LECTURE L2-9

Kinetics & Equilibrium

How Fast? Why Food Spoils Faster in Summer and How to Calculate Half-Life

Duration: 75 minutes

Advanced lecture script — pre-requisite: Level 1

HOOK (3 minutes)

Teacher holds up (or shows photos of):

A refrigerator (slows food spoilage)

An Alka-Seltzer tablet (whole vs. crushed)

A pressure cooker (cooks food faster)

A lactose-free milk carton (enzyme added)

Teacher says: "Food spoils faster on the counter than in the fridge. Crushed Alka-Seltzer fizzes faster than a whole tablet. A pressure cooker cooks dinner in half the time.

Why? Same reactions — different speeds.

- Today's question: What controls how fast a reaction happens — and how do you calculate it? *

By the end of this session, you will be able to:

Explain the four factors that affect reaction rate

Calculate half-life for radioactive decay and first-order reactions

Use the equilibrium constant (K) to predict which way a reaction favors

Apply Le Chatelier's principle to predict how changes affect equilibrium"

SEGMENT 1: Review from Level 1 and Previous Level 2 Lectures (5 minutes)

Teacher says: "Before we go deeper, let's recall what you already know."

Review from Level 1 (Kinetics & Equilibrium - Basic)

Level 1 Concept	Definition	Household Example
Kinetics	Study of reaction rates (how fast)	Fast = explosion; Slow = rust
Temperature	Hotter = faster; Colder = slower	Food spoils faster in summer
Concentration	More = faster; Less = slower	Stronger bleach = faster cleaning
Surface area	Smaller pieces = faster	Crushed Alka-Seltzer fizzes faster
Catalyst	Speeds up reaction without being used up	Enzymes in your body

Level 1 Concept	Definition	Household Example
Equilibrium	Forward and reverse reactions at same speed	Sealed soda bottle (CO_2 gas ⇌ dissolved CO_2)
Le Chatelier's principle	System shifts to oppose changes	Pressure cooker, deep-sea diving (the bends)

Review from Level 2-8 (Thermodynamics)

Level 2-8 Concept	Formula	Connection to Kinetics
Enthalpy (ΔH)	ΔH = q at constant pressure	Tells if reaction is exothermic or endothermic
Temperature effects	Higher T = faster reactions (kinetics), but also shifts equilibrium	

Quick check (show of hands / chat): "Does food spoil faster in summer or winter?" (Summer — higher temperature = faster reactions) "Does crushing a pill make it dissolve faster or slower?" (Faster — more surface area) "What does a catalyst do?" (Speeds up a reaction without being used up)

Teacher: "Good. Now let's learn how to calculate reaction rates and equilibrium constants."

SEGMENT 2: Reaction Rate — How Fast? (8 minutes)

Teacher says: "Reaction rate is how fast reactants turn into products. It's usually measured as change in concentration over time."

Average reaction rate = Δ[concentration] / Δtime

Units: M/s (moles per liter per second)

Step-by-step method:

Step	What to Do
Step 1	Measure initial concentration of a reactant or product.
Step 2	Measure final concentration after time Δt.
Step 3	Calculate change: Δ[conc] = final - initial
Step 4	Divide by time: rate = Δ[conc] ÷ Δt

Worked Example: Alka-Seltzer in Water

Problem: An Alka-Seltzer tablet produces CO_2 gas. The concentration of CO_2 in water increases from 0.00 M to 0.05 M in 10 seconds. What is the average rate of CO_2 production?

Step	Calculation
Step 1	$\Delta[CO_2]$ = 0.05 M - 0.00 M = 0.05 M
Step 2	Δt = 10 seconds
Step 3	Rate = 0.05 M ÷ 10 s = 0.005 M/s

Answer: 0.005 M/s (5×10^{-3} M/s).

Effects of Temperature: The Arrhenius Equation (Conceptual)

> Teacher says: *"The Arrhenius equation (uh-RAY-nee-us) describes how temperature affects reaction rate. The rule of thumb: For every 10°C increase, reaction rate approximately doubles."*

Temperature Change	Approximate Rate Change	Household Example
+10°C	Rate × 2	Refrigerator (4°C) vs. counter (22°C) → 18°C difference → ~3-4x faster on counter
+20°C	Rate × 4	Summer (35°C) vs. winter (15°C) → food spoils ~4x faster
+30°C	Rate × 8	Room temp vs. hot car (50°C+) → food spoils very fast

Safety connection: The 2-hour rule from Level 1: Perishable food left at room temperature for >2 hours should be thrown out. Bacteria growth doubles approximately every 20 minutes at room temperature.

> Partner talk (1 minute): "Tell your partner: If reaction rate doubles every 10°C, how many times faster is a reaction at 40°C than at 20°C?" (20°C difference = 2 doubling steps = 2 × 2 = 4 times faster)

SEGMENT 3: Rate Laws — From Concentration to Rate (10 minutes)

> Teacher says: "A rate law is an equation that shows how the rate depends on concentration of reactants."

General rate law: rate = $k[A]^n$

Where:

k = rate constant (temperature-dependent)

[A] = concentration of reactant A

n = reaction order (0, 1, or 2 for most simple reactions)

Reaction Orders (Simplified)

Order	Rate depends on ...	Example	Household Connection
0 (zero)	Rate = k (constant)	Surface-catalyzed reactions	Some enzyme reactions
1 (first)	Rate = k[A] (doubling [A] doubles rate)	Radioactive decay, many decompositions	Carbon-14 dating
2 (second)	Rate = $k[A]^2$ (doubling [A] quadruples rate)	Some gas-phase reactions	Combustion explosions

First-Order Reactions: Half-Life

First-order reaction: Rate depends linearly on concentration. Rate = k[A]

Key property of first-order reactions:

Half-life ($t_{1/2}$) = 0.693 / k

Half-life is CONSTANT — it does not depend on how much you start with.

Teacher: *"Radioactive decay is first-order. That's why carbon-14 has a constant half-life of 5,730 years, regardless of how much carbon-14 you have."*

Worked Example 1: Half-Life of Carbon-14

Problem: Carbon-14 has a half-life of 5,730 years. If you start with 100 grams of carbon-14:

How much remains after 5,730 years?

How much remains after 11,460 years?

How much remains after 17,190 years?

Step	Half-lives	Calculation	Remaining
Start	0	100 g	100 g
After 5,730 years	1	100 ÷ 2 = 50	50 g
After 11,460 years	2	50 ÷ 2 = 25	25 g
After 17,190 years	3	25 ÷ 2 = 12.5	12.5 g

Answer: 12.5 grams remain.

Worked Example 2: Finding Half-Life from k

Problem: A first-order reaction has k = 0.1386 hr^{-1}. What is the half-life?

Step	Calculation
$t_{1/2} = 0.693 \div k$	$= 0.693 \div 0.1386 = 5.00$ hours

Answer: Half-life is 5 hours.

Worked Example 3: Finding k from Half-Life

Problem: A radioactive isotope has a half-life of 10 years. What is the rate constant k?

Step	Calculation
$k = 0.693 \div t_{1/2}$	$= 0.693 \div 10 = 0.0693\ yr^{-1}$

Answer: $k = 0.0693\ yr^{-1}$.

Second-Order Reactions (Briefly)

Teacher: *"Second-order reactions are more complex. The half-life is NOT constant — it depends on starting concentration. You don't need to memorize the formula, just know that doubling concentration quadruples the rate ($2^2 = 4$)."*

Household example: Some air pollution reactions ($NO_2 + NO_2 \rightarrow N_2O_4$) are second-order.

Partner talk (1 minute): *"Tell your partner: If a first-order reaction has a half-life of 20 minutes, how much remains after 60 minutes?"* (60 ÷ 20 = 3 half-lives; remaining = $1/2^3 = 1/8$ of original)

SEGMENT 4: The Four Factors Affecting Rate — Quantitative (10 minutes)

Teacher says: "In Level 1, you learned the four factors. Now let's look at the math behind them."

Summary Table of Factors

Factor	Effect on Rate	Quantitative Relationship	Household Example
Temperature	Higher T → faster	Doubles every ~10°C (rule of thumb)	Fridge vs. counter
Concentration	Higher [A] → faster	Rate = $k[A]^n$ (n usually 0,1,2)	More bleach = faster cleaning
Surface area	More area → faster	Proportional to exposed area	Crushed vs. whole Alka-Seltzer
Catalyst	Lowers activation energy	Rate × 10 to × 10,000	Enzymes in digestion

Activation Energy (Energy Barrier)

Teacher: "Activation energy (E_a) is the minimum energy needed for a reaction to occur. Think of it like a hill: reactants must climb the hill before they can become products."

Show this visual (describe or draw):

text

Energy

↑

| Reactants

| ↗

| E_a / \

| / ↘

| / Products

|______/________________→ Reaction progress

Teacher: "A catalyst lowers the hill (reduces E_a). That's why enzymes speed up digestion so dramatically — they lower the energy barrier."

Household Example: Catalytic Converter

Teacher: "Your car has a catalytic converter that contains platinum and palladium (catalysts). These metals speed up the reaction that converts toxic CO and NO_x into less toxic CO_2 and N_2. Without the catalyst, these reactions would be too slow to clean the exhaust."

SEGMENT 5: Equilibrium Constant (K) — How Far? (12 minutes)

Teacher says: "Kinetics tells you how FAST a reaction goes. Equilibrium tells you how FAR it goes — how much product forms before the reaction stops."

Equilibrium constant (K) = [products] / [reactants] (at equilibrium, raised to powers of coefficients)

For a generic reaction: aA + bB ⇌ cC + dD

$K = [C]^c[D]^d / [A]^a[B]^b$

What K Tells You

Value of K	What It Means	Household Example
K >> 1 (very large)	Reaction favors products (goes almost to completion)	Burning wood (irreversible)
K ≈ 1	Reactants and products are roughly equal	Some gas-phase reactions
K << 1 (very small)	Reaction favors reactants (hardly any product forms)	Dissolving CO_2 in soda (most CO_2 stays as gas)

Worked Example 1: Writing K Expression

Problem: For the reaction: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ (Haber process — making ammonia for fertilizer)

Write the K expression:

Step	Calculation
$K = [NH_3]^2 \div ([N_2] \times [H_2]^3)$	

Teacher: "Notice the coefficients become exponents: 2 for NH_3, 1 for N_2, 3 for H_2."

Worked Example 2: Calculating K from Concentrations

Problem: For the reaction: $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$, at equilibrium: $[H_2] = 0.10$ M, $[I_2] = 0.10$ M, $[HI] = 0.40$ M

Calculate K:

Step	Calculation
$K = [HI]^2 \div ([H_2] \times [I_2])$	$= (0.40)^2 \div (0.10 \times 0.10)$
$K = 0.16 \div 0.01$	$= 16$

Answer: K = 16 (products favored, but not extremely).

Worked Example 3: Using K to Predict Direction

Problem: For the same reaction $H_2 + I_2 \rightleftharpoons 2HI$, K = 16 at a certain temperature. If at some moment $[H_2] = 0.20$ M, $[I_2] = 0.20$ M, $[HI] = 0.50$ M, is the reaction at equilibrium? If not, which way will it shift?

Step 1: Calculate Q (reaction quotient) — same formula as K, but with current concentrations

Step	Calculation
$Q = [HI]^2 \div ([H_2] \times [I_2])$	$= (0.50)^2 \div (0.20 \times 0.20)$
$Q = 0.25 \div 0.04$	$= 6.25$

Step 2: Compare Q to K

Step	Calculation
Q = 6.25, K = 16	$Q < K$

Step 3: Predict direction

If...	Then...
$Q < K$	Reaction shifts RIGHT (toward products)
$Q = K$	At equilibrium (no shift)
$Q > K$	Reaction shifts LEFT (toward reactants)

Answer: $Q = 6.25 < K = 16$ → Reaction shifts to the right (more HI forms).

Partner talk (1 minute): "Tell your partner: If K is very large (like 10,000), does the reaction favor reactants or products?" (Products — reaction goes almost to completion.)

SEGMENT 6: Le Chatelier's Principle — Predicting Shifts (10 minutes)

Teacher says: "Le Chatelier's principle (luh SHOT-lee-ay) says: When a system at equilibrium is disturbed, it shifts to oppose the change."

Le Chatelier's principle: If you stress a system at equilibrium, it responds to relieve that stress.

Three Types of Stress

Stress	System Response	Household Example
Add reactant	Shifts right (toward products)	Add more vinegar to baking soda → more fizz
Remove product	Shifts right (toward products)	Open soda bottle (remove CO_2 gas) → more fizz
Increase temperature	Shifts to absorb heat	Endothermic reactions favored at high T
Decrease volume (increase pressure)	Shifts to side with fewer gas molecules	Haber process (4 molecules → 2 molecules)

Household Example 1: Soda Bottle

Teacher: "In a sealed soda bottle: $CO_2(g) \rightleftharpoons CO_2(aq)$ (dissolved). When you open the bottle, you remove CO_2 gas (product). The equilibrium shifts to produce more gas — that's the fizz."

Household Example 2: Pressure Cooker

Teacher: "A pressure cooker increases pressure inside. For reactions that produce gas, higher pressure favors the side with fewer gas molecules. Cooking reactions that release gas are forced to go faster — that's why pressure cookers cook food faster."

Household Example 3: Deep-Sea Diving (The Bends)

Teacher: "Nitrogen is dissolved in your blood. At high pressure (deep underwater), more N_2 dissolves (equilibrium shifts toward dissolved N_2). When you rise too fast, pressure drops suddenly. The equilibrium shifts back to release N_2 gas — but it comes out as BUBBLES in your blood. That's the bends — painful and dangerous."

Safety rule: Ascend slowly to let equilibrium adjust gradually.

Worked Example: Temperature Effect

Problem: The reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ is exothermic ($\Delta H = -92$ kJ/mol). If you increase the temperature, which way will the equilibrium shift?

Step	Analysis
Exothermic means heat is a product	$N_2 + 3H_2 \rightleftharpoons 2NH_3$ + heat
Increasing temperature adds heat	System shifts to OPPOSE the change
To use up heat, shift LEFT (toward reactants)	

Answer: Higher temperature shifts equilibrium LEFT, decreasing NH_3 yield. (This is why the Haber process uses moderate temperatures — to balance rate and yield.)

Partner talk (1 minute): "Tell your partner: You open a soda bottle. Which way does the CO_2 equilibrium shift?" (Shifts right — toward gas production, which is why it fizzes.)

SEGMENT 7: Putting It All Together — Complete Kinetics & Equilibrium Problem (8 minutes)

Teacher says: "Let's do one complete problem that uses everything from today's lecture."

Problem: The reaction A → B is first-order with a half-life of 30 minutes. Initially, [A] = 1.00 M. K for the reaction at 25°C is 50.

After 60 minutes, what is [A]?

What is the rate constant k?

At 35°C, the reaction is twice as fast. What is the new half-life?

If Q = 10 at some moment, which way will the reaction shift (toward A or B)?

Part 1: [A] after 60 minutes

Step	Calculation
Half-lives = 60 min ÷ 30 min = 2 half-lives	
After 1 half-life: 1.00 M → 0.50 M	
After 2 half-lives: 0.50 M → 0.25 M	

Answer Part 1: [A] = 0.25 M.

Part 2: Rate constant k

Step	Calculation
$k = 0.693 \div t_{1/2}$	$= 0.693 \div 30$ min $= 0.0231$ min^{-1}

Answer Part 2: k = 0.0231 min^{-1}.

Part 3: New half-life at 35°C (rate doubles)

Step	Calculation
Rate doubles → k doubles → k_new = 0.0231 × 2 = 0.0462 min^{-1}	
$t_{1/2}$_new = 0.693 ÷ 0.0462 = 15 minutes	

Answer Part 3: New half-life = 15 minutes.

Part 4: Direction of shift

Step	Calculation
K = 50, Q = 10	
Q < K → Shift toward PRODUCTS (B)	

Answer Part 4: Shift toward B (products).

CLOSING — The 60-Second Challenge (5 minutes)

Teacher says: *"Pair up. Person A: 60 seconds — explain the four factors that affect reaction rate. Person B: 60 seconds — a first-order reaction has a half-life of 10 minutes. How much remains after 30 minutes? (1/8 of original — 3 half-lives)."*

Final takeaway table (show on screen / read aloud):

You learned...	Household Example
Reaction rate = Δ[conc] / Δt	Alka-Seltzer: 0.005 M/s CO_2 production
Temperature — rate doubles every 10°C	Food spoils 4x faster in summer (20°C diff)
Half-life (first-order) = 0.693/k	Carbon-14: 5,730 years; used for dating

You learned...	Household Example
Rate law = $k[A]^n$	First-order: doubling [A] doubles rate
Activation energy (E_a) = energy barrier	Catalyst lowers E_a (enzymes, catalytic converter)
Equilibrium constant (K) = [products]/[reactants]	K >> 1 = products favored; K << 1 = reactants favored
Q vs. K — Q < K → shift right; Q > K → shift left	Soda bottle: open → remove CO_2 (Q < K) → shift right → fizz
Le Chatelier's principle — system opposes stress	Pressure cooker, deep-sea diving (the bends)

Final line (preview of L2-10): "Next session: Gas Laws (Advanced) — calculating pressure, volume, and temperature changes using the Ideal Gas Law (PV = nRT). See you then."

SUPPLEMENTARY MATERIALS FOR L2-9 (No Grade)

Resource	Household Connection	Description	How to Find It
PhET "Reaction Rates" simulation	Interactive rate factors	Change T, concentration, surface area	Search "PhET reaction rates"
PhET "Equilibrium" simulation	See equilibrium shift	Add reactants, change T, see shift	Search "PhET equilibrium"
Half-life calculator	Carbon-14 dating	Practice problems	Search "half-life practice problems"
Le Chatelier's principle interactive	Predict shifts	Practice with different stresses	Search "Le Chatelier's principle simulation"

"This week, look at an Alka-Seltzer tablet (or any effervescent tablet). Drop a whole tablet in water and time how long it takes to stop fizzing. Crush another tablet and time it. Which is faster? (Crushed — more surface area.) Next time, tell us your results."