Teacher guide: electric circuits simulation

Quick reference

The electric circuits simulation builds direct current circuits with a battery, a switch and bulbs or resistors, and shows the voltage, current and power for each component, with the electrons moving through the wires. It has three modes: Ohm's law with one component and measuring instruments, components in series and components in parallel. Its main use is in ESO 2 and ESO 3 (Years 9 and 10 in the UK, 8th and 9th grade in the US), with occasional use in ESO 4.

Item	Details
Link	simulaciencia.es/en/simulations/circuitos/
Year groups	ESO 2 and ESO 3 (main use); occasional use in ESO 4
Subject	Physics and Chemistry
Suggested time	15–20 minutes of explanation with the simulation projected
Equipment	Projector or interactive whiteboard; runs in the browser, also on phones and tablets, with nothing to install. On narrow screens the controls move to the top and the canvas below; a large screen is better for explaining
Prior knowledge	Matter is made of atoms with electrons. For ESO 3, rearranging a formula with three quantities and reading a graph
Accessibility	Dark, light and high-contrast themes (gear button). “Electrons” button to hide the animation. Everything that can be tapped in the circuit can also be done from the panel

How the simulation works

The simulation has three modes, “Ohm's law”, “Series” and “Parallel”, chosen at the top of the left-hand panel. All three show the circuit at the top and, below it, a graph or some bar charts. Changes appear instantly: there is no button to press to make the circuit “work”.

Mode	What the teacher controls	What it shows
Ohm's law	“Resistance (R)” from 5 to 100 Ω, in steps of 5 (it starts at 20 Ω). The “▮ Record reading” and “Clear readings” buttons	A battery, a switch, an ammeter in series and a component with a voltmeter in parallel. Each instrument has a display with its reading. Below, the “CURRENT – VOLTAGE GRAPH” and the “OHM'S LAW” box with the calculation, for example “I = 6.00 V / 20 Ω = 0.300 A”
Series	“Number of components” (2 or 3), “Resistance R_1”, “R_2” and “R_3” from 5 to 100 Ω (they start at 10, 20 and 30 Ω) and the “Connected components” buttons R_1, R_2 and R_3	The components one after another along the top wire. Next to each one, its R, V, I and P. Below, the “VOLTAGES (V)” and “CURRENTS (A)” charts
Parallel	The same controls as in series	Each component on its own branch, between the top wire and the bottom wire, with its values alongside and the same bar charts

Mode	What the teacher controls	What it shows
In all three modes	“Battery voltage” from 0 to 12 V, in steps of 0.5 (it starts at 6.0 V). The switch. “Type of component”: “Bulbs” or “Resistors”	The bulbs glow brighter the more power they have; the resistors glow red hot. With the circuit open, the message “Open circuit: no current flows (I = 0).” appears

The switch is opened and closed from the panel or by tapping it in the circuit. In series and in parallel, a component is removed and put back with the “Connected components” buttons or by tapping it in the circuit; in its place the two empty terminals remain, with the label “bulb removed” or “resistor removed”.

Four elements support the explanation:

- **The electrons.** Blue dots with a “−” sign travel along the wires from − to +, faster where the current is greater. They are always in every wire: when the circuit is opened they stop, but they do not disappear. An orange arrow with “I = …” marks the conventional direction of the current, from + to − outside the battery. The “Electrons” button, at the top right of the canvas, hides them.
- **The labels in the circuit.** The battery shows its voltage and its terminals. Each component shows “R_1 = 10 Ω” and below it (or to its right) “V_1”, “I_1” and “P_1”. With the switch open and a single gap in the circuit, the voltage across its ends can be read, for example “V = 6.00 V”.
- **The I–V graph.** In “Ohm's law” mode each recorded reading is a point. Each resistance has its own colour and its own straight line I = V / R; the current component's line is dashed and a circle marks the point where it is operating. The current scale adjusts itself.
- **The bar charts.** In series and in parallel there is one bar per component and one more for the battery (voltages) or the total (currents). When the last bar is the sum of the others, it is drawn stacked with the pieces V_1, V_2, V_3 or I_1, I_2, I_3. At the top right it shows the rule that holds, for example “$V = V_1 + V_2 + V_3$”.

The “Circuit readings” drop-down is open at the start. It gives the voltage, the total current and the resistance (the “Equivalent R” in series and in parallel), a “Components” table with R, V, I and P for each one and for the total, and a sentence summarising what is happening. In “Ohm's law” mode it adds the “Table of readings”, with up to 12 rows and the V / I column. The “Key formulas” drop-down collects I = q / t, V = I · R and its rearrangements, P = V · I, the rules for series and parallel, and the units. In the header, “Description and quick rules” summarises the three key rules.

Use in each year group

In ESO 2 the simulation is used to present the electric circuit, its elements and the fundamental electrical quantities with their units and measuring instruments. In ESO 3 it works on Ohm's law, basic circuits and combining resistors in series and in parallel. In ESO 4 its use is occasional, for power and energy consumed. The curriculum content and assessment criteria quoted are from the LOMLOE Physics and Chemistry curriculum of the Community of Madrid (Spain), in our own translation.

ESO 2: the circuit and electrical quantities

Ages 13–14 · Year 9 in the UK · 8th grade in the US

Curriculum content. Block E: “Considering the electrical nature of matter and how electrical energy is obtained from different energy sources. Fundamental electrical quantities. Units of measurement. Direct current”. Block A: “the laboratory and virtual environments”, “Measuring instruments” and “units of the International System and their symbols. Measuring quantities”.

Assessment criteria. 1.1 (identifying everyday physical and chemical phenomena using appropriate scientific terminology), 3.1 (using data in different formats to interpret and communicate information) and 3.2 (identifying basic laboratory materials and instruments).

Objectives. Recognise the elements of a circuit and their symbols. Distinguish voltage, current and resistance, with their units. Know how the ammeter and the voltmeter are connected. Explain direct current as electrons moving in one direction only.

Teaching sequence (15–20 min).

1. "Ohm's law" mode with the starting values. Point out the battery, the switch, the wires and the bulb, and draw their symbols on the board. The long plate of the battery is the + terminal.
2. Open the switch. The bulb goes out and the electrons stop, but they are still in the wires: they do not come out of the battery, they were already there. The ammeter reads 0.000 A. Close it again.
3. Read the instruments. The ammeter, in series, measures the current: 0.300 A. Explain that current is the charge that passes each second ($I = q / t$): 0.3 C every second, 18 C in a minute. The voltmeter, in parallel with the bulb, measures the voltage: 6.00 V. Write down the units: volt (V), ampere (A) and ohm (Ω).
4. Raise the "Battery voltage" to 12 V. The current doubles (0.600 A), the electrons go twice as fast and the bulb glows brighter. Lower it to 0 V: the battery does not push the electrons and there is no current.
5. Explain direct current: the electrons always move in the same direction, from − to +. By convention, the direction of the current is the opposite, from + to −, as the orange arrow shows.
6. Switch to "Series" and then to "Parallel" and remove bulb R_2 in each. In series all of them go out; in parallel the others stay on. Ask how the lights at home are connected.

ESO 3: Ohm's law and combining resistors

Ages 14–15 · Year 10 in the UK · 9th grade in the US

Curriculum content. Block E: "The electrical nature of matter: charging objects and electric circuits", "Electricity as the movement of electric charges. Ohm's law. Basic electric circuits. Combining resistors. Applications of electricity in everyday life". Block A: "Recording data and results using tables, graphs and mathematical expressions" and "Applying the scientific method to simple experiments".

Assessment criteria. 1.2 (solving problems with the appropriate laws, reasoning through the procedures and expressing the results), 2.1 (using the methods of science, including logical-mathematical reasoning), 3.1 (using data in different formats) and 3.2 (using units of measurement and mathematical tools correctly).

Objectives. Verify Ohm's law experimentally and represent it on a graph. Solve problems with $V = I \cdot R$. Calculate the equivalent resistance of two or three resistors in series and in parallel. Explain how the voltage and the current are shared out in each arrangement.

Teaching sequence (15–20 min).

1. "Ohm's law" mode with R = 20 Ω. Ask the question: how does the current change when the voltage changes? Take the voltage to 2, 4, 6, 8, 10 and 12 V and press "▮ Record reading" at each one. The table gives 0.100, 0.200, 0.300, 0.400, 0.500 and 0.600 A, and the V / I column is always 20 Ω.
2. Look at the graph: the points form a straight line through the origin. Voltage and current are proportional and the constant is the resistance: $V = I \cdot R$.
3. Change to R = 40 Ω and record 4, 8 and 12 V: 0.100, 0.200 and 0.300 A. The new line has half the gradient (0.025 A/V against 0.050 A/V): with more resistance, less current flows for the same voltage.

4. Set a problem: what resistance lets 0.240 A flow with a 12 V battery? R = 12 / 0.24 = 50 Ω. Check it with the slider.
5. “Series” mode with the starting values (6.0 V; 10, 20 and 30 Ω). The current is the same in all three, 0.100 A, and the voltages, 1, 2 and 3 V, add up to the battery's 6 V: the “battery” bar is stacked. Equivalent R = 10 + 20 + 30 = 60 Ω and I = 6 / 60 = 0.100 A. Remove R_2: the only path is broken and no current flows through any of them; there are 6.00 V across the empty terminals.
6. “Parallel” mode with the same values. They all have 6 V and the currents, 0.600, 0.300 and 0.200 A, add up to 1.100 A. 1 / equivalent R = 1/10 + 1/20 + 1/30, so equivalent R = 5.45 Ω, less than the smallest one. Remove R_2: the other branches do not change and the total current drops to 0.800 A (equivalent R = 7.5 Ω).

ESO 4: occasional use

Ages 15–16 · Year 11 in the UK · 10th grade in the US

Block E includes “Work and mechanical energy. Power” and “Energy in our world: estimating the energy consumed in everyday life by searching for reliable information, experimenting and scientific reasoning”. The simulation gives the power of each component ($P = V \cdot I$) and can be used to estimate the energy consumed with $E = P \cdot t$. For example, the bulb in “Ohm's law” mode with 6 V and 20 Ω uses 1.80 W; in one hour that is 1.80 × 3600 = 6480 J. With three identical 20 Ω bulbs at 6 V, in parallel each one uses 1.80 W and in series only 0.20 W: nine times less, which is why they glow much more dimly in series. It does not deal with energy in kWh or the cost on the bill.

Misconceptions it helps to address

The simulation mainly tackles the idea that current “gets used up” as it passes through the components and the idea that the battery always gives the same current. Each row gives a common prior idea and how to break it down with the simulation.

Students' idea	Correct idea	How to show it
“Current gets used up in the bulbs: less reaches the last one”	In series the current is the same at every point in the circuit; what is transformed is energy	“Series” mode: $I_1 = I_2 = I_3$ = 0.100 A and the electrons move just as fast before and after each bulb
“Electrons come out of the battery and take time to reach the bulb”	The electrons are already in every wire; the battery sets all of them moving at once	Open and close the switch: the electrons stop and start all round the circuit at the same time
“The battery always gives the same current”	The battery maintains the voltage; the current depends on the resistance of the circuit	With 6 V: 0.300 A with one 20 Ω component, 0.100 A with three in series and 1.100 A with three in parallel
“More bulbs means more resistance”	In series the equivalent resistance increases; in parallel it decreases	Parallel with 2 components: 6.67 Ω and 0.900 A; with 3: 5.45 Ω and 1.100 A
“If one bulb blows, they all go out”	Only in series; in parallel each branch is independent	Remove R_2 in “Series” and in “Parallel”
“Voltage and current are the same thing”	There can be a voltage without a current	“Ohm's law” mode with the switch open: the ammeter reads 0.000 A and “V = 6.00 V” can be read below the switch
“The bulb with more resistance always glows more dimly”	In series the one with the highest resistance glows brightest ($P = I^2 \cdot R$); in parallel, the one with the lowest	Starting values: in series R_3 glows brightest (0.30 W); in parallel, R_1 (3.60 W)

Students' idea	Correct idea	How to show it
“Electrons go from + to −, like the current”	The conventional direction is from + to −; electrons go from − to +	The orange arrow and the blue electrons go in opposite directions

Simplifications worth knowing

The simulation makes sure the rules for series and parallel can be seen, and to do so it treats every element as ideal. It is worth knowing about these liberties so as not to reinforce wrong ideas by accident.

1. **Ideal battery.** It has no internal resistance: it always gives its voltage, whatever current flows. With three 5 Ω components in parallel at 12 V, 7.2 A flows, which a real battery could not sustain. Short circuits and fuses are not simulated.
2. **Ohmic components.** The bulbs have a constant resistance. In a real filament bulb the resistance increases a lot as it heats up, so its I–V graph is not a straight line. Ohm's law holds well for resistors at constant temperature.
3. **Ideal wires, switch and instruments.** The wires and the switch have no resistance; nor does the ammeter, and the voltmeter lets no current through.
4. **Electron speed not to scale.** The electrons in a real wire drift on average fractions of a millimetre per second. In the animation the speed is proportional to the current (70 px/s per ampere) with a cap from about 4.6 A upwards so that they can be followed by eye. The spacing between electrons is always the same.
5. **Approximate brightness.** The brightness increases with power but saturates (P / (P + 0.5 W)), so that both 0.1 W and 3 W can be told apart. It is not a measurement of the light emitted.
6. **Voltage across gaps.** With a single gap in series (a component removed or the switch open), the whole battery voltage is across its ends. With two gaps at once that voltage is not defined in an ideal circuit and “—” is shown.
7. **Direct current only.** There is no alternating current, no 230 V mains and no consumption in kWh. The resistances go in steps of 5 Ω and the voltage in steps of 0.5 V.

Student activity worksheet

The activity worksheet follows a predict, observe and explain structure. Each activity links to the simulation already set up, so it works in the computer room, with tablets or as homework. It downloads in Word and LibreOffice formats so it can be adapted.

Year group	Activities	Suggested time
ESO 2 (Year 9)	Before you start, activities 1, 2 (without the last column) and 6, Review your ideas and Self-assessment	One 50–55 minute lesson
ESO 3 (Year 10)	The whole worksheet except Going further	Two lessons, or one if the problems are set as homework
ESO 4 (Year 11)	Activities 4 to 6 and Going further, as revision with power and energy	One lesson

The “Before you start” table collects six prior ideas about electric current. It is best not to correct it at the beginning: students come back to it in “Review your ideas”. The values in the simulation are exact, so the answers are too.

Answers

Section	Answer
Before you start	All false. a) In series the current is the same in every bulb (activity 4). b) The electrons are already in all the wires and start moving at the same time (activity 1). c) The current depends on the resistance (activity 3). d) In parallel the equivalent resistance decreases (activity 5). e) Only in series; in parallel the others stay on (activities 4 and 5). f) With the switch open there is a voltage, but no current (activity 1)
Activity 1	Battery: gives the energy that moves the electrons; 6 V with the switch closed and open. Ammeter: measures the current, in series; 0.300 A closed and 0.000 A open. Voltmeter: measures the voltage across the bulb, in parallel; 6.00 V closed and 0 V open (the battery voltage appears across the terminals of the switch). The electrons stop, but they stay in the wires. The ammeter has to let all the current pass through it; the voltmeter compares two points of the circuit. Electrons move from − to +; by convention, the current goes from + to −
Activity 2	0.100, 0.200, 0.300, 0.400, 0.500 and 0.600 A; V / I = 20 Ω every time. The graph is a straight line through the origin: V and I are directly proportional. The constant is the resistance: $V = I \cdot R$
Activity 3	10 Ω: 0.600 A and 3.60 W. 20 Ω: 0.300 A and 1.80 W. 30 Ω: 0.200 A and 1.20 W. 60 Ω: 0.100 A and 0.60 W. As R increases, the current and the brightness decrease. The battery keeps the voltage; the current depends on the resistance: $I = V / R$
Activity 4	R_1: 10 Ω, 1 V, 0.100 A, 0.10 W. R_2: 20 Ω, 2 V, 0.100 A, 0.20 W. R_3: 30 Ω, 3 V, 0.100 A, 0.30 W. Total: 60 Ω, 6 V, 0.100 A, 0.60 W. When R_2 is removed they all go out: the only path is broken and there are 6.00 V across the empty terminals. The current is the same in all of them: current is not used up; what is transformed is the energy. $V = V_1 + V_2 + V_3$ and equivalent $R = R_1 + R_2 + R_3$
Activity 5	R_1: 10 Ω, 6 V, 0.600 A, 3.60 W. R_2: 20 Ω, 6 V, 0.300 A, 1.80 W. R_3: 30 Ω, 6 V, 0.200 A, 1.20 W. Total: 5.45 Ω, 6 V, 1.100 A, 6.60 W. When R_2 is removed the others stay the same and the total current falls to 0.800 A (7.5 Ω). They all have the battery voltage; $I = I_1 + I_2 + I_3$. The equivalent R is smaller than the smallest of them: each new branch is one more path for the current
Activity 6	Series: 2 V, 0.100 A and 0.20 W each; total 0.100 A; when one is removed they all go out. Parallel: 6 V, 0.300 A and 1.80 W each; total 0.900 A; the others stay on. Homes are wired in parallel: each appliance gets the full mains voltage and works even if another is switched off or breaks
Apply what you have learnt	1) $I = 9 \text{ V} / 30\ \Omega = 0.300$ A. 2) $R = 12 \text{ V} / 0.240 \text{ A} = 50\ \Omega$. 3) $R = 15 + 45 = 60\ \Omega$; $I = 12 / 60 = 0.200$ A; $V_1 = 0.2 \cdot 15 = 3$ V and $V_2 = 0.2 \cdot 45 = 9$ V (they add up to 12 V). 4) $I_1 = 12 / 15 = 0.800$ A; $I_2 = 12 / 45 \approx 0.267$ A; $I = 1.067$ A; $R = 12 / 1.067 \approx 11.25\ \Omega$ (or $1/R = 1/15 + 1/45$)
Going further	1) $E = 1.80 \text{ W} \cdot 3600 \text{ s} = 6480$ J. 2) Nine times: in parallel each bulb has three times the voltage and three times the current it has in series (1.80 W compared with 0.20 W). 3) In series R_3 shines most (0.30 W), the one with the most resistance, because $P = I^2 \cdot R$ with the same I; in parallel R_1 shines most (3.60 W), the one with the least resistance, because $P = V^2 / R$ with the same V. It is not true in series

Juan Ramón Grijota · SimulaCiencia. Guide published under a CC BY-SA 4.0 licence: you may adapt and share it, crediting the author and keeping the same licence. Latest version and simulation at simulaciencia.es/en/guides/circuitos/.