PHYS11 CH:19 The Invisible River of Energy

How Charge Flows Through the World

Mr. Gullo

December 2025

Outline

The Mystery

What if you could control
an invisible river of charge?

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From nerve impulses in your brain to hydroelectric dams sending power across continents...

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From nerve impulses in your brain to hydroelectric dams sending power across continents...

Same laws guide the flow.

The Invisible River

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The Mental Model

Electric current is like water flowing through pipes - voltage is the pressure, resistance is the friction.

Learning Objectives

By the end of this section, you will be able to:

- **19.1:** Describe how current is related to charge and time

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- **19.1:** Define resistance and verbally describe Ohm's law
- **19.1:** Calculate current and solve problems involving Ohm's law

19.1 The Flow of Charge

The Definition

$$\boxed{I = \frac{\Delta Q}{\Delta t}}$$

Current equals charge per unit time. Measured in amperes (A).

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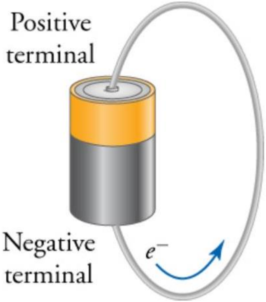
The Mental Model

If 5 coulombs flow past a point in 1 second, the current is 5 A.

19.1 The Direction Paradox



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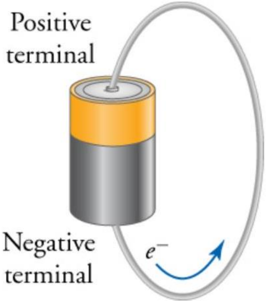

The Paradox

Reality: Electrons flow from negative to positive.
Convention: Current flows from positive to negative.

Direct Current (DC)

- Flows one direction
- Constant over time
- Batteries provide DC

19.1 Direct Current vs Alternating Current

Direct Current (DC)

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Alternating Current (AC)

- Direction alternates
- Smoothly reverses
- Wall sockets provide AC

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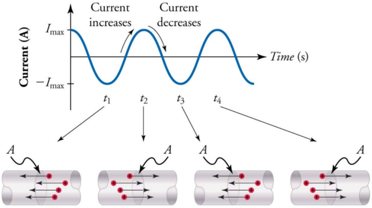

19.1 The Universal Law of Resistance

Ohm's Law

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Units: Resistance measured in ohms (Ω), where $1\Omega = 1$ V/A

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The Mental Model

Resistance is friction for electrons - it converts electrical energy to heat.

Attempt: Lightning Strike Current

The Challenge (3 min, silent)

A lightning strike transfers 10^{20} electrons from cloud to ground in 2 ms.

Given:

- $n = 10^{20}$ electrons
- $e = -1.60 \times 10^{-19}$ C
- $\Delta t = 2 \times 10^{-3}$ s

Find: Average current I

Can you calculate the current in a lightning bolt? Work silently.

Compare: Lightning Strike

Turn and talk (2 min):

1. How did you find the total charge?
2. What formula did you use for current?
3. What sign did you get for your answer?

Compare: Lightning Strike

Turn and talk (2 min):

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Name wheel: One pair share your approach (not your answer).

Reveal: The Power of Lightning

Self-correct in a different color:

Step 1: Total charge: $\Delta Q = ne = (10^{20})(-1.60 \times 10^{-19}\ \text{C}) = -16.0\ \text{C}$

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$$I = \frac{-16.0\ \text{C}}{2 \times 10^{-3}\ \text{s}} = \boxed{-8\ \text{kA}}$$

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Check: Negative sign means electrons flow down. Conventional current flows up!

Attempt: Headlight Resistance

The Challenge (3 min, silent)

An automobile headlight has 2.50 A flowing through it when 12.0 V is applied.

Given:

- $I = 2.50$ A
- $V = 12.0$ V

Find: Resistance R of the headlight

Can you find the resistance using Ohm's law?

Compare: Resistance

Turn and talk (2 min):

1. What equation did you start with?
2. How did you solve for R?
3. What units did you get?

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Start with Ohm's law: $V = IR$

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Substitute: $R = \frac{12.0\ \text{V}}{2.50\ \text{A}}$

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Start with Ohm's law: $V = IR$

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$$\boxed{R = 4.8\Omega}$$

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Substitute: $R = \frac{12.0\text{ V}}{2.50\text{ A}}$

$$\boxed{R = 4.8\Omega}$$

Check: 4.8 ohms - relatively small resistance for a headlight.

Learning Objectives

By the end of this section, you will be able to:

- **19.2:** Interpret circuit diagrams and diagram basic circuit elements

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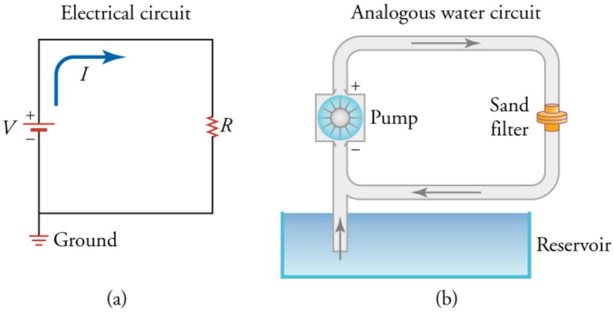
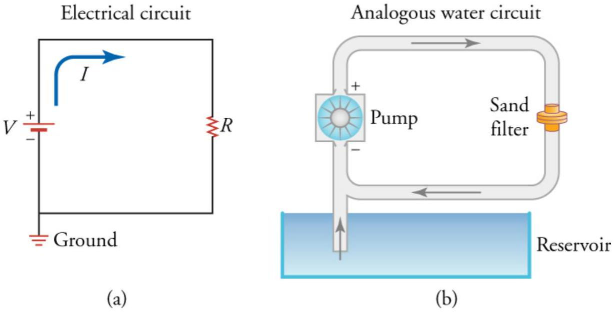
- **19.2:** Interpret circuit diagrams and diagram basic circuit elements
- **19.2:** Calculate equivalent resistance of resistors in series

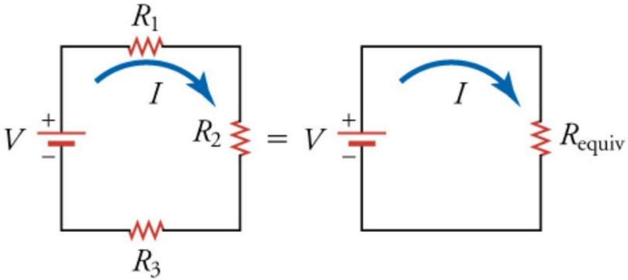

Electrical circuit
I
V
+
−
R
Ground
(a)
Analogous water circuit
+
Pump
−
Sand
filter
Reservoir
(b)



Circuit symbols:

- Battery: long line = positive, short line = negative
- Resistor: zigzag element
- Wire: perfect conductor (no resistance)
- Ground: reference point (voltage = 0)

19.2 Resistors in Series



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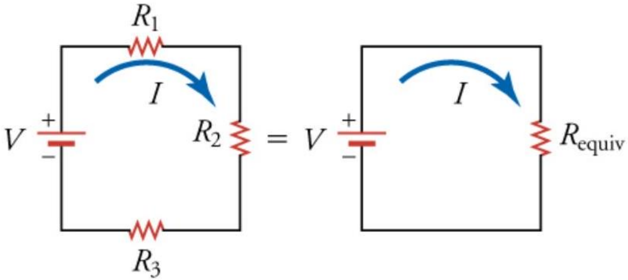

The Rule for Series

$$\boxed{R_{\text{equiv}} = R_1 + R_2 + R_3}$$

Series resistances add. One path, obstacles accumulate.

Key insight: Going around a complete loop, voltage changes sum to zero.

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The Mental Model

Like hiking in hills - total elevation gained equals total elevation lost when you return to start.

19.2 The Voltage Loop

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For series circuit: $V_{\text{battery}} = V_1 + V_2 + V_3$

19.2 The Voltage Loop

Key insight: Going around a complete loop, voltage changes sum to zero.

The Mental Model

Like hiking in hills - total elevation gained equals total elevation lost when you return to start.

For series circuit: $V_{\text{battery}} = V_1 + V_2 + V_3$

Using Ohm's law: $V = I(R_1 + R_2 + R_3)$

Attempt: Series Circuit

The Challenge (3 min, silent)

Three resistors in series: $R_1 = 1.0\Omega$, $R_2 = 6.0\Omega$, $R_3 = 13\Omega$. Battery voltage is 12 V.

Given:

- $R_1 = 1.0\Omega$, $R_2 = 6.0\Omega$, $R_3 = 13\Omega$
- $V = 12$ V

Find: (a) Equivalent resistance, (b) Current through circuit

Can you reduce the circuit to a single resistance?

Turn and talk (2 min):

1. How did you find equivalent resistance?
2. What equation did you use for current?
3. Did you get the same values?

Compare: Series Resistance

Turn and talk (2 min):

1. How did you find equivalent resistance?
2. What equation did you use for current?
3. Did you get the same values?

Name wheel: One pair share your approach.

Reveal: Series Solution

Self-correct in a different color:

Part (a): $R_{\text{equiv}} = R_1 + R_2 + R_3$

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Part (b): $I = \frac{V}{R_{\text{equiv}}}$

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Part (b): $I = \frac{V}{R_{\text{equiv}}}$

$$I = \frac{12\ \text{V}}{20\Omega} = \boxed{0.60\ \text{A}}$$

Reveal: Series Solution

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Part (a): $R_{\text{equiv}} = R_1 + R_2 + R_3$

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Part (b): $I = \frac{V}{R_{\text{equiv}}}$

$$I = \frac{12\text{ V}}{20\Omega} = \boxed{0.60\text{ A}}$$

Check: Voltage drops: $V_1 = 0.6$ V, $V_2 = 3.6$ V, $V_3 = 7.8$ V. Sum $= 12$ V!

By the end of this section, you will be able to:

- **19.3:** Interpret circuit diagrams with parallel resistors

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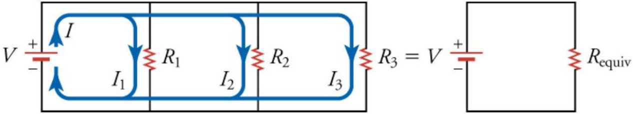
- **19.3:** Interpret circuit diagrams with parallel resistors
- **19.3:** Calculate equivalent resistance of resistor combinations

19.3 Resistors in Parallel



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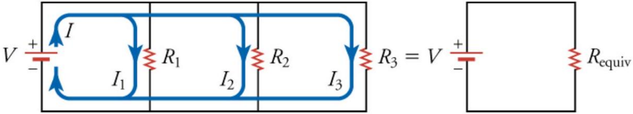

The Rule for Parallel

$$\boxed{R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}}$$

Parallel resistance is reciprocal of sum of reciprocals.

19.3 The Parallel Paradox

What Your Brain Gets Wrong

Intuition: More resistors means more resistance.

Reality: Parallel resistors provide MORE paths, so LESS resistance!

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What Your Brain Gets Wrong

Intuition: More resistors means more resistance.

Reality: Parallel resistors provide MORE paths, so LESS resistance!

Key insight: R_{equiv} is always LESS than smallest resistor in parallel.

The Mental Model

Three identical resistors R in parallel: $R_{\text{equiv}} = R/3$

19.3 Current Conservation

Key principle: Current entering a junction equals current leaving.

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For parallel resistors: $I = I_1 + I_2 + I_3$

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For parallel resistors: $I = I_1 + I_2 + I_3$

The Mental Model

Like a river splitting into three channels - total water flow is conserved.

Using Ohm's law on each: $I = V(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3})$

Attempt: Parallel Circuit

The Challenge (3 min, silent)

Three resistors in parallel: $R_1 = 10\Omega$, $R_2 = 25\Omega$, $R_3 = 15\Omega$. Battery voltage is 3 V.

Given:

- $R_1 = 10\Omega$, $R_2 = 25\Omega$, $R_3 = 15\Omega$
- $V = 3$ V

Find: (a) Equivalent resistance, (b) Total current

Can you use the reciprocal formula?

Compare: Parallel Resistance

Turn and talk (2 min):

1. How did you handle the reciprocals?
2. What calculator steps did you use?
3. Is your answer less than 10 ohms?

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Reveal: Parallel Solution

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Part (a): $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$

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Reveal: Parallel Solution

Self-correct in a different color:

Part (a): $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$

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Part (b): $I = \frac{V}{R_{\text{equiv}}} = \frac{3\text{ V}}{4.84\Omega} = \boxed{0.62\text{ A}}$

Reveal: Parallel Solution

Self-correct in a different color:

Part (a): $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$

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Part (b): $I = \frac{V}{R_{\text{equiv}}} = \frac{3\text{ V}}{4.84\Omega} = \boxed{0.62\text{ A}}$
Check: 4.84 ¡ 10 (smallest resistor). Current splits: $I_1 = 0.30$ A, $I_2 = 0.12$ A, $I_3 = 0.20$ A!

Learning Objectives

By the end of this section, you will be able to:

- **19.4:** Define electric power and describe the power equation

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- **19.4:** Define electric power and describe the power equation
- **19.4:** Calculate power in circuits

The Power Law

$$\boxed{P = IV}$$

Power equals current times voltage. Energy per unit time.

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Units: Watts (W), where 1 W = 1 J/s

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The Mental Model

A 60-W bulb transfers 60 joules per second from electrical energy to light and heat.

Using Ohm's law $V = IR$, we can derive alternate forms:

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$$P = IV \tag{1}$$

$$P = I^2R \quad (\text{using } V = IR) \tag{2}$$

$$P = \frac{V^2}{R} \quad (\text{using } I = \frac{V}{R}) \tag{3}$$

19.4 Three Forms of Power

Using Ohm's law $V = IR$, we can derive alternate forms:

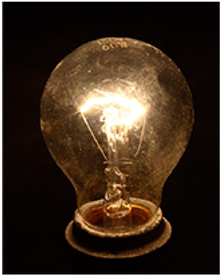
$$P = IV \tag{1}$$

$$P = I^2 R \quad (\text{using } V = IR) \tag{2}$$

$$P = \frac{V^2}{R} \quad (\text{using } I = \frac{V}{R}) \tag{3}$$

Choose the form that matches your known quantities.

19.4 The 25-W vs 60-W Mystery



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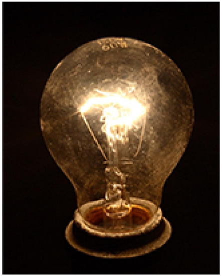
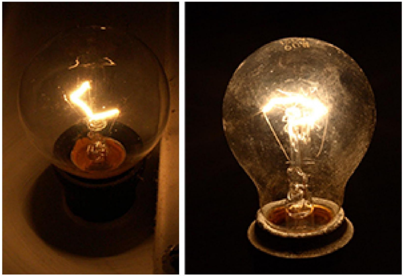


Question: Both run on 120 V. Why different brightness?



Question: Both run on 120 V. Why different brightness?

The Revelation

They have DIFFERENT resistances! Using $P = \frac{V^2}{R}$, higher power means LOWER resistance.

Attempt: Lightbulb Current

The Challenge (3 min, silent)

A 60-W incandescent bulb operates on 120 V.

Given:

- $P = 60$ W
- $V = 120$ V

Find: Current through the bulb

Which power formula should you use?

Compare: Power Formula

Turn and talk (2 min):

1. Which power formula did you use?
2. How did you solve for current?
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Reveal: Lightbulb Current

Self-correct in a different color:

Start with: $P = IV$

Reveal: Lightbulb Current

Self-correct in a different color:

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Solve for I: $I = \frac{P}{V}$

Reveal: Lightbulb Current

Self-correct in a different color:

Start with: $P = IV$

Solve for I: $I = \frac{P}{V}$

Substitute: $I = \frac{60\text{ W}}{120\text{ V}}$

Reveal: Lightbulb Current

Self-correct in a different color:

Start with: $P = IV$

Solve for I: $I = \frac{P}{V}$

Substitute: $I = \frac{60 \text{ W}}{120 \text{ V}}$

$$\boxed{I = 0.50 \text{ A}}$$

Reveal: Lightbulb Current

Self-correct in a different color:

Start with: $P = IV$

Solve for I: $I = \frac{P}{V}$

Substitute: $I = \frac{60\ \text{W}}{120\ \text{V}}$

$$\boxed{I = 0.50\ \text{A}}$$

Check: Half an ampere - significant current for a light bulb!

What You Now Know

The Revelations

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3. Series resistances add: $R_{\text{equiv}} = R_1 + R_2 + \cdots$
4. Parallel uses reciprocals: $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots}$

What You Now Know

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4. Parallel uses reciprocals: $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots}$
5. Power = energy transfer rate: $P = IV = I^2 R = \frac{V^2}{R}$

Key Equations

$$I = \frac{\Delta Q}{\Delta t} \quad \text{(current)} \tag{4}$$

$$V = IR \quad \text{(Ohm's law)} \tag{5}$$

$$R_{\text{series}} = R_1 + R_2 + \cdots + R_N \tag{6}$$

$$R_{\text{parallel}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}} \tag{7}$$

$$P = IV \tag{8}$$

$$P = I^2 R \tag{9}$$

$$P = \frac{V^2}{R} \tag{10}$$

Homework

Complete the assigned problems

posted on the LMS