5 Stoichiometry

After an oxygen tank failed on Apollo 13, the crew had enough oxygen to get home; the danger was the carbon dioxide they were breathing out. The canisters that removed it held lithium hydroxide, and each gram of it can take up only so much CO_2. How long that air lasts for three people is a calculation from the balanced equation. That is stoichiometry: the equation sets the ratio, and one reactant runs out first. The mock exam gives this chapter 8 of its 70 questions.

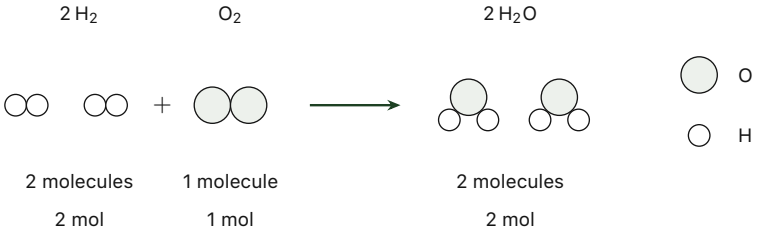
5.1 Reading and Balancing Equations

A chemical reaction rearranges atoms into new substances. It does not make or destroy any. Every atom that goes in comes out, so the two sides of an equation must hold the same number of each element. Balancing is the bookkeeping that makes the equation say so.

The number in front of a formula is its **coefficient**. In $2\,H_2 + O_2 \longrightarrow 2\,H_2O$ the coefficients say that two hydrogen molecules and one oxygen molecule make two water molecules. A mole is a fixed number of particles, so the same coefficients give the ratio of moles: 2 mol, 1 mol, 2 mol.

Coefficient
The number in front of a formula. It counts molecules or formula units, and so it counts moles.

Coefficients do not give a ratio of grams. A mole of H_2 has a mass of 2.016 g and a mole of O_2 has a mass of 32.00 g. Equal moles are not equal masses.



Subscripts and coefficients

A subscript is part of the formula. H_2O is water and H_2O_2 is a different compound. Only coefficients change when you balance.

RULE Balance by changing coefficients only. Never change a subscript.

Order of work

- Count each element on each side.
- Start with an element that appears in one formula on each side, often a metal or carbon. Leave H, O and free elements for last.
- If a polyatomic ion such as SO_4^{2-} or OH^- appears unchanged on both sides, count it as one unit instead of counting its atoms.
- If a fraction appears, multiply every coefficient by the same number to clear it.

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– Recount every element. Then confirm the coefficients share no common factor.

EXAMPLE 5.1

Balance $Al + H_2SO_4 \longrightarrow Al_2(SO_4)_3 + H_2$.

What is asked	The smallest whole-number coefficients.
Count	Left: Al 1, SO_4 1, H 2. Right: Al 2, SO_4 3, H 2. Sulfate stays together, so count it as a unit.
Sulfate	Three on the right, so put 3 in front of H_2SO_4.
Aluminum	Two on the right, so put 2 in front of Al.
Hydrogen	$3\,H_2SO_4$ holds 6 H, so put 3 in front of H_2.
Check	Left: Al 2, SO_4 3, H 6. Right: Al 2, SO_4 3, H 6. The coefficients 2, 3, 1, 3 share no factor.
Answer	$\mathbf{2\,Al + 3\,H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3\,H_2}$

A **combustion** reaction burns a fuel in oxygen. Balance carbon first, then hydrogen, then oxygen. Oxygen appears in two products, so it is the last to settle. If the oxygen count comes out as a half, double every coefficient.

Combustion
A reaction of a fuel with O_2. Carbon and hydrogen in the fuel end up as CO_2 and H_2O.

EXAMPLE 5.2

Balance $C_6H_6 + O_2 \longrightarrow CO_2 + H_2O$.

What is asked	The smallest whole-number coefficients.
Carbon	Six C on the left, so 6 CO_2.
Hydrogen	Six H on the left, so 3 H_2O.
Oxygen	The right holds $12 + 3 = 15$ O atoms. That is $\frac{15}{2}$ molecules of O_2.
Clear the fraction	Double everything: $2\,C_6H_6 + 15\,O_2 \longrightarrow 12\,CO_2 + 6\,H_2O$.
Check	C: 12 and 12. H: 12 and 12. O: 30 and $24 + 6 = 30$.
Answer	$\mathbf{2\,C_6H_6 + 15\,O_2 \longrightarrow 12\,CO_2 + 6\,H_2O}$

5.2 Reaction Types

Many reactions follow a few patterns. Naming the pattern helps you predict products and catches errors when you write an equation. The type does not change the arithmetic. Once the equation is balanced, every type is solved the same way.

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Type	Pattern	Example
Combination	$\mathrm{A + B \rightarrow AB}$	$2\,Mg + O_2 \longrightarrow 2\,MgO$
Decomposition	$\mathrm{AB \rightarrow A + B}$	$2\,KClO_3 \longrightarrow 2\,KCl + 3\,O_2$
Single replacement	$\mathrm{A + BC \rightarrow AC + B}$	$Zn + 2\,HCl \longrightarrow ZnCl_2 + H_2$
Double replacement	$\mathrm{AB + CD \rightarrow AD + CB}$	$Pb(NO_3)_2 + 2\,KI \longrightarrow PbI_2 + 2\,KNO_3$
Combustion	$\mathrm{fuel + O_2 \rightarrow CO_2 + H_2O}$	$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$

To recognize a type, look at the count of substances on each side.

- Several reactants and one product: combination. One reactant and several products: decomposition.
- One element replaces another element in a compound, and the displaced element ends up free: single replacement.
- Two ionic compounds that trade partners, often forming a solid, a gas or water: double replacement.
- Oxygen as a reactant with CO_2 and H_2O as products: combustion.

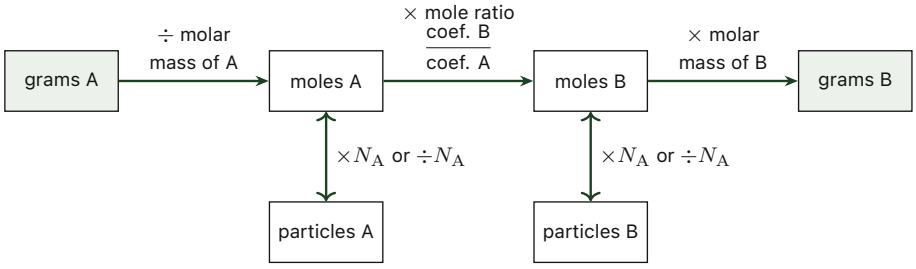
A reaction can fit two labels. Magnesium burning in oxygen is a combination reaction, and many courses also call it combustion.

5.3 The Mole Road Map

A balanced equation compares particles, and particles are counted in moles. It does not compare masses. So a mass in a problem must pass through moles on the way to the answer. Every stoichiometry problem is the same trip with a different start and finish.

The trip has three kinds of steps. Molar mass converts between grams and moles of one substance. The **mole ratio**, taken from the coefficients, converts between moles of two different substances. Avogadro's number, 6.022×10^{23} particles per mole, converts between moles and particles. Only the mole ratio crosses from one substance to the other.

Molar mass
The mass of one mole, in g/mol. Add the atomic masses in the formula.



Write the mole ratio with the wanted substance on top and the given substance on the bottom. When a problem says a reactant is in **excess**, there is more of it than the reaction can use, so it does not limit the answer. Carry at least one extra digit through the steps and round once, at the end.

RULE The mole ratio is the only step that uses the coefficients.

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PRACTICE SET 5A 12 questions · 18 minutes

1. When $C_4H_{10} + O_2 \longrightarrow CO_2 + H_2O$ is balanced with the smallest whole-number coefficients, what is the coefficient of O_2?

(A) 7 **(B)** 8 **(C)** 13 **(D)** 26

2. Balance $Al_2(SO_4)_3 + Ca(OH)_2 \longrightarrow Al(OH)_3 + CaSO_4$ with the smallest whole numbers. What is the coefficient of $Al(OH)_3$?

(A) 1 **(B)** 2 **(C)** 3 **(D)** 6

3. For $2\,H_2(g) + O_2(g) \longrightarrow 2\,H_2O(l)$, which statement is correct?

(A) 4.0 mol H_2 reacts with 2.0 mol O_2.
(B) 2.0 g H_2 reacts with 1.0 g O_2.
(C) Equal numbers of H_2 and O_2 molecules react.
(D) 2.0 mol H_2 forms 1.0 mol H_2O.

4. Which equation represents a single-replacement reaction?

(A) $2\,Mg + O_2 \longrightarrow 2\,MgO$
(B) $CaCO_3 \longrightarrow CaO + CO_2$
(C) $AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$
(D) $Zn + 2\,HCl \longrightarrow ZnCl_2 + H_2$

5. How many moles of H_2O form when 0.80 mol C_2H_6 burns completely in excess O_2? $2\,C_2H_6 + 7\,O_2 \longrightarrow 4\,CO_2 + 6\,H_2O$

(A) 2.8 **(B)** 2.4 **(C)** 0.80 **(D)** 0.27

6. What mass of $AlCl_3$ forms when 0.45 mol Cl_2 reacts completely with excess Al? $2\,Al + 3\,Cl_2 \longrightarrow 2\,AlCl_3$

(A) 90.0 g **(B)** 60.0 g
(C) 40.0 g **(D)** 21.3 g

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