Investigation 16.B: Disturbing Equilibrium Answer Key

Answers to Procedure Questions

The following responses to Procedure Questions involve predictions of the shift in equilibrium in each reaction in response to various changes in conditions.

Le Châtelier's principle helps to predict the direction in which an equilibrium reaction will shift to re-establish equilibrium when a change in concentration, pressure, volume or temperature is made. Le Châtelier's principle states that a dynamic equilibrium tends to respond so as to relieve the effect of any change in the conditions that affect the equilibrium.

Part 1 (Procedure Question 2)

$NH_3(aq) + H_2O(\ell) \leftrightarrow NH_4^+(aq) + OH^-(aq)$

Initially, the solution is basic and the phenolphthalein will be pink. The following summarizes how you might change the equilibrium and your predicted observations:

- Add HCl(aq). The addition of $H^+(aq)$ removes $OH^-(aq)$ and the equilibrium shifts to the right. A reduction in $OH^-(aq)$ will cause the solution to become clear.
- Add $NH_4Cl(s)$. The solid is soluble in water, and ionizes. The addition of $NH_4^+(aq)$ will shift the equilibrium to the left. The solution will become clear.
- Add $H_2O(\ell)$. The addition of $H_2O(\ell)$ will shift the equilibrium to the right. The solution will become more pink.
- Add $NH_3(aq)$. This will shift the equilibrium to the right and the solution will become pinker.

Part 2 (Procedure Question 3)

$Heat + Co(H_2O)_6^{2+}(aq/et) + 4Cl^-(aq/et) \leftrightarrow CoCl_4^{2-}(aq/et) + 6H_2O(\ell/et)$

pink **blue or purple**

Initially, the solution is blue–purple. The following summarizes how you might change the equilibrium and your predicted observations:

- Add $H_2O(\ell)$. The addition of $H_2O(\ell)$ will shift the equilibrium to the left. The solution will become more pink.
- Add HCl(aq). The addition of $Cl^-(aq)$ will shift the equilibrium to the right. The solution will become more blue or purple.
- Add $AgNO_3(aq)$. The addition of $Ag^+(aq)$ will precipitate AgCl(s), a white solid. The removal of of $Cl^-(aq)$ will shift the equilibrium to the left. The solution will become more pink.
- Place the test tube containing solution in a hot water bath. Heating the solution will shift the equilibrium to the right. The solution will become more blue/purple.
- Place the test tube containing solution in a cold water bath. Cooling the solution will shift the equilibrium to the left. The solution will become more pink.

Part 3 (Questions accompanying figures)

$Heat + N_2O_4(g) \leftrightarrow 2NO_2(g)$

colourless **brown**

At room temperature, the gaseous mixture is brown.

- When placed into boiling water, the equilibrium shifts to the right and the mixture of gases will become darker brown.

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- When placed into ice-cold water, the equilibrium shifts to the left and the mixture of gases will become lighter brown.
- When the mixture of gases is present in a syringe, pressing the plunger down sharply will concentrate the gases and the colour will darken. If the plunger is held in a fixed position, the colour will change over a few seconds as the system reestablishes equilibrium. The equilibrium shifts to the left and the mixture of gases will become lighter in colour.

Figure
Student Textbook p. 653 and p. 5 of BLM 16.2.2

The tubes contain a mixture of gases. The tube on the left is in ice water, so heat has been removed from the environment. According to Le Châtelier's principle, the equilibrium will respond so as to relieve the effect of this change. In this case, the shift will be to the left, as the system adds heat to the environment. This will increase the concentration of $N_2O_4(g)$ and reduce the concentration of $NO_2(g)$. Because $N_2O_4(g)$ is colourless, the colour of the gases inside the tube will become lighter. For the tube on the right in boiling water, heat has been added to the environment. In this case, the shift in equilibrium will be to the right, as the system removes heat from the environment. This will increase the concentration of $NO_2(g)$ and reduce the concentration of $N_2O_4(g)$. Because $NO_2(g)$ is brown, the colour of the gases inside the tube will become darker.

Figure
Student Textbook p. 654 and p. 6 of BLM 16.2.2

Decreasing the volume of the gases heats the mixture and causes the colour to become darker. This can be explained using the same reasoning that was used for the colour change to the tube placed into boiling water. A few seconds later, after the tube has cooled, the colour of the gaseous mixture in the photograph on the right is lighter than before. When the plunger in the syringe was forced down, the pressure on the reacting gases was increased. Le Châtelier's principle predicts that the system will respond to relieve this effect. The equilibrium will shift towards the side with fewer gas molecules, increasing the concentration of $N_2O_4(g)$ and decreasing the concentration of $NO_2(g)$. The gaseous mixture becomes lighter in colour.

Answers to Analysis Questions

1. The accuracy of your predictions may be used as a means of assessing your understanding of Le Châtelier's principle both before and after the activity.

2. In Part 1, the concentration of a reactant was increased by adding $H_2O(\ell)$ and by adding $NH_3(aq)$. In Part 2, the concentration of a reactant was increased by adding HCl(aq). Increasing the concentration of a reactant caused each equilibrium to respond by forming more product and less reactant.

In Part 1, the concentration of a product was increased by adding $NH_4Cl(s)$. In Part 2, the concentration of a product was increased by adding water. In each case, the equilibrium responded by forming more reactant and less product.

3. In Part 2, the concentration of a reactant was decreased by adding $AgNO_3(aq)$. This caused the equilibrium to respond by forming more reactant and less product.

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Investigation 16.B: Disturbing Equilibrium Answer Key (cont'd)

In Part 1, the concentration of a product was decreased by adding HCl(aq). The equilibrium responded by forming more product and less reactant.

4. **(a)** Each system is endothermic when read from left to right.

(b) When heated, each system shifted to the right. In terms of the energy change, the observed shift in equilibrium was toward the endothermic side of the reaction.

(c) The value of K_c changed when the equilibrium mixture was heated. In these reactions, because the equilibrium shifts to the right, the value of K_c is expected to increase at greater temperature.

5. **(a)** The total pressure of the mixture increased when the plunger was pushed down.

(b) The pressure of a gas, or a mixture of gases, is directly proportional to the number of gas molecules present.

(c) Pushing the plunger down increases the pressure of the gaseous mixture. Le Châtelier's principle predicts the system will respond by shifting to reduce the gas pressure. Because there are fewer gas molecules on the left side of the chemical equation, the equilibrium will shift to the left and form more $N_2O_4(g)$. You will observe (or see from the photographs on p. 654 of the student text, or p. 6 of BLM 16.2.2) the mixture of gases becoming lighter in colour.

6. Discuss any variations to the anticipated experiments, using Le Châtelier's principle to interpret the results.

Answer to Conclusion Question

7. In small groups, you should discuss and resolve any differences between your results and predictions. Think beyond experimental error when considering any differences.

Answer to Application Question

8. Changing the volume has no effect on this equilibrium system because there are the same numbers of gas molecules on both sides of the chemical equation.

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