25. Equilibria

25.1 Acids and bases

Paper 4

Question Paper

1 (b) Barium hydroxide, $Ba(OH)_2$, is a strong base.

A 250.0 cm^3 solution of $Ba(OH)_2$ with a pH of 12.2 is made by dissolving $Ba(OH)_2$ in distilled water.

Calculate the mass of $Ba(OH)_2$ required to make this solution.

Show your working.

[M_r: $Ba(OH)_2$, 171.3]

mass of $Ba(OH)_2$ = ... g [4]

(c) The solubility of iron(II) hydroxide, $Fe(OH)_2$, is 5.85×10^{-6} mol dm^{-3} at 298 K.

(i) Write the expression for the solubility product, K_{sp}, of $Fe(OH)_2$.

K_{sp} =

[1]

(ii) Calculate the value of K_{sp} of $Fe(OH)_2$. Include its units.

K_{sp} = ...

units = ...
[2]

2 **(f)** Buffer solutions are used to regulate pH.
Write **two** equations to describe how a solution containing $HC_2O_4^-$ ions acts as a buffer solution when small amounts of acid or alkali are added.

....

.... [2]

3 **(a)** Aqueous solutions of methanoic acid, HCOOH, and propanoic acid, CH_3CH_2COOH, are mixed together.

An equilibrium is set up between two conjugate acid–base pairs.

(i) Define conjugate acid–base pair.

....

.... [1]

(ii) The pK_a of HCOOH is 3.75 and of CH_3CH_2COOH is 4.87.

Complete the equation for the Brønsted–Lowry equilibrium between the stronger of these two acids and water.

.... + $H_2O \rightleftharpoons$ .... + ...

[1]

(b) **(i)** Write an expression for the acid dissociation constant, K_a, for butanoic acid, $CH_3CH_2CH_2COOH$.

K_a =

[1]

(ii) The pK_a of $CH_3CH_2CH_2COOH$ is 4.82.

A solution of $CH_3CH_2CH_2COOH(aq)$ has a pH of 3.25.

Calculate the concentration, in mol dm^{-3}, of $CH_3CH_2CH_2COOH$ in this solution.

concentration of $CH_3CH_2CH_2COOH$ = ... mol dm^{-3} [2]

(c) **(i)** Define buffer solution.

....

....

.... [2]

(ii) A buffer solution containing a mixture of CH_3COOH and CH_3COONa is prepared as follows.

A solution of 600 cm^3 of CH_3COOH is mixed with 400 cm^3 of 0.125 mol dm^{-3} CH_3COONa.

The buffer solution has pH 5.70. The K_a of CH_3COOH is 1.78×10^{-5} mol dm^{-3}.

Calculate the initial concentration, in mol dm^{-3}, of CH_3COOH used.

concentration of CH_3COOH = ... mol dm^{-3} [3]

4 **(a)** The pH of a saturated solution of calcium hydroxide is 12.35 at 298 K.

(i) Show that the concentration of hydroxide ions in a saturated solution of calcium hydroxide is 0.0224 mol dm^{-3} at 298 K.

[2]

(ii) Use data given in **(i)** to calculate the solubility product, K_{sp}, of calcium hydroxide at 298 K.

Include the units of K_{sp} in your answer.

K_{sp} = ... units .... [3]

(iii) A spatula measure of solid calcium chloride is stirred into a sample of saturated calcium hydroxide solution. All of the calcium chloride dissolves.

Describe **one** other observation that would be made and give an estimated value of the pH of the solution obtained.

Explain **both** your answers.

observation ....

pH of solution ....

explanation ....

....

[3]

(iv) Calcium hydroxide reacts with dilute sulfuric acid to form calcium sulfate. Barium hydroxide behaves in a similar way, forming barium sulfate.

Explain why calcium sulfate is more soluble in water than barium sulfate.

....

....

....

....

.... [3]

(b) Some solid calcium is added to an excess of aqueous ethanoic acid, CH_3COOH, and left until all the calcium has reacted. The resulting mixture, mixture **D**, contains no undissolved solids.

(i) Write an equation for the reaction of calcium with CH_3COOH.

.... [1]

(ii) Use formulae of molecules and ions to identify **two** conjugate acid–base pairs present in mixture **D**.

Pair 1 should consist of organic species.

pair 1: ....

conjugate acid conjugate base

pair 2: ....

conjugate acid conjugate base

[2]

(iii) Write the expression for the K_a of CH_3COOH.

K_a =

[1]

(iv) The concentration of calcium ethanoate, $(CH_3COO)_2Ca$, in mixture **D** is 0.394 mol dm^{-3}. The concentration of CH_3COOH in mixture **D** is 0.270 mol dm^{-3}.

The K_a of CH_3COOH is 1.74×10^{-5} mol dm^{-3} at 298 K.

Calculate the pH of mixture **D**.

pH = ... [2]

(v) Write **two** equations to show how mixture **D** can act as a buffer solution.

equation 1 ....

equation 2 ....

[2]

5 **(e)** Isocyanic acid, HNCO, is a weak acid.

$$HNCO + H_2O \rightleftharpoons H_3O^+ + NCO^- \qquad pK_a = 3.70 \text{ at } 25\,°C$$

(i) Write the mathematical expressions for pK_a and pH.

pK_a = ...

pH = ... [1]

(ii) Calculate the pH of 0.120 mol dm^{-3} HNCO(aq).
Give your answer to **three** significant figures.

pH = ... [2]

(iii) Calculate the percentage of HNCO molecules that are ionised in 0.120 mol dm^{-3} HNCO.

percentage ionisation of HNCO = ... [1]

6 **(b)** The amino acid alanine, $H_2NCH(CH_3)COOH$, can act as a buffer.

(i) Define a buffer solution.

....

....

.... [2]

(ii) Write **two** equations to show how an aqueous solution of alanine can act as a buffer solution.

....

.... [2]

7 **(e)** Silver sulfite, $Ag_2SO_3(s)$, is sparingly soluble in water.

(i) Give an expression for the solubility product, K_{sp}, of Ag_2SO_3.

K_{sp} =

[1]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2SO_3 at 298 K.

[K_{sp}: Ag_2SO_3, $1.50 \times 10^{-14}\ mol^3\,dm^{-9}$ at 298 K]

$[Ag^+]$ = ... mol dm^{-3} [1]

8 **(a)** Define K_w mathematically by completing the expression.

K_w = ... [1]

(b) Two solutions, **V** and **W**, are described.

- **V** is HC*l*(aq).
- **W** is NaOH(aq).
- The concentration of HC*l* in **V** is the same as the concentration of NaOH in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

(i) Calculate the concentration of HC*l* in **V**.

concentration of HC*l* in **V** = ... mol dm^{-3} [2]

(ii) Equal volumes of the two solutions **V** and **W** are mixed, giving solution **X**.

Name solution **X** and state its pH.

solution **X** .... pH ....

[1]

(iii) A 1 cm^3 sample of 1.0 mol dm^{-3} HNO_3 is added to 100 cm^3 of solution **X**, forming mixture **Y**.

A 1 cm^3 sample of 1.0 mol dm^{-3} KOH is added to 100 cm^3 of solution **X**, forming mixture **Z**.

Estimate the pH of mixtures **Y** and **Z**. No calculations are required.

mixture **Y** .... mixture **Z** ....

[1]

(c) **(i)** CH_3CH_2COOH, CH_3CCl_2COOH and H_2SO_4 are all acidic.

Suggest the trend in the relative acid strength of these three compounds.

Explain your answer.

....	....	....
strongest acid		weakest acid

explanation ....

....

....

....

....

[3]

(ii) When concentrated H_2SO_4 is added to water a series of acid-base reactions occurs.

There are three conjugate acid-base pairs that can be identified during this series of reactions.

Write the formulae of these three conjugate acid-base pairs.

conjugate acid 1 .... conjugate base 1 ....

conjugate acid 2 .... conjugate base 2 ....

conjugate acid 3 .... conjugate base 3 ....

[2]

9 Benzoic acid, C_6H_5COOH, is a weak acid. The K_a of benzoic acid is 6.31×10^{-5} mol dm^{-3} at 298 K.

A 1.00 dm^3 buffer solution is made at 298 K containing 1.00 g of C_6H_5COOH and a slightly greater mass of sodium benzoate, $C_6H_5COO^-Na^+$.

This buffer solution has a pH of 4.15.

(a) Define buffer solution.

....

.... [1]

(b) Write equations to show how this solution acts as a buffer solution when the named substances are added to it:

(i) dilute aqueous sodium hydroxide

.... [1]

(ii) dilute aqueous nitric acid.

.... [1]

(c) Calculate the H^+ concentration and the C_6H_5COOH concentration in the buffer solution described. Use the expression for the K_a of C_6H_5COOH to calculate the concentration of $C_6H_5COO^-Na^+$ in the buffer solution.

Show your working and give each answer to a minimum of **three** significant figures.

$[H^+]$ = ... mol dm^{-3}

$[C_6H_5COOH]$ = ... mol dm^{-3}

$[C_6H_5COO^-Na^+]$ = ... mol dm^{-3}
[3]

(d) A 10.0 cm^3 sample of the buffer solution is mixed with 10.0 cm^3 of 1.00 mol dm^{-3} KOH. Both solutions are at 298 K. A reaction is allowed to occur without stirring.

Two observations are recorded:

- the temperature, after the reaction is complete, is fractionally above 298 K
- the pH, after the reaction, is greater than 13.

Explain these two observations.

....

....

.... [2]

(e) Magnesium benzoate, $Mg(C_6H_5COO)_2$, has a solubility in water of less than 1.00 g dm^{-3} at 298 K.

$$K_{sp} = [Mg^{2+}][C_6H_5COO^-]^2 = 1.76 \times 10^{-7} \text{ at } 298\,K$$

(i) Calculate the solubility of $Mg(C_6H_5COO)_2$ in water at 298 K. Give your answer in g dm^{-3}.

Show your working.

[M_r: $Mg(C_6H_5COO)_2$, 266.3]

solubility = ... g dm^{-3} [2]

(ii) An excess of $Mg(C_6H_5COO)_2$ is added to a sample of 0.50 mol dm^{-3} $MgSO_4$ at 298 K.

State whether the equilibrium concentration of $Mg(C_6H_5COO)_2$ is higher than, the same as, or lower than your answer to **(i)**. Explain your answer.

The concentration is .... the concentration in **(i)**.

explanation ....

....
[1]

10 **(c)** The solubility product, K_{sp}, of $BaSO_4$ is $1.08 \times 10^{-10}\,mol^2\,dm^{-6}$ at 298 K.

Calculate the solubility of $BaSO_4$ in g per $100\,cm^3$ of solution.

solubility of $BaSO_4$ = ... g per $100\,cm^3$ of solution
[2]

11 **(b)** The solubility of $Be(OH)_2$ in water is $2.40 \times 10^{-6}\,g\,dm^{-3}$ at 298 K.

(i) Write an expression for the solubility product, K_{sp}, of $Be(OH)_2$ and state its units.

K_{sp} =

units = ...
[2]

(ii) Calculate the numerical value of K_{sp} for $Be(OH)_2$ at 298 K.

K_{sp} = ... [2]

12 **(c)** The buffer system in seawater contains a mixture of HCO_3^- and H_2CO_3.

equilibrium **5** $H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$

(i) Define a buffer solution.

....

....

.... [2]

(ii) Construct **two** equations to show how equilibrium **5** acts as a buffer solution.

....

.... [2]

(iii) The $[HCO_3^-]/[H_2CO_3]$ ratio in a sample of seawater is 14.1.

Calculate the pH of this sample.
[pK_a: H_2CO_3, 6.35]

pH = ... [3]

13 **(b)** An aqueous solution of butanoic acid can be used to make a buffer solution.

(i) Define buffer solution.

....

.... [1]

(ii) Suggest one organic compound, and one inorganic compound, that can be added to two different samples of aqueous butanoic acid to produce buffer solutions.

organic compound ....

inorganic compound ....

[1]

(c) The solubility of aluminium hydroxide, $\mathrm{A}l(\mathrm{OH})_3$, in water is $2.47 \times 10^{-9}\,\mathrm{mol\,dm^{-3}}$.

(i) Give the expression for the solubility product, K_{sp}, of aluminium hydroxide.

K_{sp} =

[1]

(ii) Calculate the numerical value of the K_{sp} of aluminium hydroxide. Include the units of K_{sp} in your answer.

K_{sp} = ...

units = ...

[3]

14 **(a)** The value of the solubility product, K_{sp}, of iron(III) hydroxide, $Fe(OH)_3$, is given by the following expression.

$$K_{sp} = [Fe^{3+}][OH^-]^3 = 2.0 \times 10^{-39}\, mol^4\, dm^{-12}$$

(i) Calculate the solubility of $Fe(OH)_3$ in water.

solubility = ... $mol\, dm^{-3}$ [1]

(ii) Calculate the solubility of $Fe(OH)_3$ in 0.010 $mol\, dm^{-3}$ barium hydroxide, $Ba(OH)_2(aq)$.

solubility = ... $mol\, dm^{-3}$ [2]

(iii) $Fe(OH)_3$ is less soluble in $Ba(OH)_2(aq)$ than it is in pure water.

Name this effect.

.... [1]

(b) The numerical value of the K_a of HBrO is 2.00×10^{-9}.

X is a solution of HBrO which contains 4.00×10^{-3} mol of HBrO in 100 cm^3 of solution. In this solution the following equilibrium is established in which there are two conjugate acid-base pairs.

$$HBrO + H_2O \rightleftharpoons BrO^- + H_3O^+$$

(i) Define conjugate acid-base pair.

....

.... [1]

(ii) Identify the two conjugate acid-base pairs shown in the equation above.

pair one	.... acid	.... base
pair two	.... acid	.... base

[1]

(iii) Calculate the pH of solution **X**. Show all your working.

pH = ... [2]

(iv) A solution containing 2.00 × 10^{-3} mol of NaOH is added to solution **X**. A buffer solution is formed.

Calculate the pH of this buffer solution.

pH = ... [1]

15 **(d)** Barium hydroxide, $Ba(OH)_2$, is completely dissociated in aqueous solution.

Calculate the pH of 0.120 mol dm^{-3} $Ba(OH)_2$(aq) at 298 K.

pH = ... [2]

16 Solution **Y** is hydrochloric acid, $HCl(aq)$. Solution **Z** is aqueous 4-chlorobutanoic acid, $Cl(CH_2)_3CO_2H(aq)$. The pK_a of $Cl(CH_2)_3CO_2H(aq)$ is 4.52. The pH of both solutions is 4.00.

(a) (i) Write an expression for the K_a of $Cl(CH_2)_3CO_2H(aq)$.

$K_a =$

[1]

(ii) Write a mathematical expression to describe the relationship between K_a and pK_a.

.... [1]

(iii) Calculate $[H^+]$ in solutions **Y** and **Z**.

$[H^+] =$ .... $mol\,dm^{-3}$ [1]

(iv) Calculate the ratio $\dfrac{[HCl]\text{ dissolved in solution }\mathbf{Y}}{[Cl(CH_2)_3CO_2H]\text{ dissolved in solution }\mathbf{Z}}$.

$\dfrac{[HCl]\text{ dissolved in solution }\mathbf{Y}}{[Cl(CH_2)_3CO_2H]\text{ dissolved in solution }\mathbf{Z}} =$ .... [2]

(b) A buffer solution of pH 5.00 is produced by adding sodium propanoate to 5.00 g of propanoic acid in $100\,cm^3$ of distilled water.

Calculate the mass of sodium propanoate that must be used to produce this buffer solution. The K_a of propanoic acid is $1.35 \times 10^{-5}\,mol\,dm^{-3}$.

[M_r: propanoic acid, 74.0; sodium propanoate, 96.0]

mass of sodium propanoate = ... g [3]

(c) Some dilute sulfuric acid is mixed with a small sample of the buffer solution described in **(b)**. The final pH of the mixture is close to 1.

Explain this observation.

....

....

....

.... [2]

17 Ethoxyethane, $C_2H_5OC_2H_5$, can dissolve both in water and in octan-1-ol. The expression and numerical value for the partition coefficient of ethoxyethane between water and octan-1-ol are given. Water and octan-1-ol are immiscible.

$$K_{pc} = \frac{\text{concentration of } C_2H_5OC_2H_5 \text{ in octan-1-ol}}{\text{concentration of } C_2H_5OC_2H_5 \text{ in water}} = 6.760 \text{ at } 20\,°C$$

(c) An aqueous solution of lead(II) nitrate is mixed with an aqueous solution of sodium iodide. A yellow precipitate of lead(II) iodide is formed and is filtered out, leaving solution **X**.

The concentration of Pb^{2+} in solution **X** is $5.68 \times 10^{-3}\,\text{mol dm}^{-3}$.

The concentration of I^- in solution **X** is $4.20 \times 10^{-4}\,\text{mol dm}^{-3}$.

(i) Use these data to calculate a value for the solubility product, K_{sp}, of lead(II) iodide.

State the units of K_{sp}.

K_{sp} = ...

units = ...
[2]

(ii) Potassium iodide is very soluble in water.

Describe and explain what is seen if a few drops of saturated potassium iodide solution are added to a portion of solution **X**.

....

....

.... [2]

18 **(a)** Compare and explain the relative acidities of 2-chloropropanoic acid, 3-chloropropanoic acid, and propanoic acid. Explain your answer.

.... > .... > ....

(b) **(i)** The numerical values of K_a for methanoic acid, HCO_2H, and pyruvic acid, CH_3COCO_2H, are given.

acid	K_a
HCO_2H	1.78×10^{-4}
CH_3COCO_2H	4.07×10^{-3}

An equilibrium mixture containing the two acid-base pairs is formed.

$$HCO_2^- + CH_3COCO_2H \rightleftharpoons HCO_2H + CH_3COCO_2^-$$

Use the K_a values to calculate the equilibrium constant, K_{eq}, for this equilibrium.

K_{eq} = ... [1]

(ii) Use your value of K_{eq} to predict the position of this equilibrium. Indicate this by placing a tick (✓) in the appropriate box in the table. Explain your answer.

equilibrium lies to the left	equilibrium lies in the middle	equilibrium lies to the right

....

....
[1]

(iii) Ethanedioic acid, HO_2CCO_2H, has two dissociation constants, K_{a1} and K_{a2}, whose pK_a values are 1.23 and 4.19.

Suggest equations to show the two dissociations that give rise to these pK_a values.

pK_{a1} 1.23 ....

pK_{a2} 4.19 ....
[2]

(iv) State the mathematical relationship between pK_a and the acid dissociation constant K_a.

.... [1]

19 **(g)** The ionic product, K_w, for D_2O has a value of 1.35×10^{-15} mol^2 dm^{-6} at 298 K.

(i) Write the expression for the K_w of D_2O.

K_w =

[1]

(ii) Calculate the pH of pure, neutral D_2O at 298 K.
Assume $[D^+]$ is equivalent to $[H^+]$ for pH calculations.

pH = ... [2]

20 **(a)** Silver carbonate, Ag_2CO_3, is sparingly soluble in water. The numerical value of the solubility product, K_{sp}, for silver carbonate is 6.3×10^{-12} at 25 °C.

(i) Write an expression for the solubility product, K_{sp}, of Ag_2CO_3, and state its units.

K_{sp} =

units = ...
[2]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2CO_3 at 25 °C.

$[Ag^+]$ = ... mol dm^{-3} [1]

(iii) Solid Ag_2CO_3 is stirred at 25 °C with 0.050 mol dm^{-3} $AgNO_3$ until no more Ag_2CO_3 dissolves.

Calculate the concentration of carbonate ions, $[CO_3^{2-}]$, in this solution.

$[CO_3^{2-}]$ = ... mol dm^{-3} [1]

21 **(a)** Explain what is meant by the term *buffer solution*.

....

....

.... [2]

(b) **(i)** Write an expression for the acid dissociation constant, K_a, for ammonium ions, $NH_4^+(aq)$.

$K_a =$

[1]

(ii) Write **two** equations to describe how a solution containing ammonium ions, $NH_4^+(aq)$, and ammonia, $NH_3(aq)$, can act as a buffer.

....

.... [2]

(iii) The numerical value of K_a for $NH_4^+(aq)$ is 5.6×10^{-10} at 298 K.
A buffer solution was prepared by adding 0.80 dm^3 of 0.25 mol dm^{-3} ammonia, an excess, to 0.20 dm^3 of 0.20 mol dm^{-3} hydrochloric acid.

Calculate the pH of the buffer solution formed at 298 K.

pH = ... [3]

22 **(d)** Calcium iodate(V), $Ca(IO_3)_2$, is sparingly soluble in water.
The concentration of its saturated solution is 5.6×10^{-3} mol dm^{-3} at 298 K.

(i) Write an expression for the solubility product, K_{sp}, of $Ca(IO_3)_2$, and state its units.

K_{sp} =

units = ... [2]

(ii) Calculate the numerical value for K_{sp} $Ca(IO_3)_2$ at 298 K.

K_{sp} = ... [1]

(iii) When a few cm^3 of concentrated $Ca(NO_3)_2(aq)$ is added to a saturated solution of $Ca(IO_3)_2$ a white precipitate forms.

Identify the white precipitate and give an explanation for this observation.

....

....

.... [2]

23 **(e)** Phenolphthalein is an indicator and is represented by the formula HIn.
Phenolphthalein, HIn, is a weak acid.

$$\mathrm{HIn} \rightleftharpoons \mathrm{H^+} + \mathrm{In^-}$$

The K_a value for phenolphthalein is $5.0 \times 10^{-10}\,\mathrm{mol\,dm^{-3}}$ at 298 K. This indicator changes colour at a pH of approximately 8.8.

Calculate the ratio $\dfrac{[\mathrm{In^-}]}{[\mathrm{HIn}]}$ at pH 8.8.

ratio $\dfrac{[\mathrm{In^-}]}{[\mathrm{HIn}]}$ = ... [2]

24 **(a)** **(i)** Give the mathematical expression for each of the terms pH and K_w.

pH = ...

K_w = ...

[2]

(ii) Calculate the pH of $0.027\,\mathrm{mol\,dm^{-3}}$ NaOH(aq).

pH = ... [1]

(b) The K_a value of chloric(I) acid, HClO, is $3.72 \times 10^{-8}\,\mathrm{mol\,dm^{-3}}$.

Calculate the pH of $0.010\,\mathrm{mol\,dm^{-3}}$ HClO(aq).

pH = ... [1]

25 **(a)** Write an expression for the K_a of the weak acid HA in terms of the concentrations of the species involved.

K_a =

[1]

(b) The hydroxylammonium ion, $HONH_3^+$, is a weak acid. A $1.00 \times 10^{-3}\,mol\,dm^{-3}$ solution of hydroxylammonium ions has a pH of 4.41.

(i) Calculate the K_a of $HONH_3^+$.

K_a = ... [2]

(ii) Calculate the pK_a of $HONH_3^+$.

pK_a = ... [1]

(c) The solubility product of manganese(II) hydroxide, $Mn(OH)_2$, in water is $1.1 \times 10^{-11}\,mol^3\,dm^{-9}$ at 298 K.

Calculate the solubility of $Mn(OH)_2$ in water at 298 K.

solubility = ... $mol\,dm^{-3}$ [2]

26 **(d)** When concentrated sulfuric acid is added to water, dissociation takes place in two stages.

stage 1 $H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$

stage 2 $HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$ $K_{a2} = 1.0 \times 10^{-2}\,mol\,dm^{-3}$

K_{a2} is the acid dissociation constant for stage 2.

(i) Write the expression for the acid dissociation constant K_{a2}.

K_{a2} =

[1]

(ii) H_2SO_4 is considered a strong acid whereas HSO_4^- is considered a weak acid.

Suggest how the magnitude of the acid dissociation constant for stage 1 compares to K_{a2}.

.... [1]

(e) Benzoic acid, $C_6H_5CO_2H$, is a weak acid. A solution of 0.0250 mol dm^{-3} benzoic acid has a pH of 2.90.

Calculate the K_a of benzoic acid.

K_a = ... mol dm^{-3}
[2]

27 (c) Consider the following two equilibria and associated data values at 298 K.

$AgBr(s) \rightleftharpoons Ag^+(aq) + Br^-(aq)$ equilibrium **1** $K_{sp} = 5.0 \times 10^{-13}\,mol^2\,dm^{-6}$

$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq)$ equilibrium **2** $K_{stab} = 1.7 \times 10^7\,mol^{-2}\,dm^6$

The equilibrium constant for equilibrium **1** is the solubility product, K_{sp}, of AgBr(s). The equilibrium constant for equilibrium **2** is the stability constant, K_{stab}, for the formation of $[Ag(NH_3)_2]^+(aq)$.

(i) Calculate the solubility of AgBr at 298 K in $mol\,dm^{-3}$.

solubility of AgBr = ... $mol\,dm^{-3}$ [1]

(ii) Use Le Chatelier's principle as applied to equilibria **1** and **2** to suggest why AgBr(s) dissolves in concentrated $NH_3(aq)$.

....

....

....

.... [2]

(iii) Use equilibria **1** and **2** to construct an equation for the reaction of AgBr(s) with concentrated $NH_3(aq)$. This is equilibrium **3**.

.... equilibrium **3** [1]

(iv) Write an expression for the equilibrium constant of equilibrium **3**, K_{eq3}, in terms of K_{sp} for equilibrium **1** and K_{stab} for equilibrium **2**.

K_{eq3} =

[1]

28 **(b)** Glycine, $H_2NCH_2CO_2H$, is the simplest amino acid.

(i) Complete the equations to show the acid-base properties of glycine.

$H_2NCH_2CO_2H(aq) + HCl(aq) \rightarrow$ ....

$H_2NCH_2CO_2H(aq) + NaOH(aq) \rightarrow$ .... [2]

(d) The amino acid alanine can be synthesised from 2-chloropropanoic acid, $CH_3CHClCO_2H$.

(i) State the reagents and conditions and name the mechanism for this reaction.

reagents and conditions ....

name of mechanism .... [2]

(ii) State and explain the relative acidities of trichloroethanoic acid, chloroethanoic acid and ethanoic acid.

....

....

....

....

.... [3]

29 Silver sulfide, Ag_2S, is very insoluble in water.

(a) (i) Write an expression for the solubility product, K_{sp}, of $Ag_2S(s)$.

K_{sp} =

[1]

(ii) The solubility of $Ag_2S(s)$ in water at 298 K is 1.16×10^{-17} mol dm^{-3}.

Calculate the numerical value of the solubility product, K_{sp}, of $Ag_2S(s)$ at 298 K.

K_{sp} = ... [2]

(iii) Calculate the minimum volume of water needed to dissolve 1.00 g of $Ag_2S(s)$ under standard conditions.

volume = ... dm^3 [2]

(b) Bromic(I) acid, HOBr(aq), is a weak acid. Its K_a is 2.0×10^{-9} mol dm^{-3}.

(i) Calculate the pH of 0.20 mol dm^{-3} HOBr(aq).

pH = ... [2]

(ii) 5.0 cm^3 of 0.20 mol dm^{-3} potassium hydroxide, KOH, are added to 20.0 cm^3 of 0.20 mol dm^{-3} HOBr(aq).

Calculate the pH of the buffer solution produced.

pH = ... [2]

30 Ammonium chloride, $NH_4Cl(s)$, dissolves in water to form an acidic solution. This is due to the dissociation of the ammonium ions.

$$NH_4^+(aq) \rightleftharpoons H^+(aq) + NH_3(aq)$$

(a) The ammonium ion is a weak acid. The pH of a 0.300 mol dm^{-3} solution of ammonium chloride is 4.89 under standard conditions.

(i) Calculate the [H$^+$] in a 0.300 mol dm^{-3} solution of ammonium chloride.

[H$^+$] = ... mol dm^{-3} [1]

(ii) Calculate the value of pK_a of the ammonium ion.

pK_a = ... [2]

(b) A buffer solution can be made by mixing ammonium chloride with ammonia solution.

(i) Explain, with the aid of an equation, how this solution can behave as a buffer when a small amount of a strong acid is added.

....

.... [1]

(ii) Explain, with the aid of an equation, how this solution can behave as a buffer when a small amount of a strong base is added.

....

.... [1]

(c) **(i)** Use the value of K_w to calculate $[H^+]$ in pure water under standard conditions.

Show your working.

$[H^+]$ = ... mol dm^{-3} [1]

(ii) The pH of pure water at 50 °C is 6.64.

Calculate the numerical value of K_w at 50 °C.

K_w = ... [2]