Lesson 5.1
Chemical Equilibrium

Chemistry 2 Honors
Northwestern High School
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The Concept of Equilibrium

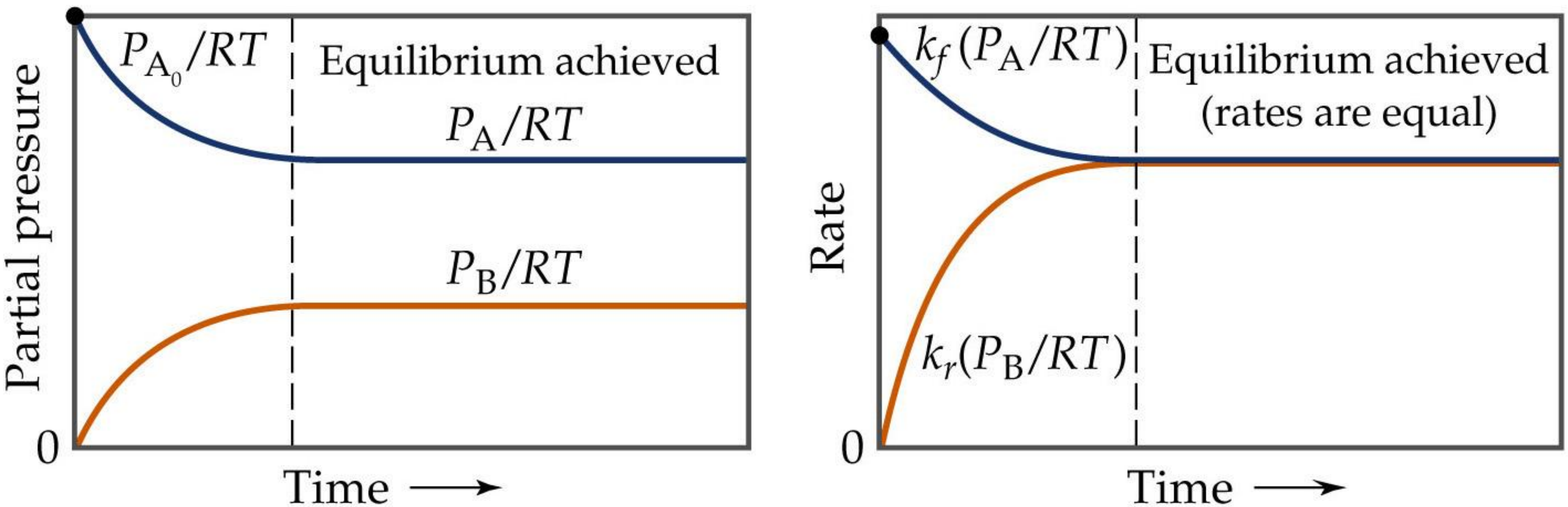
- Consider liquid water at its boiling point.
- At the boiling point, liquid and vapor are in equilibrium:

$$H_2O\ (l) \rightleftharpoons H_2O\ (g)$$

Liquid water molecules are turning to vapor, and vapor molecules are turning to liquid.

Equilibrium means that they are happening at the same rate (dynamic equilibrium).

- For an equilibrium we write $A \rightleftharpoons B$
- As the reaction progresses
  - [A] decreases to a constant,
  - [B] increases from zero to a constant.
  - When [A] and [B] are constant, equilibrium is achieved.
- Alternatively:
  - k_f[A] decreases to a constant,
  - k_r[B] increases from zero to a constant.
  - When $k_f[A] = k_r[B]$ equilibrium is achieved.



Partial pressure
P_{A_0}/RT
Equilibrium achieved
P_A/RT
P_B/RT
0
Time
Rate
$k_f(P_A/RT)$
Equilibrium achieved
(rates are equal)
$k_r(P_B/RT)$
0
Time

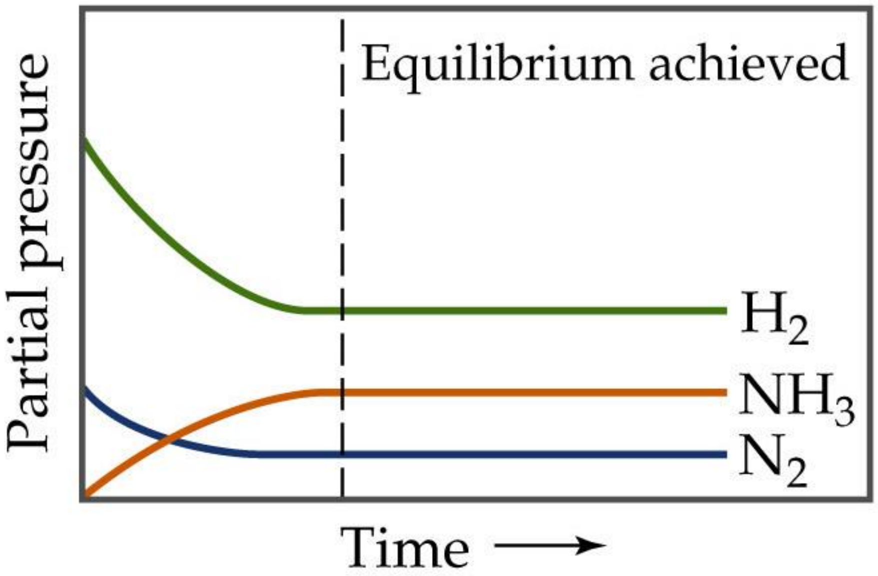
The Equilibrium Constant

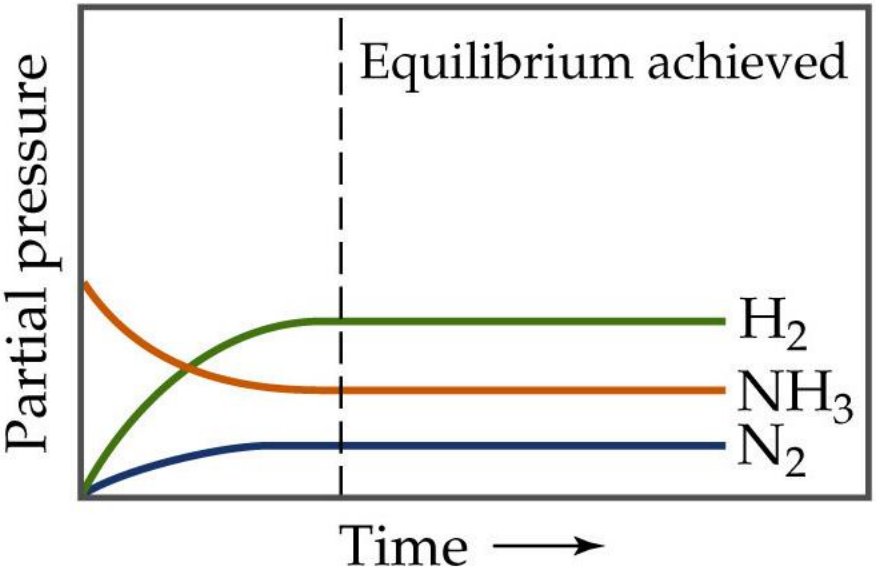
- Consider the Haber Process:

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

- If we start with a mixture of nitrogen and hydrogen (in any proportions), the reaction will reach equilibrium with a constant concentration of nitrogen, hydrogen and ammonia.
- However, if we start with just ammonia and no nitrogen or hydrogen, the reaction will proceed and N_2 and H_2 will be produced until equilibrium is achieved.

The Equilibrium Constant





- No matter the starting composition of reactants and products, the same ratio of concentrations is achieved at equilibrium.

The Equilibrium Constant

- For a general reaction in the gas phase

$$aA + bB \rightleftharpoons cC + dD$$

the equilibrium constant expression is

$$K_{eq} = \frac{P_C^c P_D^d}{P_A^a P_B^b}$$

where K_{eq} is the equilibrium constant.

The Equilibrium Constant

- For a general reaction

$$aA + bB \rightleftharpoons cC + dD$$

the equilibrium constant expression for everything in solution is

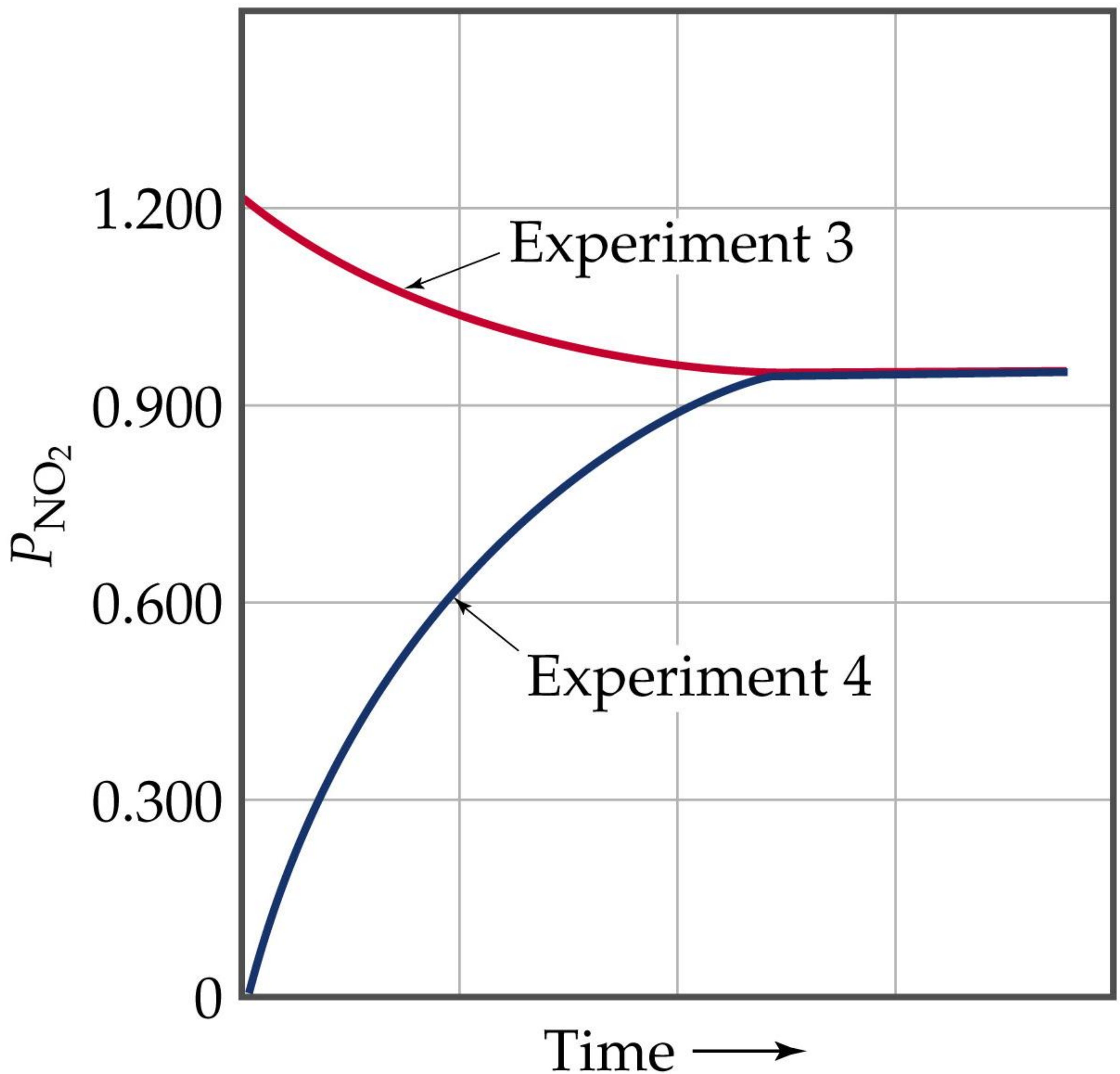
$$K_{eq} = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

where K_{eq} is the equilibrium constant.

- K_{eq} is based on the molarities of reactants and products at equilibrium.
- Units of K_{eq} depend on the reaction being studied.
- Note that the equilibrium constant expression has products over reactants.
- The same equilibrium is established no matter how the reaction is begun.

TABLE 15.1 Initial and Equilibrium Partial Pressures (P) of N_2O_4 and NO_2 at 100°C

Experiment	Initial N_2O_4 Partial Pressure (atm)	Initial NO_2 Partial Pressure (atm)	Equilibrium N_2O_4 Partial Pressure (atm)	Equilibrium NO_2 Partial Pressure (atm)	K_{eq}
1	0.0	0.612	0.0429	0.526	6.45
2	0.0	0.919	0.0857	0.744	6.46
3	0.0	1.22	0.138	0.944	6.46
4	0.612	0.0	0.138	0.944	6.46



1.200
0.900
0.600
0.300
0
P_{NO_2}
Experiment 3
Experiment 4
Time

$$CH_4\,(g) + 2\,O_2\,(g) \rightleftharpoons CO_2\,(g) + 2\,H_2O\,(g)$$

1. Write an expression for K_{eq}
2. Calculate K at a given temperature if $[CH_4]$ = 0.020 M, $[O_2]$ = 0.042 M, $[CO_2]$ = 0.012 M, and $[H_2O]$ = 0.030 M at equilibrium. (include units)

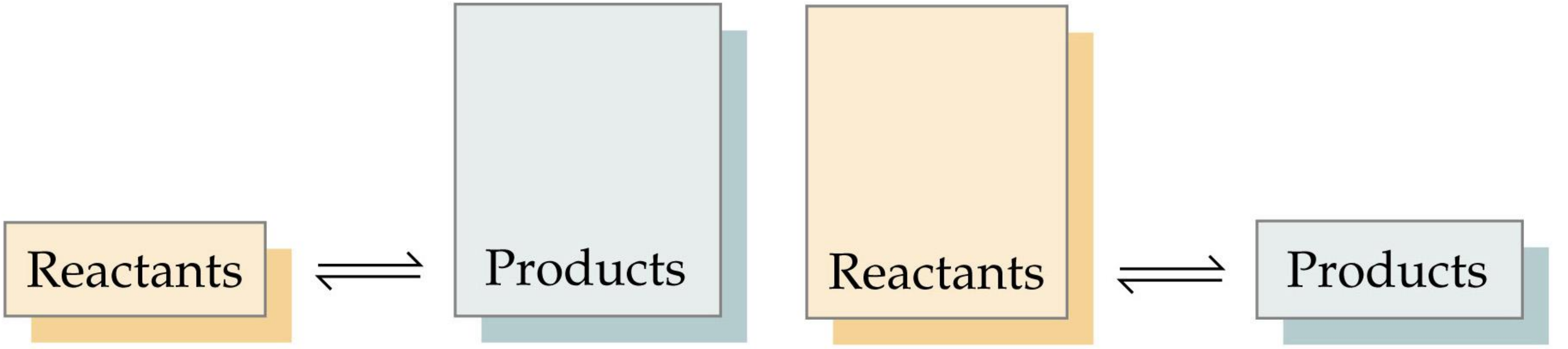
1. $$K_{eq} = \frac{[CO_2][H_2O]^2}{[CH_4][O_2]^2}$$

2. .306

The Magnitude of Equilibrium Constants

- The equilibrium constant, K, is the ratio of products to reactants.
- Therefore, the larger K the more products are present at equilibrium.
- Conversely, the smaller K the more reactants are present at equilibrium.
- If $K >> 1$, then products dominate at equilibrium and equilibrium lies to the right.

- If K << 1, then reactants dominate at equilibrium and the equilibrium lies to the left.



(a) $K_{eq} \gg 1$ (b) $K_{eq} \ll 1$

Types of Equilibrium Constant

K_{eq} = Equilibrium

K_c = concentrations

K_p = pressures