

# 25. Equilibria

## 25.1 Acids and bases

### Paper 4

#### Question Paper

- 1 (b) Barium hydroxide,  $\text{Ba}(\text{OH})_2$ , is a strong base.

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

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

Show your working.

[ $M_r$ :  $\text{Ba}(\text{OH})_2$ , 171.3]

mass of  $\text{Ba}(\text{OH})_2 = \dots\dots\dots$  g [4]

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

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

$K_{\text{sp}} =$

[1]

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

$K_{\text{sp}} = \dots\dots\dots$

units =  $\dots\dots\dots$

[2]

- 2 (f)** Buffer solutions are used to regulate pH.  
Write **two** equations to describe how a solution containing  $\text{HC}_2\text{O}_4^-$  ions acts as a buffer solution when small amounts of acid or alkali are added.

.....

..... [2]

- 3 (a)** Aqueous solutions of methanoic acid,  $\text{HCOOH}$ , and propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$ , are mixed together.

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

- (i)** Define conjugate acid–base pair.

.....  
 ..... [1]

- (ii)** The  $\text{p}K_{\text{a}}$  of  $\text{HCOOH}$  is 3.75 and of  $\text{CH}_3\text{CH}_2\text{COOH}$  is 4.87.

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

..... +  $\text{H}_2\text{O} \rightleftharpoons$  ..... + ..... [1]

- (b) (i)** Write an expression for the acid dissociation constant,  $K_{\text{a}}$ , for butanoic acid,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ .

$K_{\text{a}} =$

[1]

- (ii)** The  $\text{p}K_{\text{a}}$  of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  is 4.82.

A solution of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}(\text{aq})$  has a pH of 3.25.

Calculate the concentration, in  $\text{mol dm}^{-3}$ , of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  in this solution.

concentration of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} =$  .....  $\text{mol dm}^{-3}$  [2]

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

.....  
 .....  
 ..... [2]

- (ii) A buffer solution containing a mixture of  $\text{CH}_3\text{COOH}$  and  $\text{CH}_3\text{COONa}$  is prepared as follows.

A solution of  $600\text{ cm}^3$  of  $\text{CH}_3\text{COOH}$  is mixed with  $400\text{ cm}^3$  of  $0.125\text{ mol dm}^{-3}$   $\text{CH}_3\text{COONa}$ .

The buffer solution has pH 5.70. The  $K_a$  of  $\text{CH}_3\text{COOH}$  is  $1.78 \times 10^{-5}\text{ mol dm}^{-3}$ .

Calculate the initial concentration, in  $\text{mol dm}^{-3}$ , of  $\text{CH}_3\text{COOH}$  used.

concentration of  $\text{CH}_3\text{COOH}$  = .....  $\text{mol dm}^{-3}$  [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  $0.0224 \text{ mol dm}^{-3}$  at 298 K.

[2]

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

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

$K_{\text{sp}} = \dots\dots\dots$  units  $\dots\dots\dots$  [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  $\dots\dots\dots$

pH of solution  $\dots\dots\dots$

explanation  $\dots\dots\dots$

$\dots\dots\dots$

[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.

$\dots\dots\dots$

$\dots\dots\dots$

$\dots\dots\dots$

$\dots\dots\dots$

$\dots\dots\dots$  [3]



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



- (i) Write the mathematical expressions for  $\text{p}K_{\text{a}}$  and pH.

$\text{p}K_{\text{a}} = \dots\dots\dots$

$\text{pH} = \dots\dots\dots$

[1]

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

$\text{pH} = \dots\dots\dots$  [2]

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

percentage ionisation of HNCO =  $\dots\dots\dots$  [1]

- 6 (b) The amino acid alanine,  $\text{H}_2\text{NCH}(\text{CH}_3)\text{COOH}$ , can act as a buffer.

- (i) Define a buffer solution.

$\dots\dots\dots$

$\dots\dots\dots$

$\dots\dots\dots$  [2]

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

$\dots\dots\dots$

$\dots\dots\dots$  [2]

**7 (e)** Silver sulfite,  $\text{Ag}_2\text{SO}_3(\text{s})$ , is sparingly soluble in water.

(i) Give an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{SO}_3$ .

$$K_{\text{sp}} =$$

[1]

(ii) Calculate the equilibrium concentration of  $\text{Ag}^+$  in a saturated solution of  $\text{Ag}_2\text{SO}_3$  at 298 K.

[ $K_{\text{sp}}$ :  $\text{Ag}_2\text{SO}_3$ ,  $1.50 \times 10^{-14} \text{ mol}^3 \text{ dm}^{-9}$  at 298 K]

$$[\text{Ag}^+] = \dots\dots\dots \text{ mol dm}^{-3} \quad [1]$$

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

$K_w =$  ..... [1]

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

- **V** is  $\text{HCl}(\text{aq})$ .
- **W** is  $\text{NaOH}(\text{aq})$ .
- The concentration of  $\text{HCl}$  in **V** is the same as the concentration of  $\text{NaOH}$  in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

- (i) Calculate the concentration of  $\text{HCl}$  in **V**.

concentration of  $\text{HCl}$  in **V** = .....  $\text{mol dm}^{-3}$  [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  $1 \text{ cm}^3$  sample of  $1.0 \text{ mol dm}^{-3}$   $\text{HNO}_3$  is added to  $100 \text{ cm}^3$  of solution **X**, forming mixture **Y**.

A  $1 \text{ cm}^3$  sample of  $1.0 \text{ mol dm}^{-3}$   $\text{KOH}$  is added to  $100 \text{ cm}^3$  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)  $\text{CH}_3\text{CH}_2\text{COOH}$ ,  $\text{CH}_3\text{CCl}_2\text{COOH}$  and  $\text{H}_2\text{SO}_4$  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  $\text{H}_2\text{SO}_4$  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  $6.31 \times 10^{-5} \text{ mol dm}^{-3}$  at 298 K.

A  $1.00 \text{ dm}^3$  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.

$$[H^+] = \dots\dots\dots \text{ mol dm}^{-3}$$

$$[C_6H_5COOH] = \dots\dots\dots \text{ mol dm}^{-3}$$

$$[C_6H_5COO^-Na^+] = \dots\dots\dots \text{ mol dm}^{-3}$$

[3]

- (d) A  $10.0\text{ cm}^3$  sample of the buffer solution is mixed with  $10.0\text{ cm}^3$  of  $1.00\text{ mol dm}^{-3}$  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,  $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$ , has a solubility in water of less than  $1.00\text{ g dm}^{-3}$  at 298 K.

$$K_{\text{sp}} = [\text{Mg}^{2+}][\text{C}_6\text{H}_5\text{COO}^-]^2 = 1.76 \times 10^{-7} \text{ at } 298 \text{ K}$$

- (i) Calculate the solubility of  $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$  in water at 298 K. Give your answer in  $\text{g dm}^{-3}$ .

Show your working.

[ $M_r$ :  $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$ , 266.3]

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

- (ii) An excess of  $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$  is added to a sample of  $0.50\text{ mol dm}^{-3}$   $\text{MgSO}_4$  at 298 K.

State whether the equilibrium concentration of  $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$  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  $\text{BaSO}_4$  is  $1.08 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$  at 298 K.

Calculate the solubility of  $\text{BaSO}_4$  in g per  $100 \text{ cm}^3$  of solution.

solubility of  $\text{BaSO}_4$  = ..... g per  $100 \text{ cm}^3$  of solution  
[2]

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

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

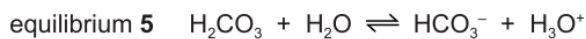
$K_{sp} =$

units = .....  
[2]

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

$K_{sp} =$  ..... [2]

- 12 (c)** The buffer system in seawater contains a mixture of  $\text{HCO}_3^-$  and  $\text{H}_2\text{CO}_3$ .



- (i) Define a buffer solution.

.....  
.....  
..... [2]

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

.....  
..... [2]

- (iii) The  $[\text{HCO}_3^-]/[\text{H}_2\text{CO}_3]$  ratio in a sample of seawater is 14.1.

Calculate the pH of this sample.  
[ $pK_a$ :  $\text{H}_2\text{CO}_3$ , 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,  $Al(OH)_3$ , in water is  $2.47 \times 10^{-9} \text{ mol dm}^{-3}$ .

(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]



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

pH = ..... [2]

(iv) A solution containing  $2.00 \times 10^{-3}$  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,  $\text{Ba}(\text{OH})_2$ , is completely dissociated in aqueous solution.

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

pH = ..... [2]

- 16** Solution **Y** is hydrochloric acid,  $\text{HCl}(\text{aq})$ . Solution **Z** is aqueous 4-chlorobutanoic acid,  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$ . The  $\text{p}K_{\text{a}}$  of  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$  is 4.52. The pH of both solutions is 4.00.

(a) (i) Write an expression for the  $K_{\text{a}}$  of  $\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}(\text{aq})$ .

$$K_{\text{a}} =$$

[1]

(ii) Write a mathematical expression to describe the relationship between  $K_{\text{a}}$  and  $\text{p}K_{\text{a}}$ .

..... [1]

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

$$[\text{H}^+] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

(iv) Calculate the ratio  $\frac{[\text{HCl}] \text{ dissolved in solution Y}}{[\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}] \text{ dissolved in solution Z}}$ .

$$\frac{[\text{HCl}] \text{ dissolved in solution Y}}{[\text{Cl}(\text{CH}_2)_3\text{CO}_2\text{H}] \text{ dissolved in solution Z}} = \dots\dots\dots [2]$$

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

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

$[M_{\text{r}}$ : propanoic acid, 74.0; sodium propanoate, 96.0]

$$\text{mass of sodium propanoate} = \dots\dots\dots \text{g} \quad [3]$$

- (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.

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

- (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  $K_{sp}$ .

$$K_{sp} = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[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]

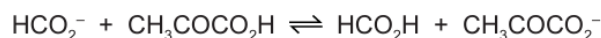
- 18 (a)** Compare and explain the relative acidities of 2-chloropropanoic acid, 3-chloropropanoic acid, and propanoic acid. Explain your answer.

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

- (b) (i)** The numerical values of  $K_a$  for methanoic acid,  $\text{HCO}_2\text{H}$ , and pyruvic acid,  $\text{CH}_3\text{COCO}_2\text{H}$ , are given.

acid	$K_a$
$\text{HCO}_2\text{H}$	$1.78 \times 10^{-4}$
$\text{CH}_3\text{COCO}_2\text{H}$	$4.07 \times 10^{-3}$

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



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

$$K_{\text{eq}} = \dots\dots\dots [1]$$

- (ii)** Use your value of  $K_{\text{eq}}$  to predict the position of this equilibrium. Indicate this by placing a tick ( $\checkmark$ ) 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,  $\text{HO}_2\text{CCO}_2\text{H}$ , has two dissociation constants,  $K_{a1}$  and  $K_{a2}$ , whose  $\text{p}K_a$  values are 1.23 and 4.19.

Suggest equations to show the two dissociations that give rise to these  $\text{p}K_a$  values.

$\text{p}K_{a1}$  1.23 .....

$\text{p}K_{a2}$  4.19 .....

[2]

- (iv)** State the mathematical relationship between  $\text{p}K_a$  and the acid dissociation constant  $K_a$ .

..... [1]

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

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

$$K_w = \dots\dots\dots [1]$$

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

$$\text{pH} = \dots\dots\dots [2]$$

**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  $6.3 \times 10^{-12}$  at  $25^\circ\text{C}$ .

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

$$K_{sp} = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots [2]$$

(ii) Calculate the equilibrium concentration of  $Ag^+$  in a saturated solution of  $Ag_2CO_3$  at  $25^\circ\text{C}$ .

$$[Ag^+] = \dots\dots\dots \text{ mol dm}^{-3} [1]$$

(iii) Solid  $Ag_2CO_3$  is stirred at  $25^\circ\text{C}$  with  $0.050 \text{ mol dm}^{-3} AgNO_3$  until no more  $Ag_2CO_3$  dissolves.  
Calculate the concentration of carbonate ions,  $[CO_3^{2-}]$ , in this solution.

$$[CO_3^{2-}] = \dots\dots\dots \text{ mol dm}^{-3} [1]$$

- 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,  $\text{NH}_4^+(\text{aq})$ .

$$K_a =$$

[1]

- (ii) Write **two** equations to describe how a solution containing ammonium ions,  $\text{NH}_4^+(\text{aq})$ , and ammonia,  $\text{NH}_3(\text{aq})$ , can act as a buffer.

.....  
..... [2]

- (iii) The numerical value of  $K_a$  for  $\text{NH}_4^+(\text{aq})$  is  $5.6 \times 10^{-10}$  at 298 K.  
A buffer solution was prepared by adding  $0.80 \text{ dm}^3$  of  $0.25 \text{ mol dm}^{-3}$  ammonia, an excess, to  $0.20 \text{ dm}^3$  of  $0.20 \text{ mol dm}^{-3}$  hydrochloric acid.

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

pH = ..... [3]

- 22 (d)** Calcium iodate(V),  $\text{Ca}(\text{IO}_3)_2$ , is sparingly soluble in water.  
The concentration of its saturated solution is  $5.6 \times 10^{-3} \text{ mol dm}^{-3}$  at 298 K.

(i) Write an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ca}(\text{IO}_3)_2$ , and state its units.

$$K_{\text{sp}} =$$

units = ..... [2]

(ii) Calculate the numerical value for  $K_{\text{sp}}$   $\text{Ca}(\text{IO}_3)_2$  at 298 K.

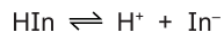
$$K_{\text{sp}} = \dots\dots\dots [1]$$

(iii) When a few  $\text{cm}^3$  of concentrated  $\text{Ca}(\text{NO}_3)_2(\text{aq})$  is added to a saturated solution of  $\text{Ca}(\text{IO}_3)_2$  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.



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

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

$$\text{ratio } \frac{[\text{In}^-]}{[\text{HIn}]} = \dots\dots\dots [2]$$

- 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  $0.027 \text{ mol dm}^{-3} \text{ NaOH(aq)}$ .

pH = ..... [1]

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

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

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,  $\text{HONH}_3^+$ , is a weak acid. A  $1.00 \times 10^{-3} \text{ mol dm}^{-3}$  solution of hydroxylammonium ions has a pH of 4.41.

- (i)** Calculate the  $K_a$  of  $\text{HONH}_3^+$ .

$$K_a = \dots\dots\dots [2]$$

- (ii)** Calculate the  $\text{p}K_a$  of  $\text{HONH}_3^+$ .

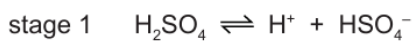
$$\text{p}K_a = \dots\dots\dots [1]$$

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

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

$$\text{solubility} = \dots\dots\dots \text{ mol dm}^{-3} [2]$$

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



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

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

$$K_{a2} =$$

[1]

(ii)  $\text{H}_2\text{SO}_4$  is considered a strong acid whereas  $\text{HSO}_4^-$  is considered a weak acid.

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

..... [1]

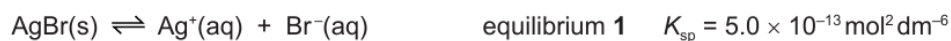
(e) Benzoic acid,  $\text{C}_6\text{H}_5\text{CO}_2\text{H}$ , is a weak acid. A solution of  $0.0250 \text{ mol dm}^{-3}$  benzoic acid has a pH of 2.90.

Calculate the  $K_a$  of benzoic acid.

$$K_a = \dots\dots\dots \text{ mol dm}^{-3}$$

[2]

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



The equilibrium constant for equilibrium **1** is the solubility product,  $K_{\text{sp}}$ , of AgBr(s). The equilibrium constant for equilibrium **2** is the stability constant,  $K_{\text{stab}}$ , for the formation of  $[\text{Ag}(\text{NH}_3)_2]^{\text{+}}(\text{aq})$ .

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

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

(ii) Use Le Chatelier's principle as applied to equilibria **1** and **2** to suggest why AgBr(s) dissolves in concentrated  $\text{NH}_3(\text{aq})$ .

.....  
 .....  
 .....

..... [2]

(iii) Use equilibria **1** and **2** to construct an equation for the reaction of AgBr(s) with concentrated  $\text{NH}_3(\text{aq})$ . This is equilibrium **3**.

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

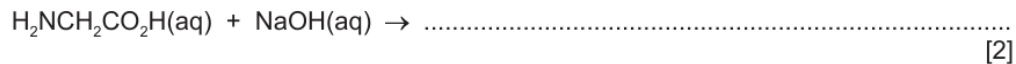
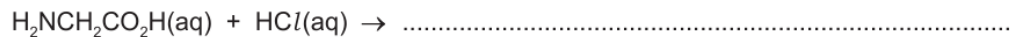
(iv) Write an expression for the equilibrium constant of equilibrium **3**,  $K_{\text{eq3}}$ , in terms of  $K_{\text{sp}}$  for equilibrium **1** and  $K_{\text{stab}}$  for equilibrium **2**.

$K_{\text{eq3}} =$

[1]

**28 (b)** Glycine,  $\text{H}_2\text{NCH}_2\text{CO}_2\text{H}$ , is the simplest amino acid.

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



[2]

**(d)** The amino acid alanine can be synthesised from 2-chloropropanoic acid,  $\text{CH}_3\text{CHClCO}_2\text{H}$ .

(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,  $\text{Ag}_2\text{S}$ , is very insoluble in water.

(a) (i) Write an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{S}(\text{s})$ .

$$K_{\text{sp}} =$$

[1]

(ii) The solubility of  $\text{Ag}_2\text{S}(\text{s})$  in water at 298 K is  $1.16 \times 10^{-17} \text{ mol dm}^{-3}$ .

Calculate the numerical value of the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{S}(\text{s})$  at 298 K.

$$K_{\text{sp}} = \dots\dots\dots [2]$$

(iii) Calculate the minimum volume of water needed to dissolve 1.00 g of  $\text{Ag}_2\text{S}(\text{s})$  under standard conditions.

$$\text{volume} = \dots\dots\dots \text{ dm}^3 [2]$$

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

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

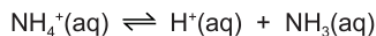
pH = ..... [2]

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

Calculate the pH of the buffer solution produced.

pH = ..... [2]

- 30** Ammonium chloride,  $\text{NH}_4\text{Cl}(\text{s})$ , dissolves in water to form an acidic solution. This is due to the dissociation of the ammonium ions.



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

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

$$[\text{H}^+] = \dots\dots\dots \text{ mol dm}^{-3} \quad [1]$$

- (ii) Calculate the value of  $\text{p}K_{\text{a}}$  of the ammonium ion.

$$\text{p}K_{\text{a}} = \dots\dots\dots [2]$$

- (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.

$$[H^+] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

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

Calculate the numerical value of  $K_w$  at 50 °C.

$$K_w = \dots\dots\dots [2]$$