

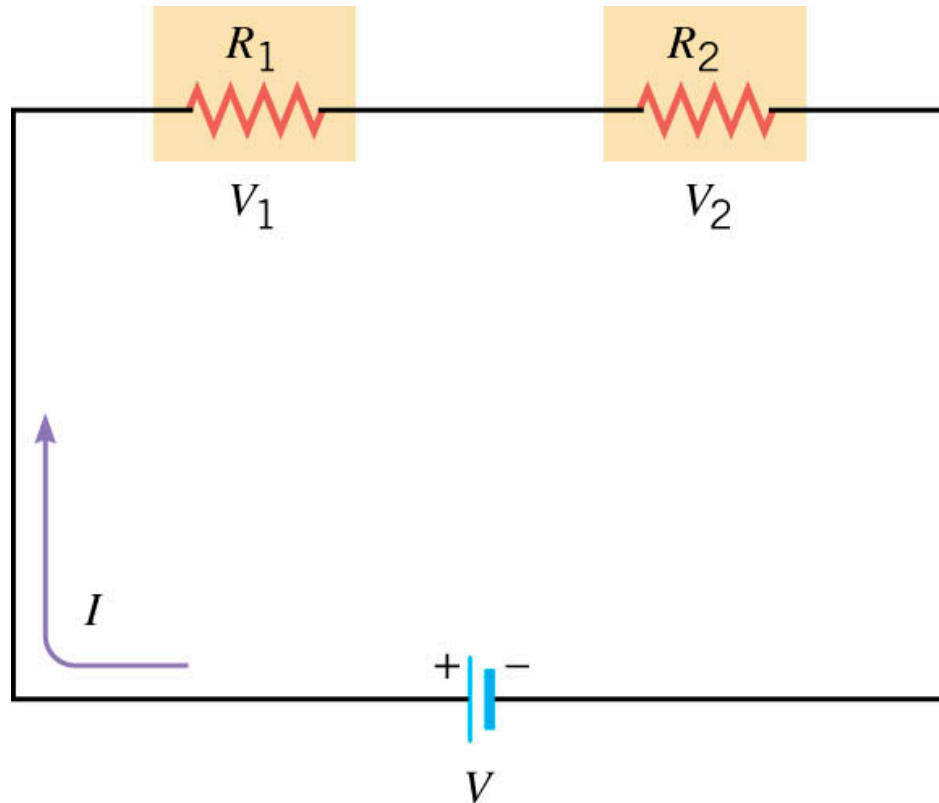
Chapter 19

Electric Circuits

Series Wiring

There are many circuits in which more than one device is connected to a voltage source.

Series wiring means that the devices are connected in such a way that there is the same electric current through each device.

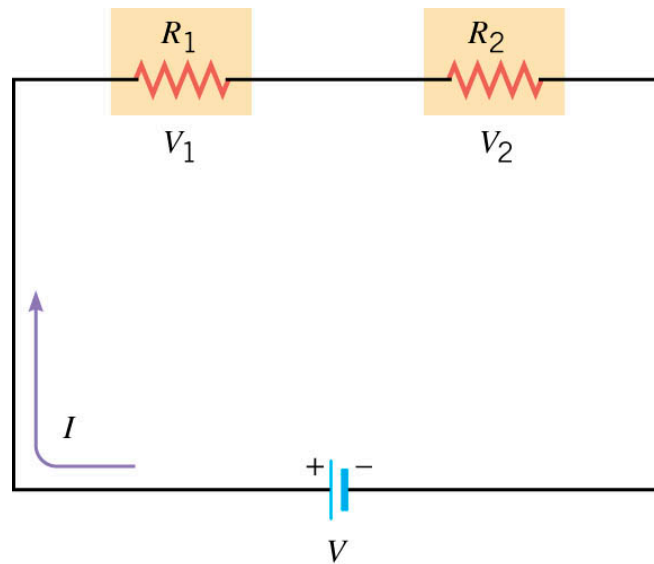


Series Wiring

$$V = V_1 + V_2 = IR_1 + IR_2 = I(R_1 + R_2) = IR_S$$



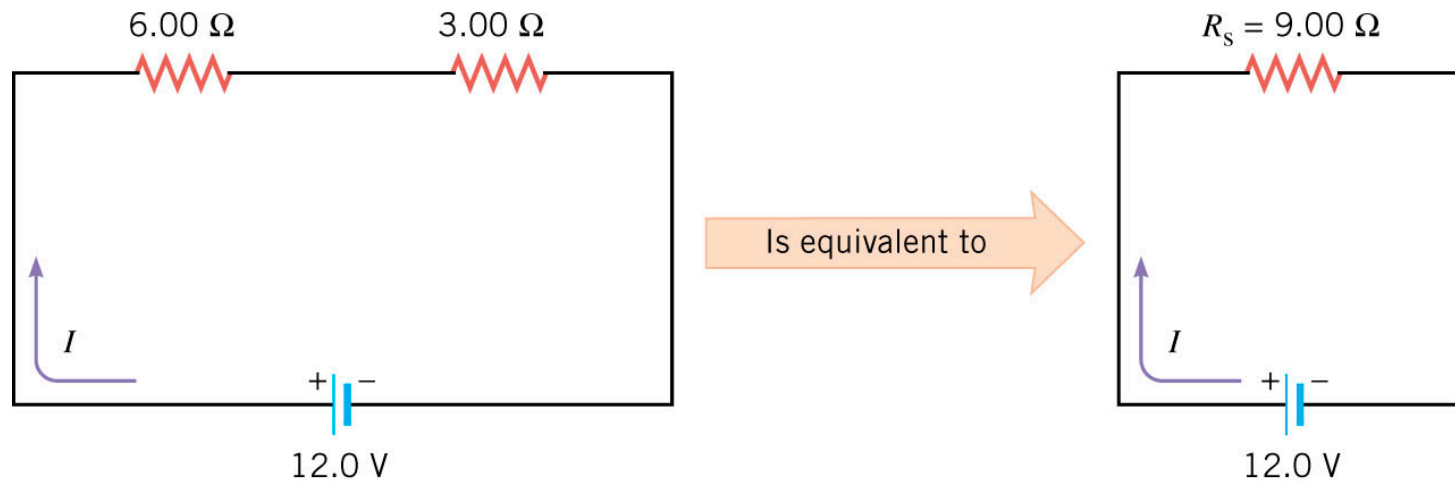
Equivalent series
resistance



Series resistors

$$R_S = R_1 + R_2 + R_3 + \dots$$

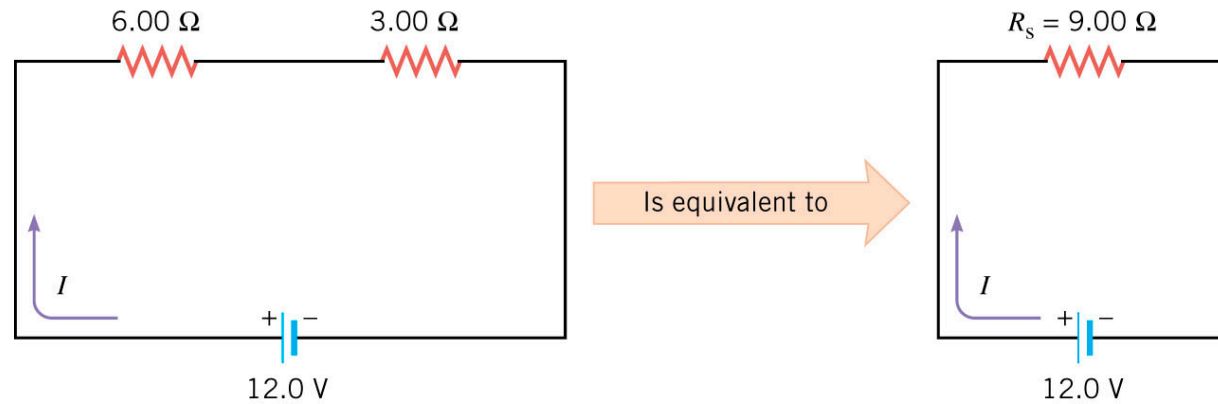
Series Wiring



Example: Resistors in a Series Circuit

A 6.00 Ω resistor and a 3.00 Ω resistor are connected in series with a 12.0 V battery. Assuming the battery contributes no resistance to the circuit, find (a) the current, (b) the power dissipated in each resistor, and (c) the total power delivered to the resistors by the battery.

Series Wiring



(a) $R_s = 6.00 \Omega + 3.00 \Omega = 9.00 \Omega$ $I = \frac{V}{R_s} = \frac{12.0 \text{ V}}{9.00 \Omega} = 1.33 \text{ A}$

(b) For $R = 6.00 \Omega$: $P = I^2 R = (1.33 \text{ A})^2 (6.00 \Omega) = 10.6 \text{ W}$

For $R = 3.00 \Omega$: $P = I^2 R = (1.33 \text{ A})^2 (3.00 \Omega) = 5.31 \text{ W}$

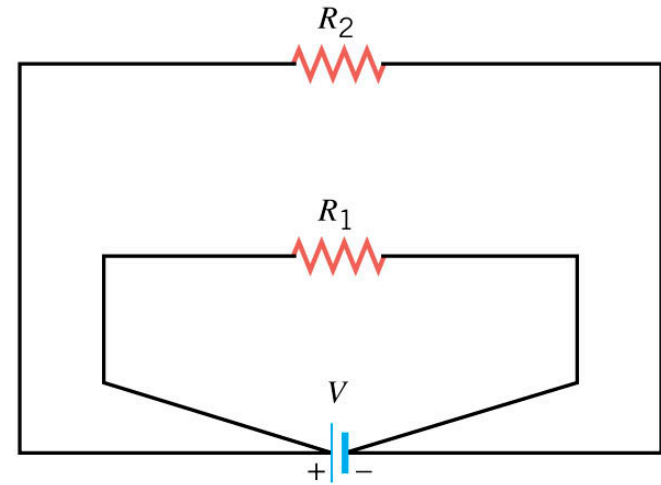
(c) Total power dissipated: $P = 10.6 \text{ W} + 5.31 \text{ W} = 15.9 \text{ W}$

Parallel Wiring

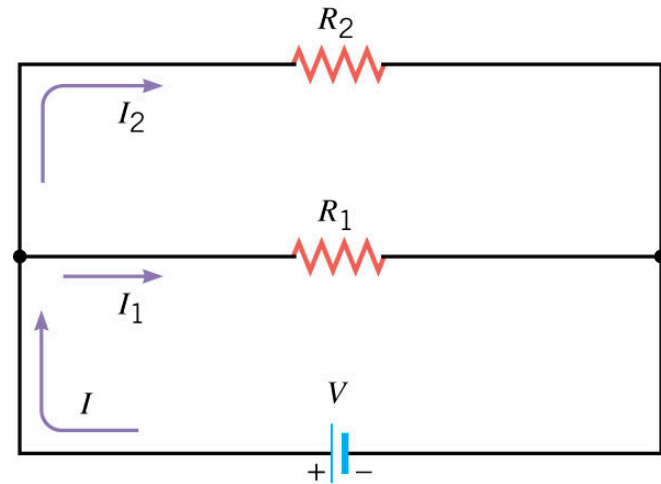
Parallel wiring means that the devices are connected in such a way that the same voltage is applied across each device.

When two resistors are connected in parallel, each receives current from the battery as if the other were not present.

Therefore the two resistors connected in parallel draw more current than does either resistor alone.

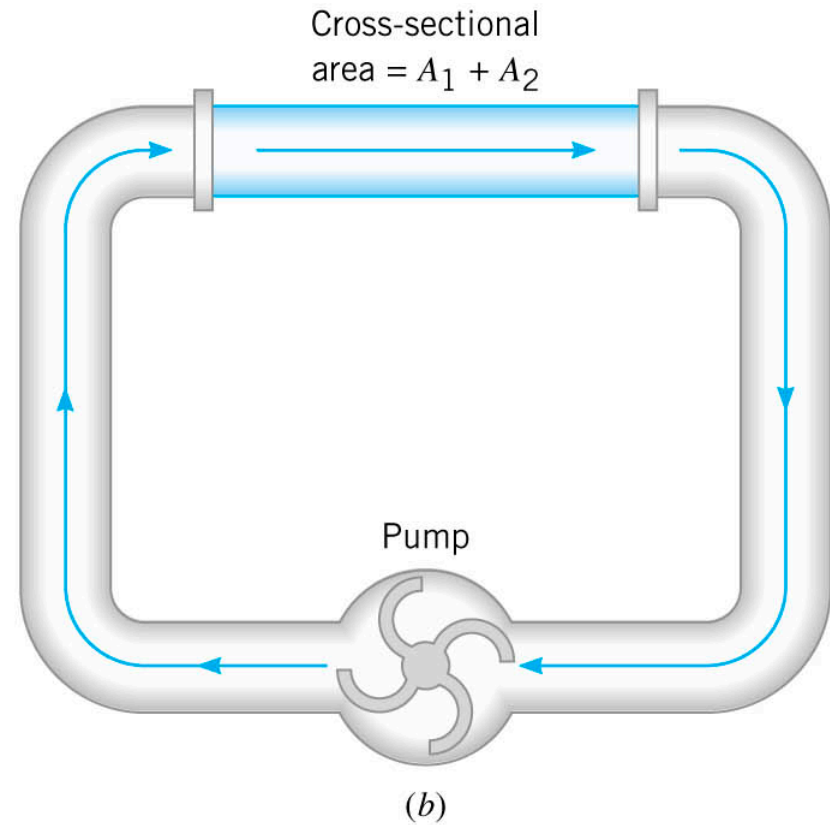
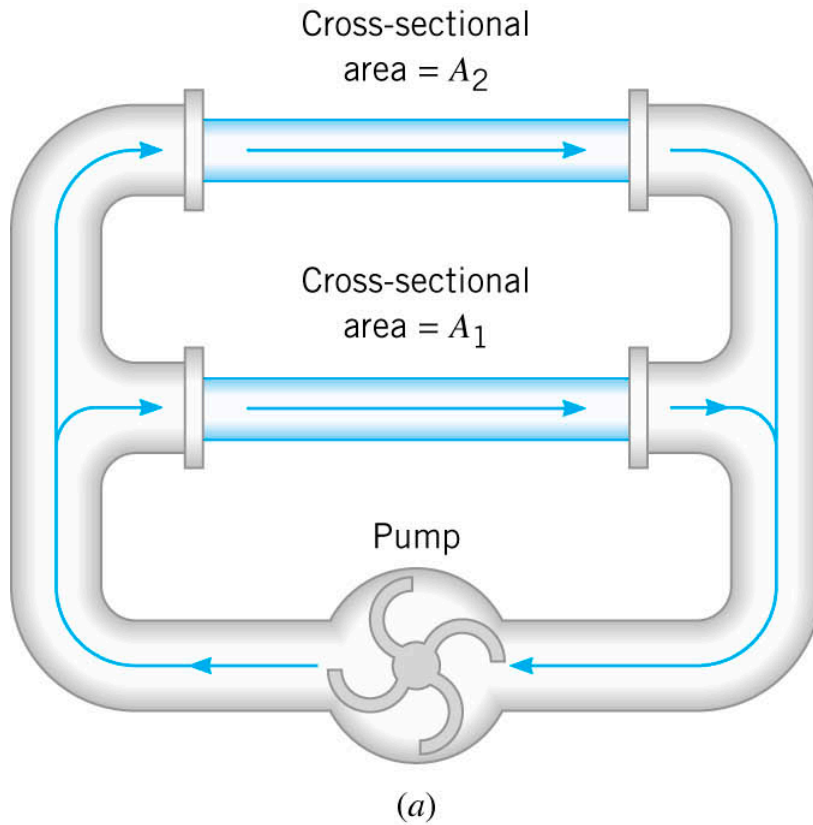


(a)



(b)

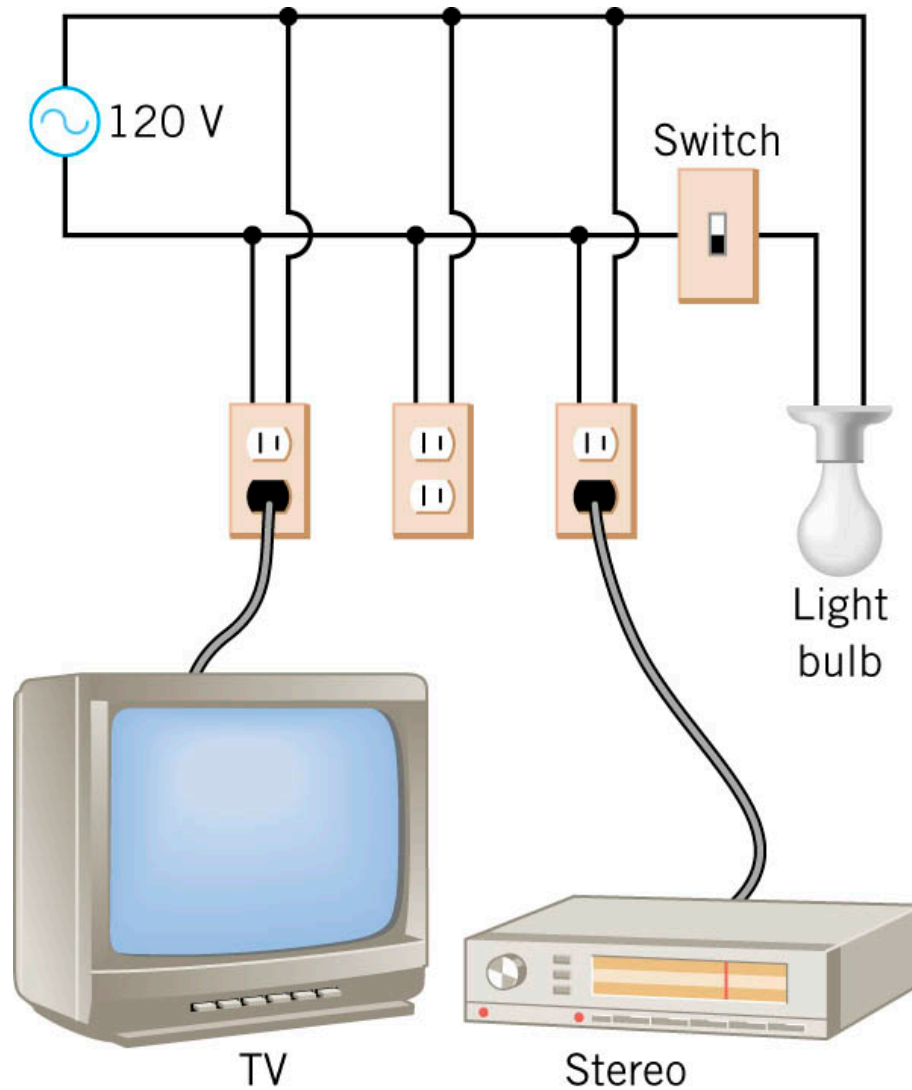
Parallel Wiring



The two parallel pipe sections are equivalent to a single pipe of the same length and same total cross sectional area.

Parallel Wiring

Household outlets are connected in **parallel** instead of series so that each appliance sees the same voltage; also, if one appliance blows out, power is not cut to all appliances.



Parallel Wiring

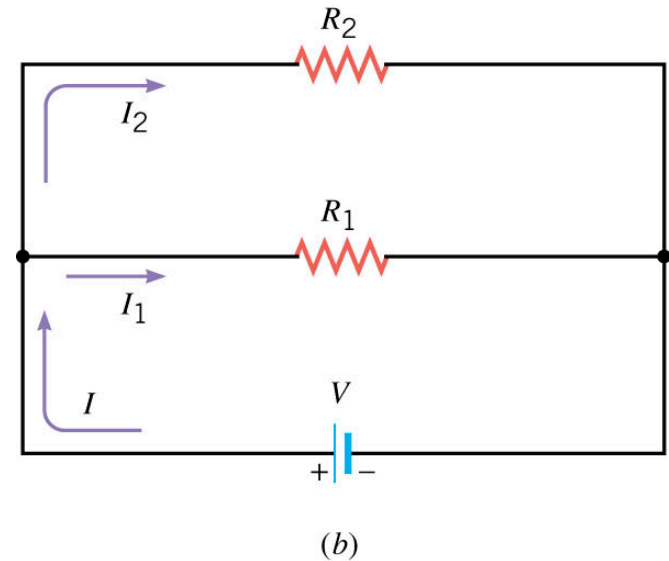
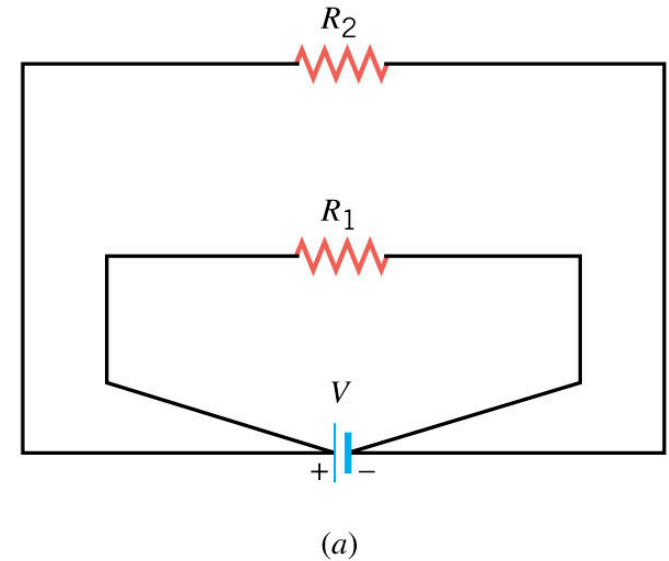
Derivation of the parallel resistor formula:

Since R_1 and R_2 are connected in parallel, they have the same voltage across them, V , so

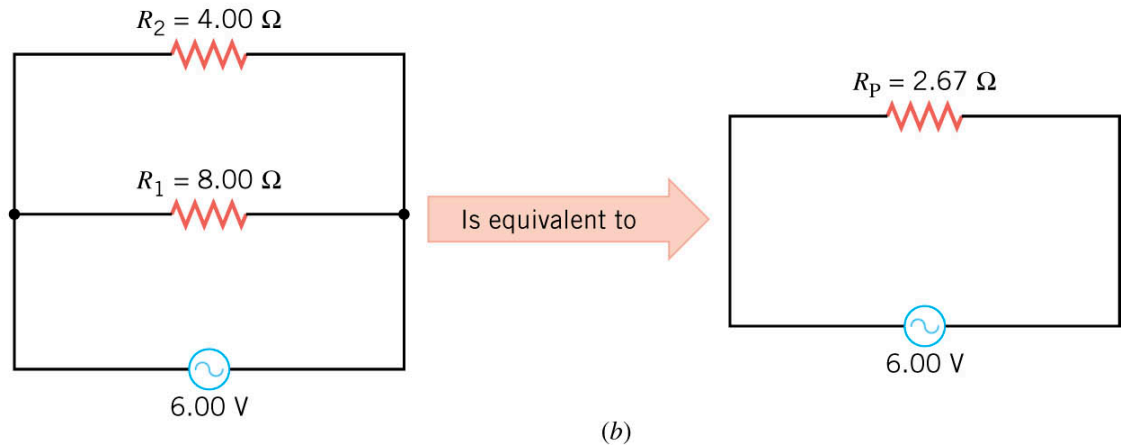
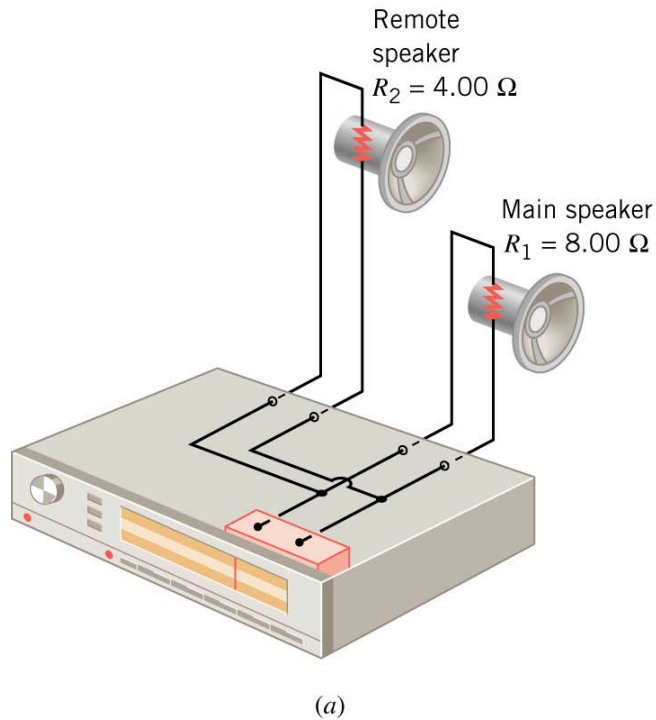
$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = V \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = V \left(\frac{1}{R_P} \right)$$

parallel resistors

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$



Parallel Wiring

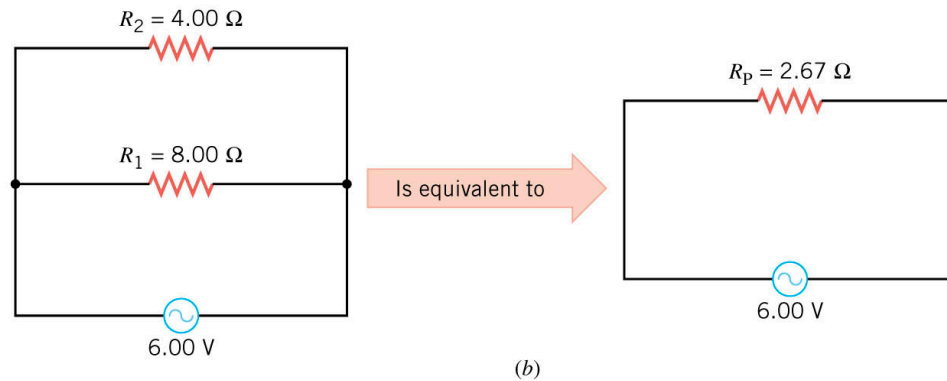
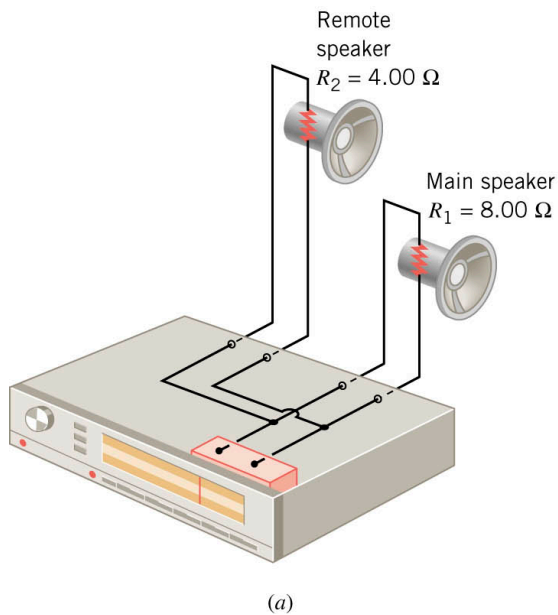


Example: Main and Remote Stereo Speakers

Most receivers allow the user to connect to “remote” speakers in addition to the main speakers. The rms voltage across the speakers is $6.00 \, \text{V}$.

Determine (a) the equivalent resistance of the two speakers, (b) the total current supplied by the receiver, (c) the current in each speaker, and (d) the power dissipated in each speaker.

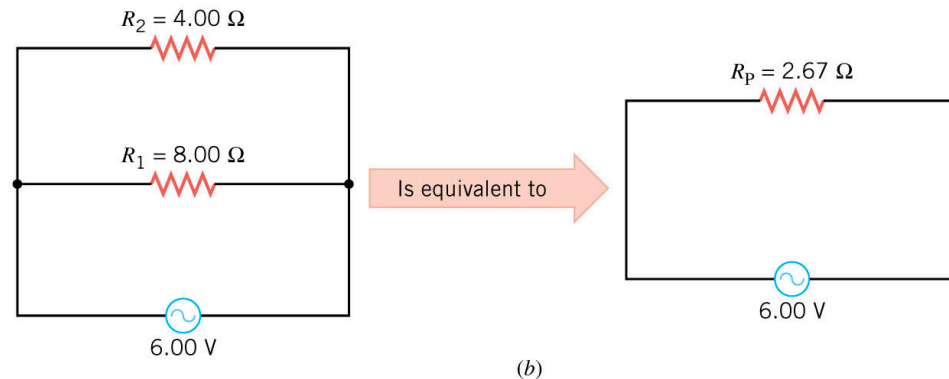
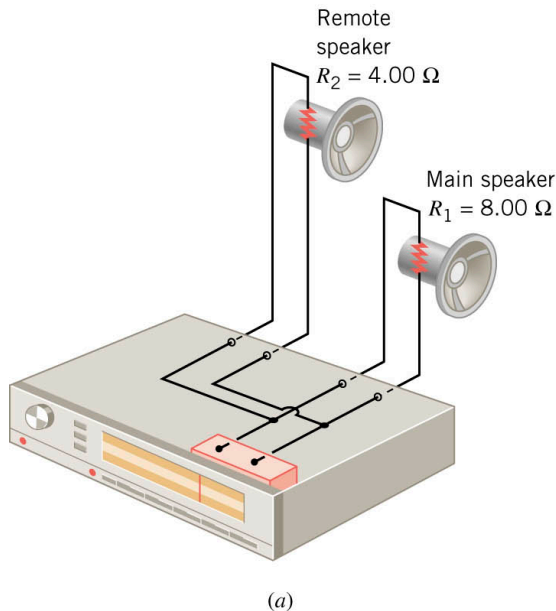
Parallel Wiring



$$(a) \quad \frac{1}{R_p} = \frac{1}{8.00 \, \Omega} + \frac{1}{4.00 \, \Omega} = \frac{3}{8.00 \, \Omega} \quad \Rightarrow \quad R_p = 2.67 \, \Omega$$

$$(b) \quad I_{\text{rms}} = \frac{V_{\text{rms}}}{R_p} = \frac{6.00 \, \text{V}}{2.67 \, \Omega} = 2.25 \, \text{A}$$

Parallel Wiring



(c) R_1 : $I_{\text{rms}} = \frac{V_{\text{rms}}}{R} = \frac{6.00 \, \text{V}}{8.00 \, \Omega} = 0.750 \, \text{A}$

R_2 : $I_{\text{rms}} = \frac{V_{\text{rms}}}{R} = \frac{6.00 \, \text{V}}{4.00 \, \Omega} = 1.50 \, \text{A}$

$I_{\text{tot}} = 0.750 \, \text{A} + 1.50 \, \text{A} = 2.25 \, \text{A}$, as in part (b)

(d) R_1 : $\bar{P} = I_{\text{rms}} V_{\text{rms}} = (0.750 \, \text{A})(6.00 \, \text{V}) = 4.50 \, \text{W}$

R_2 : $\bar{P} = I_{\text{rms}} V_{\text{rms}} = (1.50 \, \text{A})(6.00 \, \text{V}) = 9.00 \, \text{W}$

$\Rightarrow P_{\text{tot}} = 4.50 \, \text{W} + 9.00 \, \text{W} = 13.5 \, \text{W}$

Alternatively,

$P_{\text{tot}} = I_{\text{tot}} V_{\text{rms}} = (2.25)(6.00) = 13.5 \, \text{W}$

Parallel Wiring

Conceptual Example: A Three-Way Light Bulb and Parallel Wiring

Within the bulb there are two separate filaments. When one burns out, the bulb can produce only one level of illumination, but not the highest.

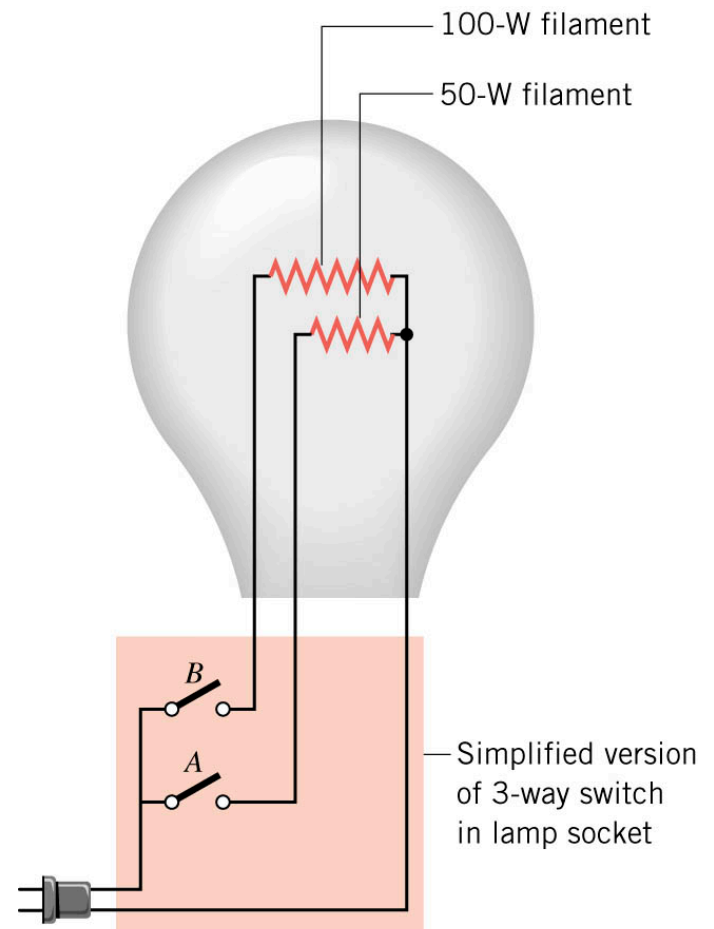
Are the filaments connected in series or parallel?

→ parallel; Find the filament resistances:

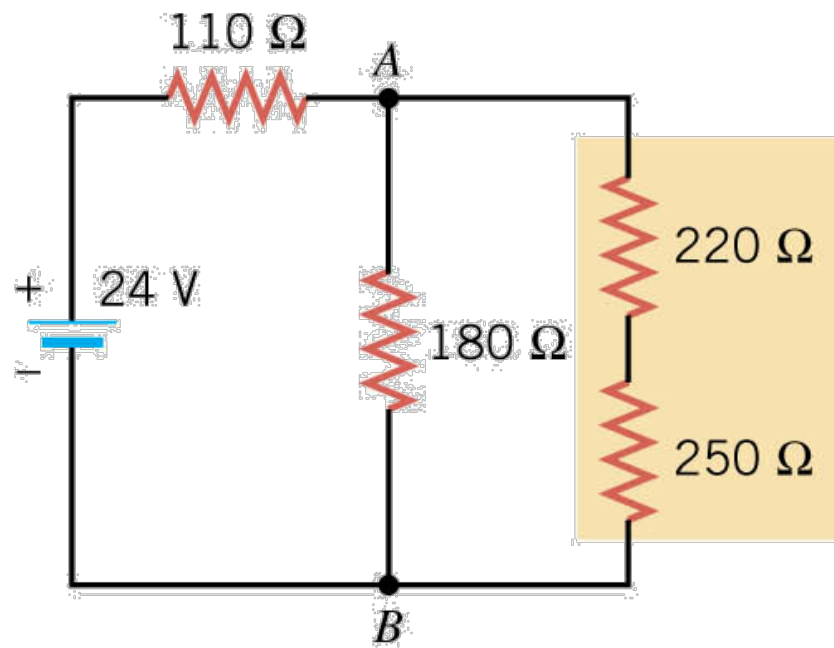
$$\begin{aligned}\text{Since } \bar{P} &= V_{\text{rms}}^2/R \rightarrow R = V_{\text{rms}}^2/\bar{P} \\ R_{100\text{W}} &= (120\text{ V})^2/(100\text{ W}) = 144\ \Omega \\ R_{50\text{W}} &= (120\text{ V})^2/(50\text{ W}) = 288\ \Omega\end{aligned}$$

How can two filaments be used to produce three different illumination levels?

- 1) A on, B off → 50 W output
- 2) A off, B on → 100 W output
- 3) A on, B on → 50 W + 100 W = 150 W output

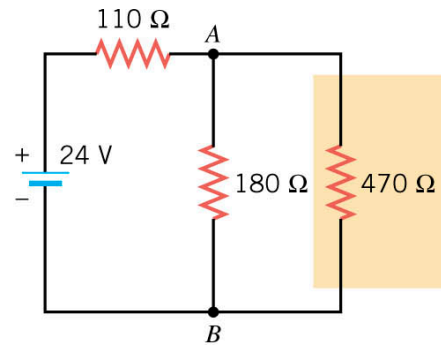
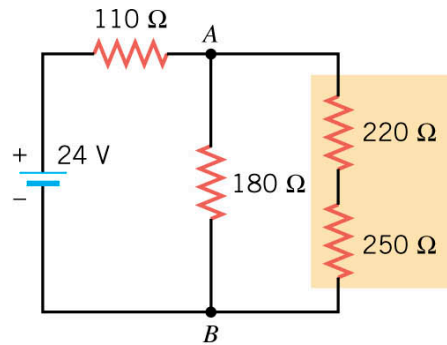


Example. The figure shows a circuit composed of a 24-V battery and four resistors, whose resistances are 110, 180, 220 and 250 Ω . Find (a) the total current supplied by the battery and (b) the voltage between points A and B in the circuit.



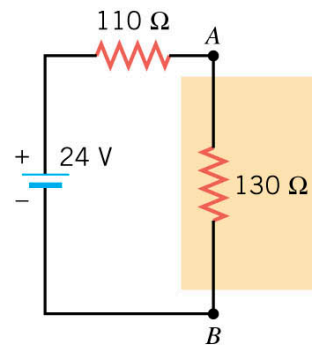
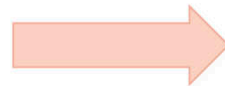
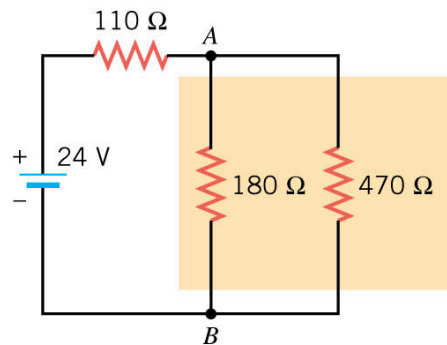
Series $R = R_1 + R_2$ and Parallel $1/R = 1/R_1 + 1/R_2$

Circuits Wired Partially in Series and Partially in Parallel



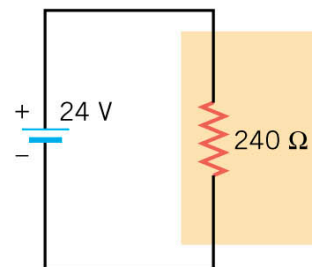
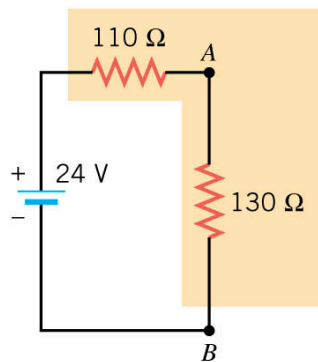
(a)

Series:
 $R = 220\ \Omega + 250\ \Omega$
 $= 470\ \Omega$



(b)

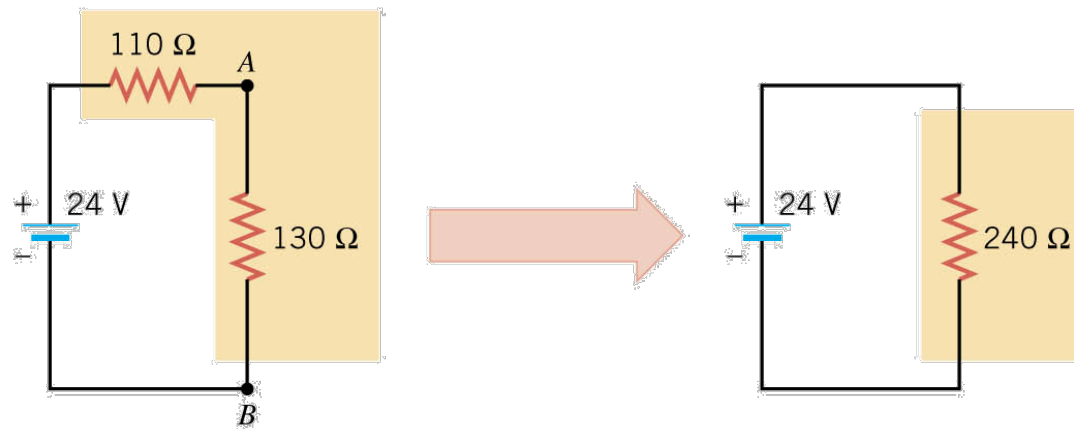
Parallel:
 $1/R = 1/(180\ \Omega) + 1/(470\ \Omega)$
 $R = 130\ \Omega$



(c)

Series:
 $R = 110\ \Omega + 130\ \Omega$
 $= 240\ \Omega$

Example -- continued



(a) Total current supplied by battery:

$I = V/R$, $V = 24 \text{ V}$, $R = 240 \Omega$ (equivalent resistance of the circuit)

$$\Rightarrow I = 24/240 = \mathbf{0.10 \text{ A}}$$

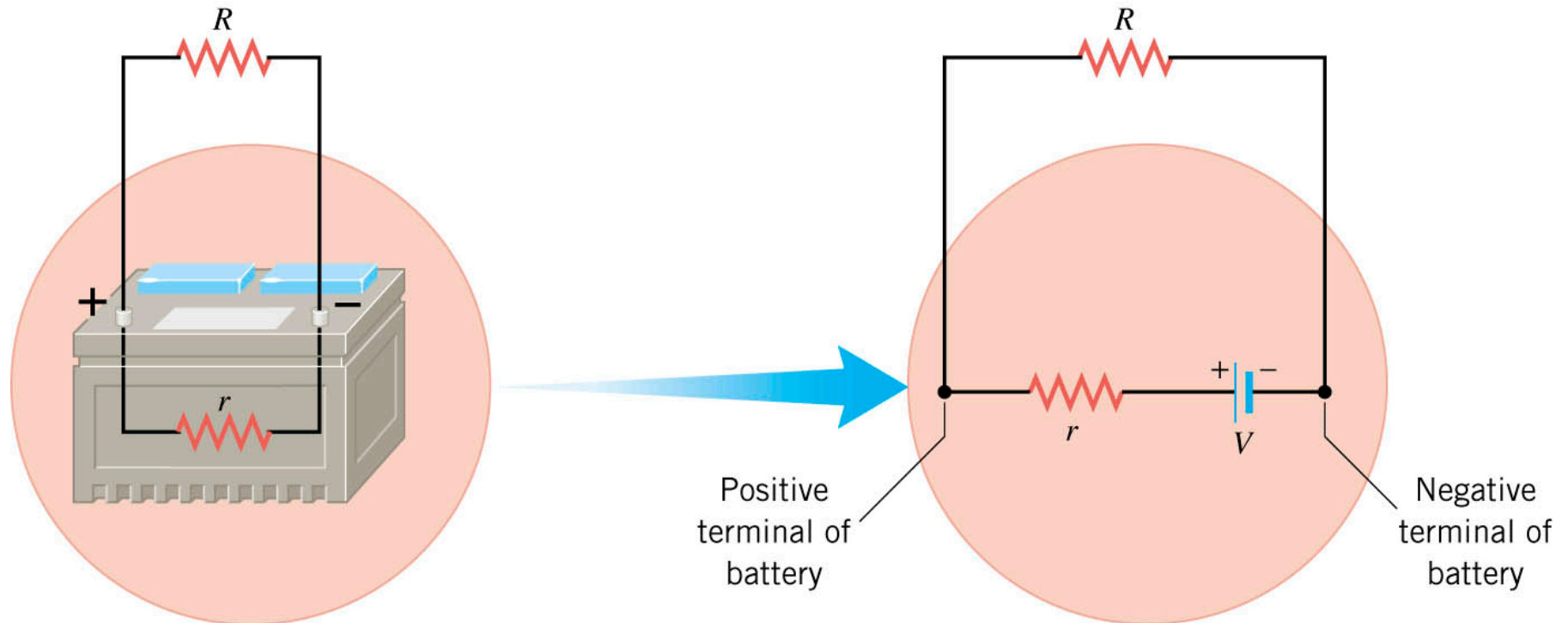
(b) Voltage between points A and B:

$$V_{AB} = IR_{AB} = (0.10)(130) = \mathbf{13 \text{ V}}$$

Internal Resistance

Batteries and generators add some resistance to a circuit. This resistance is called **internal resistance**.

The actual voltage between the terminals of a battery is known as the **terminal voltage**.



Internal Resistance

Example: The Terminal Voltage of a Battery

The car battery has an emf of 12.0 V and an internal resistance of $0.0100\ \Omega$. What is the terminal voltage when the current drawn from the battery is (a) 10.0 A and (b) 100.0 A?

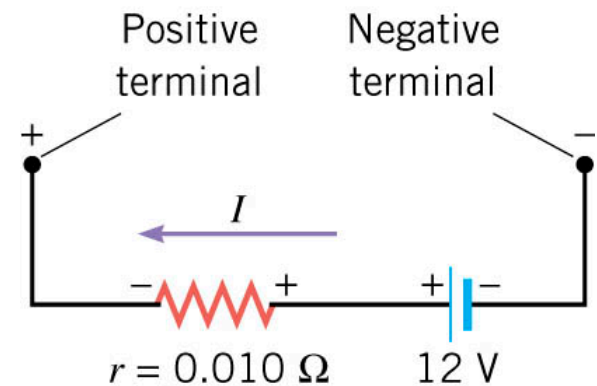
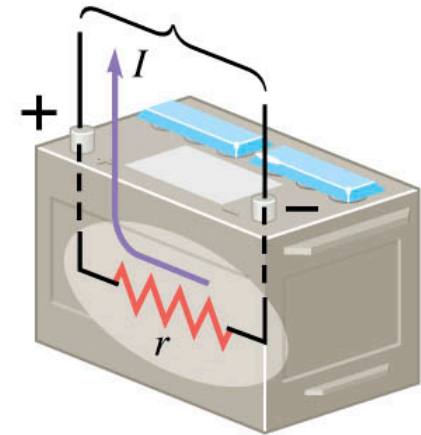
$$(a) \quad V = Ir = (10.0\ \text{A})(0.010\ \Omega) = 0.10\ \text{V}$$

$$12.0\ \text{V} - 0.10\ \text{V} = 11.9\ \text{V}$$

$$(b) \quad V = Ir = (100.0\ \text{A})(0.010\ \Omega) = 1.0\ \text{V}$$

$$12.0\ \text{V} - 1.0\ \text{V} = 11.0\ \text{V}$$

To car's electrical system
(ignition, lights, radio, etc.)



Why do your headlights dim when you start up your car?

Using the numbers in the previous example:

Before turning on the starter switch, $I_1 = 0$ A, $I = I_2 = 10$ A and $V_{AB} = 11.9$ V as in part (a).

After turning on the starter switch, a large current flows through I_1 so $I = 100$ A and $V_{AB} = 11.0$ V as in part (b). **Since the headlights see a reduced V_{AB} , they dim.**

$$(P_{\text{headlights}} = V_{AB}^2 / R_2)$$

