Industrial Chemistry Revision

1. The formation of ammonia gas from nitrogen and hydrogen takes place according to the equation

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

Different amounts of the three gases were placed in a vessel and allowed to come to equilibrium at two different temperatures. The equilibrium concentrations are tabulated.

Temperature (°C)	$[N_2]$ (mol L^{-1})	$[H_2]$ (mol L^{-1})	$[NH_3]$ (mol L^{-1})
227	0.34	0.83	3.40
427	0.88	1.46	1.01

(a) Write an expression for the equilibrium constant K for the ammonia formation reaction.
(b) Calculate the value of K at:
  (i) 227°C
  (ii) 427°C
(c) Explain whether the equilibrium is exothermic or endothermic based on your answers in (b).
(d) The reaction is carried out at 227°C, in a sealed high pressure vessel connected to a piston. Once equilibrium is established the piston is pushed in so as to reduce the volume of the vessel by half at constant temperature. When equilibrium is re-established what effect will this change have on:
  (i) K?
  (ii) the equilibrium concentration of ammonia?

2. Gaseous methanol in the presence of a suitable Cu/Zn catalyst decomposes to form carbon monoxide and hydrogen gas according to the equilibrium

$$CH_3OH(g) \rightleftarrows CO(g) + 2H_2(g) \qquad \Delta H = +52 \text{ kJ}$$

(a) Write an expression for K.
(b) Predict the effect of the following changes on the position of the equilibrium.
  (i) The temperature is raised.
  (ii) CO is injected into the constant volume vessel.
  (iii) The size of the reaction vessel is doubled at constant temperature.

3. Consider the following homogeneous equilibrium for the decomposition of phosgene ($COCl_2$):

$$COCl_2(g) \rightleftarrows CO(g) + Cl_2(g)$$

1 mole of $COCl_2$ is injected into a 1 L flask and the system allowed to reach equilibrium. Figure 24.12 shows the change in concentration of $COCl_2$ and CO.
(a) Calculate the equilibrium concentration of Cl_2.
(b) Determine the value of K.
(c) At time A, 0.2 mol of CO are injected into the constant volume vessel. The system adjusts to achieve a new equilibrium at time B.
  (i) Calculate the equilibrium concentration of each gas at B.
  (ii) Redraw the graph and show these changes in concentration of $COCl_2$ and CO.

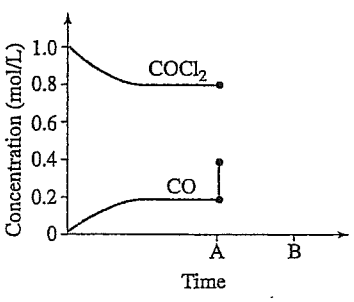

Figure 24.12

4 The ammonia industry is largely automated today. If you were an industrial chemist employed in the ammonia industry explain briefly what monitoring activities you would be required to perform.

5 In chemical industries cost minimisation is an important issue. For each of the following industries state one example of how chemical engineers have designed a plant to avoid wastage of resources.

(a) iron and steel production in a blast furnace
(b) sulfuric acid manufacture
(c) ammonia manufacture

6 (a) What is meant by the term 'yield' in relation to an industrial chemical process?
(b) 1000 kg of calcium carbonate are thermally decomposed to produce lime.
  (i) Write a balanced equation for this reaction.
  (ii) If 550 kg of lime are recovered, determine the percentage yield in this process.
(c) Why is it important to powder the limestone and conduct the decomposition in an open kiln?

7 Write equilibrium constant expressions for the following homogeneous equilibria:

(a) $2CO + O_2 \rightleftarrows 2CO_2$
(b) $2N_2 + 5O_2 \rightleftarrows 2N_2O_5$
(c) $2NO + Cl_2 \rightleftarrows 2NOCl$

8 Herman Frasch developed a method for the mining of sulfur.

(a) What physical property of sulfur is the basis of the Frasch process?
(b) What is the purpose of using pressurised air in the Frasch process?

The contact process is used to manufacture sulfuric acid.

(a) What raw materials are required for this process?
(b) Sulfur is burnt in dry air to produce sulfur dioxide. Explain why the air must be dry for this step.
(c) A catalyst is used in the process of oxidising sulfur dioxide to sulfur trioxide.
  (i) Name the catalyst used.
  (ii) Explain why a catalyst is used rather than simply raising the temperature.
  (iii) Why is the gaseous mixture passed several times over the catalyst beds?
  (iv) Why is the mixture cooled between each pass over the catalyst?
(d) Sulfur trioxide is passed into concentrated sulfuric acid to form oleum. What is the chemical formula of oleum?
(e) Explain how sulfuric acid is generated from the oleum.

9 Sulfur trioxide was allowed to come to equilibrium with sulfur dioxide and oxygen in a closed 1.4 L vessel at a constant temperature. Analysis of the equilibrium mixture showed the following quantity of each gaseous component:

SO_3: 0.35 mol SO_2: 0.42 mol O_2: 0.28 mol

(a) Calculate the equilibrium constant (K) for the equilibrium

$$2SO_3(g) \rightleftarrows 2SO_2(g) + O_2(g) \qquad \Delta H = +197 \text{ kJ mol}^{-1}$$

(b) Pellets of vanadium(V) oxide catalyst are now added to the equilibrium mixture. What effect will the presence of the catalyst have on the extent of the equilibrium?
(c) How would the value of the equilibrium constant change if the mixture were equilibrated at a higher temperature?

10 It has been suggested that in a future hydrogen economy hydrogen gas could be generated by the reaction of methane with steam at high temperatures.

$$CH_4(g) + H_2O(g) \rightleftarrows CO(g) + 3H_2(g) \qquad \Delta H = +205 \text{ kJ mol}^{-1}$$

Explain how the yield of hydrogen from this process would be affected by the following changes to the reaction conditions:

(a) increasing the temperature of the reaction mixture
(b) increasing the volume of the reaction vessel at constant temperature
(c) removal of the nickel catalyst

11. Figure O1.2 shows the change in concentration of reactants and products as a function of time for the reaction

$$2NH_3(g) \rightleftarrows N_2(g) + 3H_2(g)$$
$$\Delta H = +92.4 \text{ kJ mol}^{-1}$$

The change that occurred at time X was:

(a) the temperature was suddenly increased
(b) additional ammonia was injected into the vessel
(c) the volume of the vessel was suddenly decreased
(d) some nitrogen was removed from the vessel

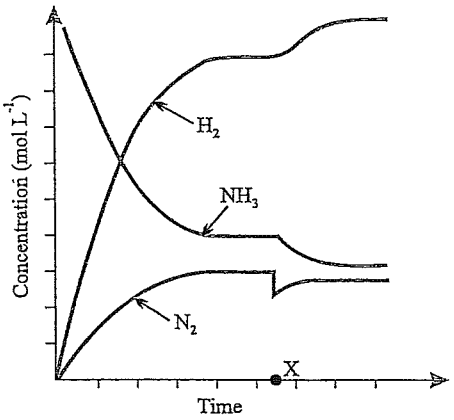

Figure O1.2

12. Figure O1.4 shows a flowchart for the contact process. Various reactants, products or processes are labelled with code letters.

(a) Replace each code letter A–F by the appropriate word.

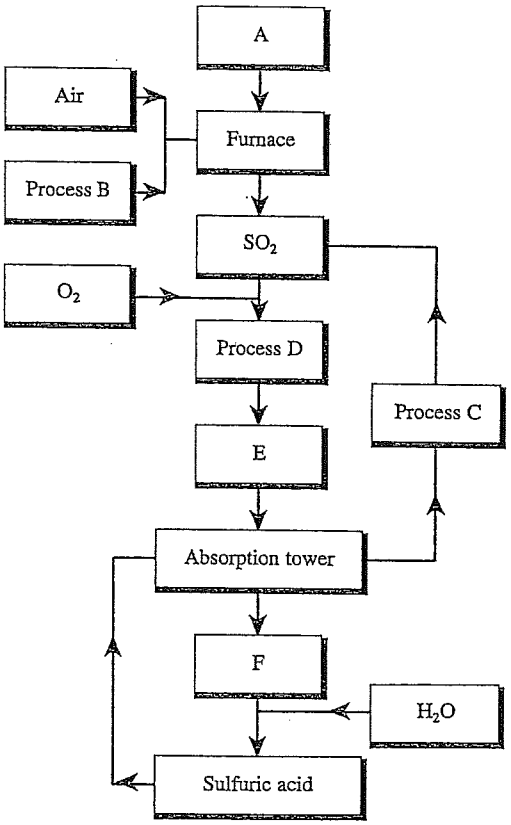

Figure O1.4

13 The Solvay process from the manufacture of sodium carbonate replaced an earlier process called the Le Blanc process. The Le Blanc process involved four steps:

Step 1 Salt was heated with sulfuric acid to produce sodium hydrogen sulfate and hydrogen chloride gas.

Step 2 Salt was further reacted with the sodium hydrogen sulfate at red heat to produce sodium sulfate and hydrogen chloride gas.

Step 3 The sodium sulfate was ground up and mixed with calcium carbonate and a mixture of coal and coke. The mixture was melted in a rotating furnace. The sodium sulfate was reduced by the coke to form sodium sulfide and carbon dioxide. The sodium sulfide formed reacted with the calcium carbonate to form sodium carbonate and calcium sulfide.

Step 4 The mixture was added to water and the insoluble calcium sulfide removed before the filtrate was collected and crystallised to obtain the sodium carbonate.

(a) Write balanced equations for the reactions described in steps 1 and 2.

(b) The hydrogen chloride evolved was passed into water. What valuable product was obtained from this process?

(c) Step 3 involved two reactions. Write balanced equations for these reactions.

(d) The calcium sulfide waste from step 4 was used to extract sulfur. The calcium sulfide is mixed to a paste with carbonated water. Hydrogen sulfide is released and calcium carbonate is formed. The hydrogen sulfide released is mixed with air and passed over iron(III) oxide at red heat. Steam and sulfur vapour form. The sulfur vapour is transferred to another vessel where it condenses.

(i) Write balanced equations for the reactions described.

(ii) What is the likely purpose of the iron(III) oxide?

(e) Suggest a reason why the Solvay process replaced the Le Blanc process for the manufacture of sodium carbonate.