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Topic 3.8: Representations of Solutions

Revision Notes · AP Chemistry

UNIT 3 · PROPERTIES OF SUBSTANCES AND MIXTURES

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Three Levels Describe the Same Solution

Chemists describe one solution at three levels, and this topic is about moving between them.

The macroscopic level is what you can observe: a clear liquid, a blue colour, an undissolved solid. The symbolic level is formulas and equations, such as $NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$, where (aq) means dissolved in water.

The particulate level draws the particles themselves: which species are present, how many of each, and how water sits around them. If the equation says a solute dissociates, the drawing shows separated ions spread evenly, not clustered.

Reading a Diagram: Key, Species and Counts

Start with the key. Each shape stands for one species, and one drawn particle stands for the same huge number of real particles in every box at that scale. Counts compare only at the same scale, and solvent particles never count as solute.

Next, name the species present. A dissolved ionic solute appears as separate cations and anions, never as joined formula unit pairs.

A dissolved molecular solute appears as intact molecules: glucose in water is whole $C_6H_{12}O_6$ molecules, with no ions and no separate atoms. Two miscible liquids draw the same way: both intact species intermingled randomly through one box, never in layers. Polyatomic ions also stay in one piece: a nitrate ion is one NO_3^- unit, hydrated as a whole.

Then count. The ratios must match the formula: $CaCl_2$ gives Ca^{2+} and Cl^- in a 1 to 2 ratio, and $AlCl_3$ gives Al^{3+} and Cl^- in a 1 to 3 ratio. The counts must also balance charge: total positive charge

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equals total negative charge, so a box holding 4 Ca^{2+} ions, carrying 8 units of positive charge, must hold 8 Cl^- ions, not 4.

Hydration Shells Point the Right Way Round

When an ionic solute dissolves, water molecules cluster around each ion in a hydration shell, held by ion-dipole attractions. Water is polar: its oxygen end carries partial negative charge, δ-, and each hydrogen end partial positive charge, δ+.

Around a cation such as Na^+, the oxygen ends point inward and the hydrogen ends outward. Around an anion such as Cl^-, the picture reverses: hydrogen ends point inward and oxygen ends outward.

Orientation is the fastest error check on a diagram. Oxygen ends facing an anion, or hydrogen ends facing a cation, puts like charges together and is wrong.

The shell has a limited size: only as many waters fit around the ion surface as can touch it at once, so a larger ion holds more in direct contact. Strength runs the other way: a small, highly charged ion such as Mg^{2+} grips its waters hardest, because concentrated charge makes the strongest ion-dipole attractions, so its shell is the most tightly held and ordered.

Pulling the lattice apart costs energy, and so does pushing water molecules apart, breaking some of their hydrogen bonds. Forming the shells' ion-dipole attractions releases energy, and dissolving happens only when that release covers the cost.

Concentration Is Particles per Volume

A diagram shows concentration only when volume enters the comparison: the rule is particles per unit volume, not particles alone.

At the same volume and scale, more solute particles means a more concentrated solution, in exact proportion: twice the particles means twice the molarity. If volumes differ, divide first: twelve particles in a double volume is the same concentration as six in a single volume.

Spacing carries the same information: in equal volumes, concentrated solutions show particles close together and dilute solutions show them far apart.

Total particle concentration is a separate count. At the same formula unit molarity, NaCl holds twice as many particles as glucose, because each formula unit dissociates into two ions while each glucose molecule stays one particle.

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A box with 5 intact HF molecules and only 1 H^+ and 1 F^- ion shows a weak electrolyte: most particles never dissociated. A strong electrolyte shows no intact formula units at all, and a non-electrolyte shows intact neutral molecules only.

Dilution, Evaporation and Mixing Redraw the Same Particles

Dilution adds water and nothing else. The solute count is unchanged, the box gets bigger, spacing grows, and molarity falls in proportion to the volume rise: doubling the volume at fixed count halves the concentration.

Evaporation reverses it. Water leaves, solute stays, the box shrinks, spacing closes up, and molarity rises in proportion to the volume fall.

Mixing puts both sets of particles into one box of combined volume. Each solute keeps its own count, and every concentration is recomputed against combined volume.

Every finished solution is drawn evenly spread. Particles clustered at the bottom describe an undissolved solid or an unmixed system, not a solution.

A Solid in the Box: Saturation and Precipitates

In a saturated solution the liquid holds a small, constant count of separated, hydrated ions, in the formula's ratio, in dynamic equilibrium with the solid: ions leave and rejoin the lattice at equal rates, so the liquid's spacing and concentration stay fixed while solid remains. A precipitate is drawn the same way: its ions sit locked in a lattice block, while the spectator ions stay mobile and hydrated in the liquid.

Worked Examples

> **Example 1: Three boxes at one scale. Three equal volume boxes share one key and scale: Box A shows 3 Ca^{2+} and 6 Cl^- ions, Box B shows 4 Na^+ and 4 Cl^- ions, and Box C shows 5 intact glucose molecules. Box B represents 0.40 M NaCl, so 1 drawn formula unit stands for 0.10 M. Box A is therefore 0.30 M $CaCl_2$ (Ca^{2+} 0.30 M, Cl^- 0.60 M) and Box C is 0.50 M glucose. Particle counts rank differently: Box A holds 9 particles (0.90 M), Box B 8 (0.80 M) and Box C 5 (0.50 M), so Box C has the highest formula unit molarity and the lowest particle concentration.**

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> **Example 2: Drawing a dilution. A box for 100 mL of 0.60 M KCl shows 6 K^+ and 6 Cl^- ions. Diluted to 200 mL, the moles stay at 0.60 × 0.100 = 0.060 mol, so the molarity halves to 0.060 ÷ 0.200 = 0.30 M, and the drawing keeps both counts, spread through twice the space.**

Traps That Cost Marks in Topic 3.8

More particles always means more concentrated. Only at equal volume and scale. Twelve particles in a double volume ties six in a single volume.

Dissolved NaCl is drawn as NaCl pairs. A soluble ionic solute is drawn as separated, individually hydrated ions. Joined pairs describe the undissolved solid.

Water orientation around ions is decorative. It carries the physics: oxygen ends toward cations, hydrogen ends toward anions. A reversed shell is wrong.

A polyatomic ion breaks into atoms on dissolving. NO_3^-, SO_4^{2-} and PO_4^{3-} move through solution as single charged units.

Dilution removes particles from the drawing. It removes none: the same count sits in a larger box. Deleting particles describes removing solute.

Equal molarity means equal particle counts. Only when solutes produce the same particles per formula unit. A 0.30 M $CaCl_2$ box holds three times the particles of a 0.30 M glucose box.

Counts in a diagram are the actual numbers present. They are a scaled sample. Counts give ratios and relative concentrations; a molarity follows only when the scale or a reference concentration is known.

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Key Relationships to Remember

- Three levels, one system: macroscopic, symbolic and particulate descriptions must agree about the same solution
- Reading order: key, species, counts, ratio against the formula, then charge balance
- Ionic solutes are drawn as separated ions; molecular solutes as intact molecules; polyatomic ions always as single intact units
- Hydration: oxygen ends (δ-) point toward cations and hydrogen ends (δ+) toward anions, held by ion-dipole attractions, strongest for small, highly charged ions; the waters touching an ion are limited by how many fit around it
- Concentration in a diagram: solute particles per unit volume at a fixed scale; equal volumes compare by count alone, unequal volumes are divided by volume first
- Total particle concentration: formula unit molarity multiplied by the particles each formula unit produces on dissolving
- Dilution and evaporation: count fixed; volume, spacing and molarity move in proportion, molarity against the volume; mixing: all counts move into one box of combined volume, concentrations recomputed against it

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