Topic 3.9: Separation of Solutions and Mixtures

Revision Notes · AP Chemistry

UNIT 3 · PROPERTIES OF SUBSTANCES AND MIXTURES

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Separation Uses a Difference in Properties

A mixture can be separated because its components keep their own properties. No reaction is needed, and each component is recovered unchanged.

Every method here exploits one named difference. Chromatography uses differences in attraction to two phases. Distillation uses differences in boiling point.

Chromatography Is a Competition Between Two Phases

Chromatography has two phases. The stationary phase stays in place. The mobile phase moves through or over it, carrying the mixture with it.

Each component is pulled both ways at once. It is attracted to the stationary phase, which holds it back, and it dissolves in the mobile phase, which carries it forward.

Strong attraction to the stationary phase, or poor solubility in the mobile phase, means most time held in place and slow travel. Weak attraction, or ready solubility, means most time moving and fast travel.

Separation happens because components strike this balance differently. Given enough distance, small differences build into separated spots or bands.

The attractions are the intermolecular forces from Topic 3.1: hydrogen bonding, dipole to dipole attractions and London dispersion forces. Polarity is usually decisive: polar components are attracted to polar partners, nonpolar components to nonpolar partners.

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Paper and Thin Layer Chromatography

In paper chromatography the stationary phase is polar cellulose paper. The mobile phase is a solvent that climbs it by capillary action, driven by attractions between solvent and fibres.

In thin layer chromatography, called TLC, the stationary phase is a thin layer of a polar solid such as silica on a flat plate, and the solvent climbs in the same way.

A small spot of mixture sits on a baseline near the bottom. The bottom edge sits in the solvent, which rises past the spot and carries each component up at its own rate.

On polar cellulose or silica, a highly polar component is held strongly and travels a short distance. A nonpolar component is held weakly and, in a less polar solvent, travels further. Predictions must name both phases, never polarity alone, because changing a phase can reverse the order.

The Retention Factor, R_f

The retention factor compares how far a component travelled with how far the solvent travelled, both from the same baseline.

R_f = distance travelled by the component ÷ distance travelled by the solvent front. Distances are measured to the centre of the spot, in the same units, usually centimetres.

R_f has no units, because it is a ratio of two distances. It cannot exceed 1.00, because a component cannot travel beyond the solvent front carrying it, and 0 means it never left the baseline.

A low R_f, such as 0.20, signals strong attraction to the stationary phase or low solubility in the mobile phase. A high R_f, such as 0.85, signals the opposite balance.

An R_f value belongs to one exact set of conditions. Change the solvent, stationary phase or temperature and the same component can give a different value.

Two spots with the same R_f under identical conditions are likely to be the same substance. That is evidence, not proof: different substances can share one value in one solvent, so a second run in a different solvent tests the match.

Column Chromatography Runs the Same Competition Downwards

In column chromatography the stationary phase, often polar silica, is packed into a column. The mobile phase is a solvent poured through it, and components leave, or elute, at the bottom at different times.

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With a polar stationary phase, a nonpolar component is held weakly and elutes first. A polar component is held strongly and elutes last. Elution order is therefore the reverse of distance travelled on a TLC plate under matching conditions.

Making the mobile phase more polar strengthens its pull on polar components, so they elute sooner.

Distillation Separates by Boiling Point

Distillation separates a liquid mixture by boiling point. The mixture is heated, and a condenser cools the vapour back to a liquid collected separately.

The component with the lowest boiling point is the most volatile. It has the weakest intermolecular forces, the highest vapour pressure at a given temperature, and it vaporises first.

While one component boils, the thermometer holds steady at its boiling point. When it has mostly boiled away, the temperature rises to the next boiling point. A plateau therefore marks one component distilling.

Boiling is a physical change. Only attractions between molecules are overcome, and covalent bonds inside molecules stay intact.

Simple distillation works well when boiling points differ widely, by roughly 25 °C or more. A fractionating column, packed with beads or plates, gives a large surface for repeated condensation and vaporisation, and separates liquids with close boiling points.

Filtration cannot recover a dissolved solid, because dissolved particles pass through filter paper with the solvent. Evaporating the solvent, or distilling it off, leaves the nonvolatile solid behind.

Worked Examples

> **Example 1: Three R_f values on one plate. The solvent front reached 8.0 cm from the baseline. Three spots reached 2.4 cm, 4.8 cm and 6.4 cm, giving R_f values of 2.4 ÷ 8.0 = 0.30, 4.8 ÷ 8.0 = 0.60 and 6.4 ÷ 8.0 = 0.80. On polar paper, the 0.30 spot was held most strongly, and the 0.80 spot was carried most readily.**

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Example 2: Matching an unknown to a standard. An unknown and three known dyes were run together, and the front reached 10.0 cm. The unknown reached 7.0 cm, so R_f = 7.0 ÷ 10.0 = 0.70. The known dyes reached 3.0 cm, 7.0 cm and 8.5 cm, giving 0.30, 0.70 and 0.85. The unknown matches the second dye under these conditions, which supports, but does not prove, that they are the same substance.

Example 3: Reading a distillation. Three miscible liquids have boiling points of 56 °C, 78 °C and 100 °C, stated in the question. The 56 °C liquid distils first, the thermometer plateaus at 56 °C, then rises and plateaus at 78 °C for the second liquid. The 100 °C liquid, left last, has the strongest intermolecular forces. Each gap is 22 °C, from 78 − 56 = 22 and 100 − 78 = 22, so a fractionating column is used.

Traps That Cost Marks in Topic 3.9

R_f is a distance. It is a ratio of two distances, so it has no units. Both distances are measured from the baseline.

A spot can have an R_f above 1. It cannot. Nothing travels further than the solvent carrying it, so a value above 1.00 signals a measurement or arithmetic error.

The most polar component always travels furthest. Only if it is also most attracted to the mobile phase. On polar paper or silica it is usually held back and travels least. Name both phases before predicting.

Equal R_f values prove two spots are one substance. They are evidence under one set of conditions only. A matching run in a second solvent is needed to secure the identification.

The baseline can sit below the solvent surface. The spots then dissolve into the solvent pool and never separate. The baseline also belongs in pencil, not ink, because ink dyes dissolve and travel, adding false spots.

Distillation breaks molecules apart. It overcomes attractions between molecules only. Breaking covalent bonds during boiling would be a reaction, not a separation.

Filtration removes a dissolved solid. Dissolved particles pass through the filter. Filtration parts an undissolved solid from a liquid; a dissolved solid is recovered by evaporation.

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Key Relationships to Remember

- Chromatography: stationary phase stays in place, mobile phase moves; a component is held back by attraction to the stationary phase and carried by solubility in the mobile phase
- Strong attraction to the stationary phase or low solubility in the mobile phase: slow travel, low R_f, late elution; the opposite balance gives fast travel, high R_f and early elution
- R_f = distance travelled by the component ÷ distance travelled by the solvent front, both from the baseline; no units, range 0 to 1.00, valid only for the stated phases and conditions
- Paper: polar cellulose; TLC: thin layer of polar solid on a plate; column: packed stationary phase, components collected in elution order
- Distillation: lowest boiling point and weakest forces distil first; temperature plateaus at each boiling point; wide gaps suit simple distillation, close gaps need a fractionating column
- Boiling overcomes intermolecular forces only; covalent bonds within molecules are never broken

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