

# PHYS11 CH:19 The Invisible River of Energy

## How Charge Flows Through the World

Mr. Gullo

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# Outline

- 1 Introduction
- 2 19.1 Ohm's Law
- 3 19.2 Series Circuits
- 4 19.3 Parallel Circuits
- 5 19.4 Electric Power
- 6 Summary

## The Mystery

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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

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- **19.1:** Calculate current and solve problems involving Ohm's law

## 19.1 The Flow of Charge

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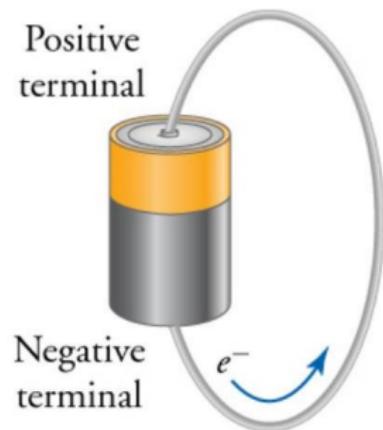
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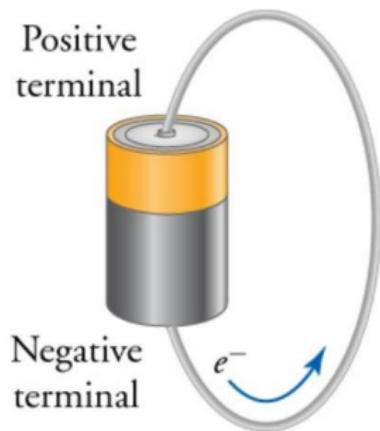
### The Mental Model

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.

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- Wall sockets provide AC

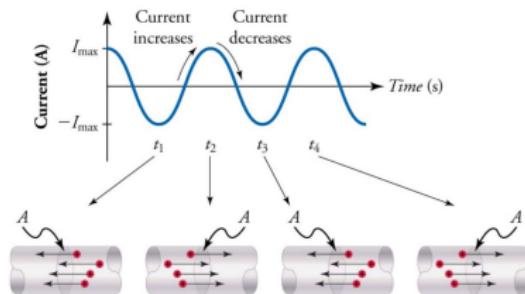
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# 19.1 The Universal Law of Resistance

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

### 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?
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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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**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:**

- $I = 2.50 \text{ A}$
- $V = 12.0 \text{ V}$

**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?
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$$R = 4.8\Omega$$

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

# Learning Objectives

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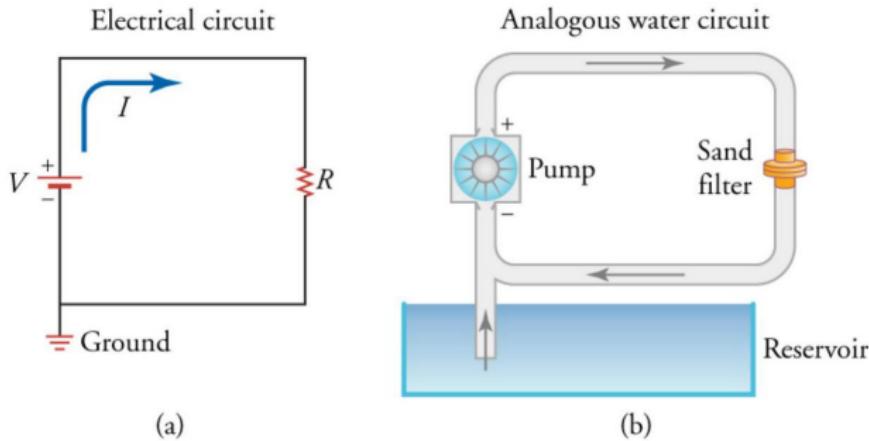
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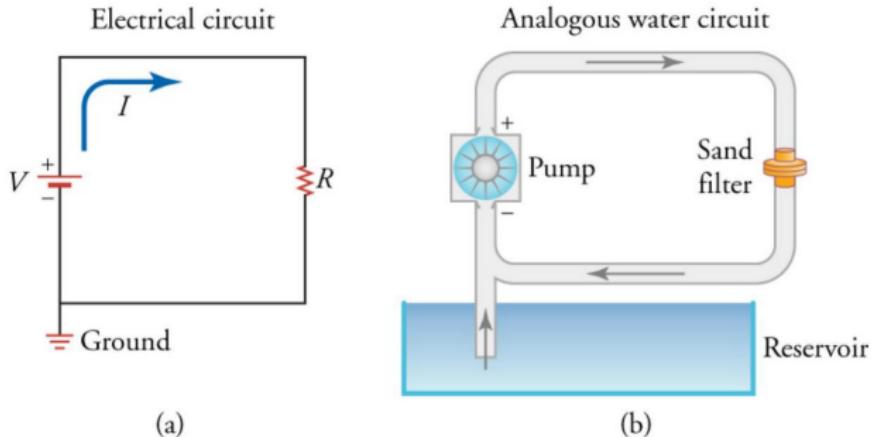
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- **19.2:** Calculate equivalent resistance of resistors in series

## 19.2 The Language of Circuits



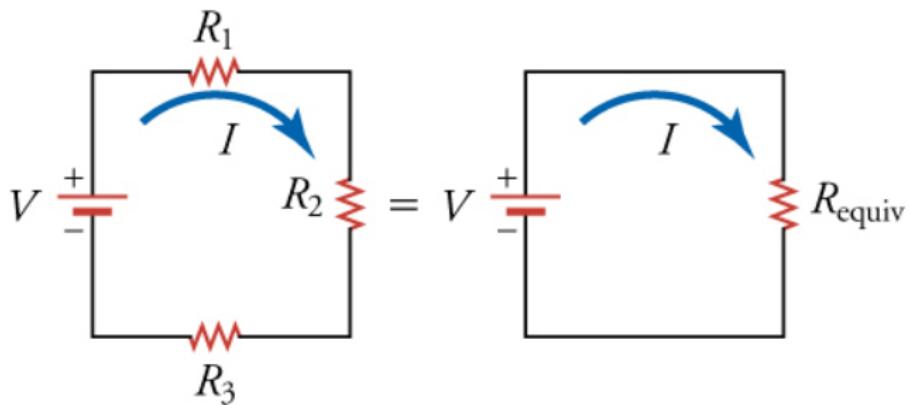
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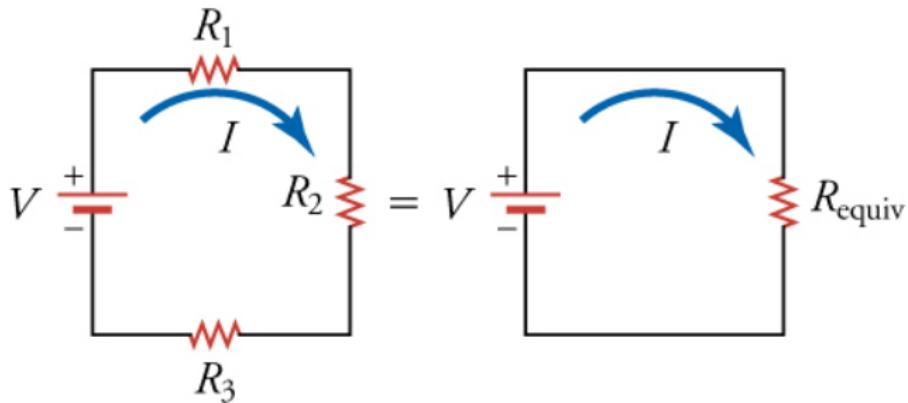
### Circuit symbols:

- 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

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

Series resistances add. One path, obstacles accumulate.

## 19.2 The Voltage Loop

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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:

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

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

*Can you reduce the circuit to a single resistance?*

## Compare: Series Resistance

## Turn and talk (2 min):

- ① How did you find equivalent resistance?
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$$I = \frac{12 \text{ V}}{20\Omega} = \boxed{0.60 \text{ A}}$$

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**Check:** Voltage drops:  $V_1 = 0.6 \text{ V}$ ,  $V_2 = 3.6 \text{ V}$ ,  $V_3 = 7.8 \text{ V}$ . Sum = 12 V!

# Learning Objectives

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

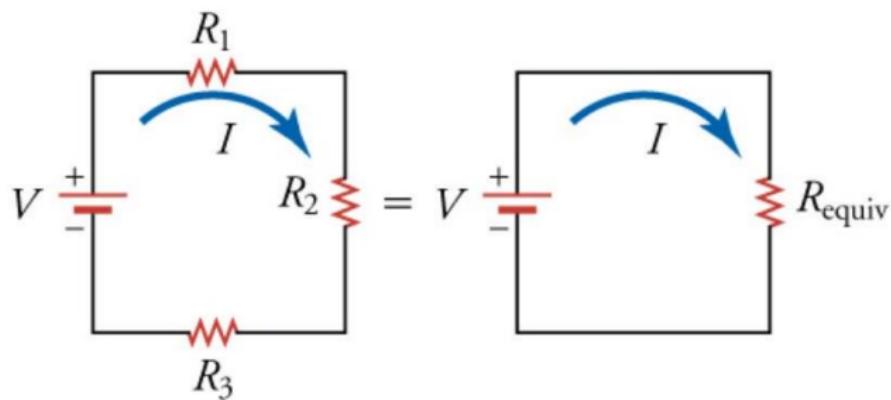
- **19.3:** Interpret circuit diagrams with parallel resistors

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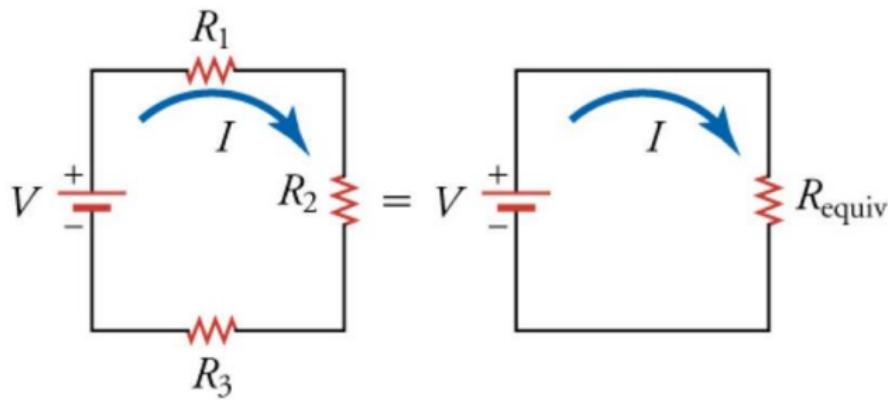
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- **19.3:** Interpret circuit diagrams with parallel resistors
- **19.3:** Calculate equivalent resistance of resistor combinations

## 19.3 Resistors in Parallel



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### The Rule for Parallel

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

Parallel resistance is reciprocal of sum of reciprocals.

### 19.3 The Parallel Paradox

## What Your Brain Gets Wrong

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**Key insight:**  $R_{\text{equiv}}$  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

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### The Mental Model

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

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

# 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:**

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

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

*Can you use the reciprocal formula?*

# Compare: Parallel Resistance

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

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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  $\downarrow$  10 (smallest resistor). Current splits:  $I_1 = 0.30 \text{ A}$ ,  $I_2 = 0.12 \text{ A}$ ,  $I_3 = 0.20 \text{ A}$ !

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  - **19.4:** Calculate power in circuits

## 19.4 The Energy Transfer Rate

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The Mental Model

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

## 19.4 Three Forms of Power

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

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

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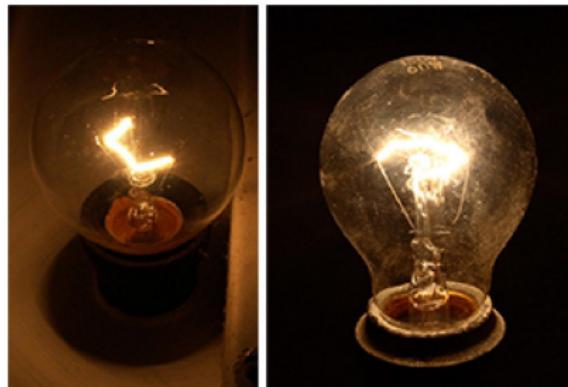
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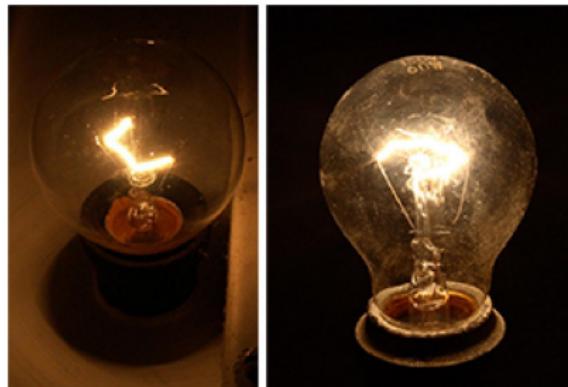
$$P = \frac{V^2}{R} \quad (\text{using } I = \frac{V}{R}) \tag{3}$$

**Choose the form that matches your known quantities.**

## 19.4 The 25-W vs 60-W Mystery

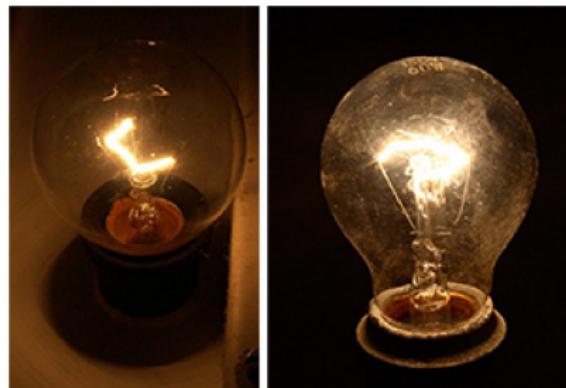


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### The Revelation

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:

- $P = 60 \text{ W}$
- $V = 120 \text{ V}$

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

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

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

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

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- ④ Parallel uses reciprocals:  $R_{\text{equiv}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots}$

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

# Key Equations

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

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

$$R_{\text{series}} = R_1 + R_2 + \dots + R_N \quad (6)$$

$$R_{\text{parallel}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_N}} \quad (7)$$

$$P = IV \quad (8)$$

$$P = I^2 R \quad (9)$$

$$P = \frac{V^2}{R} \quad (10)$$

# Homework

Complete the assigned problems  
posted on the LMS