Simple experiments to illustrate Le Chatelier's Principle

(a) The equilibrium between $CoCl_4^{2-}$ and $Co(H_2O)_6^{2+}$

Theory

Le Chatelier's Principle states that when a disturbance is imposed on a system at equilibrium, the equilibrium shifts in such a way as to minimise the effect of the disturbance. Some reactions involving cobalt compounds are suitable for illustrating Le Chatelier's Principle because they involve clear colour changes.

$Co(H_2O)_6^{2+}$ is pink in aqueous solution and $CoCl_4^{2-}$ is blue.
The equilibrium between the two species is

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

The forward reaction is exothermic. The equilibrium between the two species can be disturbed by (i) adding Cl^- ions or water **or** (ii) changing the temperature. In both cases the changes that occur are as predicted by Le Chatelier's Principle.

Procedure

NB: Wear your safety glasses.

Dissolve 4 g of cobalt chloride-6-water in 40 cm^3 of deionised water. The following equilibrium is set up when the crystals are added to water:

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

Since the pink colour is predominant, we may conclude that the equilibrium lies on the right hand side.

Using a fume cupboard, add concentrated hydrochloric acid, with stirring, until a violet solution is formed. Adding more concentrated hydrochloric acid produces a blue colour, while adding water will restore the pink colour. By trial and error produce an "in between" violet (or lilac) colour which will contain the two cobalt ions. Place this solution in each of six boiling tubes to a depth of about 2 cm (Fig. 1).

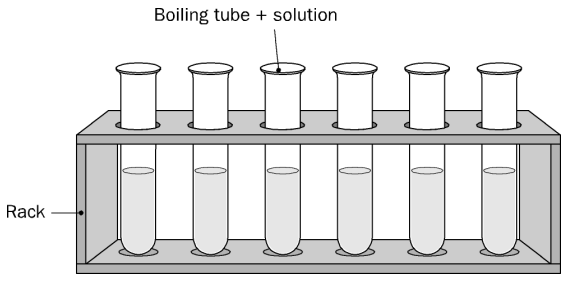

Fig. 1

To study the effects of concentration changes on equilibrium, keep one tube as a control. Add water to a second tube using a dropping pipette. The colour of the solution should change to pink. The equilibrium has now shifted to the right hand side as the forward reaction absorbs the stress of the increased concentration of water.

Using a fume cupboard add concentrated hydrochloric acid to a third tube using a dropping pipette. The colour of the solution should change to blue. The equilibrium has now shifted to the left hand side since adding the concentrated HCl increases the concentration of Cl^- ions and, in keeping with Le Chatelier's Principle, the concentration of these ions is decreased by the backward reaction taking place..

To study the effects of temperature changes on equilibrium, keep one tube as a control. Place another tube in a beaker of hot water (over 90 ^0C). Note that the colour changes to blue. This is in keeping with Le Chatelier's Principle, i.e. the endothermic reaction (reverse reaction) predominates in order to absorb the added heat.

Place another tube in a beaker of crushed ice and water. Note that the colour changes to pink. This is in keeping with Le Chatelier's Principle, i.e. the exothermic reaction (forward reaction) predominates in order to replace the lost heat.

Student Questions

Why is a control used in this experiment?

In order to be able to compare colours formed with the original colour.

Explain why there is a colour change in the mixture when a boiling tube containing it is placed in ice.

In the equilibrium

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

the forward reaction is exothermic. Lowering the temperature favours the exothermic reaction, according to Le Chatelier's Principle, and so the colour changes to pink.

Explain why there is a colour change in the mixture when a boiling tube containing it is placed in hot water.

In the equilibrium

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

the reverse reaction is endothermic. Raising the temperature favours the endothermic reaction, according to Le Chatelier's Principle, and so the colour changes to blue.

Explain why there is a colour change in the mixture when water is added.

Adding water shifts the equilibrium to the right, according to Le Chatelier's Principle, and so the colour changes to pink.

Explain why there is a colour change in the mixture when concentrated hydrochloric acid is added.

Adding hydrochloric acid shifts the equilibrium to the left, according to Le Chatelier's Principle, and so the colour changes to blue.

How can it be shown that it is the chloride ions in the hydrochloric acid that cause this colour change?

Add solid sodium chloride to the "in-between" solution – a colour change to blue occurs. Since chloride ions are the only type of ion found in both hydrochloric acid and sodium chloride, the effect must be due to the chloride ions.

(b) The equilibrium between CrO_4^{2-} and $Cr_2O_7^{2-}$

Theory

Some reactions involving chromium compounds are also suitable for illustrating Le Chatelier's Principle because they involve clear colour changes. One such equilibrium is

$$\underset{\text{orange}}{Cr_2O_7^{2-} + H_2O} \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-} + 2H^+}$$

This experiment will be used to demonstrate the effects of concentration changes on an equilibrium mixture. Adding an acid will increase the concentration of H^+, and adding a base will reduce it.

Procedure

NB: Wear your safety glasses.

Quarter fill a test tube with the solution of sodium dichromate provided. This should have an orange colour. The following equilibrium exists:

$$\underset{\text{orange}}{Cr_2O_7^{2-} + H_2O} \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-} + 2H^+}$$

Since the orange colour predominates, the equilibrium must lie on the left hand side of the equation.

Keep a second sample of the sodium dichromate solution in a test tube as a control.

Carefully add some bench dilute sodium hydroxide solution until the orange colour changes to yellow. The sodium hydroxide removes the H^+ ions giving rise to a stress and therefore, in keeping with Le Chatelier's Principle, the forward reaction predominates to produce more H^+ ions.

Carefully add dilute hydrochloric acid until the yellow colour changes back to orange. The added hydrochloric acid creates an excess of H^+ ions that causes the equilibrium reaction to be shifted to the left in order to absorb this excess of H^+ ions.

Student Questions

When sodium hydroxide solution is added to a solution of potassium dichromate, a colour change occurs. Describe the colour change, and explain why it happens.

The colour changes from orange to yellow. In the equilibrium

$$\underset{\text{orange}}{Cr_2O_7^{2-}} + H_2O \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-}} + 2H^+$$

adding sodium hydroxide solution removes H^+, and so shifts the equilibrium to the right, according to Le Chatelier's Principle. Therefore the colour changes to yellow.

Why does adding hydrochloric acid reverse the colour change referred to in question 1?

The colour changes from yellow to orange. In the equilibrium

$$\underset{\text{orange}}{Cr_2O_7^{2-}} + H_2O \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-}} + 2H^+$$

adding acid increases the concentration of H+ ions, and therefore shifts the equilibrium to the left, according to Le Chatelier's Principle. Therefore the colour changes to orange.

Why is a control used in this experiment?

In order to be able to compare colours formed with the original colour.

Describe and explain what happens when hydrochloric acid is added to a solution of potassium chromate.

The colour changes from yellow to orange. In the equilibrium

$$\underset{\text{orange}}{Cr_2O_7^{2-}} + H_2O \rightleftharpoons \underset{\text{yellow}}{2CrO_4^{2-}} + 2H^+$$

adding acid increases the concentration of H^+ ions and therefore shifts the equilibrium to the left, according to Le Chatelier's Principle. Therefore the colour changes to orange.

(c) The equilibrium between Fe^{3+} and $Fe(CNS)^{2+}$

Theory

Some reactions involving iron compounds are suitable for illustrating Le Chatelier's Principle because they also involve clear colour changes. One such equilibrium is

$$\underset{\text{yellow}}{Fe^{3+}} + CNS^- \rightleftharpoons \underset{\text{red}}{Fe(CNS)^{2+}}$$

This experiment will be used to demonstrate the effects of concentration changes on an equilibrium mixture. Adding hydrochloric acid reduces the concentration of Fe^{3+} by forming a complex ion containing iron and chlorine. This causes a shift of equilibrium to the left. The equilibrium can be shifted to the right hand side by adding some potassium thiocyanate solution.

Procedure:

NB: Wear your safety glasses

Mix together about 5 cm^3 respectively of solutions of iron(III) chloride and potassium thiocyanate in a beaker.

Note the formation of the red complex.

$$\underset{\text{yellow}}{Fe^{3+}} + CNS^- \rightleftharpoons \underset{\text{red}}{Fe(CNS)^{2+}}$$

Since the red complex above is formed, the equilibrium must lie on the right hand side of the equation.

Divide the mixture into three portions in separate boiling tubes (Fig. 2). Keep one of these as a control.

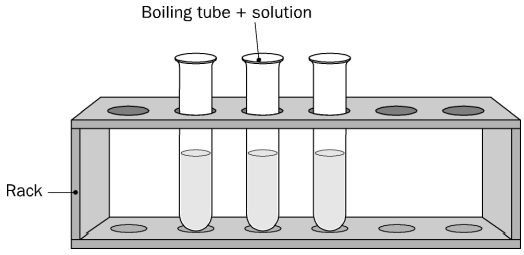

Fig. 2

Using a fume cupboard, add some concentrated hydrochloric acid to the second tube until the red colour disappears. In keeping with Le Chatelier's Principle, the red colour disappears as the equilibrium is shifted to the left hand side to replace the Fe^{3+} ions removed.

Add an equivalent amount of water to the third tube, and compare. This comparison should indicate that the extent of lightening of the colour is not due to a diluting effect. To the second tube, add some potassium thiocyanate solution. The red complex reforms because the equilibrium is shifted to the right.

Student Questions

Why is a control used in this experiment?

In order to be able to compare colours formed with the original colour.

When potassium thiocyanate solution is added to a solution of iron(III) chloride, a colour change occurs. Describe the colour change, and explain why it happens.

The colour changes from yellow to red. In the equilibrium

$$\underset{\text{yellow}}{Fe^{3+}} + CNS^- \rightleftharpoons \underset{\text{red}}{Fe(CNS)^{2+}}$$

some of the red complex $Fe(CNS)^{2+}$ is formed, giving rise to the red colour.

Why does adding hydrochloric acid reverse the colour change referred to in question 2?

In the equilibrium

$$\underset{\text{yellow}}{Fe^{3+}} + CNS^- \rightleftharpoons \underset{\text{red}}{Fe(CNS)^{2+}}$$

adding hydrochloric acid causes the removal of Fe^{3+}, due to the formation of a complex ion containing iron and chlorine. This results in a shift of the equilibrium to the left, according to Le Chatelier's Principle, and so the colour changes to yellow.

How can it be shown that it is the chloride ions in the hydrochloric acid that cause this reversal?

Add saturated potassium chloride solution (or saturated sodium chloride solution) to the red solution – a colour change to yellow occurs. Again, this is due to the removal of Fe^{3+} because of the formation of a complex ion containing iron and chlorine. Since chloride ions are the only type of ion found in both hydrochloric acid and sodium chloride, the effect must be due to the chloride ions.

Why is water added in step 4 of the procedure?

To show by comparison that the extent of lightening of the colour is not due to a diluting effect.

Name a substance other than hydrochloric acid that can reverse the colour change referred to in question 2.

Potassium chloride, or sodium chloride