Chapter 17: Reaction Kinetics

Chemistry X | Academic Revision Notes | Class X / Matriculation

Rate of Reaction: The speed at which a chemical reaction occurs. Chemical reactions are practical and useful only when they proceed at a reasonable rate. Understanding reaction kinetics reveals how factors influence these rates and provides insight into chemical mechanisms at the molecular level.

17.1 Collision Theory of Reaction Rate

A reaction occurs only when reactant particles (atoms, ions, or molecules) collide.

- **Effective Collisions:** Only a small fraction of collisions possess sufficient energy and proper orientation to result in product formation.
- **Ineffective Collisions:** Most collisions result in particles simply bouncing apart without undergoing a reaction.

Key Factors Governing Effective Collisions

1. **Number of Particles per Unit Volume:** Higher reactant concentration increases particle density, leading to more collisions per unit time.
2. **Frequency of Collisions:** Increasing molecular velocity (e.g., by raising temperature) leads to more total collisions per second, directly boosting effective collisions.
3. **Kinetic Energy of Particles:** Particles are in constant motion. Increasing temperature elevates average kinetic energy (KE), causing faster movement and higher-energy impacts.
4. **Activation Energy (E_a):** The minimum energy required to break bonds in reactant molecules to initiate a reaction.

Reaction Coordinate Insight: As reactant molecules collide, kinetic energy converts to potential energy. When particles possess energy equal to or greater than E_a, they reach a short-lived **high energy state** (activated complex) before forming stable products with lower potential energy.

Quick Check 17.1 – Solutions

Q1: How will you increase the frequency of collisions?

By increasing the temperature (which accelerates particle velocity) or by increasing the concentration/pressure of the reactants (which packs more particles into a given volume).

Q2: What happens to the reactant particles after collision?

If the collision is **effective** (energy $\geq E_a$), the reactants form a high-energy activated complex and convert into products. If the collision is **ineffective** (energy $< E_a$), the particles bounce back unchanged.

17.2 Change in Mass and Concentration During Reactions

Law of Conservation of Mass

The total mass of reactants always equals the total mass of products in a closed system.

Open Containers: Apparent changes in mass occur if gases escape or enter:

- **Evolved Gas (Mass Decrease):** Reaction of marble chips with acid in an open flask.
- **Absorbed Gas (Mass Increase):** Burning magnesium ribbon in air forms MgO by gaining O_2.

Magnesium + Oxygen → Magnesium Oxide

Carbon Dioxide Evolution Reaction

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}\uparrow$$

Concentration–Time Dynamics

- **Reactants:** Concentration starts at maximum and decreases over time as reactants are consumed.
- **Products:** Concentration starts at zero and increases, reaching a maximum plateau when reactants are fully used up.

17.3 Change in Temperature During a Chemical Reaction

Parameter	Exothermic Reactions	Endothermic Reactions
Heat Energy	Released to surroundings	Absorbed from surroundings
Temperature Effect	Surrounding temperature increases	Surrounding temperature decreases
Example Reaction	$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$ + Heat	Dissolving NH_4Cl or NH_4NO_3 in water

Temperature Rule of Thumb: For many standard chemical reactions, the rate of reaction roughly **doubles for every 10°C rise** in temperature.

17.4 Factors Affecting the Rates of Reactions

1. Concentration of Reactants

High concentration = More particles per unit volume = Increased collision frequency = Faster reaction rate.

Example: Coal burns slowly in normal air (21% O_2) but vigorously in pure oxygen (100% O_2).

2. Pressure in Gas-Phase Reactions

For gaseous reactants, increasing pressure reduces volume, effectively raising particle concentration.

Example: Doubling Cl_2 gas pressure doubles its rate of reaction with excess H_2.

3. Surface Area of Solid Reactants

Solid-phase reactions take place on the surface. Powdered or finely divided solids present significantly larger surface areas than large chunks, exposing more reaction sites.

Example: Powdered aluminum reacts rapidly with cold aqueous NaOH, whereas aluminum foil requires heat:

$$2Al_{(s)} + 2NaOH_{(aq)} + 6H_2O_{(l)} \rightarrow 2NaAl(OH)_{4(aq)} + 3H_{2(g)}$$

4. Temperature

Increasing temperature increases both the **collision frequency** and the **fraction of particles possessing $E \geq E_a$**.

5. Catalysts

A substance that speeds up a chemical reaction without being permanently consumed.

Mechanism: Provides an alternative reaction path with a lower activation energy (E_a).

Example: Platinum (Pt) catalyst in the hydrogenation of ethene weakens C=C and H–H bonds via surface adsorption.

6. Enzymes (Biological Catalysts)

Complex protein molecules that catalyze specific biochemical reactions using specialized **active sites**.

Substrates bind to active sites, weakening specific chemical bonds to accelerate body processes. Products release, leaving the enzyme unchanged to repeat the cycle.

Quick Check 17.2 – Solutions

Q1: Why is a catalyst mostly used in finely divided form?

Finely divided catalysts offer a much higher surface area per unit mass, providing more active surface sites for reactant adsorption and catalysis.

Q2: How do you increase the number of successful collisions?

By increasing reactant concentration/pressure, elevating temperature, increasing solid surface area, or adding a catalyst to lower activation energy.

Q3: How does the concentration of the products change during a reaction? Explain with the help of a graph.

Product concentration starts at zero at time t = 0, increases rapidly at first (steep curve), slows down as reactants are consumed, and flattens out into a horizontal line when the reaction completes.

17.5 Importance of Chemical Kinetics in Food Industry

Understanding kinetic mechanisms enables precise control over food preservation, processing, and transportation.

- **Ripening Control:** Fruits release ethene gas (C_2H_4) during enzyme-driven ripening (converting starches to sugars). Monitoring ethene emission rates allows farmers to determine optimal harvesting schedules.
- **Spoilage Prevention:** Microbial growth, fat oxidation, and enzymatic degradation depend on temperature. Low-temperature storage (refrigeration/freezing) slows down reaction kinetics, preserving flavor, texture, and nutrient value.

- **Biosensors:** Enzyme-based biosensors utilize kinetic specificity to measure blood glucose levels rapidly.

Quick Check 17.3 – Solutions

Q1: How would you determine the best time of fruit harvesting?

By monitoring the rate of production of ethene gas (C_2H_4) and analyzing enzymatic conversion rates of starches into sugars in the fruit tissue.

Q2: Why do some fruits and vegetables get destroyed early during summer than during winter?

Ambient temperatures are higher in summer. Higher temperatures increase kinetic energy, accelerating the enzymatic and oxidation reactions that cause decay and spoilage.