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CUET · CHEMISTRY · CLASS XII · CODE 306

Chemical Kinetics

CUET unit: Chemical Kinetics

By **UniDrill** · NCERT-grounded study material

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📌 Snapshot

- Chemical kinetics is the branch of chemistry that deals with the rate of a reaction and the factors (concentration, temperature, catalyst) that control it; thermodynamics tells whether a reaction is feasible, kinetics tells how fast (NCERT §3, p. 61–62).
- Covers the **rate of reaction** (average and instantaneous), **rate law, rate constant, order and molecularity**, and the **integrated rate equations for zero and first order reactions** and their half-lives.
- Temperature dependence is captured by the **Arrhenius equation $k = A \cdot e^{(-Ea/RT)}$**; the **Maxwell–Boltzmann distribution** explains why a 10 K rise nearly doubles the rate.
- **Collision theory** (effective collisions, collision frequency Z, steric factor P) is introduced as a deeper explanation, giving Rate = $P \cdot Z_{AB} \cdot e^{(-Ea/RT)}$.
- CUET tests this unit heavily through numerical MCQs on order, rate constant units, half-life formulae, integrated rate equations and Arrhenius-based calculations.

📖 Detailed Notes

2.1 Core concepts

- **Rate of a reaction** is the change in concentration of a reactant or product in unit time; expressed as $-\Delta[R]/\Delta t$ (disappearance of reactant) or $+\Delta[P]/\Delta t$ (appearance of product); the negative sign keeps the rate positive (NCERT §3.1, p. 62).
- The **units of rate** are concentration·time^{-1} — typically mol L^{-1} s^{-1}; for gaseous reactions, when concentration is expressed as partial pressure, the units become atm s^{-1} (NCERT §3.1, p. 63).
- **Average rate** = $\Delta[R]/\Delta t$ over a finite time interval; **instantaneous rate** = $-d[R]/dt$ = $d[P]/dt$ at a specific instant, obtained graphically as the slope of the tangent to a concentration-vs-time curve (NCERT §3.1, p. 64).
- For a reaction with unequal stoichiometric coefficients (e.g. $2HI \rightarrow H_2 + I_2$), the rate is the rate of disappearance/appearance divided by the stoichiometric coefficient: Rate = $-(1/2)\cdot\Delta[HI]/\Delta t = \Delta[H_2]/\Delta t = \Delta[I_2]/\Delta t$ (NCERT §3.1, p. 65).
- The rate of a reaction depends on the **experimental conditions** — concentration of reactants (pressure for gases), temperature and catalyst (NCERT §3.2, p. 66).

- The **rate law** (or rate expression) relates rate to molar concentrations of reactants, each raised to some power: Rate = k[A]^x [B]^y. The exponents x and y are determined experimentally and **may or may not** equal the stoichiometric coefficients (NCERT §3.2.2, p. 67).
- The **rate constant (k)** is the proportionality constant in the rate law; it is independent of concentration but depends on temperature and the presence of a catalyst (NCERT §3.2.2, p. 67).
- **Order of a reaction** = sum of the powers of concentration terms in the experimentally determined rate law; can be 0, 1, 2, 3 or a fraction; a zero-order reaction has a rate independent of reactant concentration (NCERT §3.2.3, p. 68).
- **Units of k** depend on order: zero order → mol L^{-1} s^{-1}; first order → s^{-1}; second order → mol^{-1} L s^{-1} (NCERT Table 3.3, p. 69).
- **Molecularity** = number of reacting species that must collide simultaneously in an elementary reaction; can be 1 (unimolecular), 2 (bimolecular) or 3 (termolecular, very rare); cannot be zero or fractional; defined only for elementary reactions (NCERT §3.2.4, p. 69–70).
- For a complex reaction the **rate-determining step** is the slowest step; order of the overall reaction equals molecularity of this slowest step (NCERT §3.2.4, p. 70–71).
- **Integrated rate equation, zero order:** $[R] = -kt + [R]_0$, so $k = ([R]_0 - [R])/t$; plot of [R] vs t is a straight line of slope −k; half-life $t_{1/2} = [R]_0/2k$ (depends on initial concentration). Examples: decomposition of NH_3 on hot Pt, thermal decomposition of HI on gold (NCERT §3.3.1, p. 71–72).
- **Integrated rate equation, first order:** $\ln[R] = -kt + \ln[R]_0$, or $k = (2.303/t)\cdot\log([R]_0/[R])$; plot of ln[R] vs t (or $\log[R]_0/[R]$ vs t with slope k/2.303) is a straight line; half-life $t_{1/2} = 0.693/k$ (independent of $[R]_0$). Examples: hydrogenation of ethene, all radioactive decay, decomposition of N_2O_5 and N_2O (NCERT §3.3.2 & 3.3.3, p. 72–77).
- For a first-order gas-phase reaction A(g) → B(g) + C(g): $k = (2.303/t)\cdot\log[p_i/(2p_i - p_t)]$, where p_i is initial pressure of A and p_t is total pressure at time t (NCERT §3.3.2, p. 74–75).
- **Pseudo first-order reactions** are higher-order reactions which appear first order because one reactant is in large excess and its concentration is effectively constant — e.g. acid hydrolysis of ethyl acetate, inversion of cane sugar (NCERT §3.3.3, p. 78).
- **Temperature dependence:** rate constant nearly doubles for every 10 K rise in temperature; quantified by the **Arrhenius equation $k = A\cdot e^{(-Ea/RT)}$** where A is the frequency/pre-exponential factor, Ea is activation energy and R is the gas constant (NCERT §3.4, p. 78–79).
- The **activated complex** is the unstable high-energy intermediate; Ea is the energy required to form it from reactants. A plot of ln k vs 1/T is a straight line of slope −Ea/R and intercept ln A (NCERT §3.4, p. 79–80).

- The two-temperature form: $\log(k_2/k_1) = (E_a/2.303R)\cdot[(T_2 - T_1)/(T_1T_2)]$ — used to find Ea from rate constants at two temperatures (NCERT eq. 3.22, p. 81).
- **Maxwell–Boltzmann distribution:** the fraction of molecules with energy E plotted against E peaks at the most probable kinetic energy; raising temperature shifts the peak to higher energy and broadens the curve, doubling the fraction of molecules with $E \geqslant E_a$ for a 10 K rise (NCERT §3.4, p. 79–80, Fig. 3.8 & 3.9).
- **Catalyst** increases the rate without itself being consumed; it provides an alternate path with lower activation energy. A catalyst does not change ΔG, does not catalyse non-spontaneous reactions and does not alter the equilibrium constant — it only helps equilibrium be reached faster (NCERT §3.4.1, p. 82).
- **Collision theory** treats molecules as hard spheres reacting on collision; the collision frequency Z is the number of collisions per second per unit volume; Rate = $Z_{AB}\cdot e^{-E_a/RT}$ (NCERT §3.5, p. 82–83).
- Not all collisions yield products — only **effective collisions** with sufficient kinetic energy (⩾ threshold energy) and proper orientation succeed. The **steric (probability) factor P** accounts for orientation, giving Rate = $P\cdot Z_{AB}\cdot e^{-E_a/RT}$ (NCERT §3.5, p. 83).
- **Threshold energy = Activation energy + energy possessed by reacting species** (NCERT footnote, p. 83).

2.2 Definitions to memorise

Term	Definition	Page
Rate of reaction	Change in concentration of a reactant or product per unit time	62
Average rate	$\Delta[R]/\Delta t$ or $\Delta[P]/\Delta t$ over a finite time interval	63
Instantaneous rate	$-d[R]/dt = d[P]/dt$ at a particular instant; slope of tangent at point t	64
Rate law / rate expression	Equation giving rate as a product of concentrations raised to experimentally found powers: Rate = $k[A]^x[B]^y$	67
Rate constant (k)	Proportionality factor in the rate law; independent of concentration, depends on T and catalyst	67
Order of reaction	Sum of the powers of concentration terms in the experimental rate law (x + y)	68
Molecularity	Number of reacting species that collide simultaneously in an elementary step	69
Elementary reaction	Reaction occurring in a single step	68
Complex reaction	Reaction proceeding via a sequence of elementary steps (mechanism)	68
Rate-determining step	The slowest step in a multi-step mechanism, controlling the overall rate	70

Term	Definition	Page
Half-life ($t_{1/2}$)	Time for [R] to fall to ½$[R]_0$; zero order: $[R]_0/2k$; first order: 0.693/k	76
Pseudo first-order reaction	A reaction that obeys first-order kinetics because one reactant is in large excess (e.g. ester hydrolysis)	78
Activation energy (Ea)	Minimum extra energy reactants need (above their average) to form the activated complex	79
Activated complex	Unstable, high-energy intermediate at the peak of the potential-energy curve	79
Arrhenius equation	$k = A \cdot e^{(-Ea/RT)}$; A is frequency factor, related to collision frequency	79
Collision frequency (Z)	Number of collisions per second per unit volume	83
Effective collisions	Collisions with energy ⩾ threshold energy and correct orientation that lead to product	83
Steric factor (P)	Probability factor accounting for the need for correct orientation in a collision	83
Threshold energy	Activation energy + energy already possessed by reacting species	83
Catalyst	Substance that increases the rate of a reaction by lowering Ea, without itself being consumed	82

2.3 Diagrams / processes to remember

- **Fig. 3.1 (p. 63):** Concentration of R and P vs time — slope of secant = average rate; slope of tangent = instantaneous rate.
- **Fig. 3.2 (p. 64):** Instantaneous rate of hydrolysis of butyl chloride C_4H_9Cl, obtained by drawing the tangent at t = 600 s.
- **Fig. 3.3 (p. 72):** [R] vs t straight line for a **zero-order** reaction; slope = –k, intercept = $[R]_0$.
- **Fig. 3.4 (p. 74):** ln[R] vs t for **first-order** reaction; straight line, slope = –k.
- **Fig. 3.5 (p. 74):** $\log([R]_0/[R])$ vs t; slope = k/2.303.
- **Fig. 3.6–3.7 (p. 79):** Formation of HI via an intermediate; potential energy vs reaction coordinate showing reactants → activated complex (peak, Ea) → products.
- **Fig. 3.8 (p. 79):** Maxwell–Boltzmann distribution — fraction of molecules vs kinetic energy, peak at most probable energy.
- **Fig. 3.9 (p. 80):** Distribution at T and T + 10 K — curve shifts right and broadens; the area beyond Ea (fraction of energetic molecules) roughly doubles.
- **Fig. 3.10 (p. 80):** ln k vs 1/T straight-line plot — slope = –Ea/R, intercept = ln A.

- **Fig. 3.11 (p. 82):** Effect of a catalyst on the potential-energy profile — catalyst provides an alternative path with a lower energy barrier.
- **Fig. 3.12 (p. 83):** Orientation of colliding molecules — proper orientation leads to product, improper orientation only causes bounce-back.

2.4 Common confusions / NTA trap points

- **Order vs molecularity.** Order is experimental, can be 0 or fractional, defined for both elementary and complex reactions. Molecularity is theoretical, must be a positive integer (1–3), defined only for elementary reactions (NCERT p. 70).
- **Rate vs rate constant.** Rate depends on concentration and changes during a reaction; the rate constant k depends only on temperature (and catalyst) — not on concentration. NTA likes to phrase distractors that swap these.
- **Half-life behaviour.** For a **zero-order** reaction $t_{1/2} \propto [R]_0$; for a **first-order** reaction $t_{1/2}$ is **independent** of $[R]_0$. Students often reverse these (NCERT p. 76).
- **Units of k.** Zero order → $mol\ L^{-1}\ s^{-1}$; first order → s^{-1}; second order → $mol^{-1}\ L\ s^{-1}$. A favorite NTA question identifies order from the units of k (NCERT Table 3.3, p. 69).
- **Catalyst does NOT change ΔG, K_eq, or the position of equilibrium.** It lowers Ea (forward and backward equally) so equilibrium is reached faster, not shifted (NCERT p. 82).
- **Threshold energy ≠ activation energy.** Threshold energy = Ea + energy already with the molecules (NCERT footnote p. 83).
- **Arrhenius factor A.** A relates to collision frequency Z (not to Ea or temperature directly). Higher A or lower Ea both raise k.
- **Temperature coefficient.** For most reactions, rate (or k) becomes 2–3 times for every 10 K rise — NTA sometimes paraphrases this as "doubles per °C" which is wrong.
- **Pseudo first order.** The reactant in large excess behaves as a constant; the apparent k is k′ = k[excess]. Inversion of cane sugar and ester hydrolysis with water are the two NCERT examples (p. 79).

2.5 Quick reference — kinetics at a glance

#	Item	Formula / Relation	Page
1	General rate law	Rate = $k[A]^x[B]^y$	68
2	Zero-order integrated	$[R] = [R]_0 - kt$	73
3	Zero-order $t_{1/2}$	$t_{1/2} = [R]_0 / 2k$	75
4	First-order integrated	$\ln([R]_0/[R]) = kt$	74
5	First-order $t_{1/2}$	$t_{1/2} = 0.693/k$	75
6	k units (zero order)	$mol\ L^{-1}\ s^{-1}$	69

#	Item	Formula / Relation	Page
7	k units (first order)	s^{-1}	69
8	k units (second order)	$mol^{-1}\ L\ s^{-1}$	69
9	Arrhenius equation	$k = A e^{(-Ea/RT)}$	80
10	log form (Arrhenius)	$\log k = \log A - Ea/(2.303\ RT)$	81
11	Two-T relation	$\log(k_2/k_1) = (Ea/2.303R)\cdot(T_2-T_1)/(T_1T_2)$	81
12	Temperature coefficient	$k(T+10)/k(T) \approx 2\text{–}3$	80
13	Threshold energy	$E_{thresh} = Ea + E_{avg}$	83
14	Collision theory rate	$Rate = P\cdot Z_{AB}\cdot e^{(-Ea/RT)}$	83
15	Catalyst effect	Lowers Ea forward and backward equally; ΔH, K_{eq} unchanged	82

🎯 Practice MCQs

Q1. The rate of a chemical reaction is best defined as:

A. The change in temperature of the system per unit time

B. The change in concentration of a reactant or product per unit time

C. The change in Gibbs energy per unit time

D. The change in equilibrium constant per unit time

Q2. For the reaction $5\ Br^-(aq) + BrO_3^-(aq) + 6\ H^+(aq) \rightarrow 3\ Br_2(aq) + 3\ H_2O(l)$, the rate of reaction in terms of Br^- is:

A. $-\Delta[Br^-]/\Delta t$

B. $-(1/5)\cdot\Delta[Br^-]/\Delta t$

C. $-5\cdot\Delta[Br^-]/\Delta t$

D. $+(1/5)\cdot\Delta[Br^-]/\Delta t$

Q3. The units of the rate constant for a second-order reaction (SI units) are:

A. s^{-1}

B. mol L^{-1} s^{-1}

C. mol^{-1} L s^{-1}

D. mol^{-2} L^2 s^{-1}

📊 PYQ Alignment

Chemical Kinetics is consistently one of the top three numerical-heavy units in CUET Chemistry, contributing roughly 12–15 MCQs per year across CUET 2023–2025. The most frequently tested patterns are: identification of order from the units of k (Table 3.3), half-life calculations for zero- and first-order reactions ($t_{1/2} = [R]_0/2k$ and $t_{1/2} = 0.693/k$), application of the integrated first-order equation $k = (2.303/t)\cdot\log([R]_0/[R])$, Arrhenius-based Ea calculation from rate constants at two temperatures, and conceptual questions on molecularity vs order and the role of a catalyst (lowering Ea, no effect on ΔG or K_eq).

CUET 2025 — Actual PYQs from this chapter

Q.42 (CUET 2025) Calculate the order of the reaction whose rate law is: R=k[A]1/2[B]3/2R = k[A]^{1/2}[B]^{3/2}R=k[A]1/2[B]3/2

- A) Zero order B) Half order C) First order D) Second order

Tests: Chemical Kinetics Answer: Not in extracted key

Q.43 (CUET 2025) The rate law of a reaction is: r=k(CH3CHOCH3)1/2r = k(CH_3CHOCH_3)^{1/2}r=k(CH3 CHOCH3)1/2 If pressure is measured in bar and time in minutes, the unit of the rate constant (k) will be:

- A) $bar^{3/2}$ min^{-1} B) $bar^{1/2}$ min^{-1} C) $bar^{-1/2}$ min^{-1} D) $bar^{-3/2}$ min^{-1}

Tests: Chemical Kinetics Answer: Not in extracted key

Q.44 (CUET 2025) If the rate of reaction becomes 27 times when the concentration of reactant is increased three times, the order of reaction is:

- A) 0 B) 1 C) 2 D) 3

Tests: Chemical Kinetics Answer: Not in extracted key

Q.45 (CUET 2025) The role of a catalyst is to change:

- A) Gibbs energy of reaction B) Enthalpy of reaction C) Activation energy of reaction D) Equilibrium constant

Tests: Chemical Kinetics Answer: Not in extracted key

Q.41 (CUET 2025) The rate of a gaseous reaction is given by: r=k[A][B]r = k[A][B]r=k[A][B] If the volume of the reaction vessel is suddenly reduced to 1/4, the reaction rate relative to the initial rate will become:

- A) 2 times B) 4 times C) 16 times D) 1/16 times

Tests: Effect of concentration/volume on reaction rate Answer: Not in extracted key

CUET 2024 — Actual PYQs from this chapter

Q.7 (CUET 2024) If 75% of a first-order reaction completes in 32 minutes, the time required for 50% completion is:

- A) 16 min B) 78 min C) 8 min D) 4 min

Tests: Chemical Kinetics Answer: Not in extracted key

Q.48 (CUET 2024) Which of the following factors does not affect rate of reaction?

- A) Concentration B) Temperature C) Catalyst D) Colour of reactants

Tests: Chemical Kinetics Answer: Not in extracted key

Q.49 (CUET 2024) The Arrhenius equation is:

- A) k=Ae−Ea/RTk = Ae^{-E_a/RT}k=Ae−Ea /RT B) k=AeEa/RTk = Ae^{E_a/RT}k=AeEa / RT C) k=A/RTk = A/RTk=A/RT D) k=RT/Ak = RT/Ak=RT/A

Tests: Chemical Kinetics Answer: Not in extracted key

Q.50 (CUET 2024) The activation energy of a reaction is:

- A) Minimum energy required for reactants to react B) Energy released during reaction C) Difference between enthalpy of reactants and products D) Total energy of reaction

Tests: Chemical Kinetics Answer: Not in extracted key

CUET 2023 — Actual PYQs from this chapter

Q.3 (CUET 2023) Ammonia is manufactured by: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H^\circ = -46.1$ kJ mol^{-1} The steps involved are: (A) Condensation of mixture of gases (B) Passing gaseous mixture over catalyst (C) Compression of gaseous mixture (D) Recirculation of gaseous mixture Correct order is:

- A) (C), (B), (A), (D) B) (B), (C), (D), (A) C) (A), (D), (C), (B) D) (B), (A), (D), (C)

Tests: Chemical Kinetics Answer: Not in extracted key

Q.19 (CUET 2023) Half-life of a first order reaction is 25 minutes. Rate constant is:

- A) 2.27×10^{-2} min^{-1} B) 3.2×10^{-3} min^{-1} C) 9.2×10^{-2} min^{-1} D) 2.8×10^{-2} min^{-1}

Tests: Chemical Kinetics **Answer:** Not in extracted key

Q.21 (CUET 2023) A drop of volume 0.05 mL contains (3.0×10^{-6}) mol H^+ ions. If rate of disappearance of H^+ is (1.0×10^{-7}) mol L^{-1} s^{-1}, time required is:

- A) (6×10^{-8}) s B) (6×10^{-9}) s C) (6×10^{-7}) s D) (6×10^{-10}) s

Tests: Chemical Kinetics **Answer:** Not in extracted key

Q.30 (CUET 2023) Which statement is correct about catalyst?

- A) Catalyst required in large quantity B) Same reactants may give different products with different catalysts C) Catalytic activity does not depend on chemisorption D) Catalyst does not remain same after reaction

Tests: Chemical Kinetics **Answer:** Not in extracted key

Q.34 (CUET 2023) Which of the following is not correct about the order of a reaction?

- A) Order of a reaction is the sum of powers of molar concentration of reactants in rate law expression. B) Order of reaction is always equal to the sum of stoichiometric coefficients in balanced equation. C) Order of reaction can be fractional. D) Order of reaction is experimentally determined.

Tests: Chemical Kinetics **Answer:** Not in extracted key