Le Châtelier's Principle

Unit: Kinetics & Equilibrium

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS1-6

Mastery Objective(s): (Students will be able to…)

- Use Le Châtelier's Principle to predict a shift in equilibrium in response to a change.

Success Criteria:

- Prediction correctly describes the shift in equilibrium when the concentration of one chemical species is changed.

Tier 2 Vocabulary: stress

Language Objectives:

- Explain how a change provokes a response.

Notes:

If a reaction is at equilibrium, the reaction will resist any change with a corresponding change that shifts the reaction back to its equilibrium. Because K_{eq} is a constant, after the equilibrium shifts, the value of K_{eq} will be the same as it was before the change.

In plain English, if you change something, the equilibrium will shift to partly undo the change. This principle is called Le Châtelier's Principle, named after the French chemist Henry Louis Le Châtelier who first proposed the idea.

For example, consider the reaction:

$$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightharpoons 2\,NH_{3\,(g)} + 92.1\text{ kJ}$$

For this reaction, $K_{eq} = \dfrac{[NH_3]^2}{[N_2][H_2]^3} = 835$ at 25 °C.

Suppose we started with $[N_2] = 0.05$ M, $[H_2] = 0.3$ M, and $[NH_3] = 1.06$ M.

If we add more $[H_2]$, the reaction would use more H_2, and make more NH_3. If we kept adding H_2 until $[H_2] = 0.4$ M, we would have $[N_2] = 0.026$ M, and $[NH_3] = 1.18$ M. As you can see, adding more H_2 caused the reaction to use up more N_2 and make more NH_3.

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Le Châtelier's Principle tells us that we don't have to perform the equilibrium calculation to qualitatively predict what will happen. We can just look at the equation:

$$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightharpoons 2\,NH_{3\,(g)} + 92.1\text{ kJ}$$

if we add more H_2, the equilibrium will shift to use more of it up. This means the equilibrium will shift to the right, also using up more N_2 and making more NH_3.

On the other hand, if we added NH_3, the equilibrium would instead shift to the left to use up some of the NH_3, and make more N_2 and H_2.

Action	**Equilibrium shift**
Add N_2 or H_2	to the right
Remove N_2 or H_2	to the left
Add NH_3	to the left
Remove NH_3	to the right
Increase the temperature (add heat)	to the left

Note that the value of K_{eq} is different at different temperatures. Adding reactants or products doesn't change the value of K_{eq}, but changing the temperature does. Le Châtelier tells us that adding heat must shift the equilibrium to the *left*. The equilibrium shift occurs because increasing the temperature results in a lower value of K_{eq} for this equation.

Quantitative equilibrium calculations and the relationship between the equilibrium constant and thermodynamics are studied in more depth in AP® Chemistry.

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Homework Problems

Consider the chemical equation:

$$6\,H_{2\,(g)} + P_{4\,(g)} \rightleftharpoons 4\,PH_{3\,(g)} + 53.5\,\text{kJ}$$

1. Indicate which direction the equilibrium would shift as a result of each of the following:
   a. Adding P_4
   b. Removing PH_3
   c. Removing H_2
   d. Decreasing the temperature

2. Write the equilibrium expression for the above reaction.

3. The value of K_{eq} for this reaction is 4.44 at 25 °C. If the reaction is at equilibrium at 25 °C, the concentration of H_2 is 1.00 M and the concentration of P_4 is 0.025 M, what is the concentration of PH_3?

   Answer: $[PH_3] = 0.58$ M

4. If the reaction is cooled to 4 °C, the value of the equilibrium constant increases to 4.77. Is this consistent with the prediction made by Le Châtelier's Principle in question #1d above? Explain.

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