PHYSICS

Ohm's Law

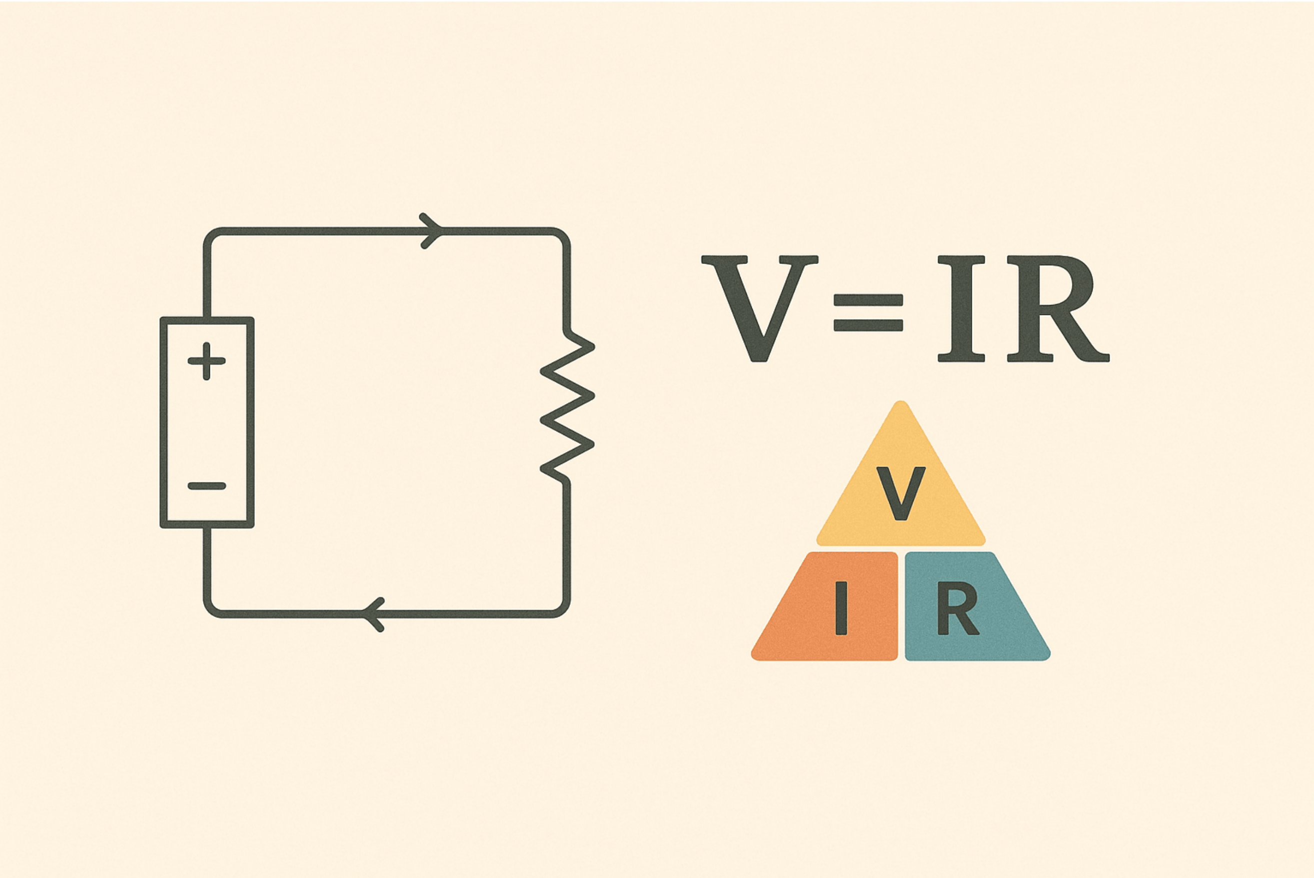
The equation, what it actually says, power, series and parallel circuits, where the law breaks down, and a 10-question practice set with full solutions.

SUBJECT	LEVEL	INCLUDES
Physics	High school and early college	Practice set, answer key, revision sheet

Read this note online, with updates: gauravtiwari.org/study-notes/ohms-law

INSIDE

Ohm's law is the most fundamental equation in electrical circuits: $V = IR$. Voltage equals current times resistance. Once you know any two of those three quantities, you can calculate the third. Georg Simon Ohm published the relationship in 1827 after extensive experiments with copper wire, and it has been the backbone of circuit analysis ever since. Every electrical engineer, every electrician, every physics student starts here. The deceptive simplicity hides the fact that this one equation lets you design and analyze nearly every direct-current circuit you'll encounter.



Ohm's law V = IR, voltage equals current times resistance, the foundational equation of direct-current circuit analysis.

The Equation

Ohm's law in its standard form:

$$V = IR$$

Each symbol has a specific meaning and unit:

- **V** = voltage (potential difference), measured in volts (V). The 'electrical pressure' that pushes current through a conductor.

- **I** = current, measured in amperes (A). The rate at which charge flows. 1 ampere = 1 coulomb per second.
- **R** = resistance, measured in ohms (Ω). How much a material opposes the flow of current.

The equation is easily rearranged to solve for any unknown:

$$V = IR \qquad I = \frac{V}{R} \qquad R = \frac{V}{I}$$

The classic 'V-I-R triangle' (V on top, I and R on the bottom) is a mnemonic: cover the quantity you want and the visible arrangement of the other two tells you the formula.

What Ohm's Law Actually Says

The physical meaning: the current through a conductor is directly proportional to the voltage across it, with resistance as the constant of proportionality. Double the voltage and (for an ohmic material) the current doubles. Double the resistance and the current halves for the same voltage.

'Ohmic' is an important qualifier. A material is ohmic if its resistance is constant, independent of the voltage applied. Most common conductors (copper, silver, aluminum) are approximately ohmic at constant temperature. Some components (diodes, transistors, light bulbs at high current) are non-ohmic, their resistance changes with voltage or current, and Ohm's law alone is not enough to describe them.

Worked Examples

Example 1. A 9-volt battery is connected to a 100-ohm resistor. What current flows?

$I = V/R = 9/100 = 0.09\,\text{A} = 90\,\text{mA}$.

Example 2. A circuit draws 2 amperes when 12 volts is applied. What is its resistance?

$R = V/I = 12/2 = 6\,\Omega$.

Example 3. What voltage is needed to push 5 amperes through a 10-ohm coil?

$V = IR = 5 \times 10 = 50\,\text{V}$.

Power and Ohm's Law

Closely related to Ohm's law is the equation for electrical power:

$$P = VI$$

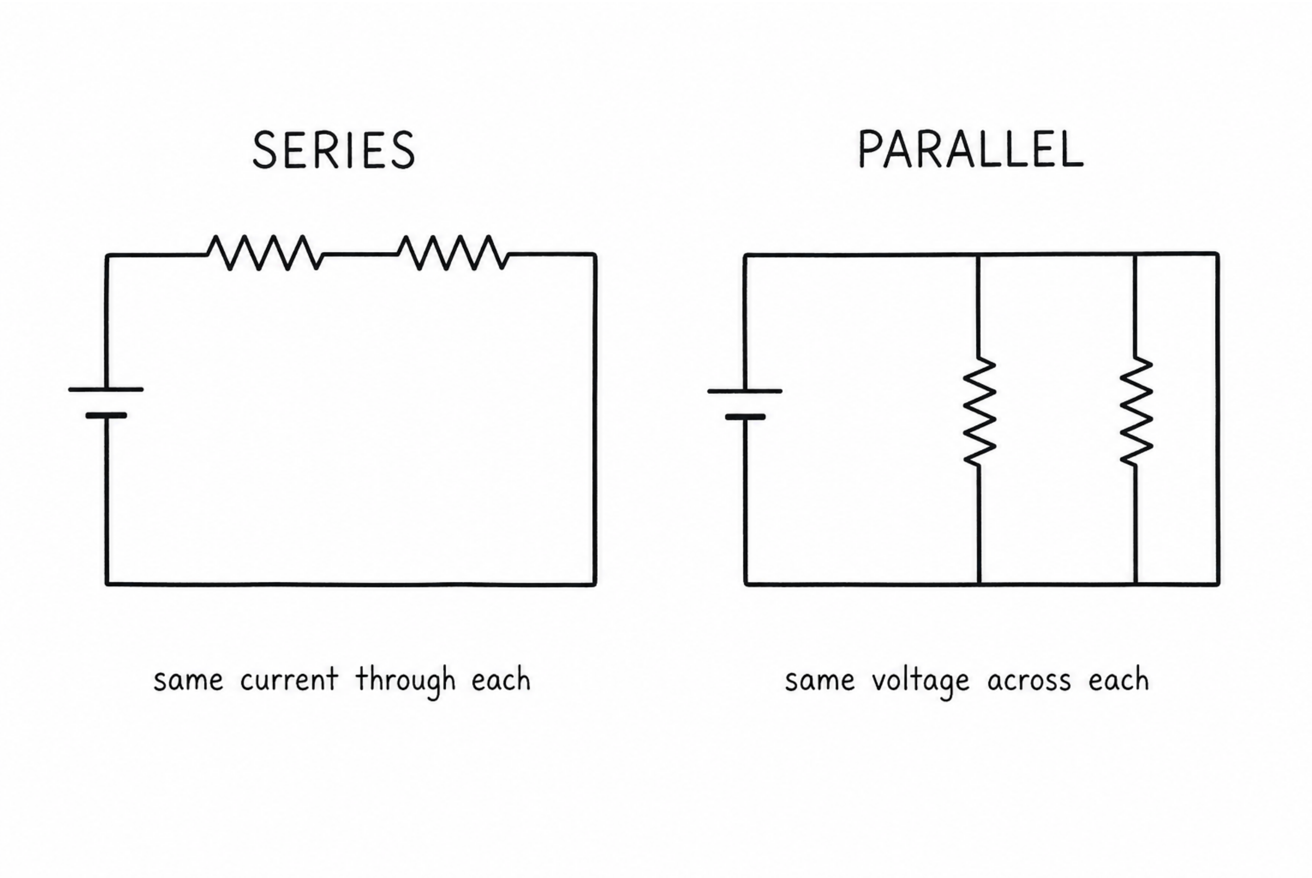
Power is measured in watts (W). Substituting Ohm's law gives three useful forms:

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

These are sometimes called Joule's law (after James Prescott Joule). They tell you how much energy a circuit element dissipates per second. A 60-watt bulb at 120 V draws 0.5 A and has resistance 240 Ω. A toaster at 1000 W and 120 V draws 8.3 A and has resistance 14.4 Ω.

Series and Parallel Circuits

Real circuits combine multiple resistors. Two basic ways to wire them, with very different consequences.



The 2 arrangements in one picture: series shares the current, parallel shares the voltage.

Series

Resistors connected end-to-end. The same current flows through each. Total resistance is the sum:

$$R_{total} = R_1 + R_2 + R_3 + \cdots$$

Voltages add: the supply voltage equals the sum of voltage drops across each resistor. If one resistor breaks (open circuit), the whole chain stops working, which is why old Christmas lights used to fail completely when one bulb died.

Parallel

Resistors connected side-by-side, each spanning the same two nodes. The same voltage appears across each. Total resistance is the reciprocal sum:

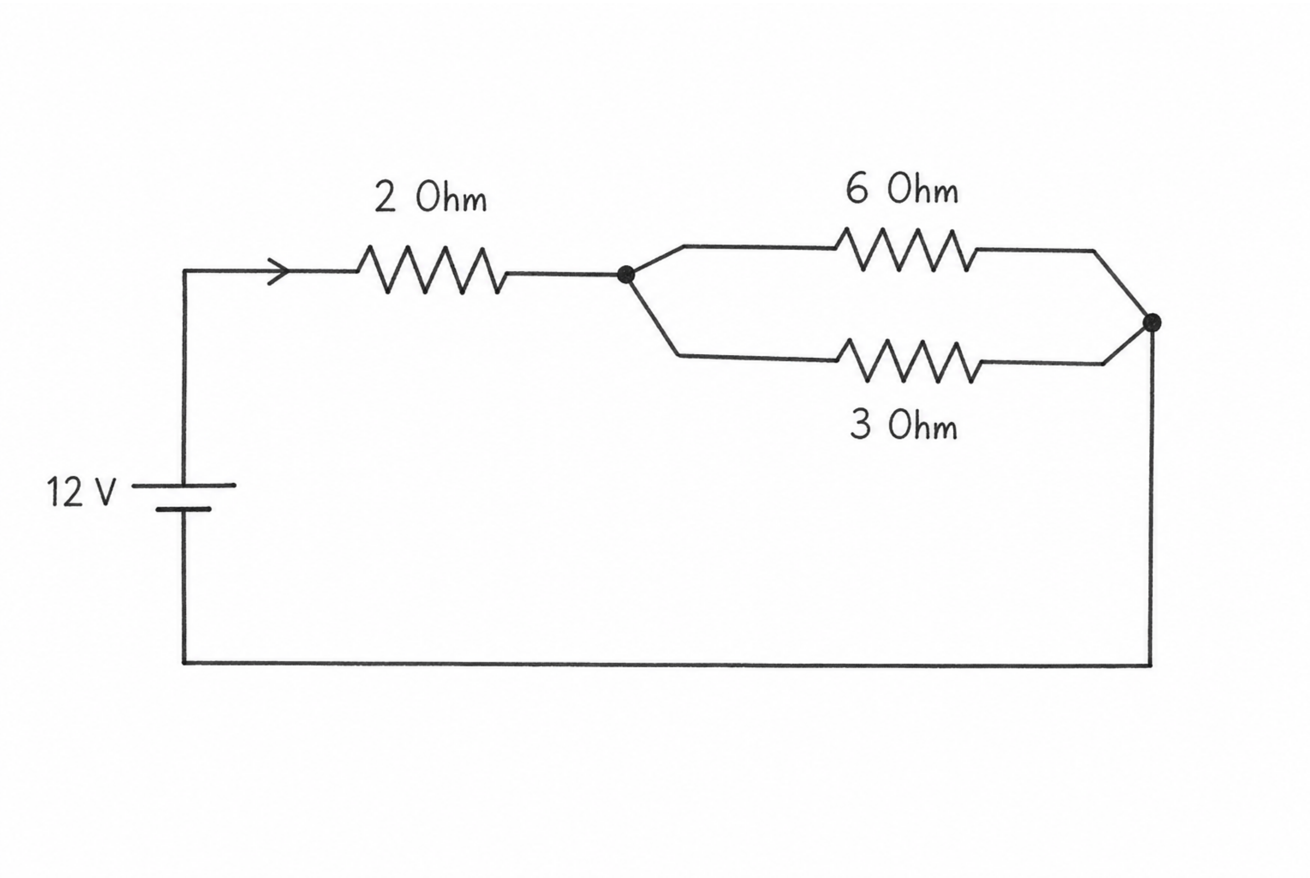
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

Currents add: total current equals the sum through each branch. If one branch breaks, the others keep working. Household wiring is parallel, that is why unplugging the toaster does not turn off the lamp.

> 2 sanity checks worth memorizing: series resistance is always larger than the largest resistor in the chain, and parallel resistance is always smaller than the smallest branch. If a computed answer violates either rule, the arithmetic is wrong.

A Combined Circuit, Solved

Exam circuits usually mix both wirings. Here is the standard 3-resistor pattern, worked completely: a 12 V battery drives a 2 Ω resistor in series with a parallel pair of 6 Ω and 3 Ω.



The combined circuit from the worked example: 2 Ω in series with a 6 Ω and 3 Ω parallel pair across 12 V.

First collapse the parallel pair: $\frac{1}{R_p} = \frac{1}{6} + \frac{1}{3} = \frac{1}{2}$, so $R_p = 2\,\Omega$. The circuit is now 2 Ω + 2 Ω in series, giving $R_{total} = 4\,\Omega$ and a battery current of $I = 12/4 = 3$ A.

That 3 A drops $V = IR = 3 \times 2 = 6$ V across the series resistor, leaving 6 V across the parallel pair. Each branch sees the full 6 V: $I_6 = 6/6 = 1$ A and $I_3 = 6/3 = 2$ A. The branch currents sum to 3 A, matching the battery current.

Every combined circuit yields to this same loop: collapse, total, then walk back out distributing voltage and current.

When Ohm's Law Breaks Down

Ohm's law assumes a few things that are not always true:

- **Temperature dependence.** Resistance of most metals increases with temperature. A tungsten light bulb's resistance is much higher when lit (hot) than when cold. Strictly speaking, Ohm's law only holds at constant temperature.
- **Non-ohmic devices.** Diodes, transistors, semiconductors, gas discharge tubes, these have voltage-dependent resistance. Their current-voltage curves are not straight lines.
- **Very high frequencies.** At high frequencies, capacitance and inductance dominate, and you need impedance (the AC generalization of resistance) plus reactance to describe the behavior fully.
- **Superconductors.** At very low temperatures, certain materials have zero resistance. Ohm's law in the form $V = IR$ breaks down, V can be zero while I is finite.

Related study notes: Coulomb's Law, Maxwell's Equations, Special Relativity, International System of Units.

Practice Questions

Work each question before reading its solution. The set runs from direct recall and substitution to the applied questions that exams actually use to separate grades.

Q1. A 12 V supply is connected across a 60 Ω resistor. What current flows?

SOLUTION

$I = V/R = 12/60 = 0.2$ A, or 200 mA.

Q2. An electric heater draws 5 A from a 230 V supply. Find its resistance and its power.

SOLUTION

$R = V/I = 230/5 = 46\,\Omega$. Power: $P = VI = 230 \times 5 = 1150$ W. Cross-check with the other form: $P = I^2R = 25 \times 46 = 1150$ W. Same answer, as it must be.

Q3. What voltage drives 0.5 A through a 440 Ω resistor?

SOLUTION

$V = IR = 0.5 \times 440 = 220$ V.

Q4. A 4 Ω and a 12 Ω resistor are in series across 24 V. Find the current and the voltage drop across each resistor.

SOLUTION

$R_{total} = 16\,\Omega$, so $I = 24/16 = 1.5$ A through both. Drops: $1.5 \times 4 = 6$ V and $1.5 \times 12 = 18$ V. Check: $6 + 18 = 24$ V, the full supply.

Q5. The same 2 resistors are now in parallel across 24 V. Find the total resistance and each branch current.

SOLUTION

$\frac{1}{R_p} = \frac{1}{4} + \frac{1}{12} = \frac{1}{3}$, so $R_p = 3\,\Omega$, smaller than the smallest branch, as it must be. Branch currents: $24/4 = 6$ A and $24/12 = 2$ A, total 8 A. Confirm: $24/3 = 8$ A.

Q6. A 12 V battery feeds a 2 Ω resistor in series with a parallel pair of 6 Ω and 3 Ω. Find the battery current and the current through the $3\,\Omega$ branch.

SOLUTION

Parallel pair: $R_p = \frac{6 \times 3}{6+3} = 2\,\Omega$. Total: $4\,\Omega$, so the battery current is $12/4 = 3$ A. The series resistor drops 6 V, leaving 6 V across the pair, so $I_3 = 6/3 = 2$ A.

Q7. A bulb is rated 60 W at 120 V. Find its operating resistance and current. If the same bulb ran at 60 V with unchanged resistance, what power would it dissipate?

SOLUTION

$I = P/V = 0.5$ A and $R = V/I = 240\,\Omega$. At 60 V with the same resistance: $P = V^2/R = 3600/240 = 15$ W. Half the voltage gives a quarter of the power, because P scales with V^2. A real filament complicates this: cooler means lower resistance, so the actual power would land somewhat above 15 W.

Q8. A 1500 W room heater runs 4 hours a day for 30 days. At \{}$0.15 per kilowatt-hour, what does the month cost?

SOLUTION

Energy: $1.5\,\text{kW} \times 4\,\text{h} \times 30 = 180\,\text{kWh}$. Cost: $180 \times 0.15 = \$27$. This is the calculation behind every electricity bill: power times time, priced per kilowatt-hour.

Q9. A wire is replaced by one of the same material with twice the length and half the cross-sectional area. What happens to its resistance?

SOLUTION

Resistance scales with length and inversely with area: $R = \rho L/A$. Doubling L doubles R; halving A doubles it again. New resistance: 4 times the original.

Q10. Why can't you assign a single resistance value to a diode?

SOLUTION

A diode's current-voltage curve is not a straight line: almost no current flows below its threshold voltage, then current rises steeply. The ratio V/I changes at every operating point, so there is no single constant R. Ohm's law describes ohmic materials, and a diode is the textbook example of a non-ohmic one.

Answer Key

QUICK ANSWERS

Q1 0.2 A **Q2** 46 Ω, 1150 W **Q3** 220 V **Q4** 1.5 A; 6 V and 18 V **Q5** 3 Ω; 6 A and 2 A

Q6 3 A; 2 A **Q7** 240 Ω, 0.5 A; 15 W **Q8** \{}$27 **Q9** 4 times the original **Q10** no constant V/I ratio exists

Revision Sheet

Ohm's law

$V = IR, I = \frac{V}{R}, R = \frac{V}{I}$. Volts, amperes, ohms. Know 2, get the third.

Series

$R_{total} = R_1 + R_2 + \cdots$. Same current everywhere; voltages add. Total exceeds the largest resistor.

Power

$P = VI = I^2R = \frac{V^2}{R}$. Watts. Energy billed as kWh = kW × hours.

Parallel

$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$. Same voltage everywhere; currents add. Total is below the smallest branch.

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