Quantities in chemical change slide deck

Chemistry 20

Unit D: Quantities in chemical change

Reaction types and balanced equations

Names and masses

- A lab page can name the chemicals in a reaction and, on the next line, record how many grams were used.
- The name answers what is present, and the gram record answers how much was measured.

Predicted products

- Five familiar patterns decide the product formulas before any coefficient is chosen.
- After the formulas are fixed, each coefficient is a count of atoms, of molecules, and of moles.

Key terms

formation reaction

A pattern in which separate reactants combine and a single product is formed. (2 Na + Cl_2 ⟶ 2 NaCl)

coefficient

A whole number written in front of a formula to count formula units while the formula stays fixed. (2 H_2)

qualitative analysis

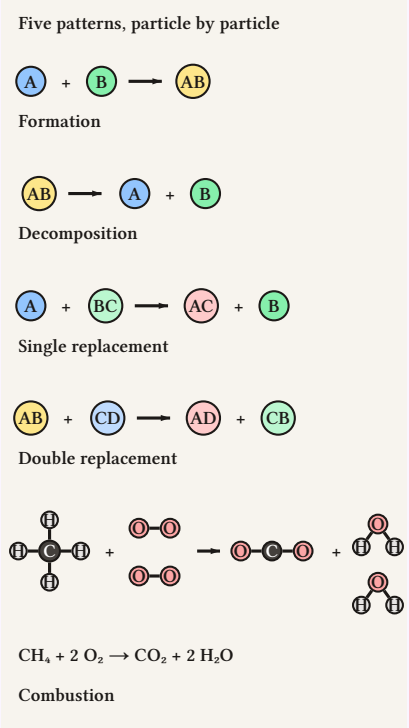
Work that names which substances are present in a sample. (identity)

quantitative analysis

Work that measures how much of a named substance is present. (mass or moles)

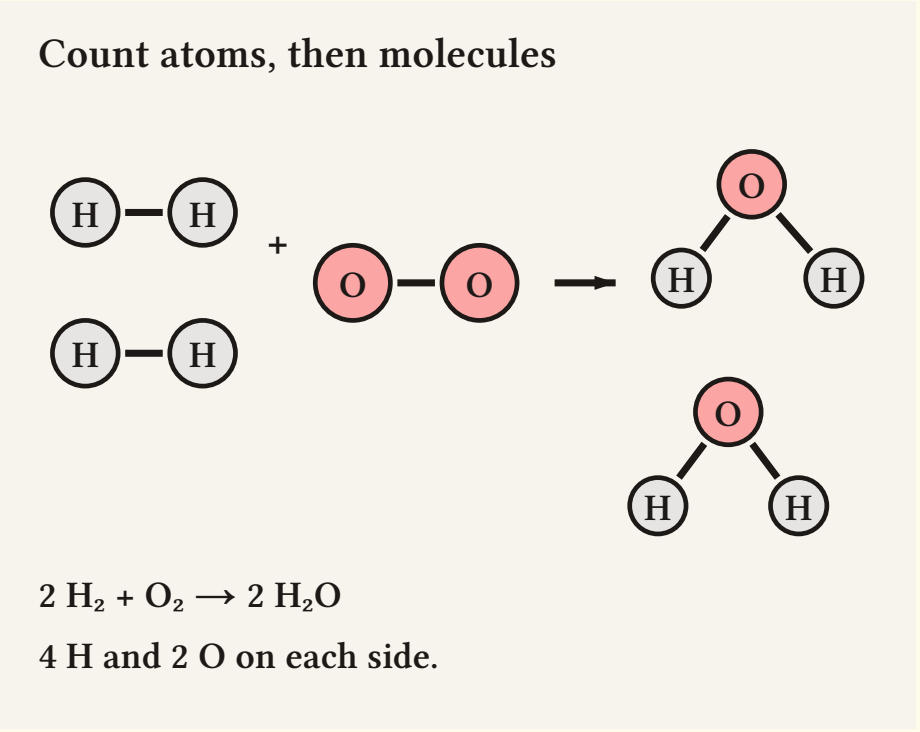
Five patterns decide the products

- Formation joins reactants into one product, and decomposition splits one reactant apart.
- Complete combustion of a hydrocarbon in oxygen produces carbon dioxide and water.



One equation, three ways to count

- The balanced hydrogen-oxygen equation uses the same formulas chemists already know from Science 10.
- Each front number is doing counting work for atoms, for molecules, and for moles.



Methane combustion

- The skeleton $CH_4 + O_2 \longrightarrow CO_2 + H_2O$ already shows the correct product formulas for complete combustion.
- Lowest whole-number coefficients finish the atom match for carbon, hydrogen, and oxygen.



Patterns and amounts

- A single heated reactant and a hydrocarbon flame are two different product predictions.
- Naming the chemicals is a different job from reporting how many moles the coefficients count.

Image credits

Lisafern, Gas stove burner flame, CC0 1.0

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Ionic and net ionic equations

A precipitate in solution

- Two clear solutions can mix and produce a white solid while the liquid around that solid stays clear.
- The solid is one new substance, and dissolved ions can remain in the liquid.



Split the solution, then keep the change

- Aqueous strong electrolytes are written as separate ions, and solids stay as complete formulas.
- Ions that match on both sides are set aside so the written change shows the new substance.

Key terms

spectator ion

An ion that stays aqueous and appears unchanged on both sides of an ionic equation. (Na^+ and NO_3^-)

net ionic equation

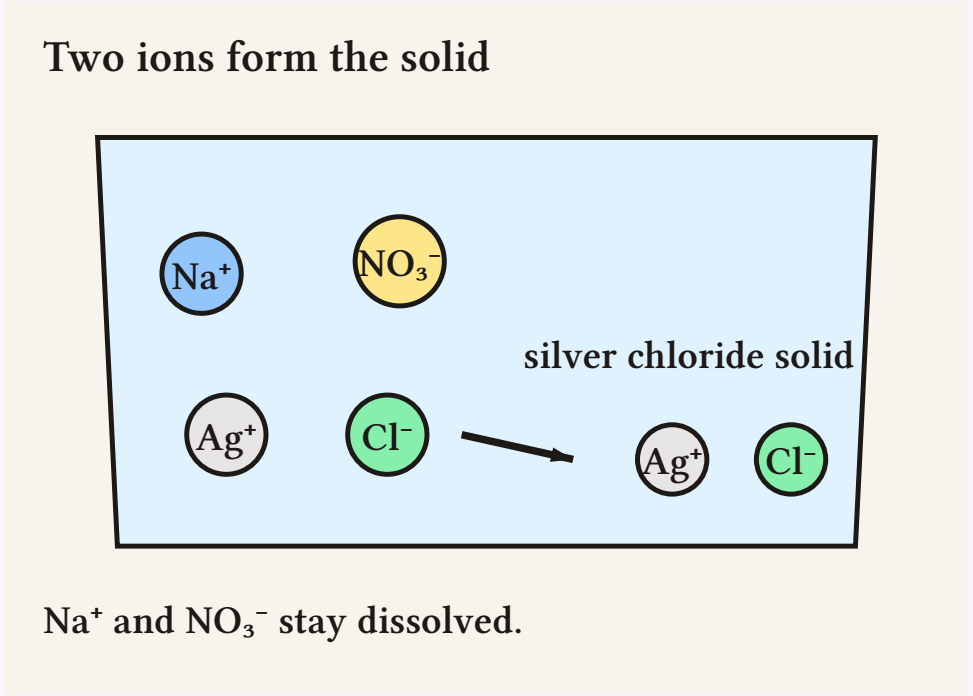
The balanced equation that remains after spectator ions are removed, with state symbols kept. ($Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$)

full ionic equation

A balanced equation that shows aqueous strong electrolytes as separate ions. ($Ag^+(aq) + Cl^-(aq) + Na^+(aq) + NO_3^-(aq)$)

Sodium and nitrate stay in solution

- The formula equation is $AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$.
- Silver chloride remains a solid formula, and the other three salts are strong electrolytes in water.



Hydronium and hydroxide become water

- The formula equation is $HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$.
- Water stays a liquid formula, and the aqueous acid, base, and salt can be written as ions.

Carbonate ions meet calcium ions

- The formula equation is $CaCl_2(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + 2\ NaCl(aq)$.
- Calcium carbonate stays a solid, and the soluble salts are written as ions.

Aqueous changes

- A precipitation and a strong-acid neutralization each leave some ions unchanged.
- The net ionic equation keeps state symbols on the ions and on the new substance.

Image credits

Dr.T, AgCl-neerslag, CC BY-SA 3.0

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Stoichiometry methods

Stoichiometry equipment

- The same balanced equation can start from grams on a balance, from millilitres in a pipette, or from litres in a gas syringe.
- Each tool measures a different quantity, and the equation still supplies the same kind of ratio.

Three lanes that meet at the mole

- Gravimetric work starts from a mass, solution work starts from a concentration and a volume, and gas work can end at a volume at SATP.
- A plan also names states, products, a theoretical yield, and the WHMIS step that comes first.

Key terms

stoichiometry

The use of a balanced equation to convert the amount of one substance into the amount of another. (mole ratio)

theoretical yield

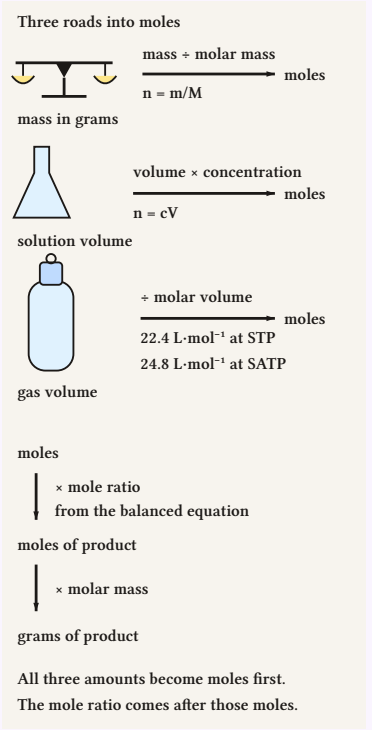
The amount of product calculated from the balanced equation and the starting measurement. (4.40 g CO_2)

molar volume

The volume of one mole of an ideal gas at a stated temperature and pressure. (24.8 $L \cdot mol^{-1}$ at SATP)

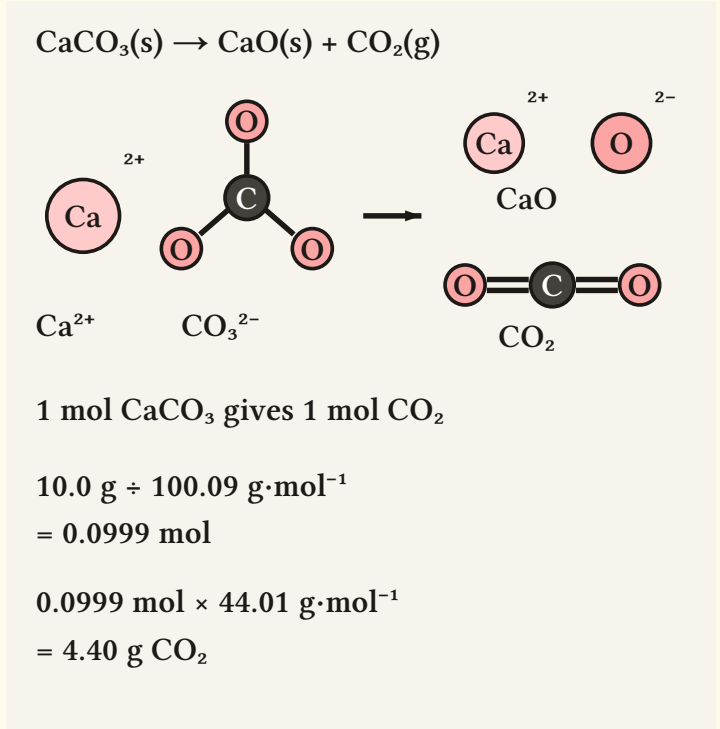
The ratio sits between two conversions

- Divide a mass by the molar mass, or multiply a concentration by the volume in litres, to reach moles.
- The mole ratio from the balanced equation then turns reactant moles into product moles.



Carbon dioxide from 10.0 g of carbonate

- Heating $CaCO_3(s)$ produces $CaO(s)$ and $CO_2(g)$ with a 1 to 1 mole ratio.
- The theoretical yield of carbon dioxide is the mass calculated from 10.0 g of reactant.



Moles of base that match the acid

- The sample is 25.0 mL of 0.200 mol·L^{-1} hydrochloric acid.
- The neutralization $\text{HCl(aq)} + \text{NaOH(aq)} \longrightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$ uses matching coefficients of 1 and 1.

Oxygen gas and a shared table

- Hydrogen peroxide decomposition uses the ratio in $2\ H_2O_2 \longrightarrow 2\ H_2O + O_2$.
- A group table keeps every trial, and an industrial use of a ratio still leaves some problems open.

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Limiting reagents and percent yield

One reactant runs out first

- A reaction stops producing the intended substance when one reactant is used up, even if another reactant is still in the flask.
- The reactant that remains is leftover, and the reactant that disappeared sets the product amount.

Limiting reagent and percent yield

- Counted atoms on both sides of a balanced equation represent equal mass.
- The calculated maximum and the measured mass are compared by a percent.

Key terms

limiting reagent

The reactant that is consumed first and therefore sets the amount of product. (H_2 in the ammonia case)

excess reagent

The reactant that remains after the limiting reagent has been consumed. (0.333 mol N_2)

percent yield

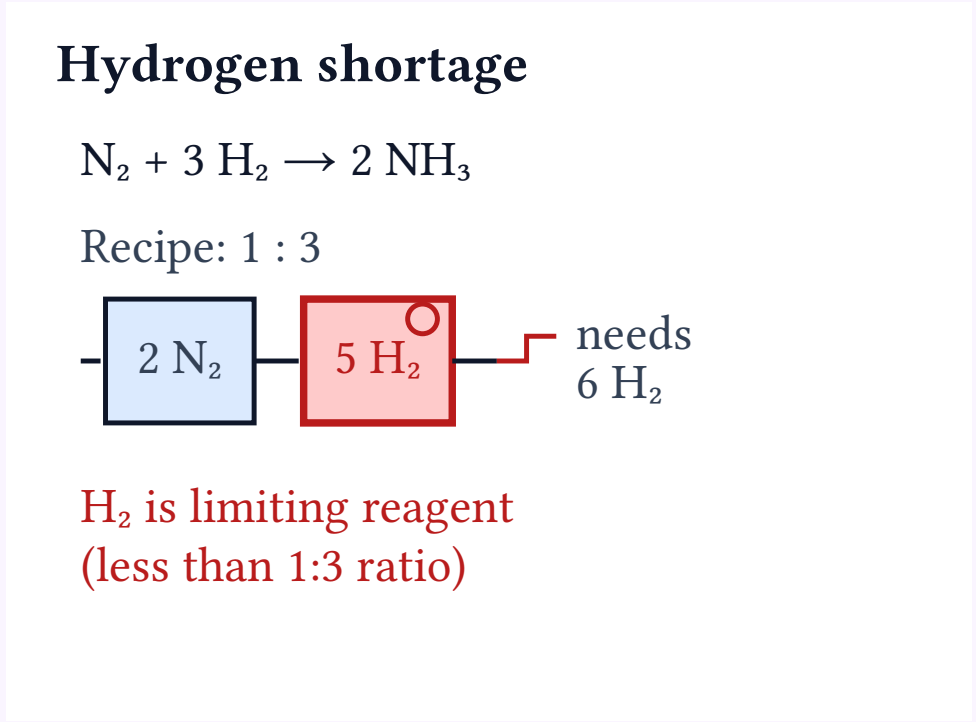
The actual mass divided by the theoretical mass, multiplied by 100. (80.0%)

actual yield

The mass of product measured after the reaction and the transfer are finished. (6.80 g)

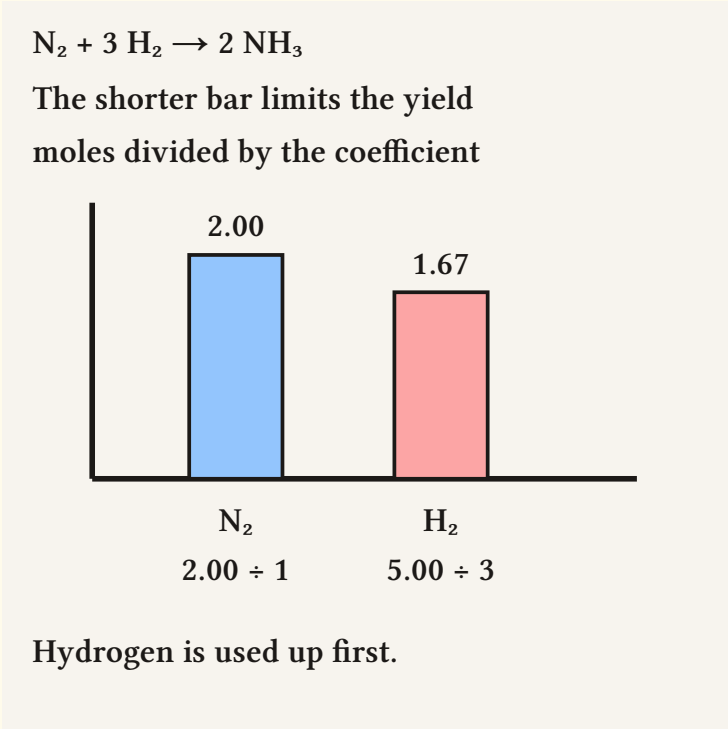
Equal mass, then a hydrogen shortage

- The equation $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$ is the mass check and the recipe for the poured mixture.
- A mixture of 2.00 mol of nitrogen and 5.00 mol of hydrogen supplies less hydrogen than the 1 to 3 recipe demands.



Hydrogen sets the ammonia amount

- Divide each available amount by its coefficient and compare the quotients.
- The smaller quotient belongs to the reactant that is consumed first.



From 8.50 g calculated to 6.80 g measured

- The theoretical yield is the mass calculated from the limiting reagent.
- The actual yield is the mass measured after collection.

Yield

- The reactant with the smaller moles-per-coefficient value is consumed first.
- A percent below 100 names a gap between the balance and the calculation.

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Titration curves and indicators

The colour waits, then flips

- Base can drip into a strong acid for a long volume while the indicator colour barely changes.
- Across a few more drops the colour flips, and that flip is a signal on the curve.



The mole match and the colour change

- The curve is a plot of pH against the volume of strong base added to a strong monoprotic acid.
- The mole match and the indicator colour change are two events to mark on that plot.

Key terms

equivalence point

The mixture in which moles of H_3O+ from the acid equal moles of OH^- from the base. (pH 7 for this pair)

end point

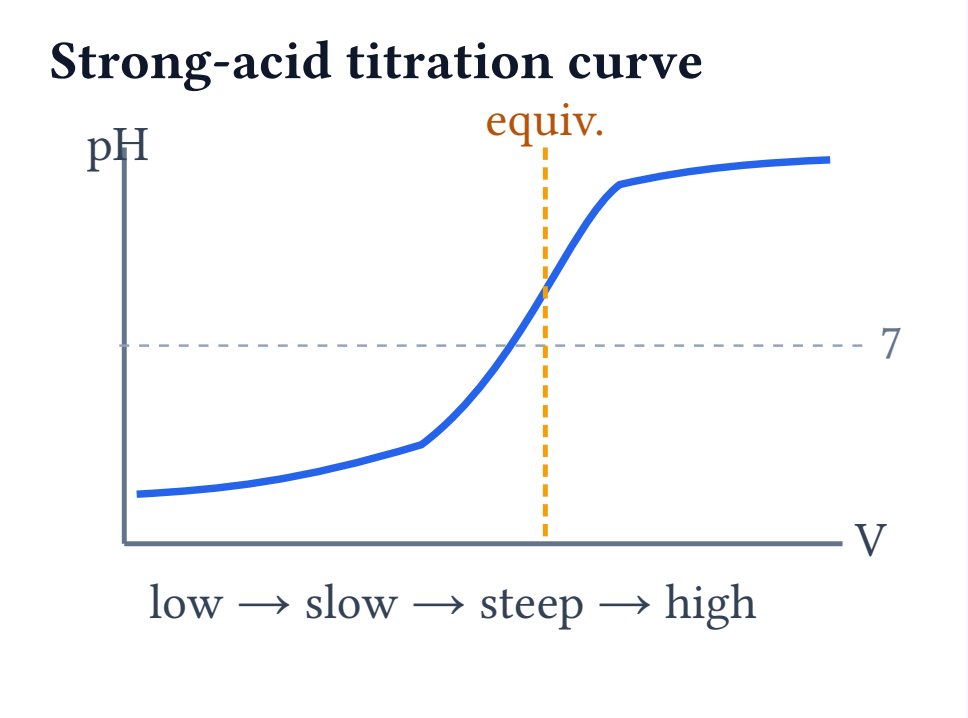
The volume at which the indicator changes colour during a titration. (bromothymol blue near pH 7)

titration curve

A graph of pH against the volume of titrant added. (steep jump near equivalence)

Four regions of the strong-acid curve

- The curve starts low, rises slowly, jumps steeply near the equivalence volume, and then levels high.
- For this acid-base pair the steep jump crosses pH 7.



Equal concentrations meet at equal volumes

- The acid sample is 25.00 mL of 0.100 mol·L^{-1} HCl.
- The titrant is 0.100 mol·L^{-1} NaOH, and the mole ratio in the neutralization is 1 to 1.

Indicators at the equivalence jump

- Bromothymol blue changes from yellow to blue across the steep region near pH 7.
- Phenolphthalein changes from colourless to pink slightly after pH 7.

Titration curves

- The equivalence point for this pair is the mole match at pH 7.
- The end point is the indicator colour change, which can sit very near that mole match.

Image credits

Lisa Simpson 23, Vinegar Titration - Color of the Phenolphthalein reacting to NaOH, CC BY-SA 4.0

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Stoichiometry in industry and the lab

Leftover feed is a cost

- A plant that pours a large excess of one reactant pays for material that ends up as leftover reactant.
- A higher percent of the calculated product collected means less of that feed was lost to an unfinished change or a side path.

Yield and by-products

- Industry uses stoichiometry to cut leftover reactant and to raise the percent of product collected.
- A lab plan names a concentration method, a predicted equivalence point, an indicator, and the WHMIS step.

Key terms

by-product

A second product, such as $SO_2(g)$ or carbon dioxide from a fuel, that still needs a risk and disposal decision. ($SO_2(g)$)

percent error

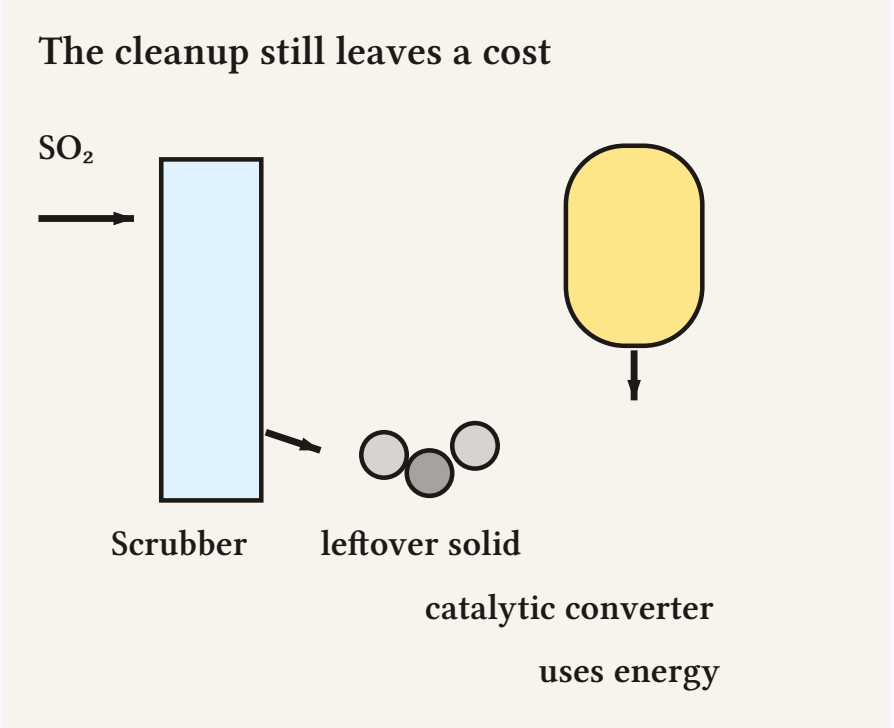
The positive difference between the measured mass and the theoretical mass, divided by the theoretical mass, times 100. (15.0%)

standard solution

A solution whose concentration is known well enough to find another concentration by titration. (0.100 $mol \cdot L^{-1}$ HCl)

Controls that still leave a cost

- A smokestack scrubber lowers $SO_2(g)$, and a catalytic converter lowers CO and NOx in exhaust.
- Each control meets an emission need and still carries a residue or an energy cost.



85.0 percent collected, 15.0 percent off

- The theoretical mass is 5.00 g and the collected mass is 4.25 g.
- Percent yield and percent error use those two masses in different fractions.

Titration plan

- A 25.00 mL acid sample near 0.100 mol·L^{-1} is expected to need about 25 mL of a base near 0.1 mol·L^{-1}.
- Bromothymol blue is the planned indicator, and a pH probe can log the curve.

A precipitate mass and two group results

- A dried precipitate mass can be turned into a solution concentration.
- Two groups can report different base concentrations, and both results stay in the shared table.