

# AP Chemistry Unit 7, Topic 1

## Introduction to Equilibrium

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**Lesson Date: January 3, 2026**

**Duration:** 60 minutes

**Core Concepts:** Reversibility, Dynamic Equilibrium & Closed Systems



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## CONCEPT 1: Reversibility of Processes

### Understanding forward and reverse reactions

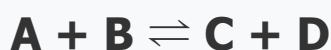
#### What is a Reversible Process?

A **reversible process** is one that can proceed in both the **forward**

**direction** and the **reverse direction** simultaneously.

Unlike irreversible reactions that go to completion (100% products), reversible reactions reach a state where both reactants and products coexist.

## General Form of a Reversible Reaction



- **Forward Reaction:**  $A + B \rightarrow C + D$
- **Reverse Reaction:**  $C + D \rightarrow A + B$

The double arrow ( $\rightleftharpoons$ ) indicates the reaction can proceed in both directions!

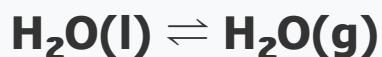
## Key Characteristics of Reversible Processes

- **✓ Bidirectional:** Can proceed forward AND backward
- **✓ Incomplete:** Do not go 100% to products; reactants remain
- **✓ Simultaneous:** Both directions occur at the same time
- **✓ Dynamic:** Continuous molecular activity even when macroscopic properties are constant
- **✓ Equilibrium State:** Eventually reach a state where forward and reverse rates are equal

## Physical Equilibria Examples

### Example 1: Liquid-Vapor Equilibrium

**System:** Water in a sealed container

**Forward Process (Evaporation):**

- Liquid water molecules gain energy
- Escape from liquid surface into gas phase
- $\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{O}(\text{g})$

**Reverse Process (Condensation):**

- Water vapor molecules lose energy
- Return to liquid phase
- $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$

**At Equilibrium: Rate of evaporation = Rate of condensation**  
**The amount of liquid and vapor remain constant, but**  
**molecules continuously move between phases!**

**Example 2: Dissolution Equilibrium**

**System:** Solid salt in saturated solution

**Forward Process (Dissolution):**

- Solid NaCl crystals break apart
- $\text{Na}^+$  and  $\text{Cl}^-$  ions enter solution

**Reverse Process (Precipitation/Crystallization):**

- Aqueous ions collide and form solid

- Ions leave solution and join crystal

**At Equilibrium: Rate of dissolution = Rate of precipitation**

**The concentration of ions stays constant, but ions continuously dissolve and crystallize!**

## Chemical Equilibria Examples

### Example 3: Haber Process (Ammonia Synthesis)

Industrial production of ammonia:



#### Forward Reaction (Synthesis):

- Nitrogen and hydrogen combine
- Ammonia is produced

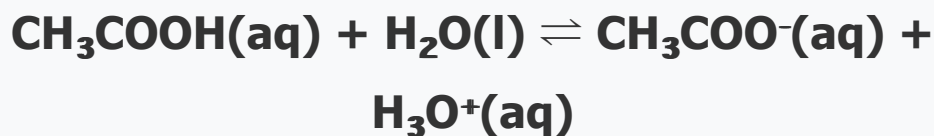
#### Reverse Reaction (Decomposition):

- Ammonia breaks down
- Forms nitrogen and hydrogen

**⚠ Important:** Even in industrial reactors, some  $\text{NH}_3$  decomposes back to reactants. The reaction never goes 100% to completion. This is why reaction conditions (temperature, pressure, catalysts) must be carefully controlled!

### Example 4: Acid-Base Proton Transfer

Weak acid dissociation:



#### Forward Reaction:

- Acetic acid donates proton ( $\text{H}^+$ ) to water
- Forms acetate ion and hydronium ion

#### Reverse Reaction:

- Hydronium ion donates proton to acetate
- Re-forms acetic acid and water

**At Equilibrium: Both molecular acetic acid AND ions coexist in solution. This is why weak acids are only partially dissociated!**

## CONCEPT 2: Dynamic Nature of Equilibrium

### Equal forward and reverse reaction rates

#### What Does "Dynamic Equilibrium" Mean?

**Dynamic equilibrium** is a state where:

1. The forward and reverse reactions **continue to occur** (not stopped!)
2. The **rates** of forward and reverse reactions are **equal**
3. The **concentrations** of all species remain **constant** over time



## The Fundamental Equilibrium Condition

$$\text{Rate}_{\text{forward}} = \text{Rate}_{\text{reverse}}$$

This is THE defining characteristic of equilibrium!

- ✓ When forward rate = reverse rate → concentrations stop changing
- ✓ When forward rate  $\neq$  reverse rate → NOT at equilibrium (still changing)



### Common Misconception

Equilibrium does **NOT** mean the concentrations are equal!

It means the **RATES** are equal.

You can have very different amounts of reactants vs products at equilibrium.

## Analogy: The Crowded Subway Platform

Imagine a subway platform at rush hour:

**People entering platform:** (Forward "reaction")

- Constant stream of people arriving from street

**People boarding trains:** (Reverse "reaction")

- Constant stream of people leaving on trains

**Dynamic Equilibrium Achieved When:**

- Rate of people arriving = Rate of people leaving
- The number of people on platform stays constant

- BUT people are continuously arriving AND leaving!
- The platform is NOT static - there's constant motion

**This is exactly like chemical equilibrium:**

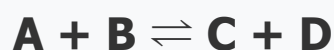
**Reactions continue, but concentrations stay constant because the rates are balanced!**

## Why Both Rates Must Be Non-Zero



### Molecular-Level Activity at Equilibrium

Consider the equilibrium:



#### At Equilibrium (Molecular View):

- ✓ A and B molecules are continuously colliding and forming C and D
- ✓ C and D molecules are continuously colliding and forming A and B
- ✓ Both reactions happen at the same rate
- ✓ Net result: No change in amounts of any species

#### ✗ WRONG Idea

"At equilibrium, all reactions stop."

This is completely false!  
Reactions never stop - they

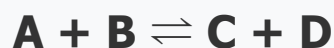
#### ✓ CORRECT Idea

"At equilibrium, forward and reverse reactions continue at equal rates."

This is dynamic equilibrium!  
Molecular activity continues forever.

## Example: Reaching Equilibrium Over Time

**Scenario:** Start with only reactants A and B



**Time = 0 (Initial):**

- [A] and [B] are high, [C] and [D] = 0
- Forward rate is high (lots of A and B colliding)
- Reverse rate = 0 (no C or D to react)
- Net direction: Forward (products forming)

**Time = t (During approach to equilibrium):**

- [A] and [B] decrease, [C] and [D] increase
- Forward rate decreases (less A and B available)
- Reverse rate increases (more C and D available)
- Net direction: Still forward, but slowing down

**Time =  $t_{\text{eq}}$  (At Equilibrium):**

- [A], [B], [C], and [D] all constant (not changing)
- Forward rate = Reverse rate (equal!)
- Both rates are non-zero
- Net change: Zero (no net change, but reactions continue!)

## CONCEPT 3: Macroscopic vs.



# Microscopic Properties

## Observable properties vs. molecular-level activity

### Two Different Perspectives on Equilibrium

When we study equilibrium, we can view it from two different scales:

1. **Macroscopic (Observable):** What we can see and measure in the lab
2. **Microscopic (Molecular):** What's happening at the atomic/molecular level

### MACROSCOPIC VIEW

**Definition:** Observable, measurable properties that we can detect with our senses or instruments

**At Equilibrium, These Are CONSTANT:**

- ✓ Concentrations of all species
- ✓ Partial pressures of gases
- ✓ Color of the solution
- ✓ pH of the system
- ✓ Temperature (if no heat exchange)
- ✓ Total pressure (in closed system)

**Key Point:** To an observer, the system appears static and unchanging!



### MICROSCOPIC VIEW

**Definition:** Molecular-level processes that we cannot directly observe but know are occurring

**At Equilibrium, These CONTINUE:**

- ✓ Molecular collisions between reactant particles
- ✓ Formation of products from reactants
- ✓ Decomposition of products back to reactants
- ✓ Bond breaking and bond forming
- ✓ Energy transfer between molecules
- ✓ Movement of all particles

**Key Point: At the molecular level, there is constant activity and motion!**

## Connecting the Two Views

**The Big Picture:**

**Constant Macroscopic Properties  $\neq$  No Molecular Activity**

**Even though we observe no change in concentration, color, pressure, etc., at the molecular level there is continuous reaction.**

**Why don't we see changes?**

Because the forward and reverse reactions occur at equal rates:

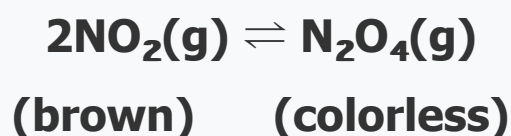
- For every molecule of product formed (forward), another molecule of product decomposes (reverse)
- For every reactant molecule consumed (forward), another reactant molecule

is re-formed (reverse)

- Net result: No observable change, but constant molecular activity

### Example: $\text{NO}_2/\text{N}_2\text{O}_4$ Equilibrium

**Reversible Reaction:**



#### **Macroscopic Observation:**

- At equilibrium, the color of the gas mixture stays constant
- The mixture appears as a steady brown color - not getting darker or lighter
- $[\text{NO}_2]$  and  $[\text{N}_2\text{O}_4]$  remain constant over time

#### **Microscopic Reality:**

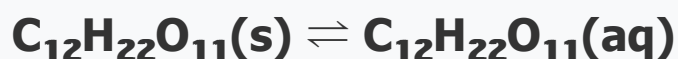
At the molecular level:

- $\text{NO}_2$  molecules are continuously colliding and forming  $\text{N}_2\text{O}_4$
- $\text{N}_2\text{O}_4$  molecules are continuously decomposing back to  $\text{NO}_2$
- Both processes happen at the same rate

**Conclusion: The unchanging brown color (macroscopic) masks the continuous interconversion of  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  (microscopic).**

### Example: Saturated Solution

**System:** Solid sugar in saturated sugar solution



### Macroscopic Observation:



- The amount of solid sugar at the bottom stays constant
- The concentration of dissolved sugar stays constant
- The solution appears unchanging

### Microscopic Reality:

- Sugar molecules at the crystal surface are continuously dissolving into solution
- Dissolved sugar molecules are continuously crystallizing back onto the solid
- Rate of dissolution = Rate of crystallization

**If you could track individual molecules with radioactive tracers, you'd see them constantly moving between solid and solution!**

## Summary Table

Property	Macroscopic (Observable)	Microscopic (Molecular)
<b>Change Over Time</b>	 No change (constant)	 Continuous change
<b>Concentrations</b>	Constant	Individual molecules changing
<b>Reactions</b>	Appear stopped	Both directions ongoing

<b>Rate</b>	Net rate = 0	Both rates > 0 and equal
<b>Energy</b>	No net energy change	Energy constantly exchanged

## CONCEPT 4: Closed Systems & Graphical Analysis



### Requirements for equilibrium and interpreting graphs

#### Why Closed Systems?

**Equilibrium can ONLY be established in a closed system.**

#### Closed System Definition

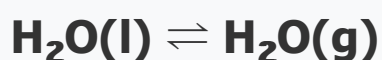
**Closed System:** A system where no matter can enter or leave, but energy can be exchanged with surroundings.

 Closed System Examples	 Open System Examples
<ul style="list-style-type: none"> <li>Sealed flask with stopper</li> <li>Closed container with tight lid</li> <li>Sealed gas cylinder</li> <li>Closed reaction vessel</li> </ul> <p>→ <b>CAN establish equilibrium</b></p>	<ul style="list-style-type: none"> <li>Open beaker (gases can escape)</li> <li>Flowing river</li> <li>Open flame</li> <li>Test tube without stopper</li> </ul> <p>→ <b>CANNOT establish equilibrium</b></p>

### Why is this important?

If reactants or products can escape, concentrations cannot remain constant. The system will never reach a state where forward rate = reverse rate because the amounts of substances keep changing due to loss to surroundings.

### Example: Water Evaporation



✗ Open Container	✓ Sealed Container
<p>Water in an open beaker:</p> <ul style="list-style-type: none"><li>• Water evaporates (forward)</li><li>• Water vapor escapes to atmosphere</li><li>• Very little condensation (reverse)</li><li>• Eventually, all water evaporates</li></ul> <p><b>NO equilibrium established!</b></p> <p>The system goes to completion (all liquid → gas).</p>	<p>Water in a sealed bottle:</p> <ul style="list-style-type: none"><li>• Water evaporates (forward)</li><li>• Water vapor cannot escape</li><li>• Vapor condenses back (reverse)</li><li>• Equilibrium established</li></ul> <p><b>Equilibrium achieved!</b></p> <p>Both liquid and vapor coexist with constant amounts.</p>

## Graphical Analysis: Concentration vs. Time

Graphs of concentration vs. time are powerful tools for identifying when a system reaches equilibrium.

## Concentration vs. Time Graph

[Imagine a graph with Time on x-axis and Concentration on y-axis]

- Reactants line starts high and decreases, then levels off
- Products line starts at zero and increases, then levels off
  - Both lines become horizontal at equilibrium
- Vertical line marked "EQUILIBRIUM" where lines flatten
- Labels: "[Reactants] constant" and "[Products] constant"

### Key Features to Identify Equilibrium:

- ✓ Lines level off (become horizontal)
- ✓ Concentrations remain constant over time
- ✓ Both reactants AND products present (not zero)
- ✓ No further change in amounts after equilibrium reached

## Graphical Analysis: Reaction Rate vs. Time

Another way to identify equilibrium is by graphing the rates of forward and reverse reactions over time.

## Reaction Rate vs. Time Graph

[Imagine a graph with Time on x-axis and Reaction Rate on y-axis]

- Rate<sub>forward</sub> line starts high and decreases
- Rate<sub>reverse</sub> line starts at zero and increases
- Both lines converge to same value at equilibrium
- Vertical line marked "EQUILIBRIUM" where rates equal
  - Label: "Rates Equal"

### Key Features to Identify Equilibrium:

- ✓ Lines converge to the same value
- ✓ Rate<sub>forward</sub> = Rate<sub>reverse</sub> (lines meet)

- ✓ Both rates remain constant after convergence
- ✓ Both rates are non-zero at equilibrium

## Interpreting Equilibrium Graphs

Graph Type	Before Equilibrium	At Equilibrium
<b>[Concentration] vs. Time</b>	<ul style="list-style-type: none"> <li>• Lines are curved/changing</li> <li>• Concentrations increasing or decreasing</li> </ul>	<ul style="list-style-type: none"> <li>• Lines are horizontal/flat</li> <li>• Concentrations constant</li> </ul>
<b>Rate vs. Time</b>	<ul style="list-style-type: none"> <li>• Forward and reverse rates different</li> <li>• Lines not equal</li> </ul>	<ul style="list-style-type: none"> <li>• Forward and reverse rates equal</li> <li>• Lines converge to same value</li> </ul>
<b>Net Direction</b>	<ul style="list-style-type: none"> <li>• Net reaction toward products OR reactants</li> <li>• System changing</li> </ul>	<ul style="list-style-type: none"> <li>• No net reaction</li> <li>• System appears static</li> </ul>



## Key Takeaways - Unit 7.1

1. Reversible processes proceed in both forward and reverse directions simultaneously ( $\rightleftharpoons$ )
2. Dynamic equilibrium:  $\text{Rate}_{\text{forward}} = \text{Rate}_{\text{reverse}}$  (THE defining condition)
3. At equilibrium, macroscopic properties are constant but microscopic activity continues
4. Equilibrium requires a closed system (no matter can enter or leave)



5. Concentration vs. time graphs show equilibrium when lines become horizontal
6. Rate vs. time graphs show equilibrium when forward and reverse rates converge



## Study Resources

**Official AP Chemistry Study Guide:**

[Unit 7 Part 1 Study Guide - AP Chemistry Rescue](#)