The Ultimate AP Chemistry Unit 4 Cheat Sheet

4.1, 4.3–4.4 Reactions, Evidence & Diagrams

Physical vs Chemical Change

Chemical change: bonds broken + formed → new substances w/ new formulas (rusting, burning).
Physical change: same substance, new form; only IMFs change (melting, boiling, dissolving sugar in water).

Evidence	Chemical?	Catch
Gas bubbles	often	boiling also bubbles
Precipitate	often	cooling can crystallize
Color change	often	dilution fades color
Temp change	often	dissolving too

Dissolving a salt: ionic bonds break but no new substance forms → has features of both; justify your call.
Energy clue: light or heat released (burning Mg glows) points to bond changes, but phase changes also move heat.
Strongest proof: a new substance w/ new properties (e.g., test the gas, isolate + identify the solid).

Balanced Equations

Conservation: same # of each atom on both sides + same total charge. Change coefficients, never subscripts.
State symbols matter: (s), (l), (g), (aq). AgCl(s) vs $Ag^+(aq)$ + $Cl^-(aq)$ are different representations of matter.

Particle Diagrams

Draw to scale: $2H_2 + O_2 \rightarrow 2H_2O$ means 4 H atoms + 2 O atoms before AND after; count every atom.
Limiting in a diagram: 6 H_2 + 2 O_2 → 4 H_2O + 2 H_2 left over. Leftover molecules must appear after.
Aqueous ions: draw ions separate; a precipitate = ions packed together as a solid at the bottom.

⚠ Atoms are conserved, molecules are not. 3 molecules can become 2 ($2H_2 + O_2 \rightarrow 2H_2O$) w/ same atoms.

✓ Diagram FRQ: count atoms of each element before + after, include excess reactant + a key.

4.2 Net Ionic Equations

Split vs Keep

Split into ions	Keep whole
Strong acids (aq)	Weak acids, NH_3
Strong bases (aq)	Solids (s), precip.
Soluble salts (aq)	Liquids, H_2O, gases
	Molecular (sugar)

Strong acids: HCl, HBr, HI, HNO_3, $HClO_4$, H_2SO_4. **Strong bases**: group 1 OH^- + Ca, Sr, $Ba(OH)_2$.
Always soluble (all the AP expects you to know): salts of Na^+, K^+, NH_4^+ + NO_3^-. Others: told or seen as (s).

3-Step Method

1. Molecular: $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$.
2. Complete ionic: split all (aq) strong electrolytes.
3. Net ionic: cancel **spectator ions** (same form on both sides) → $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$.

Must-Know Patterns

Reaction	Net ionic
Strong acid + strong base	$H^+ + OH^- \rightarrow H_2O$
Weak acid + OH^-	$HA + OH^- \rightarrow A^- + H_2O$
Carbonate + acid	$CO_3^{2-} + 2H^+ \rightarrow H_2O + CO_2$
Metal + ion	$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

Weak acids stay together: $HC_2H_3O_2 + OH^- \rightarrow C_2H_3O_2^- + H_2O$. Writing H^+ for acetic acid loses the point.
Check: atoms + charge balance; lowest whole-number coefficients; correct (s)/(aq)/(l)/(g) labels.
Reaction w/ gas: Mg(s) + $2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$. Active metal + strong acid → H_2 gas + metal ion.

⚠ Never split a solid, a weak acid or a gas into ions. $CaCO_3(s)$ stays $CaCO_3(s)$ in the net ionic.

✓ No species cancel out? Then no net reaction occurs (e.g., $NaCl(aq) + KNO_3(aq)$ → no precipitate).

4.5 Stoichiometry: The Mole Map

The Core Path

Grams A → mol A → mol B → grams B: ÷ molar mass, × mole ratio (coefficients), × molar mass of B.
Mole ratio comes only from the balanced equation's coefficients, never from subscripts or masses.

Start w/	Convert to mol	Using
Mass (g)	n = m / M	molar mass
Solution	n = M × V(L)	molarity
Gas	n = PV / RT	ideal gas law
Particles	n = N / N_A	6.022×10^{23}

Worked Example

$2H_2 + O_2 \rightarrow 2H_2O$: 16.0 g O_2 = 0.500 mol O_2 → × (2 mol H_2O / 1 mol O_2) = 1.00 mol H_2O = 18.0 g H_2O.
Solution stoich: 50.0 mL of 0.200 M $AgNO_3$ = 0.0100 mol Ag^+ → 0.0100 mol AgCl → × 143.32 g/mol ≈ 1.43 g.
Gas stoich: get n of the gas from PV = nRT (T in K, V in L), then use the mole ratio like any other.
Particles e.g.: 0.250 mol CO_2 × 6.022×10^{23} = 1.51×10^{23} molecules; × 3 atoms each = 4.52×10^{23} atoms.
Gas e.g.: 2.00 L O_2 at 1.00 atm + 298 K → n = PV/RT = 2.00/(0.08206 × 298) = 0.0818 mol O_2.

Empirical Link

Mass data → formula: g → mol of each element, ÷ smallest mole value → whole-number ratio (Unit 1 tool).
Sig figs: final answer follows the least precise measurement; keep extra digits until the very last step.
Combustion analysis: all C → CO_2, all H → H_2O. g CO_2 × 12.01/44.01 = g C; g H_2O × 2.016/18.02 = g H.

⚠ Mole ratios use moles, not grams. 2 g H_2 + 1 g O_2 is NOT the 2 : 1 ratio in the equation (it's 1 mol : 0.03 mol).

✓ Stoich FRQ: write every conversion factor w/ units so the units cancel; the setup alone earns credit.

4.5 Limiting Reactant & Yield

Find the Limiting Reactant

Method: convert each reactant to mol of the **same product**; the smaller amount wins → that reactant limits.
Shortcut: divide mol of each reactant by its coefficient; the smallest quotient = the limiting reactant.
E.g. $2H_2 + O_2 \rightarrow 2H_2O$ w/ 4.0 g H_2 (2.0 mol) + 16.0 g O_2 (0.50 mol): 2.0/2 = 1.0 vs 0.50/1 = 0.50 → **O_2 limits**.

Species	Start (mol)	Change	End
H_2	2.0	−1.0	1.0
O_2	0.50	−0.50	0
H_2O	0	+1.0	1.0

Excess left: start − used. Above, 1.0 mol H_2 (2.0 g) remains after all the O_2 is used up; it doesn't react.

Yield

Theoretical yield: max product from the limiting reactant (here 1.0 mol H_2O = 18.0 g); never from the excess.
Percent yield = actual ÷ theoretical × 100. 15.3 g collected ÷ 18.0 g possible = 85.0% yield of H_2O.
Yield < 100%: side reactions, product lost in transfer or filtering, reaction didn't go to completion.
Yield > 100%: product still wet or contaminated (e.g., not dried to constant mass) → mass too high.

Lab Error Logic

Trace the error: does it make measured mass ↑ or ↓? Then follow that through the calc to the final answer.
Spilled product → actual yield ↓ → % yield ↓. Impure reactant → less real reactant → yield ↓.
Ratio check: 3 mol N_2 + 6 mol H_2 ($N_2 + 3H_2 \rightarrow 2NH_3$): 3/1 = 3 vs 6/3 = 2 → H_2 limits → 4 mol NH_3 made.

⚠ The limiting reactant isn't always the one w/ less mass or fewer moles; the coefficients decide.

✓ Heat to constant mass: weigh, reheat, reweigh until 2 readings match → all the water is gone.

4.6 Introduction to Titration

Setup & Terms

Titration: add a **titrant** of known M from a buret to an **analyte** of unknown M until they react exactly.
Equivalence point: mol titrant added = exact stoichiometric amount of analyte (via the mole ratio).
End point: indicator changes color; a good indicator changes color very close to the equivalence point.

Glassware	Use
Buret	delivers titrant; read to ±0.01 mL
Volumetric pipet	exact analyte volume
Erlenmeyer flask	holds analyte + indicator

The Calculation

Steps: mol titrant = M × V(L) → × mole ratio → mol analyte → ÷ analyte V(L) = analyte M. Write each step.
1 : 1 e.g.: 20.00 mL of 0.100 M NaOH neutralizes 25.00 mL HCl → 2.00×10^{-3} mol → [HCl] = 0.0800 M.
2 : 1 e.g.: H_2SO_4 + 2NaOH → 30.0 mL of 0.100 M NaOH = 3.00×10^{-3} mol → 1.50×10^{-3} mol H_2SO_4.

Technique & Errors

Rinse buret w/ titrant, not water: leftover water dilutes titrant → more volume used → analyte M too high.
Overshoot the end point → V titrant too large → calculated analyte M too high. Air bubble in tip → same.
Adding water to the flask doesn't change mol analyte → no change to the volume of titrant needed.
Standard solution: titrant w/ precisely known M; prepared in a volumetric flask, then loaded in the buret.
Gravimetric cousin: precipitate the ion, filter, dry to constant mass → mol from the mass of the solid.

⚠ Equivalence point ≠ "pH 7." Only a strong acid + strong base titration is neutral at equivalence (Unit 8).

✓ Read the buret at eye level, bottom of the meniscus; record 2 decimal places (e.g., 23.45 mL).

4.7–4.8 Reaction Types & Acid–Base

3 Main Reaction Types

Type	What transfers	Clue
Acid–base	H^+ (proton)	acid + base
Redox	e^-	ox. #s change
Precipitation	ions combine	(s) forms

Precipitation: 2 soluble salts swap partners → insoluble solid forms. $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4(s)$, white solid.
Combustion + most **synthesis/decomposition** w/ elements = redox. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (C: −4 → +4).
Classify by what happens to particles, not by name: if any ox. # changes → redox, whatever else it is.

Brønsted–Lowry Acids & Bases

Acid = H^+ donor. **Base** = H^+ acceptor (needs a lone pair). H^+ in water exists as **H_3O^+** (hydronium ion).
Conjugate pair: differ by 1 H^+. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$: NH_3/NH_4^+ + H_2O/OH^- are the 2 conjugate pairs.
Amphoteric: can act as acid or base → H_2O, HCO_3^-, HSO_4^-, $H_2PO_4^-$. Role depends on the partner.
Neutralization: acid + base → water + salt. $H^+ + OH^- \rightarrow H_2O$ is the net ionic for strong acid + strong base.

Spot the Acid

Ionizable H is the one bonded to an EN atom (O, Cl): in $HC_2H_3O_2$ only the H on O is acidic, not C–H.
Polyprotic: H_2SO_4, H_3PO_4 give up H^+ one at a time; count every H^+ in titration mole ratios (H_2SO_4 : NaOH = 1 : 2).
Strong vs weak: strong acids ionize ~100% (write H^+); weak acids ionize a little (write HA, not H^+).

⚠ Conjugate base of H_2O is OH^-; conjugate acid of H_2O is H_3O^+. Don't swap them on an FRQ answer.

✓ Label conjugate pairs w/ arrows on both sides of the equation; each pair differs by exactly 1 H^+.

4.9 Oxidation Numbers & Redox

Oxidation Number Rules

Species	Ox. #	Exception
Element (Fe, O_2)	0	none
Monatomic ion	= charge	none
O in compounds	−2	H_2O_2: −1
H w/ nonmetals	+1	NaH: −1
F	−1	none

Sum rule: ox. #s add to 0 in a neutral compound, or to the charge of a polyatomic ion (e.g., −2 for SO_4^{2-}).
E.g.: Mn in MnO_4^-: x + 4(−2) = −1 → **+7**. Cr in $Cr_2O_7^{2-}$: 2x − 14 = −2 → **+6**. S in SO_4^{2-} → +6; N in NH_4^+ → −3.

Who Gets Oxidized?

OIL RIG: Oxidation Is Loss of e^- (ox. # ↑); Reduction Is Gain of e^- (ox. # ↓). Both happen together.
Oxidizing agent = species that gets **reduced**; **reducing agent** = species that gets **oxidized** (gives e^-).

$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$	Role
Zn: 0 → +2	oxidized; red. agent
Cu^{2+}: +2 → 0	reduced; ox. agent

e^- lost = e^- gained: every redox reaction transfers equal e^-; that's what balances the 2 half-reactions.

Redox Clues

Free element on 1 side + in a compound on the other → almost always redox (metal + acid → H_2 gas).
Not redox: precipitation + acid–base where every ox. # stays the same ($AgNO_3$ + NaCl, HCl + NaOH).

⚠ The agent is the whole species: say "MnO_4^- is the oxidizing agent," not just "Mn" or "manganese."

✓ Justify: give the ox. # before + after for the element that changes; don't just say "it gains e^-." Show the math.

4.9 Half-Reactions & Exam Strategy

Half-Reactions

Oxidation half: $Fe^{2+} \rightarrow Fe^{3+} + e^-$ (e^- on product side).
Reduction half: $Cu^{2+} + 2e^- \rightarrow Cu$ (e^- on reactant side).
Balance in acid: atoms other than O + H → O w/ H_2O → H w/ H^+ → charge w/ e^- → match e^- in both halves.
E.g.: $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$; multiply $Fe^{2+} \rightarrow Fe^{3+} + e^-$ by 5 → add the halves + cancel the 5 e^-.
Overall: $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$.
Check: charge +17 = +17; atoms match.
Galvanic link: separate the 2 halves + connect them w/ a wire → e^- flow = an electric current (Unit 9).
Redox titration: MnO_4^- is purple + acts as its own indicator; end point = the 1st lasting pink color in the flask.

Exam Moves

Asked	Do this
Net ionic	split strong (aq) only
Limiting reactant	mol ÷ coefficient
Titration M	mol ratio, then ÷ V
Redox ID	ox. # before + after

Units always: mL → L before M × V; g → mol w/ molar mass from the periodic table you are given.
Explain, then calculate: FRQs often want a claim (e.g., "O_2 is limiting") backed by numbers as evidence.
Sig figs + units on every final answer; keep only the digits the data support (3 s.f. data → 3 s.f.).
Pattern: claim → evidence (numbers or ox. #s) → reasoning (why the evidence supports the claim).
Check answers: does mass/mol make sense? Limiting reactant fully used? Charges balanced in net ionic?

⚠ Electrons must cancel when you add half-reactions. Leftover e^- in the final equation = error.

✓ The periodic table + equations sheet give molar masses + core formulas; you supply the setup + logic.