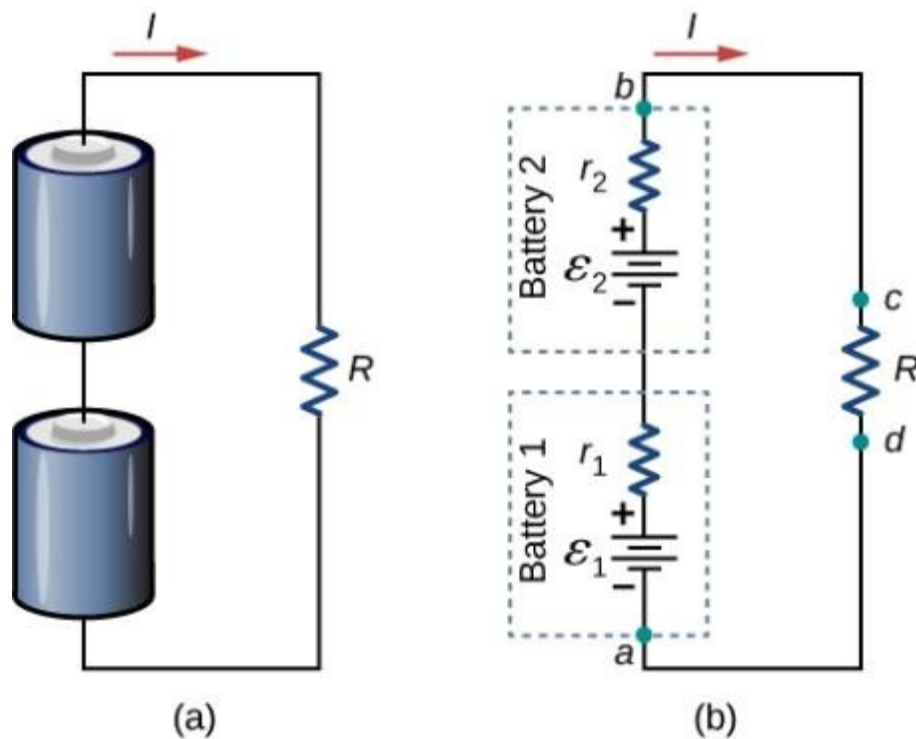


FIGURE 10.30



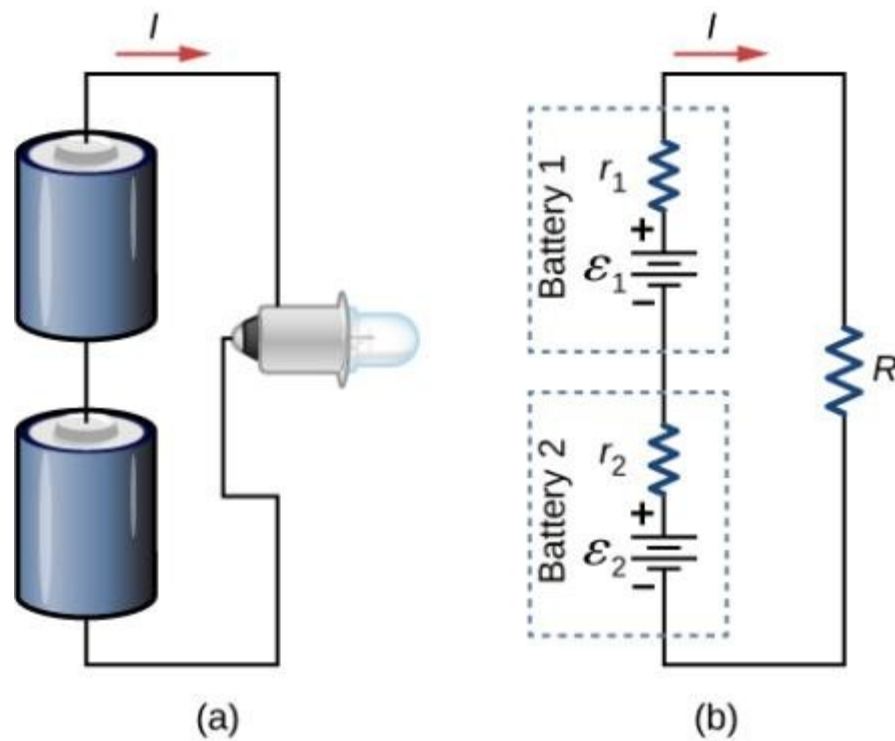
This circuit consists of three resistors and two batteries connected in series. Note that the batteries are connected with opposite polarities.

FIGURE 10.31



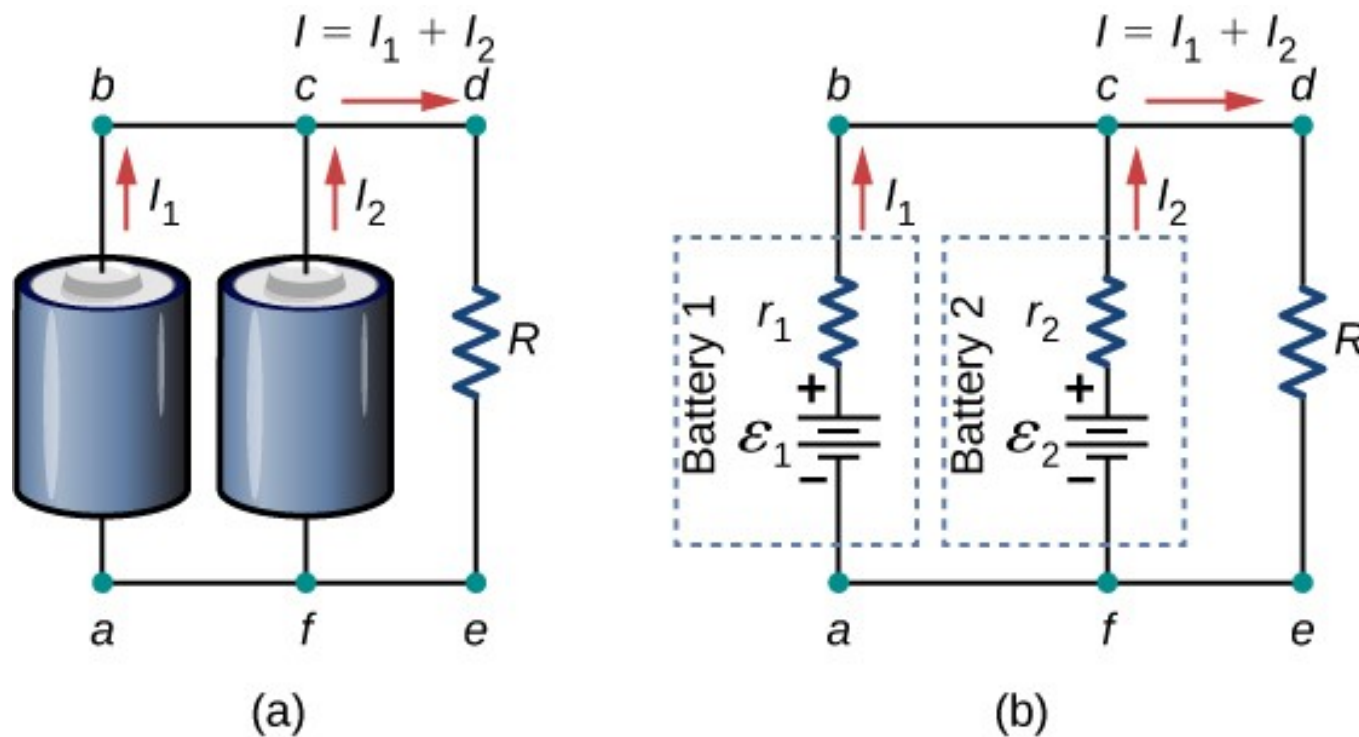
- a) Two batteries connected in series with a load resistor.
- b) The circuit diagram of the two batteries and the load resistor, with each battery modeled as an idealized emf source and an internal resistance.

FIGURE 10.32



Two batteries connect in series to an LED bulb, as found in a flashlight.

FIGURE 10.33



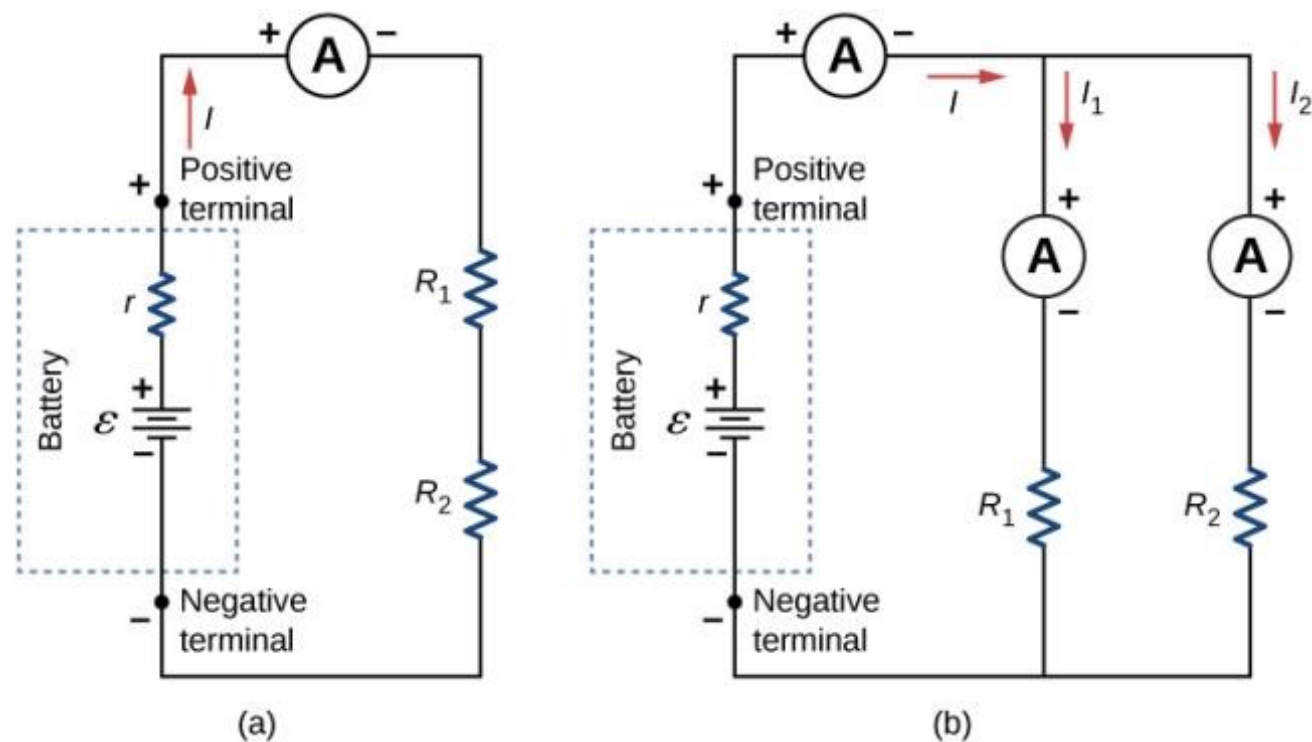
- a) Two batteries connect in parallel to a load resistor.
- b) The circuit diagram shows the shows battery as an emf source and an internal resistor. The two emf sources have identical emfs (each labeled by \mathcal{E}) connected in parallel that produce the same emf.

FIGURE 10.34



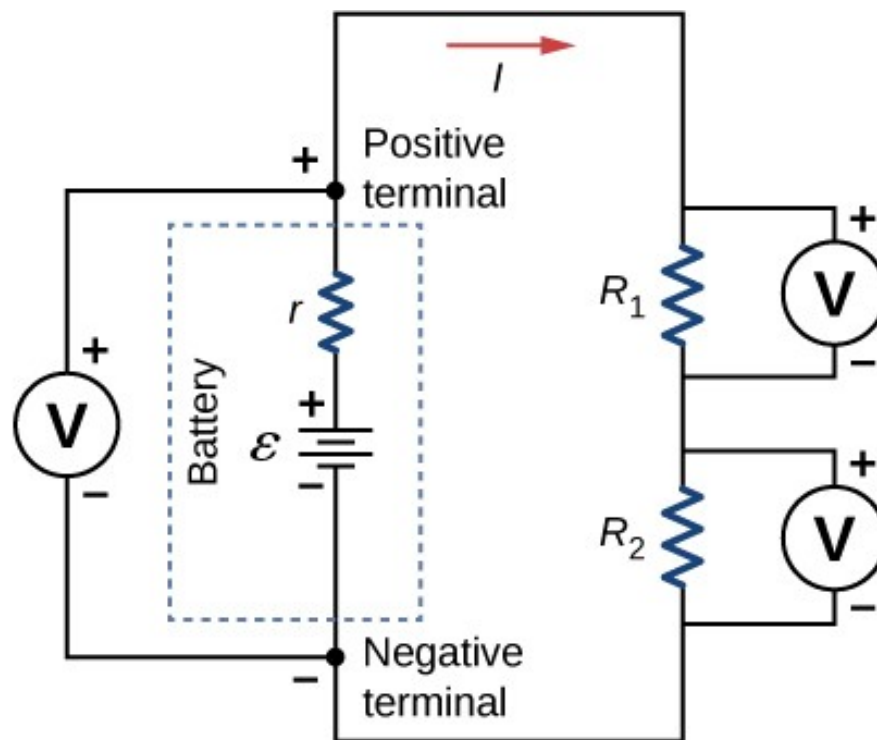
The fuel and temperature gauges (far right and far left, respectively) in this 1996 Volkswagen are voltmeters that register the voltage output of “sender” units. These units are proportional to the amount of gasoline in the tank and to the engine temperature. (credit: Christian Giersing)

FIGURE 10.35



- When an ammeter is used to measure the current through two resistors connected in series to a battery, a single ammeter is placed in series with the two resistors because the current is the same through the two resistors in series.
- When two resistors are connected in parallel with a battery, three meters, or three separate ammeter readings, are necessary to measure the current from the battery and through each resistor. The ammeter is connected in series with the component in question.

FIGURE 10.36



To measure potential differences in this series circuit, the voltmeter (V) is placed in parallel with the voltage source or either of the resistors. Note that terminal voltage is measured between the positive terminal and the negative terminal of the battery or voltage source. It is not possible to connect a voltmeter directly across the emf without including the internal resistance r of the battery.

FIGURE 10.37



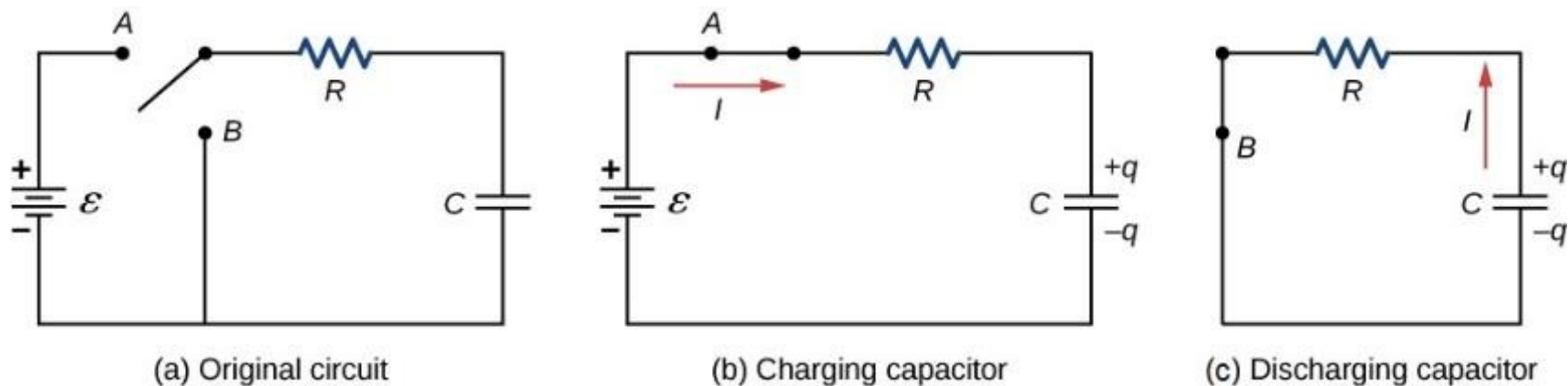
(a)



(b)

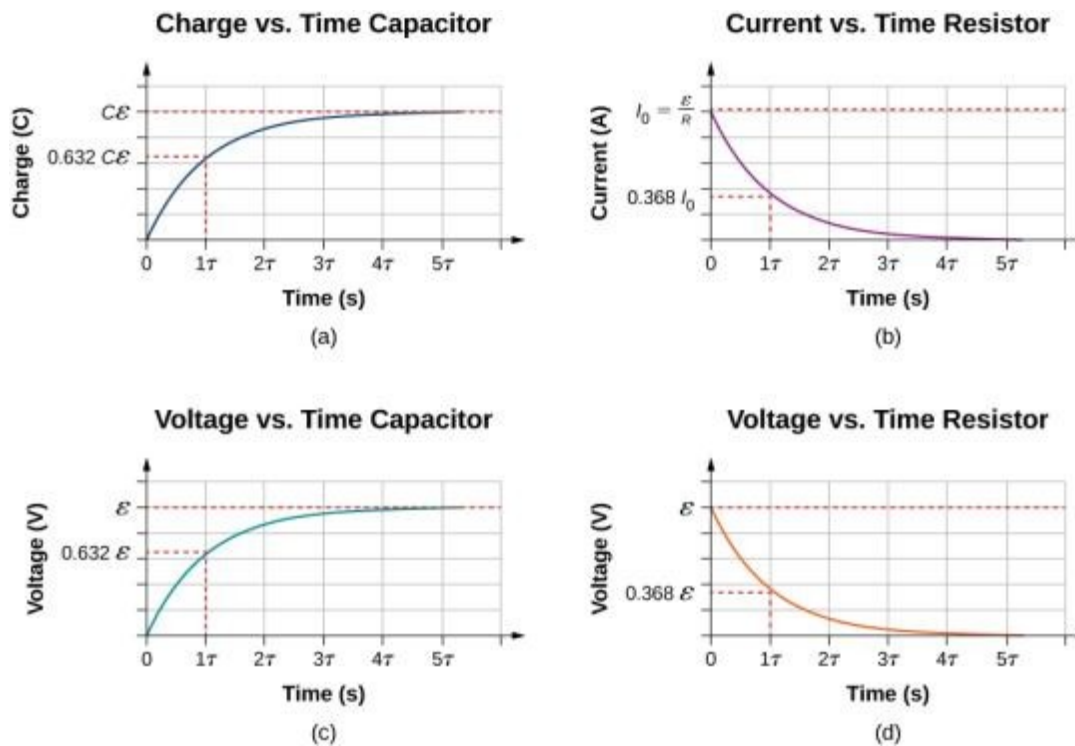
- a) An analog voltmeter uses a galvanometer to measure the voltage.
- b) Digital meters use an analog-to-digital converter to measure the voltage. (credit a and credit b: Joseph J. Trout)

FIGURE 10.38



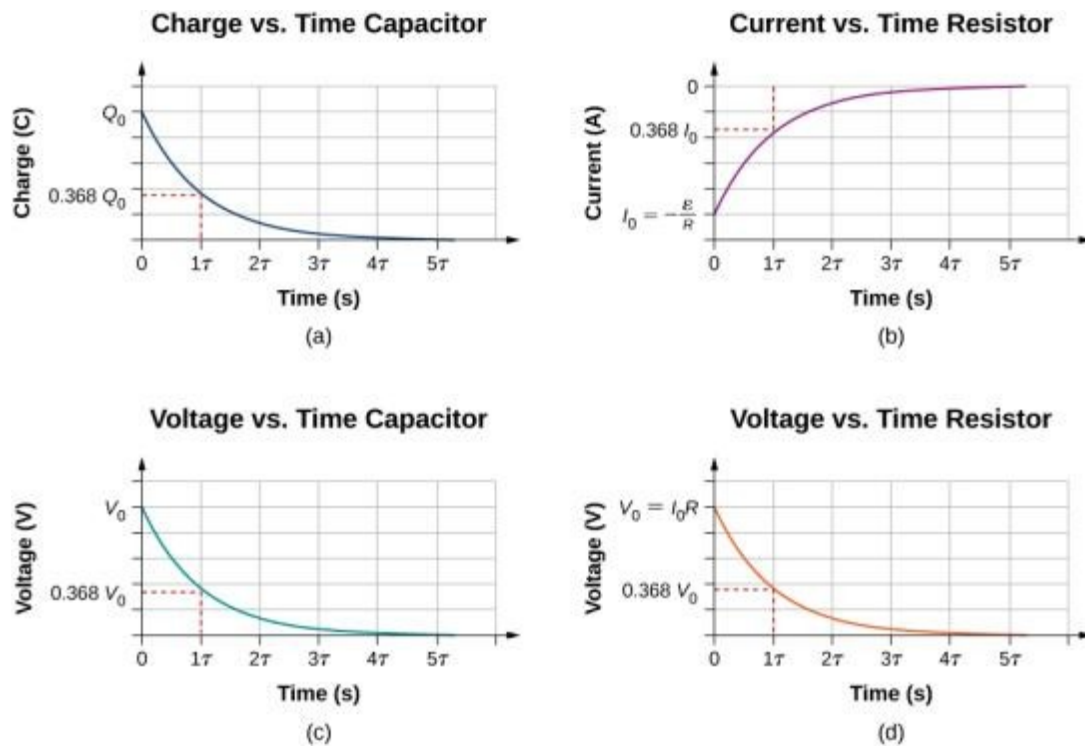
- An RC circuit with a two-pole switch that can be used to charge and discharge a capacitor.
- When the switch is moved to position A , the circuit reduces to a simple series connection of the voltage source, the resistor, the capacitor, and the switch.
- When the switch is moved to position B , the circuit reduces to a simple series connection of the resistor, the capacitor, and the switch. The voltage source is removed from the circuit.

FIGURE 10.39



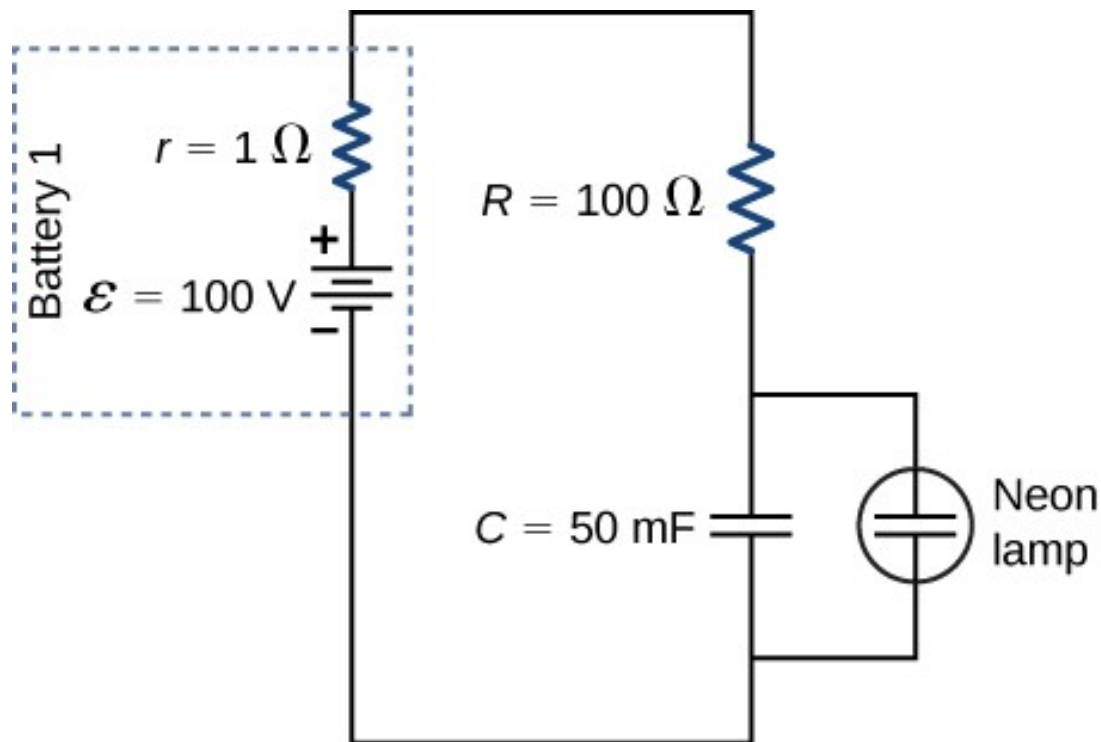
- a) Charge on the capacitor versus time as the capacitor charges.
- b) Current through the resistor versus time.
- c) Voltage difference across the capacitor.
- d) Voltage difference across the resistor.

FIGURE 10.40



- a) Charge on the capacitor versus time as the capacitor discharges.
- b) Current through the resistor versus time.
- c) Voltage difference across the capacitor.
- d) Voltage difference across the resistor.

EXAMPLE 10.8



EXAMPLE 10.9

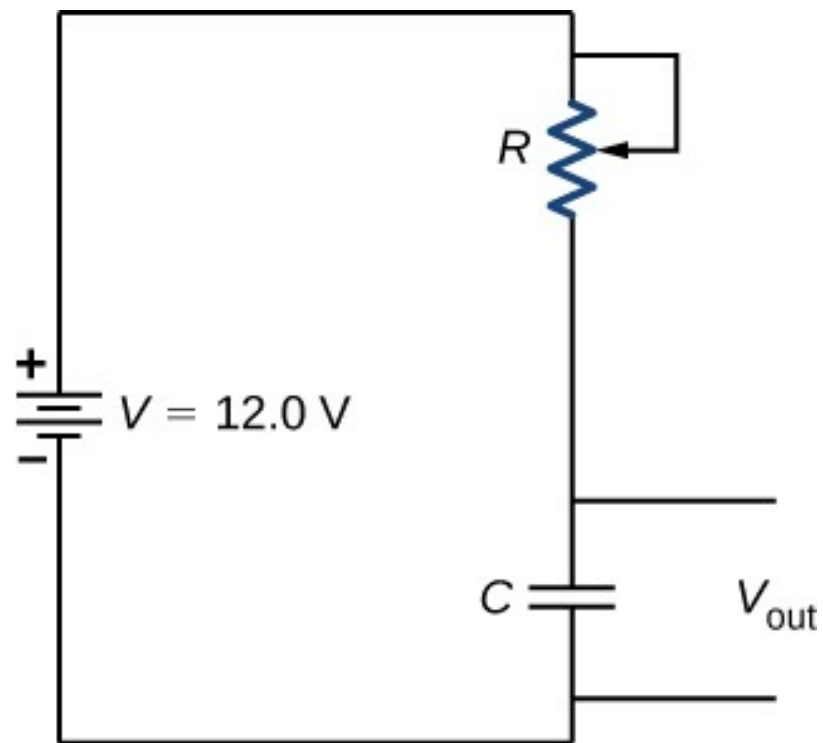
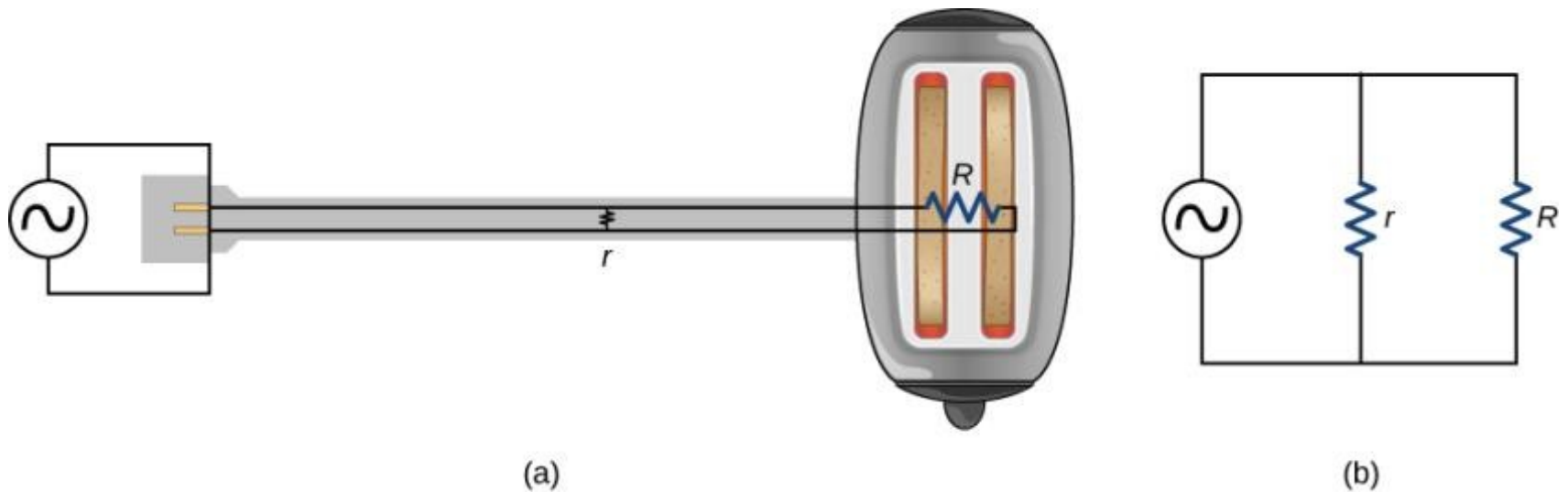


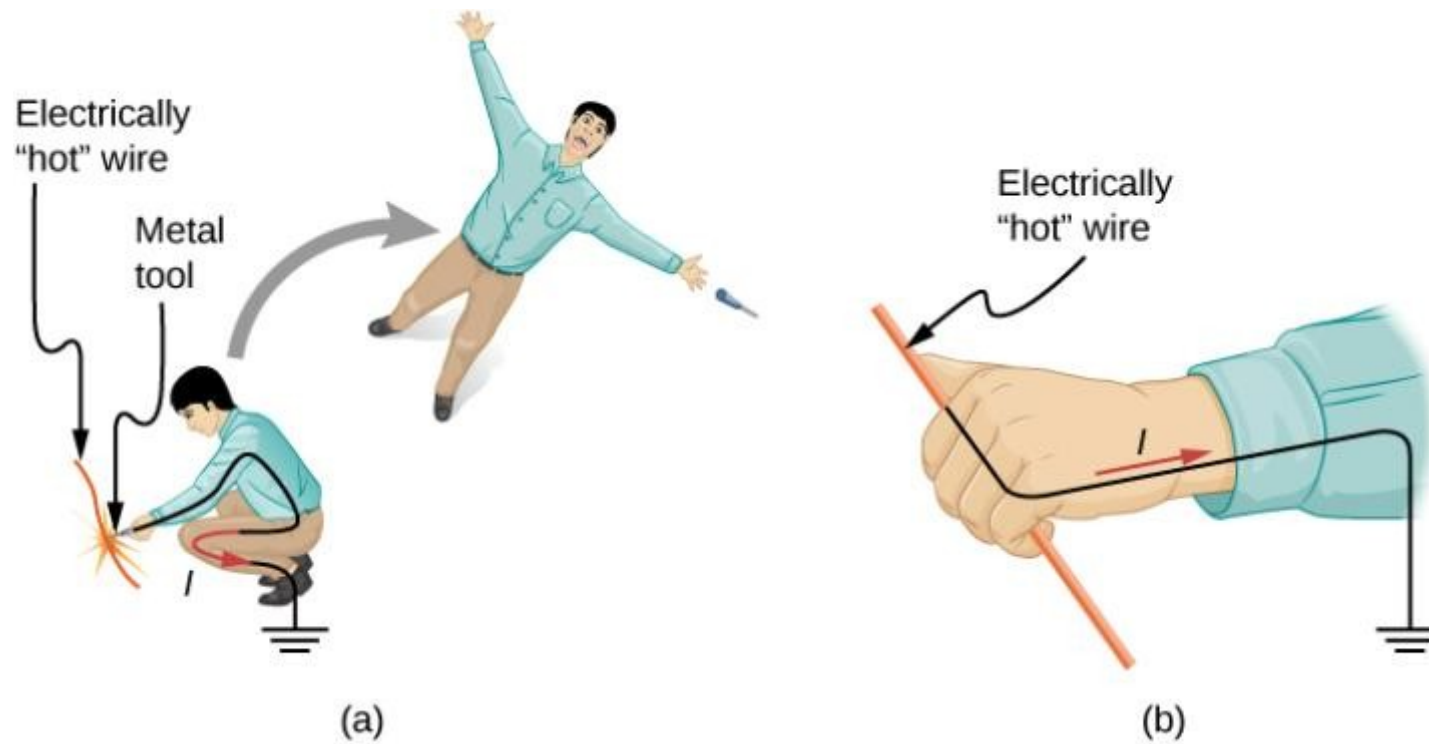
FIGURE 10.41



A short circuit is an undesired low-resistance path across a voltage source.

- a) Worn insulation on the wires of a toaster allow them to come into contact with a low resistance r . Since $P = V^2/r$, thermal power is created so rapidly that the cord melts or burns.
- b) A schematic of the short circuit.

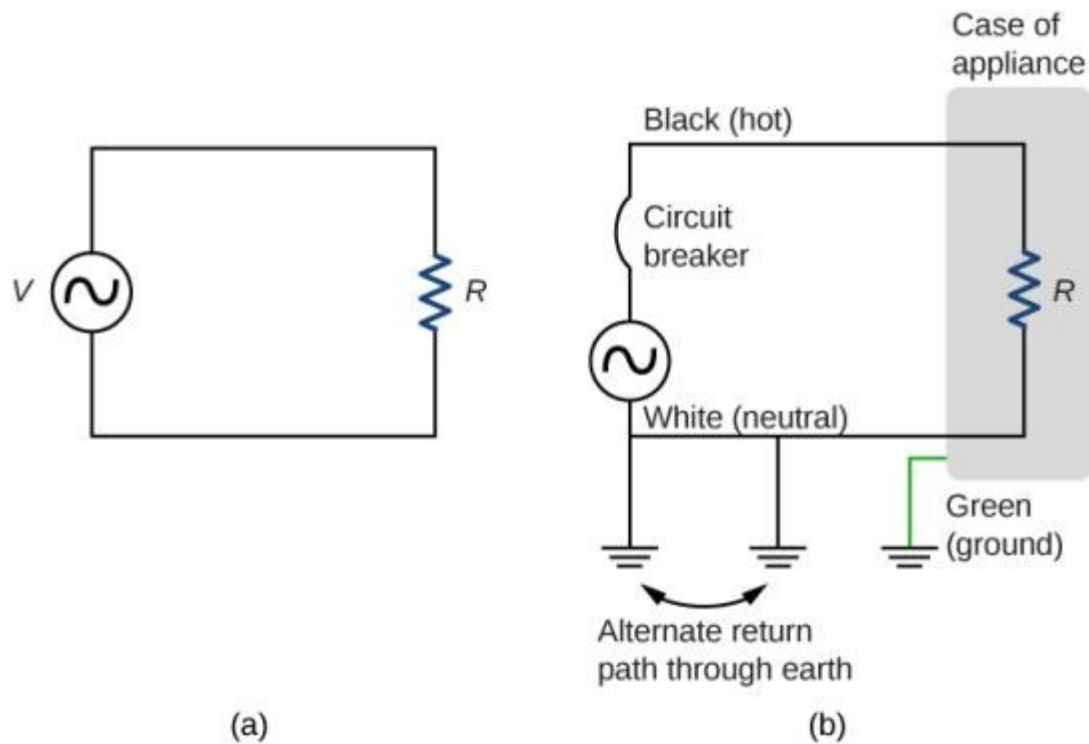
FIGURE 10.42



An electric current can cause muscular contractions with varying effects.

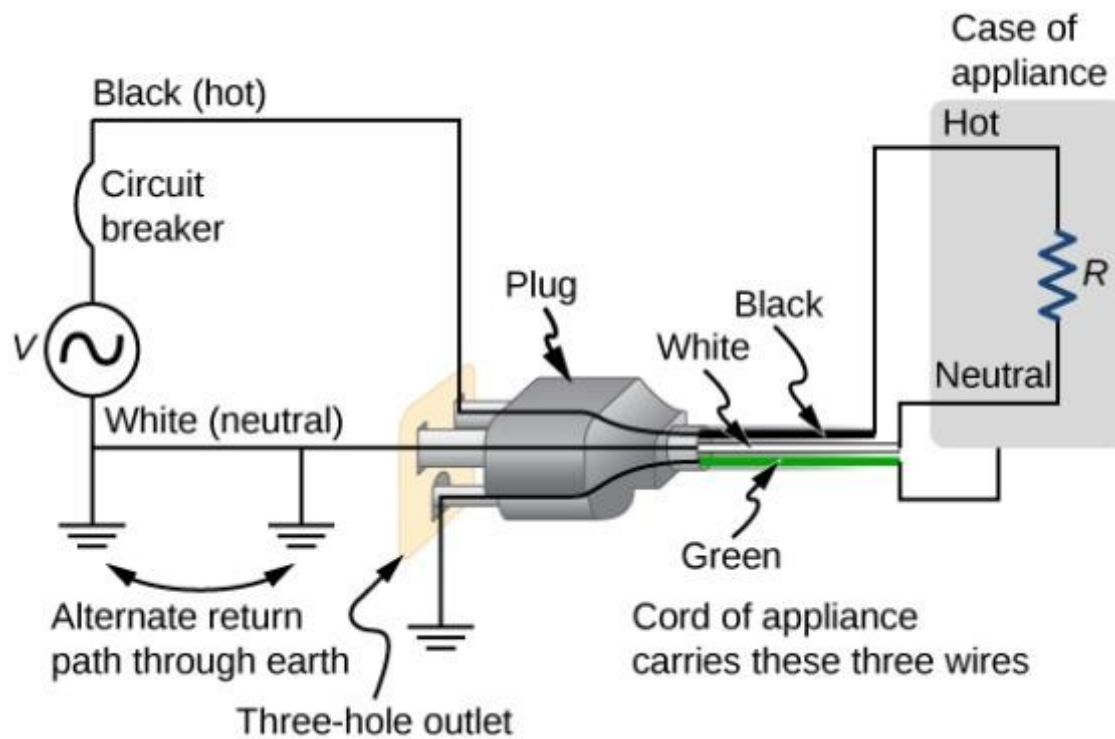
- The victim is "thrown" backward by involuntary muscle contractions that extend the legs and torso.
- The victim can't let go of the wire that is stimulating all the muscles in the hand. Those that close the fingers are stronger than those that open them.

FIGURE 10.43



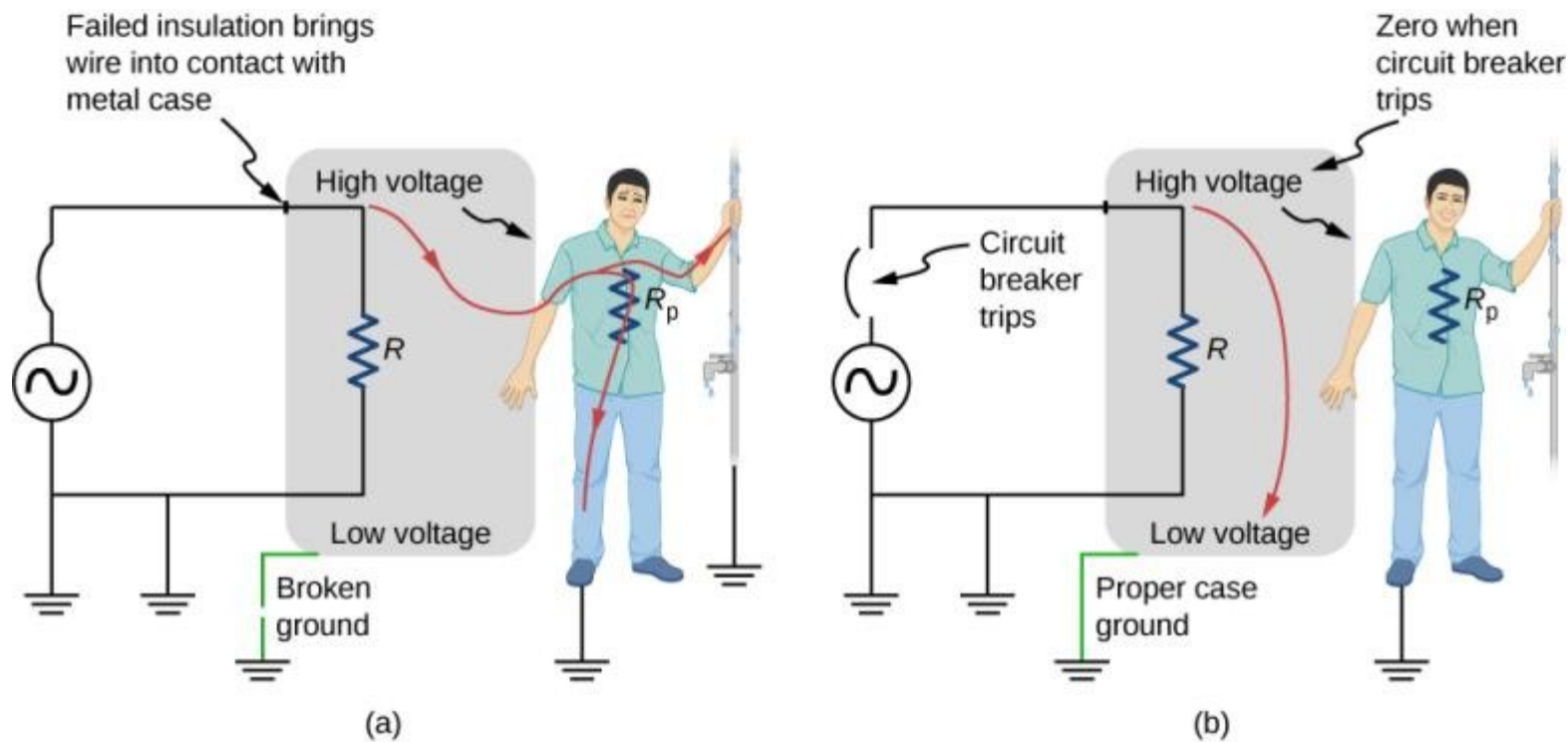
- Schematic of a simple ac circuit with a voltage source and a single appliance represented by the resistance R . There are no safety features in this circuit.
- The three-wire system connects the neutral wire to ground at the voltage source and user location, forcing it to be at zero volts and supplying an alternative return path for the current through ground. Also grounded to zero volts is the case of the appliance. A circuit breaker or fuse protects against thermal overload and is in series on the active (live/hot) wire.

FIGURE 10.44



The standard three-prong plug can only be inserted in one way, to ensure proper function of the three-wire system.

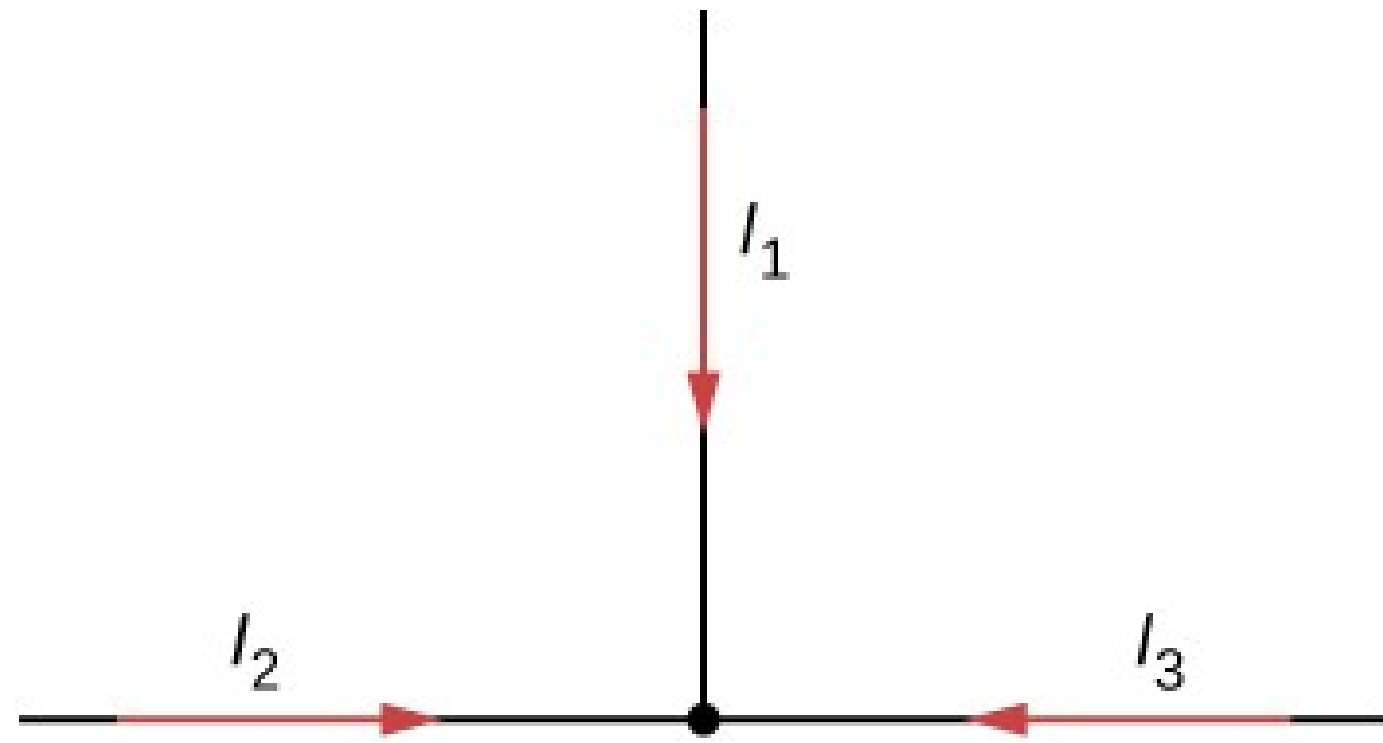
FIGURE 10.45



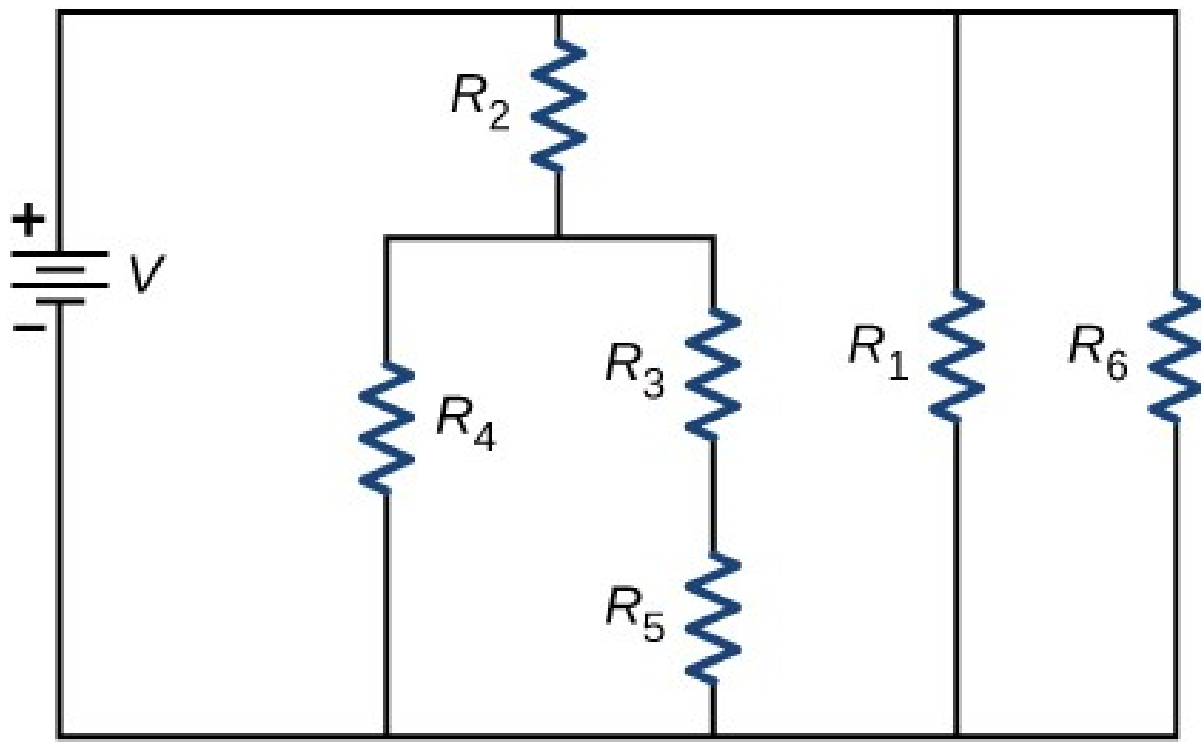
Worn insulation allows the live/hot wire to come into direct contact with the metal case of this appliance.

- The ground connection being broken, the person is severely shocked. The appliance may operate normally in this situation.
- With a proper ground, the circuit breaker trips, forcing repair of the appliance.

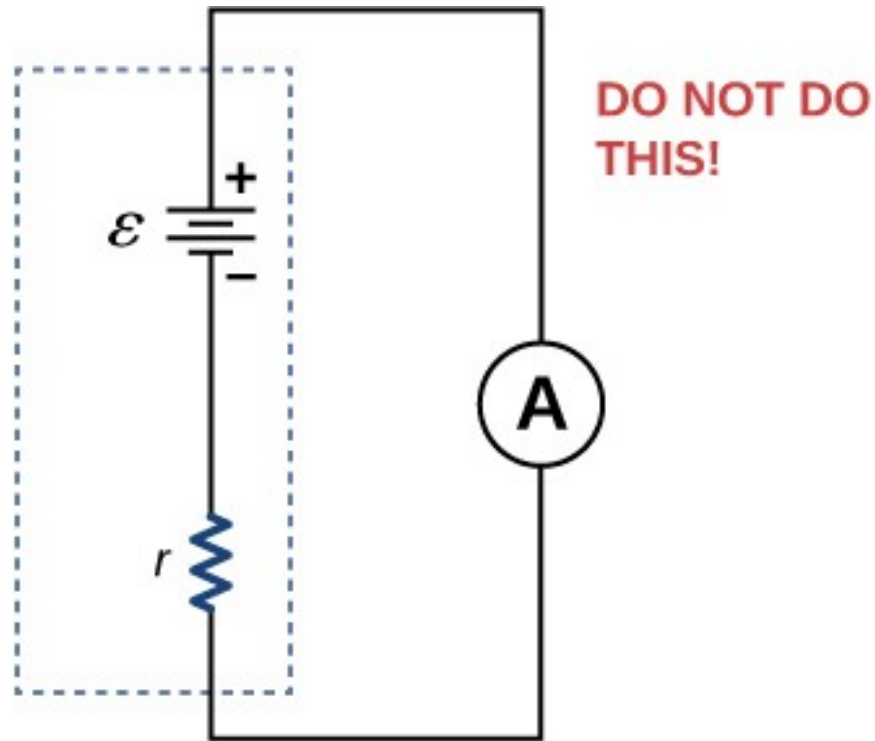
EXERCISE 8



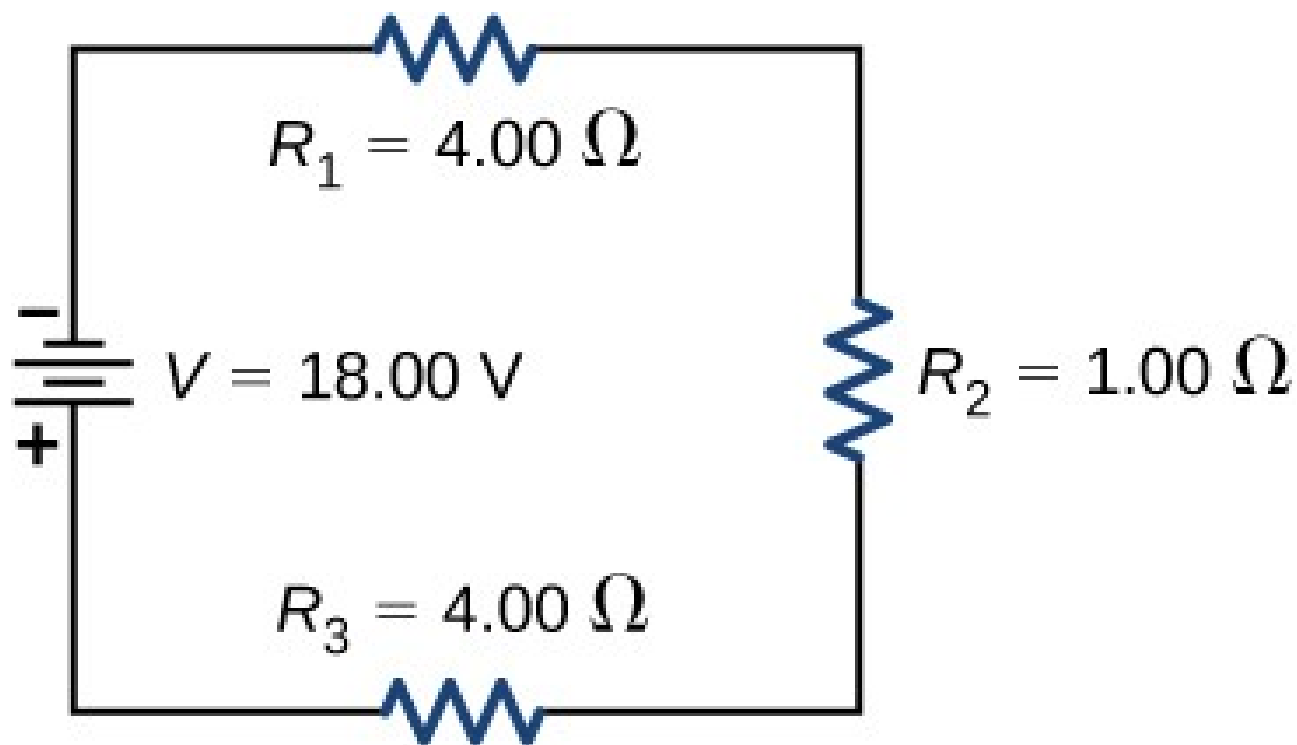
EXERCISE 9



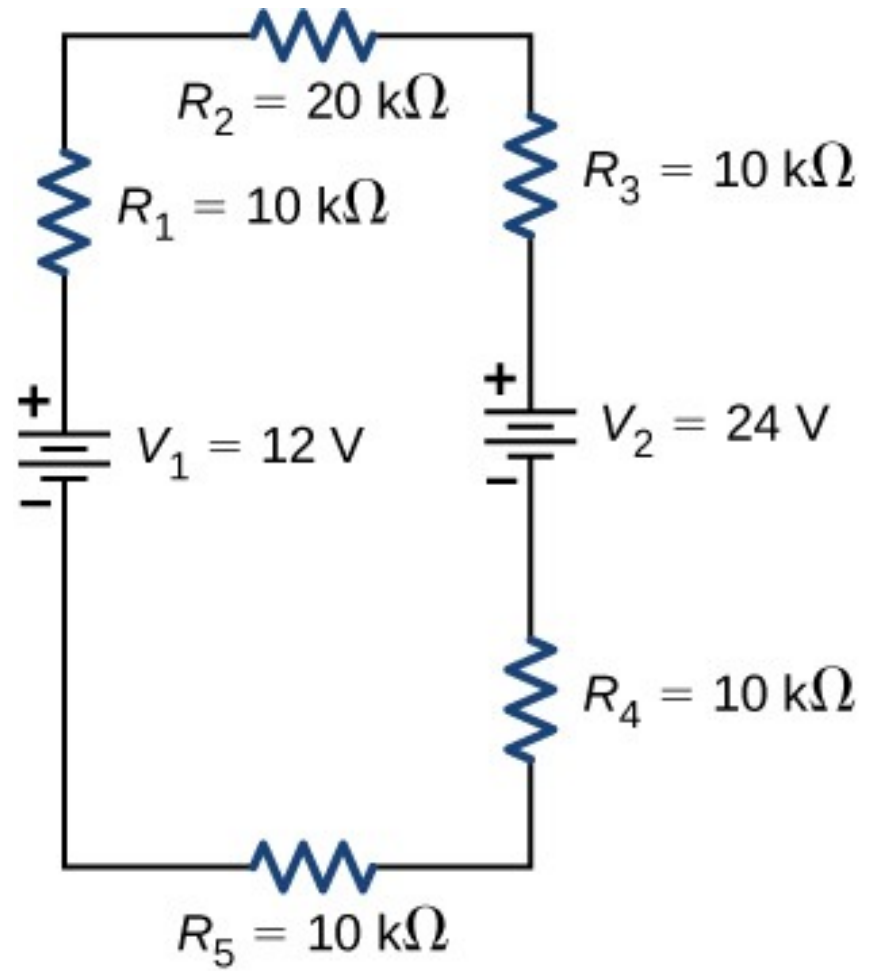
EXERCISE 15



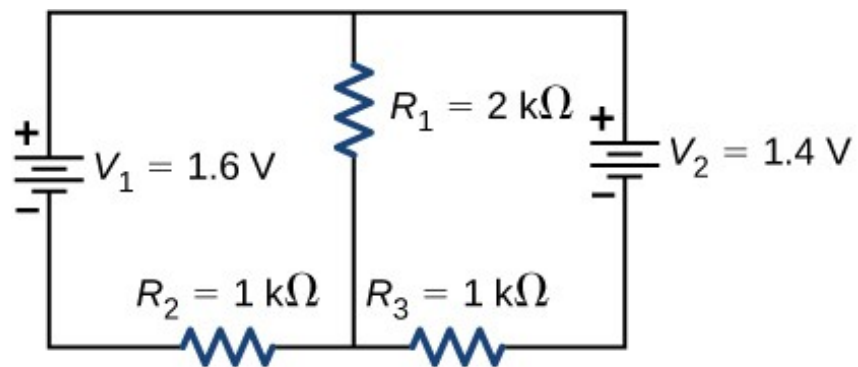
EXERCISE 35



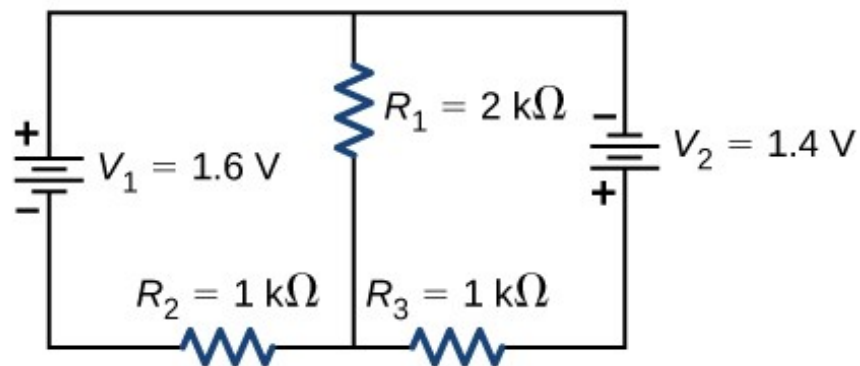
EXERCISE 36



EXERCISE 37

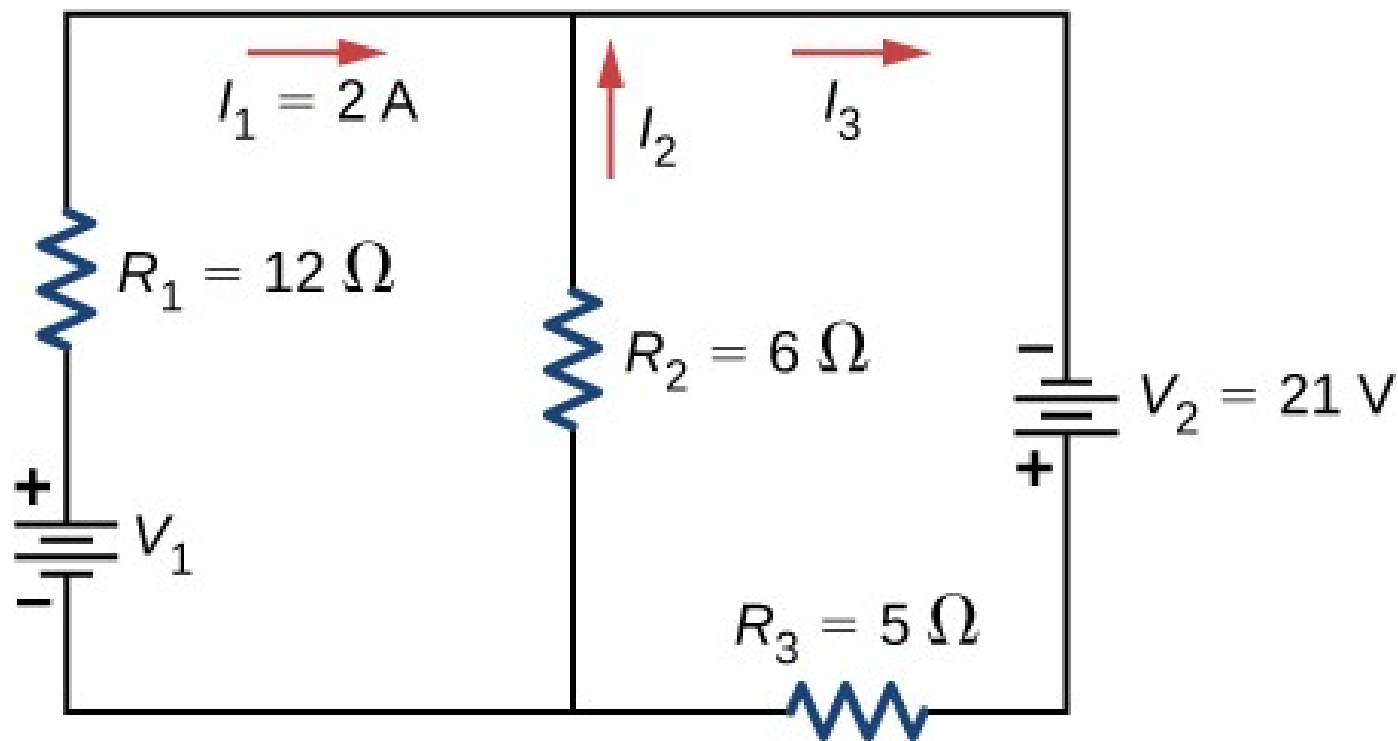


(a)

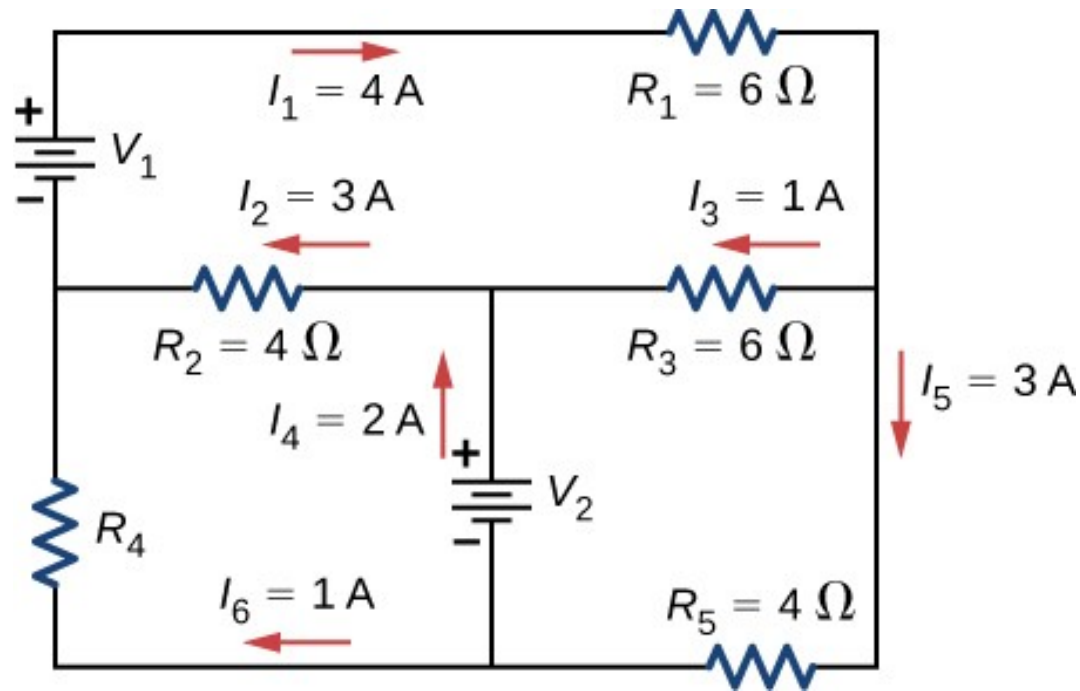


(b)

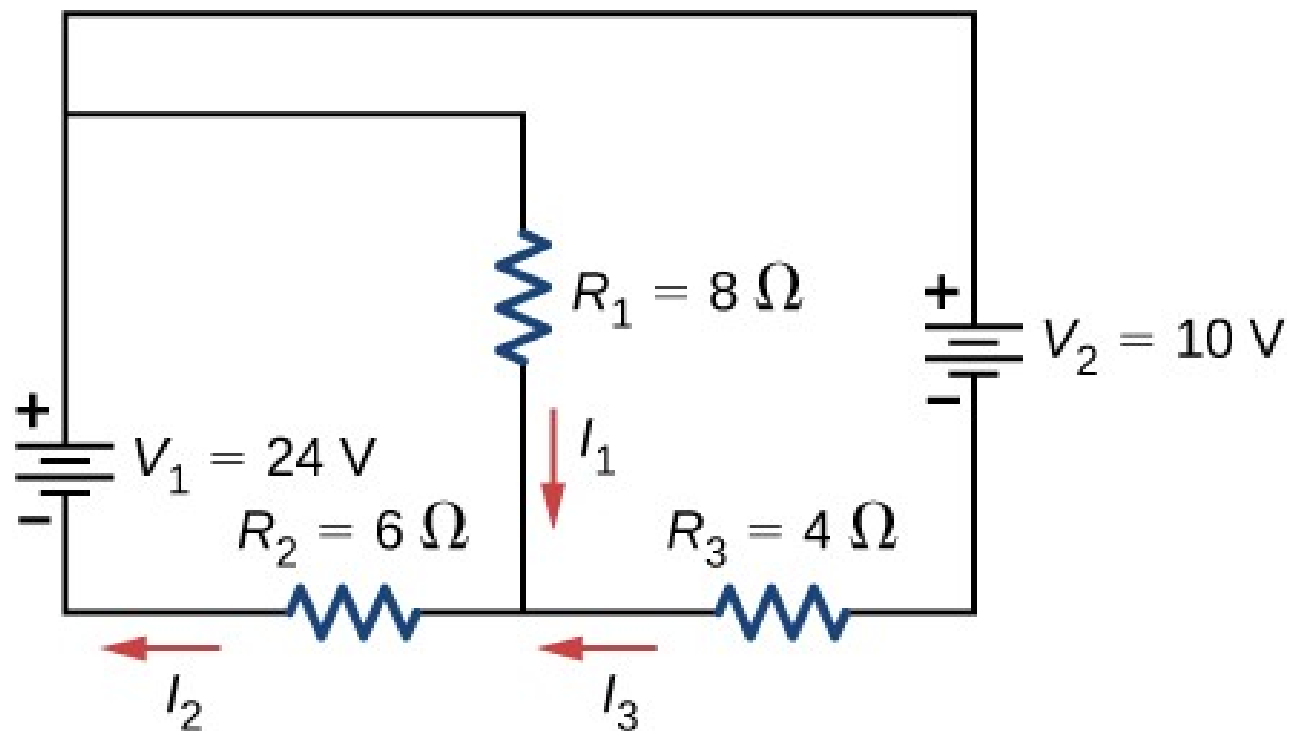
EXERCISE 38



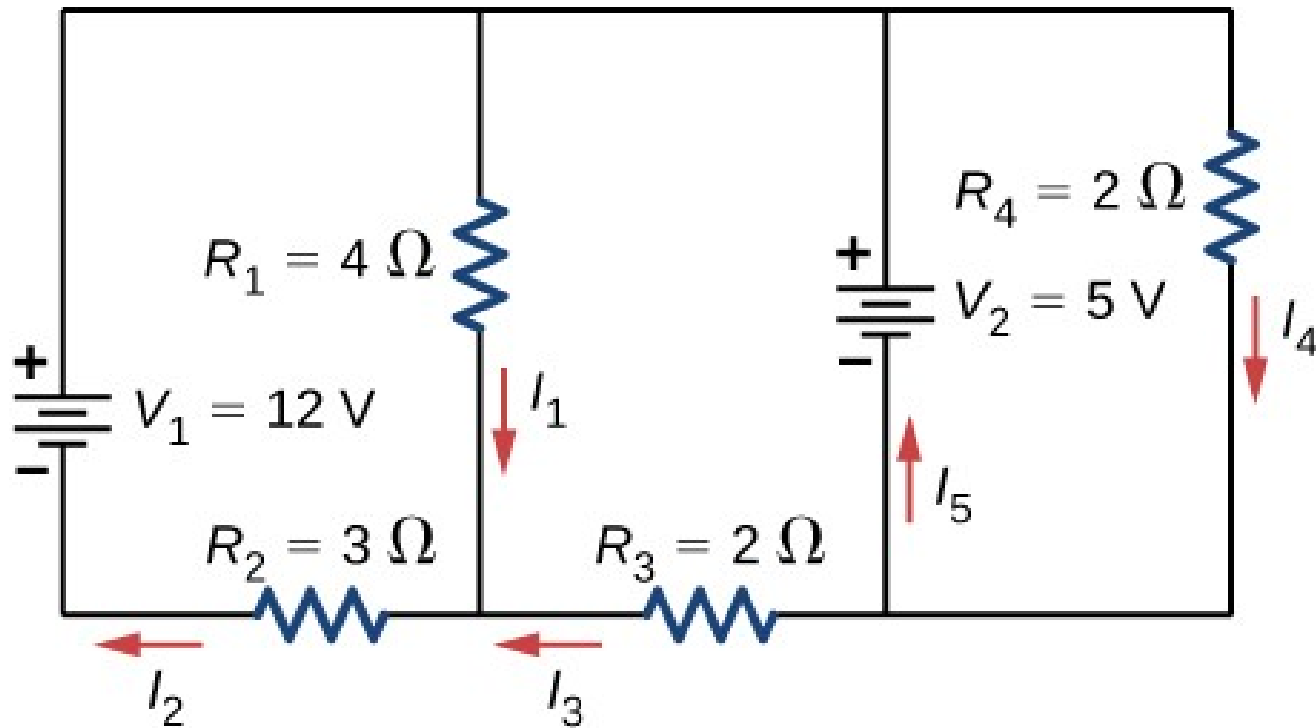
EXERCISE 39



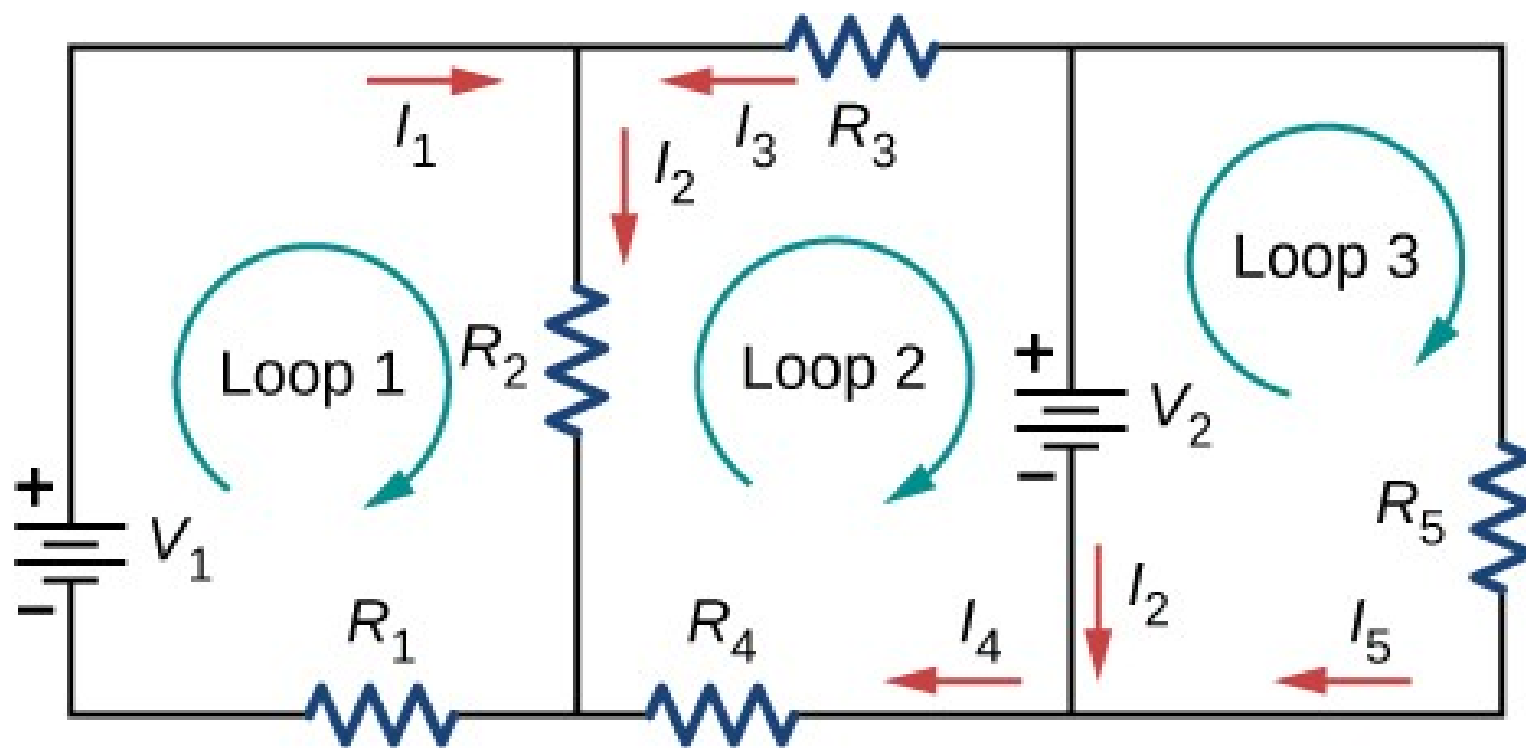
EXERCISE 40



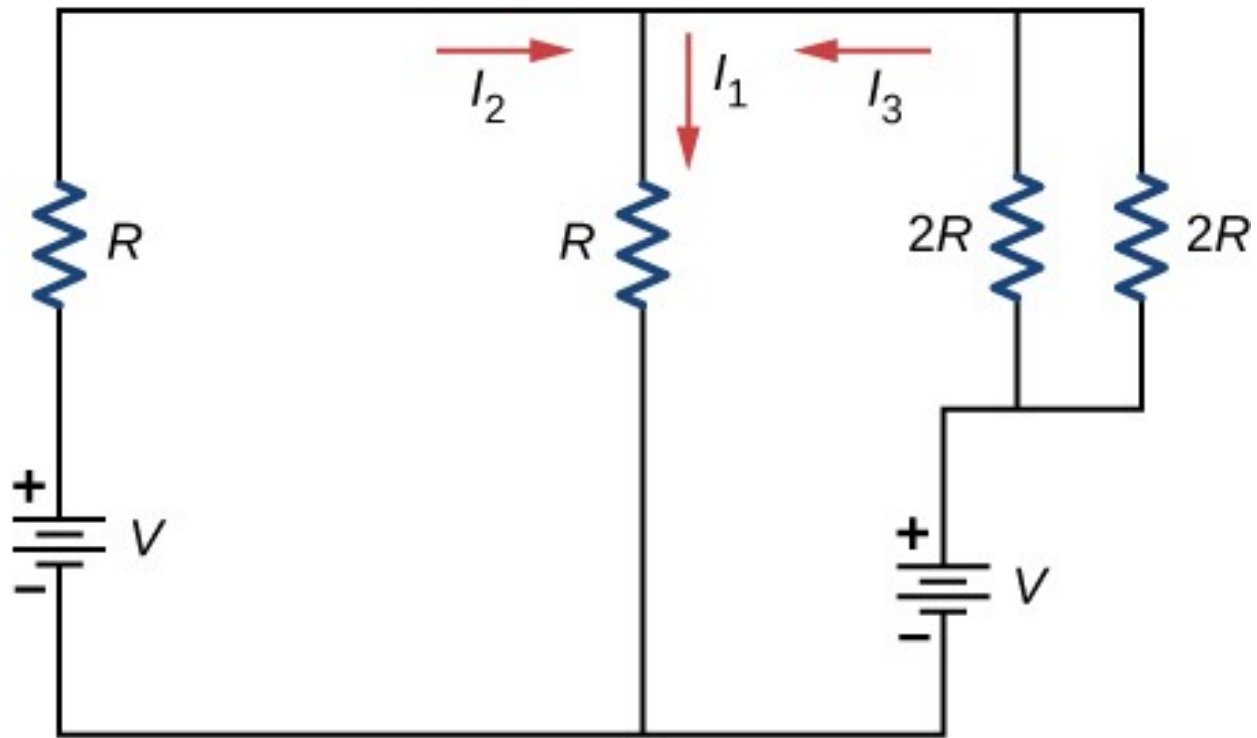
EXERCISE 41



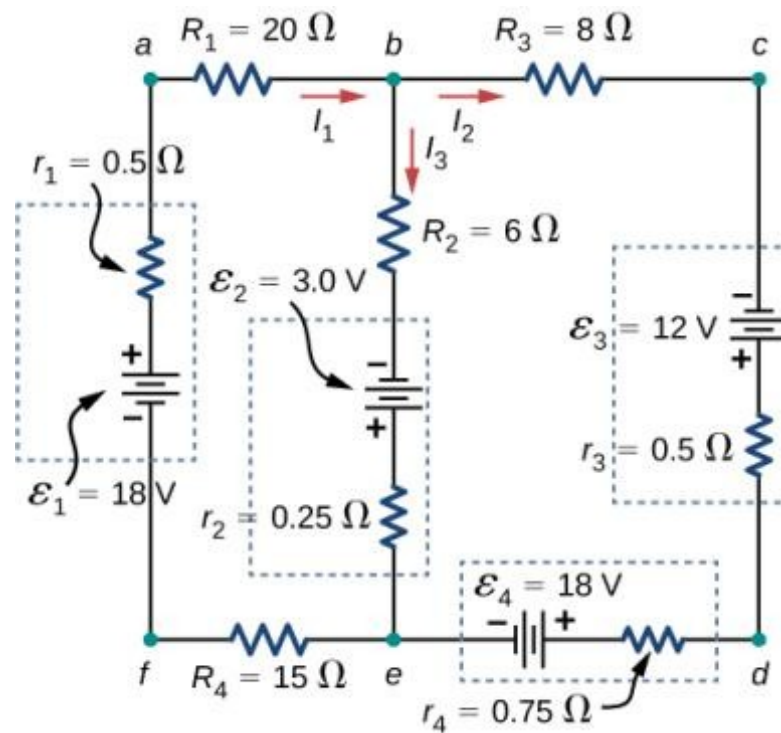
EXERCISE 42



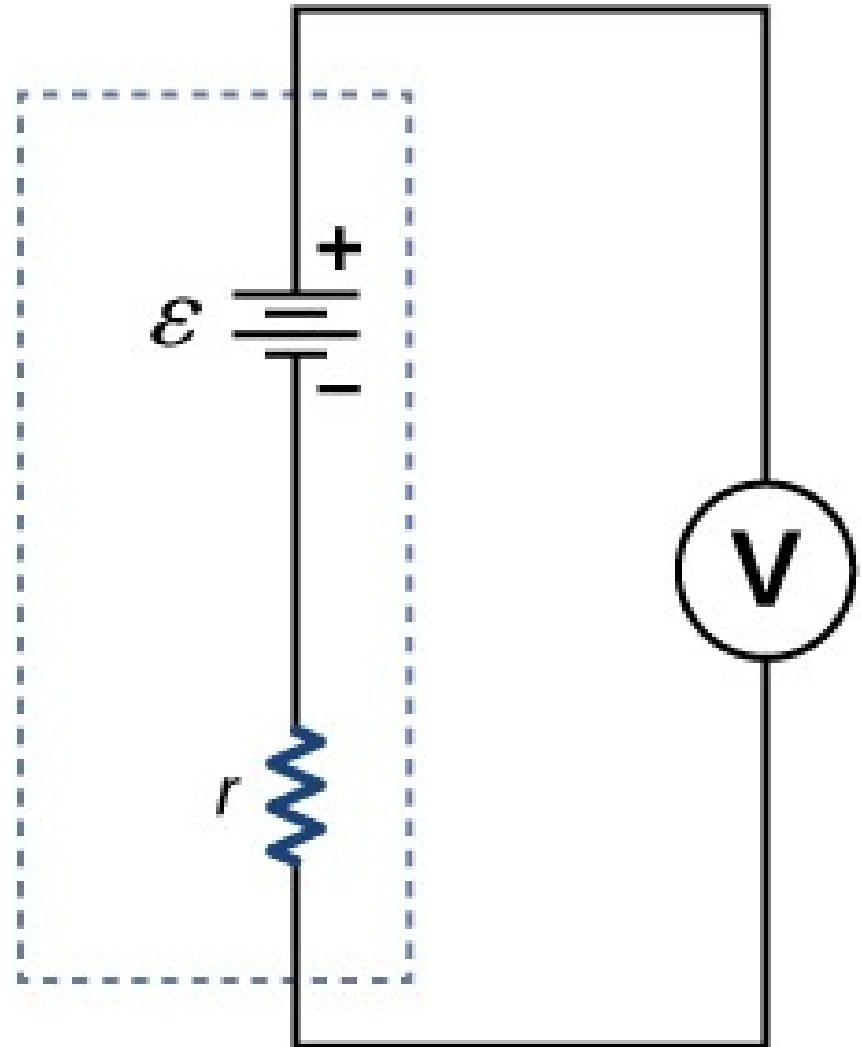
EXERCISE 43



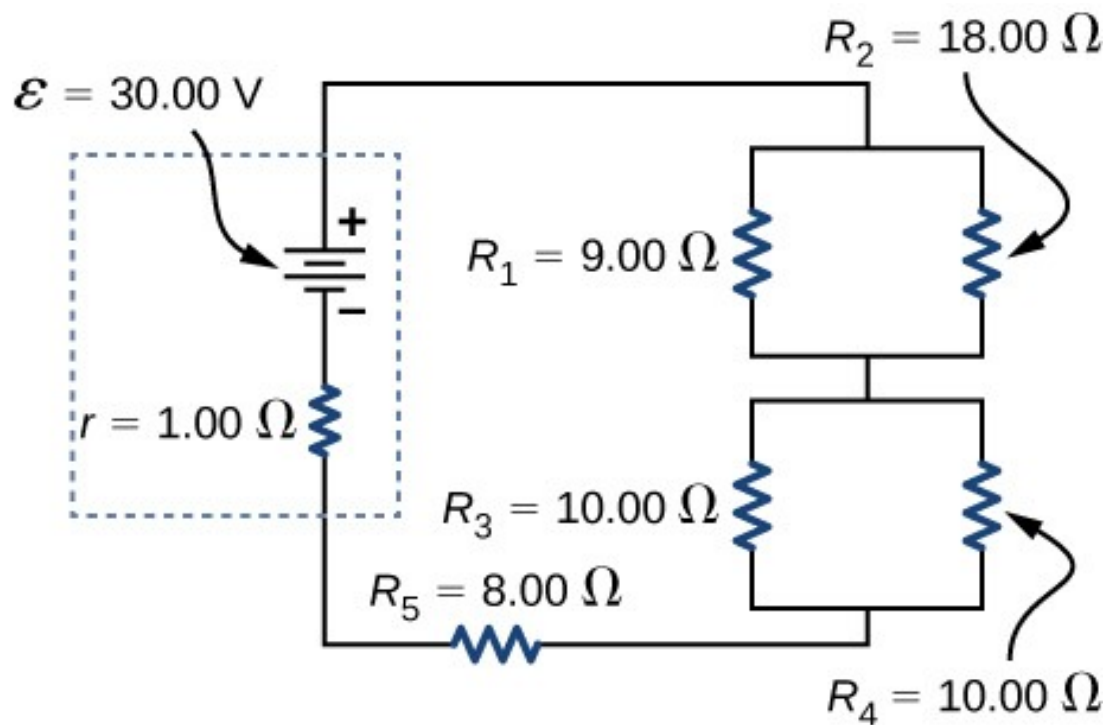
EXERCISE 46



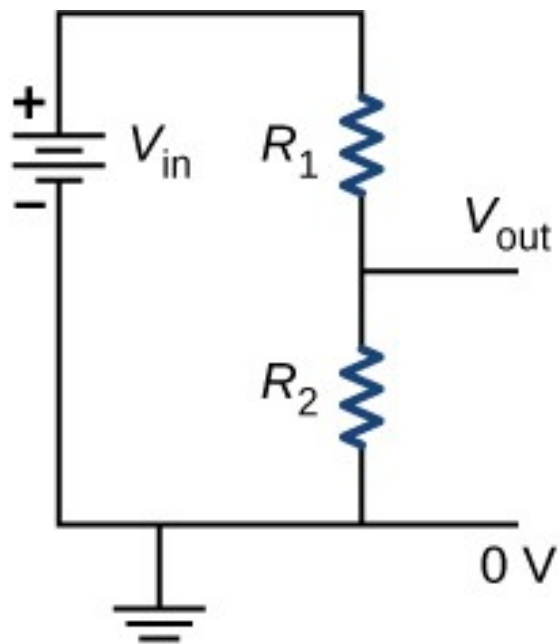
EXERCISE 48



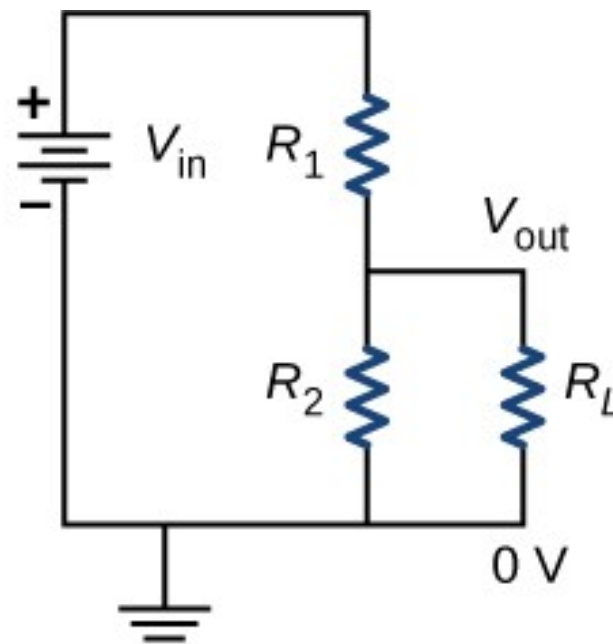
EXERCISE 69



EXERCISE 72

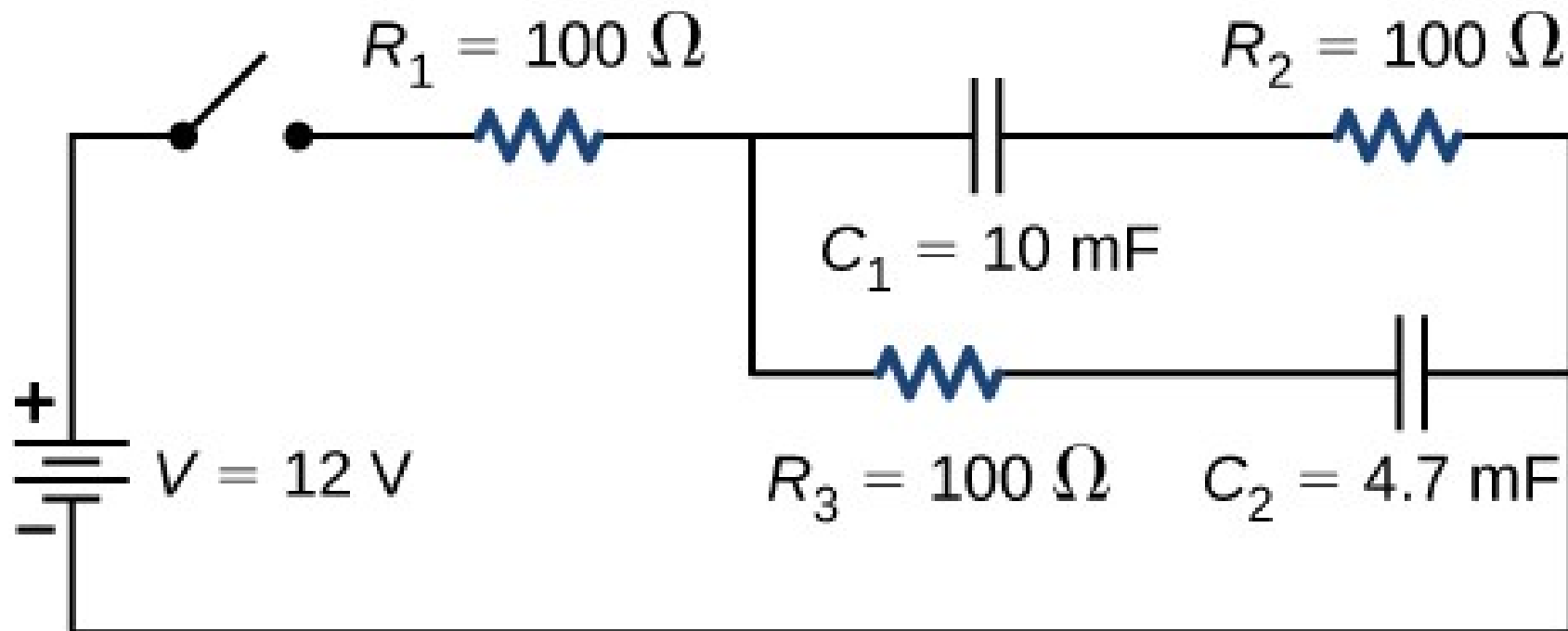


(a)

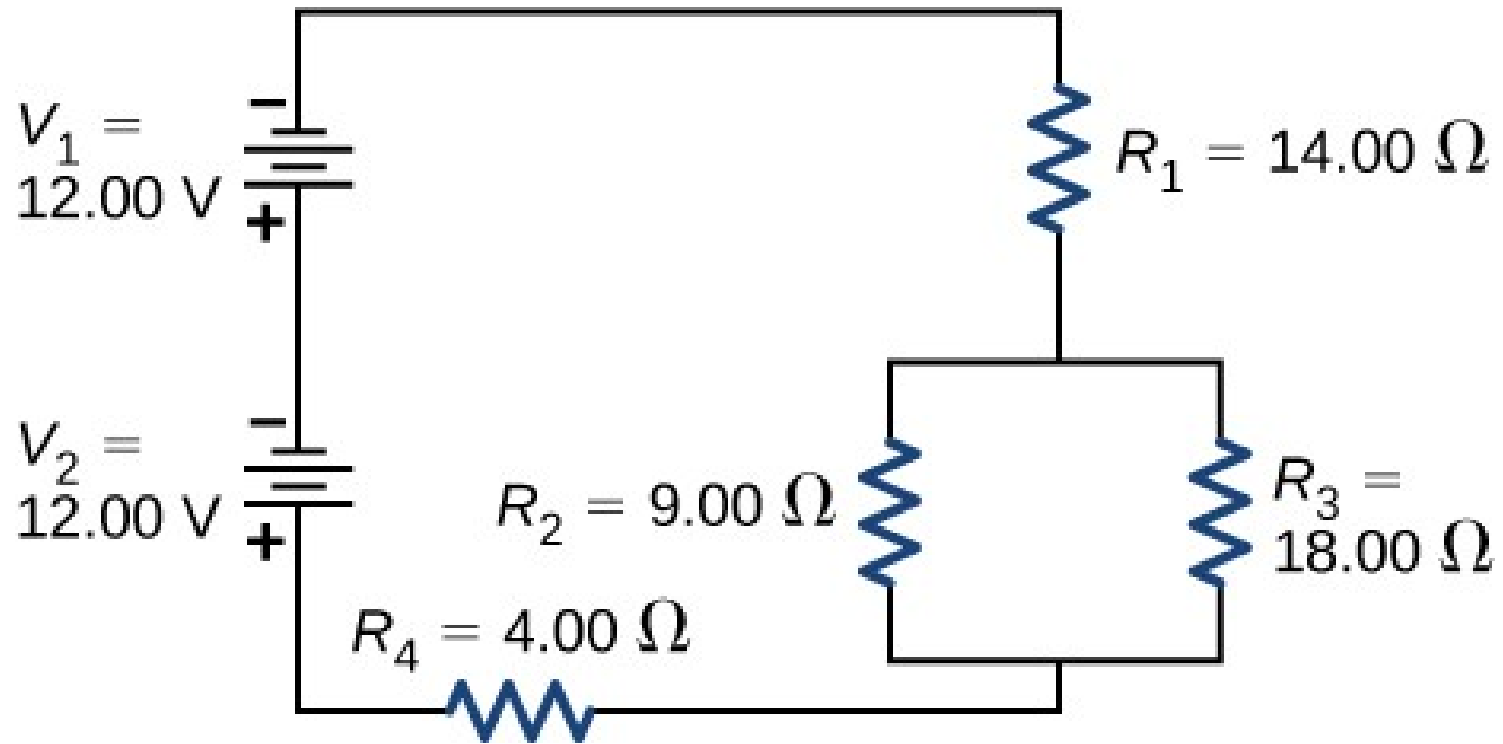


(b)

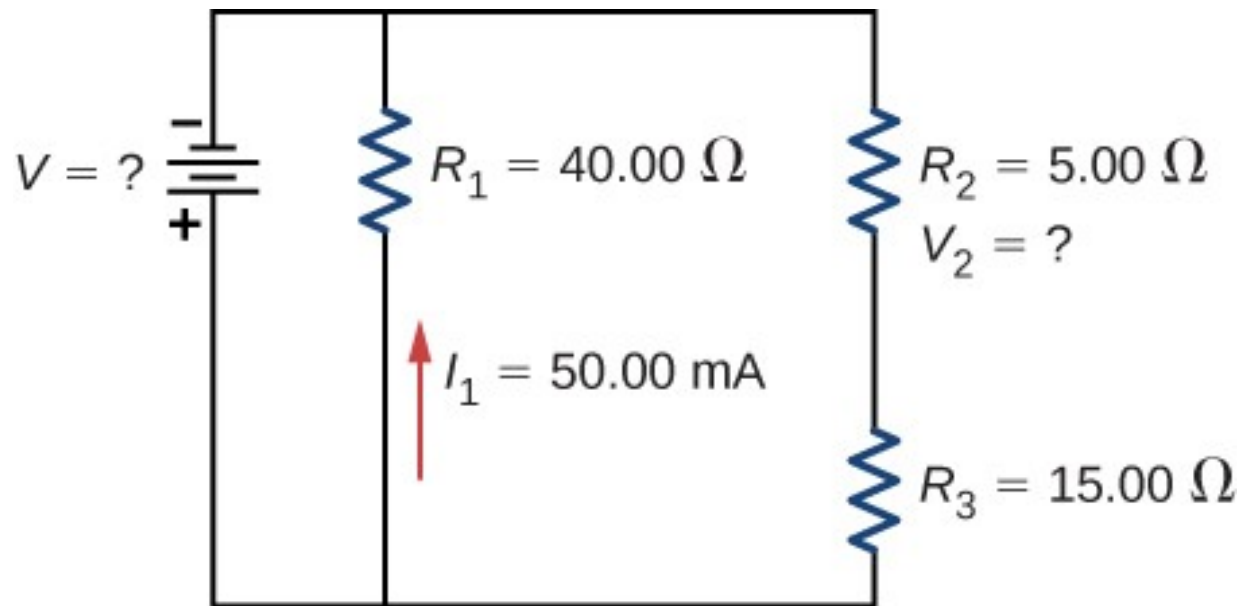
EXERCISE 75



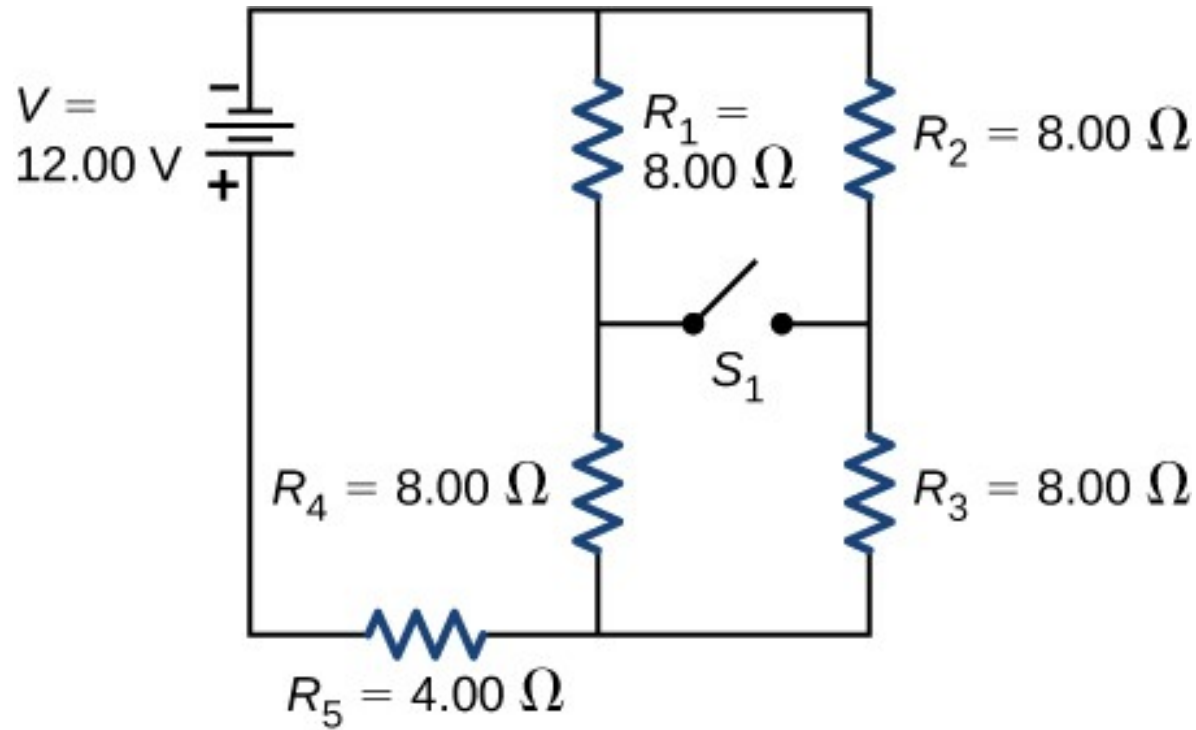
EXERCISE 77



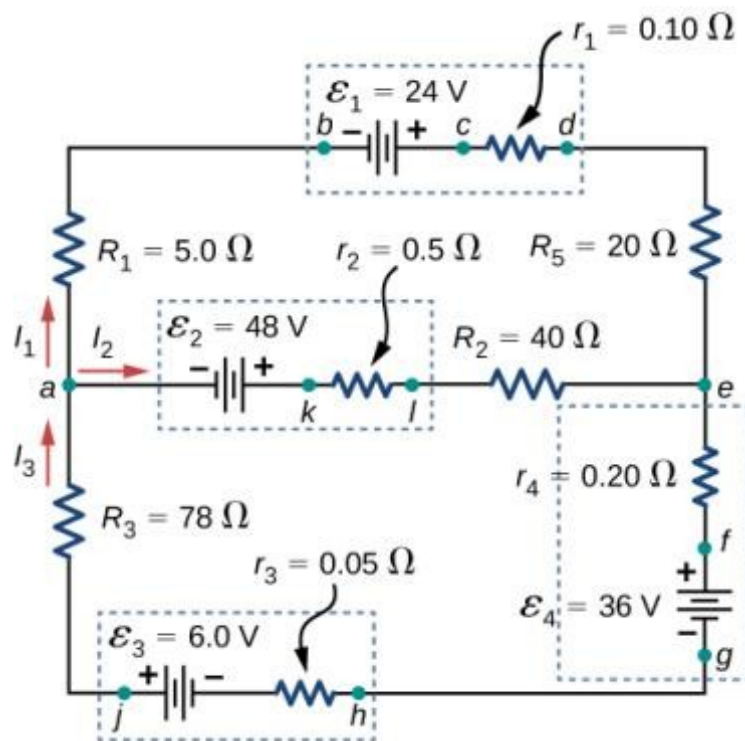
EXERCISE 78



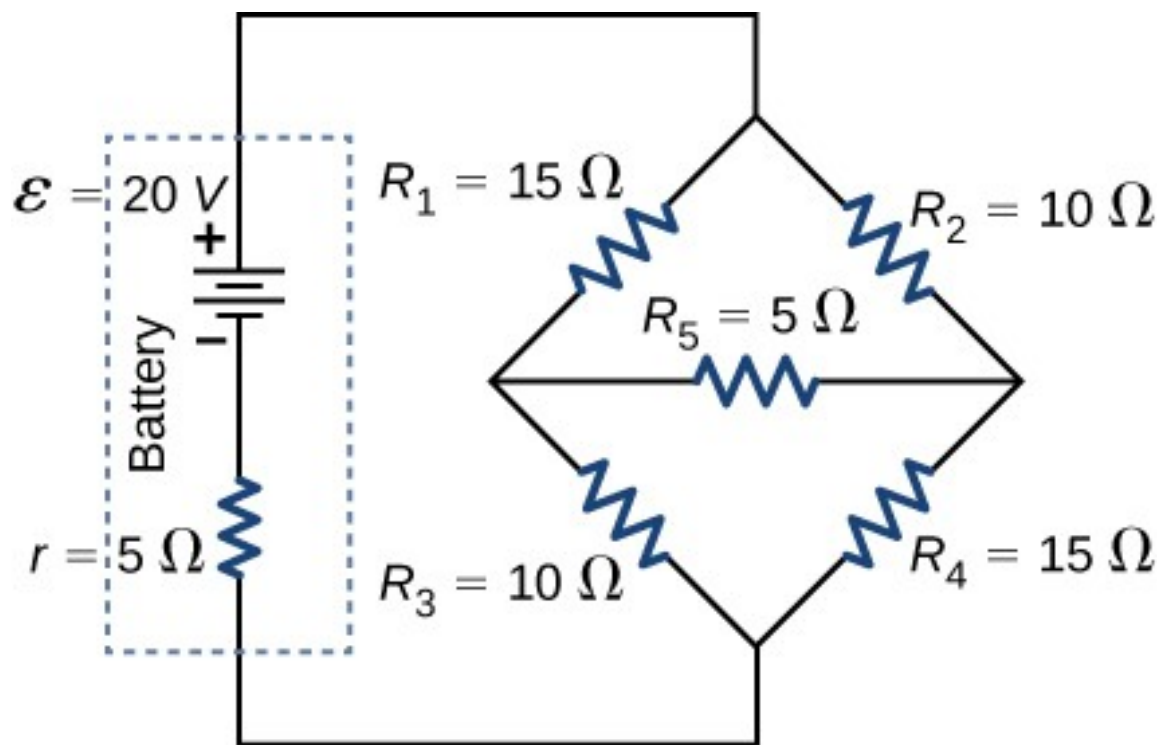
EXERCISE 79



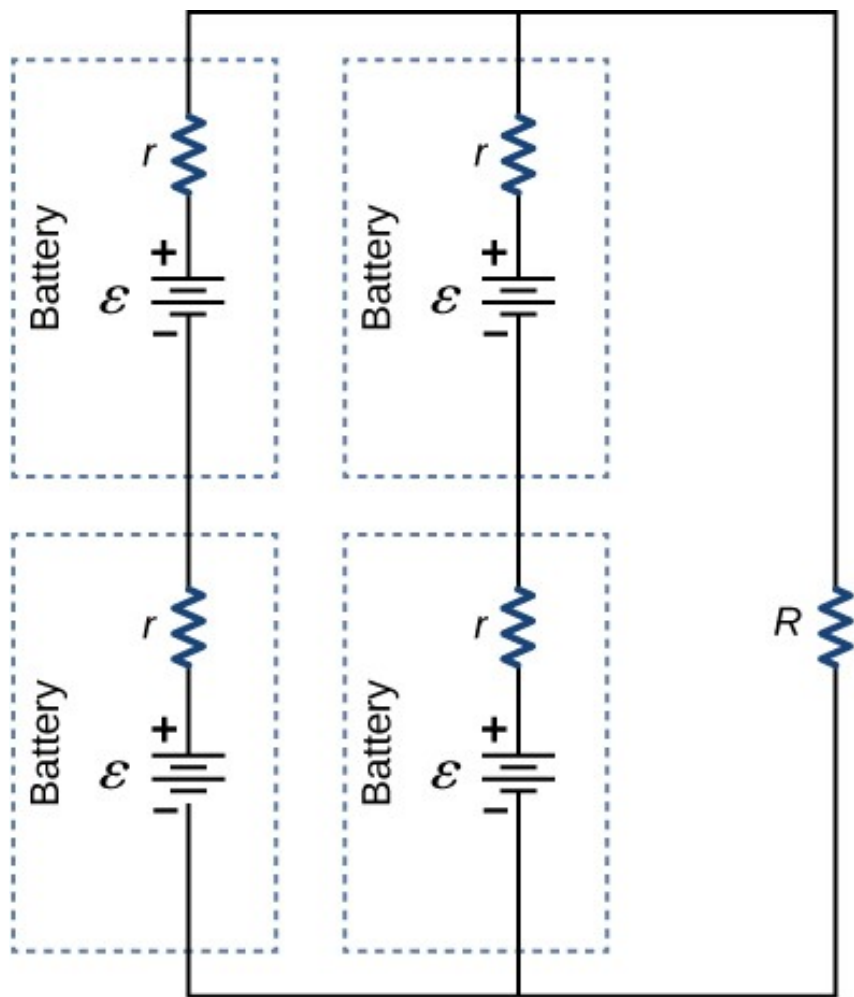
EXERCISE 82



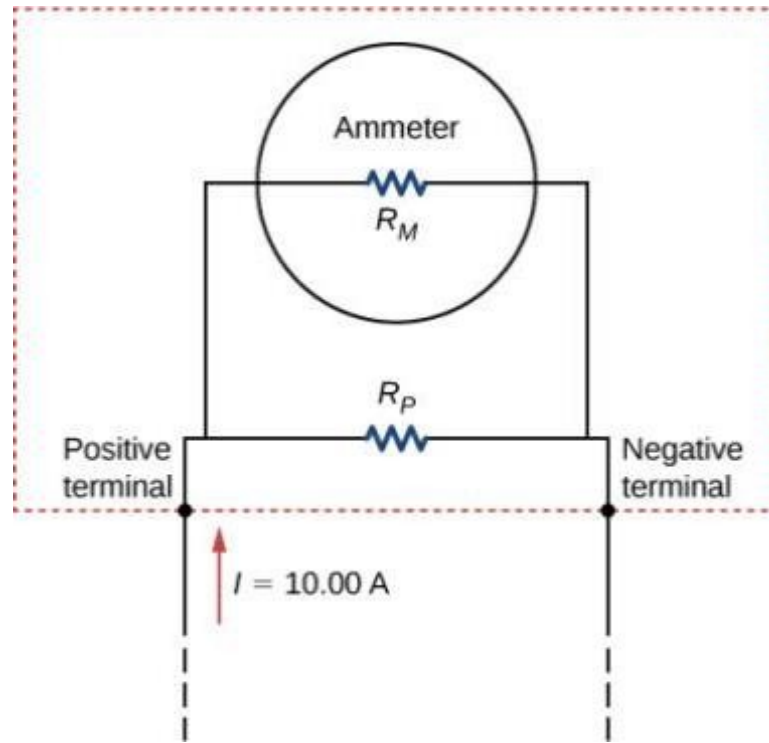
EXERCISE 85



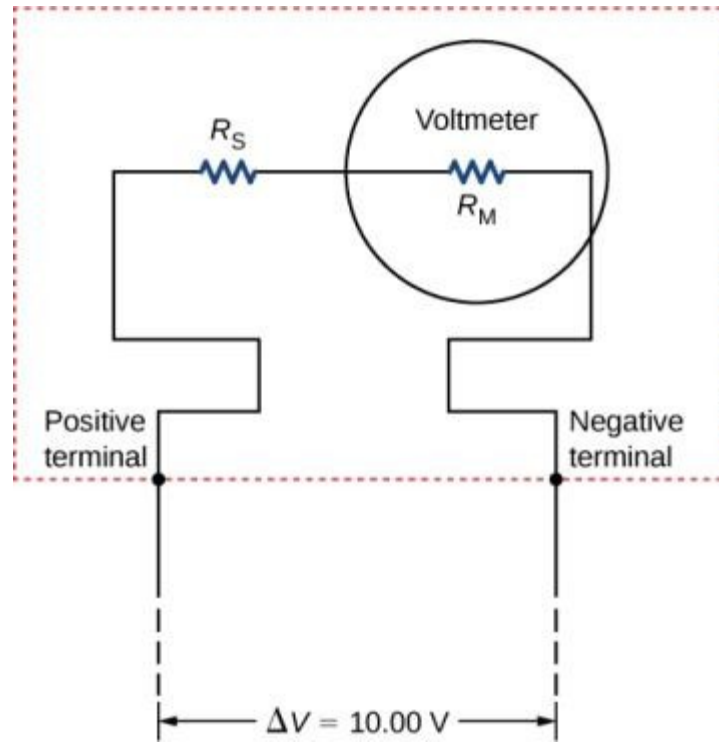
EXERCISE 89



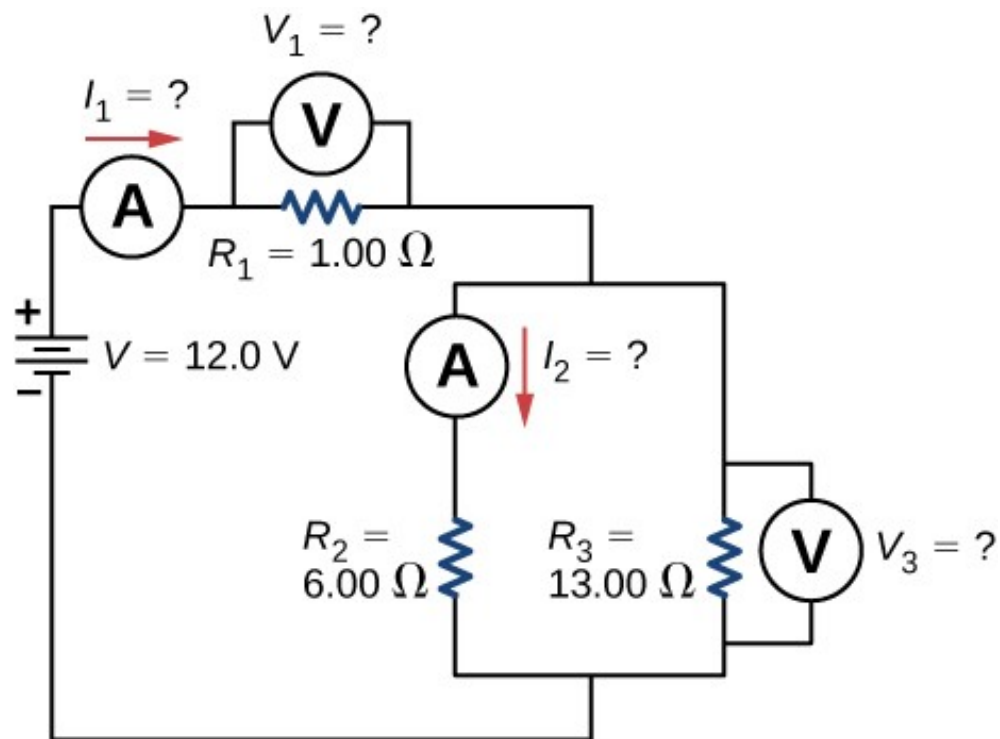
EXERCISE 90



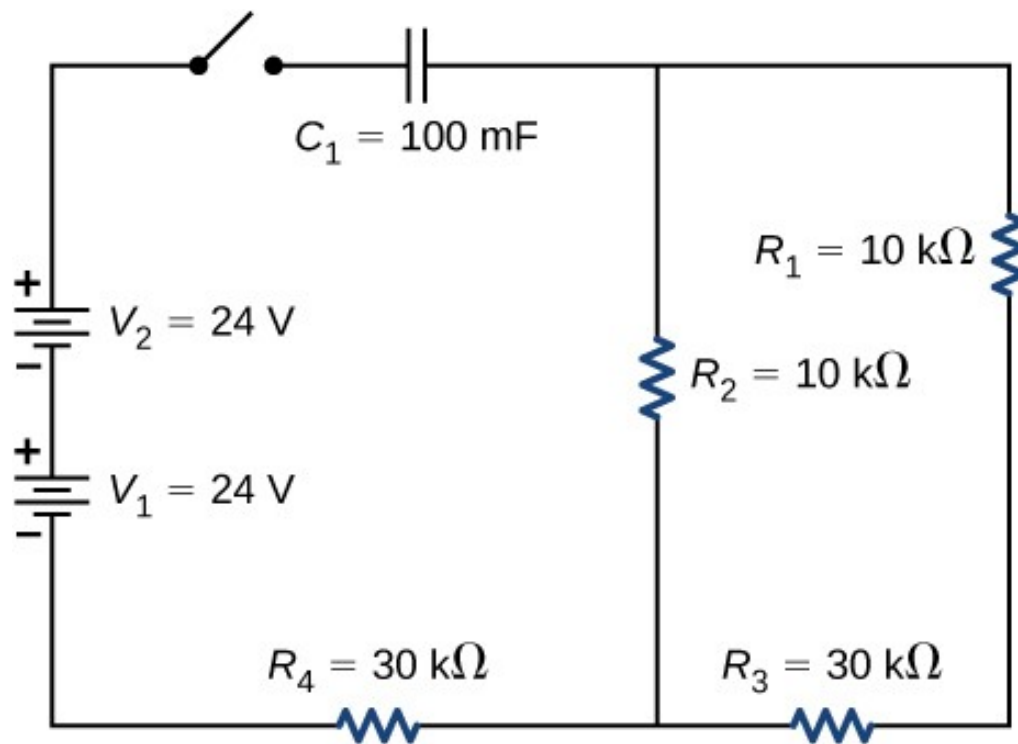
EXERCISE 91



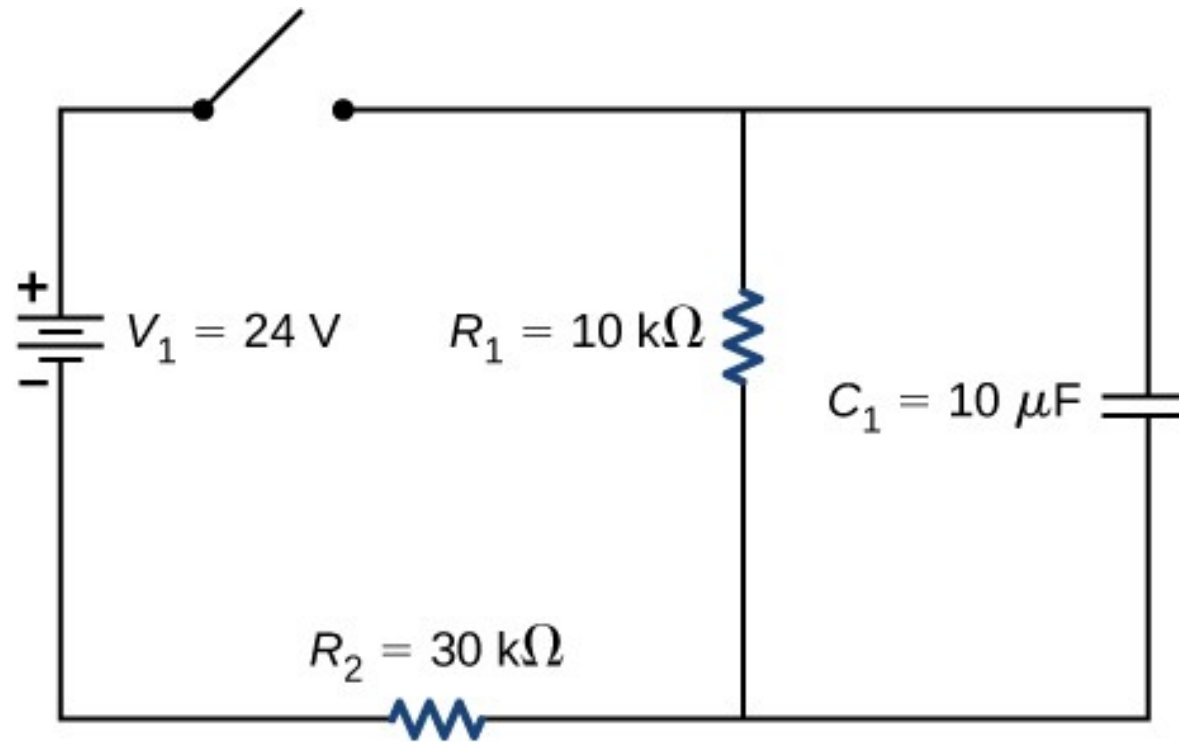
EXERCISE 92



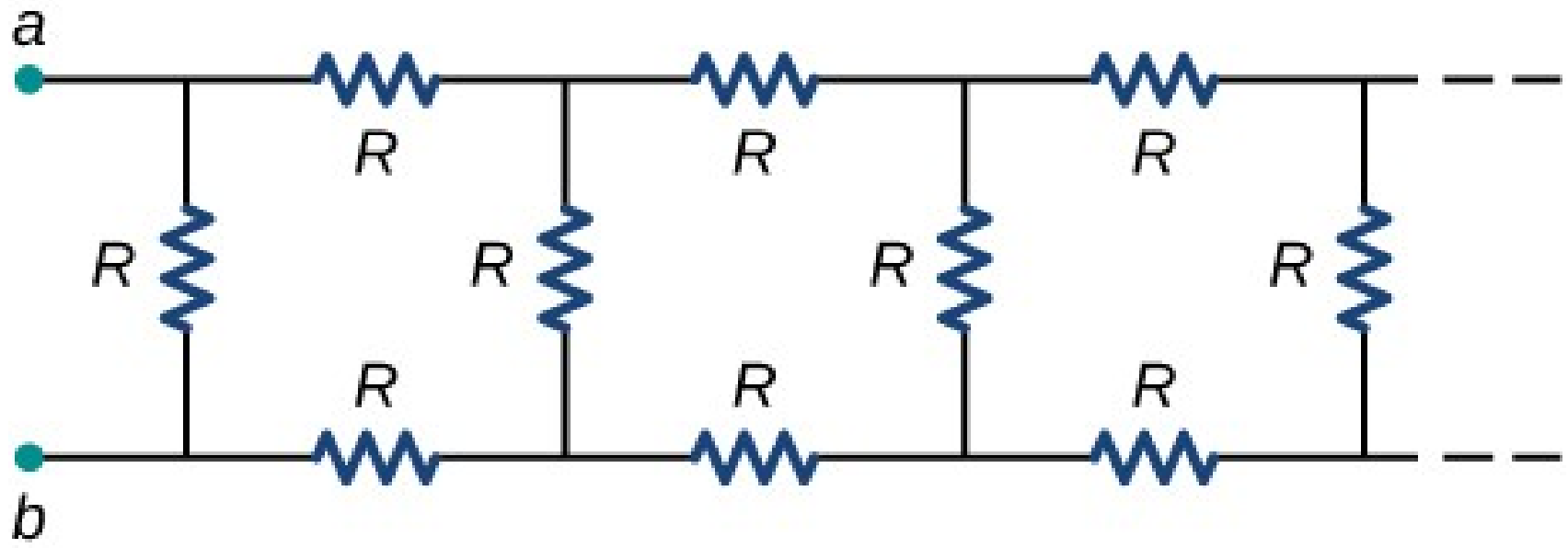
EXERCISE 93



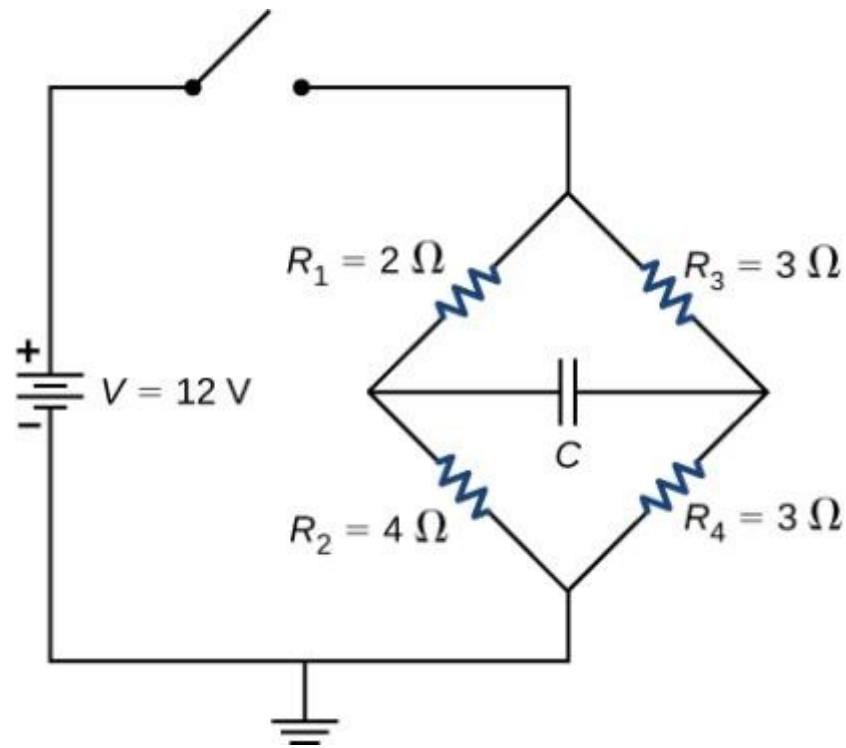
EXERCISE 94



EXERCISE 95



EXERCISE 96





This OpenStax ancillary resource is © Rice University under a CC-BY 4.0 International license; it may be reproduced or modified but must be attributed to OpenStax, Rice University and any changes must be noted.