Teacher guide: changes of state simulation

Quick reference

The simulation heats or cools a substance and shows the container, its particles and the temperature–time curve at the same time, with a second mode for the phase diagram of water, CO_2 and iodine. 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 the phase diagram as a resource for ESO 4.

Item	Details
Link	simulaciencia.es/en/simulations/cambios-estado/
Year groups	ESO 2 and ESO 3 (main use), ESO 4; occasional review in Bachillerato 1 and Bachillerato 2 Chemistry
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. The point on the diagram can be dragged with a finger
Prior knowledge	States of matter at an intuitive level, temperature in °C, reading a graph. In ESO 4, pressure in atm
Accessibility	Dark, light and high-contrast themes (gear button). The messages in the top strip are read out by screen readers

How the simulation works

The simulation has two modes, “Heat and cool” (heating curve) and “Pressure and temperature” (phase diagram), chosen at the top of the left-hand panel. The first shows three panels: “WHAT WE SEE” (container, hotplate and thermometer), “WHAT WE CANNOT SEE” (64 particles and a legend of states) and “THE GRAPH”. The second shows the diagram, the particle window and the “THINK AND CHECK” panel. In both, a strip at the top explains in one sentence what is happening.

Mode	What the teacher controls	What it shows
Heat and cool	Substance (Water, Alcohol (ethanol), Nitrogen, Iron, Dry ice (CO_2)). Bar above the simulation: “Restart”, hotplate “❄ Cool”, “Off” or “🔥 Heat” and speed ×1, ×2 or ×4. In the panel, hotplate power from −100 % (cool) to +100 % (heat) in steps of 5; it starts at +50 %. “Off” keeps the temperature fixed while the particles keep moving, so you can explain calmly. R key to restart	The container with solid, liquid, bubbles or droplets on the lid. The thermometer with the melting and boiling marks (sublimation for dry ice). The temperature–time graph with each plateau labelled. The Temperature, Time, Plate and “State of the substance” cards

Mode	What the teacher controls	What it shows
Heat and cool, particle view	“Show the attractions between particles” and “Show the speed (trails)” checkboxes	The same 64 particles in every state: a 16 × 4 lattice at the bottom that vibrates, particles that slide around or free particles. Water is drawn as an H_2O molecule, nitrogen as N_2 and dry ice as CO_2; alcohol and iron as spheres. The molecules wobble in the solid and rotate in the liquid and the gas. The attractions are strong in the solid, weak in the liquid and absent in the gas
Pressure and temperature, water	Temperature from −40 to 160 °C. Pressure from 0.003 to 5 atm on a logarithmic scale. Examples “Sea level”, “Top of Everest”, “Pressure cooker” and “Triple point”. The point can also be dragged	The SOLID, LIQUID and GAS regions, the 1 atm line with “melts at 0 °C” and “boils at 100 °C”, and the triple point. The “At this pressure, the substance…” card gives the temperatures of the changes at that pressure
Pressure and temperature, CO_2	Temperature from −120 to 30 °C. Pressure from 0.30 to 100 atm. Examples “Dry ice”, “Open air”, “CO_2 extinguisher” and “Triple point”	The same diagram for CO_2, with its triple point at 5.11 atm and −57 °C. At 1 atm it shows “sublimes at −78 °C”
Pressure and temperature, iodine	Temperature from 20 to 220 °C. Pressure from 0.0003 to 5 atm. Examples “In the lab”, “At low pressure”, “Molten iodine” and “Triple point”	The iodine diagram, with its triple point at 0.12 atm and 113.5 °C. At 1 atm it melts at 114 °C and boils at 184 °C; below 0.12 atm it sublimes

Four elements support the explanation:

- **The plateau on the graph.** During melting and boiling the curve goes flat and the label “constant temperature” appears. The thermometer stops at the same time.
- **The energy bar.** The “Where did the energy supplied go?” card has two parts: “Raising the temperature” and “Separating the particles”. It only counts the energy that has gone in since “Restart”, so it starts at 0 %. During a plateau only the second part grows. If more energy has been removed than went in, it changes to “Where did the energy removed come from?”.
- **The double view.** What happens in the container appears in the particles at the same time. The composition bar under the hotplate and the legend give the percentage of solid, liquid and gas.
- **The point on the diagram.** When it crosses a line, the strip names the change (MELTING, VAPORISATION, SUBLIMATION…). It also says whether it was caused by heating or by changing the pressure. On a line, it says which states coexist.

The “Key concepts” drop-down summarises the six changes of state and three ideas: constant temperature during the change, temperatures characteristic of each substance, and particles that do not change. In diagram mode, “How to read a phase diagram” explains regions, lines, the triple point and the compressed scale.

Use in each year group

In ESO 2 the simulation is used to introduce the states of matter and changes of state with the kinetic theory; in ESO 3, to go deeper into the kinetic-molecular model and the energy involved in the changes; in ESO 4, to relate changes of state to pressure. The curriculum content quoted is from the LOMLOE Physics and Chemistry curriculum of the Community of Madrid (Spain), in our own translation.

ESO 2: states and changes of state

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

Curriculum content. Block A: “Graphical representation of results” and “the laboratory and virtual environments”. Block B: “Introduction to the kinetic-molecular theory. States of matter”. Block E: “Temperature. Temperature scales. The concept of heat” and “Effects of heat on matter: changes of state and expansion”.

Objectives. Describe solid, liquid and gas with the particle model. Name the six changes of state. Recognise that the temperature does not change during melting and boiling. Associate each substance with its melting and boiling points.

Teaching sequence (15–20 min).

1. Heat and cool mode with water (starting set-up). Press “Off”: ice at about −20 °C. Show the magnifier: ordered particles vibrating in place. Read the “SOLID” legend.
2. Choose speed ×2, raise the hotplate to +50 % and press “Restart”: the ice goes back to −20 °C and the time to 0. Ask what the thermometer will read while the ice melts. At 5 min on the Time card it reaches 0 °C.
3. Point out the plateau: the temperature stays at 0 °C until 33 min. In the magnifier the particles leave the lattice; in the container the ice floats and gets smaller.
4. The liquid warms up to 100 °C at 85 min; on the graph it rises more slowly than the ice did. Ask what the bubbles are. The magnifier shows they are the same particles, now separated. The plateau lasts until 137 min.
5. Let the steam keep heating above 100 °C: the temperature rises again. On reaching 250 °C, the top of the thermometer, the hotplate switches itself off and “LIMIT” appears. Set the hotplate to −50 %: droplets on the lid (condensation) and then freezing. Open “Key concepts” and name the six changes.
6. Switch to Alcohol (melts at −114 °C, boils at 78 °C) and to Nitrogen (−210 °C and −196 °C). The curve has the same stages and its plateaus last the same time; what changes is the temperatures. Conclude that these are characteristic properties.

ESO 3: kinetic-molecular model and the energy of the changes

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

Curriculum content. Block A: “Recording data and results using tables, graphs and mathematical expressions”. Block B: “Further study of the kinetic-molecular model of matter and its relationship with changes of state” and “Kinetic-molecular model of matter. Changes of state of matter”.

Objectives. Use the particle model to explain why the temperature does not change on a plateau. Distinguish the energy that raises the temperature from the energy that separates particles. Interpret a heating curve and a cooling curve. Recognise sublimation.

Teaching sequence (15–20 min).

1. Water, hotplate at +100 %, speed ×2 and “Restart”. Turn on both particle-view checkboxes. Relate the vibration of the solid and the speed of the liquid to the temperature.
2. When melting has finished, read the energy bar: 16 % “Raising the temperature” and 84 % “Separating the particles”. When boiling has finished it shows 41 % and 59 %. Vaporisation needs more energy than melting: the 100 °C plateau is almost twice as long as the 0 °C one.
3. Set the hotplate to +50 %, press “Restart” and repeat. Melting takes 28 min instead of 14, but it still happens at 0 °C. More power shortens the plateau; it does not raise the temperature of the change.
4. Halfway through melting, press “Off”. The state changes to “Solid and liquid together” and the strip to EQUILIBRIUM. With no exchange of energy, the proportions do not change.

5. Heat it up to gas at 140 °C, set the hotplate to −100 % and discuss the cooling curve: the same plateaus, now CONDENSATION and FREEZING. Switch to Nitrogen and read its temperatures off the graph to identify it.
6. Go to Pressure and temperature, CO_2, “Dry ice” example (1 atm, −100 °C). Raise the temperature: at around −78 °C the solid turns straight into gas. The strip says SUBLIMATION. It can also be seen on the curve: Heat and cool with “Dry ice (CO_2)” has a single plateau, at −78 °C, labelled SUBLIMATION, with no liquid stage.

ESO 4: changes of state and pressure

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

Curriculum content. Block D: “The concept of pressure. Hydrostatic pressure. Atmospheric pressure” and “Physics of the atmosphere”. Block E: “Energy transfers: work and heat as ways of transferring energy between systems, related to forces or temperature differences” and “Effect of heat on objects”.

Objectives. Read a phase diagram. Explain that the boiling point depends on pressure. Justify the pressure cooker and cooking at high altitude. Locate the triple point and the sublimation of dry ice.

Teaching sequence (15–20 min).

1. Pressure and temperature mode, water, “Sea level” example (1 atm, 20 °C): state Liquid. Point out the 1 atm line, “melts at 0 °C” and “boils at 100 °C”. Warn that the pressure scale is compressed.
2. Collapse “Reading the diagram”, which would give the answer away. “Top of Everest” example (0.33 atm). Ask at what temperature it will boil. Raise the temperature with the slider: between 70 and 73 °C the state is “Liquid + gas”. The strip confirms that it boils at 72 °C.
3. “Pressure cooker” example (2 atm). The “At this pressure, the substance…” card says it boils at 121 °C. Relate higher pressure to a higher cooking temperature.
4. Go back to “Sea level” and lower only the pressure. At around 0.023 atm water boils at 20 °C. The strip says “Lowering the pressure makes the liquid boil without heating it!”.
5. “Triple point” example (0.006 atm and 0 °C): all three states coexist. Below that pressure there is no liquid; at 0.005 atm ice sublimes at −2 °C.
6. Switch to CO_2. “Open air” (1 atm, 20 °C) is a gas. “CO_2 extinguisher” (65 atm) is a liquid and will boil at 26 °C. At 1 atm CO_2 is never a liquid.
7. Switch to Iodine. “In the lab” (1 atm, 80 °C) is a solid and at 1 atm would melt at 114 °C. “At low pressure” (0.01 atm, 80 °C) is a gas: below 0.12 atm iodine sublimes. Ask why heating iodine in an open tube gives violet vapour with no liquid: the vapour spreads into the air and the iodine pressure stays very low.

Bachillerato 1: occasional review

Ages 16–17 · Year 12 in the UK · 11th grade in the US

The simulation fits as review when dealing with “Heat as a mechanism for transferring energy between two bodies” and “Internal energy of a system. First law of thermodynamics” (block F). During a plateau heat goes in and the temperature does not change: the energy bar lets you discuss that the internal energy increases. The attractions checkbox serves as a bridge to “Intermolecular forces” (block A), comparing the 100 °C of water with the −196 °C of nitrogen.

Bachillerato 2 Chemistry: occasional review

Ages 17–18 · Year 13 in the UK · 12th grade in the US

On the diagram, on any line or at the triple point, the particles swap state every 0.65 s and are marked with a ring. It illustrates “Chemical equilibrium as a dynamic process” (block B) without needing a reaction. The boiling points of water, ethanol and nitrogen serve as an introduction to “Macroscopic properties of elements and molecular compounds” (block A).

Misconceptions it helps to address

The simulation mainly tackles the idea that particles change when the state changes, and the confusion between heat and temperature. Each row gives a common prior idea and how to break it down with the simulation.

Students' idea	Correct idea	How to show it
“If I keep heating, boiling water keeps getting hotter”	During boiling the temperature stays constant	Water at +50 %: the thermometer stays at 100 °C from 85 to 137 min and the graph is labelled “constant temperature”
“With a bigger flame water boils at a higher temperature”	More power shortens the plateau but does not change the boiling point	Repeat at +100 %: boiling takes 26 min instead of 52 and still happens at 100 °C
“The bubbles in boiling water are air”	They are the same substance in the gas state	Watch the magnifier during BOILING: the particles of the liquid escape as gas. The container is closed and there are no other particles
“When they melt or evaporate, the particles expand, soften or change”	The particles are the same; their order, spacing and movement change	Go along the water curve: there are always the same 64 H_2O molecules. Read “Key concepts”
“In a solid the particles are still”	The particles in a solid vibrate about their position, more so the hotter it is	Press “Off” with the ice at −40 °C and then at −5 °C, and compare the vibration in the magnifier: with the hotplate off the temperature does not change and the particles keep vibrating
“There is air between the particles of a gas”	There is only empty space between the particles	Water vapour at 120 °C: the particle window is empty between them
“When a solid is heated, it always melts before turning into gas”	Some substances go straight from solid to gas at 1 atm	Dry ice (CO_2) in Heat and cool: a single plateau at −78 °C, SUBLIMATION, and no liquid ever appears in the container
“Cooling means adding cold”	Cooling means removing energy	Hotplate at −50 %: the label says “COOLING 50 % · energy out” and the arrows point out of the container
“Water always boils at 100 °C”	The boiling point depends on the pressure	Water diagram: “Top of Everest” boils at 72 °C and “Pressure cooker” at 121 °C

Simplifications worth knowing

The simulation makes sure the plateaus and the particle model are clearly visible, and to do so it scales energies and times. It is worth knowing about these liberties so as not to reinforce wrong ideas by accident.

1. **The same energies for every substance.** Melting absorbs 14 units and vaporisation 26 in every substance with a liquid; for dry ice, sublimation absorbs both together, 40. The three heating stages

share 36 units according to how much the temperature rises in each. The temperatures are real; in reality each substance has its own specific and latent heats.

2. **The proportions between stages are not real.** Vaporisation absorbs 26 units against 14 for melting, about 1.9 times more. In real water it is about 6.8 times more (2257 against 334 J/g). It is enough to say "more energy".
3. **The liquid always needs twice as much per degree.** In the substances with a liquid, the liquid needs twice as much energy per degree as the solid and the gas, so its section of the curve is less steep. That is the case for water (4.18 against about 2 J/g·°C), but for alcohol, nitrogen or iron the real ratio is different. Gradients can be compared within water, not between substances.
4. **Time is not real.** Each "min" on the Time card is one real second at ×1. With water at +50 %, the whole curve takes 147 min. The time figures are only for comparing stages with each other.
5. **A movable lid keeps 1 atm.** The container is closed with a lid that moves freely, so the pressure does not change and the plateaus are the 1 atm ones. In a rigid container the pressure would rise as vapour formed and there would be no plateau at 100 °C; the hint and the container label say so. Also, no gas appears until the boiling point: evaporation below it is not represented. It is worth adding this nuance when talking about washing drying on the line.
6. **Agitation does not depend on absolute temperature.** Each state spreads its agitation over its own temperature range. The vibration of the solid goes from 0.8 to 3.2 px and the speed of the gas from 3.2 to 4.6. Nitrogen gas at −190 °C moves just like water vapour at 120 °C. To compare substances, use the thermometer, not the magnifier.
7. **The solid lattice is a 16 × 4 block.** It is wide and low, like the liquid, so that on freezing the particles line up at the bottom. In ice the particles are 20 px apart and the solid takes up a little more room than liquid water, which brings them to 18 px; in the other substances the lattice is compact (17.5 px). In the magnifier the solid is always at the bottom; in the container, on the other hand, ice floats. The water, nitrogen, CO_2 and iodine molecules have their real shape, but the atom sizes are only indicative, and alcohol is drawn as a sphere to keep the view uncluttered.
8. **The phase diagram is schematic.** Pressure is on a logarithmic scale. The melting line of water has the real gradient (−0.0075 °C/atm), but at 5 atm it only drops to −0.03 °C and looks vertical. It cannot be used to show that anomaly. CO_2 has no critical point: its curve ends at 30 °C and 71.5 atm. For iodine, the curves are fitted to its triple point, its boiling point at 1 atm and its vapour pressure at 25 °C (0.0004 atm); the gradient of the melting line is approximate.
9. **The lines have thickness.** The point is on a line if it is less than 5 px away, and on the triple point if less than 12 px. That is why "Liquid + gas" appears over an interval, from 70 to 73 °C on Everest. On the line the particles are split half and half, whereas in reality the proportion depends on the energy supplied.

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, 4 and 5, Apply what you have learnt, Review your ideas and Self-assessment	One 50–55 minute lesson
ESO 3 (Year 10)	Activities 1 to 6 (activity 3 with the energy bar) and Apply what you have learnt	One or two lessons

Year group	Activities	Suggested time
ESO 4 (Year 11)	Activities 1 and 3 as revision and Going further, with the phase diagram	One lesson

The “Before you start” table collects six of the prior ideas from the misconceptions table. It is best not to correct it at the beginning: students come back to it in “Review your ideas”. The times depend on the power and on when “Restart” is pressed; those in the answers are with the hotplate at +50 %.

Answers

Section	Answer
Before you start	All false. a) and b) The temperature stays at 100 °C while it boils, at any power (activities 1 and 3). c) They are water vapour (activity 2). d) The particles are the same; their order, spacing and movement change (activity 2). e) They vibrate about their position (activity 2). f) It depends on the pressure (Going further)
Activity 1	It starts to melt at about 5 min at 0 °C and finishes at about 33 min, at 0 °C; it starts to boil at about 85 min at 100 °C and finishes at about 137 min. The graph has two flat sections (plateaus): the temperature does not change during melting or boiling. Boiling lasts almost twice as long as melting
Activity 2	Solid: arranged in a lattice, vibrating in place, strong bonds. Liquid: close together but disordered, sliding past each other, weak bonds. Gas: far apart, moving fast in straight lines, no bonds. The particles do not change; their order, spacing and movement change. The bubbles are the water itself in the gaseous state. Between the particles of a gas there is empty space
Activity 3	It boils at 100 °C with both powers. Boiling lasts about 52 min with +50 % and about 26 min with +100 %. More power shortens the plateau but does not raise the temperature: during boiling the energy is used to separate the particles, not to raise the temperature
Activity 4	Condensation at 100 °C (drops on the lid) and freezing at 0 °C (ice forms). Cooling is not adding cold: it is taking energy away, and the arrows come out of the container
Activity 5	Water: 0 and 100 °C, liquid at 20 °C. Alcohol: −114 and 78 °C, liquid. Nitrogen: −210 and −196 °C, gas. Iron: 1538 and 2862 °C, solid. They belong to each substance and do not depend on the amount, so they can be used to identify substances
Activity 6	A single plateau, at −78 °C (in the simulation, −78.5 °C): SUBLIMATION. No liquid appears. At atmospheric pressure solid CO_2 turns straight into gas, so it cools without making things wet
Apply what you have learnt	1) Melting, vaporisation and sublimation: energy must be supplied. Freezing, condensation and deposition: energy must be removed. 2) Gas cooling from 120 to 100 °C, condensation plateau at 100 °C, liquid from 100 to 0 °C, freezing plateau at 0 °C, solid from 0 to −20 °C. 3) Alcohol (ethanol); at 0 °C it is liquid. 4) Both are at 100 °C; the one on the high heat boils away sooner
Going further	1) About 72 °C: water boils at a lower temperature and pasta cooks less well. 2) 121 °C: liquid water reaches a higher temperature and cooks faster. 3) About 0.023 atm

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