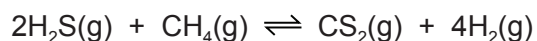


1. Question part 1/2 | 9701 May-June 2016 P4 V1 Q3

- 3** One method of producing hydrogen from natural gas is the reaction between hydrogen sulfide and methane.



- (a)** Write the expression for K_p for this reaction, and state its units.

$$K_p =$$

units
[2]

- (b)** The initial partial pressures of the two gases in a mixture at 1000 K are recorded.



The mixture is left to reach equilibrium.

It is found that the equilibrium partial pressure of $\text{CS}_2(\text{g})$ is 2 atm and that of the remaining $\text{CH}_4(\text{g})$ is 98 atm.

- (i)** Calculate the equilibrium partial pressures of $\text{H}_2\text{S}(\text{g})$ and $\text{H}_2(\text{g})$.

$$p(\text{H}_2\text{S}) = \dots\dots\dots \text{ atm}$$

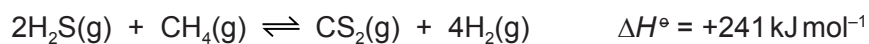
$$p(\text{H}_2) = \dots\dots\dots \text{ atm}$$

[2]

- (ii)** Calculate the value of K_p at this temperature.

$$K_p = \dots\dots\dots [1]$$

(c) (i) Predict the sign of ΔS° for this reaction. Explain your answer.



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

The free energy change, ΔG° , for this reaction at 1000 K is $+51 \text{ kJ mol}^{-1}$.

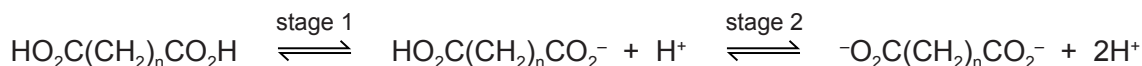
(ii) Calculate the value of ΔS° for this reaction, stating its units.

$\Delta S^\circ =$ units [2]

(d) How would the value of ΔG° , and hence the spontaneity (feasibility) of this reaction change as the temperature increases? Explain your answer.

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

[Total: 10]

5 Dicarboxylic acids dissociate in stages.

(a) The $\text{p}K_{\text{a}}$ values for stage 1 and stage 2 for some dicarboxylic acids are listed below.

n in $\text{HO}_2\text{C}(\text{CH}_2)_n\text{CO}_2\text{H}$	$\text{p}K_{\text{a}}(1)$ for stage 1	$\text{p}K_{\text{a}}(2)$ for stage 2
1	2.83	5.69
2	4.16	5.61
3	4.31	5.41

For comparison, the $\text{p}K_{\text{a}}$ of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, is 4.76.

(i) State the mathematical relationship between $\text{p}K_{\text{a}}$ and the acid dissociation constant K_{a} .

..... [1]

(ii) With reference to the table above, suggest why the $\text{p}K_{\text{a}}(1)$ values

- are all smaller than the $\text{p}K_{\text{a}}$ of ethanoic acid,

.....

- become larger as n increases.

..... [3]

(iii) Suggest why all the $\text{p}K_{\text{a}}(2)$ values in the table above are larger than the $\text{p}K_{\text{a}}$ of ethanoic acid.

.....
 [1]

(b) The monosodium salts of edible dicarboxylic acids are added to some foodstuffs as buffers.

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

.....
 [2]

(ii) Write two equations to show how monosodium butanedioate, $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{Na}$, acts as a buffer.

.....
 [2]

[Total: 9]

3. Question part 1/2 | 9701 May-June 2016 P4 V2 Q2

2 Ethanoic acid is a weak acid.

(a) Explain what is meant by the term *weak* acid.

.....

..... [1]

(b) The pK_a values of four acids are listed below.

acid	structural formula	pK_a
1	$\text{CH}_3\text{CO}_2\text{H}$	4.8
2	$\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$	4.9
3	$\text{CH}_3\text{CHClCO}_2\text{H}$	2.8
4	$\text{CH}_2\text{ClCH}_2\text{CO}_2\text{H}$	4.0

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

..... [1]

(ii) With reference to acidity, explain the difference in pK_a values between

- acid 1 and acid 2,

.....

.....

- acid 2 and acid 3,

.....

.....

- acid 3 and acid 4.

.....

.....

[3]

3. Question part 2/2 | 9701 May-June 2016 P4 V2 Q2

- (c) (i) Draw a fully labelled diagram of the equipment needed to measure the voltage of an electrochemical cell consisting of the standard hydrogen electrode and the standard Cu/Cu^{2+} electrode.

[4]

- (ii) For the cell drawn in (i), calculate the $E_{\text{cell}}^{\ominus}$ and state which electrode is positive.

$E_{\text{cell}}^{\ominus} = \dots\dots\dots$ identity of the positive electrode $\dots\dots\dots$ [1]

- (d) A monobasic acid, **D**, has $K_{\text{a}} = 1.23 \times 10^{-5} \text{ mol dm}^{-3}$.

- (i) Calculate the pH of a $0.100 \text{ mol dm}^{-3}$ solution of **D**.

pH = $\dots\dots\dots$ [2]

- (ii) An electrochemical cell similar to the one you have drawn in (c)(i) was set up using a $0.100 \text{ mol dm}^{-3}$ solution of **D** in the hydrogen electrode instead of the standard solution.

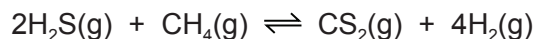
Use the data and the Nernst equation, $E = E^{\ominus} + 0.059 \log [\text{H}^+(\text{aq})]$, to calculate the new E_{cell} in this experiment.

$E_{\text{cell}} = \dots\dots\dots \text{ V}$ [2]

[Total: 14]

4. Question part 1/2 | 9701 May-June 2016 P4 V3 Q3

- 3** One method of producing hydrogen from natural gas is the reaction between hydrogen sulfide and methane.



- (a)** Write the expression for K_p for this reaction, and state its units.

$$K_p =$$

units
[2]

- (b)** The initial partial pressures of the two gases in a mixture at 1000 K are recorded.



The mixture is left to reach equilibrium.

It is found that the equilibrium partial pressure of $\text{CS}_2(\text{g})$ is 2 atm and that of the remaining $\text{CH}_4(\text{g})$ is 98 atm.

- (i)** Calculate the equilibrium partial pressures of $\text{H}_2\text{S}(\text{g})$ and $\text{H}_2(\text{g})$.

$$p(\text{H}_2\text{S}) = \dots\dots\dots \text{ atm}$$

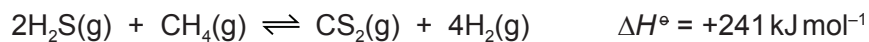
$$p(\text{H}_2) = \dots\dots\dots \text{ atm}$$

[2]

- (ii)** Calculate the value of K_p at this temperature.

$$K_p = \dots\dots\dots [1]$$

- (c) (i) Predict the sign of ΔS° for this reaction. Explain your answer.



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

The free energy change, ΔG° , for this reaction at 1000 K is $+51 \text{ kJ mol}^{-1}$.

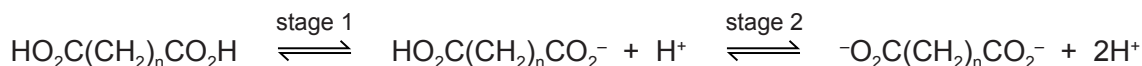
- (ii) Calculate the value of ΔS° for this reaction, stating its units.

$\Delta S^\circ =$ units [2]

- (d) How would the value of ΔG° , and hence the spontaneity (feasibility) of this reaction change as the temperature increases? Explain your answer.

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

[Total: 10]

5 Dicarboxylic acids dissociate in stages.

(a) The $\text{p}K_{\text{a}}$ values for stage 1 and stage 2 for some dicarboxylic acids are listed below.

n in $\text{HO}_2\text{C}(\text{CH}_2)_n\text{CO}_2\text{H}$	$\text{p}K_{\text{a}}(1)$ for stage 1	$\text{p}K_{\text{a}}(2)$ for stage 2
1	2.83	5.69
2	4.16	5.61
3	4.31	5.41

For comparison, the $\text{p}K_{\text{a}}$ of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, is 4.76.

(i) State the mathematical relationship between $\text{p}K_{\text{a}}$ and the acid dissociation constant K_{a} .

..... [1]

(ii) With reference to the table above, suggest why the $\text{p}K_{\text{a}}(1)$ values

- are all smaller than the $\text{p}K_{\text{a}}$ of ethanoic acid,

.....

- become larger as n increases.

..... [3]

(iii) Suggest why all the $\text{p}K_{\text{a}}(2)$ values in the table above are larger than the $\text{p}K_{\text{a}}$ of ethanoic acid.

.....
 [1]

(b) The monosodium salts of edible dicarboxylic acids are added to some foodstuffs as buffers.

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

.....
 [2]

(ii) Write two equations to show how monosodium butanedioate, $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{Na}$, acts as a buffer.

.....
 [2]

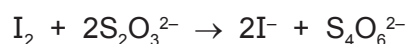
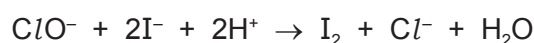
[Total: 9]

6. Question part 1/3 | 9701 Oct-Nov 2016 P4 V1 Q7

- 7 (a) Sodium chlorate(I), NaClO , is the active ingredient in commercial bleach. The concentration of chlorate(I) ions was determined by titration.

- 10.0 cm^3 of a bleach solution was diluted to 250 cm^3 in a volumetric flask using distilled water.
- Dilute sulfuric acid and an excess of potassium iodide solution were added to a 25.0 cm^3 portion of this solution to liberate iodine.
- The resulting solution required 20.80 cm^3 of 0.100 mol dm^{-3} aqueous sodium thiosulfate solution to react with the iodine produced.

The titration reactions are shown.



Calculate the concentration, in mol dm^{-3} , of ClO^- ions in the bleach solution.

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

- (b) An indicator was used in the thiosulfate-iodine titration.

- (i) Name a suitable indicator for this titration.

..... [1]

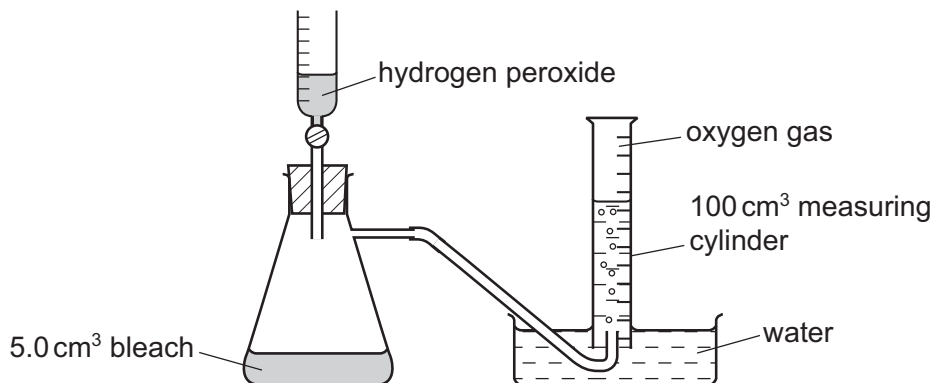
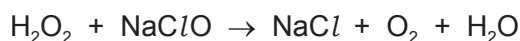
- (ii) State the expected colour change you would observe at the end-point in this titration.

from to [1]

- (iii) State when in the procedure you would add the indicator.

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

- (c) The concentration of chlorate(I) ions can also be determined by adding an excess of hydrogen peroxide to the sample of bleach and measuring the volume of oxygen gas produced.

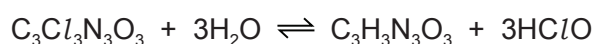


When an excess of aqueous hydrogen peroxide was added to 5.0 cm³ of a different bleach solution, 82 cm³ of oxygen was produced at room temperature and pressure.

Calculate the concentration of ClO^- ions in this bleach solution.

concentration of ClO^- = ... mol dm⁻³ [2]

- (d) Trichlorocyanuric acid, $\text{C}_3\text{Cl}_3\text{N}_3\text{O}_3$, acts as a chlorine buffer and disinfectant for swimming pools. It reacts with water to give chloric(I) acid, HClO .



- (i) Write the expression for K_c for this equilibrium.

$K_c =$

[1]

- (ii) In outdoor swimming pools, the HClO is decomposed by sunlight. The decomposition of HClO is a redox reaction which forms a gas that relights a glowing splint.

Describe and explain the effect of the decomposition of HClO on the equilibrium in (d). State the effect on K_c .

.....

effect on K_c

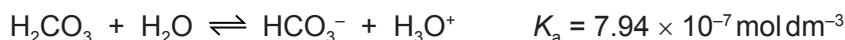
[2]

- (iii) The decomposition of HClO is a redox reaction.

Suggest an equation for this reaction.

..... [1]

- (e) The buffer solution in blood is a mixture of carbonic acid, H_2CO_3 , and hydrogencarbonate ions, HCO_3^- . Healthy blood has a pH of 7.40.



- (i) Explain how this buffer system acts to control the blood pH. Include equations in your answer.

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

- (ii) A patient's blood has a $[\text{HCO}_3^-]:[\text{H}_2\text{CO}_3]$ ratio of 9.5:1.

Calculate the pH of the patient's blood.

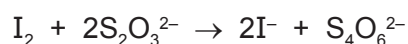
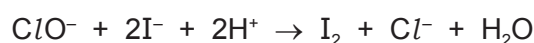
pH = ... [2]

[Total: 16]

- 7 (a)** Sodium chlorate(I), NaClO , is the active ingredient in commercial bleach. The concentration of chlorate(I) ions was determined by titration.

- 10.0 cm^3 of a bleach solution was diluted to 250 cm^3 in a volumetric flask using distilled water.
- Dilute sulfuric acid and an excess of potassium iodide solution were added to a 25.0 cm^3 portion of this solution to liberate iodine.
- The resulting solution required 20.80 cm^3 of 0.100 mol dm^{-3} aqueous sodium thiosulfate solution to react with the iodine produced.

The titration reactions are shown.



Calculate the concentration, in mol dm^{-3} , of ClO^- ions in the bleach solution.

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

- (b)** An indicator was used in the thiosulfate-iodine titration.

- (i)** Name a suitable indicator for this titration.

..... [1]

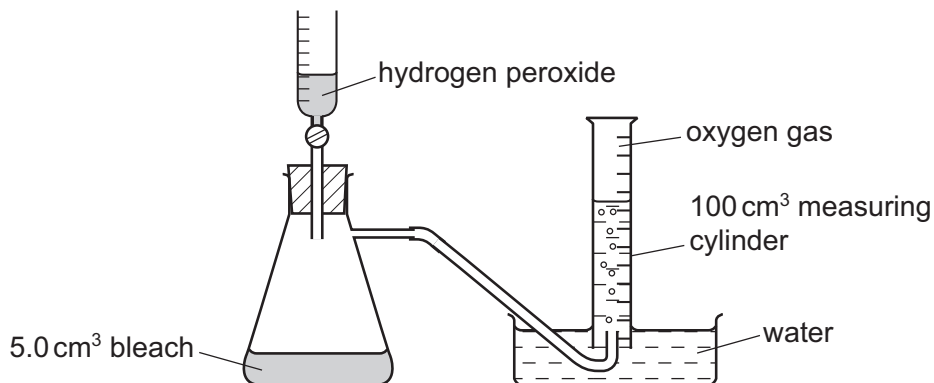
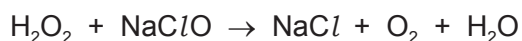
- (ii)** State the expected colour change you would observe at the end-point in this titration.

from to [1]

- (iii)** State when in the procedure you would add the indicator.

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

- (c) The concentration of chlorate(I) ions can also be determined by adding an excess of hydrogen peroxide to the sample of bleach and measuring the volume of oxygen gas produced.

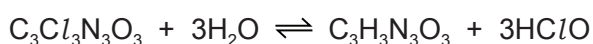


When an excess of aqueous hydrogen peroxide was added to 5.0 cm³ of a different bleach solution, 82 cm³ of oxygen was produced at room temperature and pressure.

Calculate the concentration of ClO⁻ ions in this bleach solution.

concentration of ClO⁻ = ... mol dm⁻³ [2]

- (d) Trichlorocyanuric acid, C₃Cl₃N₃O₃, acts as a chlorine buffer and disinfectant for swimming pools. It reacts with water to give chloric(I) acid, HClO.



- (i) Write the expression for K_c for this equilibrium.

$K_c =$

[1]

- (ii) In outdoor swimming pools, the HClO is decomposed by sunlight. The decomposition of HClO is a redox reaction which forms a gas that relights a glowing splint.

Describe and explain the effect of the decomposition of HClO on the equilibrium in (d). State the effect on K_c .

.....

effect on K_c

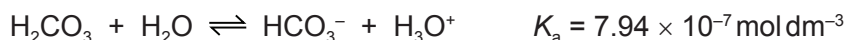
[2]

- (iii) The decomposition of HClO is a redox reaction.

Suggest an equation for this reaction.

..... [1]

- (e) The buffer solution in blood is a mixture of carbonic acid, H_2CO_3 , and hydrogencarbonate ions, HCO_3^- . Healthy blood has a pH of 7.40.



- (i) Explain how this buffer system acts to control the blood pH. Include equations in your answer.

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

- (ii) A patient's blood has a $[\text{HCO}_3^-]:[\text{H}_2\text{CO}_3]$ ratio of 9.5:1.

Calculate the pH of the patient's blood.

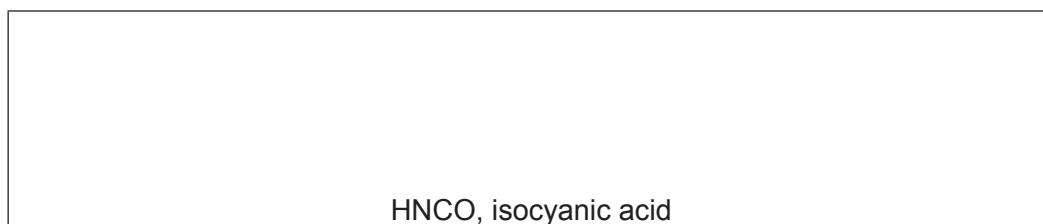
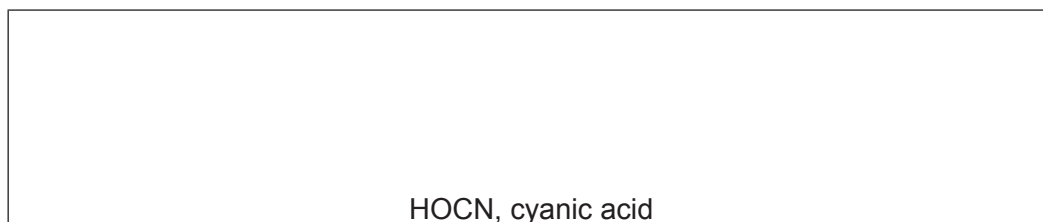
pH = ... [2]

[Total: 16]

8. Question part 1/4 | 9701 May-June 2017 P4 V1 Q2

- 2 (a) One atom of each of the four elements H, C, N and O can bond together in different ways. Two examples are molecules of cyanic acid, HOCN, and isocyanic acid, HNCO. The atoms are bonded in the order they are written.

- (i) Draw 'dot-and-cross' diagrams of these two acids, showing outer shell electrons only.



[3]

- (ii) Suggest the values of the bond angles HNC and NCO in **isocyanic acid**.

HNC NCO [1]

- (iii) Suggest which acid, cyanic or isocyanic, will have the **shorter** C–N bond length. Explain your answer.

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

- (b) (i) Isocyanic acid is a weak acid.



Calculate the pH of a 0.10 mol dm^{-3} solution of isocyanic acid.

pH = ... [2]

- (ii) Sodium cyanate, NaNCO, is used in the production of isocyanic acid. Sodium cyanate is prepared commercially by reacting urea, $(\text{NH}_2)_2\text{CO}$, with sodium carbonate. Other products in this reaction are carbon dioxide, ammonia and steam.

Write an equation for the production of NaNCO by this method.

..... [1]

8. Question part 2/4 | 9701 May-June 2017 P4 V1 Q2

- (c) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is completely ionised in aqueous solutions. During the addition of 30.0 cm^3 of 0.100 mol dm^{-3} $\text{Ba}(\text{OH})_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid, the pH was measured.

(i) Calculate the $[\text{OH}^-]$ at the end of the addition.

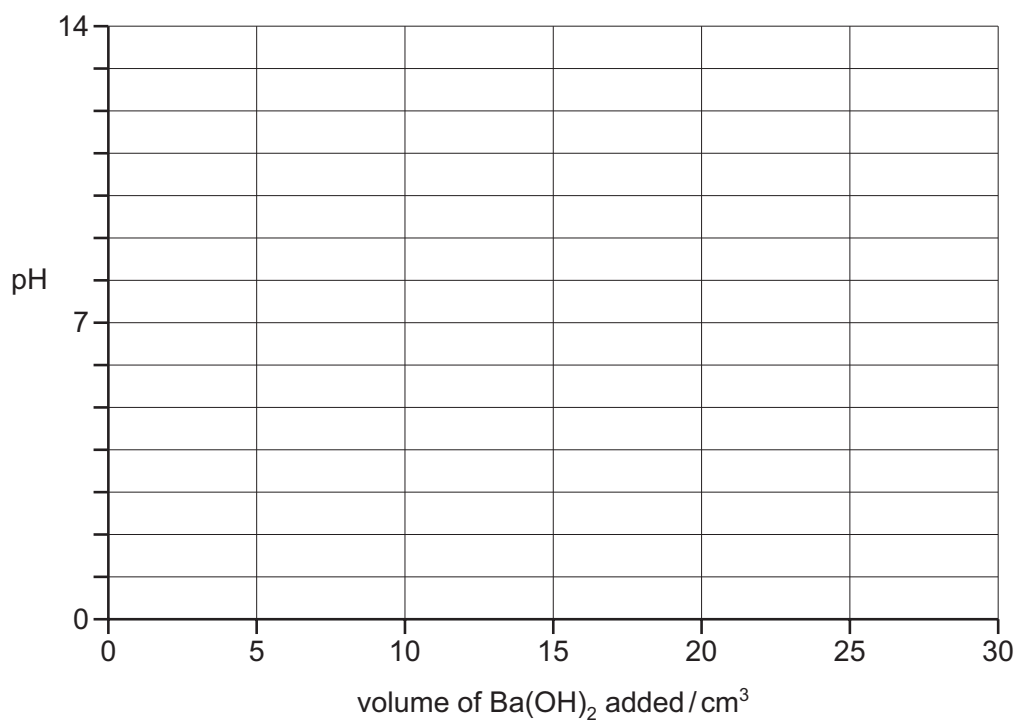
$[\text{OH}^-] = \dots\dots\dots \text{ mol dm}^{-3}$ [2]

(ii) Use your value in (i) to calculate $[\text{H}^+]$ and the pH of the solution at the end of the addition.

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

final pH = $\dots\dots\dots$
[2]

- (iii) On the following axes, sketch how the pH changes during the addition of a total of 30.0 cm^3 of 0.100 mol dm^{-3} $\text{Ba}(\text{OH})_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid.



[3]

(d) The cyanate ion, NCO^- , can act as a *monodentate ligand*.

(i) State what is meant by the terms

monodentate, ...

.....

ligand.

.....

[2]

Silver ions, Ag^+ , react with cyanate ions to form a linear complex.

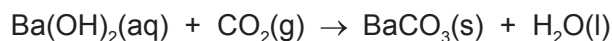
(ii) Suggest the formula of this complex, including its charge.

..... [2]

(e) When heated with $\text{HCl}(\text{aq})$, organic isocyanates, RNCO , are hydrolysed to the amine salt, RNH_3Cl , and CO_2 .



A 1.00 g sample of an organic isocyanate, RNCO , was treated in this way, and the CO_2 produced was absorbed in an excess of aqueous $\text{Ba}(\text{OH})_2$ according to the equation shown. The solid BaCO_3 precipitated weighed 1.66 g.



(i) Calculate the number of moles of BaCO_3 produced.

moles of BaCO_3 = ... [1]

(ii) Hence calculate the M_r of the organic isocyanate RNCO .

M_r of RNCO = ... [1]

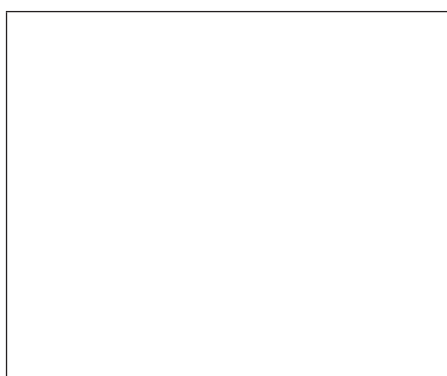
8. Question part 4/4 | 9701 May-June 2017 P4 V1 Q2

The R group in RNCO and RNH_3Cl contains carbon and hydrogen only.

- (iii) Use your M_r value calculated in (ii) to suggest the molecular formula of the organic isocyanate RNCO .

molecular formula of RNCO [1]

- (iv) Suggest a possible structure of the amine RNH_2 , which forms the amine salt, RNH_3Cl .



[1]

[Total: 23]

- 6 The table lists some organic acids and their pK_a values.

acid	formula	pK_a
ethanoic acid	$\text{CH}_3\text{CO}_2\text{H}$	4.76
chloroethanoic acid	$\text{ClCH}_2\text{CO}_2\text{H}$	2.86
aminoethanoic acid (glycine)	$\text{H}_2\text{NCH}_2\text{CO}_2\text{H}$	9.87

- (a) (i) State the relationship between pK_a and the strength of an acid.

..... [1]

- (ii) State the mathematical relationship between pK_a and the acidity constant K_a .

..... [1]

- (iii) Give reasons for why the pK_a value for chloroethanoic acid is **smaller** than that for ethanoic acid.

.....

.....

..... [2]

- (b) (i) Use the zwitterionic structure for aminoethanoic acid (glycine) in aqueous solution to write an equation for its dissociation giving $\text{H}^+(\text{aq})$ ions.

..... [1]

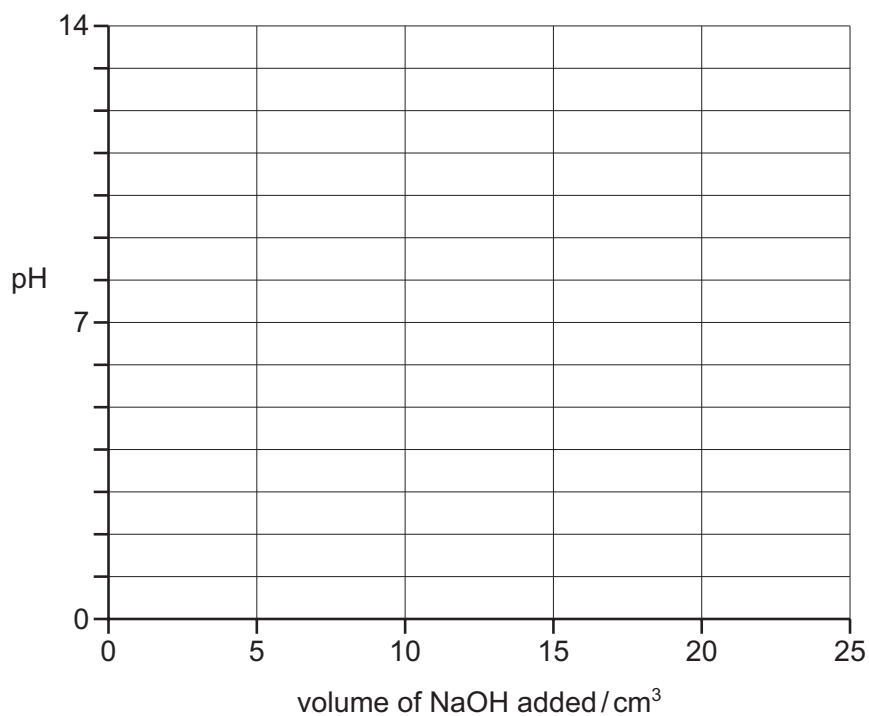
- (ii) Calculate the pH of a $0.100 \text{ mol dm}^{-3}$ solution of aminoethanoic acid.

pH = ... [2]

9. Question part 2/2 | 9701 May-June 2017 P4 V2 Q6

A 10.0 cm^3 sample of 0.100 mol dm^{-3} aminoethanoic acid (glycine) was titrated with 0.100 mol dm^{-3} NaOH. After 20.0 cm^3 of NaOH, an excess, had been added, the pH was found to be 12.5.

(iii) Using the following axes, sketch a graph showing how the pH changes during this titration.



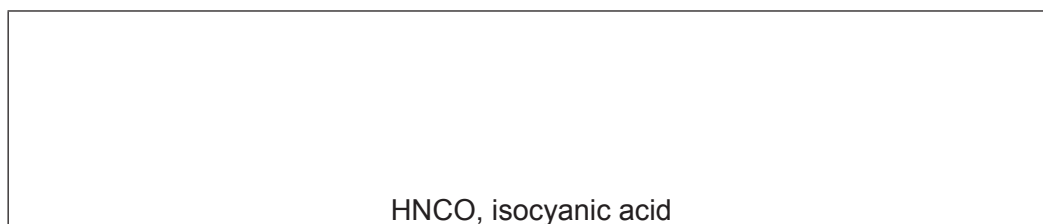
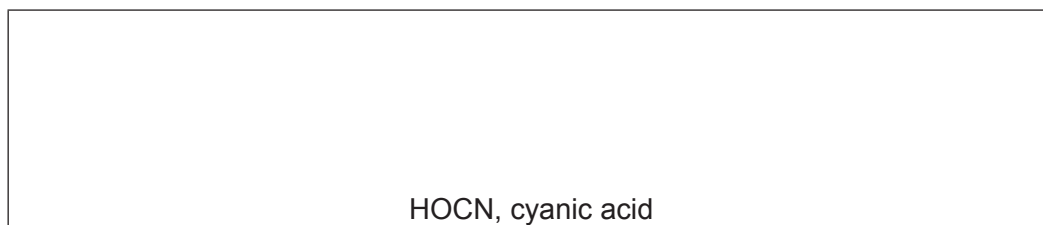
[3]

[Total: 10]

10. Question part 1/4 | 9701 May-June 2017 P4 V3 Q2

- 2 (a) One atom of each of the four elements H, C, N and O can bond together in different ways. Two examples are molecules of cyanic acid, HOCN, and isocyanic acid, HNCO. The atoms are bonded in the order they are written.

(i) Draw 'dot-and-cross' diagrams of these two acids, showing outer shell electrons only.



[3]

(ii) Suggest the values of the bond angles HNC and NCO in **isocyanic acid**.

HNC NCO [1]

(iii) Suggest which acid, cyanic or isocyanic, will have the **shorter** C–N bond length. Explain your answer.

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

(b) (i) Isocyanic acid is a weak acid.



Calculate the pH of a 0.10 mol dm^{-3} solution of isocyanic acid.

pH = ... [2]

(ii) Sodium cyanate, NaNCO, is used in the production of isocyanic acid. Sodium cyanate is prepared commercially by reacting urea, $(\text{NH}_2)_2\text{CO}$, with sodium carbonate. Other products in this reaction are carbon dioxide, ammonia and steam.

Write an equation for the production of NaNCO by this method.

..... [1]

10. Question part 2/4 | 9701 May-June 2017 P4 V3 Q2

- (c) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is completely ionised in aqueous solutions. During the addition of 30.0 cm^3 of 0.100 mol dm^{-3} $\text{Ba}(\text{OH})_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid, the pH was measured.

- (i) Calculate the $[\text{OH}^-]$ at the end of the addition.

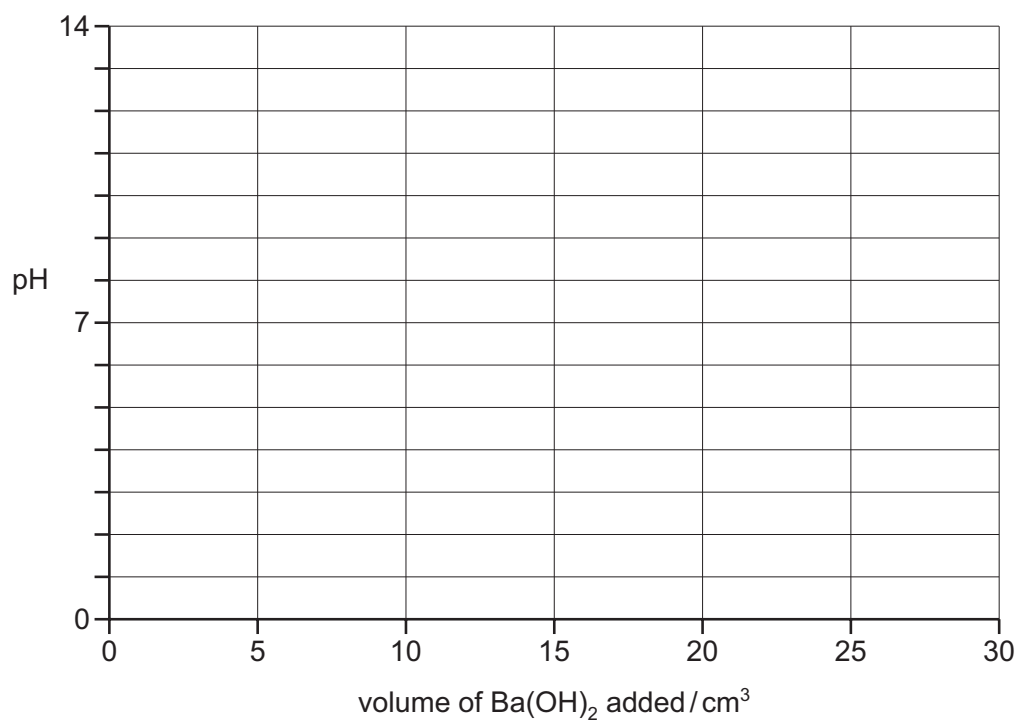
$[\text{OH}^-] = \dots\dots\dots \text{ mol dm}^{-3}$ [2]

- (ii) Use your value in (i) to calculate $[\text{H}^+]$ and the pH of the solution at the end of the addition.

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

final pH = $\dots\dots\dots$
[2]

- (iii) On the following axes, sketch how the pH changes during the addition of a total of 30.0 cm^3 of 0.100 mol dm^{-3} $\text{Ba}(\text{OH})_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid.



[3]

(d) The cyanate ion, NCO^- , can act as a *monodentate ligand*.

(i) State what is meant by the terms

monodentate, ...

.....

ligand.

.....

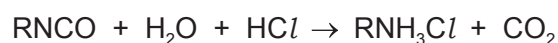
[2]

Silver ions, Ag^+ , react with cyanate ions to form a linear complex.

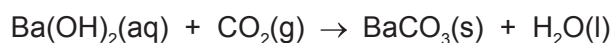
(ii) Suggest the formula of this complex, including its charge.

..... [2]

(e) When heated with $\text{HCl}(\text{aq})$, organic isocyanates, RNCO , are hydrolysed to the amine salt, RNH_3Cl , and CO_2 .



A 1.00 g sample of an organic isocyanate, RNCO , was treated in this way, and the CO_2 produced was absorbed in an excess of aqueous $\text{Ba}(\text{OH})_2$ according to the equation shown. The solid BaCO_3 precipitated weighed 1.66 g.



(i) Calculate the number of moles of BaCO_3 produced.

moles of BaCO_3 = ... [1]

(ii) Hence calculate the M_r of the organic isocyanate RNCO .

M_r of RNCO = ... [1]

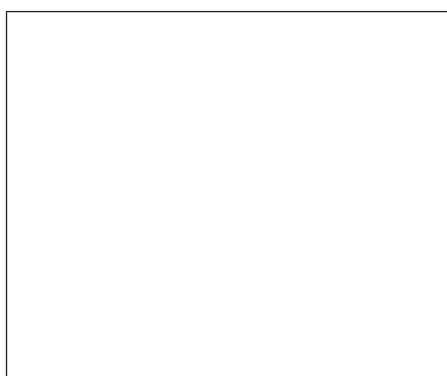
10. Question part 4/4 | 9701 May-June 2017 P4 V3 Q2

The R group in RNCO and RNH_3Cl contains carbon and hydrogen only.

- (iii) Use your M_r value calculated in (ii) to suggest the molecular formula of the organic isocyanate RNCO .

molecular formula of RNCO [1]

- (iv) Suggest a possible structure of the amine RNH_2 , which forms the amine salt, RNH_3Cl .

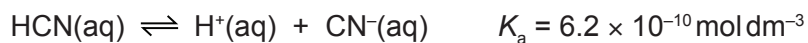


[1]

[Total: 23]

11. Question part 1/2 | 9701 Feb-March 2018 P4 V2 Q3

- 3 (a) Hydrogen cyanide, HCN, is a weak acid in aqueous solution.



- (i) Calculate the pH of 0.10 mol dm^{-3} HCN(aq).

pH = ... [2]

- (ii) Draw a 'dot-and-cross' diagram to represent the bonding in the hydrogen cyanide molecule. Show the outer shell electrons only.

[1]

- (iii) State the hybridisation of the carbon and nitrogen atoms in hydrogen cyanide, and give the H–C–N bond angle.

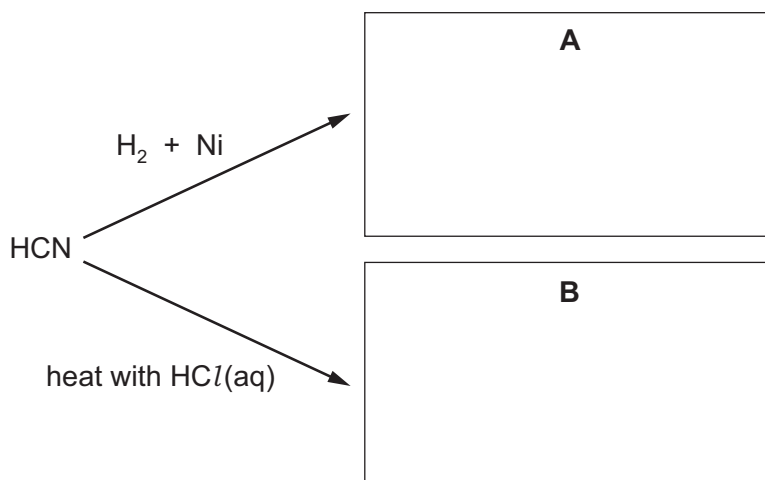
hybridisation of C

hybridisation of N

H–C–N bond angle

[2]

- (iv) Suggest structures for the organic products **A** and **B** in the following reactions. Assume that HCN reacts in a similar way to RCN.



[2]

11. Question part 2/2 | 9701 Feb-March 2018 P4 V2 Q3

(b) Adding a measured quantity of KCN to a solution of NiCl_2 produces the complex $[\text{Ni}(\text{CN})_2\text{Cl}_2]^x$.

(i) Deduce the overall charge, x , on this complex.

$x = \dots\dots\dots$ [1]

The complex can exist as two separate isomers with the same geometry (shape) around the nickel ion.

(ii) State the type of isomerism shown by these isomers.

$\dots\dots\dots$ [1]

(iii) If bromide ions are present in the solution, the complex $[\text{Ni}(\text{CN})_2\text{ClBr}]^x$ can form.

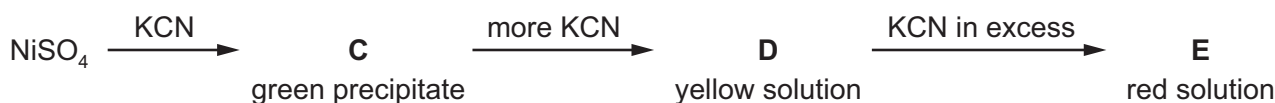
Assuming that $[\text{Ni}(\text{CN})_2\text{ClBr}]^x$ has the same geometry as $[\text{Ni}(\text{CN})_2\text{Cl}_2]^x$, state the number of isomers of $[\text{Ni}(\text{CN})_2\text{ClBr}]^x$ that could exist, and draw their structures in the box.

- number of isomers of $[\text{Ni}(\text{CN})_2\text{ClBr}]^x \dots\dots\dots$

structures of the isomers of $[\text{Ni}(\text{CN})_2\text{ClBr}]^x$

[3]

(c) An aqueous solution of KCN is gradually added to a solution of NiSO_4 until the KCN is in excess. The following series of reactions takes place.



- The oxidation state of nickel does **not** change during these reactions.
- None of **C**, **D** or **E** contains sulfur.
- C** contains no potassium.
- The K:Ni ratio in **D** is 2:1.
- The K:Ni ratio in **E** is 3:1.

Use the information to suggest the formulae of **C**, **D** and **E**.

C $\dots\dots\dots$

D $\dots\dots\dots$

E $\dots\dots\dots$

[3]

[Total: 15]

12. Question part 1/3 | 9701 Oct-Nov 2018 P4 V1 Q4

- 4 (a) The enthalpy change of solution, $\Delta H_{\text{sol}}^{\circ}$, of the Group 2 sulfates becomes more endothermic down the group.

State and explain the trend in the solubility of the Group 2 sulfates down the group.

.....

.....

.....

.....

..... [3]

- (b) (i) Write the expression for K_w , the ionic product of water.

$$K_w =$$

[1]

- (ii) The numerical value of K_w increases with increasing temperature.

Place a tick (✓) in the appropriate column in each row to show the effect of increasing the temperature of water on the pH and on the ratio $[\text{H}^+] : [\text{OH}^-]$.

effect of increasing temperature of water	decrease	stay the same	increase
pH			
ratio $[\text{H}^+] : [\text{OH}^-]$			

[2]

- (c) An aqueous solution of sodium hydroxide has a pH of 13.25 at 298 K.

Calculate the concentration of this sodium hydroxide solution.

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

12. Question part 2/3 | 9701 Oct-Nov 2018 P4 V1 Q4

- (d) Buffer solutions are used to regulate the pH of a solution to keep its pH value within a narrow range.

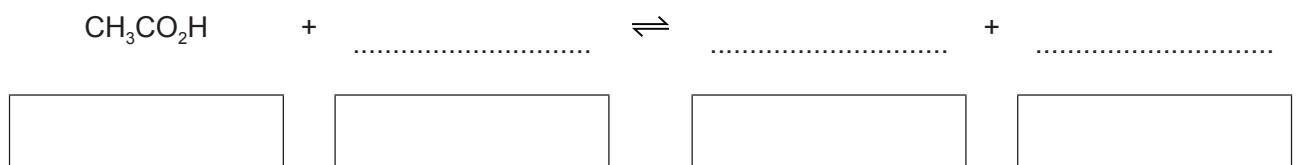
Write **two** equations to describe how hydrogencarbonate ions, HCO_3^- , and carbonic acid, H_2CO_3 , control the pH of blood.

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

- (e) The K_a for ethanoic acid is $1.75 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

- (i) When ethanoic acid is dissolved in water, an equilibrium mixture containing two acid-base pairs is formed.

Write an equation for this equilibrium. In the boxes label each species acidic or basic to show its behaviour in this equilibrium.



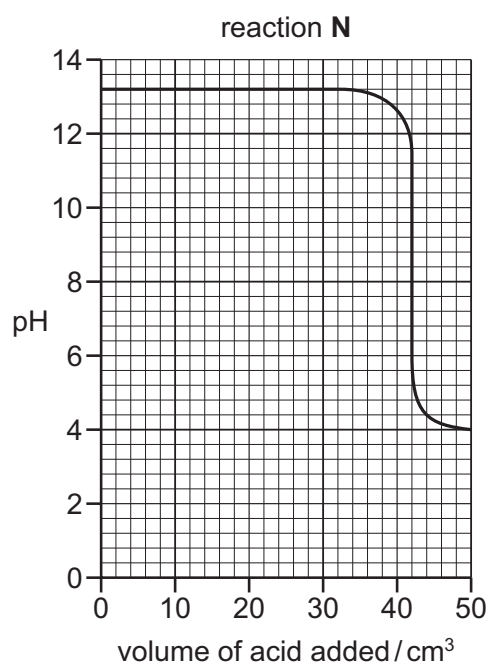
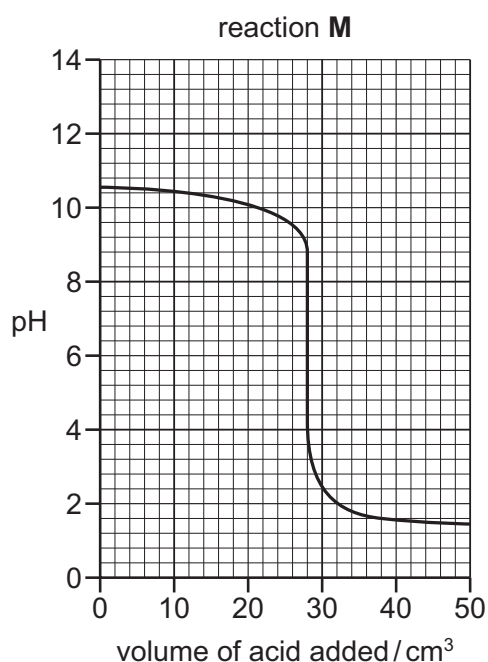
[2]

- (ii) A buffer solution was prepared by adding 30.0 cm^3 of 0.25 mol dm^{-3} ethanoic acid, an excess, to 20.0 cm^3 of 0.15 mol dm^{-3} sodium hydroxide.

Calculate the pH of the buffer solution formed at 298 K. Give your answer to **one** decimal place.

pH = ... [4]

(f) Titration curves for two different acid-base reactions, **M** and **N**, are shown.



- (i) Use the titration curve for reaction **M** to deduce the volume of acid added at the end-point for this titration.

volume of acid added at the end-point = ... cm³ [1]

- (ii) The table shows some acid-base indicators.

name of indicator	pH range of colour change
malachite green	0.2–1.8
bromocresol green	3.8–5.4
bromothymol blue	6.0–7.6
thymolphthalein	9.3–10.6

Name a suitable indicator for each of the acid-base titrations **M** and **N**. Explain your answers.

reaction **M** reaction **N**

explanation

.....

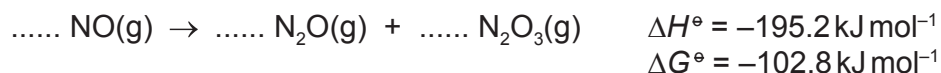
[2]

[Total: 19]

- 1 (a) State **one** natural and **one** man-made occurrence of oxides of nitrogen.

.....
 [1]

- (b) Under conditions of high pressure and a catalyst, nitrogen monoxide, NO, forms two other oxides of nitrogen, dinitrogen monoxide, N₂O, and dinitrogen trioxide, N₂O₃.



- (i) Balance the equation above for the formation of N₂O and N₂O₃ from NO. [1]

- (ii) State how the oxidation number of nitrogen changes during this reaction.

NO → N₂O from to

NO → N₂O₃ from to [1]

- (iii) Calculate the entropy change for the reaction at 298 K. Include the units in your answer.

$\Delta S^\circ = \text{.....}$

units = ... [2]

- (iv) State whether the sign of ΔS° calculated in (iii) agrees with that predicted from your balanced equation in (i). Explain your answer.

.....
 [1]

13. Question part 2/4 | 9701 Feb-March 2019 P4 V2 Q1

(c) At room temperature N_2O_3 dissociates.



(i) Write the expression for K_p for this equilibrium. Include the units in your answer.

$$K_p =$$

units = ...

[1]

A 1.00 dm^3 flask at 25°C is filled with pure $\text{N}_2\text{O}_3(\text{g})$ at an initial pressure of 0.60 atm .
At equilibrium, the partial pressure of $\text{NO}_2(\text{g})$ is 0.48 atm .

(ii) Calculate the partial pressures of $\text{NO}(\text{g})$ and $\text{N}_2\text{O}_3(\text{g})$ at equilibrium. Hence calculate the value of K_p at 25°C .

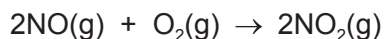
$$p(\text{NO}(\text{g})) = \dots\dots\dots$$

$$p(\text{N}_2\text{O}_3(\text{g})) = \dots\dots\dots$$

$$K_p = \dots\dots\dots$$

[2]

(d) NO reacts readily with oxygen.



The table shows how the initial rate of this reaction at 25 °C depends on the initial concentrations of the reactants.

initial concentration / mol dm ⁻³		initial rate / mol dm ⁻³ s ⁻¹
[NO(g)]	[O ₂ (g)]	
0.100	0.0500	3.50
0.0500	0.100	1.75
0.0500	0.0500	0.875

(i) Deduce the order of reaction with respect to each reactant. Explain your reasoning.

order with respect to [NO(g)]

.....

order with respect to [O₂(g)]

.....

[2]

(ii) State the rate equation for this reaction. Use the rate equation to calculate the rate constant. Include the units for the rate constant in your answer.

rate =

rate constant, k = ...

units of k = ...

[3]

13. Question part 4/4 | 9701 Feb-March 2019 P4 V2 Q1

- (e) NO reacts with iron pentacarbonyl, $\text{Fe}(\text{CO})_5$, as shown. NO and CO are both monodentate ligands.



During this reaction the co-ordination number of the iron changes.

- (i) State what is meant by the term *co-ordination number*.

.....
 [1]

- (ii) Describe how the co-ordination number of the iron changes during this reaction.

from to [1]

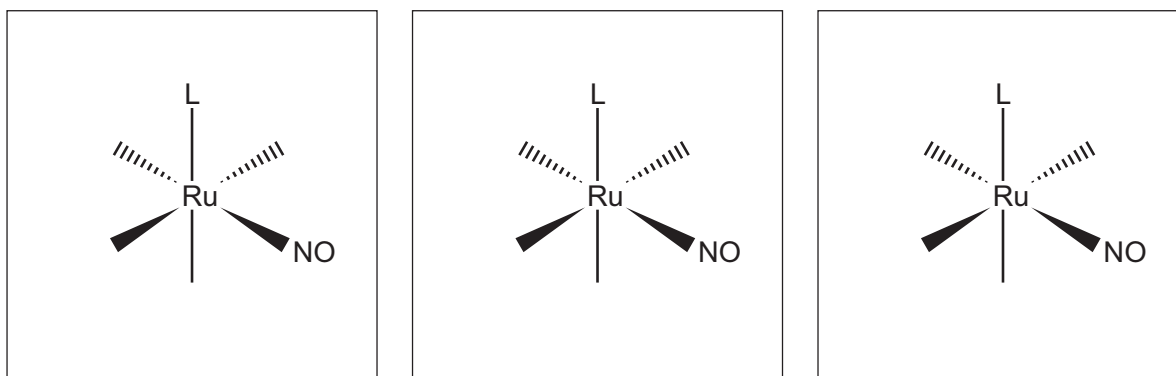
- (iii) Only one stereoisomer of $\text{Fe}(\text{CO})_2(\text{NO})_2$ exists.

Use this information to suggest the geometry of the complex.

..... [1]

- (f) The complex $\text{Ru}(\text{NO})\text{L}_2\text{Cl}_3$ exists in three isomeric forms. L represents the monodentate ligand $\text{C}_6\text{H}_5\text{P}(\text{CH}_3)_2$.

- (i) Complete the three-dimensional diagrams to show the **three** isomers of $\text{Ru}(\text{NO})\text{L}_2\text{Cl}_3$.



[2]

- (ii) Suggest the type of isomerism shown.

..... [1]

[Total: 20]

14. Question | 9701 Feb-March 2019 P4 V2 Q3

3 (a) (i) Use mathematical expressions to define the following terms.

- pH = ...
.....
 - K_a for a weak acid, HA = ...
.....
- [2]

(ii) Write equations to show how a buffer solution consisting of a mixture of HA(aq) and NaA(aq) controls pH when an acid or an alkali is added.

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

(b) When chlorine dissolves in water the following reaction occurs.



When solutions of chlorine are used for water purification, the pH of the solution of chlorine is kept near to pH 7 by the addition of a base.

Chlorine is dissolved in water to produce 1000 cm³ of a solution containing 0.170 mol of HClO and 0.170 mol of HCl.

A buffer solution is then prepared by adding 0.200 mol of NaOH(s) to this solution. The NaOH reacts initially with the HCl.

Calculate the pH of the buffer solution.

[HClO is a weak acid with $K_a = 2.9 \times 10^{-8} \text{ mol dm}^{-3}$.]

pH = ... [3]

[Total: 7]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

15. Question part 1/2 | 9701 Oct-Nov 2019 P4 V1 Q5

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

(a) (i) Write an expression for the solubility product, K_{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_{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.

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

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

15. Question part 2/2 | 9701 Oct-Nov 2019 P4 V1 Q5

(b) Bromic(I) acid, 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 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) .

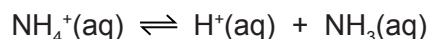
Calculate the pH of the buffer solution produced.

pH = ... [2]

[Total: 9]

16. Question part 1/2 | 9701 Oct-Nov 2019 P4 V2 Q3

- 3** 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.

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

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

16. Question part 2/2 | 9701 Oct-Nov 2019 P4 V2 Q3

- (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.

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

[Total: 8]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

17. Question part 1/2 | 9701 Oct-Nov 2019 P4 V3 Q5

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

(a) (i) Write an expression for the solubility product, K_{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_{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.

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

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

17. Question part 2/2 | 9701 Oct-Nov 2019 P4 V3 Q5

(b) Bromic(I) acid, 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 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]

[Total: 9]

18. Question part 1/2 | 9701 May-June 2020 P4 V1 Q7

- 7 (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.

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

units = ... [2]

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

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

(iii) Solid Ag_2CO_3 is stirred at 25°C with $0.050 \text{ mol dm}^{-3} \text{ AgNO}_3$ until no more Ag_2CO_3 dissolves.

Calculate the concentration of carbonate ions, $[\text{CO}_3^{2-}]$, in this solution.

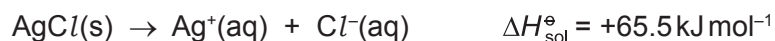
$$[\text{CO}_3^{2-}] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

(iv) An electrochemical cell is set up to measure the electrode potential, E , for the Ag^+/Ag half-cell using the saturated $\text{Ag}_2\text{CO}_3(\text{aq})$ with a standard hydrogen electrode.

Use the *Data Booklet*, your answer to (a)(ii), and the Nernst equation to calculate the electrode potential, E , for this Ag^+/Ag half-cell.

$$E \text{ for } \text{Ag}^+/\text{Ag} \text{ half-cell} = \dots\dots\dots \text{V} \quad [2]$$

- (b) Silver chloride, AgCl , is sparingly soluble in water. The equation for the enthalpy change of solution is shown.



Standard entropies are shown in the table.

species	AgCl(s)	$\text{Ag}^+(\text{aq})$	$\text{Cl}^-(\text{aq})$
$S^{\ominus} / \text{J K}^{-1} \text{ mol}^{-1}$	+96.2	+72.7	+56.5

- (i) Calculate the standard entropy change of solution, $\Delta S^{\ominus}$.

$$\Delta S^{\ominus} = \dots\dots\dots \text{J K}^{-1} \text{ mol}^{-1} \quad [1]$$

- (ii) Explain, with the aid of a calculation, why AgCl is insoluble in water at 25°C .

You should use data from this question and your answer to (b)(i).

.....
 [3]

[Total: 10]

- 8 (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 5.6×10^{-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]

[Total: 8]

- 8 (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 5.6×10^{-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]

[Total: 8]

21. Question | 9701 Oct-Nov 2020 P4 V1 Q4

- 4 (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, 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]

- (c) Water and octan-1-ol form two layers when mixed.

Ethanamide is more soluble in water than it is in octan-1-ol. When 1.00 g of ethanamide is added to 50.0 cm^3 of water and this is then shaken with 50.0 cm^3 of octan-1-ol, it is found that the water layer contains 0.935 g of ethanamide at equilibrium.

- (i) Calculate the partition coefficient, K_{pc} , for ethanamide in water and octan-1-ol.

K_{pc} = ... [1]

- (ii) The 50.0 cm^3 of water containing 0.935 g of ethanamide is then shaken with 100.0 cm^3 of pure octan-1-ol under the same conditions.

Calculate the mass of ethanamide that is dissolved in the 100.0 cm^3 of octan-1-ol at equilibrium.

mass of ethanamide = ... g
[2]

[Total: 7]

- 2 (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 $1.00 \times 10^{-3} \text{ mol dm}^{-3}$ solution of hydroxylammonium ions has a pH of 4.41.

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

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

- (ii) Calculate the $\text{p}K_a$ of HONH_3^+ .

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

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

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

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

[Total: 6]

- 4 (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, 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]

- (c) Water and octan-1-ol form two layers when mixed.

Ethanamide is more soluble in water than it is in octan-1-ol. When 1.00 g of ethanamide is added to 50.0 cm^3 of water and this is then shaken with 50.0 cm^3 of octan-1-ol, it is found that the water layer contains 0.935 g of ethanamide at equilibrium.

- (i) Calculate the partition coefficient, K_{pc} , for ethanamide in water and octan-1-ol.

K_{pc} = ... [1]

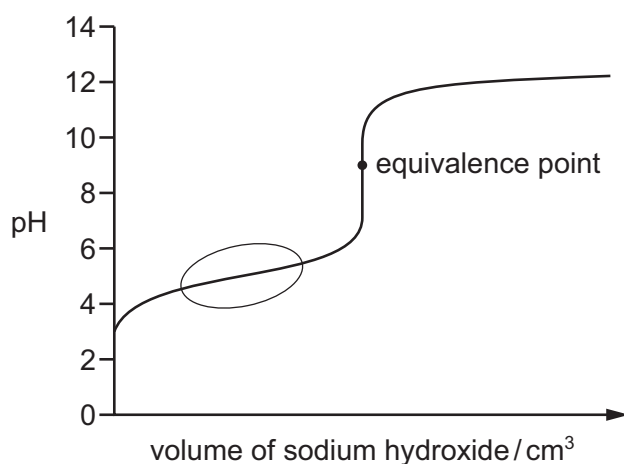
- (ii) The 50.0 cm^3 of water containing 0.935 g of ethanamide is then shaken with 100.0 cm^3 of pure octan-1-ol under the same conditions.

Calculate the mass of ethanamide that is dissolved in the 100.0 cm^3 of octan-1-ol at equilibrium.

mass of ethanamide = ... g
[2]

[Total: 7]

- 8 (a) The sketch graph for the titration of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, with sodium hydroxide is shown.



- (i) In the region circled on the graph, identify the **two** organic species that are present in the solution. Explain why the pH of the mixture only changes slowly and gradually in this region when sodium hydroxide is being added.

two species present

.....
.....
.....
..... [3]

- (ii) The equivalence point in this acid-base titration is where the two solutions have been mixed in exactly equal molar proportion.

Suggest why the pH is greater than 7 at the equivalence point in this titration.

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

24. Question part 2/2 | 9701 May-June 2021 P4 V1 Q8

- (b) An impure sample of ammonium vanadate(V), NH_4VO_3 , with mass 0.150 g, is dissolved in an excess of dilute acid.

In this solution all vanadium is present as VO_2^+ ions. An excess of zinc powder is added to the solution and all the VO_2^+ ions are reduced to V^{2+} ions. The mixture is filtered to remove any remaining zinc powder.



When the resulting solution is titrated, 20.10 cm^3 of $0.0250 \text{ mol dm}^{-3}$ acidified MnO_4^- oxidises all V^{2+} ions back to VO_2^+ ions.



Calculate the percentage by mass of NH_4VO_3 in the 0.150 g impure sample of NH_4VO_3 .

Give your answer to **three** significant figures.

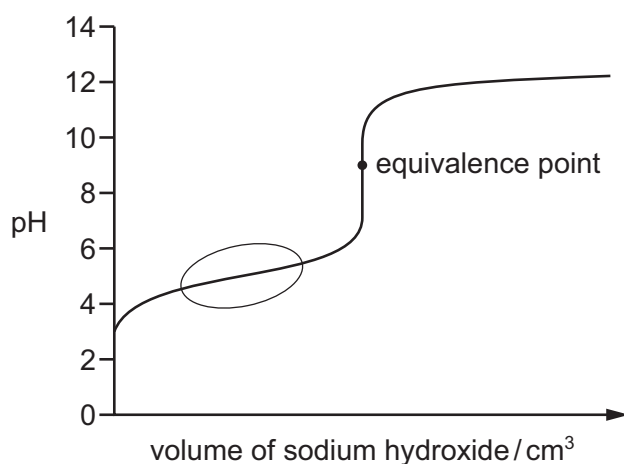
[M_r : NH_4VO_3 , 116.9]

percentage by mass of NH_4VO_3 = ... % [3]

[Total: 7]

25. Question part 1/2 | 9701 May-June 2021 P4 V3 Q8

- 8 (a) The sketch graph for the titration of ethanoic acid, $\text{CH}_3\text{CO}_2\text{H}$, with sodium hydroxide is shown.



- (i) In the region circled on the graph, identify the **two** organic species that are present in the solution. Explain why the pH of the mixture only changes slowly and gradually in this region when sodium hydroxide is being added.

two species present

.....
.....
.....
..... [3]

- (ii) The equivalence point in this acid-base titration is where the two solutions have been mixed in exactly equal molar proportion.

Suggest why the pH is greater than 7 at the equivalence point in this titration.

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

25. Question part 2/2 | 9701 May-June 2021 P4 V3 Q8

- (b) An impure sample of ammonium vanadate(V), NH_4VO_3 , with mass 0.150 g, is dissolved in an excess of dilute acid.

In this solution all vanadium is present as VO_2^+ ions. An excess of zinc powder is added to the solution and all the VO_2^+ ions are reduced to V^{2+} ions. The mixture is filtered to remove any remaining zinc powder.



When the resulting solution is titrated, 20.10 cm^3 of $0.0250 \text{ mol dm}^{-3}$ acidified MnO_4^- oxidises all V^{2+} ions back to VO_2^+ ions.



Calculate the percentage by mass of NH_4VO_3 in the 0.150 g impure sample of NH_4VO_3 .

Give your answer to **three** significant figures.

[M_r : NH_4VO_3 , 116.9]

percentage by mass of NH_4VO_3 = ... % [3]

[Total: 7]

26. Question part 1/2 | 9701 Oct-Nov 2021 P4 V1 Q2

- 2** 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_{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_{a} and $\text{p}K_{\text{a}}$.

..... [1]

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

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

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

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

(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 $1.35 \times 10^{-5} \text{ mol dm}^{-3}$.

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

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

26. Question part 2/2 | 9701 Oct-Nov 2021 P4 V1 Q2

- (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]

[Total: 10]

27. Question part 1/2 | 9701 Oct-Nov 2021 P4 V2 Q2

- 2 Ethoxyethane, $\text{C}_2\text{H}_5\text{OC}_2\text{H}_5$, 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.

$$K_{\text{pc}} = \frac{\text{concentration of } \text{C}_2\text{H}_5\text{OC}_2\text{H}_5 \text{ in octan-1-ol}}{\text{concentration of } \text{C}_2\text{H}_5\text{OC}_2\text{H}_5 \text{ in water}} = 6.760 \text{ at } 20^\circ\text{C}$$

- (a) In an experiment, octan-1-ol at 20°C is added to a solution of ethoxyethane in water at 20°C . The mixture is analysed immediately and a value of K_{pc} is calculated.

The calculation is performed correctly; the value calculated is 5.625.

Explain why the value calculated is **less** than 6.760.

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

- (b) A second experiment is performed and the value of K_{pc} is found to be 6.760. The concentration of ethoxyethane in the octan-1-ol layer is 7.62 g dm^{-3} .

- (i) Calculate the concentration, in g dm^{-3} , of ethoxyethane in the aqueous layer.

..... g dm^{-3} [1]

- (ii) 100 cm^3 of the octan-1-ol layer is taken and shaken with 100 cm^3 of water.

Calculate the maximum amount, in mol, of ethoxyethane that can be extracted into the water.

..... mol [3]

- (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} .

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

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**.

$\dots\dots\dots$

$\dots\dots\dots$

$\dots\dots\dots$ [2]

[Total: 10]

28. Question part 1/2 | 9701 Oct-Nov 2021 P4 V3 Q2

- 2** 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_{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_{a} and $\text{p}K_{\text{a}}$.

..... [1]

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

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

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

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

(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 $1.35 \times 10^{-5} \text{ mol dm}^{-3}$.

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

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

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

28. Question part 2/2 | 9701 Oct-Nov 2021 P4 V3 Q2

- (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]

[Total: 10]

- 4 (a)** A sample of butanoic acid, $\text{CH}_3(\text{CH}_2)_2\text{COOH}$, is shaken with a mixture of two immiscible solvents, ethoxyethane and water. The solvents form two layers. The butanoic acid is distributed between the two layers, its concentration in ethoxyethane being higher than its concentration in water.

(i) State what is meant by partition coefficient.

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

- (ii)** The partition coefficient, K_{pc} , for butanoic acid between ethoxyethane and water is 3.50.

A solution of 2.00 g of butanoic acid in 100cm^3 ethoxyethane is added to water. This mixture is left until there is no further change in the concentration of butanoic acid in either solvent. The mass of butanoic acid dissolved in the ethoxyethane layer is now 1.62 g.

Calculate the volume of water used.

volume of water used = ... cm^3 [2]

- (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]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

29. Question part 2/2 | 9701 Oct-Nov 2022 P4 V1 Q4

(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.

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

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

[3]

[Total: 9]

30. Question part 1/2 | 9701 Oct-Nov 2022 P4 V2 Q4

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

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

- (i) Calculate the solubility of $\text{Fe}(\text{OH})_3$ in water.

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

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

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

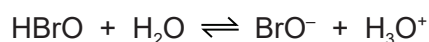
- (iii) $\text{Fe}(\text{OH})_3$ is less soluble in $\text{Ba}(\text{OH})_2(\text{aq})$ than it is in pure water.

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 $4.00 \times 10^{-3} \text{ mol}$ 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.



- (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]

[Total: 9]

31. Question part 1/2 | 9701 Oct-Nov 2022 P4 V3 Q4

- 4 (a)** A sample of butanoic acid, $\text{CH}_3(\text{CH}_2)_2\text{COOH}$, is shaken with a mixture of two immiscible solvents, ethoxyethane and water. The solvents form two layers. The butanoic acid is distributed between the two layers, its concentration in ethoxyethane being higher than its concentration in water.

- (i)** State what is meant by partition coefficient.

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

- (ii)** The partition coefficient, K_{pc} , for butanoic acid between ethoxyethane and water is 3.50.

A solution of 2.00 g of butanoic acid in 100cm^3 ethoxyethane is added to water. This mixture is left until there is no further change in the concentration of butanoic acid in either solvent. The mass of butanoic acid dissolved in the ethoxyethane layer is now 1.62 g.

Calculate the volume of water used.

volume of water used = ... cm^3 [2]

- (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]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

31. Question part 2/2 | 9701 Oct-Nov 2022 P4 V3 Q4

(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.

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

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

[3]

[Total: 9]

- 1 (a) (i) State what is meant by partition coefficient.

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

Ammonia is soluble in both water and organic solvents.

An aqueous solution of ammonia is shaken with the immiscible organic solvent trichloromethane. The mixture is left to reach equilibrium.

Samples are taken from each layer and titrated with dilute hydrochloric acid.

- A 25.0 cm^3 sample from the trichloromethane layer requires 13.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ HCl to reach the end-point.
- A 10.0 cm^3 sample from the aqueous layer requires 12.5 cm^3 of $0.100 \text{ mol dm}^{-3}$ HCl to reach the end-point.

- (ii) Calculate the partition coefficient, K_{pc} , of ammonia between trichloromethane and water. Show your working.

$$K_{\text{pc}} = \text{.....} [2]$$

- (iii) Butylamine, $\text{C}_4\text{H}_9\text{NH}_2$, is also soluble in both water and organic solvents.

Suggest how the numerical value of K_{pc} of butylamine between trichloromethane and water would compare to the value of K_{pc} calculated in (a)(ii). Explain your answer.

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

- (b) Butanamide, $\text{C}_3\text{H}_7\text{CONH}_2$, is much less basic than butylamine. Explain why.

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

[Total: 7]

- 5 (a) The exhaust systems of most modern gasoline-fuelled cars contain a catalytic converter with three metal catalysts.

These metals act as heterogeneous catalysts.

- (i) Name **three** metal catalysts used in catalytic converters.

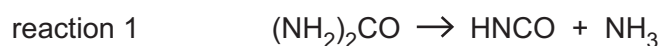
1 2 3 [1]

- (ii) Explain what is meant by a heterogeneous catalyst.

.....
 [1]

- (b) The exhaust systems of many diesel-fuelled cars contain an additional system to reduce vehicle emissions. This uses a liquid that is added to the exhaust system.

This liquid contains urea, $(\text{NH}_2)_2\text{CO}$, which decomposes on heating to isocyanic acid, HNCO , and ammonia.



Isocyanic acid reacts with water vapour to form ammonia and carbon dioxide.



Some values for standard enthalpy changes of formation, $\Delta H_f^\ominus$, and standard entropies, $S^\ominus$, are given in Table 5.1.

Table 5.1

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{HNCO}(\text{g})$	−101.7	+238.2
$\text{H}_2\text{O}(\text{g})$	−241.8	+188.8
$\text{NH}_3(\text{g})$	−45.9	+192.8
$\text{CO}_2(\text{g})$	−393.5	+213.8

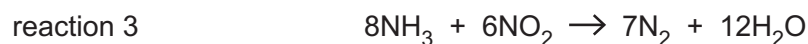
- (i) Explain what is meant by the term entropy of a system.

.....
 [1]

- (ii) Use the data in Table 5.1 to calculate $\Delta G^\ominus$ for **reaction 2** at 25 °C.
Show your working.

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (c) The ammonia formed in reactions 1 and 2 can be used to remove nitrogen dioxide from exhaust emissions, as shown.



Use the equations for reactions 1, 2 and 3 to construct an overall equation for the reduction of NO_2 by $(\text{NH}_2)_2\text{CO}$.

..... [1]

- (d) Isocyanic acid, HNCO , can form cyanuric acid, $\text{C}_3\text{H}_3\text{N}_3\text{O}_3$, under certain conditions.

$\text{C}_3\text{H}_3\text{N}_3\text{O}_3$ has a cyclic structure containing alternating carbon and nitrogen atoms in the ring system.

Suggest a structure for cyanuric acid.

[1]

(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 $0.120 \text{ mol dm}^{-3}$ $\text{HNCO}(\text{aq})$.
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 $\text{HNCO} = \dots\dots\dots$ [1]

[Total: 13]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

33. Question part 4/4 | 9701 May-June 2023 P4 V3 Q5

BLANK PAGE

34. Question part 1/2 | 9701 Oct-Nov 2023 P4 V1 Q2

- 2 (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 HCl 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 HCl in **V**.

concentration of HCl 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) $\text{CH}_3\text{CH}_2\text{COOH}$, $\text{CH}_3\text{CCl}_2\text{COOH}$ 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]

- (d) The partition coefficient, K_{pc} , of a substance, **Q**, between hexane and water is 7.84 at 298 K.

Q is more soluble in hexane than it is in water.

- (i) Define partition coefficient, K_{pc} .

.....
 [1]

- (ii) 5.00 g of **Q** is shaken with a mixture of 100.0 cm^3 of water and 100.0 cm^3 of hexane at 298 K and left until there is no further change in concentrations.

Calculate the mass of **Q** dissolved in the water.

mass of **Q** = ... g [1]

- (iii) A sample of **Q** is shaken with a different mixture of water and hexane and left until there is no further change in concentrations.

It is found that the mass of **Q** dissolved in each solvent is the same.

Use the K_{pc} value to suggest possible values for the volume of water used and the volume of hexane used.

volume of water = ... cm^3

volume of hexane = ... cm^3
 [1]

- (iv) **Q** is more soluble in hexane than it is in water.

It is suggested that **Q** is one of KCl , $\text{CH}_3(\text{CH}_2)_4\text{OH}$ or HCOOH .

Identify **Q**. Explain your answer.

.....
 [1]

[Total: 14]

35. Question part 1/2 | 9701 Oct-Nov 2023 P4 V2 Q2

- 2** Benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$, 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 dm^3 buffer solution is made at 298 K containing 1.00 g of $\text{C}_6\text{H}_5\text{COOH}$ and a slightly greater mass of sodium benzoate, $\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+$.

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 $\text{C}_6\text{H}_5\text{COOH}$ concentration in the buffer solution described. Use the expression for the K_a of $\text{C}_6\text{H}_5\text{COOH}$ to calculate the concentration of $\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+$ in the buffer solution.

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

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

$$[\text{C}_6\text{H}_5\text{COOH}] = \dots\dots\dots \text{mol dm}^{-3}$$

$$[\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+] = \dots\dots\dots \text{mol dm}^{-3}$$

[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, $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$, has a solubility in water of less than 1.00 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 g dm^{-3} .

Show your working.

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

solubility = ... 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 mol dm^{-3} 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]

[Total: 11]

36. Question part 1/2 | 9701 Oct-Nov 2023 P4 V3 Q2

- 2 (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 HCl 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 HCl in **V**.

concentration of HCl 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) $\text{CH}_3\text{CH}_2\text{COOH}$, $\text{CH}_3\text{CCl}_2\text{COOH}$ 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]

- (d) The partition coefficient, K_{pc} , of a substance, **Q**, between hexane and water is 7.84 at 298 K.

Q is more soluble in hexane than it is in water.

- (i) Define partition coefficient, K_{pc} .

.....
 [1]

- (ii) 5.00 g of **Q** is shaken with a mixture of 100.0 cm^3 of water and 100.0 cm^3 of hexane at 298 K and left until there is no further change in concentrations.

Calculate the mass of **Q** dissolved in the water.

mass of **Q** = ... g [1]

- (iii) A sample of **Q** is shaken with a different mixture of water and hexane and left until there is no further change in concentrations.

It is found that the mass of **Q** dissolved in each solvent is the same.

Use the K_{pc} value to suggest possible values for the volume of water used and the volume of hexane used.

volume of water = ... cm^3

volume of hexane = ... cm^3
 [1]

- (iv) **Q** is more soluble in hexane than it is in water.

It is suggested that **Q** is one of KCl , $\text{CH}_3(\text{CH}_2)_4\text{OH}$ or HCOOH .

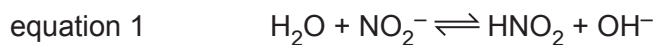
Identify **Q**. Explain your answer.

.....
 [1]

[Total: 14]

2 Water is an amphoteric compound that also acts as a good solvent of polar and ionic compounds.

(a) Equation 1 shows water acting as a Brønsted–Lowry acid.



(i) Identify the **two** conjugate acid–base pairs in equation 1.

acid I conjugate base of acid I

acid II conjugate base of acid II

[1]

(ii) Water also behaves as a Brønsted–Lowry acid when it dissolves CH_3NH_2 .

Explain the ability of CH_3NH_2 to act as a base.

..... [1]

(iii) Write an equation to show water acting as a base with CH_3COOH .

..... [1]

(b) The ionic product of water, K_w , measures the extent to which water dissociates.

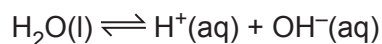


Fig. 2.1 shows how K_w varies with temperature.

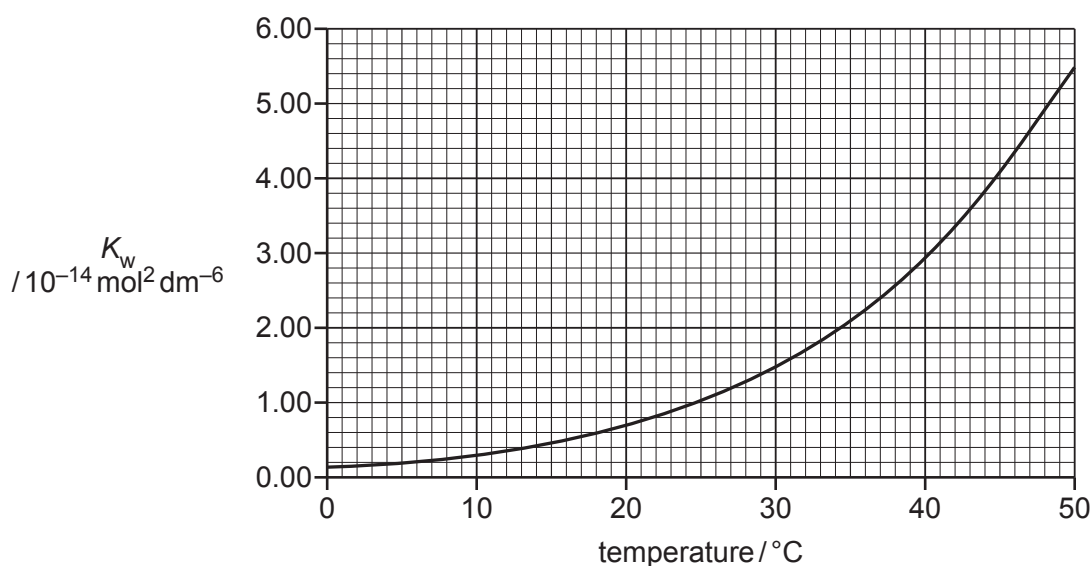


Fig. 2.1

(i) Write an expression for K_w .

..... [1]

37. Question part 2/4 | 9701 Feb-March 2024 P4 V2 Q2

- (ii) Use information from Fig. 2.1 to deduce whether the dissociation of water is an exothermic or an endothermic process.

Explain your answer.

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

- (iii) An aqueous solution has $\text{pH} = 7.00$ at 30°C .

Use information from Fig. 2.1 to explain why this solution can be considered to be alkaline at 30°C .

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

- (c) The three physical states of H_2O have different standard entropies, $S^\ominus$, associated with them. Table 2.1 shows these $S^\ominus$ values.

Table 2.1

state of H_2O	standard entropy, $S^\ominus/\text{JK}^{-1}\text{mol}^{-1}$
solid	+48.0
liquid	+70.1
gas	+188.7

- (i) Explain the difference in the $S^\ominus$ values of $\text{H}_2\text{O}(\text{s})$ and $\text{H}_2\text{O}(\text{l})$.

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

- (ii) Explain why the increase in $S^\ominus$ is **much** greater when H_2O boils than when it melts.

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

- (iii) The energy changes for $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\text{l})$ are shown.

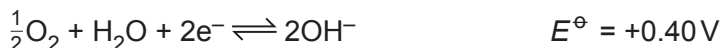
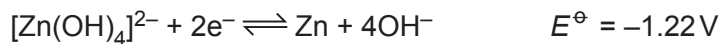
$$\begin{aligned}\Delta G &= 0.00 \text{ kJ mol}^{-1} \\ \Delta H &= +6.03 \text{ kJ mol}^{-1}\end{aligned}$$

Use these data to show that the melting point of $\text{H}_2\text{O}(\text{s})$ is 0°C .

[1]

- (d) Metal–air batteries are electrochemical cells that generate electrical energy from the reaction of metal anodes with air.

The standard electrode potentials for the zinc–air battery are shown.



- (i) Calculate the standard cell potential, $E_{\text{cell}}^\ominus$, of the zinc–air battery.

$$E_{\text{cell}}^\ominus = \dots\dots\dots \text{V} \quad [1]$$

- (ii) The zinc–air battery usually operates at pH 11 and 298 K. The overall cell potential is dependent on $[\text{OH}^-]$.

The Nernst equation shows how the electrode potential at the cathode changes with $[\text{OH}^-]$.

$$E = 0.40 - \left(\frac{0.059}{z} \right) \log([\text{OH}^-]^2)$$

Calculate the electrode potential, E , at pH 11.

$$E = \dots\dots\dots \text{V} \quad [2]$$

[Total: 13]

38. Question part 1/2 | 9701 May-June 2024 P4 V1 Q1

- 1 (a) (i) Describe the trend in the solubility of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

..... > >
most soluble least soluble

.....

.....

.....

.....

.....

.....

[4]

- (ii) Suggest the variation in pH of saturated solutions of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

.....

.....

..... [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]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

38. Question part 2/2 | 9701 May-June 2024 P4 V1 Q1

(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_{sp} , of $\text{Fe}(\text{OH})_2$.

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

[1]

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

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

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

[2]

[Total: 12]

39. Question part 1/2 | 9701 May-June 2024 P4 V2 Q6

- 6 (a)** Aqueous solutions of methanoic acid, 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 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.

..... + H_2O $\rightleftharpoons$ + ... [1]

- (b) (i)** Write an expression for the acid dissociation constant, K_{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 mol dm^{-3} , of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ in this solution.

concentration of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} = \dots\dots\dots \text{mol dm}^{-3}$ [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 $1.78 \times 10^{-5}\text{ mol dm}^{-3}$.

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

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

- (d) A fuel cell is an electrochemical cell that can be used to generate electrical energy by using oxygen to oxidise a fuel.

Methanoic acid, HCOOH , is being investigated as a fuel in fuel cells.

When the cell operates, HCOOH is oxidised to carbon dioxide.

The half-equation for the reaction at the cathode is: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$.

In this fuel cell, the overall cell reaction is the same as that for the complete combustion of HCOOH .

- (i) Deduce the half-equation for the reaction at the anode.

..... [1]

- (ii) Calculate the volume, in cm^3 , of oxygen used when a current of 3.75 A is delivered by the cell for 40.0 minutes. Assume the cell operates at room conditions.

volume of oxygen = ... cm^3 [2]

- 1 (a) (i) Describe the trend in the solubility of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

..... > >
most soluble least soluble

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

[4]

- (ii) Suggest the variation in pH of saturated solutions of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

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

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

A 250.0 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 $\text{Ba}(\text{OH})_2$ = ... g [4]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

40. Question part 2/2 | 9701 May-June 2024 P4 V3 Q1

(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_{sp} , of $\text{Fe}(\text{OH})_2$.

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

[1]

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

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

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

[2]

[Total: 12]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

41. Question part 1/2 | 9701 Oct-Nov 2024 P4 V1 Q1

1 (a) Disodium phosphate, $(\text{Na}^+)_2(\text{HPO}_4^{2-})$, reacts with an acid to form monosodium phosphate, $\text{Na}^+(\text{H}_2\text{PO}_4^-)$.

(i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid

conjugate base

..... [1]

(ii) Define buffer solution.

..... [2]

(iii) Write **two** equations to show how a mixture of $(\text{Na}^+)_2(\text{HPO}_4^{2-})$ and $\text{Na}^+(\text{H}_2\text{PO}_4^-)$ can act as a buffer solution.

equation 1

equation 2 [2]

(iv) Identify **one** inorganic ion that acts as a buffer in blood.

..... [1]

(b) Compound **E** is the hydroxide of a Group 2 element. Compound **E** is a strong alkali.

2.63 g of **E** is dissolved in water to make 250 cm^3 of solution **F**. Solution **F** has a pH of 13.09 at 298 K.

(i) Show that the concentration of hydroxide ions in solution **F** is 0.123 mol dm^{-3} .

[2]

(ii) Explain why the concentration of compound **E** in solution **F** is $0.0615\text{ mol dm}^{-3}$.

..... [1]

(iii) Use the concentration given in (ii) to identify compound **E**.

compound **E** [1]

41. Question part 2/2 | 9701 Oct-Nov 2024 P4 V1 Q1



(c) Compound **E** is much more soluble than magnesium hydroxide.

Asaturated solution of magnesium hydroxide in water has a concentration of $1.40 \times 10^{-4} \text{ mol dm}^{-3}$ at 298 K.

Calculate the solubility product, K_{sp} , of magnesium hydroxide. Include units.

$K_{\text{sp}} = \dots\dots\dots \text{ units } \dots\dots\dots$ [3]

(d) Explain why compound **E** is much more soluble than magnesium hydroxide.

.....

.....

.....

.....

.....

.....

.....

.....

..... [3]

[Total: 16]

3 (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_{sp} , of calcium hydroxide at 298 K.

Include the units of K_{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 $\dots\dots\dots$

[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]

- [1]

- [2]

[Total: 19]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

43. Question part 1/2 | 9701 Oct-Nov 2024 P4 V3 Q1

1 (a) Disodium phosphate, $(\text{Na}^+)_2(\text{HPO}_4^{2-})$, reacts with an acid to form monosodium phosphate, $\text{Na}^+(\text{H}_2\text{PO}_4^-)$.

(i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid

conjugate base

..... [1]

(ii) Define buffer solution.

..... [2]

(iii) Write **two** equations to show how a mixture of $(\text{Na}^+)_2(\text{HPO}_4^{2-})$ and $\text{Na}^+(\text{H}_2\text{PO}_4^-)$ can act as a buffer solution.

equation 1

equation 2 [2]

(iv) Identify **one** inorganic ion that acts as a buffer in blood.

..... [1]

(b) Compound **E** is the hydroxide of a Group 2 element. Compound **E** is a strong alkali.

2.63 g of **E** is dissolved in water to make 250 cm^3 of solution **F**. Solution **F** has a pH of 13.09 at 298 K.

(i) Show that the concentration of hydroxide ions in solution **F** is 0.123 mol dm^{-3} .

[2]

(ii) Explain why the concentration of compound **E** in solution **F** is $0.0615\text{ mol dm}^{-3}$.

..... [1]

(iii) Use the concentration given in (ii) to identify compound **E**.

compound **E** [1]

43. Question part 2/2 | 9701 Oct-Nov 2024 P4 V3 Q1



(c) Compound **E** is much more soluble than magnesium hydroxide.

A saturated solution of magnesium hydroxide in water has a concentration of $1.40 \times 10^{-4} \text{ mol dm}^{-3}$ at 298 K.

Calculate the solubility product, K_{sp} , of magnesium hydroxide. Include units.

$K_{\text{sp}} = \dots\dots\dots$ units $\dots\dots\dots$ [3]

(d) Explain why compound **E** is much more soluble than magnesium hydroxide.

.....

.....

.....

.....

.....

.....

.....

.....

..... [3]

[Total: 16]

44. Question part 1/2 | 9701 May-June 2025 P4 V1 Q3

- 3 (a) Chromium(III) hydroxide, $\text{Cr}(\text{OH})_3$, is only slightly soluble in water. The value of the solubility product, K_{sp} , of $\text{Cr}(\text{OH})_3$ is 1.0×10^{-33} at 298 K.

- (i) Complete the expression for K_{sp} of $\text{Cr}(\text{OH})_3$. Include the units.

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

units = ...

[2]

- (ii) Calculate the solubility, in g dm^{-3} , of $\text{Cr}(\text{OH})_3$ in pure water at 298 K.

Show your working.

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

- (iii) $\text{Cr}(\text{OH})_3$ is less soluble in $0.100 \text{ mol dm}^{-3}$ NaOH than it is in pure water.

Explain this observation.

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

- (b) The value of the acid dissociation constant, K_{a} , of butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is 1.51×10^{-5} at 298 K.

- (i) Calculate the pH of $0.100 \text{ mol dm}^{-3}$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ at 298 K.

Show your working.

pH = ... [2]

- (ii) Calculate the pH of $0.100 \text{ mol dm}^{-3}$ NaOH at 298 K.

pH = ... [1]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

44. Question part 2/2 | 9701 May-June 2025 P4 V1 Q3



- (iii) 5.00 cm^3 of 0.100 mol dm^{-3} NaOH is added to 10.00 cm^3 of 0.100 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$.

Calculate the pH of the resulting solution.

Show your working.

pH = ... [2]

- (c) 80.0 cm^3 of an aqueous solution containing 0.704 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ is shaken with 100 cm^3 of benzene, C_6H_6 .

There is 0.556 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ in the 100 cm^3 of C_6H_6 at equilibrium.

Calculate the partition coefficient, K_{pc} , of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ between C_6H_6 and water.

Show your working.

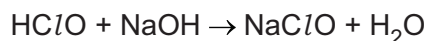
K_{pc} = ... [2]

[Total: 13]

45. Question part 1/2 | 9701 May-June 2025 P4 V2 Q5

- 5 (a) Chloric(I) acid, HClO , is a weak Brønsted–Lowry acid.

When chloric(I) acid is added to aqueous sodium hydroxide, an acid–base reaction takes place, as shown.



- (i) Identify the **two** conjugate acid–base pairs in this reaction.

acid I HClO conjugate base of acid I

acid II conjugate base of acid II

[1]

- (ii) The value for the acid dissociation constant, K_a , of $\text{HClO}(\text{aq})$ is 3.70×10^{-8} .

Calculate the concentration, in mol dm^{-3} , of $\text{HClO}(\text{aq})$ at a pH of 4.51.

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

- (iii) When a solution of $\text{HClO}(\text{aq})$ is heated, chloric(V) acid and a strong acid **not** containing oxygen are formed as the only products.

Write an equation for this reaction.

..... [1]

- (b) (i) Define a buffer solution.

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

- (ii) Suggest a substance that could be added to aqueous ethanoic acid to form a buffer solution.

Explain your answer.

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

45. Question part 2/2 | 9701 May-June 2025 P4 V2 Q5



- (c) Some fertilisers contain calcium dihydrogenphosphate, $\text{Ca}(\text{H}_2\text{PO}_4)_2$.

An aqueous solution containing dihydrogenphosphate ions, H_2PO_4^- , can act as a buffer solution.

Write **two** equations to show how H_2PO_4^- ions can act as a buffer.

equation 1

equation 2 [2]

- (d) The solubility of calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, is $1.14 \times 10^{-7} \text{ mol dm}^{-3}$ at 25°C .

- (i) The expression for the solubility product, K_{sp} , of $\text{Ca}_3(\text{PO}_4)_2$ is shown.

$$K_{\text{sp}} = [\text{Ca}^{2+}]^3[\text{PO}_4^{3-}]^2$$

Calculate the value of K_{sp} for $\text{Ca}_3(\text{PO}_4)_2$. Include units.

$K_{\text{sp}} = \dots\dots\dots$ units [3]

- (ii) Some solid sodium phosphate is added to a saturated solution of $\text{Ca}_3(\text{PO}_4)_2$.

Predict the effect, if any, on the solubility of $\text{Ca}_3(\text{PO}_4)_2$.

Explain your answer.

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

[Total: 12]

46. Question part 1/2 | 9701 May-June 2025 P4 V3 Q3

- 3 (a) Chromium(III) hydroxide, $\text{Cr}(\text{OH})_3$, is only slightly soluble in water. The value of the solubility product, K_{sp} , of $\text{Cr}(\text{OH})_3$ is 1.0×10^{-33} at 298 K.

- (i) Complete the expression for K_{sp} of $\text{Cr}(\text{OH})_3$. Include the units.

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

units = ...

[2]

- (ii) Calculate the solubility, in g dm^{-3} , of $\text{Cr}(\text{OH})_3$ in pure water at 298 K.

Show your working.

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

- (iii) $\text{Cr}(\text{OH})_3$ is less soluble in $0.100 \text{ mol dm}^{-3}$ NaOH than it is in pure water.

Explain this observation.

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

- (b) The value of the acid dissociation constant, K_{a} , of butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is 1.51×10^{-5} at 298 K.

- (i) Calculate the pH of $0.100 \text{ mol dm}^{-3}$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ at 298 K.

Show your working.

pH = ... [2]

- (ii) Calculate the pH of $0.100 \text{ mol dm}^{-3}$ NaOH at 298 K.

pH = ... [1]

46. Question part 2/2 | 9701 May-June 2025 P4 V3 Q3



- (iii) 5.00 cm^3 of 0.100 mol dm^{-3} NaOH is added to 10.00 cm^3 of 0.100 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$.

Calculate the pH of the resulting solution.

Show your working.

pH = ... [2]

- (c) 80.0 cm^3 of an aqueous solution containing 0.704 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ is shaken with 100 cm^3 of benzene, C_6H_6 .

There is 0.556 g of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ in the 100 cm^3 of C_6H_6 at equilibrium.

Calculate the partition coefficient, K_{pc} , of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ between C_6H_6 and water.

Show your working.

K_{pc} = ... [2]

[Total: 13]

47. Question part 1/4 | 9701 May-June 2025 P4 V4 Q3

- 3 (a) Nickel(II) iodate(V), $\text{Ni}(\text{IO}_3)_2$, is sparingly soluble in water. The concentration of its saturated solution is $2.30 \times 10^{-2} \text{ mol dm}^{-3}$ at 298 K.

(i) Complete the expression for the solubility product, K_{sp} , of $\text{Ni}(\text{IO}_3)_2$. Include the units.

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

units = ... [2]

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

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

(b) An electrochemical cell is set up as shown in Fig. 3.1.

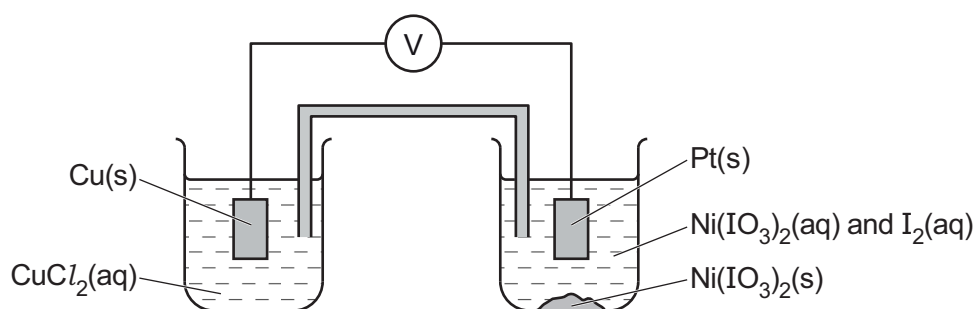
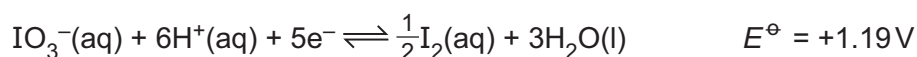


Fig. 3.1

The relevant standard electrode potentials, $E^\ominus$, for this electrochemical cell are shown.



(i) Use this information to calculate the value of $E_{\text{cell}}^\ominus$. State which electrode is positive.

$E_{\text{cell}}^\ominus =$ positive electrode is [1]

(ii) Suggest how the measured E_{cell} of this cell compares to the $E_{\text{cell}}^\ominus$ under standard conditions.

Explain your answer.

..... [1]

47. Question part 2/4 | 9701 May-June 2025 P4 V4 Q3



- (iii) Complete Table 3.1 by placing **one** tick (✓) to indicate how the E_{cell} of this cell changes when a small amount of $\text{NiSO}_4(\text{aq})$ is added to the beaker containing $\text{Ni}(\text{IO}_3)_2(\text{aq})$ and $\text{I}_2(\text{aq})$ in Fig. 3.1.

Explain your answer.

Table 3.1

change in E_{cell}		
less positive	no change	more positive

.....

.....

.....

[2]

- (c) In solution, iodic(V) acid, HIO_3 , ionises as shown.



The pH of a 1.0 mol dm^{-3} solution of HIO_3 is 0.47.

- (i) Calculate $[\text{H}^+(\text{aq})]$, in mol dm^{-3} , in a 1.0 mol dm^{-3} solution of HIO_3 .

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

- (ii) Use your answer from (c)(i) to calculate the equilibrium concentrations of $\text{HIO}_3(\text{aq})$ and $\text{IO}_3^-(\text{aq})$, in mol dm^{-3} , in a 1.0 mol dm^{-3} solution of HIO_3 .

$[\text{HIO}_3(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3}$

$[\text{IO}_3^-(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3}$
[1]

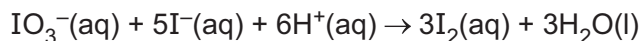
- (iii) Use your answers from (c)(i) and (c)(ii) to calculate the K_a , in mol dm^{-3} , of HIO_3 .

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

47. Question part 3/4 | 9701 May-June 2025 P4 V4 Q3



(d) The *Dushman reaction* is the reaction between iodate(V) ions and iodide ions in acid solution.



The rate equation for this reaction is shown.

$$\text{rate} = k [\text{IO}_3^-][\text{I}^-]^2[\text{H}^+]^2$$

The rate of this reaction is investigated in a buffer solution.

The initial concentrations are shown.

$$[\text{IO}_3^-] = 0.500 \text{ mol dm}^{-3} \quad [\text{I}^-] = 1.00 \times 10^{-3} \text{ mol dm}^{-3} \quad [\text{H}^+] = 1.00 \times 10^{-2} \text{ mol dm}^{-3}$$

Under these conditions the initial rate of the reaction is $2.10 \times 10^{-2} \text{ mol dm}^{-3} \text{ s}^{-1}$.

(i) Define buffer solution.

.....

 [2]

(ii) Use the information to calculate the rate constant, k . State its units.

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

(iii) This reaction is repeated at the same temperature and with the same initial values of $[\text{IO}_3^-]$ and $[\text{I}^-]$. The $[\text{H}^+]$ is increased to $3.00 \times 10^{-2} \text{ mol dm}^{-3}$.

Calculate the initial rate of this reaction.

$$\text{rate} = \dots\dots\dots \text{ mol dm}^{-3} \text{ s}^{-1} [1]$$

[Total: 15]

9701 Chemistry Paper 4 - Equilibria

Topical questions | 49 questions

47. Question part 4/4 | 9701 May-June 2025 P4 V4 Q3



BLANK PAGE

48. Question part 1/3 | 9701 Oct-Nov 2025 P4 V2 Q3

3 (a) (i) Define conjugate acid–base pair.

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

(ii) Give the formulas of the conjugate acid and the conjugate base of the hydrogen phosphate ion, HPO_4^{2-} .

conjugate acid of HPO_4^{2-}

conjugate base of HPO_4^{2-} [1]

(b) The K_a of propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, is $1.35 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

Solution **C** is a solution of $\text{CH}_3\text{CH}_2\text{COOH}$ with a pH of 3.60 at 298 K.

(i) Calculate the concentration of $\text{CH}_3\text{CH}_2\text{COOH}$ in solution **C**.

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

(ii) Calculate the concentration of hydroxide ions in solution **C**.

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

(iii) Calculate the concentration of a solution of hydrochloric acid with the same pH as solution **C**.

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

48. Question part 2/3 | 9701 Oct-Nov 2025 P4 V2 Q3



(iv) Table 3.1 shows three possible values of the K_a of dimethylpropanoic acid, $(\text{CH}_3)_3\text{CCOOH}$.

Place a tick in Table 3.1 to show the correct value. Explain your answer.

Table 3.1

value of K_a / mol dm^{-3}	place one tick (✓) in this column
9.33×10^{-6}	
1.35×10^{-5}	
3.35×10^{-5}	

explanation

.....

.....

.....

..... [3]

(c) Solution **D** is made by mixing 100 cm^3 of 0.100 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{COOH}$ and 100 cm^3 of 0.100 mol dm^{-3} NaCl .

The pH of solution **D** is measured as small amounts of $\text{H}_2\text{SO}_4(\text{aq})$ are added to it, and when small amounts of $\text{NaOH}(\text{aq})$ are added to it.

Solution **D** only acts as a buffer solution when **one** of these solutions is added to it.

(i) Complete the sentence and write an equation for the reaction that occurs.

Solution **D** acts as a buffer when is added to it.

equation [1]

(ii) Complete the sentence and explain why solution **D** does **not** act as a buffer when the other solution is added.

Solution **D** does **not** act as a buffer when is added to it.

explanation [1]

48. Question part 3/3 | 9701 Oct-Nov 2025 P4 V2 Q3



(d) Manganese(II) hydroxide, $\text{Mn}(\text{OH})_2$, is only slightly soluble in water.

The solubility of $\text{Mn}(\text{OH})_2$ in water is $3.28 \times 10^{-3} \text{ g dm}^{-3}$ at 298 K.

(i) Calculate the concentration of a saturated solution of $\text{Mn}(\text{OH})_2$ at 298 K.

$[\text{Mn}(\text{OH})_2] = \dots\dots\dots \text{mol dm}^{-3}$ [1]

(ii) Write an expression for the K_{sp} of $\text{Mn}(\text{OH})_2$. Give the units of K_{sp} .

$K_{\text{sp}} =$

units = $\dots\dots\dots$
[2]

(iii) Use your answers to **(d)(i)** and **(d)(ii)** to calculate the value of K_{sp} of $\text{Mn}(\text{OH})_2$ at 298 K.

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

[Total: 15]

49. Question part 1/4 | 9701 Oct-Nov 2025 P4 V4 Q2

- 2 (a) The Group 2 sulfates and the Group 2 chromates show similar trends in solubility.

Suggest the trend in the solubility of the Group 2 chromates down the group.

Explain your answer.

.....

.....

.....

.....

.....

..... [4]

- (b) Silver(I) chromate, Ag_2CrO_4 , is sparingly soluble in water.

- (i) Write an ionic equation to show the equilibrium between solid Ag_2CrO_4 and its aqueous solution.

Include state symbols.

..... [1]

- (ii) The value of the solubility product, K_{sp} , of Ag_2CrO_4 is 1.12×10^{-12} at 298 K.

Calculate the equilibrium concentration of Ag^+ , in mol dm^{-3} , in a saturated solution of Ag_2CrO_4 at 298 K.

equilibrium concentration of Ag^+ = ... mol dm^{-3} [3]

49. Question part 2/4 | 9701 Oct-Nov 2025 P4 V4 Q2



(c) The hydrogenchromate ion, HCrO_4^- , is a weak acid. The $\text{p}K_{\text{a}}$ of HCrO_4^- is 6.49.

(i) Calculate the pH of a $0.0250 \text{ mol dm}^{-3}$ HCrO_4^- solution.

pH = ... [2]

(ii) HCrO_4^- can show amphoteric behaviour.

State the formula of:

- the conjugate acid of HCrO_4^-
- the conjugate base of HCrO_4^-

[1]

49. Question part 3/4 | 9701 Oct-Nov 2025 P4 V4 Q2



(d) Table 2.1 shows some energy changes.

Table 2.1

energy change	value / kJ mol^{-1}
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
first ionisation energy of sulfur	+1000
second ionisation energy of sulfur	+2251
first electron affinity of sulfur	-200
second electron affinity of sulfur	+532
enthalpy change of atomisation of sulfur	+279
enthalpy change of formation of silver(I) sulfide, $\text{Ag}_2\text{S}(\text{s})$	-33
lattice energy of silver(I) sulfide, $\text{Ag}_2\text{S}(\text{s})$	-2677

(i) Define the term first electron affinity.

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

(ii) Explain why the value for the second electron affinity of sulfur is positive.

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

(iii) Construct an equation for the lattice energy of Ag_2S .

Include state symbols.

..... [1]

49. Question part 4/4 | 9701 Oct-Nov 2025 P4 V4 Q2



- (iv) Calculate the enthalpy change of atomisation, ΔH_{at} , in kJ mol^{-1} , of silver using relevant data from Table 2.1.

It may be helpful to draw a labelled Born–Haber cycle.

Show your working.

ΔH_{at} of silver = ... kJ mol^{-1} [3]

- (e) Suggest how the magnitude for the lattice energy of $\text{Ag}_2\text{S(s)}$ differs from the lattice energy of $\text{Cu}_2\text{S(s)}$.

Explain your answer.

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

[Total: 18]