PHYS11 CH:19.1-19.4

Ohm's Law, Series & Parallel Circuits, and Electric Power

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Outline

Learning Objectives

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

- State and apply Ohm's law to simple circuits
- Distinguish between series and parallel circuit configurations
- Calculate equivalent resistance for resistors in series and parallel
- Analyze current flow and voltage drops in different circuit configurations
- Compute electric power dissipation in resistive elements

Current and Resistance

Electric Current

Electric current is the rate of charge flow:

$$I = \frac{\Delta Q}{\Delta t} \tag{1}$$

where:

- I is the current (measured in amperes, A)
- ΔQ is the charge that passes (measured in coulombs, C)
- Δt is the time interval (measured in seconds, s)

Definition of Ampere

$$1\ \text{A} = 1\ \text{C/s} \tag{2}$$

Ohm's Law

Ohm's Law Statement

For ohmic materials, the voltage drop along a path is proportional to the current that runs through the path, with resistance as the constant of proportionality.

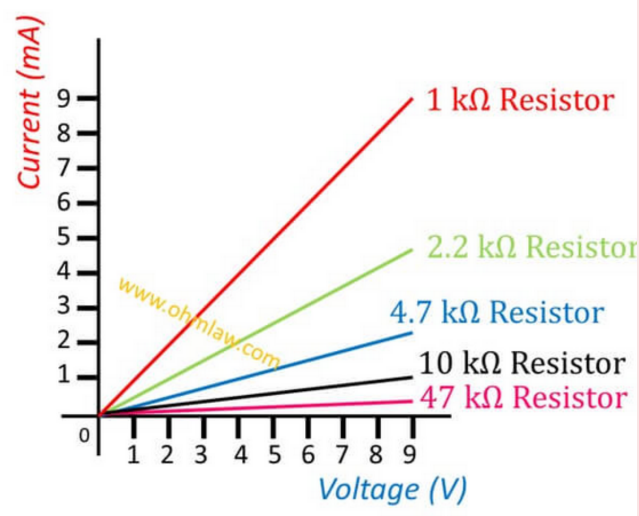
Mathematical Form

$$V = IR \tag{3}$$

where:

- V is the voltage drop (measured in volts, V)
- I is the current (measured in amperes, A)
- R is the resistance (measured in ohms, Ω)

Ohm's Law



Current (mA)
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9
Voltage (V)
1 kΩ Resistor
2.2 kΩ Resistor
4.7 kΩ Resistor
10 kΩ Resistor
47 kΩ Resistor
www.ohmlaw.com

Direct vs. Alternating Current

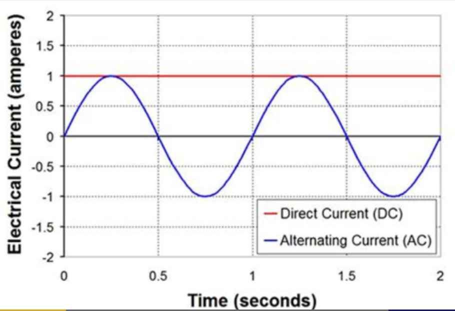
Direct Current (DC)

- Constant over time
- Flows in one direction
- Example: Batteries

Alternating Current (AC)

- Alternates back and forth over time
- Changes direction periodically
- Example: Household electricity

Current Types Visualization



Series Circuits: Characteristics

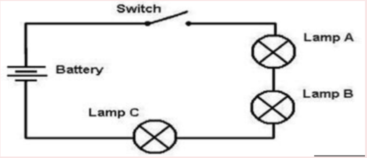
Definition

Resistors in series are connected head to tail, forming a single path for current flow.

Key Properties

- Same current flows through all resistors
- Voltage drop can be different across each resistor
- Voltage is the same at every point in a given wire
- Total voltage equals sum of individual voltage drops

Series Circuit



Series Circuits: Equivalent Resistance

Equivalent Resistance Formula

For N resistors connected in series:

$$R_{\text{equiv}} = R_1 + R_2 + \cdots + R_N \tag{4}$$

Interpretation

- The equivalent resistance is always greater than any individual resistance
- Adding resistors in series increases the total resistance
- Current is limited by the sum of all resistances

Parallel Circuits: Characteristics

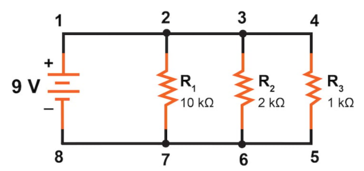
Definition

Resistors in parallel provide multiple paths for current flow, with one end of each resistor connected to a common point.

Key Properties

- Same voltage across all resistors
- Current through each resistor can differ
- Total current equals sum of individual currents
- More paths available for current flow

Parallel Circuit



Parallel Circuits: Equivalent Resistance

Equivalent Resistance Formula

For N resistors connected in parallel:

$$\frac{1}{R_{\text{equiv}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N} \tag{5}$$

Special Case: Identical Resistors

For N identical resistors each with resistance R connected in parallel:

$$R_{\text{equiv}} = \frac{R}{N} \tag{6}$$

Interpretation

- The equivalent resistance is always less than the smallest individual resistance
- Adding resistors in parallel decreases the total resistance

Electric Power: Basic Concept

Definition

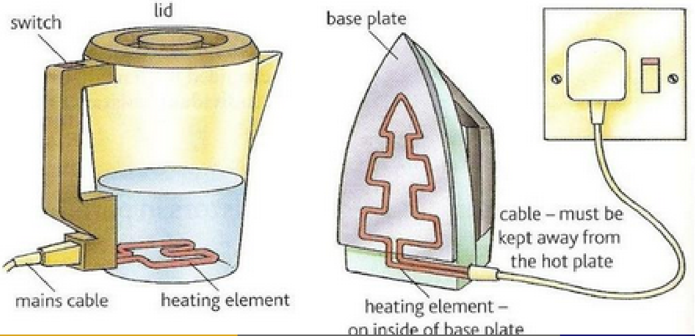
Electric power is the rate at which energy is transferred or converted in an electric circuit.

Key Points

- Electric power is dissipated in resistances of a circuit
- Capacitors do not dissipate electric power
- Power dissipation often manifests as heat
- Measured in watts (W), where $1\ \text{W} = 1\ \text{J/s}$

The heating effect of an electric current

- When an electric current flows through an electrical conductor the resistance of the conductor causes the conductor to be heated.
- This effect is used in the heating elements of various devices like those shown below:



[Heating effect of resistance Phet]

Electric Power: Mathematical Expressions

Basic Power Formula

Power is proportional to voltage and current:

$$P = IV \tag{7}$$

Alternative Expressions (Using Ohm's Law)

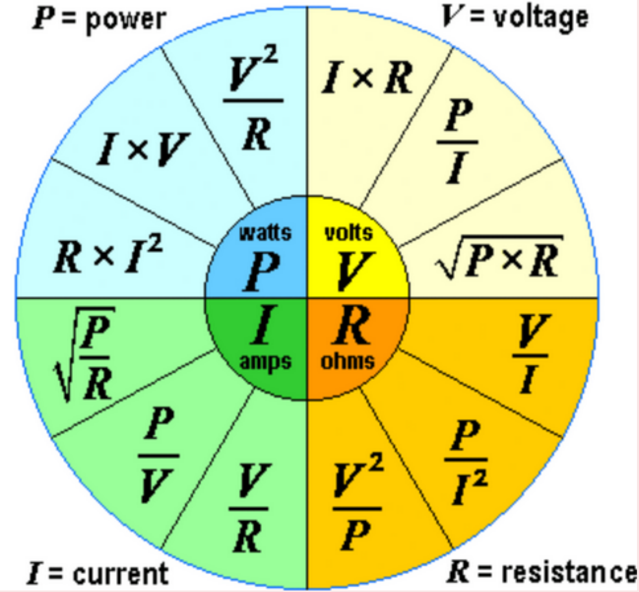
Without current term:

$$P = \frac{V^2}{R} \tag{8}$$

Without voltage term:

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

Equivalent Expressions



I Do: Ohm's Law Example

Problem

A resistor with resistance $R = 10\,\Omega$ is connected to a voltage source of $V = 12\,\mathrm{V}$. Calculate the current flowing through the resistor.

I Do: Ohm's Law Example

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A resistor with resistance $R = 10\,\Omega$ is connected to a voltage source of $V = 12\,\text{V}$. Calculate the current flowing through the resistor.

Solution

Using Ohm's law: $V = IR$
Rearranging to solve for current: $I = \frac{V}{R}$
Substituting the values:

$$I = \frac{12\,\text{V}}{10\,\Omega} \tag{10}$$
$$= 1.2\,\text{A} \tag{11}$$

Therefore, the current flowing through the resistor is $1.2\,\text{A}$.

We Do: Series Circuit Analysis

Problem

Three resistors are connected in series: $R_1 = 5\,\Omega$, $R_2 = 10\,\Omega$, $R_3 = 15\,\Omega$. If connected to a 30 V source:

1. Calculate the equivalent resistance
2. Find the current through the circuit
3. Calculate the voltage drop across each resistor

Partial Solution

1. Equivalent resistance:

$$\begin{aligned} R_{\text{equiv}} &= R_1 + R_2 + R_3 && (12) \\ &= 5\,\Omega + 10\,\Omega + 15\,\Omega && (13) \\ &= 30\,\Omega && (14) \end{aligned}$$

We Do: Series Circuit Analysis (continued)

Complete the Solution

2. Circuit current:

$$I = \frac{V}{R_{\text{equiv}}} \tag{15}$$
$$= \frac{30\,\text{V}}{30\,\Omega} \tag{16}$$
$$= 1\,\text{A} \tag{17}$$

3. Voltage drops across each resistor:
For R_1: $V_1 = I \times R_1 = 1\,\text{A} \times 5\,\Omega = ?$
For R_2: $V_2 = I \times R_2 = 1\,\text{A} \times 10\,\Omega = ?$
For R_3: $V_3 = I \times R_3 = 1\,\text{A} \times 15\,\Omega = ?$
Let's work through these calculations together.

You Do: Parallel Circuit Problem

Problem

Three resistors are connected in parallel: $R_1 = 6\,\Omega$, $R_2 = 12\,\Omega$, $R_3 = 4\,\Omega$. If connected to a 24 V source:

1. Calculate the equivalent resistance
2. Find the total current from the source
3. Calculate the current through each resistor

Work on this problem independently, and we'll review the solution together afterward.

Key Concepts Summary

Ohm's Law

- $V = IR$
- Linear relationship for ohmic materials

Series Circuits

- Same current through all resistors
- $R_{equiv} = R_1 + R_2 + \cdots + R_N$

Parallel Circuits

- Same voltage across all resistors
- $\frac{1}{R_{equiv}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$

Electric Power

- $P = IV = I^2 R = \frac{V^2}{R}$

Practice Questions

Consider This

1. How does adding more resistors in series affect the total current in a circuit?
2. Why is the equivalent resistance in a parallel circuit always less than the smallest individual resistor?
3. In what ways can you reduce power consumption in an electrical circuit?
4. How does current distribute in a parallel circuit? Why?

Next Steps

We will explore more complex circuit configurations and apply these principles to practical problems in our next lesson.