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Topic 4.1: Introduction to Reactions

Revision Notes · AP Chemistry

UNIT 4 · CHEMICAL REACTIONS

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What a Chemical Reaction Is

A chemical reaction is a rearrangement of atoms. The atoms in the reactants are regrouped, so new substances appear with different properties.

The starting substances are the reactants, and the new substances formed are the products. Reactants are consumed and products are formed, but no atom is created and none is destroyed.

At the particle level, a reaction breaks the bonds holding atoms together in the reactants and forms new bonds in the products. Energy may be released or absorbed, but the atoms themselves pass through unchanged.

A change that merely moves the same particles around, making nothing new, is a physical change rather than a reaction: melting, evaporating and dissolving are examples.

Evidence That a Reaction Has Occurred

Atoms are too small to watch directly, so a reaction is detected through signs that a new substance has formed.

Formation of a precipitate. When two clear solutions are mixed and an insoluble solid appears, clouding the mixture and settling, a new substance exists that was in neither starting solution: dissolved ions have combined into a solid that leaves the solution.

Gas evolution. Bubbles appearing when substances are mixed signal that one of the products is a gas: carbon dioxide fizzing out when an acid meets a carbonate is the standard case. Bubbles from boiling are different, because that gas is the same substance turned to vapour.

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Colour change. When zinc stands in blue copper(II) sulfate solution, the blue fades as copper ions leave the solution and reddish copper metal forms: the colour changes because a new substance appears.

Temperature change. Many reactions release heat, warming the mixture with no heating applied; others absorb heat, and the mixture cools. Either way, energy is transferred as bonds rearrange.

No single observation is proof by itself, and some reactions give no visible sign at all: the products may be colourless and dissolved, with barely any temperature change. Lack of visible evidence does not prove no reaction happened.

Physical and Chemical Change at the Particle Level

In a physical change the particles themselves stay the same; only their spacing, arrangement or motion changes. Ice melts into water whose molecules are identical to the ones in the ice, just no longer locked into fixed positions.

In a chemical change the particles change. Atoms are regrouped into new molecules or new ionic arrangements, so the products are genuinely different substances, as when iron turns into rust, hydrated iron(III) oxide.

Dissolving sits on the physical side of the line. When sodium chloride dissolves, its lattice breaks up into separate Na^+ and Cl^- ions, each surrounded by water molecules. They are the same ions the solid contained, so no new substance forms, and the salt can be recovered unchanged by evaporating the water.

When a molecular solid such as glucose dissolves, the molecules merely spread out among the water molecules, intact: no bonds inside them break, and no new substance appears.

Conservation of Mass

The law of conservation of mass states that in any chemical reaction the total mass of the products equals the total mass of the reactants. It holds because every atom present at the start is present at the end, only rearranged.

The law applies to the complete system. If gas escapes from an open beaker during a reaction, the mass left behind falls, but the escaped gas carries the missing mass; nothing is destroyed.

In a sealed container nothing can enter or leave, so the measured mass stays constant through any reaction inside it: weighing a closed system before and after gives the direct test of the law.

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Writing and Balancing Equations

A chemical equation uses formulas and symbols to show reactants becoming products: reactants on the left, an arrow, then products on the right. Plus signs separate substances on the same side, and state symbols, (s), (l), (g) and (aq), record each substance's state.

A subscript inside a formula is part of the identity of the substance: the subscript 2 in H_2O states that each water molecule contains two hydrogen atoms. Subscripts are fixed by the compound's composition and can never be changed to balance an equation.

A coefficient in front of a formula states how many units of that substance take part: individual formula units or, scaled up, moles. The 2 in $2H_2O$ means two water molecules, or two moles of water. Coefficients describe amounts only, never identity.

An equation is balanced when it shows the same number of atoms of each element on both sides. Balancing is done by adjusting coefficients only, never subscripts, and only a balanced equation fits conservation of mass.

Worked Examples

Example 1: Conservation of mass in a decomposition. Heating calcium carbonate decomposes it: $CaCO_3 \rightarrow CaO + CO_2$. When 10.0 g of calcium carbonate gives 5.6 g of calcium oxide, the carbon dioxide released must have mass 10.0 − 5.6 = 4.4 g, since total product mass must equal reactant mass. A molar mass check agrees: 10.0 g of $CaCO_3$ is 0.100 mol, forming 0.100 mol of CO_2 with mass 4.40 g.

Example 2: Balancing the combustion of methane. Begin unbalanced: $CH_4 + O_2 \rightarrow CO_2 + H_2O$. Carbon already matches, one atom on each side. Hydrogen has 4 atoms on the left and 2 on the right, so place a coefficient of 2 in front of H_2O. Oxygen on the right now totals 4 atoms (2 in CO_2, 2 in the two H_2O), so place a coefficient of 2 in front of O_2. The balanced equation, $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, shows 1 C, 4 H and 4 O atoms on each side.

Example 3: Reading amounts from coefficients. In $2H_2 + O_2 \rightarrow 2H_2O$, the coefficients say 2 mol of hydrogen reacts with 1 mol of oxygen to produce 2 mol of water, so the mole ratio of hydrogen to water is 2:2, or 1:1. The mass account balances exactly too: 4.0 g of H_2 plus 32.0 g of O_2 is 36.0 g of reactants, and 2 mol of H_2O has mass 36.0 g.

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Traps That Cost Marks in Topic 4.1

Changing a subscript to balance an equation. Rewriting H_2O as H_2O_2 for oxygen replaces water with hydrogen peroxide, a different substance. Only coefficients are adjustable.

Expecting the number of molecules to be conserved. Balancing conserves atoms, not molecules. In $2H_2 + O_2 \rightarrow 2H_2O$, three moles of reactant molecules produce two moles of product molecules, quite correctly.

Treating all bubbles as evidence of reaction. Boiling makes bubbles of the liquid's own vapour, and an opened fizzy drink releases gas dissolved under pressure. Both are physical. Bubbles count as evidence only when the reaction itself generates a new gas.

Reading a mass drop as mass destroyed. When a reaction in an open container appears to lose mass, a gaseous product has escaped. Conservation of mass covers the container and the escaping gas together.

Concluding there was no reaction because nothing was seen. Reactions between colourless solutions can form colourless, soluble products with almost no temperature change. No observation is not the same as no reaction.

Calling every colour change physical. Diluting a coloured solution lightens it physically, but when zinc fades blue copper(II) sulfate solution, Cu^{2+} ions are leaving solution to form copper metal: a colour change from a new substance forming is chemical evidence.

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Key Relationships to Remember

- A chemical reaction rearranges atoms: bonds in the reactants break, new bonds form, and the products are new substances with different properties
- Reactants are consumed and products are formed; atoms are neither created nor destroyed, so mass is conserved
- Evidence of a reaction: a precipitate forms, a new gas is evolved, the colour changes, or the temperature changes as heat is released or absorbed
- Physical change leaves the particles themselves unchanged; chemical change regroups atoms into new substances
- Dissolving an ionic solid separates its ions, each surrounded by water molecules; dissolving a molecular solid spreads intact molecules; neither creates a new substance
- In a closed system the total mass after a reaction equals the total mass before it; apparent losses in open systems are gases escaping
- A balanced equation has equal numbers of atoms of every element on both sides, achieved by adjusting coefficients only; subscripts define each substance and never change; coefficients give relative amounts in formula units or moles

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