**Kc and Le Chatelier’s principle**

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| **1.** | The reaction for the formation of hydrogen iodide does not go to completion but reaches an equilibrium: H2(g) + I2(g) == 2HI(g)  A mixture of 1.9 mol of H2 and 1.9 mol of I2 was prepared and allowed to reach equilibrium in a closed vessel on 250 cm3 capacity. The resulting equilibrium mixture was found to contain 3.0 mol of HI. Calculate the value of Kc. | |
| **2.** | Consider the equilibrium: N2O4(g) == 2NO2(g).  1 mol of dinitrogen tetroxide, N2O4, was introduced into a vessel of volume 10 dm3. At equilibrium 50% had dissociated. Calculate Kc for the reaction. | |
| **3.** | In an experiment, 9.0 moles of nitrogen and 27 moles of hydrogen were placed into a vessel of volume 10 dm3 and allowed to reach equilibrium. It was found that two thirds of the nitrogen and hydrogen were converted into ammonia. Calculate Kc for the reaction.  N2(g) + 3H2(g) == 2NH3(g) | |
| **4.** | Hydrogen chloride can be oxidised to chlorine by the Deacon process:  4HCl(g) + O2(g) == 2Cl2(g) + 2H2O(g)  0.800 mol of hydrogen chloride was mixed with 0.200 mol of oxygen in a vessel of volume 10 dm3. At equilibrium it was found that the mixture contained 0.200 mol of hydrogen chloride. Calculate Kc for the reaction. | |
| **5.** | A 0.04 sample of SO3 is introduced into a 3.04 dm3 vessel and allowed to reach equilibrium. The amount of SO3 present at equilibrium is found to be 0.0284 mole. Calculate the value of Kc for the reaction 2SO3(g) == 2SO2(g) + O2(g). | |
| **6.** | At 723K, hydrogen and iodine react together and the following equilibrium is established:  H2(g) + I2(g) == 2HI(g)  The value of Kc for this equilibrium is 64. In an experiment, equal amounts of hydrogen and iodine were mixed together, and the equilibrium mixture of the three gases in a container of volume 1 dm3 at 723K was found to contain 1.5 moles of iodine. Calculate the concentration of hydrogen iodide in the mixture at 723K. | |
| **7.** | The expression for an equilibrium constant, *K*c, for a homogeneous equilibrium reaction is given below. | |
|  | (a) | Write an equation for the forward reaction and deduce the units of *K*c |
|  | (b) | State what can be deduced from the fact that the value of *K*c is larger when the equilibrium is established at a lower temperature. |

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| **8.** | A 36.8 g sample of N2O4 was heated in a closed flask of volume 16.0 dm3. An equilibrium was established at a constant temperature according to the following equation.  N2O4(g)  2NO2(g)  The equilibrium mixture was found to contain 0.180 mol of N2O4 | | | |
|  | (a) | Write an expression for *K*c and calculate its value under these conditions. | | |
|  | (b) | Another 36.8 g sample of N2O4 was heated to the same temperature as in the original experiment, but in a larger flask. State the effect, if any, of this change on the position of equilibrium and on the value of *K*c compared with the original experiment. | | |
| **9.** | The diagram below shows the effect of temperature and pressure on the equilibrium yield of the product in a gaseous equilibrium. | | | |
|  | (a) | Use the diagram to deduce whether the forward reaction involves an increase or a decrease in the number of moles of gas. Explain your answer. | | |
|  | (b) | Use the diagram to deduce whether the forward reaction is exothermic or endothermic. Explain your answer. | | |
| **10.** | When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm3, the following equilibrium was established at 700 K.  2HI(g)   H2(g) + I2(g)  The equilibrium mixture was found to contain 0.023 mol of hydrogen. | | | |
|  | (a) | Write an expression for *K*c for the equilibrium and calculate its value at 700 K | | |
|  | (b) | Explain why the volume of the flask need not be known when calculating a value for *K*c. | | |
|  | (c) | Calculate the value of *K*c at 700 K for the equilibrium  H2(g) + I2(g)  2HI(g) | | |
| **11.** | A mixture was prepared using 1.00 mol of propanoic acid, 2.00 mol of ethanol and 5.00 mol of water. At a given temperature, the mixture was left to reach equilibrium according to the following equation.  CH3CH2COOH + CH3CH2OH  CH3CH2COOCH2CH3 + H2O       ∆*H*~~ο~~= –22 kJ mol–1  The equilibrium mixture contained 0.54 mol of the ester ethyl propanoate. | | | |
|  | (a) | Write an expression for the equilibrium constant, *K*c, for this equilibrium. Calculate its value at this temperature and explain why this value has no units. | | |
|  | (b) | For this equilibrium, predict the effect of an increase in temperature on each of the following. | | |
|  |  | (i) | the amount, in moles, of ester at equilibrium | |
|  |  | (ii) | the time taken to reach equilibrium | |
|  |  | (iii) | the value of *K*c | |
| **12.** | At high temperatures, nitrogen is oxidised by oxygen to form nitrogen monoxide in a reversible reaction as shown in the equation below.  N2(g)  + O2(g)  2NO(g)        ∆*H*~~ο~~   =   +180 kJ mol–1  State and explain the effect of an increase in pressure, and the effect of an increase in temperature, on the yield of nitrogen monoxide in the above equilibrium. | | |
| **13.** | Sulphur dioxide and oxygen were mixed in a 2:1 mol ratio and sealed in a flask with a catalyst. The following equilibrium was established at temperature *T*1  2SO2(g) + O2(g)    2SO3(g)              Δ*H* =  –196 kJ mol–1 | | |
|  | (a) | When equilibrium was established at a different temperature, *T*2, the value of *K*p was found to have increased. State which of *T*1 and *T*2 is the lower temperature and explain your answer. | |
|  | (b) | In a further experiment, the amounts of sulphur dioxide and oxygen used, the catalyst and the temperature, *T*1, were all unchanged, but a flask of smaller volume was used.  Deduce the effect of this change on the yield of sulphur trioxide and on the value of *K*c. | |
| **14.** | When heated above 100 °C, nitrosyl chloride (NOCl) partly decomposes to form nitrogen monoxide and chlorine as shown in the equation.  2NOCl(g)   2NO(g) + Cl2(g) | | |
|  | (a) | A 2.50 mol sample of NOCl was heated in a sealed container of volume 5 dm3 and equilibrium was established at a given temperature. The equilibrium mixture formed contained 0.80 mol of NO. Calculate the value of Kc for this equilibrium mixture. | |
|  | (b) | A different mixture of NOCl, NO and Cl2 reached equilibrium in a sealed container of volume 15.0 dm3. The equilibrium mixture formed contained 1.90 mol of NOCl and 0.86 mol of NO at temperature *T*. The value of *K*c for the equilibrium at temperature *T* was 7.4 × 10−3 mol dm−3. Calculate the amount, in moles, of Cl2 in this equilibrium mixture. | |
|  | (c) | Consider this alternative equation for the equilibrium at temperature *T*.  NOCl(g)   NO(g) + ½ Cl2(g)  Calculate a value for the different equilibrium constant *K*c for the equilibrium as shown in this alternative equation. Deduce the units of this *K*c | |
| **15.** |  | A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume V dm3. The mixture was left to reach equilibrium as shown by the following equation.   |  |  |  |  |  | | --- | --- | --- | --- | --- | | H2(g) | + | l2(g) |  | 2Hl(g) |   At a given temperature, the equilibrium mixture contained 2.06 mol of hydrogen iodide.  Calculate the value of Kc for this reaction at this temperature. | |

**Kp**

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| **16.** | Consider the equilibrium: N2O4(g)2NO2(g).  1 mol of dinitrogen tetroxide, N2O4, was introduced into a vessel. At equilibrium at a constant pressure of 100 kPa, 50% had dissociated. Calculate Kp for the reaction. | |
| **17.** | Hydrogen chloride can be oxidised to chlorine by the Deacon process:  4HCl(g) + O2(g)2Cl2(g) + 2H2O(g)  0.800 mol of hydrogen chloride was mixed with 0.200 mol of oxygen at a constant pressure of 100 kPa. At equilibrium it was found that the mixture contained 0.200 mol of hydrogen chloride. Calculate Kp for the reaction. | |
| **18.** | In an experiment, 9.0 moles of nitrogen and 27 moles of hydrogen were p and allowed to reach equilibrium at a constant pressure of 25 Mpa. It was found that two thirds of the nitrogen and hydrogen were converted into ammonia. Calculate Kp for the reaction.  N2(g) + 3H2(g)2NH3(g) | |
| **19.** | A 0.04 sample of SO3 is allowed to reach equilibrium at a constant pressure of 200 kPa. The amount of SO3 present at equilibrium is found to be 0.0284 mole. Calculate the value of Kp for the reaction 2SO3(g)2SO2(g) + O2(g). | |
| **20.** | The reaction between carbon monoxide and hydrogen proceeds according to the equilibrium CO(g) + 2H2(g)CH3OH(g) A vessel contains 0.1 mole of carbon monoxide. After 0.3 mole of hydrogen is added, 0.06 mol of methanol are formed. The pressure was kept constant at 300 kPa. Calculate the equilibrium constant Kp. | |
| **21.** | For the general reaction aA + bBcC + dD, derive an expression for Kp in terms of Kc, R, T and Δn (c + d – a -b) | |
| **22.** | A sealed flask containing gases **X** and **Y** in the mole ratio 1:3 was maintained at 600 K until the following equilibrium was established: X(g) + 3Y(g)  2Z(g)  The partial pressure of **Z** in the equilibrium mixture was 6.0 MPa when the total pressure was 22.0 MPa. Calculate the value of Kp for the reaction. | |
| **23.** | Sulphur dioxide and oxygen were mixed in a 2:1 mol ratio and sealed in a flask with a catalyst.  The following equilibrium was established at temperature *T*1:  2SO2(g) + O2(g)    2SO3(g)              Δ*H* =  –196 kJ mol–1 | |
|  | (a) | The partial pressure of sulphur dioxide in the equilibrium mixture was 24 kPa and the total pressure in the flask was 104 kPa. Calculate the value of Kp for the reaction. |
|  | (b) | When equilibrium was established at a different temperature, *T*2, the value of *K*p was found to have increased. State which of *T*1 and *T*2 is the lower temperature and explain your answer. |
|  | (c) | In a further experiment, the amounts of sulphur dioxide and oxygen used, the catalyst and the temperature, *T*1, were all unchanged, but a flask of smaller volume was used.  Deduce the effect of this change on the yield of sulphur trioxide and on the value of *K*p. |

**Heterogeneous equilibria and Ksp**

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| **24.** | Consider the following equilibrium: CaCO(s)CaO(s) + CO2(g). At 1073 K, the partial pressure of CO2 is found to be 23.6 kPa. Calculate Kp and Kc for the reaction at this temperature. | |
| **25.** | Consider the following equilibrium: NH4HS(s)NH3(g) + H2S(g). At 295 K, the partial pressure of each gas is 26.5 kPa. Calculate Kp and Kc for the reaction at this temperature. | |
| **26.** | Consider the following equilibrium: NH4CO2NH2(s)2NH3(g) + CO2(g). A solid sample of NH4CO2NH2 was allowed to decompose to equilibrium in an evacuated container. The total gas pressure was found to be 36.3 kPa. Calculate Kp for the reaction. | |
| **27.** | (a) | Calculate the value of Ksp for calcium sulphate (CaSO4) given that its solubility at 25 oC is 0.67 gdm-3. |
|  | (b) | Calculate the value of Ksp for PbCl2 given that its solubility is 0.011 moldm-3. |
|  | (c) | The Ksp of silver bromide (AgBr) is 7.7 x 10-13 mol2dm-6. Deduce the molar solubility of silver bromide. |
|  | (d) | The Ksp of copper hydroxide Cu(OH)2 is 2.2 x 10-20 mol3dm-9. Deduce the molar solubility of copper hydroxide. |
| **28.** | (a) | The Ksp of barium sulphate (BaSO4) is 1.1 x 10-10 mol2dm-6. Deduce whether or not a precipitate will form if 200 cm3 of 0.0040 moldm-3 BaCl2 is mixed with 600 cm3 of 0.0080 moldm-3 K2SO4. |
|  | (b) | The Ksp of calcium hydroxide Ca(OH)2 is 8.0 x 10-6 mol2dm-6. Deduce whether or not a precipitate will form if 2.0 cm3 of 0.20 moldm-3 NaOH is mixed with 1.0 cm3 of 0.10 moldm-3 CaCl2. |
| **29.** | Silver nitrate is slowly added to a solution that contains 0.020 moldm-3 Cl- and Br-. Ksp of AgCl = 1.6 x 10-10 mol2dm-6 and Ksp of AgBr = 7.7 x 10-13 mol2dm-6. | |
|  | (a) | Calculate the concentration range of Ag+ ions which could separate Br- and Cl- in solution by precipitating AgBr but not AgCl. |
|  | (b) | What is the concentration of Br- ions in the solution just before AgCl begins to precipitate? |
| **30.** | (a) | Calculate the solubility of AgCl in a 6.5 x 10-3 moldm-3 solution of AgNO3. The Ksp of AgCl = 1.6 x 10-10 mol2dm-6 |
|  | (b) | Calculate the solubility of AgBr in a 1.0 x 10-3 moldm-3 solution of NaBr. The Ksp of AgBr is 7.7 x 10-13 mol2dm-6. |
| **31.** | 75 cm3 of 0.060 moldm-3 NaF is added to 25 cm3 of 0.15 moldm-3 Sr(NO3)2. The solubility product of SrF2 is 2.0 x 10-10 mol3dm-9. Deduce the concentration of Na+, F-, Sr2+ and NO3- in the resulting solution. | |
| **32.** | Ba2+ ions are highly toxic. Barium compounds, however, are very useful for medical X-ray analysis. Patients are typically given 20 g of BaSO4 (Ksp = 1.1 x 10-10 mol2dm-6). Calculate the concentration of Ba2+ ions when this is mixed with 5.0 dm3 of a patient’s blood. | |

# Acid-Base Equilibria and pH (Kw = 1.0 x 10-14 mol2dm-6)

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| **33.** | For each of the following equilibria, identify the conjugate acid base pairs by labelling each species as Acid 1, Base 1, Acid 2 or Base 2 | | |
|  | (a) | H2O(l) + NH3(aq)NH4+(aq) + OH-(aq) | |
|  | (b) | CH3COOH(aq) + H2O(aq)CH3COO-(aq) + H3O+(aq) | |
|  | (c) | H2SO4(aq) + HNO3(aq)HSO4-(aq) + H2NO3+(aq) | |
|  | (d) | 2H2O(l)H3O+(aq) + OH-(aq) | |
|  | (e) | HCO3-(aq) + H3O+(aq)CO2(g) + H2O(l) + H2O(l) | |
| **34.** | (a) | Calculate the pH of the following solutions: | |
|  |  | (i) | 0.10 moldm-3 C6H5COOH (Ka of benzoic acid = 6.3 x 10-5 moldm-3) |
|  |  | (ii) | 0.05 moldm-3 NaHSO4 (Ka of HSO4- = 1.0 x 10-2 moldm-3) |
|  | (b) | Calculate the molarity of a solution of HCOOH (Ka = 1.6 x 10-4 moldm-3) which has a pH of 3.0 | |
|  | (c) | The pH of a 0.10 moldm-3 solution of a weak monoprotic acid, HA is 2.85. Determine the Ka of the acid. | |
|  | (d) | A 500 cm3 solution containing 1.9g of a weak acid HA has a pH of 3.5. Calculate the molar mass of the acid, given that it has a Ka of 2.0 x 10-6 moldm-3. | |
| **35.** | Pure water at 40 oC has a pH of 6.7 | | |
|  | (a) | Calculate the ionic product of water at 40 oC | |
|  | (b) | Deduce whether the auto-ionisation of water is endothermic or exothermic | |
| **36.** | Calculate the pH of the following solutions: | | |
|  | (a) | 0.02 moldm-3 Ba(OH)2. | |
|  | (b) | 0.1 moldm-3 NH3 (Kb of NH3 = 1.8 x 10-5 moldm-3) | |
|  | (c) | The solution formed after the addition of 50.0 cm3 of 0.150 moldm-3 NaOH to 25.0 cm3 of 0.06 moldm-3 HCl. | |
| **37.** | (a) | Given that the Kb for NH3 is 1.8 x 10-5 moldm-3, calculate the pH of 0.1 moldm-3 NH4Cl. | |
|  | (b) | Given that the Ka for CH3COOH is 1.7 x 10-5 moldm-3, calculate the pH of 0.25 moldm-3 CH3COONa. | |
|  | (c) | Calculate the molarity of a solution of KCN which has a pH of 11.0, given that the Ka for HCN is 4.9 x 10-10 moldm-3 | |
| **38.** | (a) | Calculate the pH of 2 x 10-8 moldm-3 H2SO4 | |
|  | (b) | Calculate the pH of the solution formed when 0.1 g of NaOH is dropped into a tank containing 5 m3 of water. | |

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| **39.** | (a) | A saturated solution of calcium hydroxide (limewater) at 25 oC has a pH of 11.5. Calculate the solubility product for calcium hydroxide at 25 oC. |
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