Section One: Multiple-choice questions (10 marks)

Consider the following equations to answer question 1.

I 2 H+(aq) + 2 e– H2(g)

II H

3

O+(aq) + OH–(aq) 2 H

2

O(

)

III HCO

3

–(aq) + H

2

O(

+ OH–(aq)

IV 2 Na(s) + 2 H

2

O(

(g)

1. Which of the above equations represent a hydrogen ion (proton) transfer reaction?

(a) I and III (b) II and III (c) I, II and III (d) II, III and IV

2. Identify each species acting as an acid in the following reaction at equilibrium?

H

2

O

(a) H

2

PO

4

– + H

3

O+ H

3

PO
4
+ H
2
PO
4
– and H
2
O (b) H
2
PO
4
– only (c) H
3
PO
4
and H
3
O+ (d) H
3
PO
4
only
3. The following equilibrium has a K > 1.
HF(aq) + N
2
+(aq)
Consider the following statements about this equilibrium to answer question 3.
I N
2
H
4
(aq) F–(aq) + N
2

H

5

is acting as a Brønsted-Lowry acid.

II K

a

H

4 for HF is greater than K

a

for N

2

H

5

+.

III This is not an acid-base equilibrium.

IV F– is acting as a Brønsted-Lowry base.

Which of the above statements is true for the equilibrium?

(a) I only (b) III only (c) I and IV (d) II and IV

) 2 Na+(aq) + 2 OH–(aq) + H

2

) H

2

CO

3

Use the information in the table below to answer questions 4 and 5.

Indicator Colour (low pH – high

pH)

pH range

Methyl yellow Red – yellow 2.4 – 4.0 Bromocresol purple Yellow – purple 5.2 – 6.8 Phenol red Yellow – red 6.8 – 8.4 Cresol red Yellow – red 7.2 – 8.8

4. Which indicator in the table above would be most suitable to identify the end point in a titration of hydrochloric acid solution against sodium carbonate solution?

(a) Methyl yellow (b) Bromocresol purple (c) Phenol red (d) Cresol red

5. In an acid-base titration with an end point of pH 8.2, a chemist uses bromocresol purple as

the indicator. The acid is added from the burette to the base in a conical flask and the base has an initial pH of 10.5.

What effect will this procedure have on the calculation of the unknown concentration for the base?

(a) The concentration calculated will be higher than its true concentration. (b) The concentration calculated will be lower than its true concentration. (c) The concentration calculated will be accurate. (d) A calculation cannot be done as no colour change will be seen during the titration.

6. Which one of the following statements concerning acids is true?

(a) Only organic acids are weak. (b) Diluting a strong acid produces a weak acid. (c) Weak acid solutions do not contain H_3O^+. (d) H_2O and OH^- are a conjugate acid/base pair.

7. Acetic acid (CH_3CO_2H) is a weak acid. This means that

(a) it dissociates completely to ions when placed in water. (b) it exists mainly as CH_3CO_2H molecules in water. (c) aqueous solutions of CH_3CO_2H contain equal concentrations of H^+ and $CH_3CO_2^-$ ions. (d) it cannot be neutralised by a strong base.

8. Which one of the following statements about a 1.0 mol L^{-1} aqueous solution of sodium

chloride at 25 °C with pH = 7 is correct?

(a) There are no hydrogen ions or hydroxide ions in the solution. (b) The K_w value is no longer equal to 1×10^{-14}. (c) The concentration of hydronium ions equals the concentration of hydroxide ions. (d) The concentration of sodium ions is greater than the concentration of chloride ions.

9. Which one of the following correctly arranges 0.1 mol L^{-1} solutions of the substances in order of increasing pH (the solution of lowest pH first and highest pH last)?

(a) $NaOH < CH_3COOH < H_3PO_4 < HCl$ (b) $HCl < CH_3COOH < H_3PO_4 < NaOH$ (c) $HCl < H_3PO_4 < CH_3COOH < NaOH$ (d) $H_3PO_4 < HCl < CH_3COOH < NaOH$

10. A buffer solution is prepared by mixing equal moles of sodium dihydrogenphosphate and sodium hydrogenphosphate in water. Which one of the following statements applies to the buffer solution?

(a) Addition of a few drops of concentrated hydrochloric acid solution will produce

more dihydrogenphosphate ions. (b) Addition of a few drops of concentrated sodium chloride solution will produce

more dihydrogenphosphate ions and hydrogenphosphate ions. (c) Most of the hydrogen ions will be supplied by water. (d) Addition of water to the buffer will reduce its buffering capacity.

Multiple Choice ANSWER SHEET (10 marks)

1. (a) (b) (c) (d)

2. (a) (b) (c) (d)

3. (a) (b) (c) (d)

4. (a) (b) (c) (d)

5. (a) (b) (c) (d)

6. (a) (b) (c) (d)

7. (a) (b) (c) (d)

8. (a) (b) (c) (d)

9. (a) (b) (c) (d)

10. (a) (b) (c) (d)

Section Two: Short answers (29 marks)

11. (a) Use the table below to rank the following from weakest (1) to strongest (5) acid.

Acid Formula

Rank weakest (1) – strongest (5) Phosphoric acid H

3

Acidity constant

(K

a

)

PO

4

7.5 × 10-3

Hydrocyanic acid HCN 5.9 × 10-10

Aluminium hexahydrate ion

Al(H

2

O)

6

3+ 1.4 × 10-5

Chlorous acid HC

1.2 × 10-2

Hydrogensulfite ion HSO

3

– 6.2 × 10-8

(2 marks)

(b) Clearly explain your ranking using the appropriate chemistry principles. (3 marks)

____

____

____

____

____

____

____

____

O

2

12. (a) Examine the substances below and classify them as acidic, neutral or basic by placing them in the appropriate column in the table.

sodium sulfate (Na

2

SO

4

) magnesium hydrogencarbonate

(Mg(HCO

3

)

2

)

potassium nitrate (KNO

3

) sodium nitrite (NaNO

2

)

sodium fluoride (NaF) ammonium chloride (NH

4

)

Acidic Neutral Basic

(6 marks)

(b) Aqueous solutions of sodium cyanide (NaCN) are basic. Explain this observation with the support of an appropriate equation. (2 marks)

____

____

____

____

____

(c) Methylamine (CH

3

C

NH

2

) is similar in structure to ammonia (NH

3

). It is formed by replacing one of the hydrogen atoms in ammonia by a methyl group (-CH

3

). The Lewis (electron dot) structures for ammonia and methylamine are shown below. State the reason methylamine can act as a base. (1 mark)

H

H N H

H

C N

H

H

H

H

---

13. Thymol blue, a weak diprotic organic acid used as an acid-base indicator, changes

colour at two pH ranges – from red to yellow between pHs 1.2 and 2.8 and from yellow to blue between pHs 8.0 and 9.6. Structures 1 and 2, below, show the structures for thymol blue in solution at pH less than 1.2 (1) and pH range 2.8–8.0 (2).

The acidic hydrogen ions are indicated in the boxes in structure 1.

CH 3

CH

3

CH 3

CH

3

CH 3

CH

3

CH 3

CH

3

acidic

OH

CH

3

O

CH

3

OH

OH

CH

3

SO

3

O

3

1 2 3 pH < 1.2 2.8 < pH < 8.0 pH > 9.6 red yellow blue

Note: Initially, when base is added to a solution of 1, removal of the first hydrogen ion gives the structure below. The bonds in this structure quickly rearrange to give structure 2.

OH

(a) As base is added to a solution of thymol blue initially at pH 2.8, structure 2 reacts to give structure 3. On structure 2 above, circle the group from which the hydrogen ion will be removed. Draw structure 3 that forms with removal of the acidic hydrogen ion by completing the basic skeleton of thymol blue shown below.

Note: Structure 2 converts directly to structure 3. After removal of the hydrogen ion from 2, there is no rearrangement. (2 marks)

CH 3

CH

3

hydrogen

S ion

O

acidic hydrogen ion

- O

CH 3

CH

3

CH 3

CH

3

O

CH

3

-

acidic hydrogen ion has been removed from here

O

CH

3

S

O

O

CH

3

CH 3

CH

3

CH

3

(b) What term is used to describe the relationship between structures 1 and 2 and between structures 2 and 3? (1 mark)

Below pH 1.2, a solution of thymol blue is red; between pHs 1.2 and 2.8, the solution is a shade of orange. As the pH approaches 2.8, it becomes lighter orange until, eventually, at pH 2.8, it is yellow.

(c) Explain these colour changes in terms of the concentrations of the structures present in the solution. (3 marks)

(d) Explain, using the appropriate chemistry principle, the changes in concentrations of structures 1 and 2 that occur as the pH increases from 1.2 to 2.8. (2 marks)

14. (a) Calculate the pH of a 0.749 mol L–1 solution of nitric acid. (2 marks)

(b) Calculate the hydroxide ion concentration in a solution with a hydrogen ion

concentration of 1.55 × 10–4 mol L–1. The solution is at a temperature of 25 °C.

(2 marks)

15. Explain why a 1.0 × 10–3 mol L–1 solution of the weak acid acetic acid has a pH between

3 and 7.

(3 marks)

Section Three: Extended answer (11 marks)

16. Benzoic acid ($C_7H_6O_2$) is a weak monoprotic acid used as a preservative in many foods.

As part of a food production company's quality assurance process, it periodically samples its oyster sauce product to measure its benzoic acid concentration. The required concentration of the benzoic acid is 800.0 ppm.

A chemist pipettes 200.0 mL samples of the sauce for testing by titration with a standard 0.120 mol L–1 sodium hydroxide solution.

The chemist first weighs the 200.0 mL sample and finds it has a mass of 200.6 g.

The chemist also finds that 11.29 mL of the standard sodium hydroxide solution is required to reach the end point in the titration. The colour of the oyster sauce requires the end point be determined using a pH meter.

(a) Determine whether the benzoic acid in the oyster sauce is at the required

concentration. Show clear working to support your answer. (7 marks)

(b) Identify one source of systematic error in the procedure used to determine the

benzoic acid concentration. State how this source may contribute to an inaccurate result. (2 marks)

___

___

___

(c) Why is it difficult to determine the benzoic acid concentration by simply measuring

the pH of the oyster sauce with the pH meter? (2 marks)

___

___

___

END OF TEST

Marking key for sample assessment task 5 – Unit 3

Section One: Multiple-choice

Question Answer 1 B 2 C 3 D 4 B 5 A 6 D 7 B 8 C 9 C 10 A

Description Marks 1 mark for each question 1–10

Total /10

Section Two: Written answers

11. (a) Use the table below to rank the following from weakest (1) to strongest (5) acid.

Acid Formula Acidity constant (K

a1

Rank weakest (1) – strongest (5)

Phosphoric acid H

3

)

PO

4

7.5 × 10-3 4

Hydrocyanic acid HCN 5.9 × 10-10 1

Aluminium hexahydrate ion Al(H

2

O)

6

3+ 1.4 × 10-5 3

Chlorous acid HC

1.2 × 10-2 5

Hydrogensulfite ion HSO

3

– 6.2 × 10-8 2

Description Marks Ranking correct (as above) 2 1–2 acids incorrectly ordered 1 More than two acids incorrectly ordered 0

Total /2

(b) Clearly explain your ranking using the appropriate chemistry principles.

O

2

Description Marks Recognition that order is based on the value of the acidity constant – strongest acid has highest K

a

value

1

Recognition that K value is primarily an expression of the ratio of the concentration of products to concentration of reactants

1

Recognition that the higher the value of K, the more the reaction has moved in the forward direction; or the higher the product concentration relative to the reactant concentration

1

Total /3

12. (a) Examine the substances below and classify them as acidic, neutral or basic by placing them in

the appropriate column in the table.

sodium sulfate (Na

2

SO

4

) magnesium hydrogencarbonate (Mg(HCO

3

)

2

)

potassium nitrate (KNO

3

) sodium nitrite (NaNO

2

)

sodium fluoride (NaF) ammonium chloride (NH

4

)

Acidic Neutral Basic NH

4

C

C

)

2 NaNO

2

Description Marks 1 mark for each correctly classified substance as in the table above 1–6

Total /6

(b) Aqueous solutions of sodium cyanide (NaCN) are basic. Explain this observation with the support of an appropriate equation.

Description Marks Recognition that CN– hydrolyses to give OH– in aqueous solution (or statement showing recognition that CN– can behave as a proton acceptor)

1

Equation for hydrolysis provided as follows: CN–(aq) + H

2

O(

1

Total /2

(c) Methylamine (CH

3

NH

2

) is similar in structure to ammonia (NH

3

). It is formed by replacing one of the hydrogen atoms in ammonia by a methyl group (-CH

3

). The Lewis (electron dot) structures for ammonia and methylamine are shown below. State the reason methylamine can act as a base.

Description Marks Recognition that the nitrogen in methylamine has a lone pair of electrons that can accept a proton (hydrogen ion)

1

Total /1

13. Thymol blue, a weak diprotic organic acid used as an acid-base indicator, changes colour at two

pH ranges – from red to yellow between pHs 1.2 and 2.8 and from yellow to blue between pHs

) HCN(aq) + OH–(aq)

SO Na

2

4 KNO

3

NaF Mg(HCO

3

8.0 and 9.6. Structures 1 and 2, below, show the structures for thymol blue in solution at pH less than 1.2 (1) and pH range 2.8–8.0 (2).

The acidic hydrogen ions are indicated in the boxes in structure 1.

CH 3

CH

3

CH 3

CH

3

CH 3

CH

3

CH 3

CH

3

OH

OH

OH

O

acidic

CH

3 hydrogen

CH

3

SO

3

1 2 3 pH < 1.2 2.8 < pH < 8.0 pH > 9.6 red yellow blue

Note: Initially, when base is added to a solution of 1, the removal of the first hydrogen ions gives the structure below. The bonds in this structure quickly rearrange to give structure 2.

OH

(a) As base is added to a solution of thymol blue initially at pH 2.8, structure 2 reacts to give

structure 3. On structure 2 above, circle the group from which the hydrogen ion will be removed. Draw structure 3 that forms with removal of the acidic hydrogen ion by completing the basic skeleton of thymol blue shown below.

Note: Structure 2 converts directly to structure 3. After removal of the hydrogen ion from 2, there is no rearrangement.

Description Marks Hydroxyl group circled in 2 as below:

1

3

O

CH

3

ion

acidic hydrogen ion

CH

3

S O

- O

CH 3

CH

3

CH 3

CH

3

O

CH

3

-

acidic hydrogen ion has been removed from here

OH

O

CH

3

S O

O

CH 3

CH

3

CH 3

CH

3

O

CH

3

SO

3

CH

3 -

Description Marks Structure 3 drawn as below:

1

Total /2

(b) What term is used to describe the relationship between structures 1 and 2 and between structures 2 and 3?

Description Marks Recognition that 1 and 2 are an acid-base conjugate pair (similarly, 2 and 3 are an acid-base conjugate pair)

CH 3

CH

3

CH 3

CH

3

O

-

O

CH

3

SO

3

CH

3 -

1

Total /1

Below pH 1.2, a solution of thymol blue is red; between pHs 1.2 and 2.8, the solution is a shade of orange. As the pH approaches 2.8, it becomes lighter orange until, eventually, at pH 2.8, it is yellow.

(c) Explain these colour changes in terms of the concentrations of the structures present in

the solution.

Description Marks Recognition that, at pH 1.2, the concentration of structure 1 is much higher than structure 2, thus giving the solution its red colour

1

Recognition that, between pHs 1.2 and 2.8, the concentration of structure 1 decreases as the concentration of structure 2 increases, thus giving the solution its orange colour

1

Recognition that, at pH 2.8, the concentration of structure 2 is much higher than structure 1, thus giving the solution its yellow colour

1

Total /3

(d) Explain, using the appropriate chemistry principle, the changes in concentrations of

structures 1 and 2 that occur as the pH increases from 1.2 to 2.8.

Description Marks Recognition that, as pH increases, the rate of reaction between 1 and hydroxide ions increases relative to the rate of reaction in which 2 reacts to form 1

1

Recognition that this leads to the equilibrium shifting to increase the concentration of structure 2

1

Total /2

Note: Marks should not be awarded for trying to explain using Le Châtelier's principle – this principle is predictive, not explanatory.

14. (a) Calculate the pH of a 0.749 mol L–1 solution of nitric acid.

Description Marks pH = -log

10

0.749 1 = 0.126 1

Total /2

(b) Calculate the hydroxide ion concentration in a solution with a hydrogen ion concentration of

1.55 × 10–4 mol L–1. The solution is at a temperature of 25 °C.

Description Marks K

w

= 1 × 10–14 = [H

3

O+][OH–] 1

[OH–] =

101

× O[H 3

-14 -14

+]

=

1.55

101

×

×

10 4-

=

6.45

× 10 11-

mol L 1- 1

Total /2 Accept pH + pOH = 14 and [OH–] = 10–pOH as an alternative method.

15. Explain why a 1.0 × 10–3 mol L–1 solution of the weak acid acetic acid has a pH between 3 and 7.

Description Marks Recognition that, as an acid, its pH must be less than 7 1 Recognition that a strong (fully ionised) acid with concentration of 1.0 × 10–3 mol L–1 will have a pH of 3

1

Recognition that, as a weak acid, it is not fully ionised, so will have pH greater than 3 1

Total /3

16. Benzoic acid (C

7

H

6

O

2

) is a weak monoprotic acid used as a preservative in many foods.

As part of a food production company's quality assurance process, it periodically samples its oyster sauce product to measure its benzoic acid concentration. The required concentration of the benzoic acid is 800.0 ppm.

A chemist pipettes 200.0 mL samples of the sauce for testing by titration with a standard 0.120 mol L–1 sodium hydroxide solution.

The chemist first weighs the 200.0 mL sample and finds it has a mass of 200.6 g.

The chemist also finds that 11.29 mL of the standard sodium hydroxide solution is required to reach the end point in the titration. The colour of the oyster sauce requires the end point be determined using a pH meter.

(a) Determine whether the benzoic acid in the oyster sauce is at the required concentration.

Show clear working to support your answer.

Description Marks n(NaOH) = C(NaOH) × V = 0.12 × 0.01129 = 1.355 × 10–3 mol 1 n(C

7

H

6

O

2

) = n(NaOH) = 1.355 × 10–3 mol 1 M(C

7

H

6

O

2

) = 122.118 g mol–1 (must show working out) 1 m(C

7

H

6

O

2

) = 122.118 × 1.355 × 10–3 = 0.1654 g 1 Conversion to milligrams: m(C

7

H

6

O

2

) = 165.4 mg 1

ppm =

mass of solute in mg mass of solution in kg =

165.4 0.2006

= 825 ppm

1

The concentration is above the required level 1

Total /7

(b) Identify one source of systematic error in the procedure used to determine the benzoic

acid concentration. State how this source may contribute to an inaccurate result.

Description Marks Identification of a source of systematic error 1 The way in which the identified error contributes to an inaccurate result given 1

Total /2 Answer could include, but is not limited to:

- Incorrectly calibrated pipette – changes volume of sauce sampled
- Incorrectly calibrated pH meter – end point will be inaccurate and, so, volume of NaOH added will be incorrect
- Incorrectly calibrated burette – volume of NaOH delivered will be inaccurate

(c) Why is it difficult to determine the benzoic acid concentration by simply measuring the pH of the oyster sauce with the pH meter?

Description Marks Recognition that, as a weak acid, the benzoic acid only partially ionises 1 Thus, a [H+] determined from a pH measurement will not be in a simple 1:1 ratio to the benzoic acid concentration

1

Total /2