Chapter 8: Equilibrium

Homework questions

1 Nitrogen dioxide is a toxic, brown, acidic gas that can be formed in the atmosphere by a number of reactions. It exists in equilibrium with its dimer, dinitrogen tetroxide.
The equation for the reversible reaction is given below:

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$

a The standard enthalpies of formation of these two compounds are given in the table below:

Compound	Standard enthalpy change of formation ΔH_f^θ / kJ mol^{-1}
NO_2	+33.2
N_2O_4	+9.2

i Calculate the standard enthalpy change of reaction for the reaction of dinitrogen tetroxide to form nitrogen dioxide. [3]

ii Explain the effect of raising the temperature on the position of equilibrium. [3]

iii Explain the effect of raising the temperature on the value of K_p for the reaction. [2]

b Give **two** conditions for this equilibrium to exist. [2]

c In an experiment to investigate the equilibrium between dinitrogen tetroxide to form nitrogen dioxide, the system was allowed to reach equilibrium. It was found that under the conditions of the experiment, 80% of the dinitrogen tetroxide was converted to nitrogen dioxide. The pressure of the system was 1×10^5 Pa.

i Write the expression for K_p for this reaction and give its units. [2]

ii Calculate the value of K_p under these conditions. [5]

iii If the temperature remains constant, what would the new pressure have to be if the conversion of dinitrogen tetroxide is reduced to 20%? [5]

iv Comment on the new value for the pressure. [2]

d A group of students prepared 480 cm^3 nitrogen dioxide for an investigation. As nitrogen dioxide is toxic, they were required to pass the nitrogen dioxide through 0.25 mol dm^{-3} sodium hydroxide solution. The equation for the reaction is as follows:
$2NaOH(aq) + 2NO_2(g) \rightarrow NaNO_2(aq) + NaNO_3(aq) + H_2O(l)$

i Explain why this is a redox reaction. [3]

ii What is the minimum volume of sodium hydroxide solution required to neutralise the nitrogen dioxide. [3]

Total = 30

2 The Haber process is an extremely important industrial process that produces ammonia.
The equation for the reaction is:

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

When the molar ratio of nitrogen : hydrogen is 1 : 3 and the temperature is 450 °C and the pressure is 2×10^7 Pa, 15% of the nitrogen is converted into ammonia.

a Write the expression for K_p for this reaction and give the units. [3]

b Calculate the value for K_p under these conditions. [5]

c What information does the value of K_p give about the reaction? [1]

d The value of K_p decreases as the temperature increases.
What does this tell you about the reaction to form ammonia? Explain your answer. [4]

e If the pressure was changed from 2×10^7 Pa to 1×10^7 Pa what effect would this have on the following:

i The yield of ammonia? Explain your answer. [2]

ii The value of K_p? Explain your answer. [2]

f Draw a dot-and-cross diagram to show the bonding in:

i ammonia [2]

ii the ammonium ion. [2]

g The H–N–H bond angle in ammonia is 107° whilst in the ammonium ion it is 109.5°. Explain the difference. [3]

h Draw a diagram to show the hydrogen bonding in ammonia. Show any dipoles present. [3]

Total = 27

3 Nitrogen monoxide (NO) is a very reactive compound that has been found to play a major role as a messenger molecule in the cardiovascular system. In the atmosphere it is formed by the reaction between nitrogen and oxygen.

The equation for the formation of nitrogen and oxygen in this way is shown below:

$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ $\Delta H^\theta = +180$ kJ mol^{-1}

a What is the standard enthalpy change of formation for nitrogen monoxide? Explain your answer. [2]

b In air, the concentrations of oxygen and nitrogen are 8.42×10^{-3} mol dm^{-3} and 3.59×10^{-2} mol dm^{-3} respectively. At 293 K the equilibrium constant for the reaction is 4×10^{-31}.

i Write the expression for the equilibrium constant (K_c) and give the units. [2]

ii Calculate the concentration of NO under these conditions. Assume that the concentrations of oxygen and nitrogen are unchanged. [3]

iii How many NO particles are there per m^3? (Avogadro's constant = 6.023×10^{23}; 1 m^3 = 10^3 dm^3) [2]

c Nitrogen monoxide reacts with bromine to form nitrosyl bromide (Br–N=O).

i Write the balanced symbol equation for the reaction. [1]

ii Explain why it is a redox reaction. [2]

iii Draw a dot-and-cross diagram (outer electrons only) for NOBr. [3]

iv Draw the molecule and give the value for the bond angle. Explain how you arrived at your answer. [4]

Total = 19