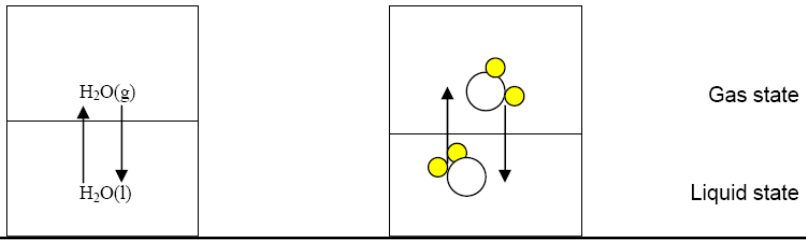
Chemical Equilibrium

Physical Equilibrium

- Requires a closed system at constant temperature
  - Liquid water in a sealed container is at equilibrium with its water vapor
  - Rate of evaporation is equal to the rate of condensation



Chemical Equilibrium

- Some chemical reactions go to completion
  - All reactants are converted to products
- However…
- Most chemical reactions do not go to completion. They appear to stop.
- These reactions are reversible

Reversible Reaction

- A chemical reaction that can occur in both the forward and reverse direction
- Forward: $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$
- Backward: $N_2(g) + 3\ H_2(g) \leftarrow 2\ NH_3(g)$
- Written: $N_2(g) + 3\ H_2(g) \leftrightarrow 2\ NH_3(g)$

Chemical Equilibrium

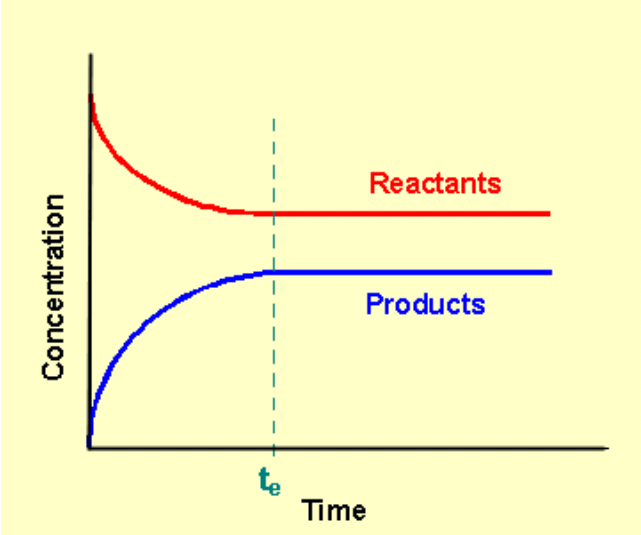
- A state in which the forward and reverse reactions balance each other because they take place at equal rates.

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

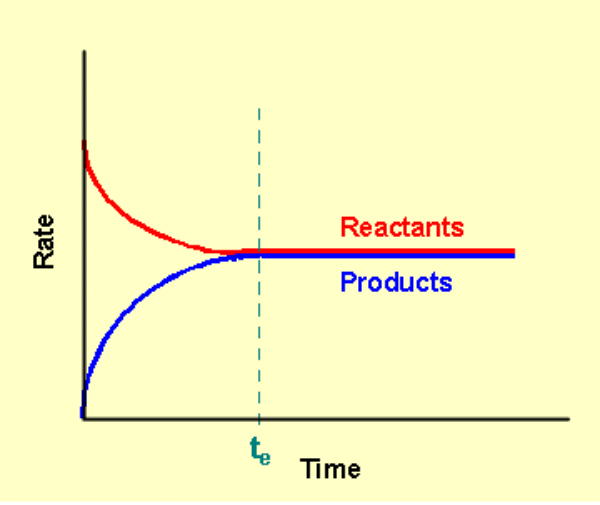
Conditions for Chemical Equilibria

- Constant observable macroscopic properties
  - Temperature, pressure, concentration
- A closed system
- Constant temperature
- Reversibility
- Rates of opposing changes are equal

Concentration vs Time



Rate vs Time



Law of Chemical Equilibrium

$aA + bB \leftrightarrow cC + dD$

$$K_{eq} = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

(K_{eq} is constant only at a specified temperature)

K_{eq}

- $K_{eq} > 1$
  - More products than reactants at equilibrium
- $K_{eq} < 1$
  - More reactants than products at equilibrium

Homogeneous Equilibria

- All reactants and products are in the same physical state

Example

- Write the equilibrium constant expression for the reaction in which ammonia gas is produced from hydrogen and nitrogen.

$$N_2(g) + 3\ H_2(g) \leftrightarrow 2\ NH_3(g)$$

$$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Heterogeneous Equilibria

- The reactants and products are in different physical states

Pure Substances

- The concentration of a pure substance is its density in moles per liter
- At any given temperature, density does not change
- Therefore, the concentration of pure substances does not change
- So, pure substances do not appear in the equilibrium constant expression

- Solids and liquids are pure substances
- Therefore, solids and liquid in the reaction are not included in the equilibrium constant expression

Example 1

- When ethanol is placed in a closed flask, a liquid-vapor equilibrium is established. Write the equilibrium constant expression for this process.

$$C_2H_5OH(\ell) \leftrightarrow C_2H_5OH(g)$$

$$K_{eq} = [C_2H_5OH(g)]$$

Example 2

- Write the equilibrium constant expression for the decomposition of sodium hydrogen carbonate.

$2\ NaHCO_3(s) \leftrightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

$$K_{eq} = [CO_2][H_2O]$$