Government of **Western Australia**
School Curriculum and Standards Authority

SAMPLE ASSESSMENT TASKS

CHEMISTRY
ATAR YEAR 12

Sample assessment task

Chemistry – ATAR Year 12

Task 1 – Unit 3

Assessment type: Science inquiry – investigation

Conditions
Time for the task: 120 minutes

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

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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 planning and amend your plans, if necessary.
- Working in your group, prepare your experiment and collect your data as in your experimental plan.
- Working in your group, discuss your results to identify any trends or patterns in the data.
- Working individually, complete the questions in the Processing and Analysis and Conclusion and Evaluation sections 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: _____

    _____

    Foods: _____

    _____

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

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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)

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(b) Dependent variable   (1 mark)

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(c) Control variables   (3 marks)

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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

Description of experimental procedure

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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)

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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 spreadsheet. Attach the table, or a print out of your table from the spreadsheet, 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)

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Part 5 – Conclusion and evaluation

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

(3 marks)

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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)

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

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Marking key for sample assessment task 1 – 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	2
• 1–2 given	1
Foods:	
• four given	2
• 1–3 given	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 the 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 in the presence of a 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 (one mark for each)	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 spreadsheet 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. Does 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 2 – Unit 3

Assessment type: Science inquiry – practical

Conditions
Time for the task: Pre-laboratory Questions – 20 minutes; Post-laboratory Questions – 30 minutes

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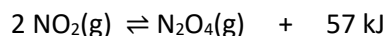5% of the school mark for this pair of units

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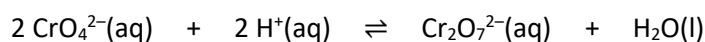**Equilibrium Laboratory Assessment** **(45 marks)**

In this laboratory activity, you will examine the effects of changing the conditions (such as concentration of species in solution, partial pressures of gases and temperature) on the relative amounts of reactants and products in chemical systems initially at equilibrium.

Three equilibria will be studied:

1. The nitrogen dioxide/dinitrogen tetroxide equilibrium

    $2\ NO_2(g) \rightleftharpoons N_2O_4(g) \quad + \quad 57\ kJ$

2. The chromate/dichromate equilibrium

    $2\ CrO_4^{2-}(aq) \quad + \quad 2\ H^+(aq) \quad \rightleftharpoons \quad Cr_2O_7^{2-}(aq) \quad + \quad H_2O(l)$

3. The cobalt/cobalt chloride equilibrium

    $[Co(H_2O)_6]^{2+}(aq) \quad + \quad 4\ Cl^-(aq) \quad \rightleftharpoons \quad [CoCl_4]^{2-}(aq) \quad + \quad 6\ H_2O(l)$
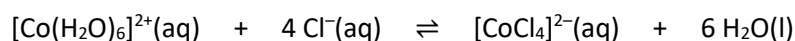
What you need to do
- Read the laboratory activity before completing the **Pre-laboratory Questions**.
- Complete the **Pre-laboratory Questions** in class and submit these to your teacher.
- Working in your group, complete the laboratory activity, including recording all observations.
- Discuss your observations with your group and complete your laboratory report, including a discussion of whether your predictions are accurate or not. Use appropriate chemical equilibrium principles, including collision theory, to explain why or why not your predictions were correct.
- Complete the **Post-laboratory Questions** in class and submit these to your teacher.

Equilibrium Laboratory Assessment

Pre-laboratory Questions **(15 marks)**

1. Predict the observations for the effect of increased pressure on the nitrogen dioxide/dinitrogen tetroxide equilibrium. Justify your prediction. (3 marks)

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2. Predict the observations for the effect of

    (a) increased temperature on the nitrogen dioxide/dinitrogen tetroxide equilibrium.

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    (b) decreased temperature on the nitrogen dioxide/dinitrogen tetroxide equilibrium.

    _____

    _____

    (c) Justify your predictions.

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    (4 marks)

3. Predict the observations for the effect of

    (a) addition of HCl solution on the chromate/dichromate equilibrium.

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    (b) addition of NaOH solution on the chromate/dichromate equilibrium.

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    _____

(c) Justify your predictions.

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(4 marks)

4. Predict the observations for the effect of

(a) addition of water on the cobalt/cobalt chloride equilibrium.

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(b) addition of HCl solution on the cobalt/cobalt chloride equilibrium.

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(c) Justify your predictions.

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(4 marks)

Note for the teacher:

The following Syllabus *Science Inquiry Skills* dot points are assessed in the pre-laboratory questions:

- identify, research, construct and refine questions for investigation; propose hypotheses; and **predict possible outcomes***
- interpret a range of scientific texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, including confidence intervals in secondary data; and **use reasoning to construct scientific arguments**

*Bold text within content dot point indicates the syllabus content that the questions are assessing

## Equilibrium Laboratory Assessment

Post-laboratory Questions **(30 marks)**

1. Provide tables showing your observations when each of the following equilibria were subjected to changes.

   (a) $2\,NO_2(g) \rightleftharpoons N_2O_4(g) \quad + \quad 57\,kJ$

   (b) $2\,CrO_4^{2-}(aq) \quad + \quad 2\,H^+(aq) \quad \rightleftharpoons \quad Cr_2O_7^{2-}(aq) \quad + \quad H_2O(l)$
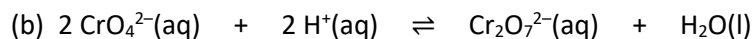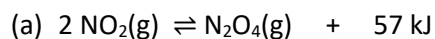
   (2 marks)

2. Using a labelled time versus concentration graph for the CrO_4^{2-} solution, represent the colour changes that occur when HCl solution is added and then a new equilibrium established, and then later when NaOH solution is added and a new equilibrium established. (3 marks)

3. Using a labelled time versus rate graph for the cobalt/cobalt chloride equilibrium shown below, represent the changes that occur in the rates of the forward and reverse reactions when the solution is heated and then reaches a new equilibrium. (3 marks)

$$[Co(H_2O)_6]^{2+}(aq) \quad + \quad 4\,Cl^-(aq) \quad \rightleftharpoons \quad [CoCl_4]^{2-}(aq) \quad + \quad 6\,H_2O(l)$$
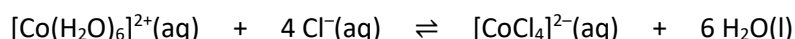
Notes for the teacher:

For question 1, syllabus **Science Inquiry Skills** dot points assessed are:
- conduct investigations safely, competently and methodically for the **collection of valid** and reliable **data**
- **represent data in meaningful and useful ways**

For questions 2 and 3, syllabus **Science Inquiry Skills** dot point assessed is:
- **represent data in meaningful and useful ways, including using appropriate graphic representations** and correct units and symbols; organise and **process data to identify** trends, **patterns and relationships**

4. Consider the changes made to each of the equilibria in the table below to state whether, through your observations, collision theory is supported or not. Explain your reasoning. (6 marks)

Equilibrium	Collision theory supported (yes or no)	Reasoning
$2\ NO_2(g) \rightleftharpoons N_2O_4(g)\ +\ 57\ kJ$ Change: Decrease temperature		
$2\ CrO_4{}^{2-}(aq)\ +\ 2\ H^+(aq)\ \rightleftharpoons\ Cr_2O_7{}^{2-}(aq)\ +\ H_2O(l)$ Change: Addition of HCl(aq)		
$2\ CrO_4{}^{2-}(aq)\ +\ 2\ H^+(aq)\ \rightleftharpoons\ Cr_2O_7{}^{2-}(aq)\ +\ H_2O(l)$ Change: Addition of NaOH(aq)		

5. Consider the changes made to each of the equilibria in the table below to state whether, through your observations, Le Châtelier's Principle (LCP) is supported or not. Explain your reasoning.   (6 marks)

Equilibrium	LCP supported (yes or no)	Reasoning
$2 NO_2(g) \rightleftharpoons N_2O_4(g) + 57 kJ$ Change: Increase temperature		
$[Co(H_2O)_6]^{2+}(aq) + 4 Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6 H_2O(l)$ Change: Addition of water		
$[Co(H_2O)_6]^{2+}(aq) + 4 Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6 H_2O(l)$ Change: Addition of HCl(aq)		

Note for the teacher:

For questions 4 and 5, syllabus **Science Inquiry Skills** dot points assessed are:

- organise and **process data to identify** trends, **patterns** and **relationships**
- **synthesise and use evidence to make and justify conclusions**

6. Predict the expected observations when 10 drops of $AgNO_3$ solution are added to the cobalt equilibrium. Give the reasoning for your prediction. (4 marks)

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7. Consider the equilibrium below involving yellow aqueous iron(III) ions and blood red iron(III) thiocyanate ions.

$$[Fe(H_2O)_6]^{3+}(aq) \; + \; SCN^-(aq) \; \rightleftharpoons \; FeSCN^{2+}(aq) \; + \; 6\,H_2O(l) \quad \Delta H\,-ve$$

   Yellow   blood red

Predict the expected observations when the following changes are made to a test tube containing a solution of the above equilibrium. In each case, give the reasoning for your prediction.

(a) 10 drops of KSCN solution are added. (3 marks)

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(b) The test tube is placed in a hot water bath. (3 marks)

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Note for the teacher:

For questions 6 and 7, syllabus **Science Inquiry Skills** dot points assessed are:
- identify, research, construct and refine questions for investigation; propose hypotheses; and **predict possible outcomes**

- interpret a range of scientific texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, and **use reasoning to construct scientific arguments**

Marking key for sample assessment task 2 – Unit 3

Pre-laboratory Questions

1. Predict the observations for the effect of increased pressure on the nitrogen dioxide/dinitrogen tetroxide equilibrium. Justify your prediction.

Description	Marks
Predicts that increased pressure makes the tube a lighter shade of brown	1
Recognition that the lighter shade of brown is due to increased concentration of N_2O_4 (and reduced concentration of NO_2)	1
Justification shows recognition that according to Le Châtelier's Principle the equilibrium favours the formation of N_2O_4 because this leads to a reduction in pressure	1
Total	**/3**
Note: accept a justification based on collision theory	

2. Predict the observations for the effect of

    (a) increased temperature on the nitrogen dioxide/dinitrogen tetroxide equilibrium.
    (b) decreased temperature on the nitrogen dioxide/dinitrogen tetroxide equilibrium.
    (c) Justify your predictions.

Description	Marks
(a) Predicts that increased temperature makes the tube a darker shade of brown	1
(b) Predicts that decreased temperature makes the tube a lighter shade of brown	1
(c) Justification shows recognition that according to Le Châtelier's Principle • an increase in temperature favours the endothermic reaction which for this equilibrium is the formation of (brown) NO_2 because this leads to a reduction in temperature	1
• a decrease in temperature an equilibrium favours the exothermic reaction which for this equilibrium is the formation of (colourless) N_2O_4 because this leads to an increase in temperature	1
Total	**/4**
Note: accept a justification based on collision theory	

3. Predict the observations for the effect of

   (a) addition of HCl solution on the chromate/dichromate equilibrium.
   (b) addition of NaOH solution on the chromate/dichromate equilibrium.
   (c) Justify your predictions.

Description	Marks
(a) Predicts that addition of HCl solution makes the solution more orange	1
(b) Predicts that addition of NaOH solution makes the solution more yellow	1
(c) Justification shows recognition that according to Le Châtelier's Principle, the addition of • HCl increases the concentration of H^+ in solution so reaction to form (orange) $Cr_2O_7^{2-}$ is favoured as this reduces concentration of H^+ • NaOH decreases the concentration of H^+ in solution (due to its reaction with OH^-) so reaction to form (yellow) CrO_4^{2-} is favoured leading to an increase in the concentration of H^+ ions	1 1
Total	**/4**
Note: accept a justification based on collision theory	

4. Predict the observations for the effect of

   (a) addition of water on the cobalt/cobalt chloride equilibrium.
   (b) addition of HCl solution on the cobalt/cobalt chloride equilibrium.
   (c) Justify your predictions.

Description	Marks
(a) Predicts that addition of water makes the solution more pink (and less blue)	1
(b) Predicts that addition of HCl solution makes the solution more blue	1
(c) Justification shows recognition that according to Le Châtelier's Principle, the addition of • water decreases the concentration of all ions in the system so the reaction to form the most ions is favoured which in this system is the formation of (pink) $[Co(H_2O)_6]^{2+}$ ions • HCl increases the concentration of Cl^- ions in solution so reaction to form (blue) $[CoCl_4]^{2-}$ is favoured leading to a reduction in the concentration of Cl^- ions	1 1
Total	**/4**
Note: accept a justification based on collision theory	

Post-laboratory Questions

1. Provide tables showing your observations when each of the following equilibria were subjected to changes.

   (a) $2 NO_2(g) \rightleftharpoons N_2O_4(g) + 57 kJ$
   (b) $2 CrO_4^{2-}(aq) + 2 H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$
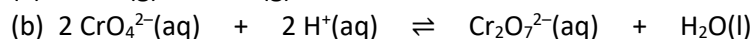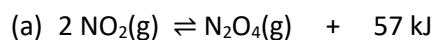
Description	Marks
1 mark for each of the two tables with observations for each equilibrium system	2
Total	/2

2. Using a labelled time versus concentration graph for the CrO_4^{2-} solution, represent the colour changes that occur when HCl solution is added and then a new equilibrium established, and then later when NaOH solution is added and a new equilibrium established.

Description	Marks
Time on horizontal axis and concentration on vertical axis, and axes correctly labelled	1
Concentration of CrO_4^{2-} shown curving down when HCl added and curving up when NaOH added	1
Concentration of $Cr_2O_7^{2-}$ shown curving up when HCl added and curving down when NaOH added	1
Total	/3
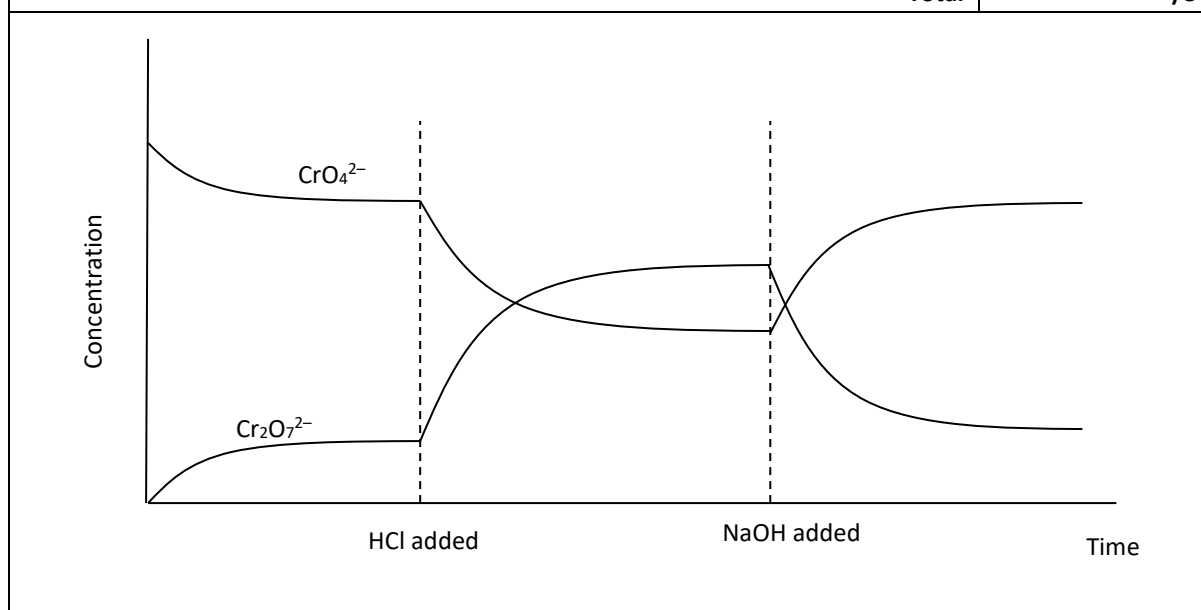
3. Using a labelled time versus rate graph for the cobalt/cobalt chloride equilibrium shown below, represent the changes that occur in the rates of the forward and reverse reactions when the solution is heated and then reaches a new equilibrium.

$$[Co(H_2O)_6]^{2+}(aq) \quad + \quad 4\,Cl^-(aq) \quad \rightleftharpoons \quad [CoCl_4]^{2-}(aq) \quad + \quad 6\,H_2O(l)$$
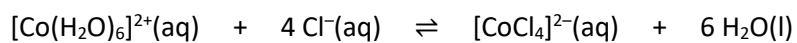
Description	Marks
Time on horizontal axis and rate on vertical axis, and axes correctly labelled	1
Rates of both forward and reverse reactions shown to increase when temperature is increased but increase greater for forward reaction	1
Rates of both forward and reverse reactions curving down and up, respectively, to be equal when the new equilibrium is established	1
Total	**/3**

4. Consider the changes made to each of the equilibria in the table below to state whether, through your observations, collision theory is supported or not. Explain your reasoning. (6 marks)

Description	Marks
For the nitrogen dioxide/dinitrogen tetroxide equilibrium recognition that	
• collision theory predicts that a decrease in temperature decreases the rate of both the forward and reverse reactions but the rate of the exothermic direction decreases less, and	1
• for this system, this is the reaction to form (colourless) N_2O_4 which is what was observed when we did the experiment	1
For the chromate/dichromate equilibrium: addition of HCl, recognition that	
• collision theory predicts that increased concentration of H^+ initially increases the rate of the forward reaction but the rate of the reverse reaction is unchanged, and	1
• leads to the solution becoming more orange which is what was observed when we did the experiment	1
For the chromate/dichromate equilibrium: addition of NaOH, recognition that	
• collision theory predicts that decreased concentration of H^+ initially decreases the rate of the forward reaction but the rate of the reverse reaction is unchanged, and	1
• leads to the solution becoming more yellow which is what was observed when we did the experiment	1
Total	**/6**

Notes:
1. No marks awarded for stating yes or no without a reason.
2. Award marks for responses based on incorrect observations that show the correct understanding of the science inquiry process. For example, when the observation is in contradiction with what is expected, if support for collision theory is given as 'no' but the reasoning has a correct prediction, based on the collision theory and a statement recognising that the prediction and observation contradict each other so theory is not supported, award the marks.
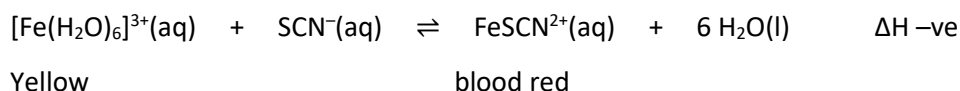
5. Consider the changes made to each of the equilibria in the table below to state whether, through your observations, Le Châtelier's Principle (LCP) is supported or not. Explain your reasoning.

Description	Marks
For the nitrogen dioxide/dinitrogen tetroxide equilibrium, recognition that	
• Le Châtelier's Principle predicts that an increase in temperature favours the endothermic direction, and	1
• for this system, this is the reaction to form (brown) NO_2 which is what was observed when we did the experiment	1
For the cobalt/cobalt chloride equilibrium: addition of water, recognition that	
• Le Châtelier's Principle predicts that addition of water reduces the concentration of all ions initially so the reaction producing more ions is favoured, and	1
• for this system leads to the formation of pink $[Co(H_2O)_6]^{2+}$ which is what was observed when we did the experiment	1
For the cobalt/cobalt chloride equilibrium: addition of HCl, recognition that	
• Le Châtelier's Principle predicts that increased concentration of Cl^- favours the reaction that decreases concentration of Cl^-, and	1
• produces blue $[CoCl_4]^{2-}$ which is what was observed when we did the experiment	1
Total	**/6**
Notes:	
1. No marks awarded for stating yes or no.	
2. Award marks for responses based on incorrect observations that show the correct understanding of the science inquiry process. For example, when the observation is in contradiction with what is expected, if support for Le Châtelier's Principle is given as 'no' but the reasoning has a correct prediction, based on the Le Châtelier's Principle and a statement recognising that the prediction and observation contradict each other so LCP is not supported, award the marks.	

6. Predict the expected observations when 10 drops of $AgNO_3$ solution is added to the cobalt equilibrium. Give the reasoning for your prediction.

Description	Marks
Recognition that a (white) precipitate of AgCl will form	1
Recognition that the solution will become a deeper pink colour	1
Justification shows recognition that according to Le Châtelier's Principle addition of $AgNO_3$ solution	
• decreases the concentration of Cl^- ions in the system so the reaction to form more Cl^- ions is favoured, and	1
• in this system leads to the formation of (pink) $[Co(H_2O)_6]^{2+}$ ions	1
Total	**/4**
Note: accept a justification based on collision theory	

7. Consider the equilibrium below involving yellow aqueous iron(III) ions and blood red iron(III) thiocyanate ions.

$$[Fe(H_2O)_6]^{3+}(aq) \quad + \quad SCN^-(aq) \quad \rightleftharpoons \quad FeSCN^{2+}(aq) \quad + \quad 6\,H_2O(l) \qquad \Delta H \text{ } -ve$$

Yellow   blood red

Predict the expected observations when the following changes are made to a test tube containing a solution of the above equilibrium. In each case, give the reasoning for your prediction

(a) 10 drops of KSCN solution are added.

Description	Marks
Predicts that the solution will become a deeper red	1
Justification shows recognition that according to Le Châtelier's Principle addition of KSCN solution	
• increases the concentration of SCN^- ions in the system so the reaction to reduce concentration of SCN^- ions is favoured, and	1
• in this system leads to the formation of (blood red) $FeSCN^{2+}$ ions	1
Total	/3
Note: accept a justification based on collision theory	

(b) The test tube is placed in a hot water bath.

Description	Marks
Predicts that the solution will become more yellow	1
Justification shows recognition that according to Le Châtelier's Principle heating the solution	
• favours the endothermic reaction, and	1
• in this system leads to the formation of (yellow) $[Fe(H_2O)_6]^{3+}$ ions	1
Total	/3
Note: accept a justification based on collision theory	

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

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Acids and Bases test

Structure of the test:

Section	Suggested working time	Number of questions	Marks
ONE Multiple choice	10 minutes	10	10
TWO Written answers	50 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 $2\,Na(s)\ +\ 2\,H_2O(\ell)\ \rightleftharpoons\ 2\,Na^+(aq)\ +\ 2\,OH^-(aq)\ +\ H_2(g)$
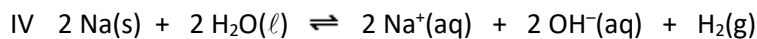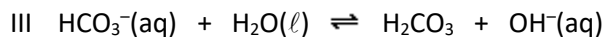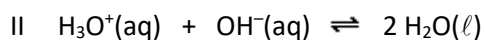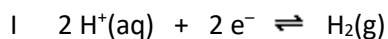
1. Which of the above equations represent a hydrogen ion (proton) transfer reaction?

    (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?

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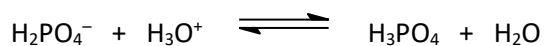
    (a) $H_2PO_4^-$ and H_2O
    (b) $H_2PO_4^-$ only
    (c) H_3PO_4 and H_3O^+
    (d) H_3PO_4 only

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. (2 marks)

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}	

(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. (6 marks)

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_4Cl)

Acidic	Neutral	Basic

(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)
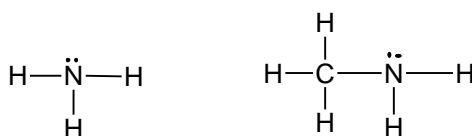
$$H-\ddot{N}-H \qquad H-C-\ddot{N}-H$$

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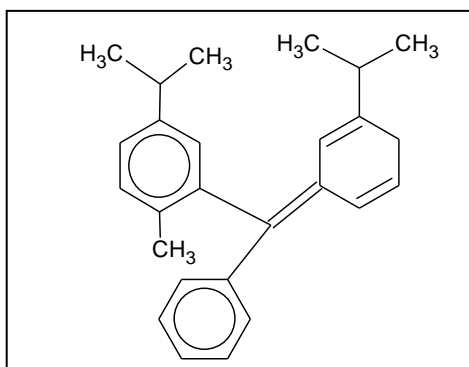
(b) What term is used to describe the relationship between structures **1** and **2** and between structures **2** and **3**? (1 mark)

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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	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	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.

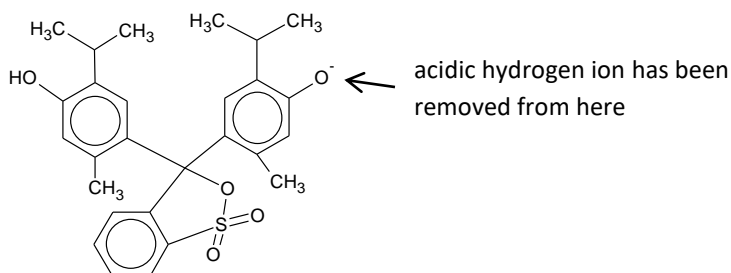| Description	Marks
Recognition that the nitrogen in methylamine has a lone pair of electrons that can accept a proton (hydrogen ion)	1
Total	**/1**

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).

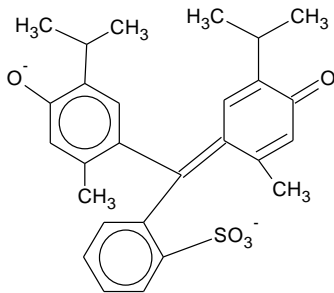The acidic hydrogen ions are indicated in the boxes in structure 1.

1	**2**	**3**
pH < 1.2	2.8 < pH < 8.0	pH > 9.6
red	yellow	blue
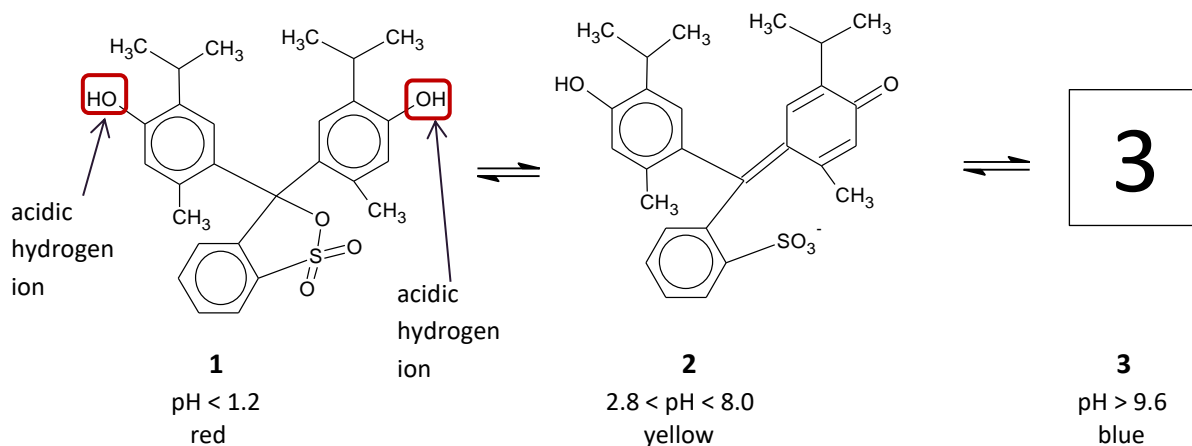
Note: Initially, when base is added to a solution of **1**, the removal of the first hydrogen ions gives the structure below. The bonds in this structure quickly rearrange to give structure **2**.

(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
$[OH^-] = \dfrac{1 \times 10^{-14}}{[H_3O^+]} = \dfrac{1 \times 10^{-14}}{1.55 \times 10^{-4}} = 6.45 \times 10^{-11} \, mol L^{-1}$	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 ($C_7H_6O_2$) 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
ppm = $\dfrac{\text{mass of solute in mg}}{\text{mass of solution in kg}}$ = $\dfrac{165.4}{0.2006}$ = 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**

Sample assessment task

Chemistry – ATAR Year 12

Task 11 – 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

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Waste chicken feathers as a potential source of ammonia (42 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 and kept at this temperature 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.

$$NH_4HCO_3(s) \quad \rightarrow \quad NH_3(g) \; + \; CO_2 \; + \; H_2O(l) \quad \Delta H = 163 \text{ kJ mol}^{-1}$$
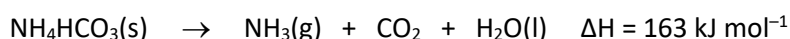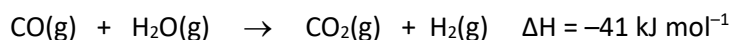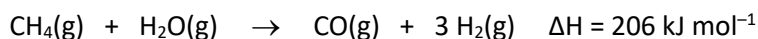
Typically, ammonia is produced industrially by the Haber process in which nitrogen and hydrogen gases react to produce ammonia. The equation for this reaction is represented below.

$$N_2(g) \; + \; 3\,H_2(g) \quad \rightarrow \quad 2\,NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$
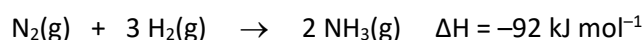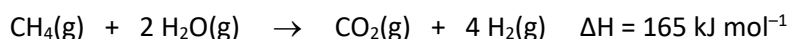
The nitrogen comes from air and the hydrogen generally comes from methane through the steam reforming process. Methane is reacted with steam to give hydrogen and carbon monoxide. The carbon monoxide is then further reacted with more steam to give hydrogen and carbon dioxide.

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.) (4 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)

Marking key for sample assessment task 11 – 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
$3\ CH_4(g)\ +\ 6\ H_2O(g)\ \rightarrow\ 3\ CO_2(g)\ +\ 12\ H_2(g)$ $4\ N_2(g)\ +\ 12\ H_2(g)\ \rightarrow\ 8\ NH_3(g)$	1
That is, 3 mol CH_4 produces 8 mol NH_3	1
$n(CH_4) = \dfrac{1}{M(CH_4)} = \dfrac{1}{16.042} = 6.324 \times 10^{-2}$ mol	1
$n(NH_3) = \dfrac{8}{3} \times 6.324 \times 10^{-2} = 0.166$ mol	1
$m(NH_3) = n \times M = 0.166 \times 17.034 = 2.83$ g i.e. at 100% efficiency, 2.83 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, $m(NH_3) = 0.7 \times 2.83 = 1.98$ 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
$n(NH_4HCO_3) = \dfrac{0.26}{M(NH_4HCO_3)} = \dfrac{0.26}{79.06} = 3.29 \times 10^{-3}$ 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
$\dfrac{\text{Mass of NH}_3 \text{ produced by steam reforming/Haber processes}}{\text{Mass of NH}_3 \text{ produced by feathers}} = \dfrac{1.98}{0.0504} = 39.3$	1
The steam reforming/Haber process produces approximately 39 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$_4$HCO$_3$	1
i.e. m(N) going to NH$_4$HCO$_3$ = 0.306 × 15 = 4.59 g	1
Decomposition of NH$_4$HCO$_3$ is 90% efficient so, m(N) going to NH$_3$ = 0.9 × 4.59 = 4.13 g	1
$\therefore$ % efficiency = $\dfrac{4.13}{15} \times 100 = 27.5\%$	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$_2$O – 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$_2$O – the forward reaction is endothermic, so high temperatures favour the forward reaction	1–2
• high pressures (~200 atm) for reaction of CO with H$_2$O – increases the rate of reaction without compromising equilibrium yield	1–2
• low to moderate temperature for reaction of CO with H$_2$O – 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

Acknowledgements