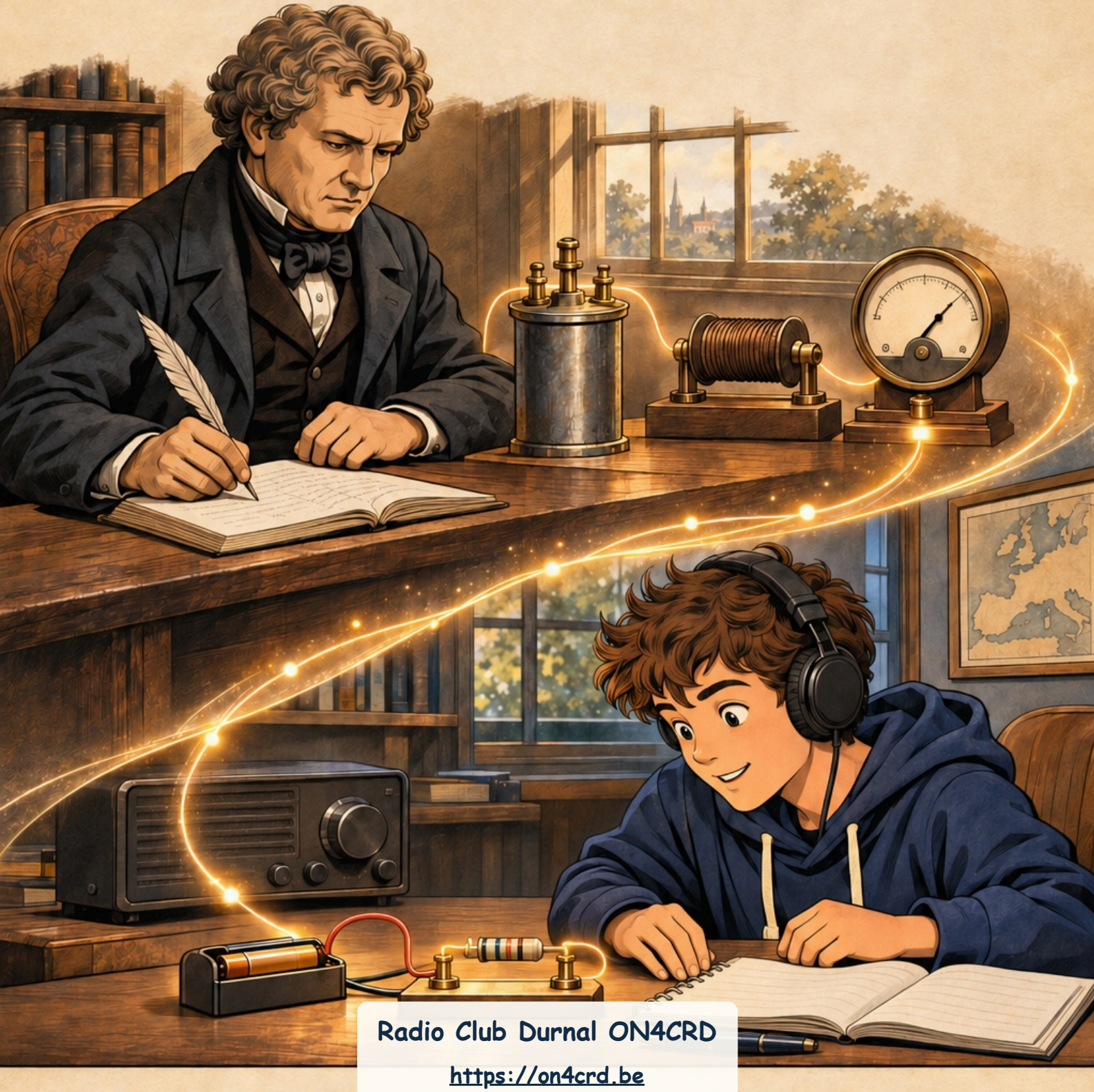
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Volume 04

The Discovery of Ohm's Law



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Illustrations created with assistance from artificial intelligence.

A question at the club



After his first QSO, Lucas returns to the club workshop.



A small resistor lies on the table beside a notebook.



How can such a modest component guide so many calculations?



Henri suggests an investigation, followed by an experiment.



Together, they will prepare a demonstration for visitors.

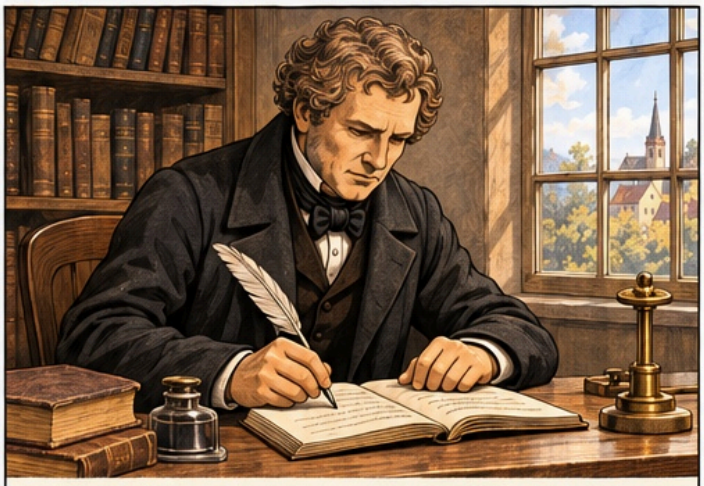


Their first clue has a name: Georg Simon Ohm.

The face behind the name



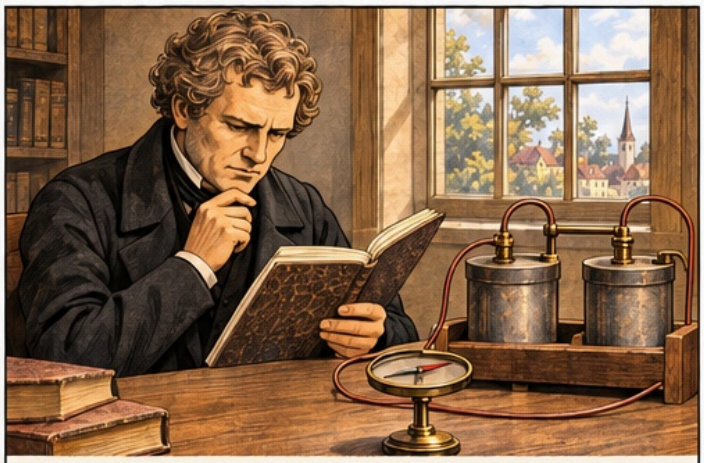
A curly-haired man appears in the book.



Georg Simon Ohm teaches and studies electrical phenomena.



His age already has batteries and conducting wires.



Connecting observations through a law takes patient work.



The youngster imagines the silence of an old workshop.

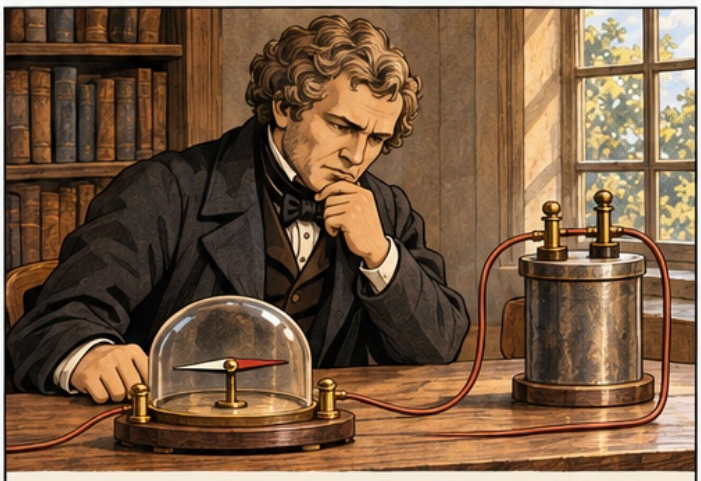


The story leads them into Ohm's research.

Before radio stations



We are in the 1820s, long before amateur radio.



Ohm wants to understand the flow of electricity.



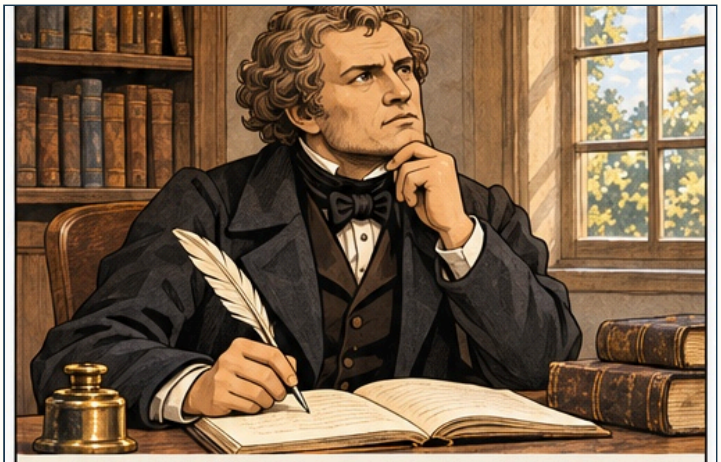
He is preparing neither a modern transmitter nor a distant contact.



Experiments on conductors occupy his workbench.

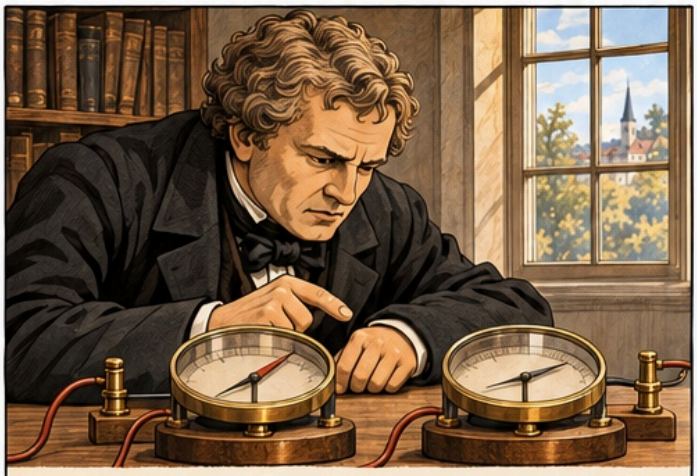


He seeks a relationship that can be tested.

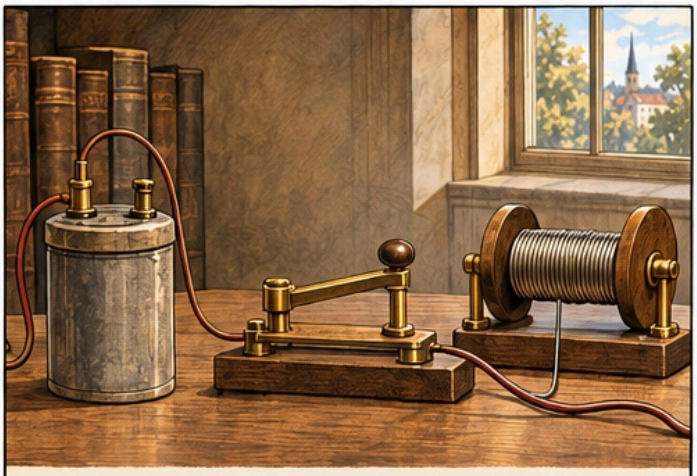


A precise question beats an explanation accepted too quickly.

When results vary



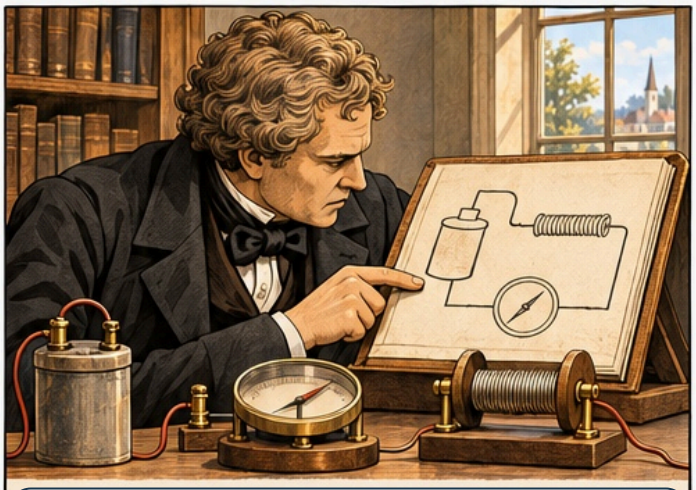
An experiment does not always give the same result.



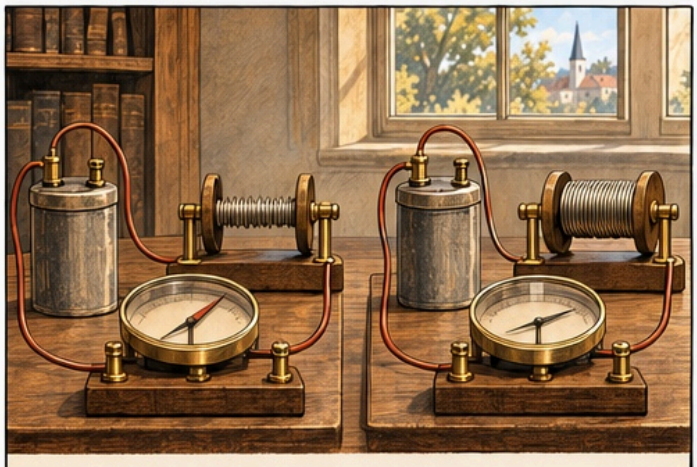
The electrical source and contacts can vary too.



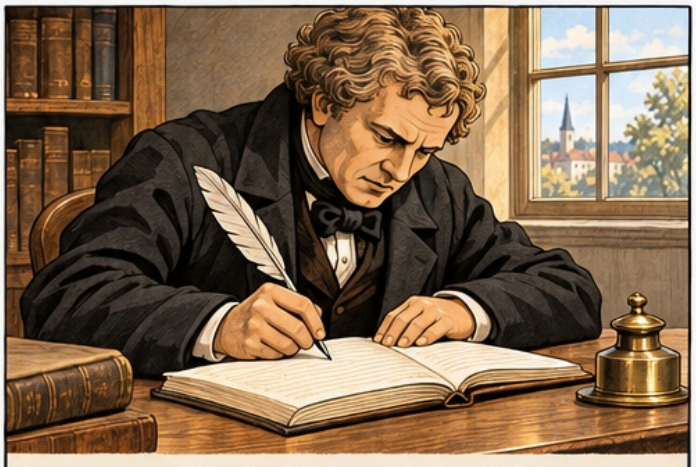
Immediately blaming the wire would not explain these differences.



Ohm reviews the conditions of his observations.



He seeks what changes and what must remain stable.



Discovery begins with this careful attention.

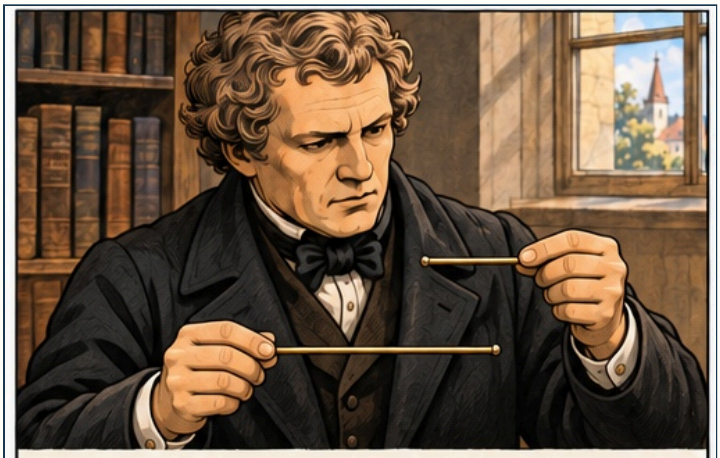
One question at a time



Comparisons require knowing what has changed.



Changing everything together would obscure the answer.



One wire can be compared with another by a chosen criterion.



Other conditions must remain as similar as possible.

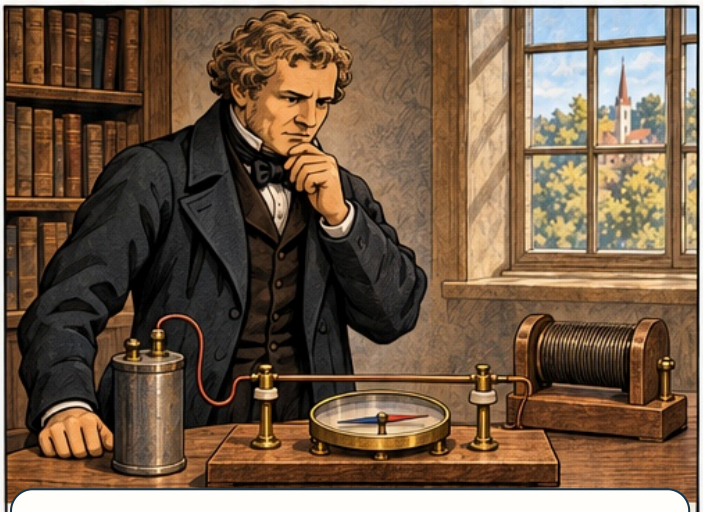


Notes preserve a record of each trial.

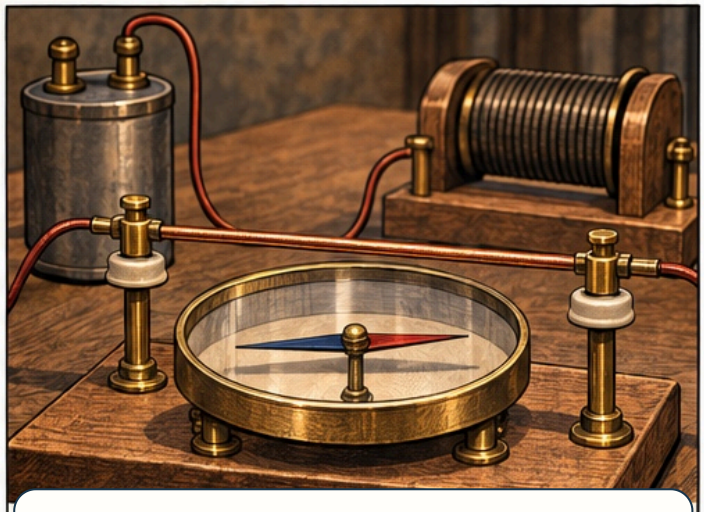


The youngster will recognise this method in his own workshop.

Instruments of their time



Ohm's instruments differ from our multimeters.



A magnetic needle can reveal the effect of current.



A movement becomes a clue to compare carefully.



Understanding the instrument helps interpret its response.



The book recounts research, not instructions to reproduce at home.

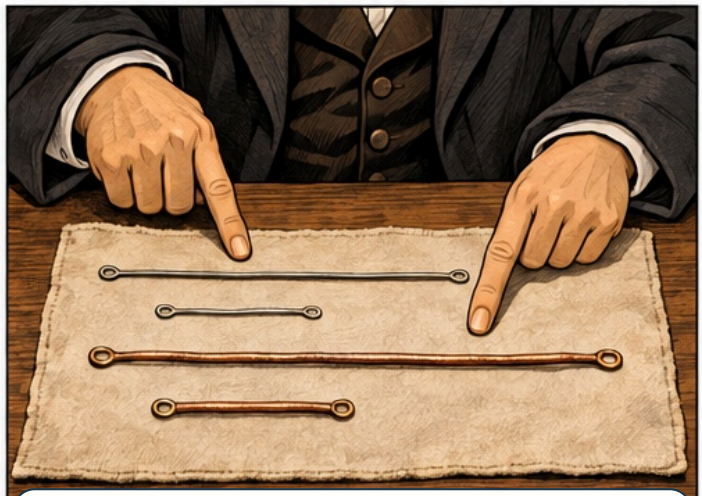


Their club demonstration will use suitable modern equipment.

The wire offers resistance



A conductor's material and shape affect current flow.



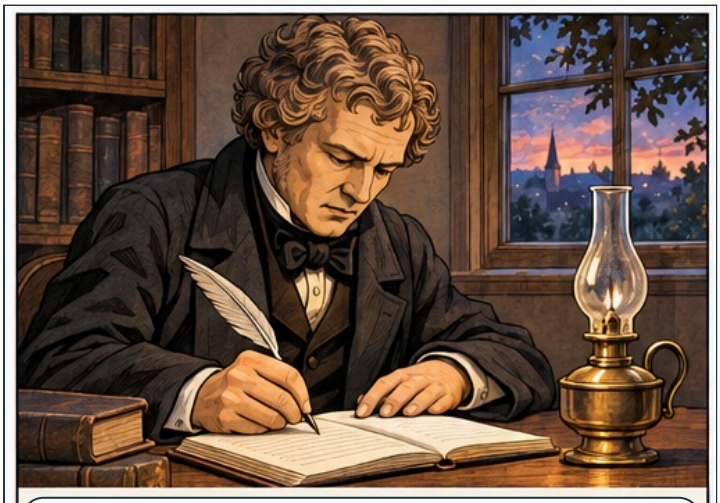
For the same material, length and cross-section matter.



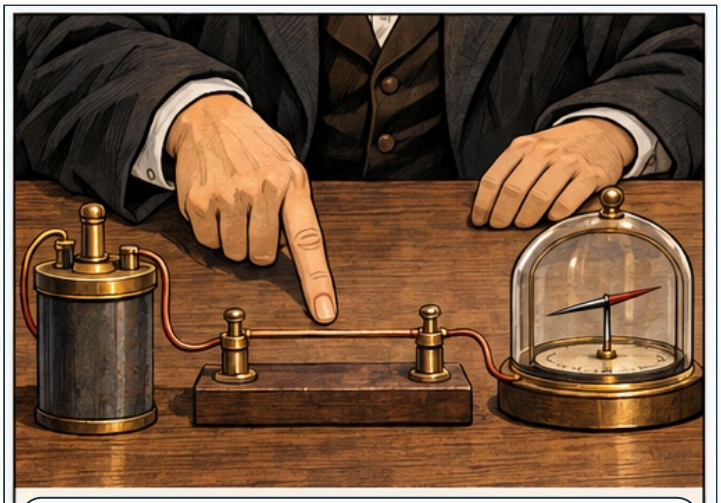
One observation alone cannot establish a law.



Comparisons and a consistent description are needed.



Ohm continues his measurements and reflection.

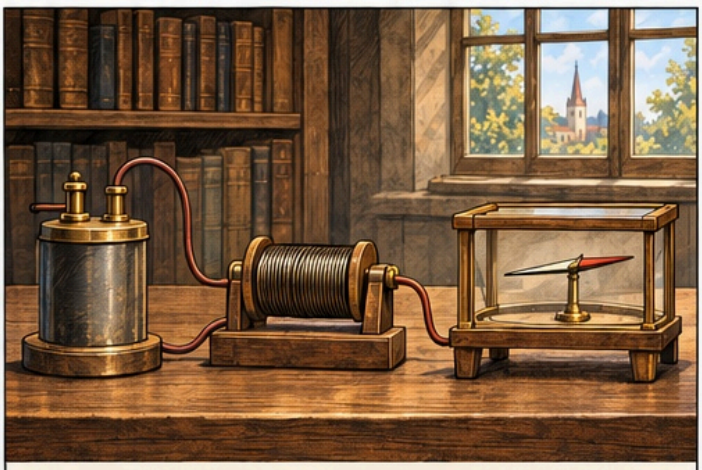


Resistance will take its place among electrical quantities.

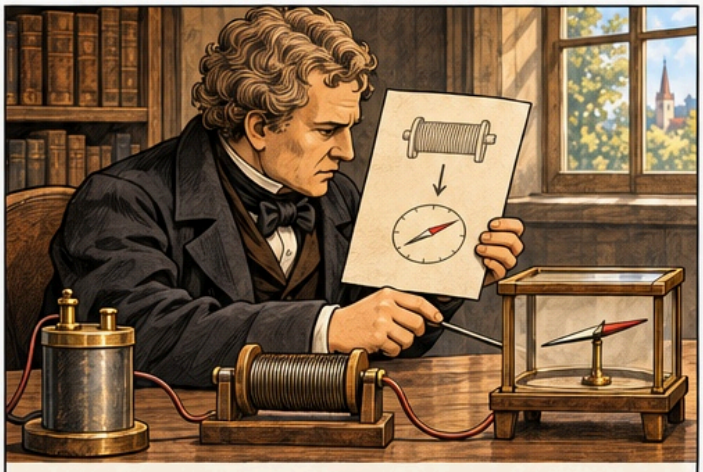
From observations to a relationship



The scientist wants more than a collection of numbers.



He seeks to connect the electrical cause, current and conductor.



A useful relationship also predicts a result.



Its conditions of application must be specified.



At the club, the youngster writes two verbs: observe and predict.

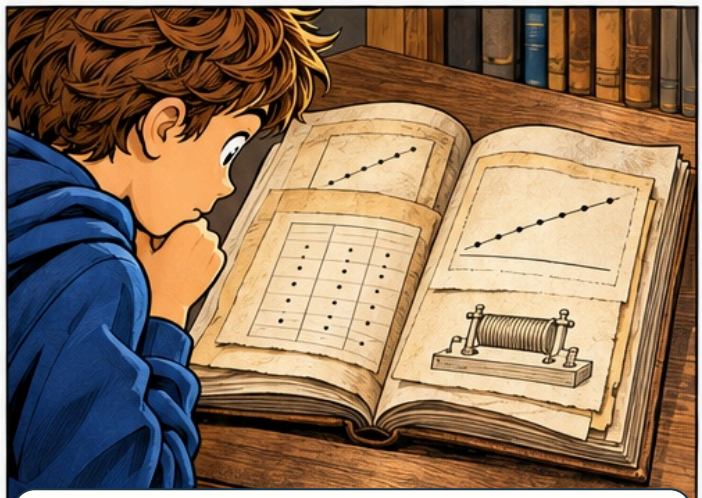


His investigation is becoming a method.

The notebook connects them



An old page can contain trials, doubts and corrections.



Keeping only the formula hides the path of research.



The youngster prepares a notebook for his own observations.



He will separate calculated and measured values.

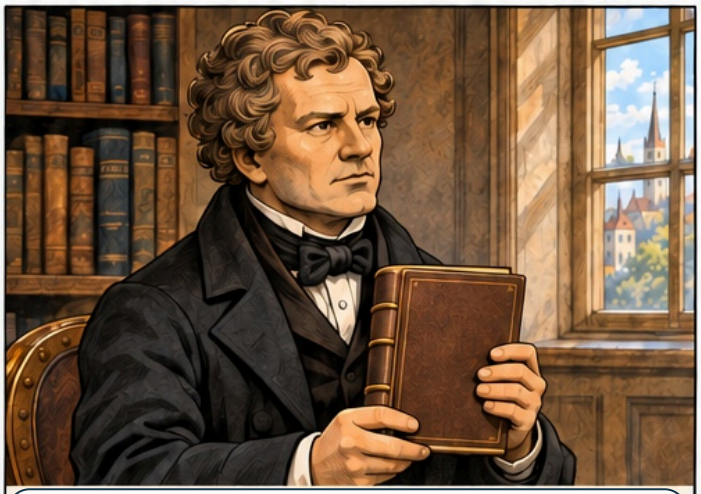


He will also record the circuit and units.



Understanding will help more than reciting.

A book in 1827



In 1827, Ohm publishes his mathematical work on the galvanic circuit.



The book develops his research in detail.



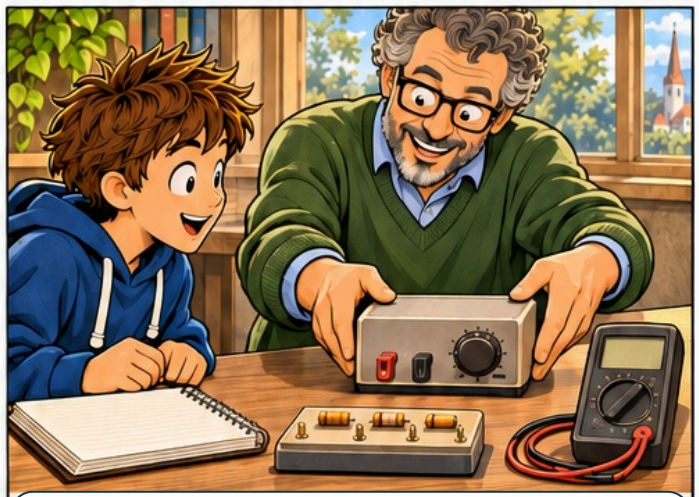
Science advances through relationships others can examine.



Ohm's name will also become the unit of resistance.



The youngster sees the small component differently.



Now he too will connect an idea with observations.

The club experiment



They choose a very simple direct-current circuit.



A low-voltage source supplies a suitable resistor.



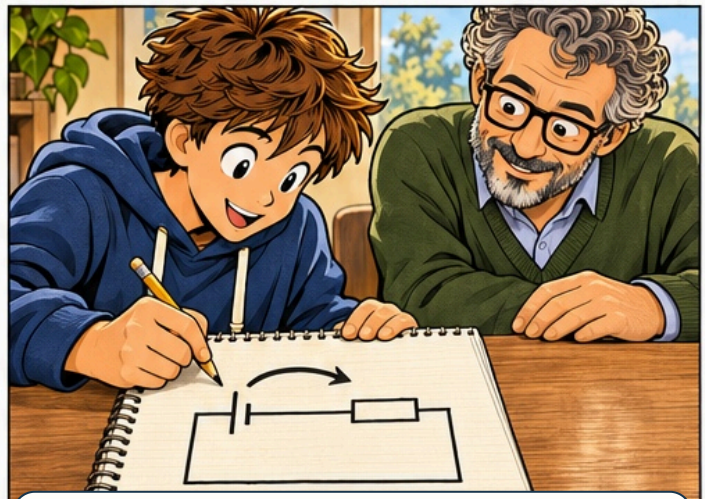
The teaching equipment includes current limiting.



No mains-connected device will be opened or modified.



The mentor checks equipment, instructions and operating limits.



Their question: what happens to current when voltage changes?

Voltage between two points



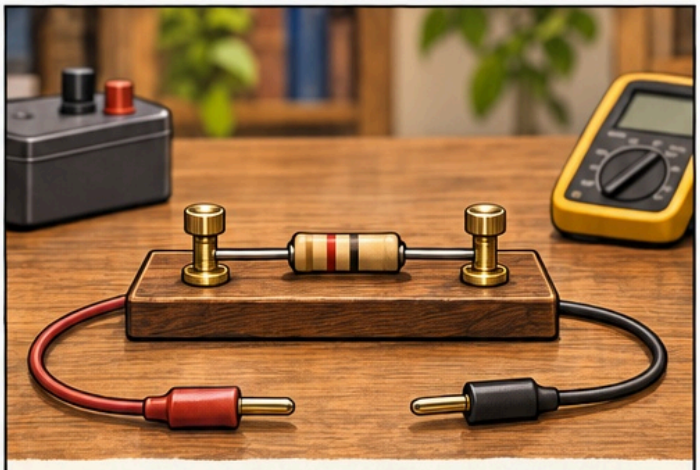
Voltage is defined between two points in a circuit.



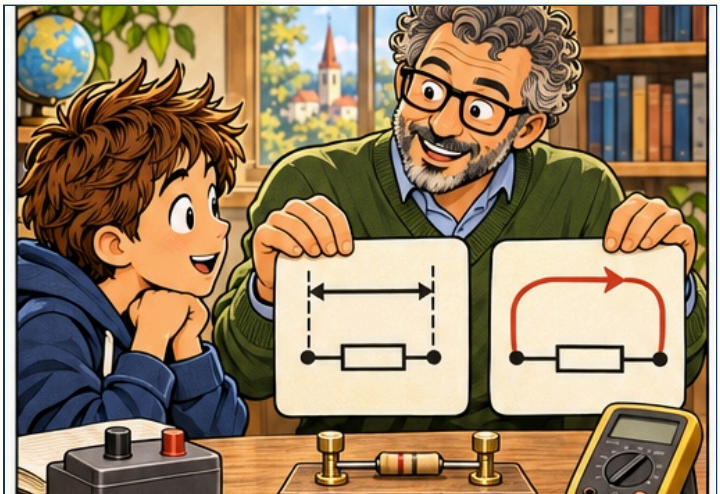
We call it U and express it in volts, symbol V.



A voltage therefore requires specifying which two points.



Here they consider the resistor's two terminals.



Voltage is not a quantity of current hidden in a wire.



The youngster draws the two points in his notebook.

Current around the loop



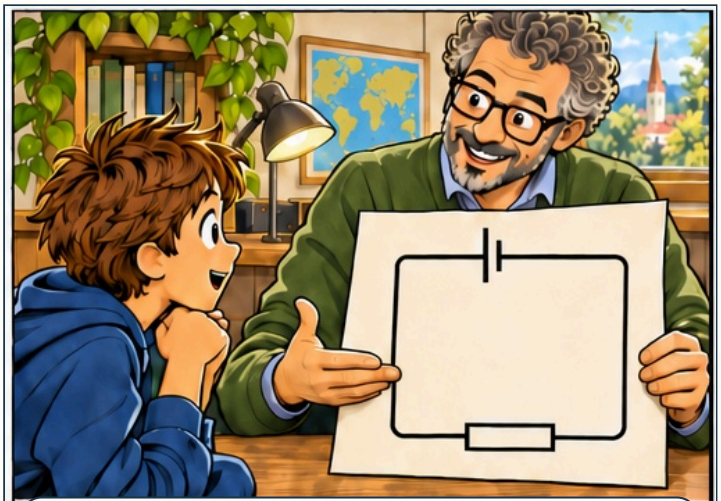
Current is denoted I and measured in amperes, symbol A.



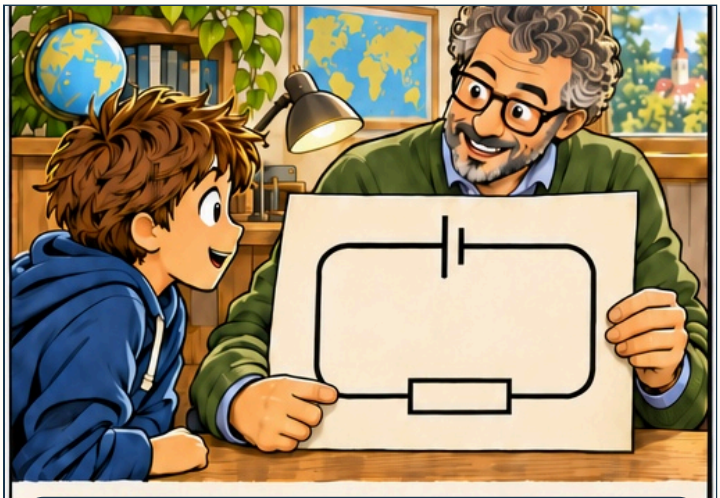
Here, sustained current requires a closed conducting loop.



With an open loop, current does not pass through the resistor.



The same current passes through every element of this simple loop.



Outside the source, conventional current runs from positive to negative.

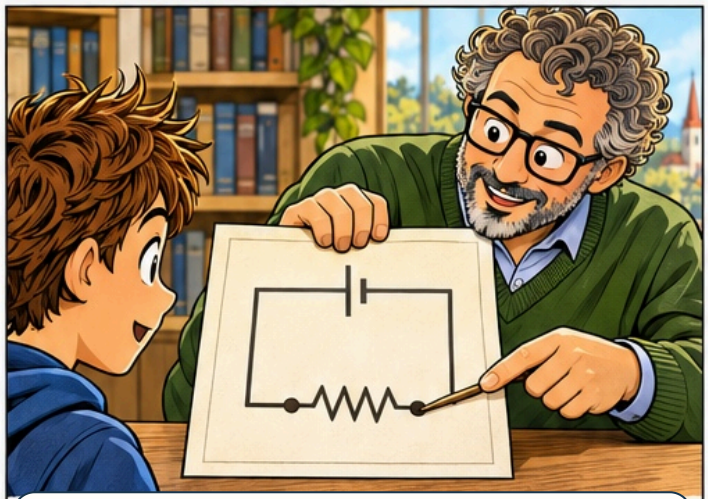


The youngster traces a drawing, without connecting anything yet.

The role of resistance



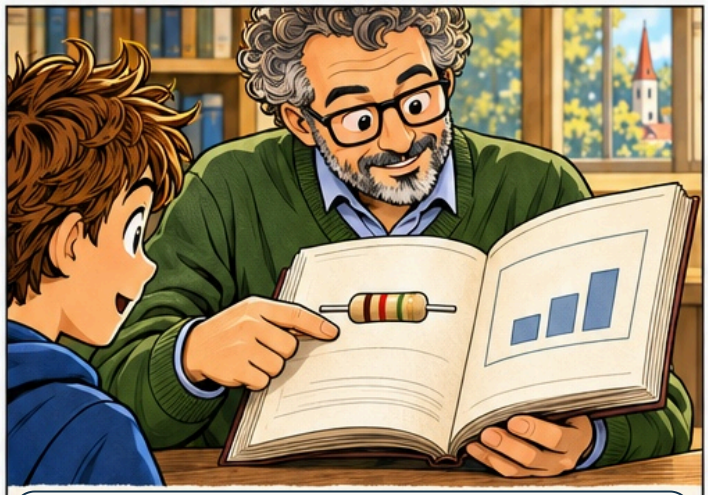
Resistance is denoted R and expressed in ohms, symbol Ω.



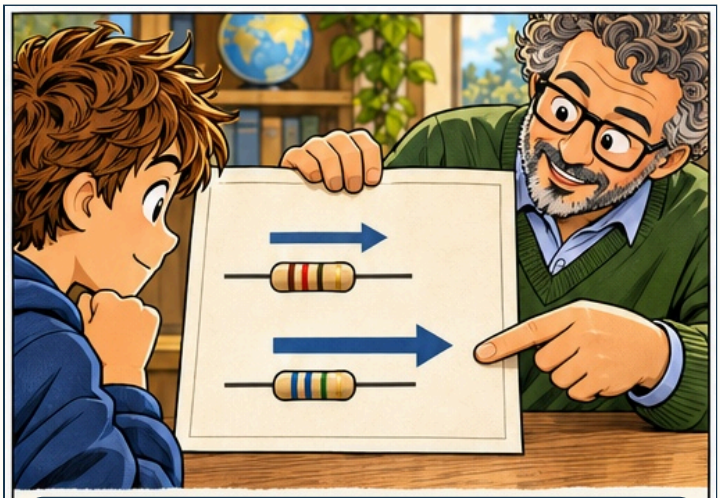
Here it relates voltage across the component to current through it.



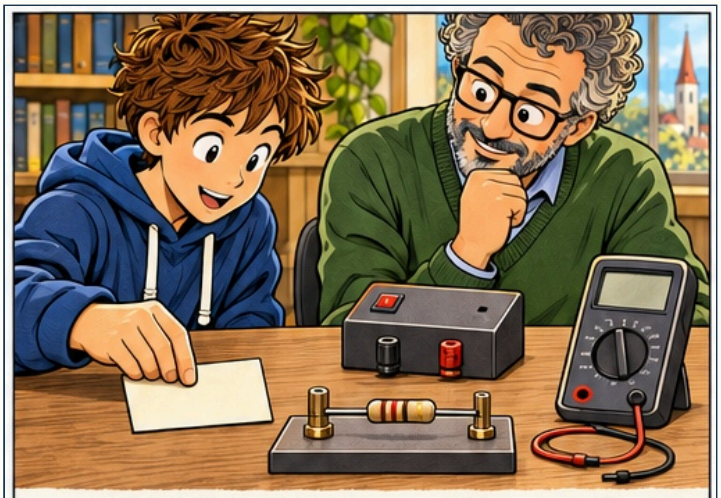
They choose a resistor with ohmic behaviour.



Its temperature must remain sufficiently stable.



At the same voltage, greater resistance gives less current.

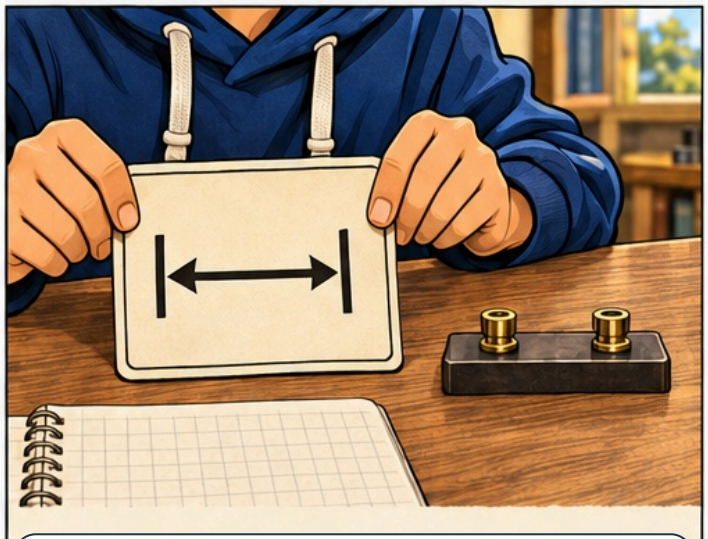


That last statement still needs testing.

Three quantities, three units



The notebook distinguishes U, I and R.



Voltage U is expressed in volts V.



Current I is expressed in amperes A.



Resistance R is expressed in ohms Ω.



A quantity's letter and its unit's symbol serve different purposes.



Every result will keep its unit beside the number.

Prepare before connecting



The source stays disconnected during preparation.



They choose a 100 Ω resistor rated at 1 W.



The demonstration will stay between 1,5 V and 4,5 V DC.



The mentor checks that every part can handle the trial.



Leads are intact and connections accessible without improvising.



The youngster draws the circuit before using it.

Measuring an isolated resistor



Before the trial, they check the resistor with a multimeter.



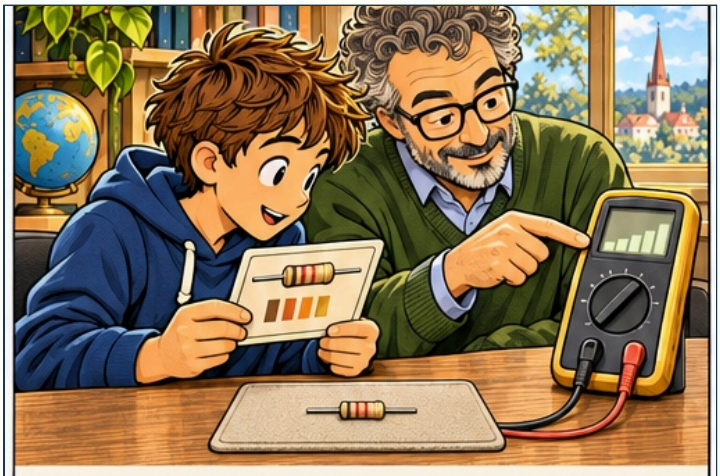
The component is isolated and every source disconnected.



The instrument is set to resistance according to its instructions.



A reading near 100 Ω confirms the selected component.



Tolerance explains why a real value differs from its nominal value.

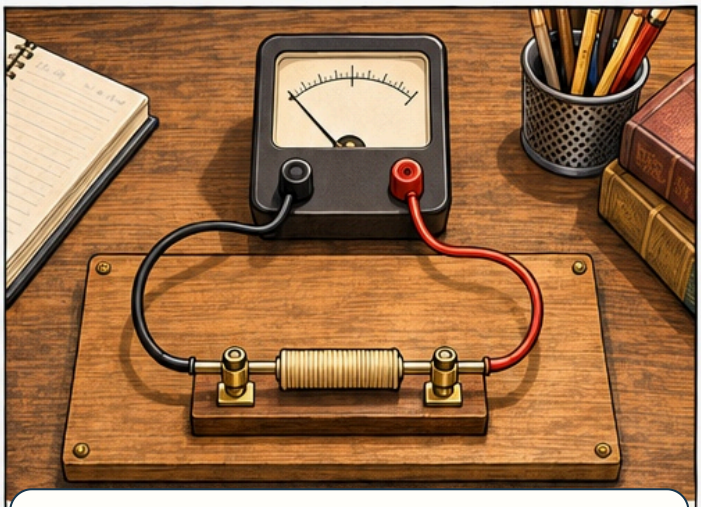


They record the reading, then remove the probes.

Voltage is measured in parallel



To measure U, the voltmeter connects across the resistor's terminals.



It forms a branch in parallel with the resistor.



The source is disconnected while positioning leads.



The mentor checks sockets, DC voltage function and range.



They then power the circuit to read the voltage.



They record the value before disconnecting the supply.

Current is measured in series



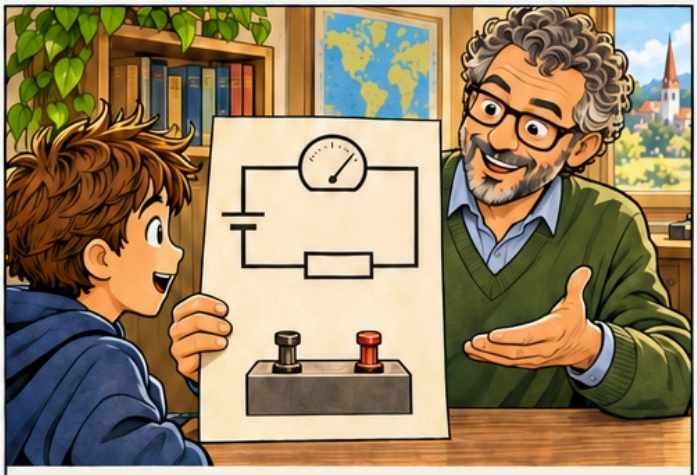
Measuring I needs a different arrangement.



With the source disconnected, the mentor opens the loop and inserts the ammeter in series.



He checks the current socket, fuse, DC function and suitable range.



Never connect an ammeter directly across the source.



After checking the circuit, they power it and read current.

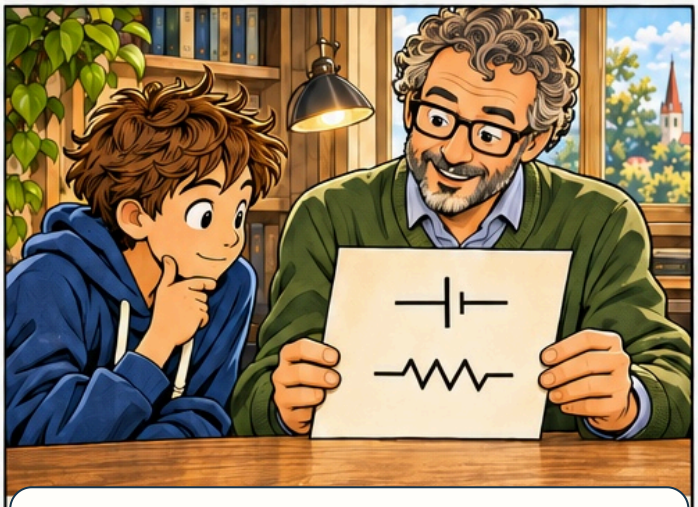


They disconnect before any change, then restore the leads for voltage.

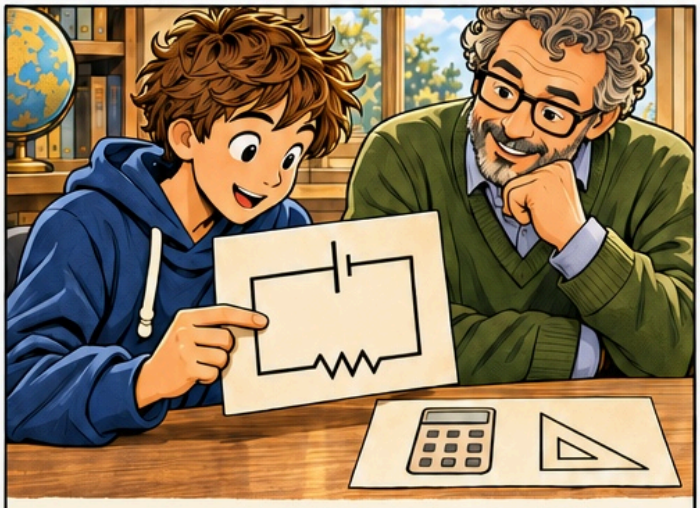
A first comparison point



They begin with the lowest planned voltage.



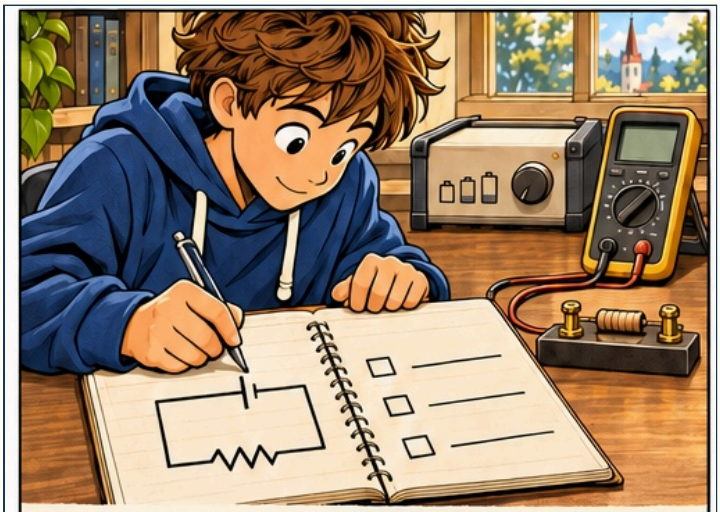
Their ideal example combines 1,5 V with 100 Ω.



The expected current is 0,015 A, or 15 mA.



Actual measurements are recorded separately from ideal values.



Lucas notes the circuit and units.



One first row is only a starting point.

Doubling the voltage



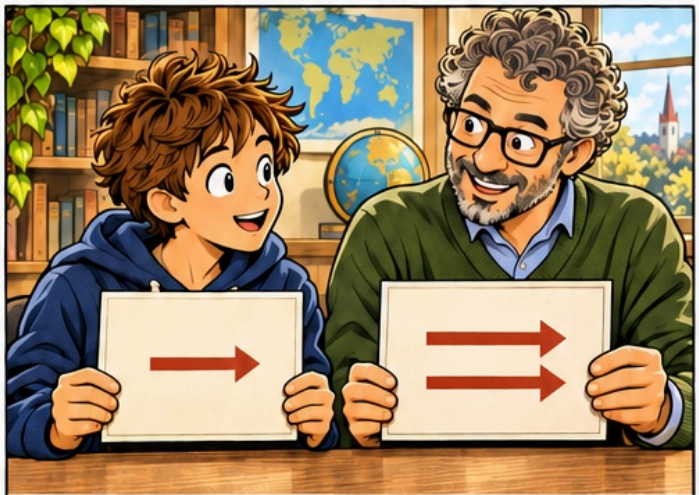
They disconnect the source before changing its setting.



They keep the same resistor and measurement conditions.



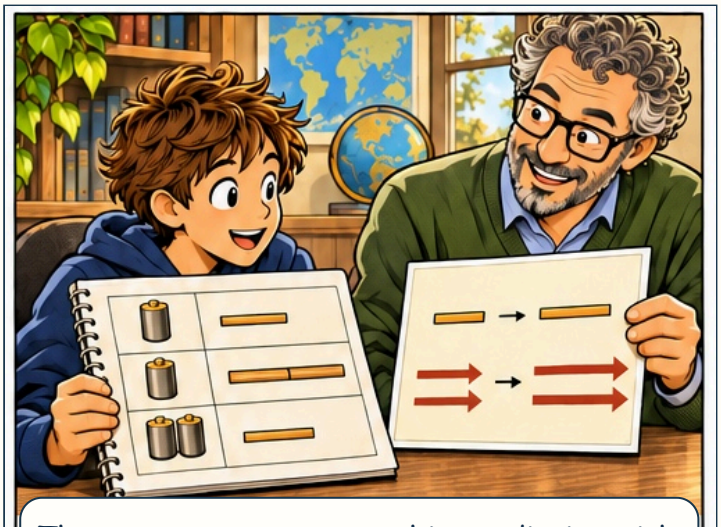
In the ideal example, voltage rises from 1,5 V to 3 V.



Current then rises from 15 mA to 30 mA.



Voltage has doubled; current has too.



The youngster compares this prediction with fresh observations.

A third trial



Another trial must confirm the trend, beyond words alone.



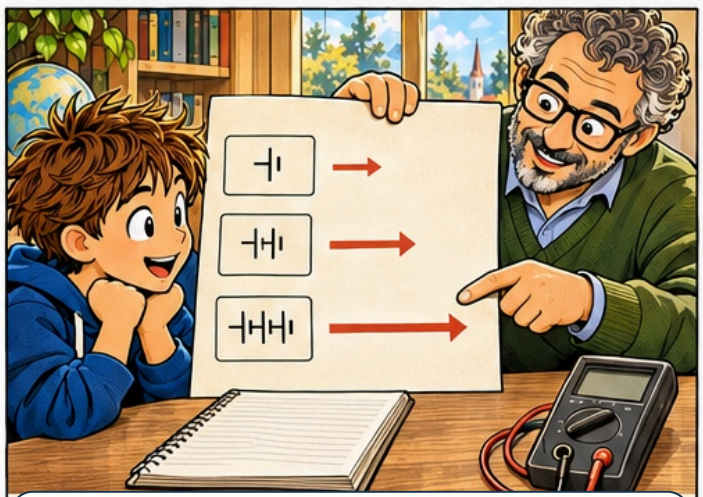
They follow the same procedure up to 4,5 V.



With 100 Ω, the ideal model predicts 0,045 A, or 45 mA.



The example now includes 1,5 V, 3 V and 4,5 V.

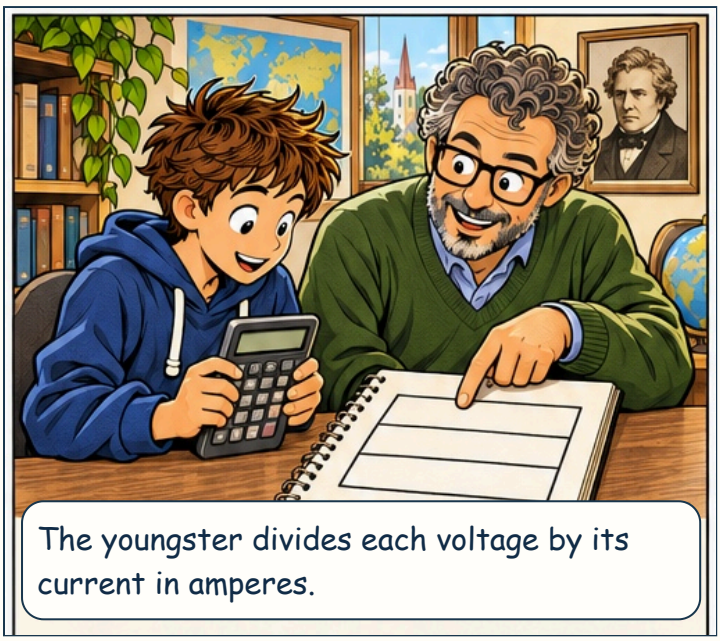


The corresponding currents are 15 mA, 30 mA and 45 mA.

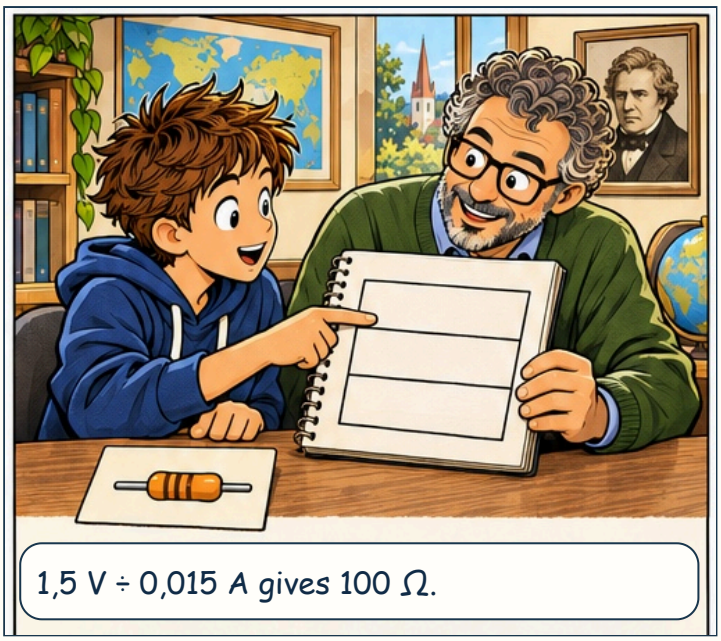


After reading, they disconnect the source again.

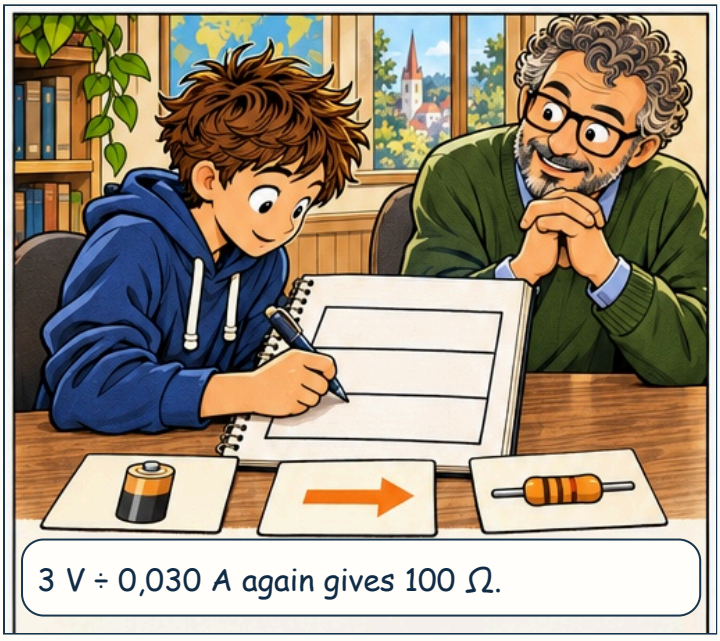
What remains constant



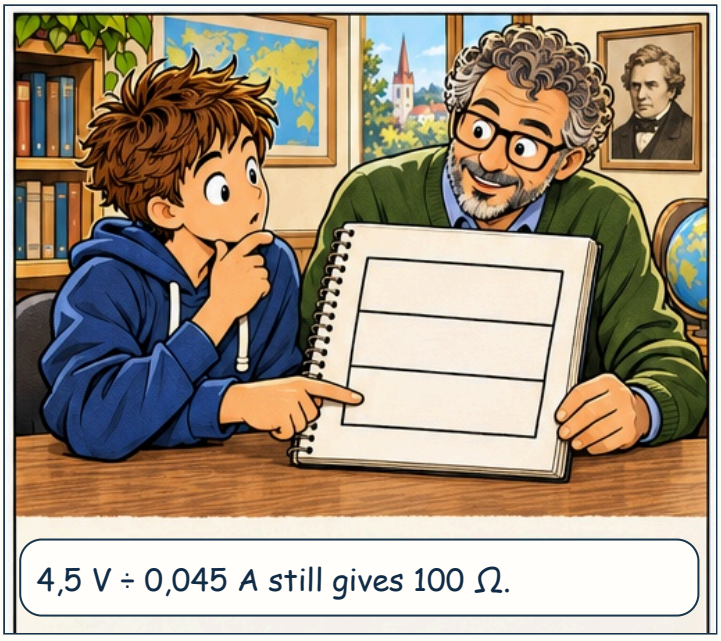
The youngster divides each voltage by its current in amperes.



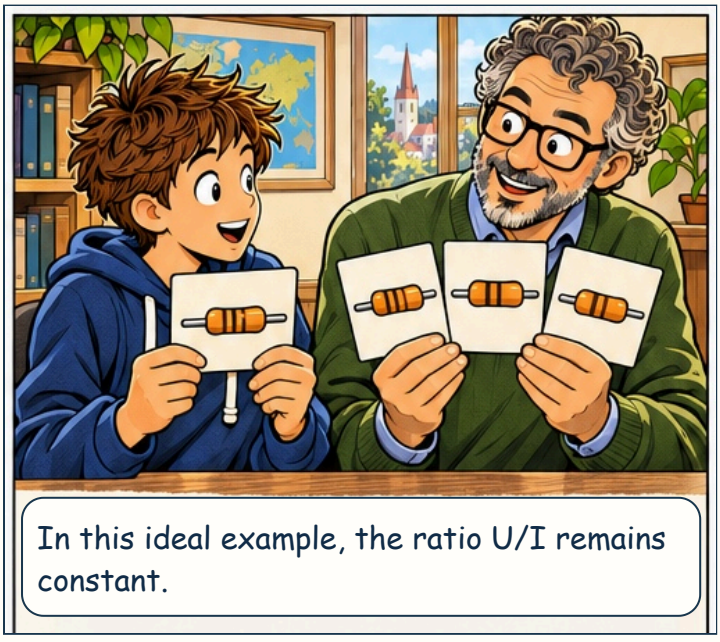
1,5 V ÷ 0,015 A gives 100 Ω.



3 V ÷ 0,030 A again gives 100 Ω.



4,5 V ÷ 0,045 A still gives 100 Ω.



In this ideal example, the ratio U/I remains constant.



This constant represents resistance R.

The relationship takes shape



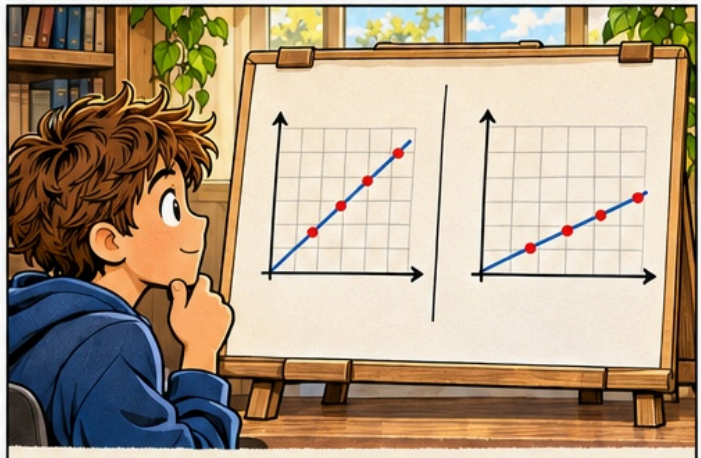
A graph helps reveal proportionality.



For their ideal resistor, the points align through the origin.



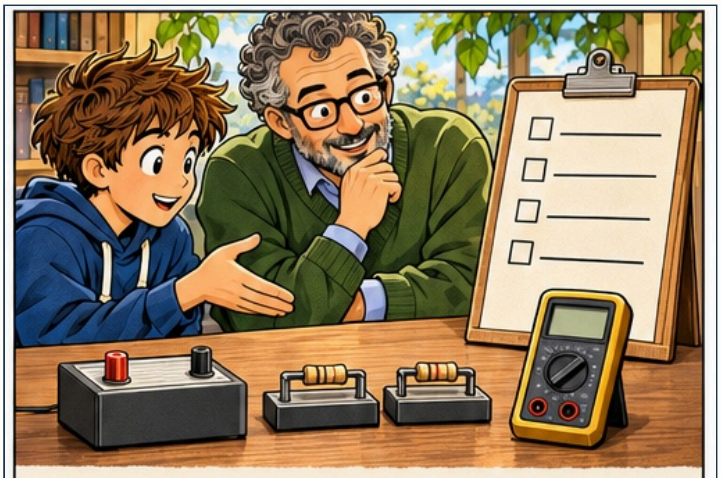
With U horizontal and I vertical, the slope is 1/R.



Swapping axes would change the slope's interpretation.



Real measurements may differ slightly from this line.



The drawing clarifies numbers without replacing experimental conditions.

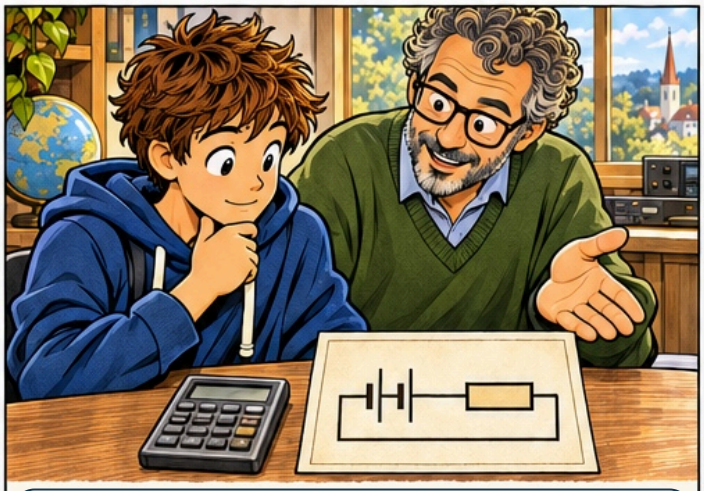
U = R × I



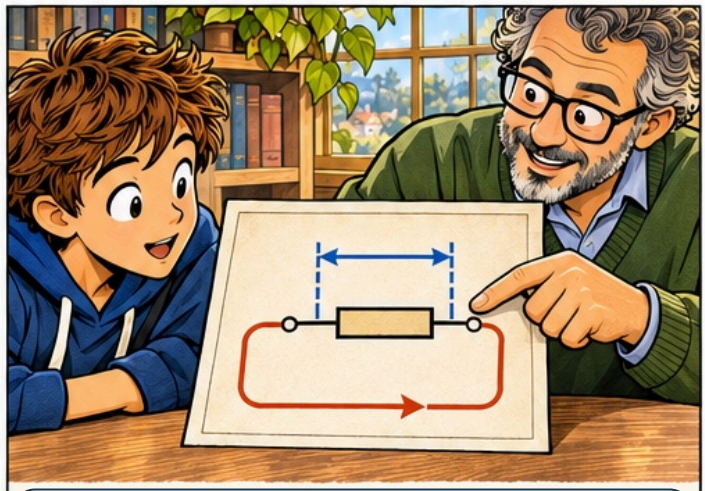
The relationship is written U = R × I.



Voltage across an ohmic resistor equals R multiplied by I.



With R = 100 Ω and I = 0,030 A, we obtain U = 3 V.



The quantities must refer to the same component.



Current is expressed in amperes for this calculation.



The youngster finally understands what the formula connects.

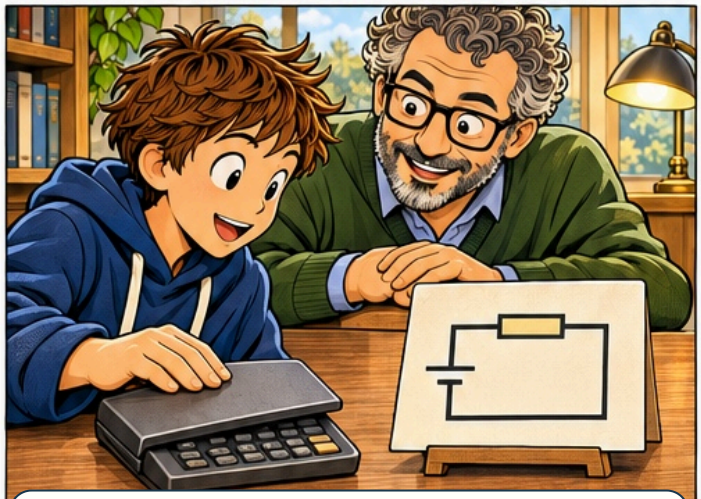
Finding the current



Knowing U and R lets the youngster predict I.



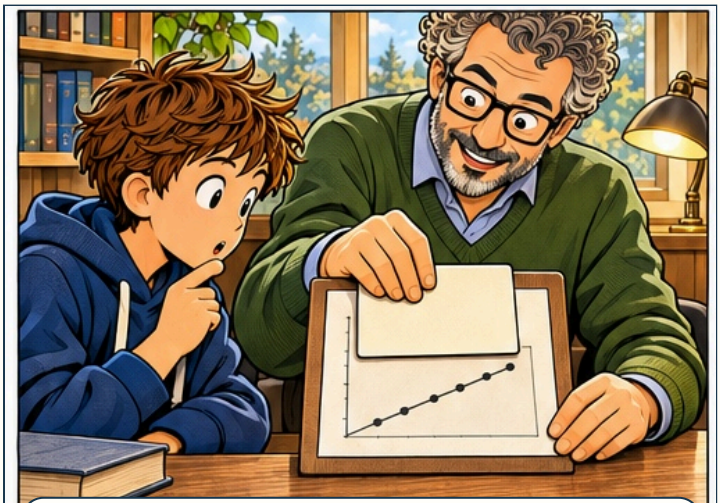
He rearranges the relationship as I = U/R.



For 3 V and 100 Ω, he calculates 3 ÷ 100 = 0,030 A.



This corresponds to 30 mA.



He states his prediction before checking the measurement.



The calculation becomes a question for the experiment.

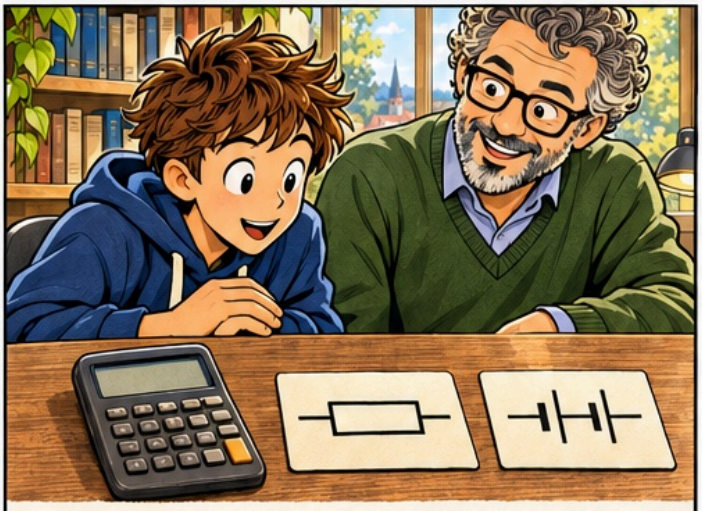
Finding the resistance



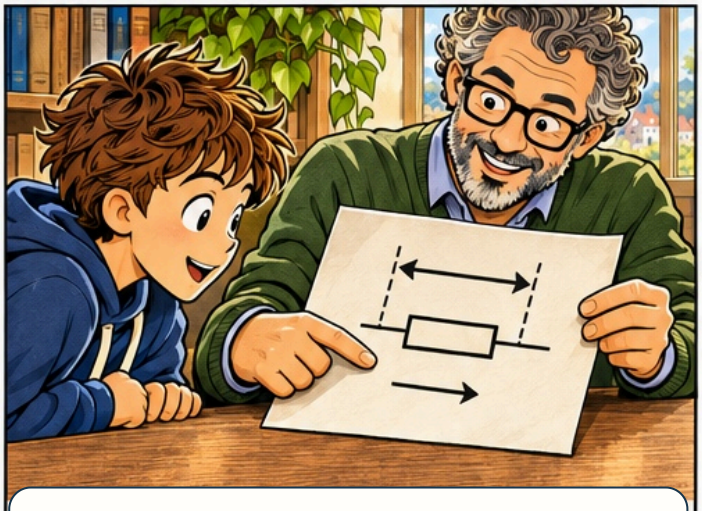
Another question starts with U and I.



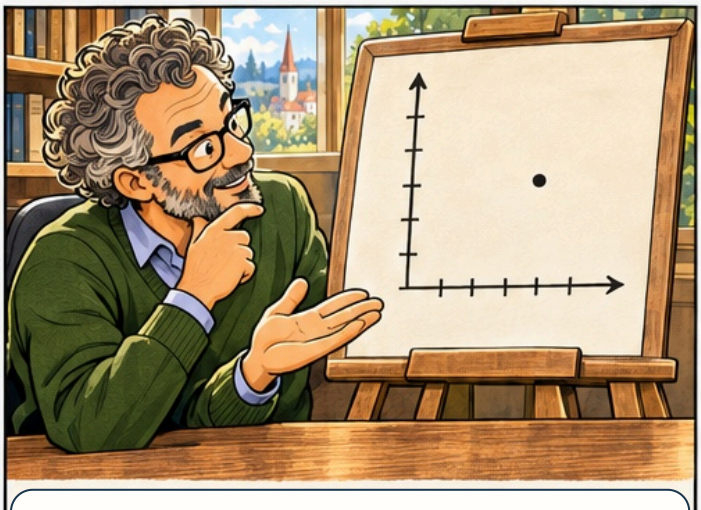
The relationship becomes R = U/I.



In one example, 3 V and 0,015 A give 200 Ω.



Voltage and current must concern the same two-terminal component at the same time.



This ratio alone does not prove that a component is ohmic.



Its behaviour must also be observed at several points.

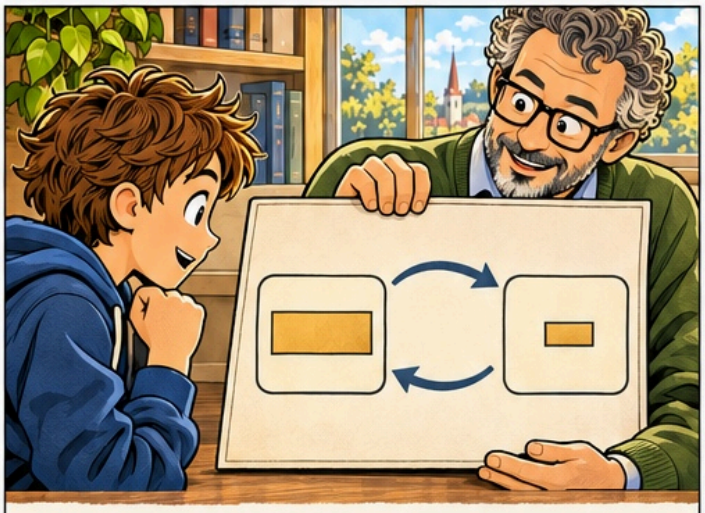
Mind the milliamperes



The youngster copies 30 mA, then pauses over his calculator.



A milliampere is one thousandth of an ampere.



30 mA = 0,030 A; 15 mA = 0,015 A.



Entering 30 instead of 0,030 changes the result a thousandfold.



He converts first, then calculates with consistent units.



An order-of-magnitude check completes his answer.

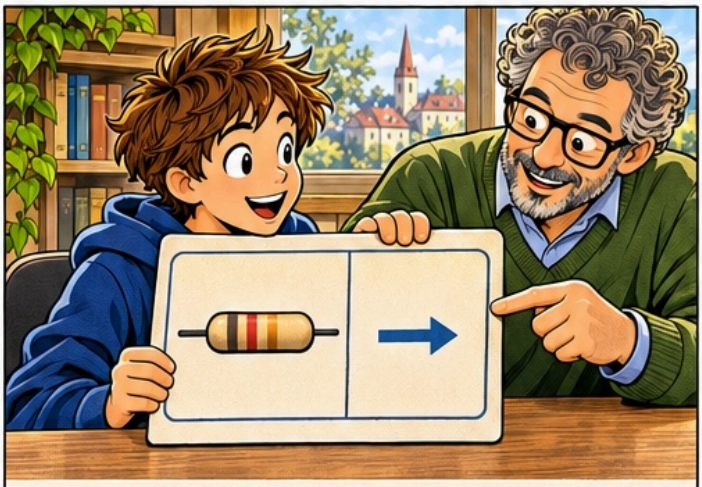
Predict before changing



They now compare two resistors at the same voltage.



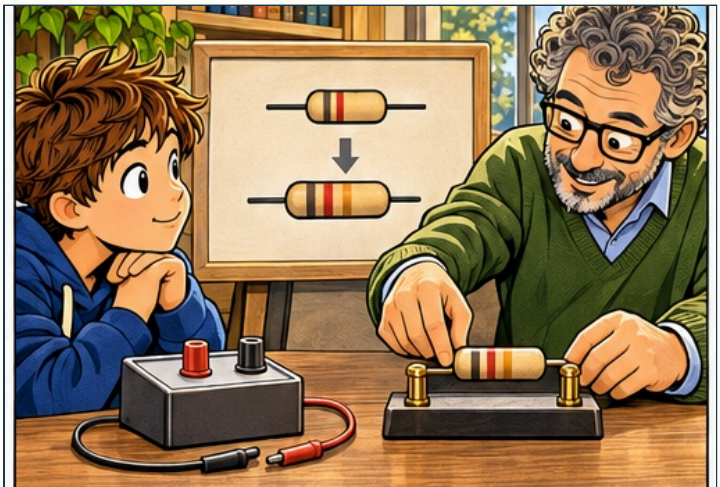
With 3 V and 100 Ω, ideal current is 30 mA.



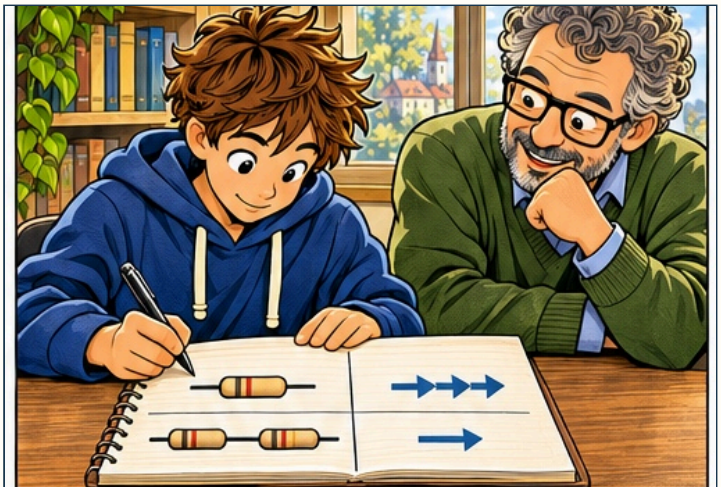
With 3 V and 200 Ω, it will be 15 mA.



Doubling R halves I if U remains constant.



They disconnect the source before replacing the component.

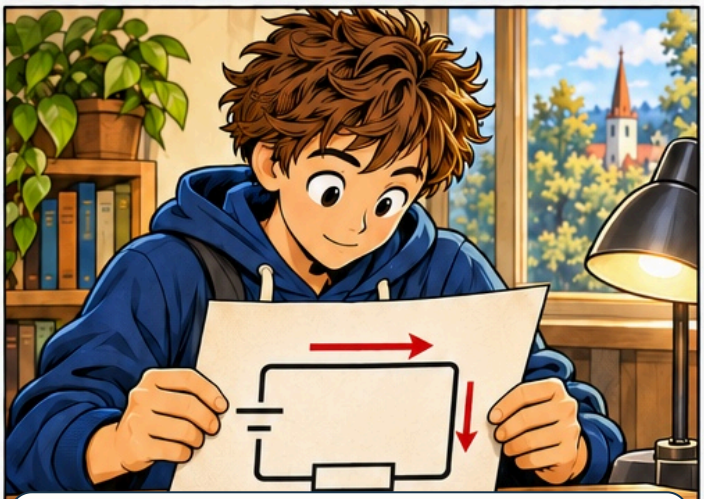


The youngster records his prediction first, then measured values.

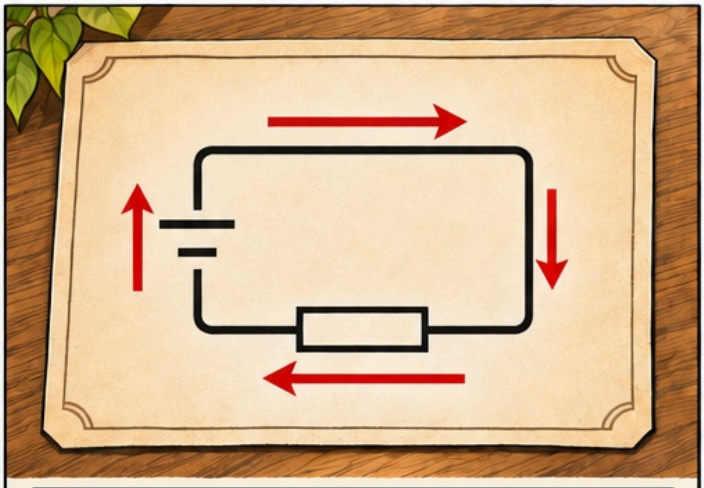
Neither blockage nor storage



Current is not stored in the resistor to emerge later.



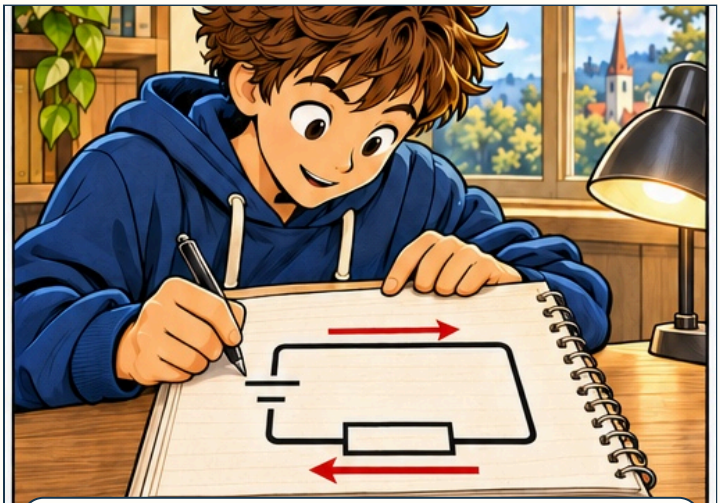
The resistor does not gradually consume current in this loop.



In steady conditions, current is identical before and after it.



Electrical energy is transformed, particularly into heat.

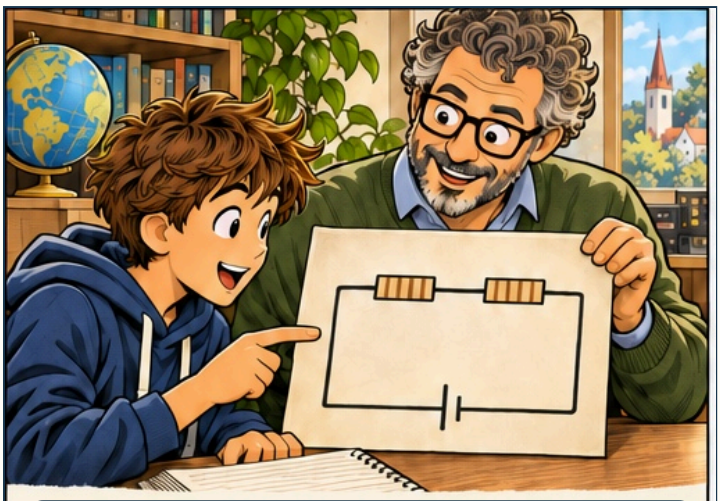


The youngster corrects his first sketch, with arrows shrinking after the component.



His model now better matches his observations.

Two resistors in series



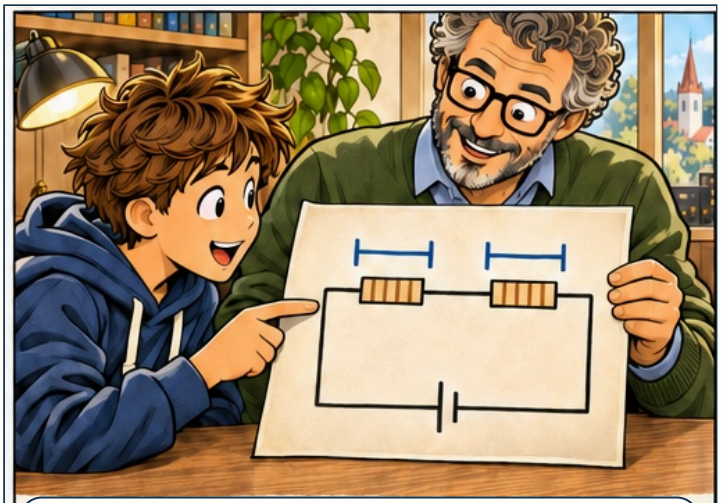
On paper, two 100 Ω resistors sit one after another.



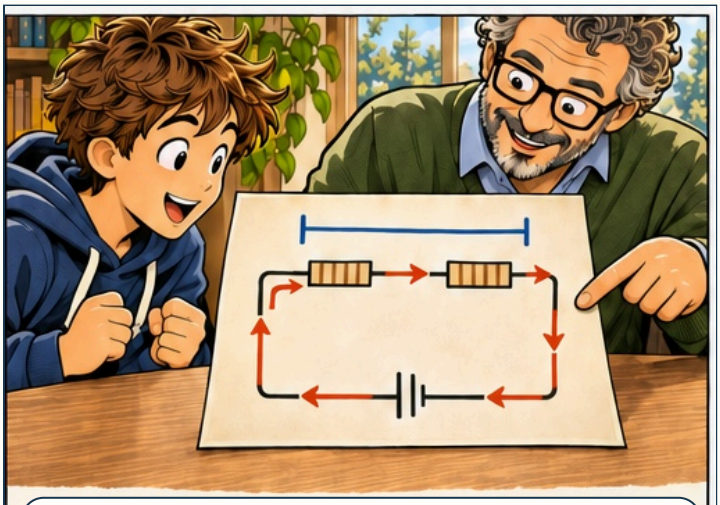
In series, their equivalent resistance is 100 Ω + 100 Ω = 200 Ω.



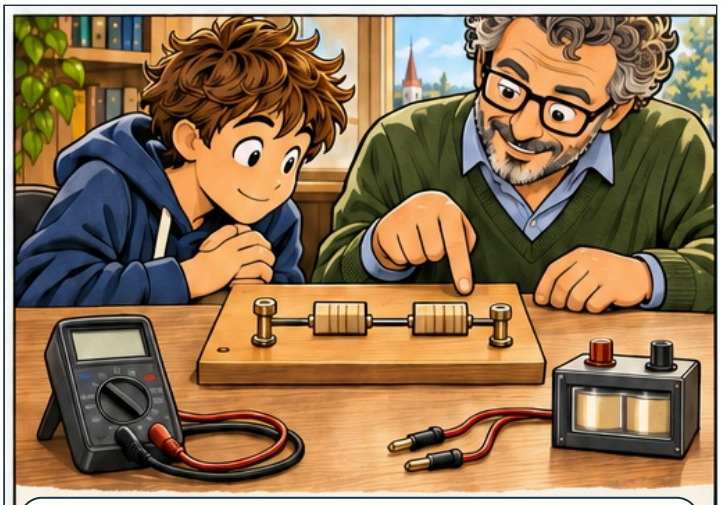
At 3 V, the ideal loop current is therefore 15 mA.



Each resistor then has 1,5 V across its terminals.

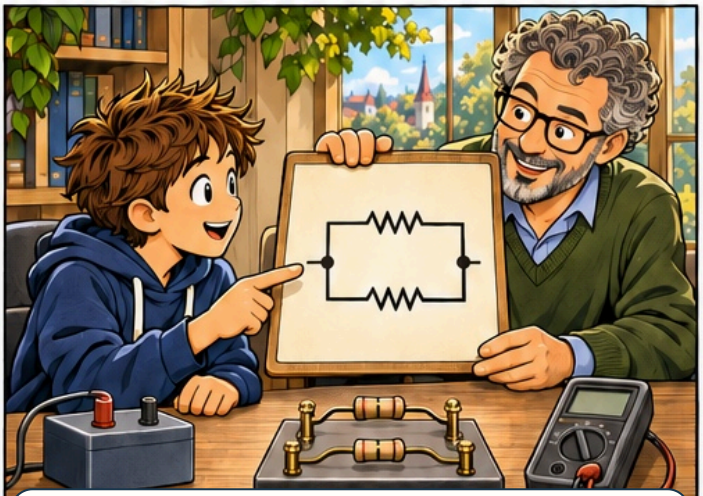


Voltages add; the same current passes through both components.

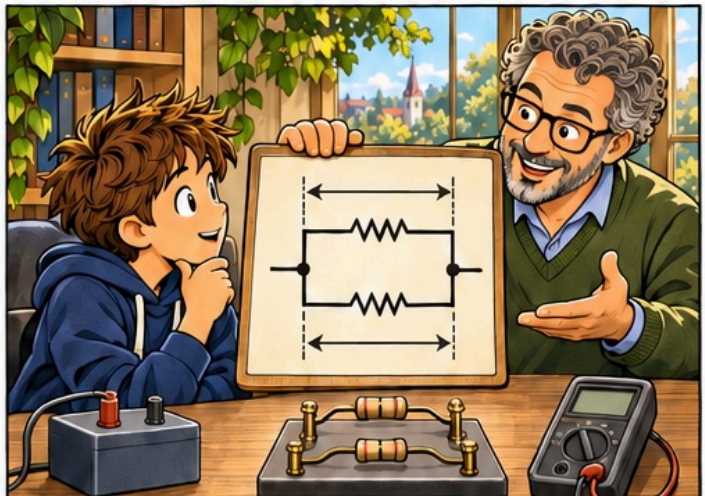


They verify this on suitable equipment, modified with power disconnected.

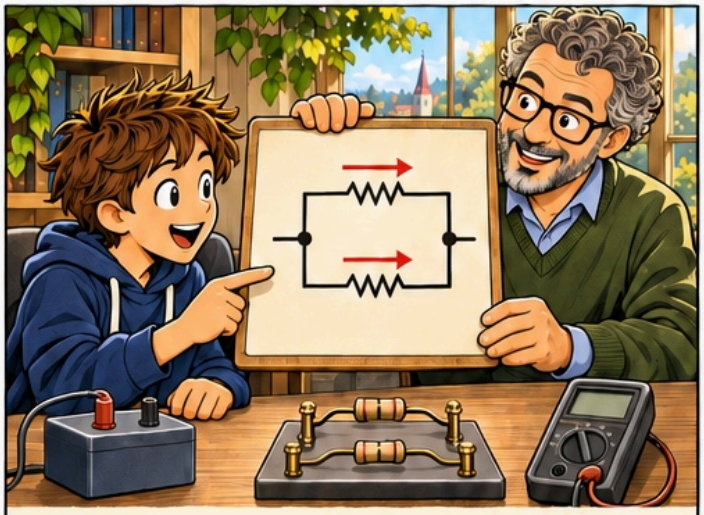
Two parallel paths



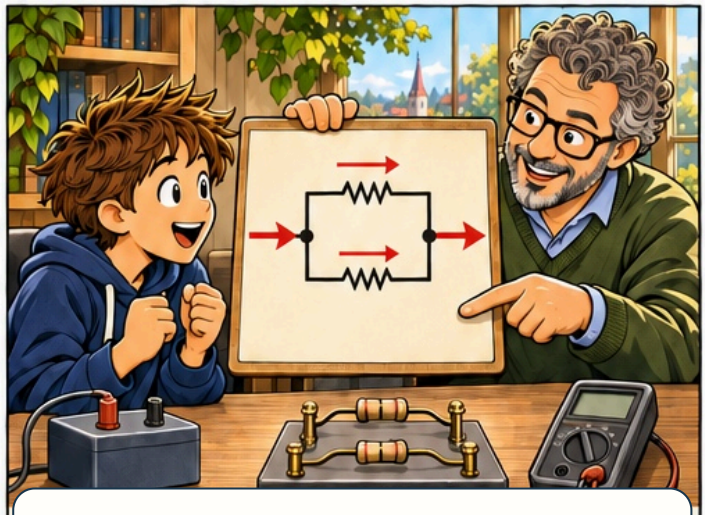
Another drawing places two 100 Ω resistors on parallel branches.



Each branch receives the same 3 V.



Ideally, 30 mA passes through each resistor.



Total current is 60 mA: branch currents add together.

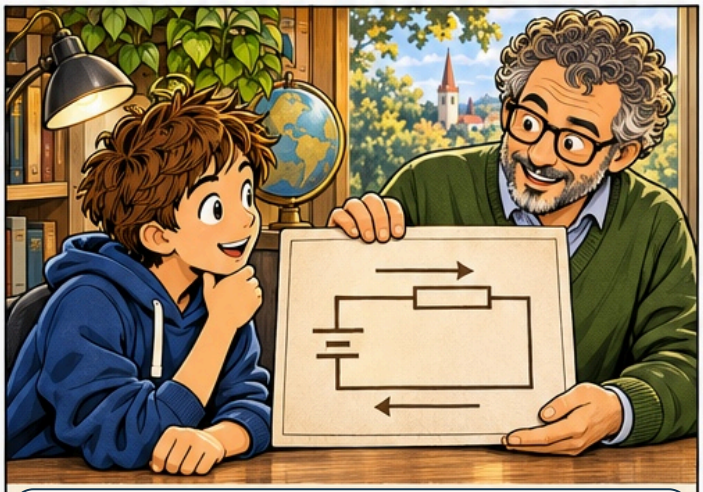


Equivalent resistance is 3 V ÷ 0,060 A = 50 Ω.



This concerns this particular circuit; simply adding resistances cannot give it.

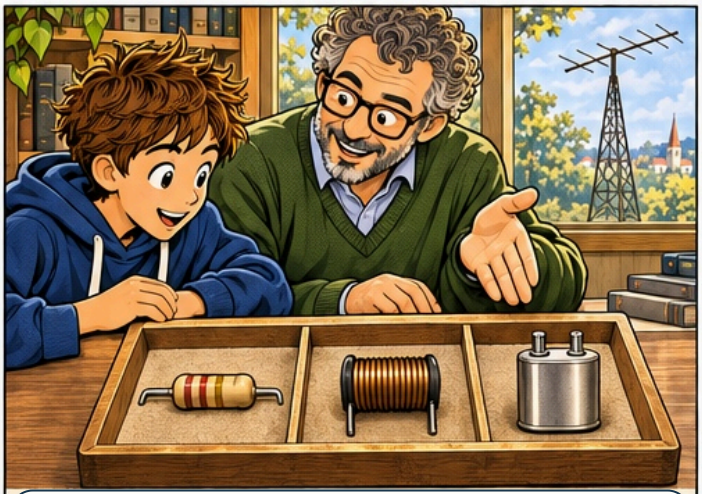
The scope of their model



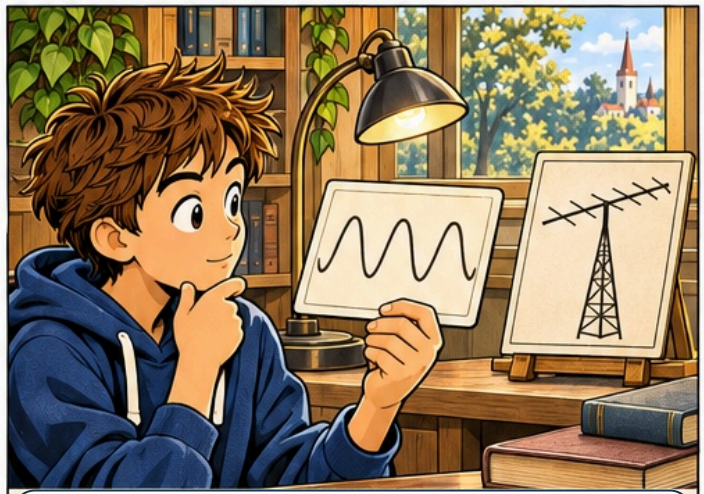
Their calculations concern ohmic resistors in direct current.



Temperature and component characteristics still matter.



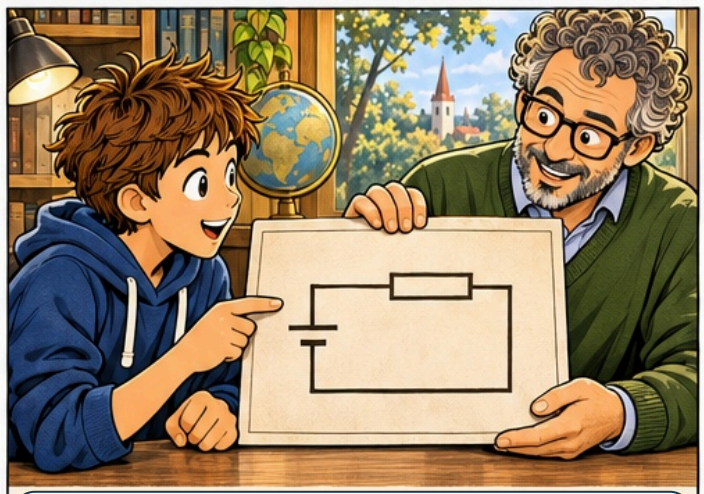
A coil, capacitor or antenna cannot always be reduced to this resistance.



At radio frequencies, other effects lead to impedance.



The youngster saves this new question for another adventure.



Understanding a model includes knowing its limits.

Energy has a calculation too



Their demonstration must also consider dissipated power.



In direct current, P = U × I, with P in watts W.



For 3 V and 0,030 A, P = 0,090 W.



In a resistor, this energy mainly becomes heat.



The component's power rating must be respected.



A small circuit still requires this check.

Choosing a margin



At the planned maximum of 4,5 V, 100 Ω ideally gives 45 mA.



Calculated power is 4,5 × 0,045 = 0,2025 W.



Their 1 W resistor leaves a margin for this prepared trial.



The rating also depends on the manufacturer’s operating conditions.



They never check heating by touching a powered component.



Henri keeps equipment limits central to the choice.

The mysterious resistance



The mentor offers a final puzzle on an example card.



Voltage is 3 V and current 0,020 A in an ohmic resistor.



The youngster calculates R = 3 ÷ 0,020 = 150 Ω.



Then he checks P = 3 × 0,020 = 0,060 W.



He explains every step without guessing the expected answer.



The puzzle demonstrates his method.

When measurement differs slightly



A measured result may differ slightly from the ideal.



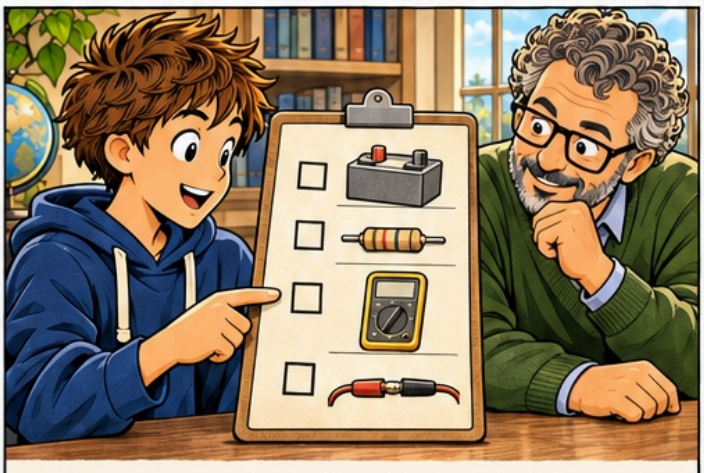
The resistor has tolerance and the source an actual voltage.



The measuring instrument has limits too and can affect the circuit.



Imperfect contacts may also alter the observation.



They compare conditions before declaring the law wrong.



The youngster records an explainable difference instead of altering his reading.

Learning from an error



In a draft, the youngster finds current a thousand times too large.



He does not try obtaining it by changing the source.



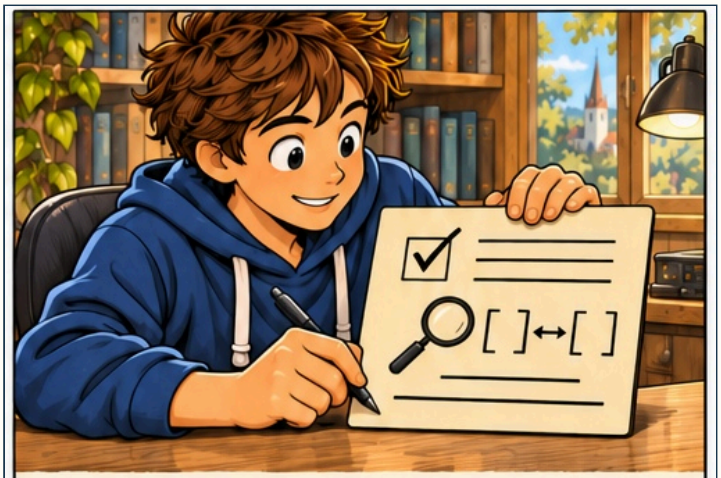
Checking units reveals milliamperes treated as amperes.



The circuit stays disconnected during this check.



After conversion, the values regain a sensible order of magnitude.

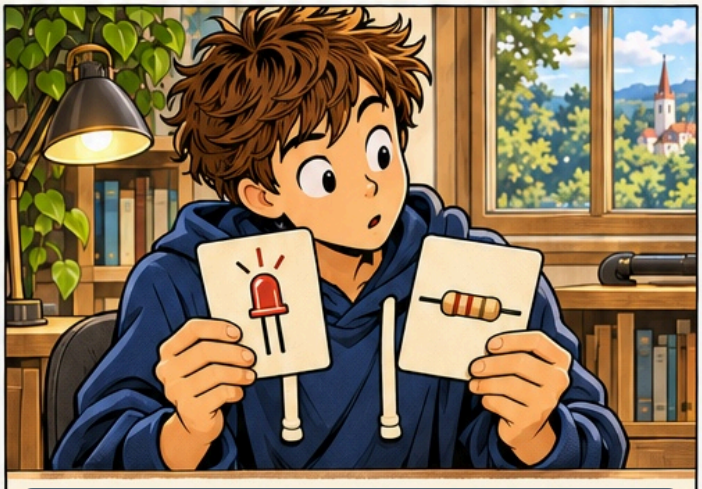


Recognising an error creates a useful reminder.

A diode raises another question



The youngster notices a light-emitting diode in a nearby box.



Can it be treated as a resistor of fixed value?



His mentor explains its nonlinear relationship between voltage and current.



The simple model U = R × I with constant R cannot describe every diode.



They leave it boxed: studying it needs a suitable circuit.



Understanding a law also prevents careless application.

Temperature can matter



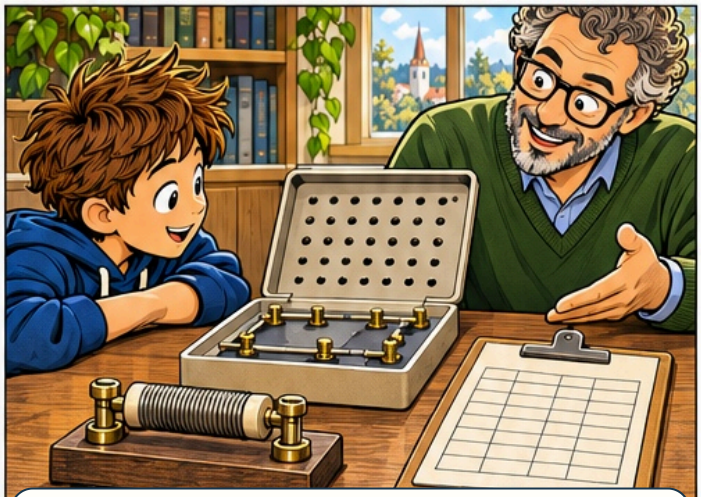
A filament lamp offers another example of different behaviour.



Its resistance changes with temperature.



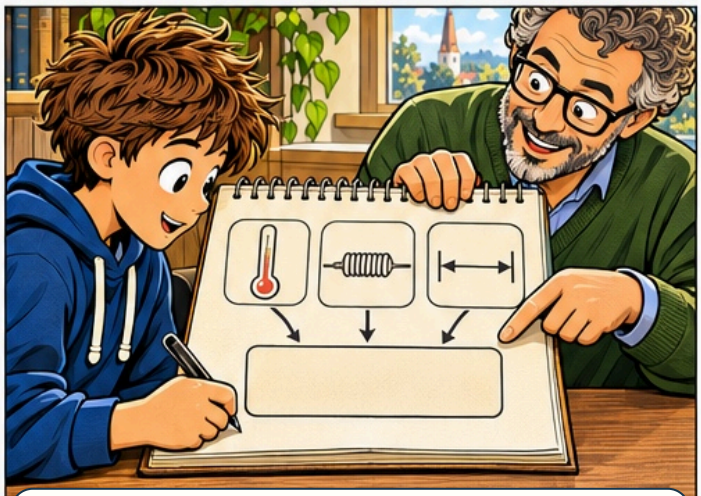
A value deduced at one moment is no universal constant.



Their own resistor must also stay within normal operating conditions.



They conduct no heating experiment to demonstrate this.



The youngster adds conditions beside the formula.

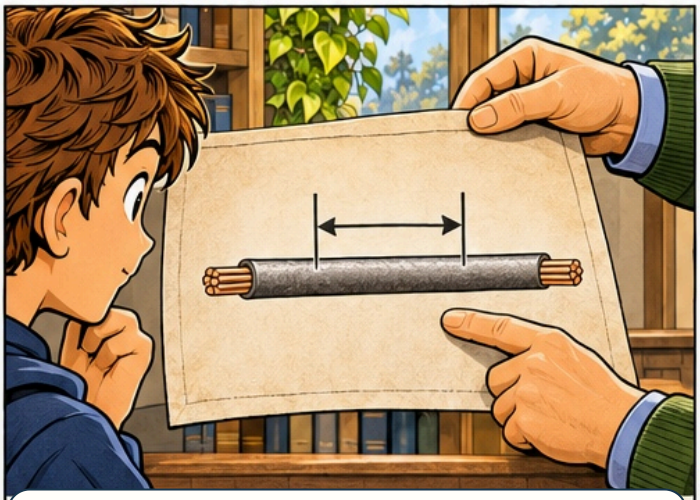
All the way to station wiring



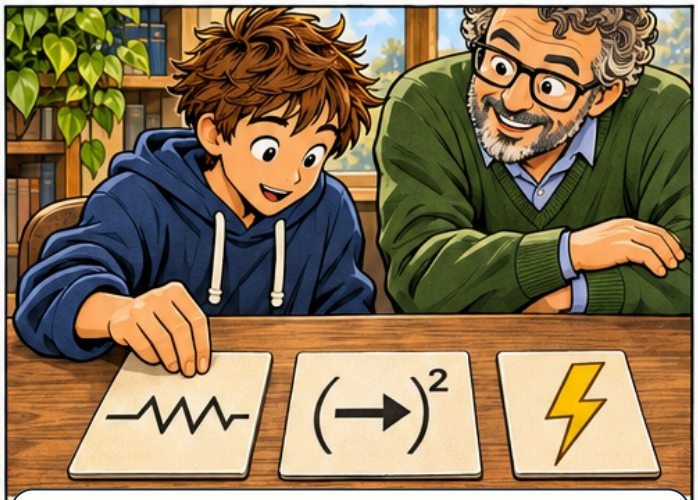
The youngster now looks at his circuit's wires.



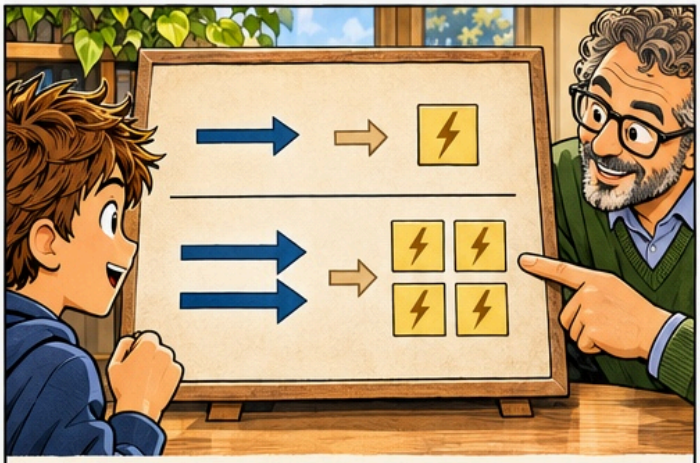
A real conductor can also have resistance.



Current through it then produces a voltage drop.



For a resistance, dissipated power can be written $P = R \times I^2$.



At the same resistance, doubling I quadruples this power.



He better understands suitable cables and connections, without working on the station.

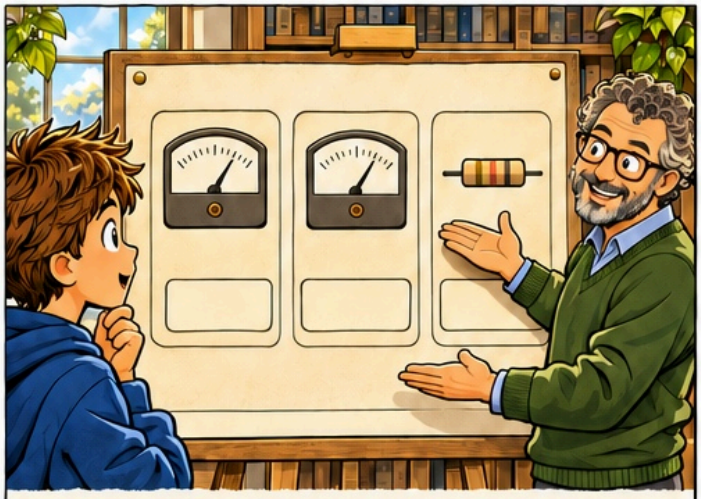
Preparing the demonstration



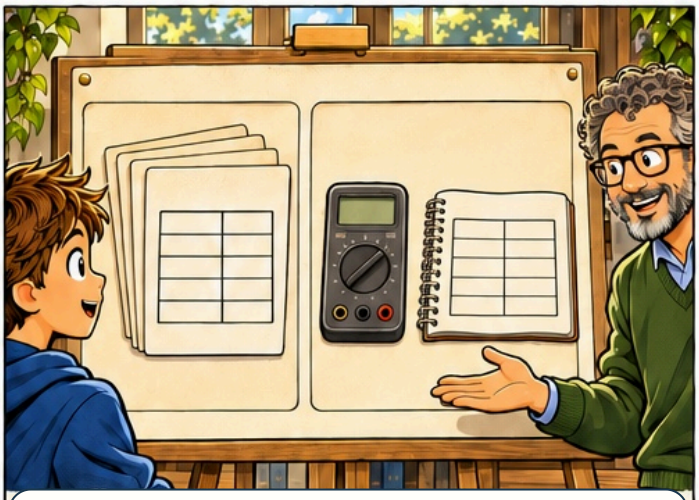
The visitors' activity is approaching.



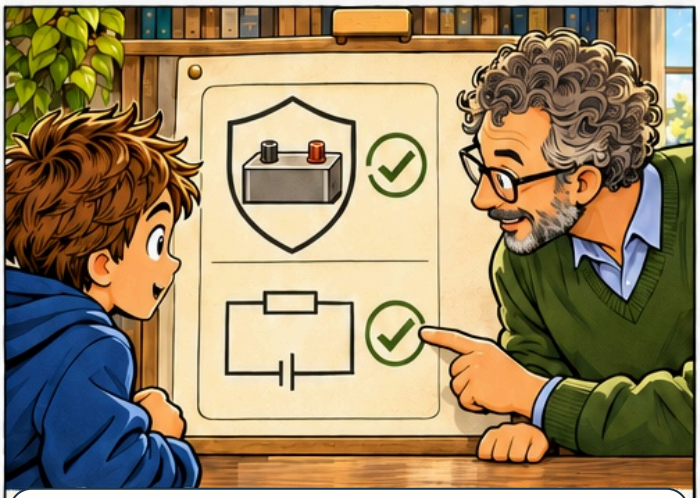
The youngster chooses one circuit to explain the essentials.



He presents U, I and R with their units.



He keeps an ideal example and a separate space for measurement.



Connection instructions and model limits remain visible.



His story will begin with a question, like Ohm's investigation.

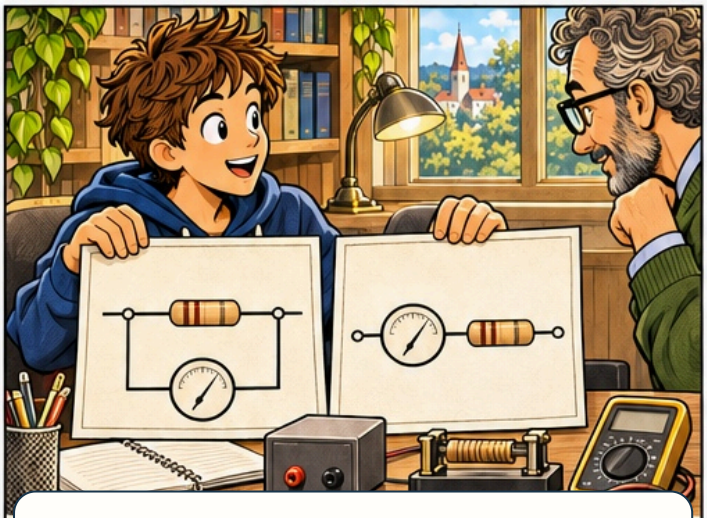
Reviewing together



Henri plays a curious visitor.



Lucas explains why voltage is measured between two points.



He distinguishes voltmeter and ammeter connections.



He recalls that connections change only with the source disconnected.



Then he justifies the resistor and its power rating.



A difficult question helps him make his explanation clearer.

Predict, measure, understand



Rehearsal ends with a trial within prepared limits.



The youngster predicts current from voltage and resistance.



The mentor checks the circuit and supervises measurements.



Then the youngster compares prediction and observation, with their units.



He can now explain a small difference without inventing results.



After the trial, the source is disconnected and equipment stored.

A discovery that travels



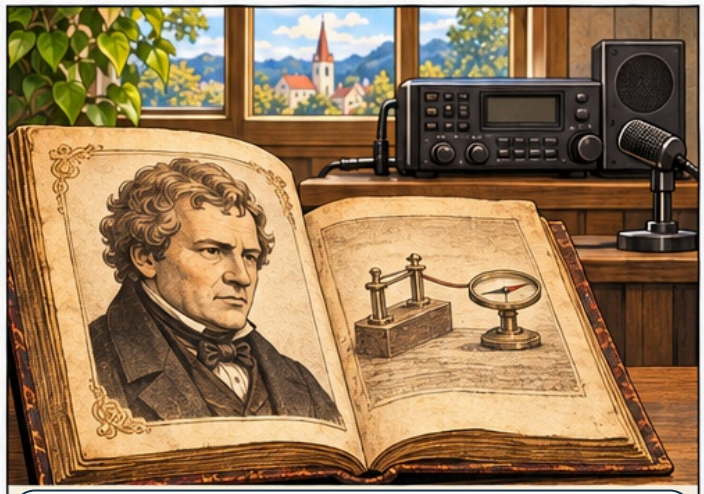
Lucas reopens the book at Georg Simon Ohm.



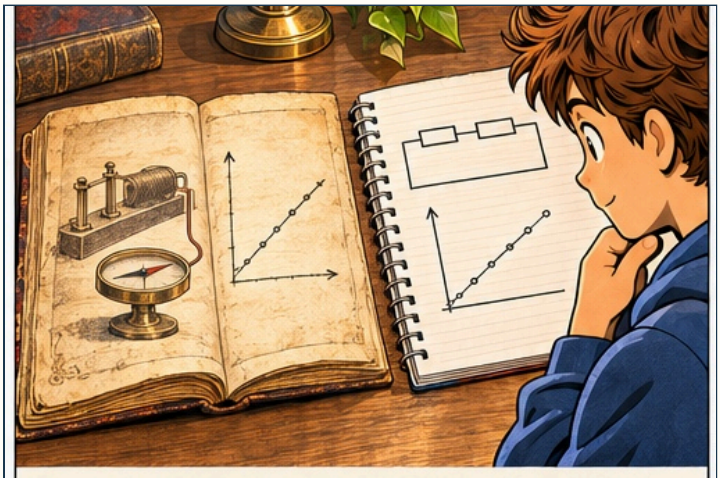
Instruments have changed between the old workshop and the club.



Patient observation nevertheless feels familiar.



Ohm did not build their station, but his work helps explain it.



The modern notebook echoes the scientist's imagined notebook.



An idea travels far when people keep questioning it.

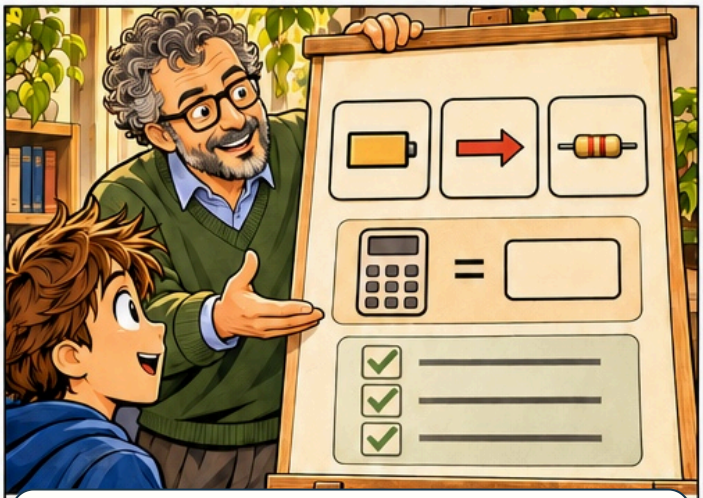
A formula becomes a tool



The small resistor returns to its box, no longer mysterious.



U = R × I now connects quantities the youngster can distinguish.



He can convert, predict, measure and check the model's conditions.



He knows a formula replaces neither method nor equipment limits.



Henri smiles at the demonstration ready to share.



At the club, a new question already awaits his next notebook.