Government of Western Australia
School Curriculum and Standards Authority

SAMPLE ASSESSMENT TASKS

CHEMISTRY
ATAR YEAR 12

2015/42318v4

Sample assessment task

Chemistry – ATAR Year 12

Task 2 – Unit 3

Assessment type: Investigation

Conditions
Time for the task: 120 minutes

Task weighting
5% of the school mark for this pair of units

Reaction rates and catalysis **(57 marks)**

In this investigation, you will examine the rate of decomposition of hydrogen peroxide with and without catalysts, as well as comparing different catalysts, including enzymes.

You will need to choose **two** non-biological catalysts and **two** food catalysts to use in your investigation of the rate of decomposition of hydrogen peroxide.

What you need to do

- Working individually, complete the questions in the *Planning* section of the activity sheet. Show this to your teacher before moving to the next part.
- Working in your group, discuss your individual planning and amend your plans, if necessary.
- Working in your group, prepare your experiment and collect your data as in your experimental plan.
- Working individually, complete the questions in the *Processing and Analysis* section of the activity sheet. Show this to your teacher before moving to the next part.
- Working in your group, discuss your individual *Processing and analysis* section and amend your answers, if necessary.
- Working individually, complete the questions in the *Conclusion and Evaluation* section of the activity sheet.

Investigating the effect of catalysts on the rate of decomposition of hydrogen peroxide

Part 1 – Planning

1. Give the balanced equation for the decomposition of hydrogen peroxide. (2 marks)

2. Hydrogen peroxide can be decomposed by non-biological catalysts and enzymes found in a number of foods. Identify **three** non-biological catalysts and **four** foods that have an enzyme that decomposes hydrogen peroxide. Give the reference(s) for where you found this information. (6 marks)

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Choose **two** of the non-biological catalysts and **two** of the foods you have identified to use in the investigation. You will need to confirm the availability of the non-biological catalysts with your teacher.

Non-biological catalysts: ____

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Foods: ____

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3. Write a hypothesis for your investigation. (2 marks)

Individual ideas

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Any refinements after group discussion

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4. Make a prediction about the results of your experiment based on your hypothesis. (1 mark)

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5. Identify the following variables for the investigation:

(a) Independent variable (1 mark)

Individual ideas

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Any refinements after group discussion

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(b) Dependent variable (1 mark)

Individual ideas

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Any refinements after group discussion

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(c) Control variables (3 marks)

Individual ideas

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Any refinements after group discussion

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6. Plan and describe how you will collect your data. Indicate the type(s) of data you will collect, how it will be collected and any equipment needed to collect it. As part of the planning, you should also decide how to record your data. If data is to be recorded in a table, this can be done in a spread sheet or a table drawn up on paper. (6 marks)

List of equipment and data to be collected

Individual ideas	Any refinements after group discussion

Description of experimental procedure

Individual ideas

Any refinements after group discussion

7. Identify any particular precautions needed in handling hydrogen peroxide and state why these precautions need to be taken.

   Describe any other safety precautions that need to be taken in the conduct of the experiment and list any safety equipment needed. (4 marks)

Individual ideas

Any refinements after group discussion

Part 2 – Experimental

Carry out the experiment according to your plan. Ensure that it has been approved by your teacher.

Mark allocation for the *Experimental* section will be as follows:

- Equipment set up correctly (2 marks)
- Chemicals/foods measured correctly (2 marks)
- Safe work practices (2 marks)
- Measurements correctly taken and recorded (2 marks)
- Cleaning up of equipment and work space after completion of experiment (2 marks)

Part 3 – Results (4 marks)

Record your results on paper or a spread sheet. Attach the table or a print out of your table from the spread sheet to your report.

Part 4 – Processing and analysis

8. Present your results as a graph (you need to decide the most suitable type of graph for this data). This can be done using a suitable graphing program or on graph paper. Attach the printed graph to your report. (4 marks)

9. Describe any trends in the graph. (2 marks)

 Individual ideas

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 Any refinements after group discussion

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Part 5 – Conclusion and evaluation

10. Do the data support the hypothesis? Support your answer using the results of the experiment. (3 marks)

11. State the role of a catalyst in a chemical reaction.

    Explain how a catalyst achieves this effect. Support your answer with a suitable diagram for the decomposition of hydrogen peroxide. Clearly label the diagram. (6 marks)

12. Describe **one** way in which the results of the experiment may be improved (either in terms of validity or reliability). (2 marks)

Marking key for sample assessment task 2 – Unit 3

1. Give the balanced equation for the decomposition of hydrogen peroxide.

$$2\,H_2O_2 \rightarrow 2\,H_2O + O_2$$

Description	Marks
Reactants and products correct	1
Balanced equation	1
Total	**/2**

2. Hydrogen peroxide can be decomposed by non-biological catalysts and enzymes found in a number of foods. Identify **three** non-biological catalysts and **four** foods that have an enzyme that decomposes hydrogen peroxide. Give the reference(s) for where you found this information.

Description	Marks
Non-biological catalysts: • three given • 1–2 given	 2 1
Foods: • four given • 1–3 given	 2 1
References provided with sufficient detail to enable checking	1–2
Total	**/6**

3. Write a hypothesis for your investigation.

Description	Marks
Appropriate statement relating rate of decomposition to presence/absence of catalyst	1–2
Total	**/2**
Answer could include, but is not limited to:	
For 1 mark, a statement relating rate of decomposition to presence/absence of catalyst; for example, • The hydrogen peroxide will decompose faster in the presence of a catalyst. For 2 marks, a statement relating rate of decomposition to presence/absence of catalyst and nature of catalyst; for example, • The hydrogen peroxide will decompose faster in the presence of a non-biological catalyst than food (enzyme) catalyst.	

4. Make a prediction about the results of your experiment based on your hypothesis.

Description	Marks
Suitable prediction provided to match the given hypothesis	1
Total	**/1**

5. Identify the following variables for the investigation:

(a) Independent variable

Description	Marks
The type of catalyst	1
Total	**/1**

(b) Dependent variable

Description	Marks
Rate of reaction	1
Total	**/1**
Answer could include, but is not limited to:	
This could be expressed by measuring: • mass lost in a given time • volume of oxygen gas generated in a given time.	

(c) Control variables

Description	Marks
Identifies at least three control variables	1–3
Total	**/3**
Answer could include, but is not limited to:	
• mass of each food (or moles of enzyme in food) • moles of each non-biological catalyst • surface area of catalysts • volume of hydrogen peroxide solution • concentration of hydrogen peroxide solution • temperature of hydrogen peroxide solution	

6. Plan and describe how you will collect your data. Indicate the type(s) of data you will collect, how it will be collected and any equipment needed to collect it. As part of the planning, you should also decide how to record your data. If data is to be recorded in a table, this can be done in a spread sheet or a table drawn up on paper.

Description	Marks
Equipment list provided may include: • beakers/conical flasks • foods • non-biological catalysts • balance • device to collect and measure volume of oxygen • thermometer • timer	1–2
Procedure indicates: • what is to be measured • how measurements are to be taken • sufficient detail that another person could conduct the experiment	 1 1 1–2
Total	**/6**

7. Identify any particular precautions needed in handling hydrogen peroxide and state why these precautions need to be taken.

   Describe any other safety precautions that need to be taken in the conduct of the experiment and list any safety equipment needed.

Description	Marks
Recognises H_2O_2 can burn/irritate skin and clothes	1
Recognises that care needs to be taken to avoid spillage of H_2O_2 and rubber gloves should be worn as an added precaution when handling the H_2O_2	1
Describes general laboratory safety practices	1
Lists personal protective equipment to be warn (safety glasses, laboratory coat) (and, where necessary, tying back long hair)	1
Total	**/4**

Experimental

Mark allocation for the *Experimental* section

Description	Marks
Equipment set up correctly	1–2
Chemicals/foods measured correctly	1–2
Safe work practices	1–2
Measurements correctly taken and recorded	1–2
Cleaning up of equipment and work space after completion of experiment	1–2
Total	**/10**

Results

Mark allocation for the results table

Description	Marks
Column for catalysts	1
Column for mass lost (or volume of O_2 produced)	1
Units included in mass (or volume) column	1
Results recorded clearly	1
Total	**/4**

8. Present your results as a graph (you need to decide the most suitable type of graph for this data). This can be done using a suitable graphing program or on graph paper. Attach the printed graph to your report.

Description	Marks
Column/bar graph used	1
y axis has mass (or volume) and is labelled with units	1
x axis with catalyst named	1
Plot of bars accurate	1
Total	**/4**

9. Describe any trends in the graph.

Description	Marks
The only clear trend is the much slower rate of decomposition in the absence of a catalyst	1
Gives a statement about any trend or absence of trend for other catalysts	1
Total	**/2**

10. Do the data support the hypothesis? Support your answer using the results of the experiment.

Description	Marks
Statement about support or not of hypothesis provided	1
Explanation for support or not of hypothesis uses evidence from the experimental work	1–2
Total	**/3**

11. State the role of a catalyst in a chemical reaction.

    Explain how a catalyst achieves this effect. Support your answer with a suitable diagram for the decomposition of hydrogen peroxide. Clearly label the diagram.

Description	Marks
Role of catalyst is to increase the rate of a reaction	1
Catalyst achieves this by providing an alternative reaction path with a lower activation energy than the uncatalysed pathway	1
Energy profile diagram provided with • *x* and *y* axes labelled correctly • catalysed and uncatalysed pathways correctly shown • E_a labelled for both catalysed and uncatalysed pathways • reaction shown as exothermic	 1 1 1 1
Total	**/6**

12. Describe **one** way in which the results of the experiment may be improved (either in terms of validity or reliability).

Description	Marks
Describes one way in which results can be improved	1–2
Total	**/2**
Answer could include, but is not limited to:	
• reliability may be improved by repeat trials for each catalyst • for foods, validity may be improved by extracting enzyme (or obtaining it from a commercial source) for direct comparison of enzymes • for solid non-biological catalysts, grinding powders to a consist particle size would improve validity	

Sample assessment task

Chemistry – ATAR Year 12

Task 5 – Unit 3

Assessment type: Test

Conditions
Time for the task: 60 minutes

Task weighting
4% of the school mark for this pair of units

ACIDS AND BASES TEST

Structure of the test:

Section	Suggested working time	Number of questions	Marks
ONE Multiplechoice	10 minutes	10	10
TWO Written answers	40 minutes	6	40
		Total	**50**

You may use the School Curriculum and Standards Authority Chemistry Data Sheet.

DO NOT OPEN THE TEST UNTIL INSTRUCTED TO DO SO

Section One: Multiple-choice questions **(10 marks)**

Consider the following equations to answer question 1.

I $2\,H^+(aq) + 2\,e^- \rightleftharpoons H_2(g)$

II $H_3O^+(aq) + OH^-(aq) \rightleftharpoons 2\,H_2O(\ell)$

III $HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3 + OH^-(aq)$

IV $2\,Na(s) + 2\,H_2O(\ell) \rightleftharpoons 2\,Na^+(aq) + 2\,OH^-(aq) + H_2(g)$

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?

$$H_2PO_4^- + H_3O^+ \rightleftharpoons H_3PO_4 + H_2O$$

(a) $H_2PO_4^-$ and H_2O
(b) $H_2PO_4^-$ only
(c) H_3PO_4 and H_3O^+
(d) H_3PO_4 only

3. The following equilibrium has a K > 1.

$$HF(aq) + N_2H_4(aq) \rightleftharpoons F^-(aq) + N_2H_5^+(aq)$$

Consider the following statements about this equilibrium to answer question 3.

I N_2H_4 is acting as a Brønsted-Lowry acid.

II K_a for HF is greater than K_a for $N_2H_5^+$.

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

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.

Section Two: Written answers **(40 marks)**

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_3PO_4	7.5×10^{-3}	
Hydrocyanic acid	HCN	5.9×10^{-10}	
Aluminium hexahydrate ion	$Al(H_2O)_6^{3+}$	1.4×10^{-5}	
Chlorous acid	$HC\ell O_2$	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)

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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_2SO_4) magnesium hydrogencarbonate ($Mg(HCO_3)_2$)

potassium nitrate (KNO_3) sodium nitrite ($NaNO_2$)

sodium fluoride (NaF) ammonium chloride ($NH_4C\ell$)

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)

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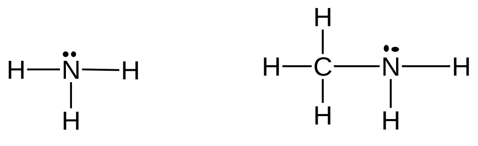
(c) Methylamine (CH_3NH_2) is similar in structure to ammonia (NH_3). It is formed by replacing one of the hydrogen atoms in ammonia by a methyl group ($-CH_3$). The Lewis (electron dot) structures for ammonia and methylamine are shown below. State the reason methylamine can act as a base. (1 mark)



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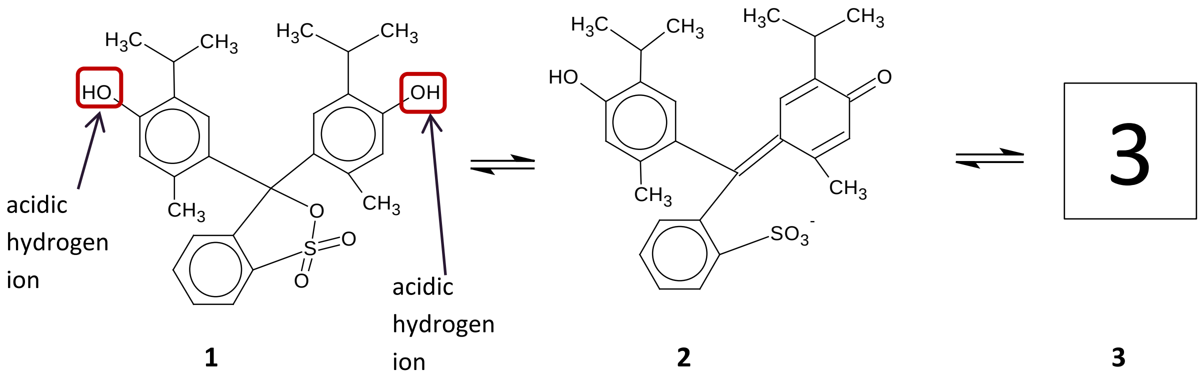
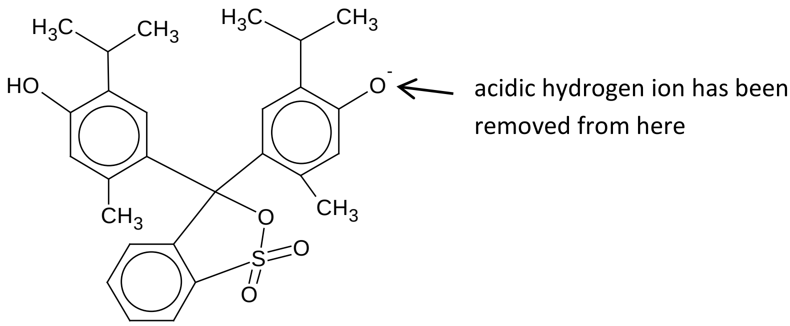
13. Thymol blue, a weak diprotic organic acid used as an acid-base indicator, changes colour at two pH ranges – from red to yellow between pHs 1.2 and 2.8 and from yellow to blue between pHs 8.0 and 9.6. Structures **1** and **2**, below, show the structures for thymol blue in solution at pH less than 1.2 (**1**) and pH range 2.8–8.0 (**2**).

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



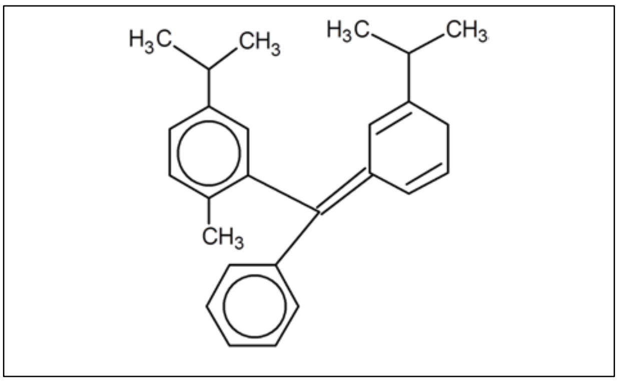
1	**2**	**3**
pH < 1.2	2.8 < pH < 8.0	pH > 9.6
red	yellow	blue

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**.



(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)



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

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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)

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(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)

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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)

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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)

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(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)

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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_3PO_4	7.5×10^{-3}	4
Hydrocyanic acid	HCN	5.9×10^{-10}	1
Aluminium hexahydrate ion	$Al(H_2O)_6^{3+}$	1.4×10^{-5}	3
Chlorous acid	$HC\ell O_2$	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.

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_2SO_4) magnesium hydrogencarbonate ($Mg(HCO_3)_2$)

potassium nitrate (KNO_3) sodium nitrite ($NaNO_2$)

sodium fluoride (NaF) ammonium chloride ($NH_4C\ell$)

Acidic	Neutral	Basic
$NH_4C\ell$	Na_2SO_4 KNO_3	NaF $Mg(HCO_3)_2$ $NaNO_2$

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.

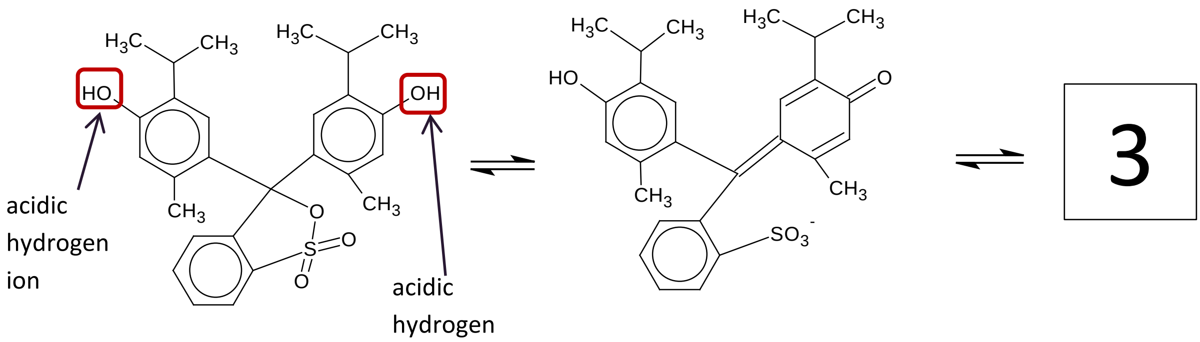
Description	Marks
Recognition that CN^- hydrolyses to give OH^- in aqueous solution (or statement showing recognition that CN^- can behave as a proton acceptor)	1
Equation for hydrolysis provided as follows: $CN^-(aq) + H_2O(\ell) \rightleftharpoons HCN(aq) + OH^-(aq)$	1
Total	**/2**

(c) Methylamine (CH_3NH_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**

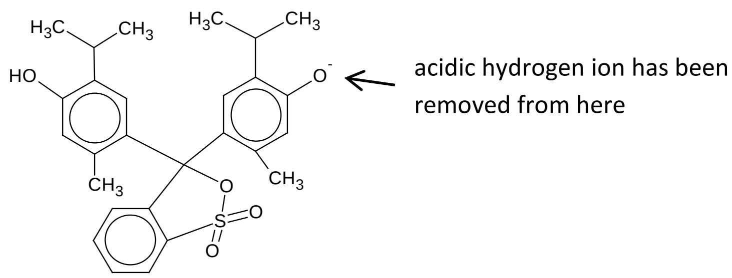
13. Thymol blue, a weak diprotic organic acid used as an acid-base indicator, changes colour at two pH ranges – from red to yellow between pHs 1.2 and 2.8 and from yellow to blue between pHs 8.0 and 9.6. Structures **1** and **2**, below, show the structures for thymol blue in solution at pH less than 1.2 (**1**) and pH range 2.8–8.0 (**2**).

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



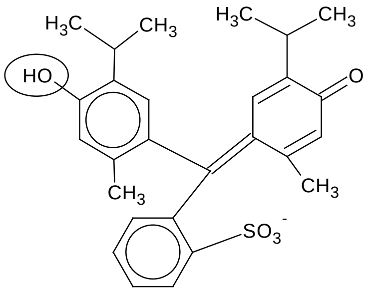
1 pH < 1.2 red | **2** 2.8 < pH < 8.0 yellow | **3** pH > 9.6 blue

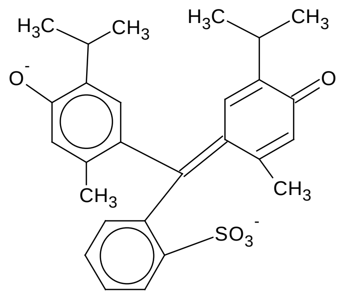
Note: Initially, when base is added to a solution of **1**, the removal of the first hydrogen ions gives the structure below. The bonds in this structure quickly rearrange to give structure **2**.



(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

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)	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
= 0.125	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
$K_w = 1 \times 10^{-14} = [H_3O^+][OH^-]$	1
$[OH^-] = \frac{1\times10^{-14}}{[H_3O^+]} = \frac{1\times10^{-14}}{1.55\times10^{-4}} = 6.45\times10^{-11}\,mol\,L^{-1}$	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 ($C_7H_6O_2$) 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.

Description	Marks
n(NaOH) = C(NaOH) × V = 0.12 × 0.01129 = 1.355 × 10^{-3} mol	1
n($C_7H_6O_2$) = n(NaOH) = 1.355 × 10^{-3} mol	1
M($C_7H_6O_2$) = 122.118 g mol^{-1}	1
m($C_7H_6O_2$) = 122.118 × 1.355 × 10^{-3} = 0.1654 g	1
Conversion to milligrams: m($C_7H_6O_2$) = 165.4 mg	1
$\text{ppm} = \frac{\text{mass of solute in mg}}{\text{mass of solution in kg}} = \frac{165.4}{0.2006} = 825 \text{ ppm}$	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**

Sample assessment task

Chemistry – ATAR Year 12

Task 14 – Unit 4

Assessment type: Extended response

Conditions
Period allowed for completion of the task: two weeks; combination of in-class and out-of-class time

Task weighting
5% of the school mark for this pair of units

Waste chicken feathers as a potential source of ammonia **(41 marks)**

Introduction

Chicken feathers are composed of approximately 90–92% keratin proteins (1, 2). Keratin is a group of fibrous structural proteins and is chemically stable, most likely as a result of the tight coiling of its polypeptide chain in α-helix and β-pleated sheet structures. Recent research has shown that the carbon and nitrogen in feathers can be converted to carbon microspheres and ammonium hydrogencarbonate, two useful products (3).

The researchers placed 1 g of chicken feathers and 12 g of solid carbon dioxide in a 25 mL autoclave that was heated to 600 °C, at which temperature it was maintained for 3 hours. Reactions took place at the pressure generated in the sealed autoclave, which reached levels to make the carbon dioxide supercritical. After cooling the autoclave to room temperature, 0.26 g of ammonium hydrogencarbonate and 0.25 g of carbon microspheres were recovered. Analysis indicated approximately 30.6% and 21.1% by mass of the nitrogen from the feathers was transferred to the ammonium hydrogencarbonate and carbon microspheres, respectively. Analysis also showed the nitrogen content of the carbon microspheres was 12.8% by mass. When the autoclave was opened, carbon dioxide gas rushed out, accompanied by an odour strongly suggestive of ammonia gas. The researchers also found other nitrogen-containing substances, such as amino acids and the polymer nylon-6, react to produce ammonium hydrogencarbonate and carbon microspheres using this method. This could divert these substances from landfill which is where they often end up.

The elemental composition (mass %) of chicken feathers is approximately 47.5% carbon, 15% nitrogen, 7% hydrogen and 30.5% other elements (1).

The thermal decomposition of ammonium hydrogencarbonate gives it potential as a source of ammonia which, in turn, is used for a range of industrial processes, including the production of the fertiliser urea. Ammonium hydrogencarbonate decomposes in the range 36-60 °C to ammonia, carbon dioxide and water, as represented by the equation below.

$$NH_4HCO_3(s) \rightarrow NH_3(g) + CO_2 + H_2O(l) \quad \Delta H = 163\ kJ\ mol^{-1}$$

Typically, ammonia is produced industrially by the Haber process in which nitrogen and hydrogen gases react to produce ammonia. The equation for this reaction is represented below.

$$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

The nitrogen comes from air and the hydrogen generally comes from methane through the steam reforming process. Methane is reacted with steam to give hydrogen and carbon monoxide. The carbon monoxide is then further reacted with more steam to give hydrogen and carbon dioxide. The equations for the production of hydrogen in the steam reforming process are represented below.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3\,H_2(g) \quad \Delta H = 206 \text{ kJ mol}^{-1}$$

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g) \quad \Delta H = -41 \text{ kJ mol}^{-1}$$

The sum of these reactions is

$$CH_4(g) + 2\,H_2O(g) \rightarrow CO_2(g) + 4\,H_2(g) \quad \Delta H = 165 \text{ kJ mol}^{-1}$$

It has been estimated that the Haber process accounts for 1–2% of the world's annual energy consumption (3).

References

1. Onifade, A.A., Al-Sane, N.A., Al-Musallam, A.A., & Al-Zarban, S. *Bioresource Technology,* **66**(1), 1–11.
2. Salminen, E. & Rintala, J. *Bioresource Technology*, **83**(1), 13–26.
3. Gao, L., Hu, H., Sui, X., Chen, C., & Chen, Q. *Environmental Science and Technology*, **48**(11), 6500–6507.

What to do

Prepare a report based on the following questions about the production of ammonia from chicken feathers, and from the steam reforming and Haber processes. Where calculations are required, show clear working to support your answer.

1. Assuming 100% efficiency in the steam reforming and Haber processes, determine the mass of ammonia produced per gram of methane reacted. (5 marks)

2. Research and briefly discuss the typical efficiencies for the steam reforming process and Haber process. Determine the mass of ammonia produced per gram of methane based on the typical efficiencies. Cite the source of your information for the efficiency of the process. (5 marks)

3. Based on the information above, determine the mass of ammonia produced per gram of chicken feather in the feather process. Note: The decomposition of the ammonium hydrogencarbonate is typically about 90% efficient. (5 marks)

4. Compare the ratio of ammonia produced on a gram of starting material basis in the steam reforming/Haber processes to the chicken feather process. (2 marks)

5. Based on the researchers' analysis of the efficiency with which the nitrogen in the feathers is converted to ammonium hydrogencarbonate, determine the efficiency of the process for converting the nitrogen in feathers to ammonia. Note again, the decomposition of the ammonium hydrogencarbonate is about 90% efficient. (5 marks)

6. Describe the typical temperature and pressure conditions for steam reforming/Haber processes. Explain the choice (based on the appropriate chemistry concepts and other relevant factors) of temperature and pressure conditions for the reactions. (12 marks)

7. Compare and contrast the temperature and pressure conditions for steam reforming/Haber processes to those used in the production of ammonia from chicken feathers. (You will need to consider how the information provided may allow a pressure for the chicken process to be estimated.) (3 marks)

8. The researchers suggest that producing ammonia from feathers (via decomposition of ammonium hydrogencarbonate) may be more sustainable than through the steam reforming and Haber processes. Discuss this suggestion. (4 marks)

ACKNOWLEDGEMENTS

Introduction information from:

Gao, L., Hu, H., Sui, X., Chen, C., & Chen, Q. (2014, April). One for two: Conversion of waste chicken feathers to carbon microspheres and (NH4)HCO3. *Environmental Science and Technology*, *48*(11), pp. 6500–6507.

Onifade, A.A., Al-Sane, N.A., Al-Musallam, A.A., & Al-Zarban, S. (1998, October). A review: Potentials for biotechnological applications of keratin-degrading microorganisms and their enzymes for nutritional improvement of feathers and other keratins as livestock feed resources. *Bioresource Technology, 66*(1), pp. 1–11.

Salminen, E. & Rintala, J. (2002, May). Anaerobic digestion of organic solid poultry slaughterhouse waste—a review. *Bioresource Technology*, *83*(1), pp. 13–26.

Marking key for sample assessment task 14 – Unit 4

1. Assuming 100% efficiency in the steam reforming and Haber processes, determine the mass of ammonia produced per gram of methane reacted.

Description	Marks
$3\ CH_4(g) + 6\ H_2O(g) \rightarrow 3\ CO_2(g) + 12\ H_2(g)$ $4\ N_2(g) + 12\ H_2(g) \rightarrow 8\ NH_3(g)$ That is, 3 mol CH_4 produces 8 mol NH_3	1 1
$n(CH_4) = \frac{1}{M(CH_4)} = \frac{1}{20.032} = 4.992 \times 10^{-2}$ mol	1
$n(NH_3) = \frac{8}{3} \times 4.992 \times 10^{-2} = 0.133$ mol	1
$m(NH_3) = n \times M = 0.133 \times 17.034 = 2.27$ g i.e. at 100% efficiency, 2.27 g of NH_3 is produced for each gram of CH_4 reacted	1
Total	**/5**

2. Research and briefly discuss the typical efficiencies for the steam reforming process and Haber process. Determine the mass of ammonia produced per gram of methane based on the typical efficiencies. Cite the source of your information for the efficiency of the process.

Description	Marks
For steam reforming process, common values for efficiency range from 65–75%	1
For the Haber process, at each pass of the gases through the reactor, only about 15% of the nitrogen and hydrogen converts to ammonia. (This figure varies from plant to plant.) By continual recycling of unreacted nitrogen and hydrogen, the overall conversion is about 98%	1
For calculation of overall efficiency, a value of ~70% is realistic (accept any values around this range)	1
At 70% efficiency, $m(NH_3) = 0.7 \times 2.27 = 1.59$ g	1
Reference(s) cited with sufficient detail to allow checking	1
Total	**/5**

3. Based on the information above, determine the mass of ammonia produced per gram of chicken feather in the feather process. Note: The decomposition of the ammonium hydrogencarbonate is typically about 90% efficient.

Description	Marks
From information provided, 1 g of chicken feathers gives 0.26 g NH_4HCO_3	1
$n(NH_4HCO_3) = \frac{0.26}{M(NH_4HCO_3)} = \frac{0.26}{79.06} = 3.29 \times 10^{-3}$ mol	1
$n(NH_3) = n(NH_4HCO_3) = 3.29 \times 10^{-3}$ mol	1
$m(NH_3) = 17.034 \times 3.29 \times 10^{-3} = 5.604 \times 10^{-2}$ g	1
At 90% efficiency, $m(NH_3) = 0.9 \times 5.604 \times 10^{-2} = 5.04 \times 10^{-2}$ g	1
Total	**/5**

4. Compare the ratio of ammonia produced on a gram of starting material basis in the steam reforming/Haber processes to the chicken feather process.

Description	Marks
$\frac{\text{Mass of } NH_3 \text{ produced by steam reforming/Haber processes}}{\text{Mass of } NH_3 \text{ produced from feathers}} = \frac{1.59}{0.0504} = 31.5$	1
The steam reforming/Haber process produces approximately 31 times more NH_3 on a gram basis of their starting material	1
Total	**/2**

5. Based on the researchers' analysis of the efficiency with which the nitrogen in the feathers is converted to ammonium hydrogencarbonate, determine the efficiency of the process for converting the nitrogen in feathers to ammonia. Note again, the decomposition of the ammonium hydrogencarbonate is about 90% efficient.

Description	Marks
From information provided, 15% by mass of chicken feathers is N (i.e. for every 100 g of chicken feathers there is 15 g of N)	1
From information provided, 30.6% of the N in feathers goes into NH_4HCO_3	1
i.e. m(N) going to NH_4HCO_3 = 0.306 × 15 = 4.59 g	1
Decomposition of NH_4HCO_3 is 90% efficient so, m(N) going to NH_3 = 0.9 × 4.59 = 4.13 g	1
$\therefore$ % efficiency = $\frac{4.13}{15} \times 100 = 27.5\%$	1
Total	**/5**

6. Describe the typical temperature and pressure conditions for steam reforming/Haber processes. Explain the choice (based on the appropriate chemistry concepts and other relevant factors) of temperature and pressure conditions for the reactions.

Description	Marks
Temperature and pressure conditions for the steam reforming process	
• moderate pressures (~20 atm) for reaction of CH_4 with H_2O – high pressures would favour reverse reaction but low pressures would give too slow a reaction rate	1–2
• high temperature (~800 °C) for reaction of CH_4 with H_2O – the forward reaction is endothermic, so high temperatures favour the forward reaction	1–2
• high pressures (~200 atm) for reaction of CO with H_2O – increases the rate of reaction without compromising equilibrium yield	1–2
• low to moderate temperature for reaction of CO with H_2O – forward reaction is exothermic so high temperatures favour the reverse reaction but too low a temperature slows reaction rate	1–2
Temperature and pressure conditions for the Haber process	
• high pressures (~200 atm) – favour forward reaction and increase rate of reaction	1–2
• moderate temperature (~400 °C) – forward reaction is exothermic, so high temperatures favour the reverse reaction but too low a temperature slows reaction rate	1–2
Total	**/12**

7. Compare and contrast the temperature and pressure conditions for steam reforming/Haber processes to those used in the production of ammonia from chicken feathers. (You will need to consider how the information provided may allow a pressure for the chicken process to be estimated.)

Description	Marks
Temperatures for chicken feather process does not reach as high as for steam reforming process but is higher than for Haber process	1
Estimate of pressure for chicken feather process may be based on the supercritical nature of the CO_2 – CO_2 is supercritical at about 73 atm	1
Pressures for the Haber process and one stage of steam reforming process are very high (in an industrial sense). Whilst the information provided does not state explicit pressures for the chicken feather process, CO_2 is supercritical at about 73 atm, less than half the pressures for the Haber process.	1–2
Total	**/4**

8. The researchers suggest that producing ammonia from feathers (via decomposition of ammonium hydrogencarbonate) may be more sustainable than through the steam reforming and Haber processes. Discuss this suggestion.

Description	Marks
Discussion includes relevant points taken from information provided and researched	1–4
Total	**/4**
Answer could include, but is not limited to:	
Aspects that may be in a discussion include: • high pressures need to be maintained in Haber process and second stage of reforming process which uses a lot of energy • the decomposition of ammonium hydrogencarbonate occurs at low temperature, so reduces energy demands • high temperatures in steam reforming and Haber require high energy • hydrogen for the Haber process is generated from a fossil fuel – a non-renewable resource • feathers are a renewable resource • carbon dioxide generated in the feather process and decomposition of ammonium hydrogencarbonate may be recycled • other nitrogen containing compounds that would otherwise go to landfill may be used in the process developed for chicken feathers	