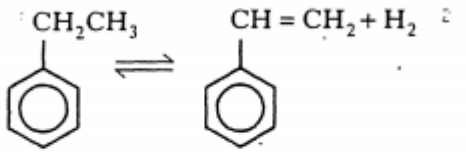
AH Exercise 1.4a

Equilibrium

2001 AH MC8 (71%)

8. The following endothermic reaction is carried out in the gaseous state.



The conditions which most favour the forward reaction are

A high temperature and low pressure

B high temperature and high pressure

C low temperature and low pressure

D low temperature and high pressure.

2002 AH MC1 (66%)

1. $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$

$\Delta H°_{forward} = +92{\cdot}4\,kJ\ mol^{-1}$

The conditions favouring the decomposition of ammonia are

A low pressure and low temperature

B high pressure and low temperature

C low pressure and high temperature

D high pressure and high temperature.

2004 AH MC13 (77%)

13.

$C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)\ \ \Delta H° = +157\,kJ\ mol^{-1}$

The conditions favouring the highest equilibrium yield of ethene in the above reaction are

A low pressure and high temperature

B low pressure and low temperature

C high pressure and high temperature

D high pressure and low temperature.

2010 AH MC11 (75%)

11. $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)\ \ \Delta H° = 92\,kJ\ mol^{-1}$

The conditions favouring the decomposition of ammonia are

A low pressure and low temperature

B high pressure and low temperature

C low pressure and high temperature

D high pressure and high temperature.

2003 AH MC13 (76%)

13. Phosphoric acid undergoes partial dissociation according to the equation

$$H_3PO_4 \rightleftharpoons H_2PO_4^- + H^+$$

The extent of dissociation at equilibrium could be increased by the addition of

A sodium hydroxide

B sulphuric acid

C a catalyst

D sodium dihydrogenphosphate.

2004 AH MC12 (83%) 2008 AH MC13 (89%)

13.

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

The above reaction can be said to have reached equilibrium when

A the equilibrium constant K is equal to 1

B the reaction between the acid and the alcohol has stopped

C the concentrations of the products equal those of the reactants

D the rate of production of ethyl ethanoate equals its rate of hydrolysis.

2005 AH MC13 (88%)

13. In which of the following will an increase in pressure lead to an increase in concentration of the product(s)?

A $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$

B $2N_2O_5(g) \rightleftharpoons 2N_2O_4(g) + O_2(g)$

C $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

D $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

2006 AH MC11 (90%)

11. Which change in reaction conditions will shift the position of equilibrium to the right in this reaction?

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^\circ = -197\ kJ\ mol^{-1}$$

A Increasing the temperature

B Removal of some oxygen gas

C Increasing the pressure

D Adding a catalyst

2013 AH MC18 (80%) and 2013 revAH MC13 (80%)

18. Phosphoric acid is a weak acid and undergoes partial dissociation according to the equation

$$H_3PO_4 \rightleftharpoons H_2PO_4^- + H^+$$

The position of equilibrium would be shifted to the right by the addition of

A a catalyst

B sulphuric acid

C sodium hydroxide

D sodium dihydrogenphosphate.

2005 AH MC14 (66%) 2008 AH MC14 (68%)

14. When sulphur dioxide and oxygen react the following equilibrium is established.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The equilibrium constant for the reaction is 3300 at 630 °C and 21 at 850 °C.

Which line in the table is correct for the reaction?

	Sign of ΔH	Product yield as the temperature increases
A	–	increases
B	–	decreases
C	+	increases
D	+	decreases

2007 AH MC14 (77%)

14. $N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H^\circ = +57\ kJ\ mol^{-1}$

Which of the following will increase the equilibrium constant for the reaction?

A Use of a catalyst

B Increase of pressure

C Increase of temperature

D Decrease of temperature

2009 AH MC12 (80%)

12. In the equilibrium $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ the forward reaction is endothermic.

Which one of the following causes an increase in the value of the equilibrium constant?

A The removal of NO_2

B An increase of pressure

C A decrease of temperature

D An increase of temperature

2011 AH MC12 (85%)

12. Hydrogen for use in ammonia production is produced by the endothermic reaction:

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$

Which of the following will increase the equilibrium yield of hydrogen?

A Decrease the methane concentration

B Decrease the temperature

C Decrease the pressure

D Add a catalyst

2008 AH MC12 (43%)

12. $P + Q \rightleftharpoons R + S$

At 298 K the equilibrium constant for this reaction is $1{\cdot}2 \times 10^{10}$.

Which of the following is true?

A The value of $\Delta S°$ must be positive.

B The value of $\Delta G°$ must be positive.

C Adding a catalyst will change the equilibrium constant.

D Increasing the concentration of P will not change the equilibrium constant.

2012 AH MC8 (80%)

8. $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

Adding PCl_3 to the above system will

A increase the value of the equilibrium constant

B decrease the value of the equilibrium constant

C increase the concentration of PCl_5 and decrease the concentration of Cl_2

D decrease the concentration of PCl_5 and increase the concentration of Cl_2.

2013 revAH MC17 (71%)

17. Iodide ions are oxidised by acidified nitrite ions according to the equation

$2NO_2^- + 2I^- + 4H^+ \rightarrow 2NO + I_2 + 2H_2O$

Addition of sodium ethanoate to the reaction mixture slows down the formation of iodine.

The most likely explanation for this effect is that ethanoate ions

A remove iodine

B reduce the concentration of iodide ions

C react with nitrite ions

D react with hydrogen ions.

2014 AH MC11 (86%)

11. A reaction in dynamic equilibrium is one in which

A the concentration of the product is always independent of reaction conditions

B the enthalpy changes for the forward and the reverse reactions are equal

C the activation energies for the forward and the reverse reactions are equal

D the rates of the forward and the reverse reactions are equal.

2003 AH MC14 (63%) 2009 AH MC10 (64%)

14. When one mole of phosphorus(V) chloride was heated in a closed vessel, 50% dissociated as shown.

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

How many moles of gas were present in the equilibrium mixture?

A 0·5

B 1·0

C 1·5

D 2·0

2012 AH MC10 (30%)

10. At a particular temperature, 8·0 mole of NO_2 was placed in a 1 litre container and the NO_2 dissociated by the following reaction:

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

At equilibrium the concentration of NO(g) is 2·0 mol l^{-1}.

The equilibrium constant will have a value of

A 0·11

B 0·22

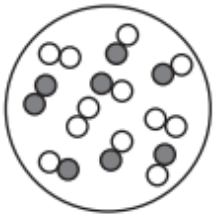
C 0·33

D 9·00.

2014 AH MC13 (80%)

13. The diagram below represents an equilibrium mixture for the reaction

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$



What is the value of equilibrium constant?

A 0·083

B 0·50

C 2·0

D 12

2011 AH MC13 (75%)

13. The reaction

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$$

has an equilibrium constant of 3·9 at 950 °C.

The equilibrium concentrations of CO(g), $H_2(g)$ and $H_2O(g)$ are given in the table.

Substance	Equilibrium concentration/mol l^{-1}
CO(g)	0·500
$H_2(g)$	0·100
$H_2O(g)$	0·040

What is the equilibrium concentration of $CH_4(g)$, in mol l^{-1}, at 950 °C?

A 0·049

B 0·200

C 4·90

D 20·0

2014 AH MC12 (49%)

12. The reaction

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$$

has an equilibrium constant of 3·9 at 950 °C.

The equilibrium concentrations of CO(g), $H_2(g)$ and $H_2O(g)$ are given in the table.

Substance	Equilibrium concentration/mol l^{-1}
CO(g)	$5{\cdot}0 \times 10^{-2}$
$H_2(g)$	$1{\cdot}0 \times 10^{-2}$
$H_2O(g)$	$4{\cdot}0 \times 10^{-3}$

What is the equilibrium concentration of $CH_4(g)$, in mol l^{-1}, at 950 °C?

A $2{\cdot}0 \times 10^{-7}$

B $4{\cdot}9 \times 10^{-5}$

C $3{\cdot}1 \times 10^{-5}$

D $4{\cdot}9 \times 10^{-1}$

2002 AH L4c+d

4. Difluoromethanimine, FN = CHF, can exist in two isomeric forms.

When a sample of the *trans*-isomer was dissolved in an organic solvent at 22 °C it was slowly converted into the *cis*-isomer. After 7 days, 95% of the *trans*-isomer had been converted and no further conversion occurred thereafter.

(*c*) Calculate the equilibrium constant for the conversion of *trans*-difluoromethanimine into its *cis*-isomer at 22 °C. **1**

(*d*) Suppose a sample of *cis*-difluoromethanimine was dissolved in the same organic solvent at 22 °C. Predict the percentage amount of the *cis*-isomer present in the solution after 7 days. **1**

2007 AH L2

2. Consider the following reaction.

$$CS_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2S(g)$$

At 900 °C the equilibrium concentrations are:

$[CS_2] = 0{\cdot}012 \text{ mol l}^{-1}$ $\quad$ $[H_2] = 0{\cdot}0020 \text{ mol l}^{-1}$

$[H_2S] = 0{\cdot}00010 \text{ mol l}^{-1}$ $\quad$ $[CH_4] = 0{\cdot}0054 \text{ mol l}^{-1}$

(*a*) Write down the expression for the equilibrium constant, K, for this reaction. **1**

(*b*) Calculate the value of the equilibrium constant, K, at 900 °C. **1**

2010 AH L7

7. The expression for the equilibrium constant of an esterification reaction is

$$K = \frac{[CH_3COOCH_2CH_3]\,[H_2O]}{[CH_3COOH]\,[CH_3CH_2OH]}$$

(*a*) Write the chemical equation for this esterification reaction. **1**

(*b*) In an experiment to determine the value of the equilibrium constant, 0·70 moles of ethanoic acid and 0·68 moles of ethanol were mixed in a conical flask. The flask was stoppered to prevent the contents escaping and then placed in a water bath at 50 °C.

At equilibrium the mixture contained 0·24 moles of ethanoic acid.

(i) Why is it important to prevent the contents of the flask escaping? **1**

(ii) Calculate K at 50 °C. **3**

2015 AH L5a and 2015 revAH L6a

5. Nitrogen forms a variety of oxides.

(*a*) Dinitrogen tetroxide, $N_2O_4(g)$, dissociates to form nitrogen dioxide, $NO_2(g)$, according to the equation.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

0·28 mol of N_2O_4 gas is placed in an empty 1·00 litre flask and heated to 127 °C. When the system reaches equilibrium, 0·24 mol of NO_2 gas is present in the flask.

(i) Calculate the equilibrium constant, K, for the reaction at 127 °C. **3**

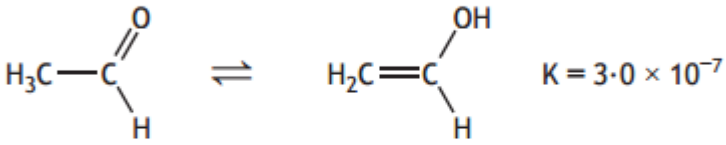
(ii) At 25 °C, the numerical value of the equilibrium constant for this reaction is 0·12.

Explain whether the forward reaction is endothermic or exothermic. **1**

2016 AH L7a

7. Aldehydes and ketones can exist in two forms, a keto form and an enol form.

For example, the aldehyde ethanal exists in equilibrium with its enol form, ethenol.



ethanal (keto form) ⇌ ethenol (enol form)

These two different molecules are known as tautomers.

(a) State which of the tautomers is the more abundant in this equilibrium. **1**

AH Exercise 1.4b

Acid Base Definitions

2004 AH MC2 (65%) 2008 AH MC3 (47%) 2015 revAH MC4 (75%)

2. A Lewis base may be regarded as a substance which is capable of donating an unshared pair of electrons to form a covalent bond.

Which of the following could act as a Lewis base?

A BCl_3

B NH_4^+

C PH_3

D Co^{3+}

2008 AH MC16 (78%)

16. The Bronsted-Lowry definition of a base is a substance which acts as a

A proton donor to form a conjugate acid

B proton donor to form a conjugate base

C proton acceptor to form a conjugate acid

D proton acceptor to form a conjugate base.

2010 AH MC13 (89%)

13. An acid is a substance which

A donates a proton leaving a conjugate acid

B donates a proton leaving a conjugate base

C accepts a proton leaving a conjugate acid

D accepts a proton leaving a conjugate base.

2011 AH MC16 (74%)

16. Under certain conditions liquid ammonia ionises as shown:

$$2NH_3 \rightleftharpoons NH_4^+ + NH_2^-$$

Which line in the table shows the correct conjugate acid and conjugate base for this ionisation?

	Conjugate acid	Conjugate base
A	NH_3	NH_4^+
B	NH_4^+	NH_3
C	NH_2^-	NH_4^+
D	NH_4^+	NH_2^-

2016 AH MC6 (83%)

6. $HCN(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$

In the above equation HCN(aq) is acting as

A an acid

B a conjugate acid

C a base

D a conjugate base.

2001 AH L6a

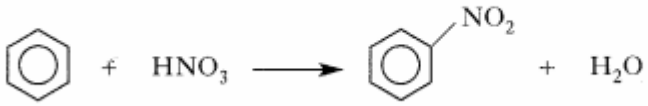
6. When ethanoic acid is added to water the following equilibrium is established.

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

(*a*) Identify the conjugate base of CH_3COOH. **1**

2002 AH L5b

5. Benzene can be nitrated by reaction with concentrated nitric acid.



(*b*) The nitration of benzene is normally achieved using a mixture of concentrated nitric and sulphuric acids. The latter react in the following way:

$$HNO_3 + 2H_2SO_4 \rightarrow NO_2^+ + H_3O^+ + 2HSO_4^-$$

Give the formula of the acid and its conjugate base in this reaction. **1**

2005 AH L8a

8. Hypochlorous acid is a weak acid which dissociates in water as shown.

$$HClO(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + ClO^-(aq)$$

(*a*) What is the conjugate base of hypochlorous acid? **1**

2007 AH L3

3. Fizzy drinks contain carbon dioxide dissolved in water which dissociates, as shown, to produce carbonic acid.

$$H_2O(\ell) + CO_2(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq) \qquad pK_a = 6{\cdot}4$$

(*a*) What is the Bronsted-Lowry definition of an acid? **1**

(*b*) Write the formula for the conjugate base in this reaction. **1**

2006 AH L5c

5. Solutions of NaH_2PO_4 are acidic because the $H_2PO_4^-$ ion partially dissociates.

$$H_2PO_4^-(aq) \rightleftharpoons H^+(aq) + HPO_4^{2-}(aq) \quad pK_a = 7{\cdot}2$$

(*c*) NaH_2PO_4 is used with $NaHCO_3$ in baking powders, to produce carbon dioxide.

$$H_2PO_4^-(aq) + HCO_3^-(aq) \rightleftharpoons HPO_4^{2-}(aq) + H_2O(\ell) + CO_2(g)$$

Explain how HCO_3^- acts as a base in this reaction. **1**

2009 AH L6a

6. When an ant bites, it injects methanoic acid (HCOOH).

(*a*) Methanoic acid is a weak acid.

$$HCOOH(aq) + H_2O(\ell) \rightleftharpoons HCOO^-(aq) + H_3O^+(aq)$$

(i) What is the conjugate base of methanoic acid? **1**

(ii) Write the expression for the dissociation constant, K_a, of methanoic acid. **1**

2012 AH L7c

7. Balsamic vinegar is a dark brown liquid containing ethanoic acid. The pH of a sample of balsamic vinegar was 2·5.

(*c*) Write the formula for the conjugate base of ethanoic acid. **1**

AH Exercise 1.4c

Calculating pH in Strong Acids

2003 AH MC17 (77%)

17. What is the concentration of hydroxide ions, in mol l^{-1}, in an aqueous solution of pH 14?

A 10^{-14}

B 10^{0}

C 10^{1}

D 10^{14}

2005 AH MC15 (72%)

15. Which of the following statements is **not** always true for aqueous solutions at 298 K?

A $[H^+] = [OH^-] = 10^{-7}$ mol l^{-1}

B $K_w = 10^{-14}$

C $[H^+]\,[OH^-] = 10^{-14}$

D $pH = -\log_{10}[H^+]$

2008 AH MC15 (39%)

15. 500 cm^3 of 0·022 mol l^{-1} hydrochloric acid is mixed with 500 cm^3 of 0·020 mol l^{-1} sodium hydroxide solution. The pH of the resulting solution will be

A 2

B 3

C 4

D 5.

2012 AH MC12 (50%)

12. 5·0 cm^3 of a solution of hydrochloric acid was diluted to exactly 250 cm^3 with water. The pH of this diluted solution was 2·00.

The concentration of the original undiluted solution, in mol l^{-1}, was

A $2{\cdot}0 \times 10^{-2}$

B $4{\cdot}0 \times 10^{-2}$

C $4{\cdot}0 \times 10^{-1}$

D $5{\cdot}0 \times 10^{-1}$.

2001 AH L4

4. The equilibrium in water can be represented by the equation

$$H_2O(\ell) \rightleftharpoons H^+(aq) + OH^-(aq)$$

The ionic product for water (K_w) is $1{\cdot}00 \times 10^{-14}$ $mol^2\,l^{-2}$ at 297 K.

As shown in the table below, K_w is temperature dependent.

Temperature/K	K_w/$mol^2\,l^{-2}$
273	$1{\cdot}14 \times 10^{-15}$
283	$2{\cdot}93 \times 10^{-15}$
298	$1{\cdot}01 \times 10^{-14}$
323	$5{\cdot}48 \times 10^{-14}$
373	$5{\cdot}13 \times 10^{-13}$

(*a*) Write the expression for K_w. 1

(*b*) Give a reason for the variation of K_w with temperature. 1

(*c*) Calculate the pH of water at 323 K. 2

AH Exercise 1.4d

pH of Salts

2005 AH MC16 (45%)

16. Which of the following, when dissolved in distilled water, gives rise to a solution with a pH value greater than 7?

A Lithium chloride

B Potassium ethanoate

C Sodium sulphate

D Ammonium nitrate

2011 Higher MC36 (45%)

36. Which of the following solutions contains equal concentrations of $H^+(aq)$ and $OH^-(aq)$ ions?

A $NH_4Cl(aq)$

B $Na_2CO_3(aq)$

C $KNO_3(aq)$

D $CH_3COOK(aq)$

2009 Higher MC35 (39%)

35. Solid sodium sulphite is dissolved in distilled water, producing an alkaline solution.

Which of the following processes is the most important in causing this change?

A Sodium ions reacting with hydroxide ions

B Hydrogen ions reacting with sulphite ions

C Sodium ions reacting with sulphite ions

D Hydrogen ions reacting with hydroxide ions

2009 Higher MC36 (50%)

36. Which of the following salts dissolves in water to form an acidic solution?

A CH_3COONa

B Na_2SO_4

C KCl

D NH_4NO_3

2015 revAH MC20 (53%)

20. Which of the following salts will form a solution with the lowest pH?

A Potassium chloride

B Potassium ethanoate

C Ammonium chloride

D Ammonium ethanoate

2008 Higher MC36 (46%)

36. Which of the following compounds dissolves in water to form an acidic solution?

A Sodium nitrate

B Barium sulphate

C Potassium ethanoate

D Ammonium chloride

2006 Higher MC36 (47%)

36. Which of the following compounds dissolves in water to give an alkaline solution?

A Sodium nitrate

B Potassium ethanoate

C Ammonium chloride

D Lithium sulphate

2005 Higher MC37 (53%)

37. A white solid dissolves in water, giving an alkaline solution, and reacts with dilute hydrochloric acid, giving off a gas.

(You may wish to refer to the data booklet.)

The solid could be

A copper(II) ethanoate

B potassium carbonate

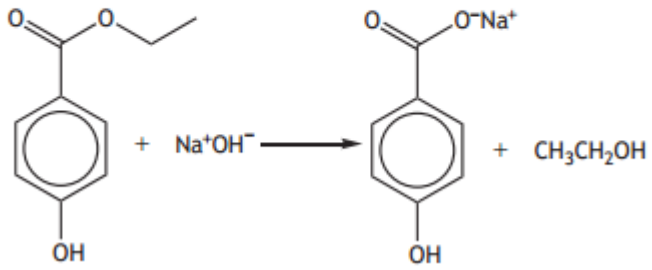
C ammonium chloride

D lead(II) carbonate.

2016 AH L9b(iii)

9. (continued)

(b) Another preservative is sodium 4-hydroxybenzoate. It can be prepared by refluxing ethylparaben with sodium hydroxide solution.



(iii) Explain fully why a solution of the salt sodium 4-hydroxybenzoate has a pH greater than 7. **2**

AH Exercise 1.4e

Calculation of pH in Weak Acids

2001 AH MC24 (52%)

24. Which of the following is most acidic?

A Methanoic acid

B Methanol

C Phenol

D Propanoic acid

2009 AH MC16 (33%)

16. Which of the following 0·01 $mol\,l^{-1}$ aqueous solutions has the highest pH value?

A Sodium fluoride

B Sodium benzoate

C Sodium propanoate

D Sodium methanoate

2006 AH MC14 (55%)

14. Ethanoic acid is a weak acid and hydrochloric acid is a strong acid.

Which of the following is **not** correct?

A The pH of 0·1 $mol\,l^{-1}$ hydrochloric acid is 1.

B 20·0 cm^3 of 0·1 $mol\,l^{-1}$ sodium hydroxide is exactly neutralised by 20·0 cm^3 of 0·1 $mol\,l^{-1}$ ethanoic acid.

C The pH of 0·1 $mol\,l^{-1}$ hydrochloric acid is lower than that of 0·1 $mol\,l^{-1}$ ethanoic acid.

D The K_a value of ethanoic acid is greater than that of hydrochloric acid.

2003 AH MC16 (63%) 2013 AH MC21 (72%) 2013 revAH MC16 (72%)

16. Which of the following decreases when an aqueous solution of ethanoic acid is diluted?

A pH

B $[H^+]$

C pK_a

D Degree of dissociation

2015 AH MC14 (27%)

14. Solution **X** has a pH of 4·38. When it is diluted tenfold the pH changes to 4·88.

X is likely to be

A a partly soluble acid

B a buffered acid

C a strong acid

D a weak acid.

2002 AH L10c

10. Butanoic acid can be synthesised from 1-bromopropane by a two stage process.

$$CH_3CH_2CH_2Br \xrightarrow[KCN(aq)]{\text{stage 1}} \mathbf{Y} \xrightarrow{\text{stage 2}} CH_3CH_2CH_2COOH$$

(*c*) Using information from the Data Booklet, calculate the pH of 0·010 $mol\,l^{-1}$ aqueous butanoic acid. **2**

2003 AH L11

11. Octanoic acid is a weak acid with a dissociation constant, $K_a = 1{\cdot}27 \times 10^{-5}$ and $pK_a = 4{\cdot}9$.

One litre of $0{\cdot}20\,mol\,l^{-1}$ octanoic acid solution was prepared.

(*a*) Calculate the pH of the solution. **2**

(*b*) $0{\cdot}20\,mol\,l^{-1}$ sodium hydroxide solution was then added to the solution of the acid until the pH became 4·5. It was observed that when a few drops of dilute hydrochloric acid were added to this new solution, the pH remained at 4·5.

Explain briefly why the pH of this solution does not change. **2**

2005 AH L8b+c

8. Hypochlorous acid is a weak acid which dissociates in water as shown.

$$HClO(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + ClO^-(aq)$$

(*b*) Write the expression for the dissociation constant, K_a, of hypochlorous acid. **1**

(*c*) Given that the K_a for hypochlorous acid is $3{\cdot}98 \times 10^{-8}$ and that the solution has a pH of 5·4, calculate the following ratio.

$$\frac{[ClO^-(aq)]}{[HClO(aq)]}$$ **2**

2006 AH L5a+b

5. Solutions of NaH_2PO_4 are acidic because the $H_2PO_4^-$ ion partially dissociates.

$$H_2PO_4^-(aq) \rightleftharpoons H^+(aq) + HPO_4^{2-}(aq) \quad pK_a = 7{\cdot}2$$

(*a*) Write the expression for the acid dissociation constant, K_a. **1**

(*b*) Calculate the pH of $0{\cdot}1\,mol\,l^{-1}$ NaH_2PO_4 solution. **2**

2007 AH L3c

3. Fizzy drinks contain carbon dioxide dissolved in water which dissociates, as shown, to produce carbonic acid.

$$H_2O(\ell) + CO_2(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq) \qquad pK_a = 6{\cdot}4$$

(*c*) Calculate the pH of a $0{\cdot}1\,mol\,l^{-1}$ solution of carbonic acid. **2**

2009 AH L6b

6. When an ant bites, it injects methanoic acid (HCOOH).

(*b*) (i) In a typical bite, an ant injects $3{\cdot}6 \times 10^{-3}$ g of methanoic acid.

Assuming that the methanoic acid dissolves in $1{\cdot}0\,cm^3$ of water in the body, calculate the concentration of the methanoic acid solution in $mol\,l^{-1}$. **2**

(ii) Calculate the pH of this methanoic acid solution. **2**

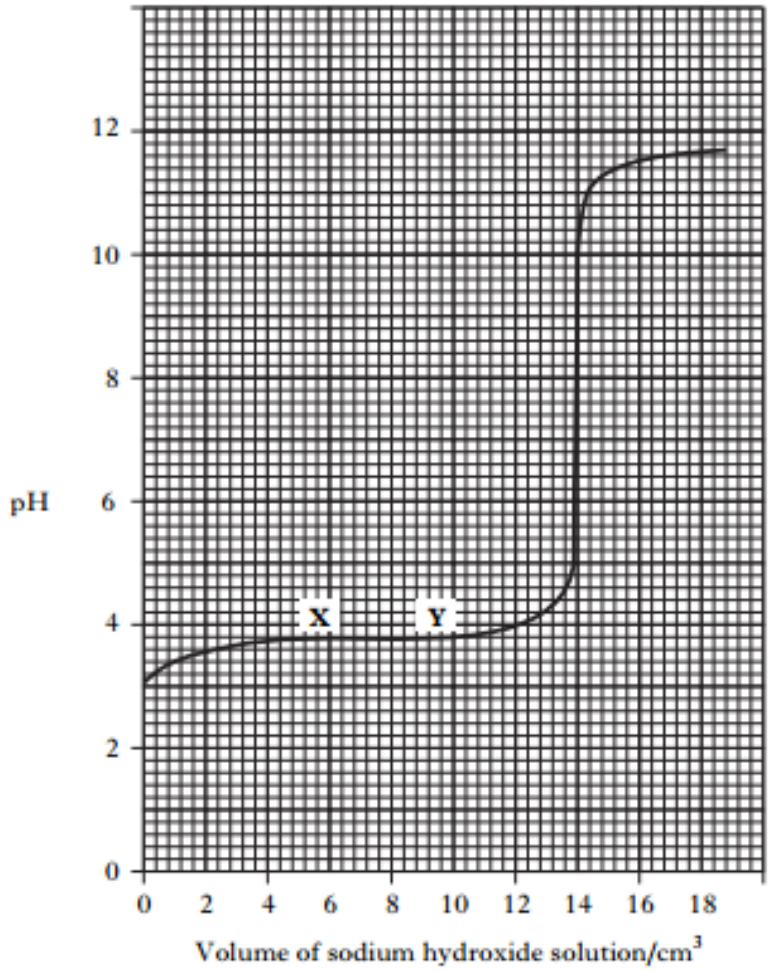
2008 AH L9a+b

9. Hydrofluoric acid, HF, is a weak acid.

$$HF(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + F^-(aq)$$

A student neutralised 25 cm^3 of hydrofluoric acid solution with sodium hydroxide solution and followed the reaction by measuring the pH.

The graph obtained for this reaction is shown below.



(*a*) Write the expression for the dissociation constant, K_a, of hydrofluoric acid. **1**

(*b*) When exactly half the acid has been neutralised, $pK_a = pH$.
Using only information from the graph, deduce pK_a and thus calculate K_a for hydrofluoric acid. **2**

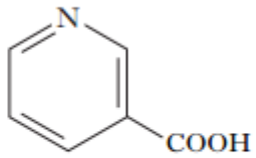
2013 AH L6a and 2013 revAH L6a

6. Propanoic acid is a weak acid. Sodium propanoate is a salt which can be formed from it. Both propanoic acid and sodium propanoate can be used as mould inhibitors.

(*a*) Calculate the pH of 0·10 $mol\,l^{-1}$ propanoic acid solution. **2**

2010 AH L8

8. Nicotinic acid is used in the treatment of high cholesterol levels. A structural formula for nicotinic acid is



(*a*) Write an equation to show the dissociation of nicotinic acid in water. **1**

(*b*) The K_a value of nicotinic acid is $1{\cdot}4 \times 10^{-5}$.

Calculate the concentration of a nicotinic acid solution which has a pH of 3·77. **3**

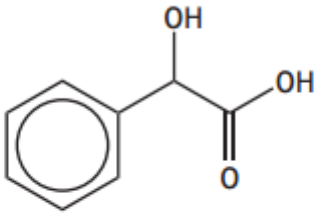
2012 AH MC7a

7. Balsamic vinegar is a dark brown liquid containing ethanoic acid. The pH of a sample of balsamic vinegar was 2·5.

(*a*) Calculate the concentration of ethanoic acid in the sample of balsamic vinegar. **2**

2016 AH L5a+b

5. Mandelic acid, 2-hydroxy-2-phenylethanoic acid, is a component of skin care products.



mandelic acid

(a) Mandelic acid is a weak acid.

$$C_6H_5CH(OH)COOH(aq) + H_2O(\ell) \rightleftharpoons C_6H_5CH(OH)COO^-(aq) + H_3O^+(aq)$$

Write the expression for the dissociation constant, K_a, for mandelic acid. **1**

(b) A 100 cm^3 sample of skin care product contained 10·0 g of mandelic acid. The K_a of mandelic acid is $1{\cdot}78 \times 10^{-4}$.

(i) Calculate the concentration of the mandelic acid, in $mol\,l^{-1}$, present in the skin care product. **2**

(ii) Using your answer to (b)(i), calculate the pH of a solution of mandelic acid of this concentration. **3**

AH Exercise 1.4f

Buffers

2005 AH MC17 (55%)

17. Which of the following when added to aqueous NH_4Cl can produce a buffer solution?

A Ammonia

B Ethanoic acid

C Potassium chloride

D Ammonium sulphate

2006 AH MC13 (61%)

13. The pH of a buffer prepared by mixing equal volumes of 0·1 mol l^{-1} ethanoic acid and 0·2 mol l^{-1} sodium ethanoate is

A 2·1

B 2·7

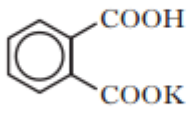
C 4·5

D 5·1.

2012 AH MC11

11. A buffer solution can **not** be made from

A CH_3CH_2COOH and CH_3CH_2COONa

B 

C HNO_3 and $NaNO_3$

D NH_3 and NH_4Cl.

2009 AH MC15 (72%) 2015 AH MC13 (77%) 2015 revAH MC21 (75%)

15. Which of the following would **not** be suitable to act as a buffer solution?

A Boric acid and sodium borate

B Nitric acid and sodium nitrate

C Benzoic acid and sodium benzoate

D Propanoic acid and sodium propanoate

2016 AH MC8 (59%)

8. Which of the following can produce a buffer solution when added to aqueous NH_4Cl?

A Ammonia

B Ethanoic acid

C Potassium chloride

D Ammonium sulfate

2001 AH L6b

6. When ethanoic acid is added to water the following equilibrium is established.

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

(*b*) $100\,cm^3$ of buffer solution was prepared by dissolving 3·74 g of sodium ethanoate (CH_3COONa) in 0·20 mol l^{-1} ethanoic acid solution.

(i) Calculate the concentration of sodium ethanoate, in mol l^{-1}, in this buffer solution. **1**

(ii) Using data on page 12 of the Data Booklet, calculate the pH of this buffer solution. **2**

(iii) Explain why the addition of a small volume of sodium hydroxide solution will have little effect on the pH of this buffer solution. **2**

2002 AH L2d

10. Butanoic acid can be synthesised from 1-bromopropane by a two stage process.

$$CH_3CH_2CH_2Br \xrightarrow[KCN(aq)]{\text{stage 1}} \mathbf{Y} \xrightarrow{\text{stage 2}} CH_3CH_2CH_2COOH$$

(*d*) A buffer solution can be prepared by mixing aqueous solutions of butanoic acid and sodium butanoate. Explain how this solution can maintain its pH when a small volume of acid is added to it. **2**

2004 AH L8

8. Before a pH electrode can be used to measure the pH of a solution it must be calibrated by placing it in a series of buffer solutions of known pH.

One buffer solution used to calibrate a pH electrode was made by dissolving 2·24 g of potassium propanoate, C_2H_5COOK, in $250\,cm^3$ of 0·20 mol l^{-1} propanoic acid.

(*a*) What property of buffer solutions makes them ideal for calibrating pH electrodes? **1**

(*b*) Calculate the pH of the buffer solution described above. **3**

2012 AH L7b

7. Balsamic vinegar is a dark brown liquid containing ethanoic acid. The pH of a sample of balsamic vinegar was 2·5.

(*b*) A student chose to use a pH meter rather than use an indicator for the titration of balsamic vinegar with sodium hydroxide.

Apart from being more accurate, suggest why the student chose to use a pH meter rather than an indicator for this particular titration. **1**

2013 AH L6b and 2013 revAH L6b

6. Propanoic acid is a weak acid. Sodium propanoate is a salt which can be formed from it. Both propanoic acid and sodium propanoate can be used as mould inhibitors.

(*b*) 0·20 moles of sodium propanoate are added to $100\,cm^3$ of the 0·10 mol l^{-1} solution of propanoic acid.

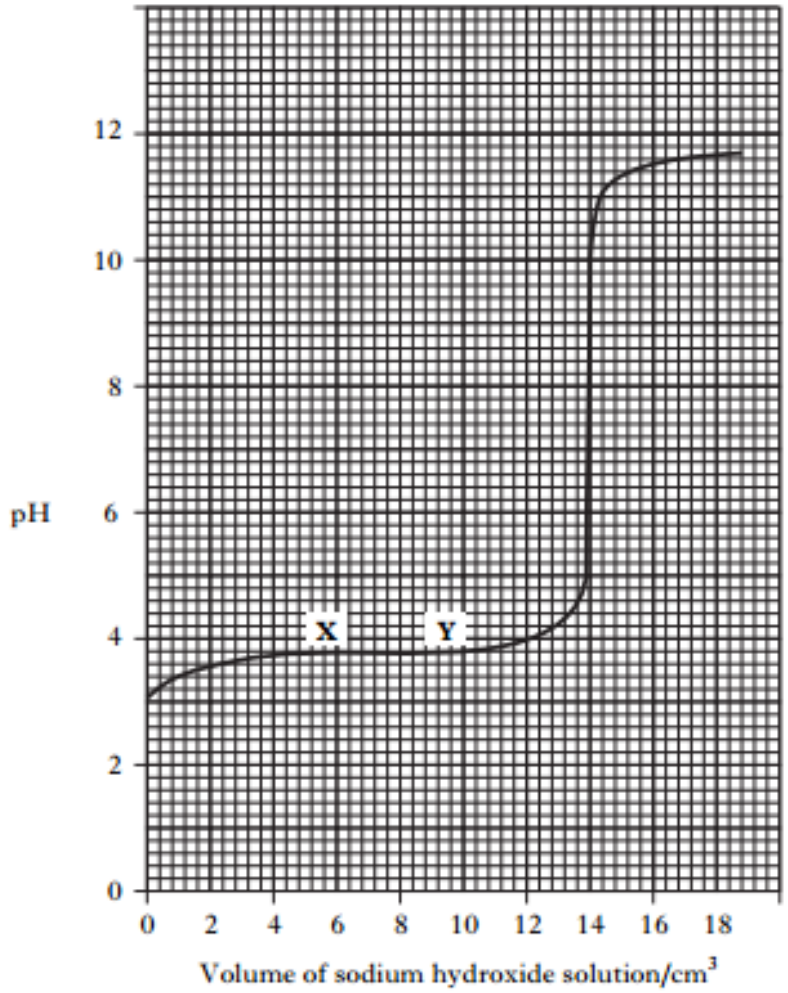
Calculate the pH of the buffer solution formed. **2**

9. Hydrofluoric acid, HF, is a weak acid.

$$HF(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + F^-(aq)$$

A student neutralised 25 cm^3 of hydrofluoric acid solution with sodium hydroxide solution and followed the reaction by measuring the pH.

The graph obtained for this reaction is shown below.



(*c*) The region **XY** on the graph is sometimes referred to as the buffer region.
Apart from HF, what else is present in the solution which enables it to act as a buffer? **1**

2011 AH L9

9. Buffer solutions are important in human biochemistry.

(*a*) What is meant by a "buffer solution"? **1**

(*b*) Suggest the name of a salt which could be mixed with propanoic acid to prepare an acidic buffer solution. **1**

(*c*) The pH of an alkaline buffer solution can be found using the formula

$$pH = pK_w - pK_b + \log \frac{[base]}{[salt]}$$

where K_w is the ionic product of water

and K_b is the dissociation constant of the base.

1·05 g of ammonium nitrate, NH_4NO_3, is dissolved in 100 cm^3 of a 0·15 mol l^{-1} ammonia solution at 25 °C.

Calculate the pH of this buffer solution given that the pK_b for ammonia is 4·76. **3**

2014 AH L12 and 2014 revAH L13

12. An acidic buffer consists of a solution of a weak acid and one of its salts. This can be prepared by reacting a weak acid with an alkali.

20·0 cm^3 of 1·00 mol l^{-1} potassium hydroxide solution was added to 40·0 cm^3 of 1·00 mol l^{-1} aqueous ethanoic acid forming a buffer solution.

(a) Calculate the concentration of

(i) $K^+(aq)$ **1**

(ii) $H^+(aq)$ **3**

in the buffer solution.

(*b*) Explain how this solution would resist change in pH if a few more drops of the potassium hydroxide solution were added. **2**

AH Exercise 1.4g

Indicators

2001 AH MC13 (61%) and 2010 AH MC14 (70%)

13. Some indicators and their pH ranges are shown below. Which is the most suitable indicator to use in a titration of 0·1 mol l^{-1} hydrochloric acid solution with 0·1 mol l^{-1} ammonia solution?

A Methyl orange (4·2–6·3)

B Bromothymol blue (6·0–7·6)

C Phenol red (6·8–8·4)

D Phenolphthalein (8·3–10·0)

2002 AH MC11 (65%)

11. The pH ranges over which some common indicators change colour are given below. Which indicator would be most suitable for the titration of ethanoic acid with sodium hydroxide?

	Indicator	pH range
A	Methyl orange	3·1 – 4·5
B	Methyl red	4·2 – 6·3
C	Bromothymol blue	6·0 – 7·6
D	Phenolphthalein	8·3 – 10·0

2003 AH MC15 (76%)

15. Which of the following indicators should be used in the titration of aqueous potassium hydroxide solution with aqueous ethanoic acid solution?

A Phenolphthalein, pH range 8·3 – 10·0

B Bromothymol blue, pH range 6·0 – 7·6

C Methyl red, pH range 4·2 – 6·3

D Methyl orange, pH range 3·1 – 4·4

2005 AH MC18 (51%)

18. For any acid-base indicator, the colour change occurs around pH = pK_{In}. The equilibrium constant, K_{In}, of an indicator used in an acid-base titration where the pH at the end point was 5·2, is

A $6{\cdot}3 \times 10^{-6}$

B 0·72

C 5·2

D $1{\cdot}6 \times 10^{-5}$.

2013 AH MC23 (81%) and 2013 revAH MC18 (81%)

23. Which of the following indicators should be used in the titration of potassium hydroxide solution with ethanoic acid solution?

A Phenolphthalein, pH range 8·0 – 9·8

B Bromothymol blue, pH range 6·0 – 7·6

C Methyl red, pH range 4·2 – 6·2

D Methyl orange, pH range 3·1 – 4·4

2010 AH MC14 (70%)

14. The pH ranges over which some indicators change colour are shown below.

Which line in the table shows the indicator most suitable for the titration of hydrochloric acid with ammonia solution?

	Indicator	pH range
A	Methyl orange	4·2 – 6·3
B	Bromothymol blue	6·0 – 7·6
C	Phenol red	6·8 – 8·4
D	Phenolphthalein	8·3 – 10·0

2006 AH MC15 (48%)

15. The use of an indicator is **not** appropriate in titrations involving

A hydrochloric acid solution and methylamine solution

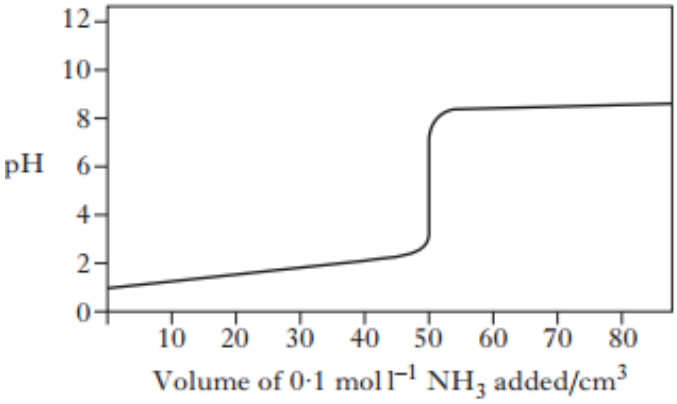
B nitric acid solution and potassium hydroxide solution

C methanoic acid solution and ammonia solution

D propanoic acid solution and sodium hydroxide solution.

2012 AH MC13 (92%)

13. The graph below shows the pH changes when 0·1 mol l^{-1} ammonia solution is added to 50 cm^3 of 0·1 mol l^{-1} hydrochloric acid solution.



Which line in the table shows an indicator which is **not** suitable for use in determining the equivalence point for the above reaction?

	Indicator	pH range of indicator
A	methyl orange	3·1 – 4·4
B	bromophenol red	5·2 – 6·8
C	bromothymol blue	6·0 – 7·6
D	phenolphthalein	8·3 – 10·0

2016 AH MC7 (49%)

7. The use of an indicator is **not** appropriate in titrations involving

A hydrochloric acid solution and methylamine solution

B nitric acid solution and potassium hydroxide solution

C methanoic acid solution and ammonia solution

D propanoic acid solution and sodium hydroxide solution.

2003 AH L12

12. A very dilute solution of a pH indicator in a pH 7 buffer solution was prepared. This was placed in a spectrophotometer and the absorption spectrum was recorded. The indicator is a weak acid and dissociates as shown below.

$$HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$$

Two peaks were observed in the absorption spectrum, one corresponding to the undissociated form of the indicator, (HIn (aq)) and one to the indicator ion (In^- (aq)). The intensity of each absorption was used to determine the concentration of each species.

Species	Colour	Concentration/mol l^{-1}
HIn(aq)	blue	$1{\cdot}3 \times 10^{-5}$
In^-(aq)	yellow	$3{\cdot}9 \times 10^{-4}$

(*a*) Calculate the value of K_{In} for this indicator. **3**

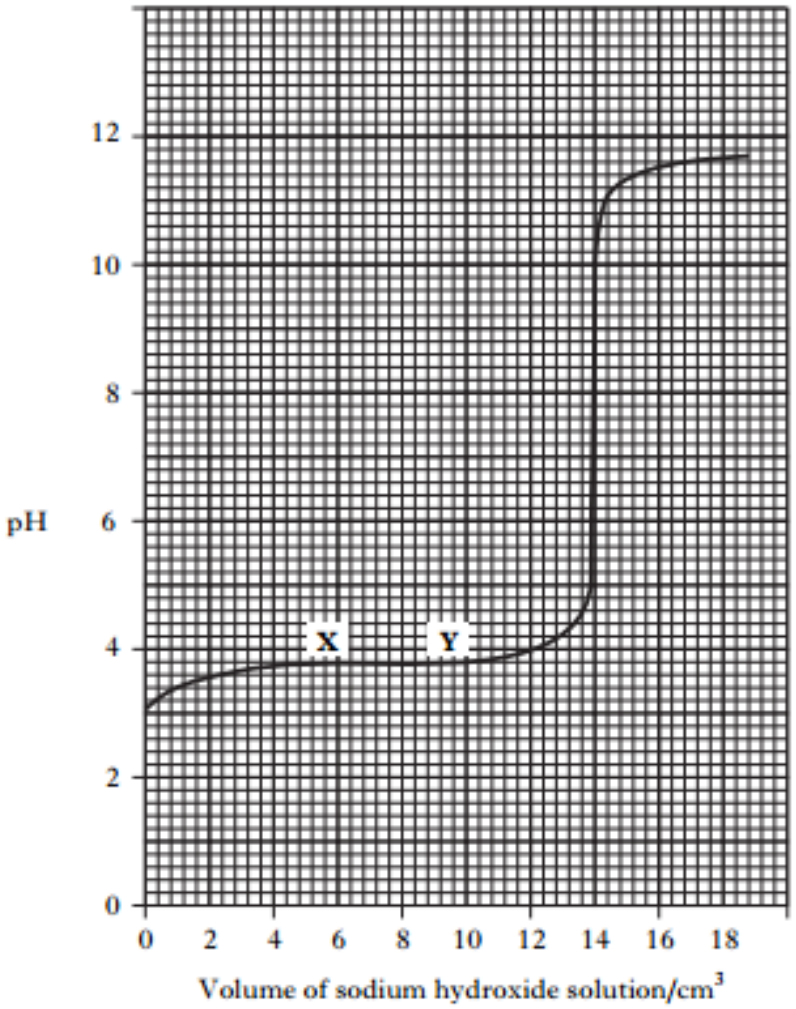
(*b*) What colour will the indicator appear when added to a solution with a pH value of 10? **1**

9. Hydrofluoric acid, HF, is a weak acid.

$$HF(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + F^-(aq)$$

A student neutralised 25 cm^3 of hydrofluoric acid solution with sodium hydroxide solution and followed the reaction by measuring the pH.

The graph obtained for this reaction is shown below.



(*d*)

Indicator	pK_{In}
Methyl orange	3·7
Alizarin red	6·6
Cresol red	8·0
Alizarin yellow	11·1

Which of the above indicators could be used to detect the end point of this neutralisation reaction? **1**