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Topic 4.4: Physical and Chemical Changes

Revision Notes · AP Chemistry

UNIT 4 · CHEMICAL REACTIONS

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The Particle Test: What Actually Changes

Every change is classified by one question about its particles: afterwards, are the particles the same substances as before, or have the atoms been regrouped into new substances?

In a physical change, the particles keep their identity. The same molecules or ions are present before and after; only their spacing, arrangement, motion or state has altered.

In a chemical change, atoms are regrouped. Bonds in the reactants break, new bonds form, and the products are different substances with different properties.

The atoms themselves never change: no atom is created, destroyed or turned into another element. The same elements appear before and after a chemical change; only their combinations differ.

What Breaks in a Physical Change

A physical change overcomes attractions between particles, never the bonds within them. Melting frees molecules from fixed positions; boiling pulls them completely apart into a gas.

The energies show the scale of what is overcome. Melting one mole of ice takes 6.01 kJ and vaporising one mole of water takes 40.7 kJ, and both leave every H_2O molecule intact.

Set that beside the bonds inside the molecule: each O-H bond needs about 463 kJ per mole of bonds to break, so splitting one mole of water molecules into separate atoms would take about 926 kJ, roughly 23 times the energy of boiling the same amount.

Cutting, tearing, crushing and grinding are physical for the same reason: the material is divided into smaller pieces, and every piece is still the same substance, made of the same particles.

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Mixing without reaction is physical too. The particles are intermingled, each keeping its own identity, and can in principle be separated again by physical means.

Dissolving: Separation Without New Substances

When sodium chloride dissolves in water, the lattice comes apart and each Na^+ and Cl^- ion leaves the crystal surrounded by water molecules. The ions in the solution are exactly the ions the solid contained: water has separated them, not changed them.

The energy account confirms how little is disturbed. Pulling the lattice apart into isolated ions costs 787 kJ per mole, while the ion-dipole attractions formed with water release 783 kJ per mole, so the net enthalpy change of dissolving is only about +4 kJ per mole.

Because the particles are unchanged, the change can be undone physically: evaporate the water and the same salt crystallises out, identical to what went in.

A molecular solid such as sugar dissolves even more simply. Its molecules spread out among the water molecules whole, with every bond inside them intact and no ions formed.

Dissolving is not automatically physical, though. Sodium metal fizzes violently in water because it reacts, forming the new substances sodium hydroxide and hydrogen. The classification follows the particles, not the name of the process.

What Breaks in a Chemical Change

A chemical change breaks bonds within particles and forms new ones, so the substances themselves are replaced. Rusting turns iron into iron oxide, and burning turns wood into ash, carbon dioxide and water vapour.

Photosynthesis is the same kind of event: carbon dioxide and water are rearranged into glucose and oxygen, substances that were not present before the change began.

Cooking an egg is chemical because heat permanently rearranges the protein structures. The set white and yolk cannot be returned to the raw state simply by cooling.

Chemical changes usually move much more energy than physical ones, because breaking and forming bonds shifts far more energy than separating molecules does. The size or sign of an energy change can support a classification, but it never decides one.

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Evidence: Useful Signs, Not Proof

A precipitate appearing, a new gas with its own smell, a colour change or an unexpected temperature change all suggest that new substances have formed, and each is worth citing as evidence.

Every sign has a physical look-alike. Bubbles also appear when a liquid boils, and that gas is only the liquid's own vapour. A colour can grow paler simply by dilution, with no reaction at all.

The opposite error is just as real: a reaction between colourless solutions can produce colourless dissolved products with almost no temperature change, so nothing is seen even though new substances exist.

Reversibility is a clue, not a test. Many physical changes reverse readily, and most chemical changes do not, yet shattered glass never rebuilds itself, and dehydrating blue copper(II) sulfate crystals, a chemical change, reverses when water is added back.

The deciding question is always the particle one: are new substances present afterwards, or only the same particles in new positions?

Worked Examples

Example 1: Boiling water versus breaking it apart. Vaporising 1 mol of water takes 40.7 kJ and overcomes only the hydrogen bonds between molecules; each molecule leaves the liquid still as H_2O. Breaking both O-H bonds in every molecule of the same 1 mol would take 2 × 463 = 926 kJ, about 23 times as much, and only then would the substance itself be destroyed. Boiling works against attractions between particles and leaves the particles alone, so it is a physical change.

Example 2: Rusting conserves mass while making a new substance. The equation is $4Fe + 3O_2 \rightarrow 2Fe_2O_3$. Four moles of iron have mass 4 × 55.85 = 223.4 g, and three moles of oxygen have mass 3 × 32.00 = 96.0 g, giving 319.4 g of reactants. Two moles of Fe_2O_3 have mass 2 × 159.7 = 319.4 g. The masses match because the atoms are conserved, yet iron oxide is a different substance from iron and oxygen, so the change is chemical.

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> **Example 3: A colour fade that is a reaction. Zinc placed in blue copper(II) sulfate solution makes the blue fade. At the particle level, Cu^{2+} ions leave the solution and become copper atoms on the zinc surface, while zinc atoms become Zn^{2+} ions entering the solution: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$, balanced for atoms and for the +2 charge on each side. Copper metal and zinc ions are new substances, so this quiet colour change is chemical, not dilution.**

Traps That Cost Marks in Topic 4.4

Calling boiling a chemical change because bubbles appear. The bubbles are the liquid's own vapour. Bubbles signal a reaction only when a new gas is generated, as when an acid fizzes on a carbonate.

Calling dissolving a chemical change because the solid disappears. The particles of the solid are still present, separated and surrounded by solvent. A vanished appearance is not a new substance.

Treating every colour change the same way. Dilution lightens a colour physically; a colour change caused by a new substance forming, such as copper ions leaving solution, is chemical evidence. Ask which one happened.

Using reversibility as the definition. Shattering glass is physical but effectively irreversible, and some chemical changes reverse, such as rehydrating anhydrous copper(II) sulfate. Reversibility hints; particle identity decides.

Thinking a chemical change creates new elements. The elements present are identical before and after; the atoms are regrouped into new combinations. New substances, never new elements.

Missing the reaction hiding inside a familiar process. Sodium in water looks like dissolving but is a violent reaction, and burning wood runs physical changes, warming and evaporation, alongside the chemical change of combustion.

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Key Relationships to Remember

- Physical change: the particles keep their identity; only spacing, arrangement, motion or state changes, and only attractions between particles are overcome
- Chemical change: bonds within reactants break and new bonds form, regrouping the same atoms into new substances with new properties
- Atoms and elements are conserved in both kinds of change; nothing is created, destroyed or transmuted
- Phase changes and dissolving work against intermolecular or lattice attractions of at most tens of kJ per mole, far less than the hundreds of kJ per mole needed to break covalent bonds
- Dissolving an ionic solid separates its ions, each surrounded by solvent molecules; dissolving a molecular solid spreads intact molecules; both are physical and can be reversed by removing the solvent
- Evidence of chemical change (a precipitate, a new gas, a colour change, a temperature change) suggests new substances, but each sign has a physical look-alike and some reactions show no visible sign
- Reversibility is a clue, not the test: the classification is decided by whether new substances are present after the change

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