A course in Equilibrium.

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Contents

Equilibrium

After completing this section, students should be able to do the following.

- Understand that equilibrium reactions are reversible.
- Recognize equilibrium arrows.
- Use the Law of Mass action.

Learning outcomes:
Author(s):

Equilibrium

Two chemists discuss reversible reactions.

Check out this dialogue between two chemistry students.

Student 1: My professor showed this incredible demonstration in class today. He created a flame that was green and, it was a tornado flame!

Student 2: I love demos!

Student 1: The professor said the fire resulted from this reaction:

$\mathrm{CH_3OH + O_2 \rightarrow CO_2 + H - 2O}$

also, the tornado resulted from the air current.

Student 2: That tornado flame is cool!

Student 1: I know. I was thinking, though, could we get the $\mathrm{CO_2}$ and $\mathrm{H_2O}$ to go back to CH_3OH an O_2?

Student 2: Not likely. I think that is an irreversible reaction.

Student 1: Irreversible?

Student 2: Yeah. You can?t easily get the reactants back. However, some reactions are reversible.

Student 1: Tell me more.

Student 2: My lecture professor showed this demo in class:

$\mathrm{CoCl_4^{2-} + 6H_2O \rightleftharpoons Co(H_2O)_6^{2+} + 4Cl^-}$

He was able to change the colors back and forth.

Student 1: Cool colors. So, that means this reaction is reversible.

Student 2: Yes. This is an equilibrium reaction where the forward and reverse reactions both continue.

Student 1: Good point. Does this work with all equilibrium reactions?

Question 1 *Which reaction arrows represent an equilibrium reaction? (pick all that apply)*

Select All Correct Answers:

(a) $\leftarrow$

Learning outcomes: Introduce equilibrium. Reaction arrows.
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(b) $\rightleftharpoons$ ✓

(c) $\leftrightarrow$

(d) $\leftrightharpoons$ ✓

(e) $\Leftarrow$

Hint: *Think about the arrow!*

Question 2 *Does this reaction system will go in ?reverse??* $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

Multiple Choice:

(a) *Yes* ✓

(b) *No*

(c) *I don't know*

Equilibrium

Here, we discuss the conditions of equilibrium.

Under certain conditions, an equilibrium reaction will appear to remain unchanged. The reactant and product concentration are not changing. That is, the reaction of the reactants combining to form products occurs at the same time as products decomposing back into reactants. So, the net concentration of these species are constant. We call this a dynamic equilibrium system because the reactions continue even when there appears to be no change.

In an everyday situation, this is analogous to people both entering and exiting a store. Some people can walk through an entryway, while at the same time others leave through an exit. In a situation where an equal number of people enter the store as those that leave the store, the net number of people inside the store remains constant. While different people may be inside, the total number of people is the same. To a casual observer, there seems to be no change, despite the continual entering and leaving.

This same situation can happen in a chemical system. Take, for instance, the pink/blue reaction system described previously,

$CoCl_4^{2-} + 6H_2O \rightleftharpoons Co(H_2O)_6^{2+} + 4Cl^-$

The forward and reverse reactions both continue to occur at equilibrium. At equilibrium, there would be no apparent change in the color because the $CoCl_4^{2-}$ reacting with water to form the pink and Cl^- happens at the same speed as the pink compound degrading back to blue $CoCl_4^{2-}$. Hence, there is no net change in overall color. So, we say the reactions are occurring at the same rate(or speed), which results in no net change.

Question 3 *Consider the following reaction:*

$A + B \rightleftharpoons C$

At equilibrium, there is no change in the concentration of C, but the concentrations of A and B do change.

Multiple Choice:

(a) *Yes*

(b) *No* ✓

(c) *Yes, but only at low temperature*

Learning outcomes: Introduce equilibrium. Reaction arrows.
Author(s):

Question 4 *Consider the (same) following reaction:*

$A + B \rightleftharpoons C$

Do the forward and reverse reactions continue when equilibrium is reached.

Multiple Choice:

(a) *Yes* ✓

(b) *No*

(c) *Yes, but only at low temperature*

Question 5 *Which of the following are correct at equilibrium? (pick all that apply)*

Select All Correct Answers:

(a) *The concentration of A does not change.* ✓

(b) *The reverse reaction stops.*

(c) *The forward reaction continues.* ✓

(d) *The concentration of A increases.*

(e) *The concentration of B stays the same.* ✓

Hint: *Think about what happens, at the molecular level, at equilibrium.*

Equilibrium

Here, we discuss the Equilibrium Constant Expression.

At equilibrium, we have seen that the rates of forward and reverse reactions are the same. So, while the rates are the same for the reactions, the concentrations of the reactants and products are different. In fact, the concentrations of two (or more) reactants in a reaction need not be equal; same goes for the products.

One of the ways to quantitate the ratio of the species of the reactants and products is using the Law of Mass Action. This law gives a numerical value for a given reaction.

$\mathrm{aA + bB \rightleftharpoons cC + dD}$

where A, B, C and D are hypothetical chemical species. The lower case letters are corresponding stoichiometric coefficients. The ratio of products to reactants is given by:

$\mathrm{K_c = \dfrac{[C]^c[D]^d}{[A]^a[B]^b}}$

The $\mathrm{K_c}$ is called the equilibrium constant. The entire mathematical formula is called the Equilibrium Constant Expression.

Question 6 *For the following reaction:*

$\mathrm{N_2 + 3H_2 \rightleftharpoons 2NH_3}$

The equilibrium constant expression is:

Multiple Choice:

(a) $\mathrm{K_c = \dfrac{[NH_3]^2}{[N_2 + H_2]}}$

(b) $\mathrm{K_c = \dfrac{[NH_3]^2}{[N_2][H_2]^3}}$ ✓

(c) $\mathrm{K_c = \dfrac{[N_2][H_2]^3}{[NH_3]^2}}$

(d) $\mathrm{K_c = \dfrac{[N_2] + [H_2]^3}{[NH_3]^2}}$

Learning outcomes: Introduce the Equilibrium Constant Expression Understand the Law of Mass Action.

Author(s):