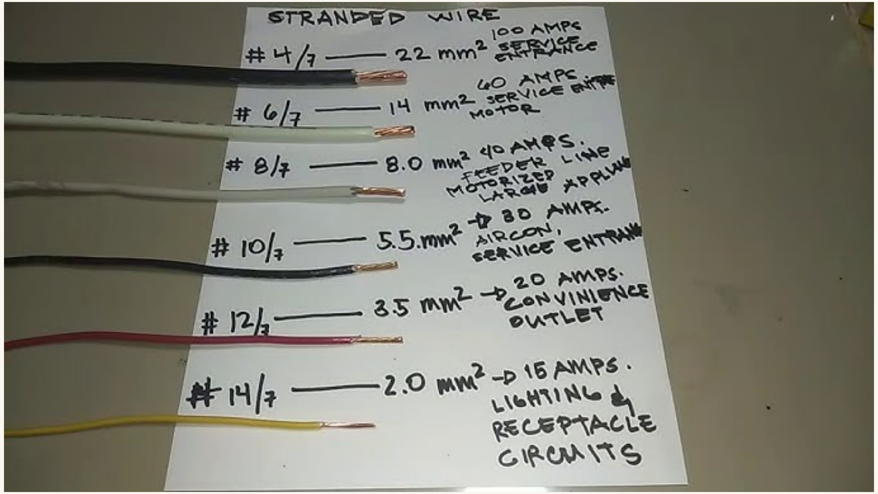
Resistance of a Conductor

Senior High Physics · Electric Circuits

OPENING QUESTION

Why are these wires so different?



Household wiring: every gauge carries a different maximum current

High-voltage lines: thick, bare aluminium — why?

> *Same metal, same electricity — yet thickness, length and material all matter. By the end of this lesson you will be able to say exactly how much they matter.*

CONTEXT

Sometimes resistance is the whole point

Every conductor resists

Wires, filaments, even your body — anything that carries current opposes it to some degree.

Resistors are deliberate

Manufactured components that provide a precise, reliable amount of resistance.

Why we need them

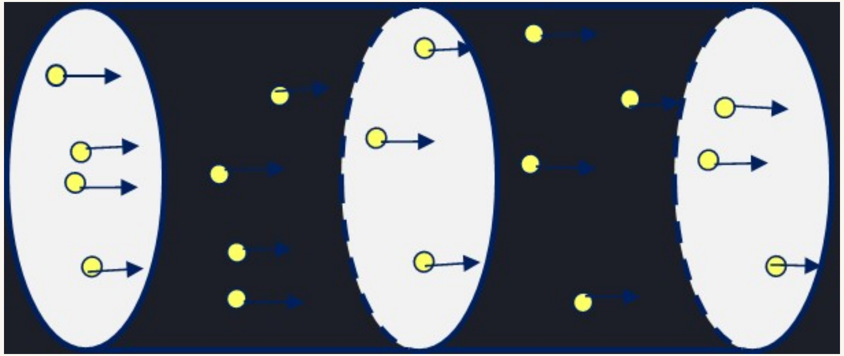
They set currents and divide voltages — the quiet workhorses of every circuit.

Fixed, variable, thermal, light-dependent — a family portrait of resistors

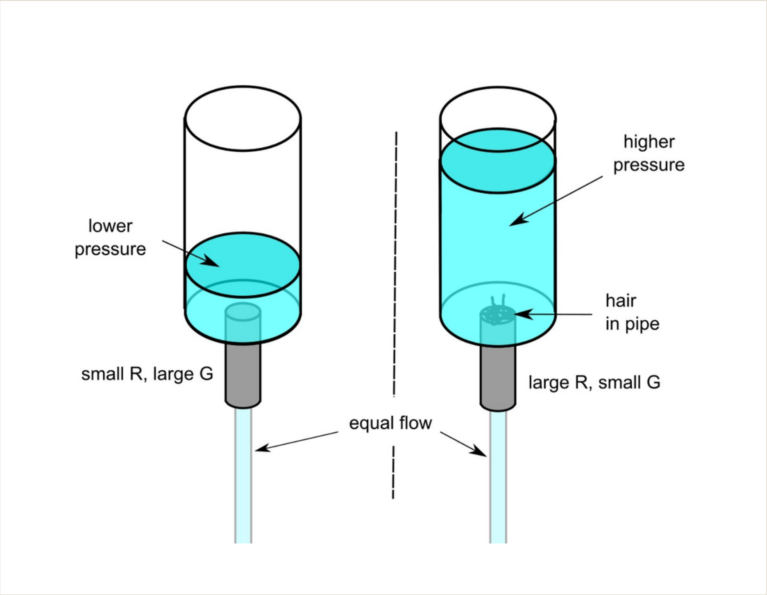
Where does resistance come from?

Inside a metal, free electrons drift through a lattice of vibrating positive ions.

Each collision with an ion disturbs the drift — the accumulated effect is what we call resistance.



Drifting electrons scatter off lattice ions



Water analogy: an obstructed pipe needs more pressure for the same flow

DEFINITION

Putting a number on it

$$R = \frac{U}{I}$$

unit: ohm — 1 Ω = 1 V/A

$$1\,\mathrm{k}\Omega = 10^3\,\Omega \qquad 1\,\mathrm{M}\Omega = 10^6\,\Omega$$

A ratio at one operating point

R compares the voltage across a conductor with the current through it — measured together, at the same moment.

A property of the conductor

R is set by the conductor itself — its material, its dimensions, its temperature — not by the circuit you put it in.

Universal

R = U/I defines resistance for every element — linear or not. No assumptions required.

LAW

Ohm's law — and its limits

$$I = \frac{U}{R}$$

current is proportional to voltage — for some conductors, at steady temperature

✓ **WHERE IT HOLDS**

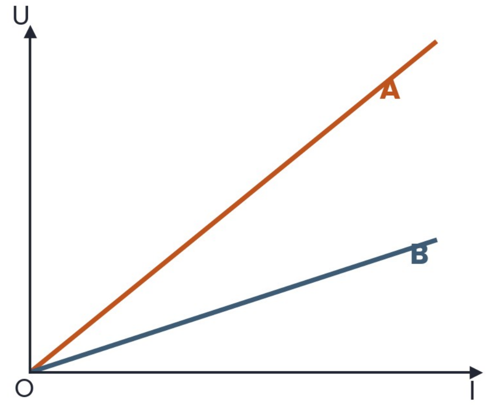
- Metallic conductors
- Electrolyte solutions

✗ **WHERE IT FAILS**

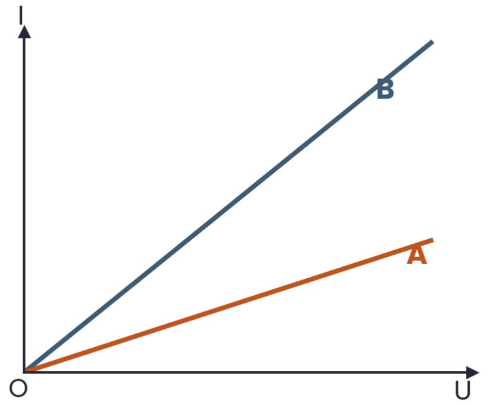
- Gas discharge tubes
- Semiconductor devices
- Motors, electrolytic cells

> *Keep the two ideas apart: R = U/I defines resistance — always. Ohm's law claims I grows in proportion to U — a special property of some materials, not a definition.*

Reading resistance from a graph



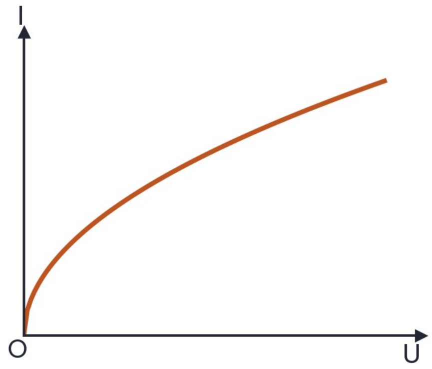
U–I graph: slope = R. The steeper line (A) has the larger resistance.



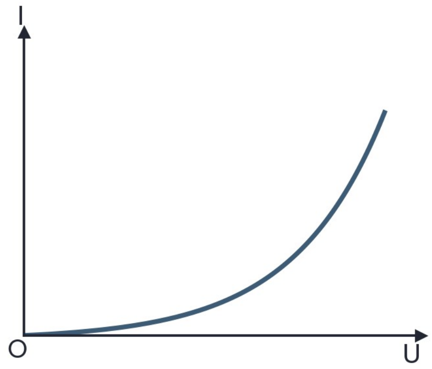
I–U graph: slope = 1/R. The steeper line (B) has the smaller resistance.

The same two conductors — opposite-looking pictures. Check the axes before you compare slopes.

Non-ohmic elements



Filament lamp. Current heats the filament; R rises, the curve bends toward the U axis.

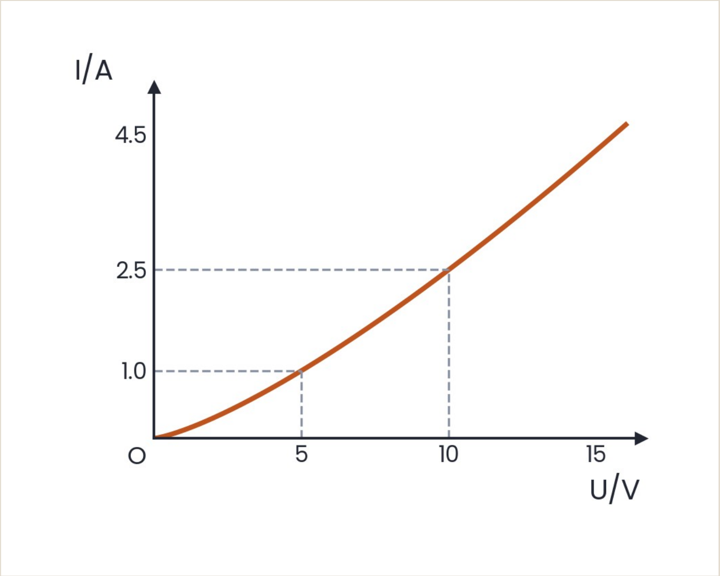


Semiconductor diode. Resistance collapses as U rises; the curve bends toward the I axis.

> *R = U/I still gives the resistance at every point of these curves — what is lost is only the proportionality.*

QUICK CHECK

The graph shows I against U for a conductor



Which statements are correct? Choose all that apply.

A The element is non-linear, so R = U/I cannot be used to find its resistance

✓ **B** At U = 5 V its resistance is about 5 Ω

C Its resistance increases as the voltage rises

✓ **D** Its resistance decreases as the voltage rises

ANSWER **B · D** *Read R = U/I at each point: 5 V / 1.0 A = 5 Ω, but 10 V / 2.5 A = 4 Ω — the ratio is falling. The definition works fine on a curve; only Ohm's law is off-limits.*

EXPERIMENT

What determines the resistance of a wire?

01
Length

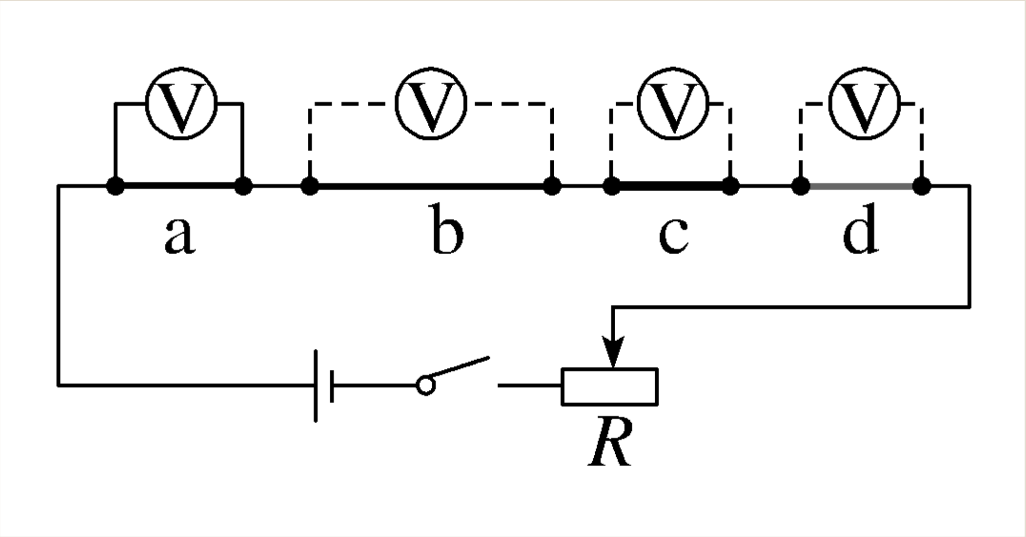
02
Cross-section

03
Material

04
Temperature

> *Four suspects — so we change one at a time and hold the rest fixed: the control-variables method.*

One circuit, three fair comparisons



Conductors a–d in series — a voltmeter across each

a vs b	only the length differs
a vs c	only the cross-section differs
a vs d	only the material differs

In series the current is the same everywhere, so $U = IR$ makes each voltmeter reading directly proportional to that conductor's resistance.

EXPERIMENT · RESULT

The resistance law

$$R = \rho \frac{L}{S}$$

ρ resistivity (Ω·m) — set by the material

L length S cross-sectional area

RESISTIVITY AT 20 °C

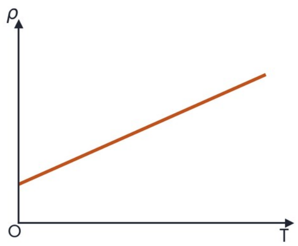
Silver	1.6×10^{-8} Ω·m
Copper	1.7×10^{-8} Ω·m
Aluminium	2.9×10^{-8} Ω·m
Tungsten	5.3×10^{-8} Ω·m
Nichrome (alloy)	$\approx 110 \times 10^{-8}$ Ω·m

> *Double the length — double the resistance. Double the cross-section — halve it. The alloy stands a hundred times higher: that is why heating elements are nichrome, not copper.*

GOING FURTHER

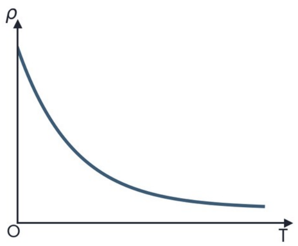
Resistivity moves with temperature

Metals



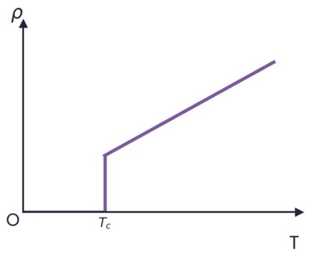
ρ rises steadily with T — the basis of resistance thermometers

Semiconductors



ρ falls sharply as T rises — thermistors exploit this

Superconductors



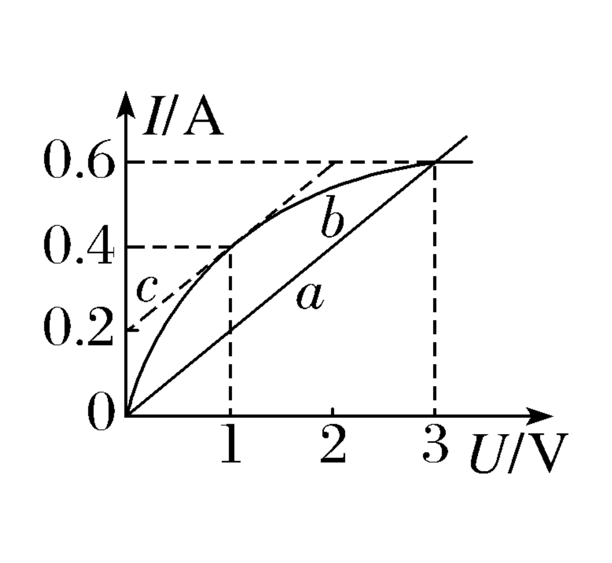
below a critical temperature, resistivity vanishes entirely

> *Alloys such as manganin barely move with temperature — exactly what you want in a standard resistor.*

WORKED EXAMPLE 1

Resistance from a characteristic curve

Solid lines: the I–U characteristics of resistors a and b. Dashed line c is the tangent to b at U = 1 V, drawn parallel to a. Which statements are correct?



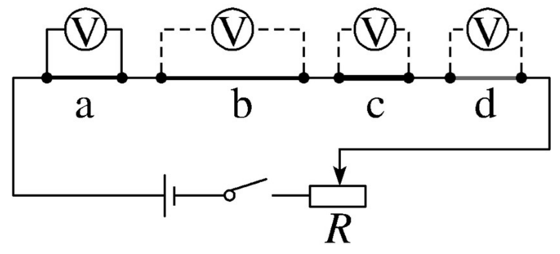
- **A** At U = 1 V, the resistance of b is 5 Ω
- **B** At U = 1 V, a and b have equal resistance
- ✓ **C** The resistance of b rises as U rises
- ✓ **D** At U = 3 V, a and b have equal resistance

ANSWER **C · D** *Resistance is U/I at the point — never the slope of tangent c. For b it rises from 1 V/0.4 A = 2.5 Ω to 3 V/0.6 A = 5 Ω, matching a there — and a stays at 5 Ω throughout.*

WORKED EXAMPLE 2

Testing the factors fairly

In the series circuit from our experiment, b differs from a only in length, c only in cross-section, d only in material. Which statement is correct?



- **A** Without an ammeter, no quantitative study is possible
- ✓ **B** a vs b: the longer conductor gives the larger voltmeter reading
- **C** a vs c: the thicker conductor gives the larger reading
- **D** a vs d: a larger reading means the better-conducting material

ANSWER **B** *Same current everywhere, so U = IR ranks the resistances. Longer → larger R → larger reading (B). Thicker means smaller R (C ✗); a larger reading marks the worse conductor (D ✗); and the reading ratios already give the quantitative law (A ✗).*

WORKED EXAMPLE 3

Thinking straight about resistivity

Which statement about the resistivity of materials is correct?

- **A** Cut a wire into three equal lengths — each piece has a third of the resistivity
- **B** Every material's resistivity rises with temperature
- ✓ **C** An alloy's resistivity exceeds that of the pure metals composing it
- **D** The larger the resistivity, the more a conductor opposes current

KEEP APART

ρ belongs to the material (and its temperature).

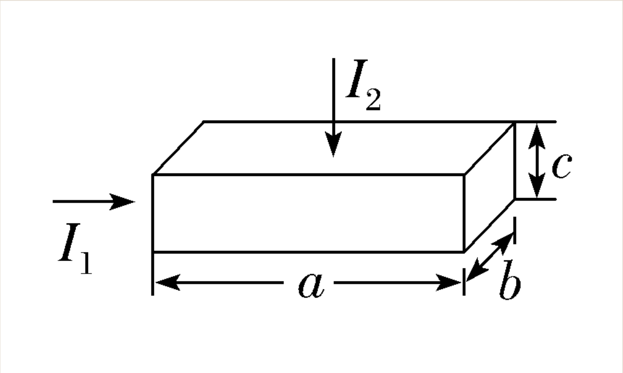
R belongs to the object: geometry included, via $R = \rho L/S$.

ANSWER **C** *Resistivity never depends on shape (A ✗). Semiconductors fall with temperature (B ✗). Opposition to current is R, which geometry also sets (D ✗). Alloys do exceed their constituent metals (C ✓).*

WORKED EXAMPLE 4

One block, two resistances

A copper block has edges a > b > c. Current can be sent lengthwise (along edge a, as shown by the left arrow) or down through the thickness (edge c, top arrow). Find the ratio of the two resistances, R1 : R2.



A 1 : 1

✓ B $a^2 : c^2$

C $a^2 : b^2$

D $b^2 : c^2$

$$R_1 = \rho \frac{a}{bc} \qquad R_2 = \rho \frac{c}{ab} \qquad \Rightarrow \qquad \frac{R_1}{R_2} = \frac{a^2}{c^2}$$

ANSWER **B** *Same material, same block — different geometry, different resistance.*

SUMMARY

What to take away

01	**Definition**	$R = U/I$ — any conductor, any operating point. A ratio, never a tangent slope.
02	**Ohm's law**	$I = U/R$ with R constant — a straight-line I–U graph. Metals and electrolytes only.
03	**Resistance law**	$R = \rho L/S$ — longer means more, thicker means less, material sets the scale.
04	**Resistivity**	A material property that moves with temperature: up for metals, down for thermistors, zero below the critical temperature of a superconductor.