Teacher guide: balancing equations simulation

Quick reference

The simulation represents chemical reactions with atoms and molecules: it lets you balance equations while watching the atoms rearrange, check Lavoisier's and Proust's laws with a balance, and find the limiting reactant and the yield. Its main use is in ESO 3 (Year 10 in the UK, 9th grade in the US), with applications in ESO 4 and Bachillerato 1.

Item	Details
Link	simulaciencia.es/en/simulations/ajuste-reaccion/
Year groups	ESO 3 (main use), ESO 4, Bachillerato 1; occasional use in ESO 2 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
Prior knowledge	Atoms and molecules, simple chemical formulas, reactants and products; in ESO 4 and Bachillerato 1, relative molecular mass and the mole
Accessibility	Dark, light and high-contrast themes (gear button, “Appearance”)

How the simulation works

The simulation has three modes, chosen in the “Mode” card: “Balancing (Lavoisier)”, “Definite proportions (Proust)” and “Limiting reactant and yield”. In all three, each ball is an atom with its symbol and colour, and each group of joined balls is a molecule or the formula unit of an ionic compound. The “Key” card shows the elements in the chosen reaction with their atomic mass.

Mode	What the teacher controls	What it shows
Balancing (Lavoisier)	“Reaction” (16 equations in three groups: “Simple”, “Combustion” and “Harder”). The coefficient of each substance, from 1 to 9, with the − and + buttons. “Live count” switch and “✓ Check”, “▶ Show the reaction” and “↺ All to 1” buttons	The equation with its coefficients, the particles of the reactants and products, the “ATOM COUNT” for each element with ✓ or ✗ and a “BALANCE (TOTAL MASS)” with the mass on each side
Definite proportions (Proust)	“Reaction”: seven compounds (H_2O, H_2O_2, CO_2, CO, NH_3, FeS and MgO). Starting amount of each reactant. “▶ React”, “↺ Restart” and “🗑️ Clear the results table” buttons	The container with the particles, the mass ratio of the two elements in the compound, its percentage composition, a graph of combined masses and a table with each experiment
Limiting reactant and yield	“Reaction” (seven balanced reactions). Starting amount of each reactant, “Yield” from 10 % to 100 % and “Your prediction: which reactant runs out?”	The container with the particles, a “Start / Change / End” table with the final mass of each substance, bars for the amounts and the results: limiting reactant, reactant in excess, theoretical product, actual product and yield

In all three modes, the “Each particle represents” drop-down changes the scale. With “One molecule or atom (mass in u)” the amounts are particles and the masses are atomic mass units. With “One mole (mass

in g)" each particle drawn is one mole and the masses are given in grams: the numbers do not change, only the unit.

Four elements support the explanation:

- **The flying atoms.** In balancing mode, "▶ Show the reaction" takes each atom of the reactants to a slot in the products. If the equation is not balanced, some atoms stay in the reactants surrounded by a red ring ("Atoms left over") or dashed empty slots remain in the products ("atoms missing"). In the reactor, each group of reactants breaks apart and its atoms form the products.
- **The atom count.** One row per element with the atoms in the reactants and in the products. With "Live count" switched off, the table and the balance show "?" until "✓ Check" is pressed.
- **The balance and the mass bar.** The balance in balancing mode tips towards the side with more mass and levels out when the equation is balanced. In the reactor, the "TOTAL MASS IN THE CONTAINER" bar shares out the mass between the substances, and its total length does not change while the reaction takes place.
- **The status message.** Below the equation appears "✗ Not balanced...", "✓ Balanced equation: atoms and mass are conserved" or, if the coefficients have a common factor, "✓ Balanced, but it can be simplified".

In Proust mode and limiting reactant mode, the amount sliders move in steps of the coefficient: with $2\ H_2 + O_2 \rightarrow 2\ H_2O$, hydrogen goes up 2 at a time. That way the limiting reactant always runs out completely. The "How does it work?" drop-down, closed at the start, summarises the three modes.

Use in each year group

In ESO 3 the simulation supports balancing simple equations and Lavoisier's and Proust's laws as evidence for the atomic-molecular model. In ESO 4 it is used to balance combustion reactions and for the first stoichiometric calculations with moles, including yield. In Bachillerato 1 it supports the laws of chemical combination (Dalton's law too), percentage composition, the limiting reactant and yield. The curriculum content quoted is from the LOMLOE curriculum of the Community of Madrid (Spain), in our own translation.

The masses quoted are those the simulation shows, using IUPAC atomic masses rounded to two decimal places.

ESO 2: occasional use

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

There is no content on balancing. Balancing mode can illustrate "Physical and chemical changes in material systems" and "Introduction to chemical reactions" (block C), and "Atoms and molecules: common, well-known elements and compounds" (block B). With "Formation of water" already balanced (2, 1 and 2), "▶ Show the reaction" shows that the hydrogen and oxygen atoms separate and join up again to form a new substance, without appearing or disappearing.

ESO 3: balancing and Lavoisier's and Proust's laws

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

Curriculum content. Block C: "Microscopic interpretation of chemical reactions" with "Balancing simple chemical equations", and "Applying the law of conservation of mass (Lavoisier's law) and the law of definite proportions (Proust's law): applying these laws as experimental evidence that validates the

atomic-molecular model of matter. Simple stoichiometric calculations". Block B: "Atomic mass and molecular mass".

Objectives. Balance simple equations by changing only the coefficients. Explain conservation of mass through conservation of atoms. Check that a compound always has the same mass ratio of its elements.

Teaching sequence (15–20 min).

1. Balancing mode, "Formation of water" with every coefficient at 1. The count shows H 2 against 2 ✓ and O 2 against 1 ✗; the balance tips: 34.01 u against 18.02 u. Press "▶ Show the reaction": "✗ Atoms left over: 1 O".
2. Ask how to fix it. If someone suggests writing H_2O_2, explain that this is hydrogen peroxide, a different substance: the simulation only lets you change coefficients. Put a 2 in front of H_2O: now oxygen balances, but hydrogen does not (2 against 4). "▶ Show the reaction": "✗ Atoms missing: 2 H".
3. Put a 2 in front of H_2. "✓ Balanced equation: atoms and mass are conserved" appears and the balance levels out: 36.03 u on each side. Show the reaction: "✓ Every atom finds its place". State Lavoisier's law.
4. Count the particles in each box: 3 molecules in the reactants and 2 in the products. The statistics, on the other hand, give 6 atoms on each side. Atoms and mass are conserved, not molecules.
5. Switch off "Live count" and ask students to balance "Synthesis of ammonia" (1, 3, 2) and "Oxidation of magnesium" (2, 1, 2) before pressing "✓ Check".
6. Proust mode, "Water (H_2O)", with the starting values (4 H_2 and 4 O_2). "▶ React": 4 H_2O form and 2 O_2 are left over. The table records m(O)/m(H) = 7.94. Raise H_2 to 24 and repeat: 8 H_2O form, 16 H_2 are left over and the ratio is still 7.94. The points on the graph fall on the same straight line: this is Proust's law.

ESO 4: balancing combustion reactions and stoichiometry

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

Curriculum content. Block C: "Chemical equations: balancing chemical equations and making qualitative and quantitative predictions based on stoichiometry", with "Balancing chemical equations. Stoichiometric calculations. Yield of a reaction", and "Qualitative description of chemical reactions of interest: combustion reactions". Block B: "Atomic and molecular mass. The concept of the mole. The Avogadro constant".

Objectives. Balance combustion reactions of hydrocarbons. Interpret the coefficients as a ratio in moles. Calculate the amount of product from the amount of a reactant and apply the yield.

Teaching sequence (15–20 min).

1. Balancing mode, "Combustion of methane". Balance in the usual order: first carbon (already balanced), then hydrogen (2 in front of H_2O) and finally oxygen (2 in front of O_2). The balance shows 80.04 u on each side.
2. "Combustion of propane" with "Live count" switched off: students suggest the coefficients (1, 5, 3 and 4) and they are checked with "✓ Check". Mass on each side: 204.09 u.
3. "Combustion of ethane": balancing the oxygen gives 7/2 in front of O_2; multiply everything by 2 to get 2, 7, 4 and 6. The other way round, if someone balances water with 4, 2 and 4, the simulation warns: "✓ Balanced, but it can be simplified: divide the coefficients by 2".
4. Change "Each particle represents" to "One mole (mass in g)". The balance switches to grams with the same numbers: the molar mass in g/mol is the same as the molecular mass in u.
5. "Limiting reactant and yield" mode, "Combustion of methane", with the starting values: 4 mol CH_4 and 10 mol O_2. Ask how much CO_2 will form: 4 mol, that is, 176.04 g. Press "▶ React" and check it in the

table.

6. Lower “Yield” to 75 % in “Formation of water” (8 mol H_2 and 5 mol O_2). 6 mol H_2O (108.09 g) form out of a theoretical 8 (144.12 g): “Yield = actual / theoretical · 100 = 75 %”.

Bachillerato 1: laws of chemical combination, limiting reactant and yield

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

Curriculum content. Block B: “Applying the fundamental laws of chemistry to understand the stoichiometric relationships in chemical reactions and in the composition of compounds”, with “Lavoisier's law of conservation of mass, Proust's law of definite proportions and Dalton's law of multiple proportions. Percentage composition of a compound” and “Stoichiometric calculations in chemical reactions. Purity of a reactant. Yield of a reaction. Limiting reactant and reactant in excess”. Also “Synthesis, substitution, double substitution, decomposition and combustion reactions” and “Observing different types of reaction and checking their stoichiometry”.

Objectives. Relate the laws of chemical combination to Dalton's atomic theory. Calculate percentage composition. Identify the limiting reactant and calculate the theoretical product, the excess and the yield.

Teaching sequence (15–20 min).

1. Proust mode, “Water (H_2O)”: the percentage composition is 11.2 % H and 88.8 % O, and m(O)/m(H) = 7.94. Do two or three experiments with different amounts and check that the ratio does not change.
2. Switch to “Hydrogen peroxide (H_2O_2)”: m(O)/m(H) = 15.87, exactly twice 7.94. Repeat with “Carbon monoxide (CO)” (1.33) and “Carbon dioxide (CO_2)” (2.66). State the law of multiple proportions and explain it with atoms: the second compound has twice as many oxygen atoms for each atom of the other element.
3. “Limiting reactant and yield” mode, “Formation of water”, with the starting values (8 H_2 and 5 O_2). Ask for a prediction in “Your prediction: which reactant runs out?”. Many students choose O_2 because there is less of it. React: the limiting reactant is H_2, “In excess: O_2 (only 4 of 5 are needed)”.
4. Solve the same case on the board with “One mole (mass in g)”: 16.13 g of H_2 and 159.99 g of O_2 give 144.12 g of H_2O, with 32.00 g of O_2 left over. The total mass bar shows 176.12 g before and after.
5. Set 8 H_2 and 4 O_2: “Stoichiometric ratio: there is no limiting reactant and none in excess”.
6. Go back to 8 H_2 and 5 O_2 and lower “Yield” to 75 %: 6 H_2O form and 2 H_2 and 2 O_2 are left unreacted. Mention that in industry the yield is lowered by incomplete reactions, side reactions and losses when separating the product.

Bachillerato 2 Chemistry: occasional review

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

There is no specific content. It can be used for review before “Stoichiometric calculations and redox titrations” (block B, 5). The simulation only balances by inspection and does not cover the “ion-electron method”; it is worth reminding students that this method is also based on conserving atoms, and charge as well.

Misconceptions it helps to address

The simulation mainly tackles the idea that balancing is a numbers game with no connection to atoms. Each row gives a common prior idea and how to break it down with the simulation.

Students' idea	Correct idea	How to show it
“You can change the subscripts to balance an equation”	Changing a subscript changes the substance; only the coefficients are changed	Balancing mode: there are buttons only for the coefficients. Proust mode: H_2O and H_2O_2 have different ratios (7.94 and 15.87) because they are different substances
“Mass is lost in a reaction (when something burns, it weighs less)”	The total mass is conserved because the atoms are conserved	“Combustion of methane” balanced: 80.04 u on each side of the balance. In the reactor, the total mass bar does not change while it reacts
“If the equation is balanced, there are the same molecules on each side”	Atoms are conserved, not molecules	$2\ H_2 + O_2 \rightarrow 2\ H_2O$: 3 molecules against 2, but 6 atoms on each side
“The coefficients give the ratio by mass”	They give the ratio in particles or in moles	$2\ H_2 + O_2$: there are twice as many H_2 molecules, but the O_2 contributes 32.00 u against 4.03 u
“The limiting reactant is the one there is least of”	It is the one that runs out first according to the ratio in the equation	Starting values in limiting reactant mode: with 8 H_2 and 5 O_2, the limiting reactant is H_2
“If I add more of a reactant, more product always forms”	If that reactant is in excess, the product does not change	Proust mode, water: with 4 O_2 fixed, going from 8 to 24 H_2 does not change the 8 H_2O; only what is left over increases
“With a 100 % yield nothing is left over”	At 100 % the limiting reactant runs out; the reactant in excess is still left over	Starting values in limiting reactant mode: 1 O_2 is left over with a 100 % yield
“The equation is better balanced with bigger numbers”	The smallest whole-number coefficients are used	“Formation of water” with 4, 2 and 4: “Balanced, but it can be simplified: divide the coefficients by 2”

Simplifications worth knowing

The simulation puts the conservation of atoms and the ratio in the equation first, and to do so it simplifies the shape of the molecules, the mechanism and the amounts. It is worth knowing about these liberties so as not to reinforce wrong ideas by accident.

1. **The molecules are flat diagrams.** The positions of the atoms are approximate and two-dimensional: methane is drawn as a cross rather than a tetrahedron, and the bond angles are not the real ones.
2. **Ionic solids, metals and solid non-metals are separate particles.** NaCl, MgO, Fe_2O_3, Al_2O_3, $CaCO_3$, $KClO_3$, FeS, CaO and KCl are drawn as a formula unit, although they are crystal lattices. The metals (Na, Mg, Al, Fe), carbon and sulfur appear as isolated atoms; real sulfur forms S_8 molecules.
3. **The atoms fly straight to the products.** Collisions, step-by-step bond breaking, intermediates and energy are not shown. That is what the rate of reaction simulation is for.
4. **Not every equation happens as written.** Some have been chosen for their teaching value: hydrogen peroxide is not made by combining H_2 and O_2, and NO_2 forms in two steps. Physical states and conditions are not shown either.
5. **The amounts go up in steps of the coefficient.** In Proust and limiting reactant modes, each reactant is chosen in multiples of its coefficient (up to a maximum of 24 particles), so that the limiting reactant always runs out completely. In the laboratory the amounts are continuous.
6. **Yield is modelled by stopping the reaction.** With a yield below 100 %, the reaction stops earlier and part of both reactants is left unreacted. In reality side reactions and losses when separating the product

also play a part. Also, the actual product is rounded to whole particles: with few particles the yield obtained may not match the one chosen, and then "(rounded to whole particles)" is shown.

7. **One mole per particle.** With "One mole (mass in g)" each particle drawn represents $6.022 \cdot 10^{23}$ particles. The amounts are always whole numbers of moles.
8. **Atomic masses with more decimal places than the textbook.** The IUPAC values are used (H = 1.008; O = 15.999…). That is why m(O)/m(H) for water comes out as 7.94 and not 8, as it would with H = 1 and O = 16. It is worth warning students if they check the calculations with rounded masses.
9. **The coefficients go from 1 to 9.** That is enough for every equation on the list, whose largest coefficient is 7 (ethane).

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 3 (Year 10)	Before you start, activities 1 to 4, problems 1 to 3 of Apply what you have learnt, Review your ideas and Self-assessment	One 50–55 minute lesson
ESO 4 (Year 11)	Activities 2, 5 and 6 and all of Apply what you have learnt	One lesson
Bachillerato 1 (Year 12)	Activities 4 to 6 and Going further	One lesson

The "Before you start" table collects five prior ideas about reactions. It is best not to correct it at the beginning: students come back to it in "Review your ideas".

Answers

Section	Answer
Before you start	All false. a) Changing a subscript changes the substance (activity 1). b) Atoms are conserved, not molecules (activity 3). c) Mass is conserved; if the gas escapes it is missing from the balance, but it has not disappeared (activity 3). d) A compound always has the same proportion (activity 4). e) One runs out first: the limiting reactant (activity 5)
Activity 1	1, 1, 1: H 2/2, O 2/1, 34.01 u against 18.02 u, "✗ Not balanced" and "Atoms left over: 1 O". 1, 1, 2: H 2/4, O 2/2, "atoms missing: 2 H". 2, 1, 2: H 4/4, O 2/2, 36.03 u on each side, "✓ Balanced equation". H_2O_2 is hydrogen peroxide, a different substance. The balance levels out because there are the same atoms on each side
Activity 2	$N_2 + 3\ H_2 \rightarrow 2\ NH_3$. $2\ Mg + O_2 \rightarrow 2\ MgO$. $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$. $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$. Convenient order: carbon, hydrogen and oxygen last, because O_2 is an element and its coefficient does not upset any other element
Activity 3	Reactants: 3 molecules, 6 atoms, 36.03 u. Products: 2 molecules, 6 atoms, 36.03 u. Lavoisier's law: in a chemical reaction the total mass is conserved, because the atoms are only rearranged
Activity 4	$4\ H_2 + 4\ O_2$: $4\ H_2O$, $2\ O_2$ left over. $24\ H_2 + 4\ O_2$: $8\ H_2O$, $16\ H_2$ left over. $8\ H_2 + 12\ O_2$: $8\ H_2O$, $8\ O_2$ left over. m(O)/m(H) = 7.94 every time: Proust's law. A reactant is left over when the amounts are not in the 2 : 1 ratio of molecules

Section	Answer
Activity 5	Limiting: CH_4. The 4 CH_4 need 8 O_2 and there are 10, so all the CH_4 is used up and 2 O_2 are left over (in excess). 4 CO_2 (176.04 u) and 8 H_2O form. It is not enough: with 4 CH_4 and 6 O_2 the limiting reactant is O_2 even though there are more molecules of it, because each CH_4 needs 2 O_2 (3 CO_2 form and 1 CH_4 is left over). The limiting reactant depends on the ratio in the equation
Activity 6	Limiting: H_2 (8 mol need 4 mol of O_2; 1 mol is left over). Theoretical: 8 mol of H_2O = 144.12 g. Actual: 6 mol = 108.09 g. Yield 75 %. There are side reactions, losses when separating and purifying, and reactions that do not go to completion
Apply what you have learnt	1) $4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$; $2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$. 2) 44 g, Lavoisier's law. 3) 5 g, Proust's law. 4) Limiting O_2 (2 mol need 4 mol of H_2); 4 mol of H_2O form and 2 mol of H_2 are left over
Going further	1) 11.2 % H and 88.8 % O. 2) In H_2O_2, m(O)/m(H) = 15.87, twice that of water: a 2 ∶ 1 ratio, Dalton's law of multiple proportions

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/ajuste-reaccion/.