<u>*Chemical equilibria miscellaneous exercise*</u>
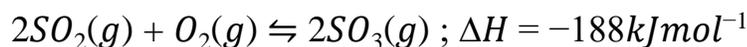
1   (a)   During the manufacture of sulphuric acid by contact process, sulphur dioxide is oxidized to sulphur (VI) oxide according to the following equation.

$$2SO_2(g) + O_2(g) \leftrightharpoons 2SO_3(g) \; ; \; \Delta H = -188 kJmol^{-1}$$

   (b)   State the effect on the yield of sulphur (VI) oxide if

    (i)   Temperature was increased

    (ii)   Pressure was decreased

    (iii)   Concentration of sulphur dioxide was increased

   (c)   Write equation to show how sulphuric acid can be obtained from sulphur(VI) oxide

2   Nitrogen monoxide combines with oxygen according to the following equation

$$N_2(g) + 2O_2(g) \leftrightharpoons 2NO_2(g)$$
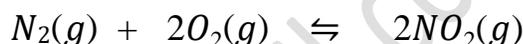
   (a)   Write an expression for the equilibrium constant K_C
   (b)   3.0 moles of nitrogen monoxide and 1.5 moles of oxygen were put in a 1 litre vessel. When equilibrium was attained, the vessel was found to contain 0.5 mole of oxygen. Calculate the equilibrium constant Kc at this temperature.

   (c)   When temperature was raised to 500ºC, the mixture in (b) was found to contain 25% of the initial nitrogen monoxide. Calculate the equilibrium constant Kc at this temperature.
   (d)   From your answers in (b) and (c), deduce whether the process is endothermic or exothermic.

3   Consider the reaction between sulphur dioxide and oxygen to produce sulphur trioxide at 700ºC.

$$2SO_2(g) + O_2(g) \leftrightharpoons 2SO_3(g) \quad \Delta H = -ve$$
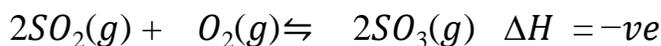
   (a)   Write the expression for the equilibrium constant, Kc, and state its units.
   (b)   What happens to the sulphur trioxide in the equilibrium mixture if,

(i)   Temperature was raised from 700°C to 800°C
(ii) More oxygen is added
(iii) More nitrogen is added
(iv) Volume of the reaction vessel is increased.

(c)   The equilibrium mixture above at 700°C contains 0.4 mol of sulphur dioxide and 0.03 moles of oxygen and 1.00 mole of sulphur trioxide in 20 dm^3 container. Calculate the value of equilibrium constant Kc

4   The reaction between nitrogen and hydrogen takes place as follows.

$$N_2(g) \ + \ 3H_2(g) \ \leftrightharpoons \ 2NH_3(g) \qquad \Delta H = -ve$$

(a)   Write the expression for the equilibrium constant, K, for the forward reaction

(b)   At 500°c, the equilibrium concentration of hydrogen is 0.25moldm^{-3} and that of nitrogen is 0.27moldm^{-3}. Calculate the equilibrium concentration of ammonia at the same temperature given that the equilibrium constant, Kc is 6.0×10^{-2} mol^{-2}dm^6

(c)   What would happen to the ammonia at equilibrium if
(i) Helium was added at a constant pressure
(ii)Temperature was increased

5   (a)   The degree of dissociation of 3.4 mole of hydrogen iodide at 460°C was found to be 20%. Calculate the

(i).   Number of moles of hydrogen iodide, hydrogen and iodine formed at equilibrium

(ii).   Equilibrium constant, KC, for the dissociation reaction.

(b)   A mixture containing 28 moles of hydrogen and 22 moles of iodine was heated in a sealed tube at 460°C until equilibrium was attained when 36 moles of hydrogen iodide was obtained. Calculate the degree of dissociation of hydrogen iodide at 460°C

6   (a)   In the Haber process, ammonia is synthesized from nitrogen and hydrogen.

(i)   Write the equation for the reaction leading to the formation of ammonia

(ii)   Write an expression for the equilibrium constant, Kc.

(b)   When nitrogen was reacted with hydrogen at 690K, the total pressure of the system at equilibrium was 32 atmospheres and the partial pressure of hydrogen and nitrogen were 8 and 3 atmospheres respectively. Calculate the;

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(i). Partial pressure of ammonia in equilibrium mixture
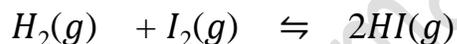
(ii). Equilibrium constant for the reaction

7 Phosphorus(V) chloride decomposes at high temperature according to the following equation

$$PCl_5(g) \leftrightharpoons PCl_3(g) + Cl_2(g)$$

When 40.2 g of phosphorus(V) chloride was placed in 4.5 litre vessel and heated at a certain pressure, 4.2g of chlorine was formed at equilibrium.

(a) Calculate the
   (i) Amount of phosphorus (V) chloride and phosphorus (III) chloride at equilibrium in moles per litre.
   (ii) Equilibrium constant, K , for the reaction and state its units

(b) State how the value of equilibrium constant would be affected and in each case, give a reason for your answer if
   (i) The pressure was increased
   (ii) Some chlorine was removed.

8 Hydrogen and iodine react to form hydrogen iodide according to the equation

$$H_2(g) + I_2(g) \leftrightharpoons 2HI(g)$$

(a) (i) Write an expression for the equilibrium constant, K_C , for the reaction

   (ii) 1 mole of hydrogen and 1 mole of iodine were heated together at 450ºC until equilibrium was attained. Calculate the number of moles of hydrogen iodide present in the equilibrium mixture at 450ºC. (K_C for the reaction between hydrogen and iodine is 50)

(b) Briefly describe how the concentration of iodine in the equilibrium mixture can be determined.

(c) Describe an experiment to determine the equilibrium constant, K_C , for the decomposition of phosphorus(V) chloride

9   (a)   Ethanol reacts with ethanoic acid to form ethylethanoate according to
           the equation

$$CH_3COOH(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH3(l) + H_2O(l) ; \Delta H = -ve$$

           (i)   State the conditions for the reaction
           (ii) Describe how the equilibrium constant, K, for the reaction can
                 be determined by a titrimetric method.
     (b)   Explain what would happen to the equilibrium constant if
           (i) A catalyst was added
           (ii). Temperature was increased
     (c)   A mixture of 0.69g of ethanol and 0.9g of ethanoic acid were
             allowed to react at 90°C until equilibrium was reached. Calculate
             the mass of ethylethanoate formed. (Equilibrium constant, K, for
             the reaction is 3.6)

10   (a)   At a certain temperature, the equilibrium constant for the reaction
           between nitrogen and hydrogen, Kp, is $4.82 \times 10^{-2}\ atm^{-2}$ and the
           partial pressures of nitrogen and hydrogen are 30 and 120 atm
           respectively
                 (i)   Write the expression for the equilibrium constant. Kp,
                        for the   reaction
                 (ii)   Calculate the partial pressure of ammonia at
                        equilibrium

     (b)   1 mole of sulphur trioxide was introduced into a 1dm^3 vessel. The
           vessel was heated to 1000K until equilibrium was attained. At , 0.35
           mol of sulphur trioxide was present.
                 (i)   Write equation for the decomposition of sulphur trioxide
                 (ii)   Write an expression for the equilibrium constant, Kc.
                 (iii) Calculate the value of K.

11   Nitrogen (II) oxide combines with oxygen at 80°C and 200atm to form
   nitrogen (IV) oxide according to the equation.

$$N_2(g) + 2O_2(g) \rightleftharpoons 2NO_2(g) ; \Delta H = -ve$$

     (a)   (i).   Write an expression for the equilibrium constant, Kp, for
                          reaction.

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(ii) Calculate the value of Kp if the mixture contained 67% nitrogen (IV) oxide at equilibrium

(b) State how the value of Kp will be affected if
  (i) Temperature was increased
  (ii) A catalyst was added

12 (a) At 26.7°C, and 25 atmospheres, 20% of phosphorus (V) chloride is dissociated. Calculate
  (i) The partial pressure of each component in the equilibrium mixture
  (ii) The equilibrium constant, Kp, for the reaction
  (iii). The pressure that would be required to increase the dissociation to 30% at the same temperature.

(b) When 0.2 mole of nitrogen and 0.4 mole of hydrogen were introduced in a 1 litre vessel at 300°C and 500 atm equilibrium was attained when 0.18 mole of ammonia was formed. Calculate the equilibrium constant, Kp, for the reaction at this temperature.

(c) When stoichiometric amounts of nitrogen and hydrogen were introduced into a vessel and heated to 250°C and 210 atm, the equilibrium mixture contained 7.5% nitrogen. Calculate the equilibrium constant Kp for the reaction.

(d) When 0.58 moles of nitrogen and 1.03 moles of hydrogen were reacted in a 1liter vessel at 200°C and 350 atm, equilibrium was established when 21.36% of hydrogen had remained. Calculate the value of Kc.

13 (a) Sulphur dioxide decomposes according to the equation when heated
$$2SO_3(g) \leftrightharpoons 2SO_2(g) + O_2(g) ; \quad \Delta H = +ve$$

  (i) State the conditions for the reaction
  (ii) Write an expression for the equilibrium constant for the reaction, Kp

(b) When sulphur trioxide was heated in a closed vessel, at 270°C and 0.25 atmospheres, 46% of sulphur trioxide was decomposed at equilibrium. Calculate the value of Kp

(c) Calculate the heat of decomposition of sulphur trioxide (the heat of formation of sulphur dioxide and trioxide are −279 and −392 $kJmol^{-1}$)

(d)   Explain how the position of the equilibrium, value of equilibrium constant and the rate of attainment of equilibrium would be affected if

  (i).   The temperature of the reaction was increased
  (ii).   The pressure of the reaction was decreased
  (iii).   A catalyst was added to the reaction mixture

14 Nitrogen combines with hydrogen according to the equation
$$N_2(g) + 3H_2(g) \leftrightharpoons 2NH_3(g)$$
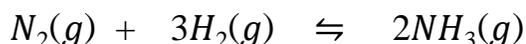
(a)   Find the equilibrium constant, Kp, for the reaction given that the equilibrium mixture contains

  (i). 20% ammonia at 110atm of pressure
  (ii). 50% ammonia at 700 atm of pressure
  (iii). 45% ammonia at 600 atm of pressure

(b)   Find the equilibrium constant, K_C, for the above reaction when

  (i)   0.007 moles of nitrogen and 0.073 moles of hydrogen are heated and at equilibrium 0.01 moles of ammonia were formed

  (ii)   0.2 moles and 0.47 moles of nitrogen and hydrogen respectively when heated to equilibrium in a 1 litre vessel and 0.18 moles of ammonia were formed

  (iii)   0.03 moles of nitrogen and 0.05 moles of hydrogen are heated at equilibrium to from 0.015 moles of ammonia

15 (a).   Discuss the effect of the following on the position of equilibrium of a reversible reaction, the rate of attainment of equilibrium and the value of equilibrium constant.

  (i)   Temperature
  (ii)   Pressure
  (iii)   Catalyst

(b).   Write an expression for the equilibrium constant K_C or Kp as appropriate for the following reactions at equilibrium and indicate the units in each case.
$$2A + B \leftrightharpoons C + 3D$$

  (i).   A, B, C and D are all gases
  (ii).   A, B, C, and D are all liquids
  (iii).   A, B, C are solids and D is a gas

16 (a). Manganese(IV) sulphide reacts with acids according to the equation

$$Mn(s) + 2H_3O^+(aq) \leftrightharpoons Mn^{2+}(aq) + 2H_2O(l) + H_2S(aq)$$
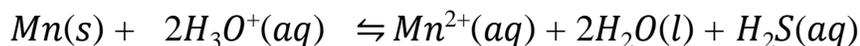
State giving a reason in each case, what would happen to the equilibrium if

(i)   Hydrogen chloride is bubbled in the equilibrium mixture
(ii)   pH of the mixture is increased
(iii) The mixture was diluted with water.

(b) Hydrogen reacts with iodine according to the following equation

$$H_2(g) + I_2(g) \leftrightharpoons 2HI(g)$$

A mixture of 0.8 mole of hydrogen and 0.6 mole of iodine was allowed to react in a sealed tube at 450ºC at equilibrium, 0.2 mole of iodine had reacted.

(i)   Write an expression for the equilibrium constant, K, for the reaction

(ii)   Calculate the value of Kc at 450ºC.

17   (a) In the industrial production of sulphuric acid by contact process, sulphur dioxide is oxidized to sulphur trioxide in the presence of a catalyst according to the equation.

$$2SO_2(g) + O_2(g) \leftrightharpoons 2SO_3(g) \quad \Delta H = -96 \; Kjmol^{-1}$$

(i)   Name the catalyst used in the process
(ii)   Explain why the reaction is carried out at 500ºC
(iii) Sulphuric acid is used in the manufacture of superphosphate fertilizer. Write the equation for the reaction
(iv)   Give one other large scale of sulphuric acid.

(b)   Concentrated sulphuric acid contains 98% of the acid. Calculate the mass of concentrated sulphuric acid required to make 2.0M solution of sulphuric acid.

(c)   Name one reagent that can be used to identify the anion in sulphuric acid. State what would be observed and write the equation for the reaction that takes place when the reagent you have named is used

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