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Topic 4.7: Types of Chemical Reactions

Revision Notes · AP Chemistry

UNIT 4 · CHEMICAL REACTIONS

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Two Ways of Sorting the Same Reaction

Chemists sort reactions in two independent ways; one reaction normally takes a label from each.

The first sorts by pattern, the arrangement of reactants and products: synthesis, decomposition, single replacement, double replacement and combustion.

The second sorts by what changes hands. Acid-base reactions transfer H^+ ions, precipitation reactions lock ions into an insoluble solid, and redox reactions transfer electrons; acid-base is developed in Topic 4.8 and redox in Topic 4.9.

The two systems overlap freely: one reaction can be a double replacement and a precipitation at the same time.

Synthesis and Decomposition: Opposite Patterns

A synthesis reaction builds one product from two or more reactants: A + B → AB. Two elements combining, as in $2Mg + O_2 \rightarrow 2MgO$, is the clearest case, but compounds can join too: $CaO + H_2O \rightarrow Ca(OH)_2$.

A decomposition reaction runs the pattern in reverse: one reactant splits into two or more products, AB → A + B. Heating calcium carbonate gives $CaCO_3 \rightarrow CaO + CO_2$, and heating potassium chlorate gives $2KClO_3 \rightarrow 2KCl + 3O_2$.

The products need not be elements: $CaCO_3$ gives two compounds, and only some decompositions, such as $2HgO \rightarrow 2Hg + O_2$, end at elements.

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Single Replacement and the Activity Series

In a single replacement reaction, a free element takes the place of a similar element in a compound: A + BC → AC + B.

Zinc pushes copper out of copper(II) sulfate solution, $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$, and chlorine does the same to bromide, $Cl_2 + 2NaBr \rightarrow 2NaCl + Br_2$.

The activity series, the ranking of elements by reactivity, decides whether the swap happens: a free element displaces only elements below it.

Copper sits above silver, so $Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$ runs. Copper sits below zinc, so copper metal in zinc sulfate solution does nothing: it is not reactive enough to displace the zinc.

Hydrogen also holds a place in the series. Metals above it displace it from dilute acids, as in $Zn + 2HCl \rightarrow ZnCl_2 + H_2$; copper, below it, does not react.

Double Replacement: Swapping Partners

In a double replacement reaction, two compounds exchange ions: AB + CD → AD + CB. The way to predict the products is to swap the cations, giving each cation the other compound's anion: $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$.

Swapping writes candidate products, not a guaranteed reaction: it runs only if a precipitate, a gas or water leaves the solution, as insoluble AgCl does here.

When the product that leaves is a solid, as $BaSO_4$ in $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$, the reaction is also a precipitation.

Swapped formulas must balance charges: Al^{3+} with SO_4^{2-} gives $Al_2(SO_4)_3$, never $AlSO_4$.

Acid-Base Reactions: Salt, Water, and a Gas From Carbonates

An acid reacting with a metal hydroxide produces a salt and water: $HCl + NaOH \rightarrow NaCl + H_2O$. The acid's H^+ and the base's OH^- form the water; the salt pairs the base's cation with the acid's anion.

By pattern it is double replacement; by family it is acid-base, the neutralisation developed in Topic 4.8.

Carbonates behave as bases but add a third product. Acid plus a metal carbonate gives a salt, water and carbon dioxide: $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$.

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The fizzing is the CO_2 escaping: spot a carbonate among the reactants, and CO_2 must appear among the products.

Combustion: Burning in Oxygen

Combustion is a rapid reaction with oxygen, releasing energy as heat and light; oxygen is a required reactant.

A hydrocarbon burned in excess oxygen burns completely: every carbon ends as CO_2 and every hydrogen as H_2O. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ and $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ follow that rule, so the products can be written before balancing.

In limited oxygen the burn is incomplete: carbon monoxide or soot (carbon) replaces some of the CO_2, so the CO_2 and H_2O rule holds only with oxygen in excess.

Metals burn to metal oxides: $2Mg + O_2 \rightarrow 2MgO$ is a synthesis and a combustion at once. Every combustion is redox, the fuel losing electrons to oxygen.

Redox: The Electron-Transfer Test

A redox reaction is one in which electrons are transferred, and the reliable sign is that oxidation numbers change. The substance that loses electrons is oxidised; the one that gains them is reduced.

In $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$, zinc moves from 0 to +2 in Zn^{2+}, losing two electrons per atom: zinc is oxidised. Copper moves from +2 to 0: copper ions are reduced.

In $Cl_2 + 2NaBr \rightarrow 2NaCl + Br_2$, chlorine falls from 0 to −1 and is reduced; bromide rises from −1 to 0 and is oxidised.

Single replacement reactions are always redox, because a neutral atom and an ion trade places. Double replacement and acid-base reactions are never redox: no ion changes its charge, so no oxidation number moves.

Worked Examples

> **Example 1: Predicting and classifying. Iron filings in copper(II) sulfate solution. Iron is above copper in the activity series, so the replacement runs: $Fe + CuSO_4 \rightarrow FeSO_4 + Cu$. Pattern: single replacement. Family: redox, iron moving 0 to +2 while copper moves +2 to 0. The blue colour fades as Cu^{2+} leaves solution, and brown copper coats the iron.**

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Example 2: Combustion with numbers. 8.02 g of methane (0.500 mol) burns completely: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. Products: 0.500 mol of CO_2 (0.500 × 44.01 = 22.0 g) and 1.00 mol of H_2O (18.0 g); oxygen used: 1.00 mol (32.0 g). Mass check: 8.02 + 32.0 = 40.0 g in, 22.0 + 18.0 = 40.0 g out.

Example 3: A double replacement carried through. $BaCl_2$ and Na_2SO_4 solutions are mixed. Swap the cations: Ba^{2+} takes SO_4^{2-}, Na^+ takes Cl^-. $BaSO_4$ is insoluble, so $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$ runs: a double replacement and a precipitation. With 0.0100 mol of $BaCl_2$ and excess sulfate, 0.0100 mol of $BaSO_4$ forms: 0.0100 × 233.39 = 2.33 g.

Traps That Cost Marks in Topic 4.7

Giving a reaction only one label. $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$ is a double replacement and a precipitation; $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$ is a single replacement and redox. A question asking what is "also true" is usually fishing for the second label.

Assuming every cation swap is a reaction. Swapping partners only proposes products: if both are soluble and no gas or water forms, every ion stays in solution and nothing has reacted. NaCl with KNO_3 is the standard case.

Ignoring the activity series. A single replacement runs only when the free element sits above the element it would displace: silver does nothing in copper(II) nitrate (below copper), while copper reacts in silver nitrate (above silver).

Losing the carbon dioxide from a carbonate. Acid plus carbonate makes three products: a salt, water and CO_2. Stopping at the salt and water drops a product and leaves the equation unbalanced.

Writing charge-unbalanced formulas for swapped products. An ionic product must be neutral overall: aluminium sulfate is $Al_2(SO_4)_3$, its +6 from two Al^{3+} ions balancing −6 from three SO_4^{2-} ions. $AlSO_4$ carries a net charge and cannot be a product.

Confusing combustion with synthesis, or with the absence of redox. $2Mg + O_2 \rightarrow 2MgO$ is synthesis and combustion in one equation, and every combustion is redox. Test each label on its own terms.

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Key Relationships to Remember

- Pattern forms: synthesis A + B → AB; decomposition AB → A + B; single replacement A + BC → AC + B; double replacement AB + CD → AD + CB; combustion: fuel + O_2 → oxides
- The three families: acid-base transfers H^+, precipitation locks ions into an insoluble solid, redox transfers electrons; pattern and family labels overlap freely
- A hydrocarbon in excess oxygen gives CO_2 and H_2O only; in limited oxygen, expect carbon monoxide or carbon as well
- Acid + metal hydroxide → salt + water; acid + metal carbonate → salt + water + CO_2
- Activity series: a free element displaces only elements ranked below it; metals above hydrogen displace H_2 from dilute acids, metals below it do not
- Double replacement prediction: swap the cations, write charge-balanced formulas, then check for a precipitate, a gas or water; none of the three means no reaction
- Single replacement and combustion are always redox; double replacement and acid-base reactions never are, because no oxidation number changes

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