

Chemistry 30

2013 Classroom Assessment Materials and Examples

This document was written primarily for:

Students	✓
Teachers	✓ of Chemistry 30
Administrators	✓
Parents	
General Audience	
Others	

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Introduction

The items here are intended to promote the use of extended-response items in high-quality classroom assessments. Teachers may wish to use these items in a variety of ways to improve the degree to which students develop and demonstrate an understanding of the concepts described in the [*Chemistry 30 Program of Studies*](#).

Assessment of Communication Skills in the Classroom

Although written-response questions are no longer part of the Chemistry 30 Diploma Examination, we encourage the use of written-response questions in classroom assessment. In this way, there can be a greater assessment of the outcomes included in the program of studies.

The following pages give examples of written-response questions, together with scoring rubrics and examples of student work.

Chemistry is a discipline in which there is a stringent set of rules for proper scientific communication. Communication skills are most evident in, and can be directly assessed on, the written-response questions.

In previous years, we have scored analytic-style written-response questions out of 6, with 5 marks for chemistry content and 1 mark for communication. The communication mark is partially determined by the extent to which the question has been attempted. Communication is marked based on organization, clarity, use of correct scientific conventions, and use of proper language conventions.

Proper scientific conventions include:

- labelling of graphs and diagrams
- mathematical formulas and equations
- significant digits, units of measurement, and unit conversion
- states of matter
- abbreviations

In previous years, we have scored holistic written-response questions using the holistic scoring rubrics, which integrate the assessment of communication skills into the marking matrix that is used to assess the overall response.

Therefore, on the analytic questions, communication skills can be assessed more independently; whereas on the holistic question, communication can be assessed as part of the total response.

The intent of evaluating communication is to reward students for creating responses that are on topic, clear, concise, and well written using the conventions of scientific language.

Communication Guidelines for Classroom Assessment

The following list is a set of guidelines that were used during the marking of the communication scale for any of the written-response questions.

- Do not score work that the student has indicated should not be scored—this includes partially erased or clearly crossed-out work.
- If a student's response contains contradictory information, then score the work as either ambiguous or incorrect.
- Do not score any irrelevant and extra information that is not incorrect but that does not contribute to the correct response.
- The omission of leading zeros is not a scientific error and therefore will not be scored as such.
- States, units, significant digits, and ion charges must be included within the response. The student must be consistent in their use. (The exception to this is equilibrium expressions, which do not require units.) Units used should respect the conventions of the International System of Units (SI).
- Significant digits in the final recorded answer must be correct. It is not necessary to carry extra significant digits in intermediate steps, but it is a preferred practice to carry at least one extra digit throughout intermediate steps. If the number of significant digits in intermediate steps has been truncated (is less than the required number), then this will be considered an error.
- If spelling and grammatical errors limit the understanding of the response and cause ambiguity, then this will be considered a communication error.
- Graphs should include an appropriate title, labelled axes with units, and an appropriate scale. The manipulated variable should always be on the x -axis.
- When the student is asked to draw a diagram of a cell, the diagram should include labels for the anode, cathode (or the specific substances), reagent solutions (electrolytes), a salt bridge or porous cup, voltmeter or power source, and a connecting wire to the electrodes. Students are not required, unless specifically asked, to label the migration of ions, the solution in the salt bridge (although the diagram or procedure should indicate that there is a solution present), or the electron flow. If a student chooses to include these labels, then they will also be marked as part of the response.
- The y -axis on an energy diagram can be labelled E_p , H , or ΔH with appropriate units. However, on diploma examinations and field tests the y -axis will be labelled E_p (kJ).
- Portions of a response not assessed for chemistry marks will not be assessed for communication.

Significant Digits

The examples below illustrate the proper use of significant digits for the Chemistry 30 Diploma Examination in a response.

Example 1

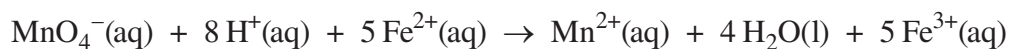
A 10.0 mL sample of a $\text{Fe}^{2+}(\text{aq})$ solution of unknown concentration is titrated with a standardized 0.120 mol/L $\text{KMnO}_4(\text{aq})$ solution. The following data are recorded.

2 decimal places
(10.10–1.00)
according to the
addition/subtraction
rules leaves
3 significant digits

Trial	I	II	III
Final burette reading (mL)	10.10	19.22	28.33
Initial burette reading (mL)	1.00	10.10	19.22
Titrant added (mL)	9.10*	9.12	9.11

The concentration of the $\text{Fe}^{2+}(\text{aq})$ is _____.

Reaction Equation



Average volume of titrant added is 9.11 mL

$$[\text{Fe}^{2+}(\text{aq})] = 9.11 \text{ mL MnO}_4^-(\text{aq}) \times 0.120 \text{ mol/L MnO}_4^-(\text{aq}) \times \frac{5 \text{ mol Fe}^{2+}(\text{aq})}{1 \text{ mol MnO}_4^-(\text{aq})} \times \frac{1}{10.0 \text{ mL Fe}^{2+}(\text{aq})}$$

$$[\text{Fe}^{2+}(\text{aq})] = \mathbf{0.547} \text{ mol/L}$$

* Final answer has 3 significant digits (least number present according to the multiplication/division rule)

Exact number,
therefore does **not**
change the
final number of
significant digits

Example 2

K_a value has 2 significant digits

The pH of a 0.100 mol/L solution of ethanoic acid is _____.

$$K_a = \mathbf{1.8 \times 10^{-5}} = \frac{x^2}{(0.100 \text{ mol/L} - x)}$$

The value of x can be ignored when compared to 0.100 mol/L in the case of such a weak acid.

$$K_a \text{ is approximately } \frac{x^2}{0.100 \text{ mol/L}}$$

$$x = [\text{H}_3\text{O}^+(\text{aq})] = \mathbf{0.001342}$$
$$\text{pH} = -\log(0.001342 \text{ mol/L})$$

$$= \mathbf{2.87}$$

Additional digits
carried through on
an interim basis

Final answer has
2 significant digits

Example 3

A student conducts a calorimetry experiment to determine the energy transferred when Solution A is mixed with Solution B. The data collected are shown below. Assume the specific heat capacity for each solution is the same as that of water.

Mass of Solution A (g)	100.0
Mass of Solution B (g)	100.0
Mass of final solution mixture (g)	200.0
Initial temperature of solutions A and B (°C)	20.0
Final temperature of the solution mixture (°C)	23.0

The original data are limited to 3 significant digits.

$$\Delta H = mc\Delta t$$

$$\Delta H = (200.0 \text{ g}) (4.19 \text{ J/g}\cdot\text{°C}) (3.0 \text{ °C})$$

The resulting temperature has 2 significant digits.

$$\Delta H = 2.5 \text{ kJ}$$

The final answer should be rounded to the same number of significant digits contained in the input data for the calculation $\Delta H = mc\Delta t$ that has the fewest number of significant digits.

The final answer has 2 significant digits because the input data for the $\Delta H = mc\Delta t$ calculation is limited by the temperature difference of 3.0 °C, which has 2 significant digits.

Analytic Communication Scoring Guide

Communication Scoring Guide for Closed-Response (Analytic) Questions

Score	Criteria
1	The teacher does not have to interpret any part of the response, and no reference to the question is needed to understand the response. The response is clear, concise, and presented in a logical manner. Scientific conventions have been followed. The response may contain a minor error.
0 Ambiguous or >1 scientific error	The teacher has to interpret the response (ambiguous) or the response is so poorly organized that the marker has to refer to the question in order to understand the response. The response may be ambiguous, incomprehensible, and/or disorganized, and/or contains errors (more than one) in scientific conventions.
0	50% or less of the question has been attempted. There is not enough of a response present to be able to score for communication.
NR	No response given.

Scientific conventions to be followed:

- Correct, appropriate units are used throughout the response.
- States are given throughout the response except in calculation labels and when a formula replaces a word in a sentence.
- Significant digits are used throughout the response.
- Branch names in organic molecules are in alphabetical order, using lowest possible numbers to indicate the position of branches.

***Note:** Content and communication are scored on separate scales for the analytic question.

Explanation of the Holistic Scoring Guide

Holistic questions are designed so that students can demonstrate their understanding of science from more than one valid approach or perspective and are assessed in a holistic fashion. The holistic question will be scored on two rubrics that combine to form a 5-point scale.

Teachers must read the student response in its entirety in order to decide whether it contains the key component(s) for the particular question. The teacher then looks for the necessary support details. These two aspects are used to assess the quality of students' responses. Communication skills and scientific conventions are considered in the determination of the overall quality of the key component(s) and support.

Holistic Scoring Rubrics

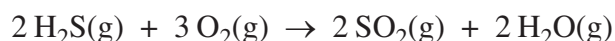
Score	Key–no Key Criteria
1 Key (weight of 2)	The student has addressed the key component(s) of the question asked. The key component(s) of the question can be found in the stem of the question.
0 No Key	The student has not addressed the key component(s) of the question asked.

Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets. The support provided may contain minor errors/weaknesses. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

Sample Written-Response Questions and Responses for Classroom Assessment

Use the following information to answer the first question.

Sour gas contains a significant amount of hydrogen sulfide gas mixed with methane gas. Hydrogen sulfide gas is a colourless, toxic gas that smells like rotten eggs. Hydrogen sulfide gas can be converted to sulfur dioxide gas in a process called flaring, as represented by the equation below.



1. a. **Determine** the enthalpy change for the flaring process represented by the equation above. (3 marks)
- b. **Sketch** and label a potential energy diagram that represents the enthalpy change for the flaring process. (2 marks)

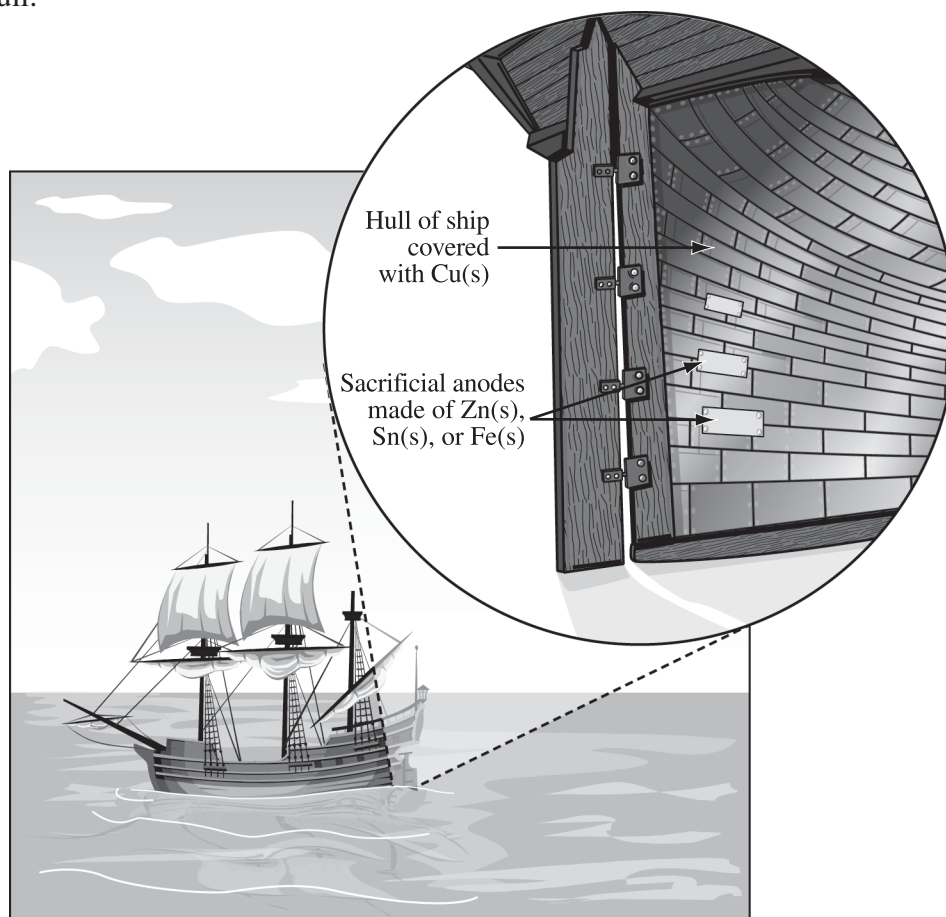
Use the following information to answer the next question.

Large amounts of ammonia for the production of fertilizers and other consumer goods are made by the Haber process. During the Haber process, hydrogen gas combines with nitrogen gas to produce ammonia gas. This process is carried out in the presence of a catalyst.

2. a. Write a balanced equilibrium equation for the Haber process. Include the enthalpy change as an energy term in the balanced equation. (3 marks)
- b. **Describe** what happens to the equilibrium position and the value of the equilibrium constant when the temperature of the system is increased from 200 °C to 500 °C. (2 marks)

Use the following information to answer the next question.

The copper covering on the hull of a ship, which is the main body of the ship that is in contact with water, corrodes when it is exposed to water and oxygen. To protect against such corrosion on British naval ships, Sir Humphry Davy was the first to use blocks of either zinc, tin, or iron as sacrificial anodes, which were attached to the ship's hull.

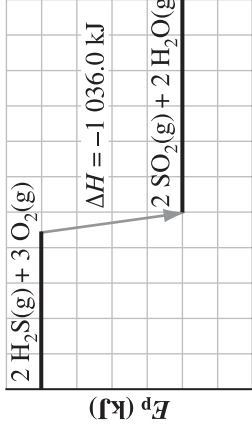


3. **Explain** how a block of zinc, tin, or iron would prevent the corrosion of the copper on a ship's hull.

Your response should include

- an explanation of the corrosion of copper
- an explanation of how a block of zinc, tin, or iron protects the copper from corrosion
- relevant balanced equations and E°_{cell} calculations to support each of your explanations

Analytic-Style Written-Response Question Sample Response

Question	Marks	Sample Response	Comments
1.a.	3	$2 \text{H}_2\text{S}(\text{g}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{SO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$ $\Delta H^\circ = \sum n \Delta_f H^\circ_{(\text{products})} - \sum n \Delta_f H^\circ_{(\text{reactants})}$ $= [(2 \text{ mol})(-296.8 \text{ kJ/mol}) + (2 \text{ mol})(-241.8 \text{ kJ/mol})]$ $- [(2 \text{ mol})(-20.6 \text{ kJ/mol}) + (3 \text{ mol})(0 \text{ kJ/mol})]$ $= (-1\ 077.2 \text{ kJ}) - (-41.2 \text{ kJ})$ $= -1\ 036.0 \text{ kJ}$	<ul style="list-style-type: none"> • 1 mark for correct method • 1 mark for substitution consistent with method • 1 mark for correct answer
1.b.	2	<p style="text-align: center;">Combustion of H₂S(g)</p> 	<ul style="list-style-type: none"> • 1 mark for correct labels • 1 mark for shape of graph consistent with calculation
	1	<p style="text-align: center;">Note: Can also be labelled reactants and products.</p> <p style="text-align: center;">Communication—See Guide</p>	Use Analytic Scoring Guide
		Total possible marks = 6	

Analytic-Style Written-Response Question Sample Response

Question	Marks	Sample Response	Comments
2.a.	3	$3\text{H}_2(\text{g}) + \text{N}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) + 91.8\text{ kJ}$	<ul style="list-style-type: none"> • 1 mark for balanced equation • 1 mark for the correct enthalpy value • 1 mark for the inclusion of the enthalpy term on the correct side
2.b.	2	The equilibrium position would shift toward the reactants because the forward reaction is exothermic, and the K_c value would decrease.	<ul style="list-style-type: none"> • 1 mark for correct shift in equilibrium consistent with enthalpy term • 1 mark for a change in K_c consistent with the shift
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Holistic-Style Written-Response Question Sample Response

Question	Marks	Sample Response	Comments
3.		<p>Corrosion Explanation</p> <p>The corrosion of copper is the spontaneous oxidation reaction that occurs when copper reacts with water and oxygen. Solid copper is oxidized to $\text{Cu}^{2+}(\text{aq})$.</p> $\text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^- \rightarrow 4 \text{OH}^-(\text{aq}) \quad E^\circ = +0.40 \text{ V}$ $\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2 \text{e}^- \quad E^\circ = +0.34 \text{ V}$ $\text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 2 \text{Cu}(\text{s}) \rightarrow 4 \text{OH}^-(\text{aq}) + 2 \text{Cu}^{2+}(\text{aq}) \quad E^\circ_{\text{cell}} = +0.06 \text{ V}$ <p style="text-align: center;">OR $\rightarrow 2 \text{Cu}(\text{OH})_2(\text{s})$</p> <p>Sacrificial Anode Explanation</p> <p>The metal found in the sacrificial anode prevents the corrosion of copper because it (Zn, Sn, or Fe) is a stronger reducing agent than copper and the metal undergoes oxidation before the copper.</p> <p>If both iron and copper are present with water and oxygen, the reaction that occurs is the following.</p> $\text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 2 \text{Fe}(\text{s}) \rightarrow 4 \text{OH}^-(\text{aq}) + 2 \text{Fe}^{2+}(\text{aq}) \quad E^\circ = +0.85 \text{ V}$ <p style="text-align: center;">OR $\rightarrow 2 \text{Fe}(\text{OH})_2(\text{s})$</p>	<p><i>Key Component</i></p> <ul style="list-style-type: none"> • explanation that Fe(s), Sn(s) or Zn(s) reacts spontaneously with the oxidizing agent before Cu(s) <p><i>Support</i></p> <ul style="list-style-type: none"> • explanation of the corrosion of copper • explanation of the sacrificial anode • relevant equations and potential difference calculation

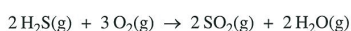
Sample Student Responses and Rationales

A number of sample responses to written-response questions are given on the following pages. For each, the score awarded and a rationale for that score are also provided.

Written-Response Questions—Student Response 1

Use the following information to answer the first question.

Sour gas contains a significant amount of hydrogen sulfide gas mixed with methane gas. Hydrogen sulfide gas is a colourless, toxic gas that smells like rotten eggs. Hydrogen sulfide gas can be converted to sulfur dioxide gas in a process called flaring, as represented by the equation below.

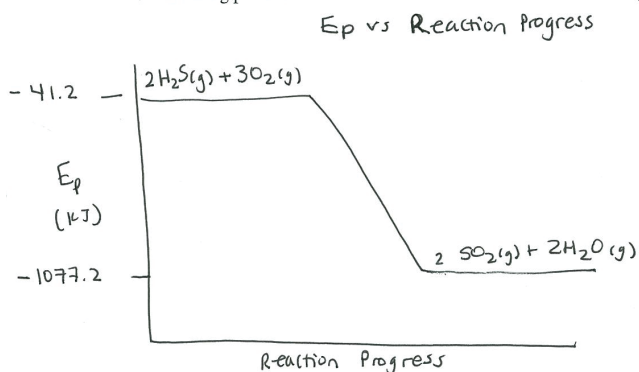


Written Response—10%

1. a. Determine the enthalpy change for the flaring process represented by the equation above. (3 marks)

$$\begin{aligned} \Delta H &= \sum p - \sum r \\ &= \left(2 \text{ mol} \left(-296.8 \frac{\text{kJ}}{\text{mol}} \right) \right) + \left(2 \text{ mol} \left(-241.8 \frac{\text{kJ}}{\text{mol}} \right) \right) - \left[2 \text{ mol} \left(-20.6 \frac{\text{kJ}}{\text{mol}} \right) \right] \\ &= -593.6 \text{ kJ} + (-483.6 \text{ kJ}) - (-41.2 \text{ kJ}) \\ &= -1036 \text{ kJ} \end{aligned}$$

- b. Sketch and label a potential energy diagram that represents the enthalpy change for the flaring process. (2 marks)



Score—6 out of 6
(5 for content and 1 for communication)

Rationale

This example meets the requirements of the *standard of excellence*.

Rationale

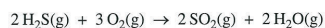
The correct method for determining ΔH is used, but the final answer does not have the correct number of significant digits. The enthalpy diagram has the correct shape and is labelled.

The response received 1 mark for communication because the only error in communication was in part **a** with the significant digits in the final answer.

Written-Response Questions—Student Response 2

Use the following information to answer the first question.

Sour gas contains a significant amount of hydrogen sulfide gas mixed with methane gas. Hydrogen sulfide gas is a colourless, toxic gas that smells like rotten eggs. Hydrogen sulfide gas can be converted to sulfur dioxide gas in a process called flaring, as represented by the equation below.



Written Response—10%

1. a. Determine the enthalpy change for the flaring process represented by the equation above. (3 marks)

$$2\text{H}_2\text{S}(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$$

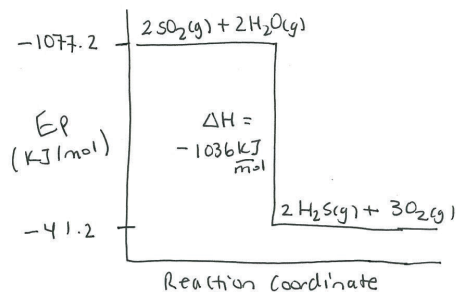
$$\Delta H = \sum \text{products} - \sum \text{reactants}$$

$$\Delta H = \left[\begin{array}{l} 2 \text{ mol SO}_2(\text{g}) (-296.8 \text{ kJ/mol}) \\ + 2 \text{ mol H}_2\text{O}(\text{g}) (-241.8 \text{ kJ/mol}) \end{array} \right] - \left[\begin{array}{l} 2 \text{ mol H}_2\text{S}(\text{g}) (-20.6 \text{ kJ/mol}) \\ + 3 \text{ mol O}_2(\text{g}) (0 \text{ kJ/mol}) \end{array} \right]$$

$$(-1077.2 \text{ kJ/mol}) - (-41.2 \text{ kJ/mol})$$

$$\Delta H = -1036 \text{ kJ/mol}$$

- b. Sketch and label a potential energy diagram that represents the enthalpy change for the flaring process. (2 marks)



Score—4 out of 6
(4 for content and 0 for communication)

Rationale

This example meets the requirements of the *acceptable standard*.

The correct method for determining ΔH is used, but the units included are incorrect, as are the significant digits.

The shape of the enthalpy diagram is correct but the diagram is missing a title.

The response received 0 marks for communication because of the errors in significant digits and in units.

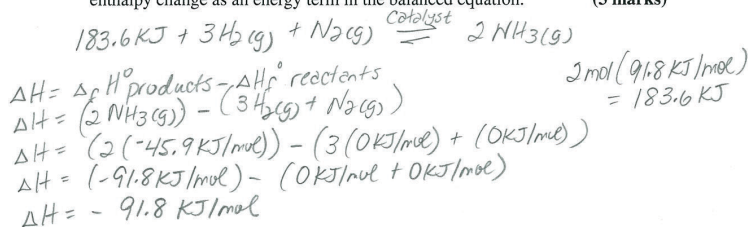
Written-Response Questions—Student Response 3

Use the following information to answer the next question.

Large amounts of ammonia for the production of fertilizers and other consumer goods are made by the Haber process. During the Haber process, hydrogen gas combines with nitrogen gas to produce ammonia gas. This process is carried out in the presence of a catalyst.

Written Response—10%

2. a. Write a balanced equilibrium equation for the Haber process. Include the enthalpy change as an energy term in the balanced equation. (3 marks)



- b. Describe what happens to the equilibrium position and the value of the equilibrium constant when the temperature of the system is increased from 200 °C to 500 °C. (2 marks)

As the temperature of the system is increased from 200 °C to 500 °C products will be more favored than reactants. The value of the equilibrium constant will increase.

Score—3 out of 6
(3 for content and 0 for communication)

Rationale

This example meets the minimum requirements of the *acceptable standard*.

The equation was correctly balanced with an equilibrium arrow. The enthalpy calculation appears to have been done correctly, but an incorrect value was substituted into the equation, and was on the wrong side of the equation. The shift and the change in the K_c were consistent with the student's equation.

The response received 0 for communication, as units were incorrect more than once.

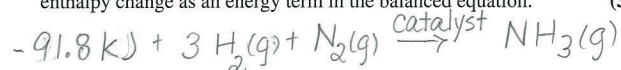
Written-Response Questions—Student Response 4

Use the following information to answer the next question.

Large amounts of ammonia for the production of fertilizers and other consumer goods are made by the Haber process. During the Haber process, hydrogen gas combines with nitrogen gas to produce ammonia gas. This process is carried out in the presence of a catalyst.

Written Response—10%

2. a. Write a balanced equilibrium equation for the Haber process. Include the enthalpy change as an energy term in the balanced equation. (3 marks)



- b. Describe what happens to the equilibrium position and the value of the equilibrium constant when the temperature of the system is increased from 200 °C to 500 °C. (2 marks)

There would be no change in the value of the equilibrium constant.

Score—2 out of 6
(1 for content and 1 for communication)

Rationale

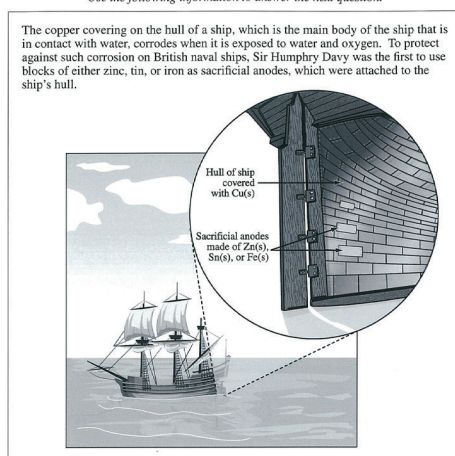
This example does not meet the requirements of the *acceptable standard*.

The equation was not correctly balanced and did not have an equilibrium arrow. The value for the enthalpy change was correct. The enthalpy change was on the wrong side of the equation. The change in the value of the equilibrium constant was incorrect and no shift was indicated.

The response received 1 mark for communication, as states and units were correct.

Written-Response Questions—Student Response 5

Use the following information to answer the next question.



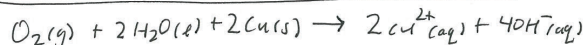
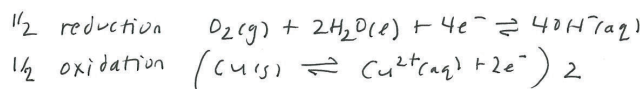
Written Response—15%

3. Explain how a block of zinc, tin, or iron would prevent the corrosion of the copper on a ship's hull.

Your response should include

- an explanation of the corrosion of copper
- an explanation of how a block of zinc, tin, or iron protects the copper from corrosion
- relevant balanced equations and E°_{cell} calculations to support each of your explanations

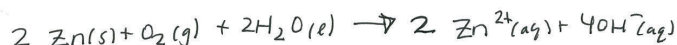
The corrosion of Cu(s) is when Cu(s) spontaneously reacts with $O_2(g)$ and $H_2O(l)$ to form $Cu^{2+}(aq)$ and $OH^-(aq)$. Cu(s) is the reducing agent and the O atom is the oxidizing agent.



$$\begin{aligned} E^\circ &= +0.40V - +0.34V \\ &= 0.06V \end{aligned}$$

A block of Zn(s), Sn(s) or Fe(s) could act as a sacrificial anode protecting the Cu(s) by being a stronger reducing agent. This would mean that instead of Cu(s) donating electrons to become $Cu^{2+}(aq)$, Zn(s) or Sn(s) or Fe(s) would donate electrons and become a cation.

Zn(s) as an example



$$\begin{aligned} E^\circ &= +0.40V - -0.76V \\ &= +1.16V \end{aligned}$$

Since the electrical potential of this reaction is higher than the corrosion of Cu(s), the Zn(s) is more likely to be oxidized instead of Cu(s).

Score—5 out of 5
(Holistically Scored)

Rationale

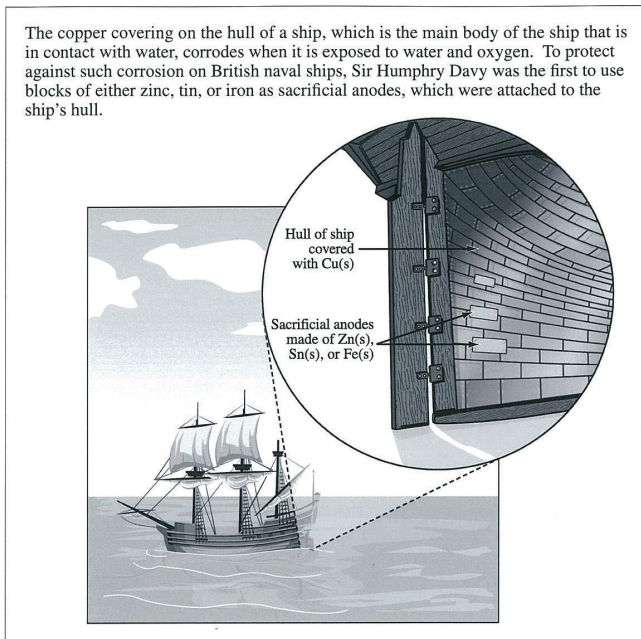
This example meets the requirements of the *standard of excellence*.

The response addresses the question asked by making reference to the sacrificial anode reacting instead of copper (key component). The response explains why the sacrificial anode reacts instead of copper and it is supported with correct equations and potential difference calculations. Scientific conventions are followed and the information is clearly communicated.

A total score of 5 was awarded (2 for key component and 3 for support).

Written-Response Questions—Student Response 6

Use the following information to answer the next question.



Written Response—15%

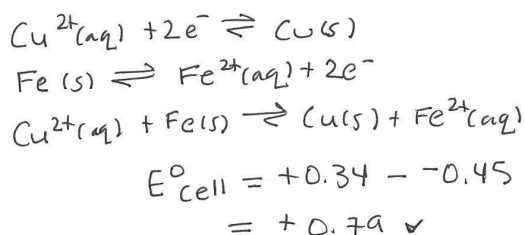
3. Explain how a block of zinc, tin, or iron would prevent the corrosion of the copper on a ship's hull.

Your response should include

- an explanation of the corrosion of copper
- an explanation of how a block of zinc, tin, or iron protects the copper from corrosion
- relevant balanced equations and E°_{cell} calculations to support each of your explanations

The corrosion of copper takes place when copper is exposed to water and oxygen because the water and oxygen react with the copper to form Copper(I) or Copper(II) oxides.

Other metals such as zinc, tin or iron can protect copper from corrosion because they are more likely to react with the oxygen and water, therefore they corrode instead of copper.



Score—3 out of 5
(Holistically Scored)

Rationale

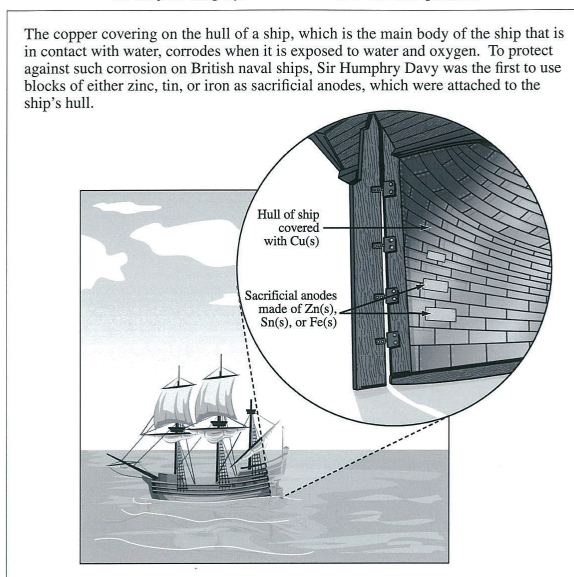
This example just meets the minimum requirements of the *acceptable standard*.

The student has addressed the question by making reference to the sacrificial anode in a comparison to copper in a minimal way (key component). The student does not provide correct equations, or an explanation of why the sacrificial anode reacts instead of copper. The student does provide a potential difference calculation for the equation the student provided. The student has provided minimal support for one of the bullets, but there is more incorrect than correct support.

A total score of 3 was awarded (2 for key component and 1 for support).

Written-Response Questions—Student Response 7

Use the following information to answer the next question.

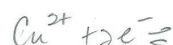


Written Response—15%

3. Explain how a block of zinc, tin, or iron would prevent the corrosion of the copper on a ship's hull.

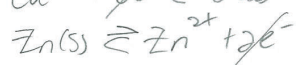
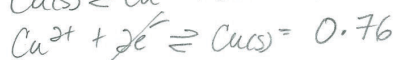
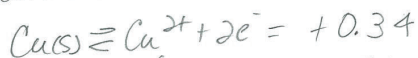
Your response should include

- an explanation of the corrosion of copper
- an explanation of how a block of zinc, tin, or iron protects the copper from corrosion
- relevant balanced equations and E°_{cell} calculations to support each of your explanations



The copper is reduced as the $\text{H}_2\text{O(l)} + \text{O}_2\text{(g)}$ acts as oxidizing agents the copper loses e^- and is corroded by the $\text{H}_2\text{O(l)}$ & $\text{O}_2\text{(g)}$

The zinc however is a stronger oxidizing agent than the $\text{H}_2\text{O(l)}$ & $\text{O}_2\text{(g)}$ so it acts as a sacrificial anode that gains the e^- saving the Cu(s) from corrosion.



1.10 V

Score—1 out of 5
(Holistically Scored)

Rationale

This example does not meet the requirements of the *acceptable standard*.

The student has not addressed the question as the student has not made a correct reference to Zn as a sacrificial anode in comparison to copper. The student does not provide correct equations or an explanation of why zinc reacts instead of copper. The student does provide a potential difference calculation for the equation they provided. The student has provided an explanation of the corrosion of copper, but there is more incorrect than correct support.

A total score of 1 was awarded (0 for key component and 1 for support).

Sample Written-Response Questions for Classroom Assessment

Use the following information to answer the first question.

A student titrated 10.0 mL of a 0.10 mol/L solution of sodium hypochlorite, NaOCl(aq), with 0.10 mol/L HCl(aq) and recorded the pH. The data are shown in the table below.

Volume of HCl(aq) (mL)	pH
0.0	10.2
2.0	8.0
4.0	7.6
6.0	7.2
8.0	6.8
10.0	4.2
12.0	2.0
14.0	1.8
16.0	1.6
18.0	1.5
20.0	1.5

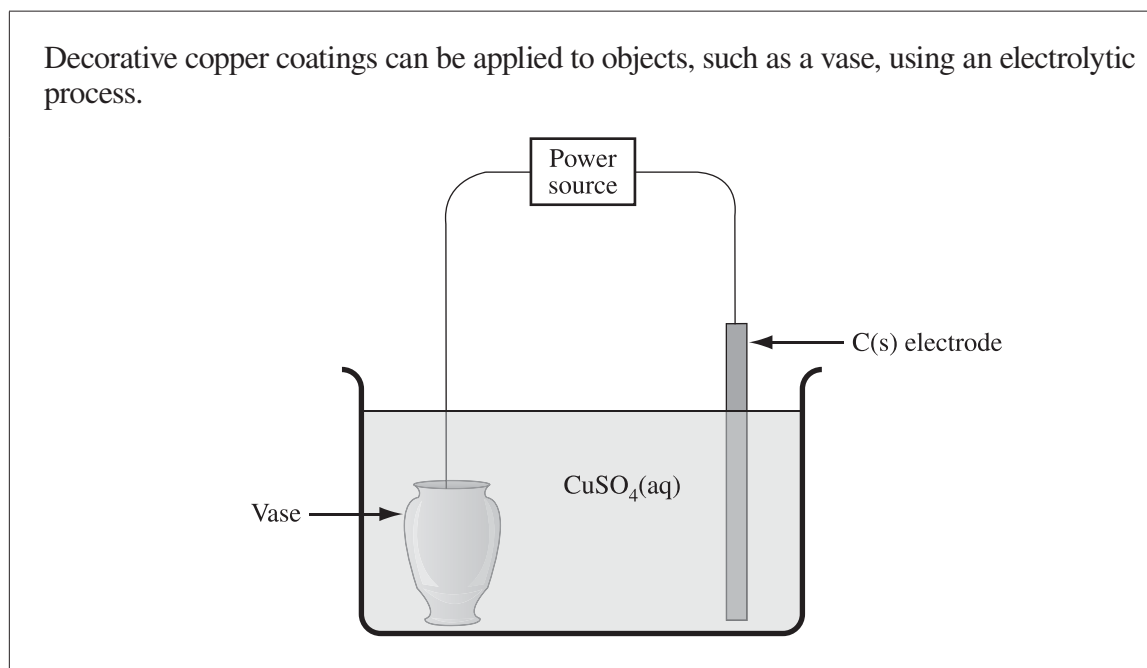
Written Response—10%

1. a. On the grid below, **plot** and **label** the data given above. **Identify** a buffering region. (3 marks)



- b. **Describe** the role of a buffer, and **write** the net ionic equation that represents the buffer reaction that occurs in the buffer region that you identified on your graph. (2 marks)

Use the following information to answer the next question.



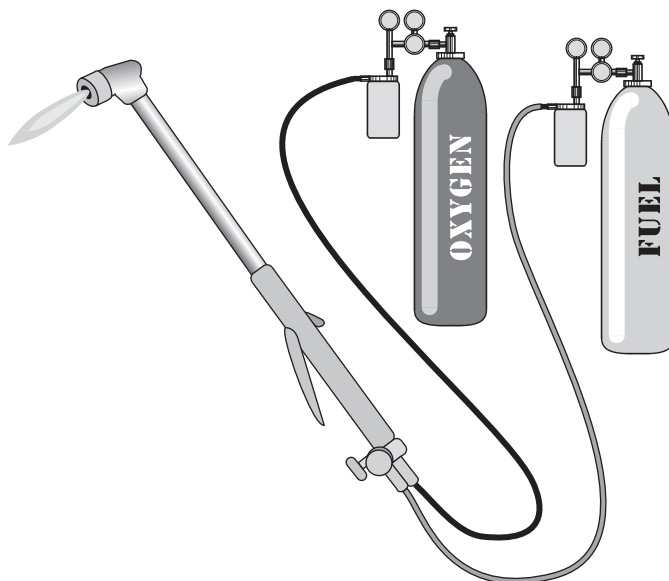
Written Response—10%

2. a. **Write** the two half-reaction equations that occur in this cell, and **identify** one observation that could be made during the operation of the cell. (3 marks)
- b. **Calculate** the mass of copper that could be produced in the electrolytic cell when a current of 3.00 A is applied for 20.0 min. (2 marks)

Use the following information to answer the next question.

A cutting torch can be used to cut metal in places such as construction sites, shipyards, and rail yards. The flame used for cutting is produced by a combustion reaction in which a gaseous fuel is mixed with oxygen and forced through a nozzle in the cutting torch. Gaseous products are formed.

Two gases that can be used as fuel in a cutting torch are hydrogen gas, $\text{H}_2(\text{g})$, and ethyne gas, $\text{C}_2\text{H}_2(\text{g})$, which is commonly known as acetylene.



Written Response—15%

3. **Compare**, in terms of enthalpy, the use of hydrogen gas and ethyne gas as fuels, and **identify** which of the two is the better fuel to use in a cutting torch.

Your response should include

- a balanced chemical equation representing the combustion reaction for each fuel
- enthalpy calculations for the combustion of 1.00 g of each fuel in kJ/g
- identification of the better fuel in terms of energy per gram of fuel and one other reason for choosing the fuel

Question	Marks	Sample Response	Comments	Bubble #
1.a.	3	<p style="text-align: center;">Titration of NaOCl(aq) with HCl(aq)</p> <p style="text-align: center;">Note: the buffer region as shown on their graph, and not a single point</p>	<ul style="list-style-type: none"> • 1 mark for title and axis labels (with appropriate scale) • 1 mark for plotted points (or correct curve) • 1 mark for labelling the buffer region, approx. 2-8 mL, (consistent with graph before equivalence point) 	1
1.b.	2	<p>Note: the buffer region as shown on their graph, and not a single point</p> <p>A buffer maintains a relatively constant pH (resists change in pH) <u>Or</u> reacts with a strong acid or base to form its conjugate weak acid/base pair.</p> $\text{OCl}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ <p>OR</p> $\text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{OCl}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ <p>Note: equilibrium equation is acceptable because it can indicate either direction, and $\text{H}^+(\text{aq})$ ion versus $\text{H}_3\text{O}^+(\text{aq})$ is acceptable</p>	<ul style="list-style-type: none"> • 1 mark for description • 1 mark for net ionic equation consistent with label on graph 	2
	1	Communication—See Guide		3
		Total possible marks = 6		

Question	Marks	Sample Response	Comments	Bubble #
2.a.	3	<p>Cathode $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$ Anode $2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$</p> <p>Observations</p> <ul style="list-style-type: none"> • Blue colour in solution disappears. • Copper-coloured electroplate forms at the cathode (vase). • Mass of the cathode (vase) increases. • Gas bubbles form at the anode (inert C(s) electrode). Relight glowing splint • Solution becomes more acidic over time (pH decreases). 	<ul style="list-style-type: none"> • 1 mark for oxidation half-reaction equation • 1 mark for reduction half-reaction equation • 1 mark for one observation consistent with reactions 	1
2.b.	2	<p>$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$</p> $m_{\text{Cu}} = \frac{(3.00 \text{ C/s})(20.0 \text{ min} \times 60 \text{ s/min})}{9.65 \times 10^4 \text{ C/mol}} \times \frac{1}{2} \times 63.55 \text{ g/mol}$ <p>(0.0373 moles of electrons) (0.0187 moles of Cu(s))</p> <p>=1.19 g</p>	<ul style="list-style-type: none"> • 1 mark for method • 1 mark for correct answer 	2
	1	Communication—See Guide	Use Analytic Scoring Guide	3
		Total possible marks = 6		

Marks	Sample Response	Comments	Bubble #
5	$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$ $\Delta H^\circ = (2 \text{ mol})(-241.8 \text{ kJ/mol}) = -483.6 \text{ kJ}$ $\Delta H^\circ_{\text{H}_2} = n\Delta H^\circ_{\text{H}_2} = \frac{-483.6 \text{ kJ}}{2 \text{ mol}} \times \frac{1 \text{ mol}}{2.02 \text{ g}} = -120 \text{ kJ/g}$ $2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$ $\Delta H^\circ_{\text{C}_2\text{H}_2} = \sum n\Delta_f H^\circ_{\text{products}} - \sum n\Delta_f H^\circ_{\text{reactants}}$ $= \left[(4 \text{ mol}) \frac{-393.5 \text{ kJ}}{\text{mol}} + (2 \text{ mol}) \frac{-241.8 \text{ kJ}}{\text{mol}} \right]$ $- \left[(2 \text{ mol}) \frac{+22.74 \text{ kJ}}{\text{mol}} + (5 \text{ mol}) \frac{0 \text{ kJ}}{\text{mol}} \right] = -2512.4 \text{ kJ}$ $\Delta H^\circ_{\text{C}_2\text{H}_2} = n\Delta H^\circ = \frac{-2512.4 \text{ kJ}}{2 \text{ mol}} \times \frac{1 \text{ mol}}{26.04 \text{ g}} = -48.2 \text{ kJ/g}$ <p>Sample Considerations to Support the Fuel Chosen</p> <p>$\text{H}_2(\text{g})$ – more energy produced per gram of fuel</p> <ul style="list-style-type: none"> – environmentally safe fuel because only water vapour is produced – $\text{H}_2(\text{g})$ is produced from fossil fuels, using a process that creates greenhouse gases – the lightest of all the gases <p>$\text{C}_2\text{H}_2(\text{g})$ – more energy produced per mole of fuel, or total energy released</p> <ul style="list-style-type: none"> – produces $\text{CO}_2(\text{g})$, a greenhouse gas that contributes to climate change – readily available, or widely used, or burns hotter 	<p><i>Key Component</i></p> <ul style="list-style-type: none"> • an enthalpy comparison of the combustion of the two fuels (in terms of Hess's Law, kJ/mol or kJ/g) <p><i>Support Components</i></p> <ul style="list-style-type: none"> • correct balanced equation • ΔH° calculation in kJ/g • identification of the better fuel based on energy and one other consideration to support the fuel chosen 	1
			2

June 2009 Holistic Split Scoring Guide

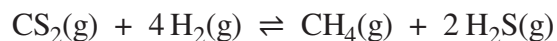
Score	Key–no Key Criteria
1 Key (weighted 2)	The student has addressed the question by comparing the two fuels, hydrogen and ethyne gas, in terms of an enthalpy (enthalpy of combustion) comparison. This may be in terms of kJ/g, kJ/mol, or total kJ produced using the results obtained through their calculations. Note that there may be errors in their calculations: e.g., reversing Hess’s law or missing coefficients, correct calculation of Hess’s Law but incorrect kJ/mol or kJ/g.
0 No Key	The student has not addressed the question asked, or only one fuel has been addressed and there is no comparison.

Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets; the support provided may contain minor errors/weaknesses. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

- Minor errors:
- Unbalanced equation
 - Method for calculating kJ/g is correct, but the student has made a minor calculation error (the comparison is g/kJ versus kJ/g)
 - Identifying the best fuel in terms of energy, and then a positive reason for the other fuel
 - Using H₂O(l) instead of H₂O(g)
- Major errors:
- Incorrect method for calculating Hess’s Law, or kJ/mol or kJ/g
 - Incorrect products in the equation, or a fuel other than hydrogen or ethyne is used
 - Not making a choice for the best fuel in terms of energy

Use the following information to answer the first question.

Methane gas can be produced in a laboratory by reacting carbon disulfide, $\text{CS}_2(\text{g})$, and hydrogen gas, as represented by the equation below.



The initial concentrations that are placed into an empty flask at a temperature of $90.0\text{ }^\circ\text{C}$ are $0.175\text{ mol/L CS}_2(\text{g})$ and $0.310\text{ mol/L H}_2(\text{g})$. When equilibrium is established, $0.125\text{ mol/L CS}_2(\text{g})$ is present.

Written Response—10% (5 marks for content, 1 mark for overall communication)

1. a. **Determine** the concentration of hydrogen gas present in the flask at equilibrium. (3 marks)

- b. Write the equilibrium law expression for the reaction, and **determine** the value of the equilibrium constant for the reaction at $90.0\text{ }^\circ\text{C}$. (2 marks)

Question 1 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Sample Response	Comments
1.a.	3	$\begin{array}{ccccccc} \text{CS}_2(\text{g}) & + & 4\text{H}_2(\text{g}) & \rightleftharpoons & \text{CH}_4(\text{g}) & + & 2\text{H}_2\text{S}(\text{g}) \\ \text{initial} & & & & & & \\ 0.175 \text{ mol/L} & & 0.310 \text{ mol/L} & & 0 & & 0 \\ \text{change} & & & & & & \\ -0.050 \text{ mol/L} & - & \frac{4}{1}(0.050 \text{ mol/L}) & + & \frac{1}{1}(0.050 \text{ mol/L}) & + & \frac{2}{1}(0.050 \text{ mol/L}) \\ \hline \text{equilibrium} & & 0.125 \text{ mol/L} & & 0.110 \text{ mol/L} & & 0.050 \text{ mol/L} \end{array}$ <p>The concentration of $\text{H}_2(\text{g}) = 0.110 \text{ mol/L}$ (3 significant digits contained in the original data)</p> <p>Note: Also allow 0.11 mol/L (0.050 may be considered original data)</p>	<ul style="list-style-type: none"> 1 mark for correct change in concentration (can be implied) 1 mark for correct mole ratio for $\text{H}_2(\text{g})$ 1 mark for correct answer (consistent with change and mole ratio) for $\text{H}_2(\text{g})$
1.b.	2	$K_c = \frac{[\text{CH}_4(\text{g})][\text{H}_2\text{S}(\text{g})]^2}{[\text{CS}_2(\text{g})][\text{H}_2(\text{g})]^4}$ $= \frac{(0.050 \text{ mol/L})(0.100 \text{ mol/L})^2}{(0.125 \text{ mol/L})(0.110 \text{ mol/L})^4}$ $= 27.3 \text{ (3 significant digits contained in the original data)}$ <p>Note: Also allow 27 (0.050 may be considered original data)</p>	<ul style="list-style-type: none"> 1 mark for equilibrium law expression 1 mark for correct answer consistent with the concentrations obtained in part 1.a.
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

Potassium permanganate in an acidic solution is commonly used in redox titrations.

Written Response—10% (5 marks for content, 1 mark for overall communication)

2. a. Choose an aqueous solution that could be titrated with aqueous potassium permanganate in an acidic solution. Write the balanced net ionic equation for the titration reaction and **determine** the potential difference for the reaction.

(3 marks)

Use the following additional information to answer the next part of the question.

A student places a strip of solid iron metal into a beaker that contains aqueous potassium permanganate in an acidic solution.

- b. **Describe** what happens to the iron metal strip when it is added to the solution in the beaker, and **identify** the oxidizing agent and the reducing agent.

(2 marks)

Question 2 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Sample Response	Comments
2.a.	3	<p>Reduction Half-Reactions:</p> $\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^-(\text{aq}) \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l}) \quad E^\circ = +1.51\text{ V}$ $\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq}) \quad E^\circ = -0.77\text{ V}$ <hr/> <p>net $\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{Fe}^{2+}(\text{aq}) \rightarrow 5\text{Fe}^{3+}(\text{aq}) + \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$</p> $E^\circ_{\text{cell}} = +1.51\text{ V} - 0.77\text{ V}$ $= +0.74\text{ V}$	<ul style="list-style-type: none"> 1 mark for suitable reducing agent 1 mark for balanced net ionic equation 1 mark for potential difference consistent with net ionic equation
2.b.	2	<p>Oxidizing agent is acidified $\text{KMnO}_4(\text{aq})$ (or $\text{MnO}_4^-(\text{aq})$). Reducing agent is $\text{Fe}(\text{s})$.</p> <p>Electrons are transferred from the iron strip to the oxidizing agent, $\text{MnO}_4^-(\text{aq})$ (or $\text{MnO}_4^-(\text{aq}) + \text{H}^+(\text{aq})$).</p> <p>or</p> <p>The iron strip is oxidized (mass decreases) by the $\text{MnO}_4^-(\text{aq})$ solution. (The iron metal reacted.)</p>	<ul style="list-style-type: none"> 1 mark for identifying $\text{MnO}_4^-(\text{aq}) + \text{H}^+(\text{aq})$ as OA, and $\text{Fe}(\text{s})$ as RA 1 mark for description of what happens to the iron strip
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

A student is investigating the amount of carbon dioxide that is produced during the combustion of fossil fuels commonly used in automobiles. In order to identify the best fuel to use in automobiles, the student determines the enthalpy change needed to produce gaseous products from the combustion of each of the following three fuels: propane gas, liquid octane, and liquid ethanol.

Written Response—15%

3. **Compare** the three fuels listed above in terms of energy and the production of carbon dioxide gas, and **identify** the best fuel to burn in automobiles.

To support your choice, your response should include

- balanced chemical equations for the combustion of each fuel and an enthalpy calculation for each reaction
- the number of moles of carbon dioxide produced per kilojoule of energy produced by each fuel
- an explanation of the rationale that supports the fuel you have identified as the best one to use in automobiles

Question 3 – Holistic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Marks	Sample Response	Comments
5	$\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g})$ $\Delta H = [4 \text{ mol}(-241.8 \text{ kJ/mol}) + 3 \text{ mol}(-393.5 \text{ kJ/mol})] - [1 \text{ mol}(-103.8 \text{ kJ/mol}) + 0 \text{ kJ}]$ $\Delta H = -2\,043.9 \text{ kJ}$ $\text{C}_8\text{H}_{18}(\text{l}) + \frac{25}{2} \text{O}_2(\text{g}) \rightarrow 8 \text{CO}_2(\text{g}) + 9 \text{H}_2\text{O}(\text{g})$ $\Delta H = [9 \text{ mol}(-241.8 \text{ kJ/mol}) + 8 \text{ mol}(-393.5 \text{ kJ/mol})] - [1 \text{ mol}(-250.1 \text{ kJ/mol}) + 0 \text{ kJ}]$ $\Delta H = -5\,074.1 \text{ kJ}$ $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g})$ $\Delta H = [3 \text{ mol}(-241.8 \text{ kJ/mol}) + 2 \text{ mol}(-393.5 \text{ kJ/mol})] - [1 \text{ mol}(-277.6 \text{ kJ/mol}) + 0 \text{ kJ}]$ $\Delta H = -1\,234.8 \text{ kJ}$ $\frac{3 \text{ mol CO}_2(\text{g})}{2\,043.9 \text{ kJ}} = 1.47 \times 10^{-3} \frac{\text{mol CO}_2(\text{g})}{\text{kJ}}$ $\frac{8 \text{ mol CO}_2(\text{g})}{5\,074.1 \text{ kJ}} = 1.58 \times 10^{-3} \frac{\text{mol CO}_2(\text{g})}{\text{kJ}}$ $\frac{2 \text{ mol CO}_2(\text{g})}{1\,234.8 \text{ kJ}} = 1.62 \times 10^{-3} \frac{\text{mol CO}_2(\text{g})}{\text{kJ}}$ <p>$\text{C}_3\text{H}_8(\text{g})$ produces the least amount of $\text{CO}_2(\text{g})$ per 1 kJ of energy.</p> <p>Note: Also acceptable is kJ/mol $\text{CO}_2(\text{g})$ comparison.</p>	<p><i>Key Component</i></p> <ul style="list-style-type: none"> a comparison in terms of enthalpy and $\text{CO}_2(\text{g})$ for each fuel <p><i>Supports</i></p> <ul style="list-style-type: none"> balanced combustion equations including enthalpy calculations calculation for moles of $\text{CO}_2(\text{g})$ per kJ of energy for each fuel identify and provide a rationale to support choice of fuel

Question 3 – Holistic Split Scoring Guide

Score	Key–no Key Criteria
2 Key	The student has addressed the question asked by making a comparison between at least two of the equations in terms of energy (reasonable approach to enthalpy change or molar enthalpy change) and amount of CO ₂ (g) (mol CO ₂ (g)/kJ, kJ/mol CO ₂ (g), mol of CO ₂ (g)).
0 No Key	The student has not addressed the question asked.

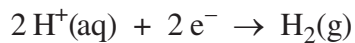
Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets; the support provided may contain minor errors/weaknesses. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

Minor errors: Unbalanced equation
 Calculator error, but substitution is correct
 Solving for kJ/mol versus mol/kJ

Major errors: Substitution error in enthalpy calculation
 Incorrect approach to enthalpy change
 Incorrect fuel used in the comparison (i.e., methanol)

Use the following information to answer the next question.

An electrolytic cell is set up that uses a copper anode. The products of the electrolysis are hydrogen gas and aqueous copper(II) ions. The half-reaction involving hydrogen gas is represented by the following equation.



Written Response—10% (5 marks for content, 1 mark for overall communication)

4. a. **Write** the half-reaction equation that represents the reaction that occurs at the anode, and **write** the balanced equation that represents the net redox reaction that occurs during the electrolysis. **(2 marks)**
- b. If a current of 3.00 A is applied to a cell containing a 400 g copper anode, **determine** the final mass of the copper anode after the cell runs for 48.0 h. **(3 marks)**

Question 4 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Sample Response	Comments
4.a.	2	$\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-}$ $2\text{H}^{+}(\text{aq}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g})$ <hr/> $\text{Cu(s)} + 2\text{H}^{+}(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + \text{H}_2(\text{g})$	1 mark each for <ul style="list-style-type: none"> • correct oxidation half-reaction • valid net redox reaction (consistent)
4.b.	3	$n_{\text{e}^{-}} = 5.37 \text{ mol}$ $n_{\text{Cu}} = \frac{1}{2} n_{\text{e}^{-}} = 2.69 \text{ mol}$ $m_{\text{Cu}} = 2.69 \text{ mol}(63.55 \text{ g/mol}) = 171 \text{ g}$ $\Delta m_{\text{anode}} = 400 \text{ g} - 171 \text{ g} = 229 \text{ g}$	1 mark each for <ul style="list-style-type: none"> • valid method to determine mass consumed • correct final mass of Cu(s) consumed • correct final mass of anode (consistent with their calculations)
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

A student obtained a 25.0 mL sample of a 0.176 mol/L unknown acid solution, HA(aq). The pH of the sample was 2.25.

Written Response—10% (5 marks for content, 1 mark for overall communication)

5. a. **Write** the balanced chemical equation that represents the ionization of the unknown acid and write the equilibrium law expression.

(2 marks)

- b. **Determine** the value of K_a and **identify** one property, other than the value of K_a , of the unknown acid.

(3 marks)

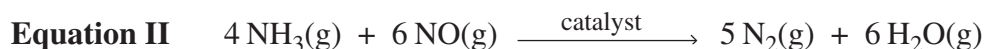
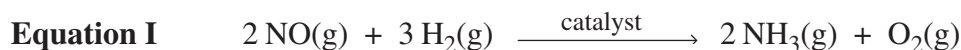
Question 5 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Acceptable Response	Comments
5.a.	2	$\text{HA(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{A}^{\text{-}}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \text{ or } \text{HA(aq)} \rightleftharpoons \text{H}^+(\text{aq}) + \text{A}^{\text{-}}(\text{aq})$ $K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{A}^{\text{-}}(\text{aq})]}{[\text{HA(aq)}]}$	<ul style="list-style-type: none"> 1 mark for balanced equation 1 mark for K_a expression
5.b.	3	<p>Initial pH = 2.25</p> $[\text{H}_3\text{O}^+(\text{aq})] = [\text{A}^{\text{-}}(\text{aq})] = 10^{-\text{pH}}$ $= 5.6 \times 10^{-3} \text{ mol/L}$ $K_a = \frac{(5.6 \times 10^{-3} \text{ mol/L})^2}{(0.176 \text{ mol/L} - 5.6 \times 10^{-3} \text{ mol/L})} = 1.9 \times 10^{-4}$ <p>Properties</p> <ul style="list-style-type: none"> weak acid only partially ionizes in water most of the acid does not dissociate proton donor monoprotic $[\text{H}_3\text{O}^+(\text{aq})]$ is less than $[\text{HA(aq)}]$ when titrated with a strong base, pH at equivalence point is above 7 <ul style="list-style-type: none"> low conductivity sour taste 	<ul style="list-style-type: none"> 1 mark for substitution consistent with method 1 mark for correct answer 1 mark for the valid property of the acid
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

A two-layer catalytic converter has been designed for diesel engines in automobiles. The first layer in the catalytic converter removes some nitrogen monoxide gas from the exhaust gas and converts it to ammonia gas. In the second layer, ammonia gas is removed as it reacts with the remaining nitrogen monoxide gas. The reactions in the two layers occur at 300 °C and are represented by the following equations.



Written Response—15%

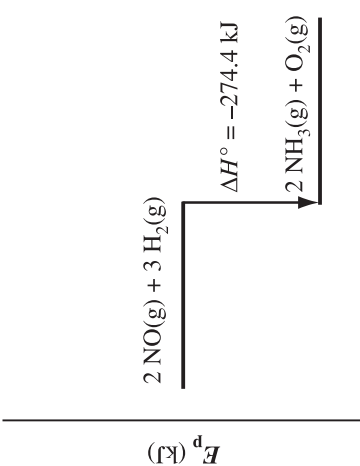
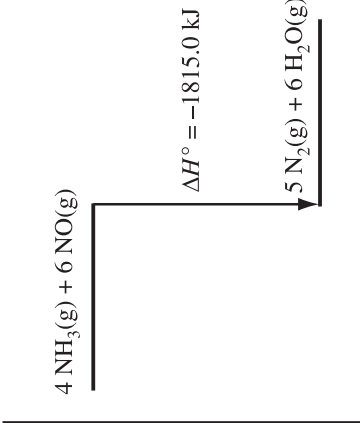
6. **Compare** the two reactions that occur in the catalytic converter. **Identify** one similarity and one difference between the reactions in terms of enthalpy.

Your response should include

- enthalpy calculations per mole of nitrogen monoxide gas for each reaction
- enthalpy diagrams that represent the enthalpy change that occurs in each reaction
- explanations of the similarity and difference you have identified

Question 6 – Holistic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Marks	Sample Response	Comments
5	<p>Calculations</p> $\Delta H = \sum n\Delta_f H^\circ(\text{products}) - \sum n\Delta_f H^\circ(\text{reactants})$ <p>Equation 1</p> $2 \text{NO}(\text{g}) + 3 \text{H}_2(\text{g}) \xrightarrow{\text{catalyst}} 2 \text{NH}_3(\text{g}) + \text{O}_2(\text{g})$ $\Delta H = [(2 \text{ mol})(-45.9 \text{ kJ/mol}) + 0 \text{ kJ}] - [(2 \text{ mol})(+91.3 \text{ kJ/mol}) + 0 \text{ kJ}]$ $= -274.4 \text{ kJ/2 mol} = -137.2 \text{ kJ/mol of NO}(\text{g})$ <p>Equation 2</p> $4 \text{NH}_3(\text{g}) + 6 \text{NO}(\text{g}) \xrightarrow{\text{catalyst}} 5 \text{N}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{g})$ $\Delta H = [0 \text{ kJ} + (6 \text{ mol})(-241.8 \text{ kJ/mol})] - [(4 \text{ mol})(-45.9 \text{ kJ/mol}) + (6 \text{ mol})(+91.3 \text{ kJ/mol})]$ $= -1815.0 \text{ kJ/6 mol} = -302.5 \text{ kJ/mol of NO}(\text{g})$ <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p>Equation 1</p>  </div> <div style="text-align: center;"> <p>Equation 2</p>  </div> </div>	<p>Key Component:</p> <ul style="list-style-type: none"> a comparison between each reaction is made in terms of energy (kJ or kJ/mol) <p>Support:</p> <ul style="list-style-type: none"> enthalpy change calculations (kJ/mol of NO(g)) enthalpy diagrams consistent with calculations explanation and identification of a similarity and a difference

Note: E_p , ΔH , or Energy are acceptable for the y-axis label, and reaction progress, reaction coordinate, reaction, or time are acceptable for the x-axis.

Similarities — Both are exothermic because the calculated ΔH is negative.

— Both are exothermic because the reactants have more potential energy than the products.

Differences — Equation 2 releases more energy per mol of NO(g) than Equation 1 (consistent with calculations).

— The products of Equation 2 have a higher potential energy than the products of Equation 1.

Question 6 – Holistic Split Scoring Guide

Score	Key–No Key Criteria
2 Key	<p>The student has addressed the question by making a comparison between the two reactions in terms of enthalpy (reasonable approach to enthalpy change or molar enthalpy change).</p> <p>Note: There may be errors in their calculations (e.g., reversing Hess’s Law) or missing coefficients or correct Hess’s Law but incorrect kJ/mol calculation.</p>
0 No Key	The student has not addressed the question asked.

Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets. The support provided may contain minor errors/weaknesses or a major weakness in one of the bullets. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

Minor errors:

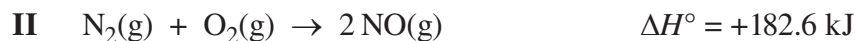
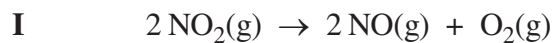
- Unbalanced equation
- Method for kJ/mol is correct but has a minor calculation error

Major errors:

- Incorrect method for kJ/mol
- No similarities or differences identified

Use the following information to answer the next question.

Nitrogen monoxide is a commonly used gas in the chemical industry, and is also a toxic air pollutant produced by automobiles. Two reactions involving nitrogen monoxide gas are represented below.



Written Response—10% (5 marks for content, 1 mark for overall communication)

7. a. **Determine** the enthalpy change for reaction I, and **sketch** an enthalpy diagram that represents reaction I.

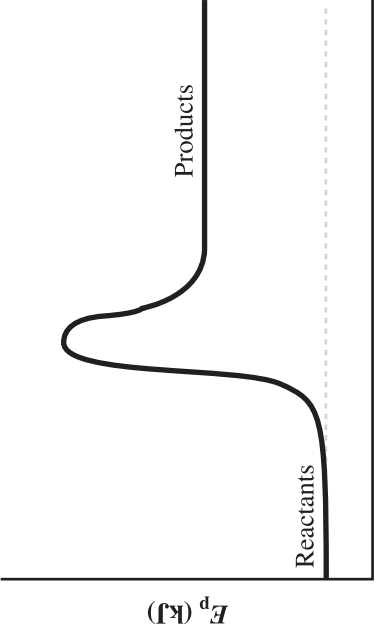
(3 marks)

- b. In terms of energy, **identify** two similarities **or** two differences between the two reactions involving nitrogen monoxide gas represented above.

(2 marks)

Question 7 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Acceptable Response	Comments
7.a.	3	$\Delta H^\circ = \sum n\Delta_f H^\circ(\text{products}) - \sum n\Delta_f H^\circ(\text{reactants})$ $\Delta H^\circ_1 = [(2 \text{ mol})(+91.3 \text{ kJ/mol}) + 0 \text{ kJ}] - [(2 \text{ mol})(+33.2 \text{ kJ/mol})]$ $= +116.2 \text{ kJ}$ <p style="text-align: center;">Enthalpy Diagram</p>  <p>Note:</p> <ul style="list-style-type: none"> The activation energy barrier does not need to be included on the energy diagram. The terms <i>reaction progress</i>, <i>reaction coordinate</i>, <i>reaction</i>, or <i>time</i> may be used to label the x-axis. A title is not required. 	<ul style="list-style-type: none"> 1 mark for correct method to calculate enthalpy change 1 mark for correct answer, including the sign (consistent with method) 1 mark for enthalpy diagram (correct or consistent with answer)

Question 7 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

7.b.	2	<p>Similarities: (Note: This is the correct response if the response to question 1.a. is correct.)</p> <ul style="list-style-type: none"> • Both absorb energy from the surroundings during the reaction. • Both are endothermic. • The products of both reactions have a higher potential energy than the reactants. • The energy term would be included as a reactant in both chemical equations. <p>Differences:</p> <ul style="list-style-type: none"> • Reaction I absorbs less energy per mole of NO(g) than reaction II. • Reactants in reaction I have higher potential energy than the reactants in reaction II. <p>(If in part (a) student shows an exothermic reaction)</p> <p>Differences:</p> <ul style="list-style-type: none"> • Reaction II absorbs energy; reaction I releases energy (consistent with diagram). • Reaction I is exothermic; reaction II is endothermic (consistent with ΔH°). • The products of reaction II have a higher potential energy than the reactants; the opposite is true for reaction I (consistent with diagram). • In reaction I the energy term would be included as a product; in reaction II the energy term would be included as a reactant (consistent with ΔH°). 	<ul style="list-style-type: none"> • 1 mark for each similarity or difference that is consistent with the information provided in part a
	1	Communication—See Guide	Use Analytic Scoring Guide
	6	Total possible marks = 6	

Use the following information to answer the next question.

A student predicts that the value of K_a of ethanoic acid, a weak monoprotic acid, may be affected by the temperature of the acid.

Written Response—15%

8. **Design** an experiment to test this prediction using commonly available laboratory apparatus, and a 0.100 mol/L solution of ethanoic acid.

Your response should include

- a detailed procedure
- a definition for the term K_a
- a relevant equilibrium law expression and balanced chemical equation, and the formula(s) necessary for the calculation(s) to solve for K_a

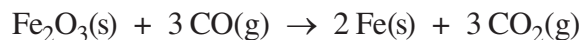
Question 8 – Holistic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

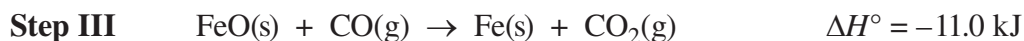
Question	Marks	Acceptable Response	Comments
8	2 for key 3 for support	<p>Procedure:</p> <ol style="list-style-type: none"> Obtain three 100.00 mL beakers, and fill each beaker with 50.0 mL of 0.100 mol/L ethanoic acid solution. Using three water baths at different temperatures, warm or cool, place one beaker of ethanoic acid in each water bath. Measure and record the temperature of each ethanoic acid solution. Using a pH meter, measure and record the pH of each acid sample. <p>Note: This can also be done by titration to determine hydronium ion concentration at the half equivalence point.</p> <p>Variables: (may be implied)</p> <ul style="list-style-type: none"> controlled – same acid, concentration of acid, amount of acid manipulated – temperature of ethanoic acid solution responding – pH of the ethanoic acid solution <p>K_a is a measure of the extent to which an acid ionizes.</p> <p>Expressions and Formulas:</p> $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq})$ $K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{A}^-(\text{aq})]}{[\text{HA}(\text{aq})]}$ <p>(The ionization equation may be implied if the equilibrium expression is correct.)</p> $[\text{H}_3\text{O}^+(\text{aq})] = [\text{CH}_3\text{COO}^-(\text{aq})] = 10^{-\text{pH}}$ <p>Total possible marks = 5</p>	<p>Key Component:</p> <ul style="list-style-type: none"> an experiment or design for an experiment that could allow the student to measure the pH of the acid at different temperatures (pH probe, meter, titration, universal indicators, indicators) <p>Support:</p> <ul style="list-style-type: none"> definition of K_a details of procedure (identifying the manipulated, responding and controlled variables, may be implied) relevant equation(s) and formula(s)
			Use Holistic Scoring Guide

Use the following information to answer the next question.

The smelting of iron occurs in a blast furnace, as represented by the following overall equation.



In a blast furnace, the smelting process occurs in three steps, as represented by the following equations.



Written Response—10% (5 marks for content, 1 mark for overall communication)

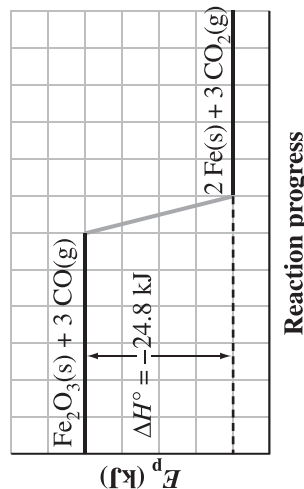
9. a. **Determine** the enthalpy change for the overall reaction. Write the equation representing the overall reaction, including the enthalpy change as a term in the equation. **(3 marks)**

- b. **Sketch** and label an enthalpy diagram to represent the energy change(s) that occur in the overall reaction. **(2 marks)**

Question 9 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Acceptable Response	Comments
9.a.	3	$\text{Fe}_2\text{O}_3(\text{s}) + \frac{1}{3}\text{CO}(\text{g}) \rightarrow \frac{2}{3}\text{Fe}_3\text{O}_4(\text{s}) + \frac{1}{3}\text{CO}_2(\text{g}) \quad \Delta H^\circ = \frac{1}{3}(-47.2 \text{ kJ})$ $\frac{2}{3}\text{Fe}_3\text{O}_4(\text{s}) + \frac{2}{3}\text{CO}(\text{g}) \rightarrow 2\text{FeO}(\text{s}) + \frac{2}{3}\text{CO}_2(\text{g}) \quad \Delta H^\circ = \frac{2}{3}(+19.4 \text{ kJ})$ $2\text{FeO}(\text{s}) + 2\text{CO}(\text{g}) \rightarrow 2\text{Fe}(\text{s}) + 2\text{CO}_2(\text{g}) \quad \Delta H^\circ = 2(-11.0 \text{ kJ})$ <hr/> $\text{Fe}_2\text{O}_3(\text{s}) + 3\text{CO}(\text{g}) \rightarrow 2\text{Fe}(\text{s}) + 3\text{CO}_2(\text{g}) \quad \Delta H^\circ = -24.8 \text{ kJ}$ <p>or</p> $\Delta H^\circ = \sum n\Delta_f H^\circ_{(\text{products})} - \sum n\Delta_f H^\circ_{(\text{reactants})}$ $= [(2 \text{ mol})(0 \text{ kJ/mol}) + (3 \text{ mol})(-393.5 \text{ kJ/mol})]$ $- [(1 \text{ mol})(-824.2 \text{ kJ/mol}) + (3 \text{ mol})(-110.5 \text{ kJ/mol})]$ $= -24.8 \text{ kJ}$ $\text{Fe}_2\text{O}_3(\text{s}) + 3\text{CO}(\text{g}) \rightarrow 2\text{Fe}(\text{s}) + 3\text{CO}_2(\text{g}) + 24.8 \text{ kJ}$	<ul style="list-style-type: none"> 1 mark for correct method 1 mark for correct answer 1 mark for energy term on side of equation consistent with calculation
9.b.	2	<p>Note: Vertical axis can be labelled ΔH°, E_p, or <i>energy</i>. Horizontal axis can be labelled <i>Reaction progress</i>, <i>Reaction coordinate</i>, <i>Reaction</i>, or <i>Time</i>.</p> <p>Note: A title is not required, and neither is the enthalpy change (ΔH°).</p>	<ul style="list-style-type: none"> 1 mark for labels (must include <i>x</i>- and <i>y</i>-axes and identification of reactants and products) 1 mark for shape of enthalpy diagram consistent with enthalpy calculation
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	



Use the following information to answer the next question.

Dinitrogen tetroxide was used as one of the rocket fuels on the lunar landers of the Apollo missions. In the gaseous phase, it decomposes according to the following equation.



A technician placed a sample of $\text{N}_2\text{O}_4(\text{g})$ in a 2.00 L flask and allowed the system to reach equilibrium. At 25 °C, the K_c was 5.40×10^{-3} , and the concentration of $\text{N}_2\text{O}_4(\text{g})$ at equilibrium was 3.00×10^{-1} mol/L.

Written Response—10% (5 marks for content, 1 mark for overall communication)

10. a. **Determine** the amount, in moles, of $\text{NO}_2(\text{g})$ present in the 2.00 L flask at equilibrium. **(3 marks)**

- b. **Identify** whether the value of K_c will increase, decrease, or remain the same when heat is added to the system. Support your answer with an explanation. **(2 marks)**

Question 10 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Acceptable Response	Comments
10.a.	3	$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ $K_c = \frac{[\text{NO}_2(\text{g})]^2}{[\text{N}_2\text{O}_4(\text{g})]}$ $[\text{NO}_2(\text{g})] = \sqrt{K_c[\text{N}_2\text{O}_4(\text{g})]}$ $= \sqrt{(5.40 \times 10^{-3})(3.00 \times 10^{-1} \text{ mol/L})}$ $= 4.02 \times 10^{-2} \text{ mol/L}$ $\text{mol of NO}_2(\text{g}) = (4.02 \times 10^{-2} \text{ mol/L})(2.00 \text{ L}) = 8.05 \times 10^{-2} \text{ mol}$	<ul style="list-style-type: none"> 1 mark for correct K_c expression/method 1 mark for correct concentration of $\text{NO}_2(\text{g})$ 1 mark for answer in moles consistent with concentration
10.b.	2	K_c will increase because the reaction will shift to the right to consume the added heat (endothermic reaction) or because the concentration of $\text{NO}_2(\text{g})$ increases, and the concentration of $\text{N}_2\text{O}_4(\text{g})$ decreases, and $K_c = \frac{[\text{products}]}{[\text{reactants}]}$.	<ul style="list-style-type: none"> 1 mark for K_c increases 1 mark for explanation of the shift consistent with answer of increase/decrease.
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

A student hypothesizes that if the mass of the iron electrode is increased in a lead–iron voltaic cell, the cell potential will also increase.

Written Response—15%

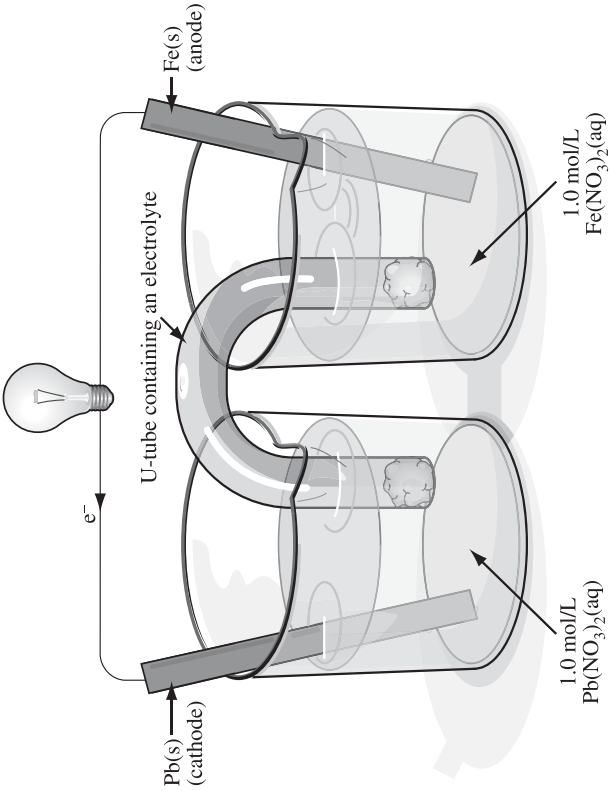
- 11.** **Design** an experiment that would allow you to test the student’s hypothesis using a lead–iron voltaic cell.

Your response should include

- a detailed procedure
- a labelled diagram of the lead–iron voltaic cell
- relevant balanced equation(s) and a potential difference calculation for your voltaic cell

Question 11 – Holistic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Marks	Sample Response	Comments
5	<p>Procedure:</p> <ol style="list-style-type: none"> Construct a voltaic cell, using the reagents given in the diagram. Place 100.0 mL of 1.0 mol/L $\text{Pb}(\text{NO}_3)_2(\text{aq})$ in the beaker containing the $\text{Pb}(\text{s})$ electrode and 100.0 mL of 1.0 mol/L $\text{Fe}(\text{NO}_3)_2(\text{aq})$ in the beaker containing the $\text{Fe}(\text{s})$ electrode. Measure and record the cell potential using a voltmeter after the cell operates for 5 minutes. Repeat steps 1 to 3 using different masses of $\text{Fe}(\text{s})$ for the iron electrode. <p>Variables: Manipulated – mass of iron electrode Responding – the cell potential (or cell voltage) Controlled – temperature, concentration of electrolytes, time the cell runs, cell setup, etc.</p> <p>Note: The variables can be implied in the procedure.</p> <p>Diagram:</p>  <p>* Or any other version of a working lead–iron voltaic cell</p> <p>Equation and Calculation</p> $\text{Pb}^{2+}(\text{aq}) + \text{Fe}(\text{s}) \rightarrow \text{Pb}(\text{s}) + \text{Fe}^{2+}(\text{aq}) \quad E^\circ_{\text{cell}} = -0.13 \text{ V} - (-0.45 \text{ V}) = +0.32 \text{ V}$	<p>Key Component</p> <ul style="list-style-type: none"> experimental design or procedure that attempts to manipulate the mass of $\text{Fe}(\text{s})$ in an electrochemical cell, and measure potential difference <p>Support Components</p> <ul style="list-style-type: none"> detailed procedure labelled lead–iron voltaic cell diagram relevant balanced equation(s) and potential difference calculation (half reactions or net reaction)

Question 11 – Holistic Split Scoring Guide

Score	Key–no Key Criteria
2 Key	The student has addressed the question by designing an experiment (procedure or design) involving a cell (voltaic or electrolytic, and not necessarily lead–iron) and has manipulated the mass of one of the electrodes (or in the student’s understanding manipulated the mass), and the student’s responding variable relates to measuring the cell potential.
0 No Key	The student has not addressed the question asked.

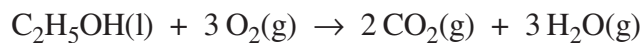
Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets; the support provided may contain minor errors/weaknesses. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

Minor errors: Unbalanced equation
 Method for calculating potential difference is correct, but the student has made a calculation error
 Using a solution in the salt bridge that would precipitate

Major errors: Electrolytic cell
 A voltaic cell other than a lead–iron cell
 Missing electrolyte or other major error in the cell diagram
 Experimental design or procedure provided

Use the following information to answer the next question.

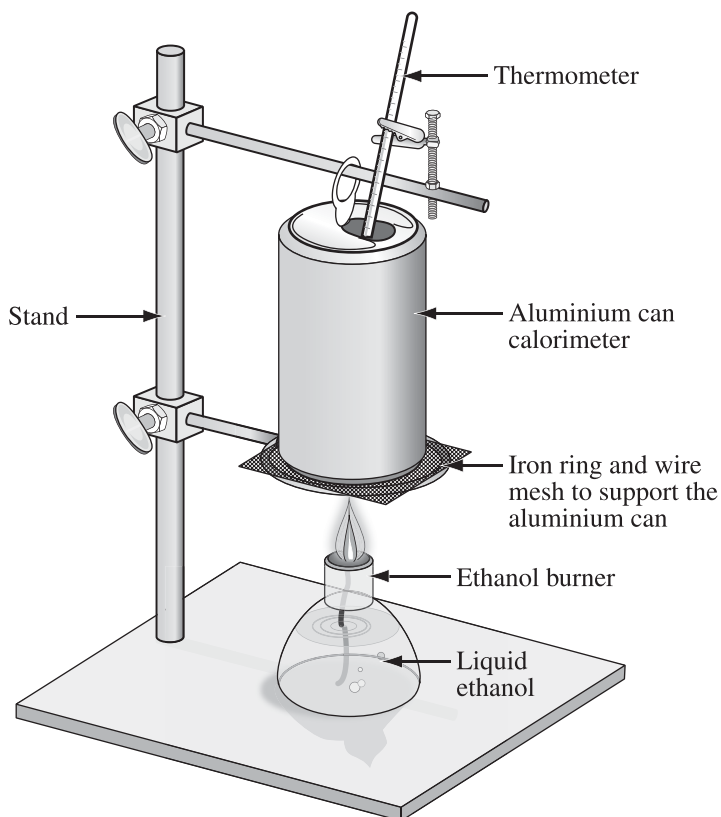
A student performs a calorimetry experiment to determine the molar enthalpy of combustion of ethanol. The student uses an aluminium can as a calorimeter. The combustion of liquid ethanol produces gaseous products, as represented by the equation below.



The data collected during the experiment are recorded below.

Calorimetry Experiment Data

Mass of aluminium can	10.65 g
Mass of water	250.00 g
Initial mass of ethanol burner	256.34 g
Final mass of ethanol burner	252.45 g
Initial temperature of water and aluminium can	21.40 °C
Final temperature of water and aluminium can	82.30 °C



Written Response—10% (5 marks for content, 1 mark for overall communication)

- 12.** a. **Calculate** the student's experimental molar enthalpy of combustion of ethanol. **(3 marks)**

- b. The theoretical value of the molar enthalpy of combustion of ethanol is higher than that obtained in the student's experiment. **Identify** an improvement that could be made to the experimental design and **explain** how your suggestion would reduce experimental error in the calorimetry experiment. **(2 marks)**

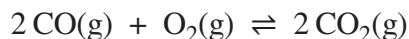
Question 12 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

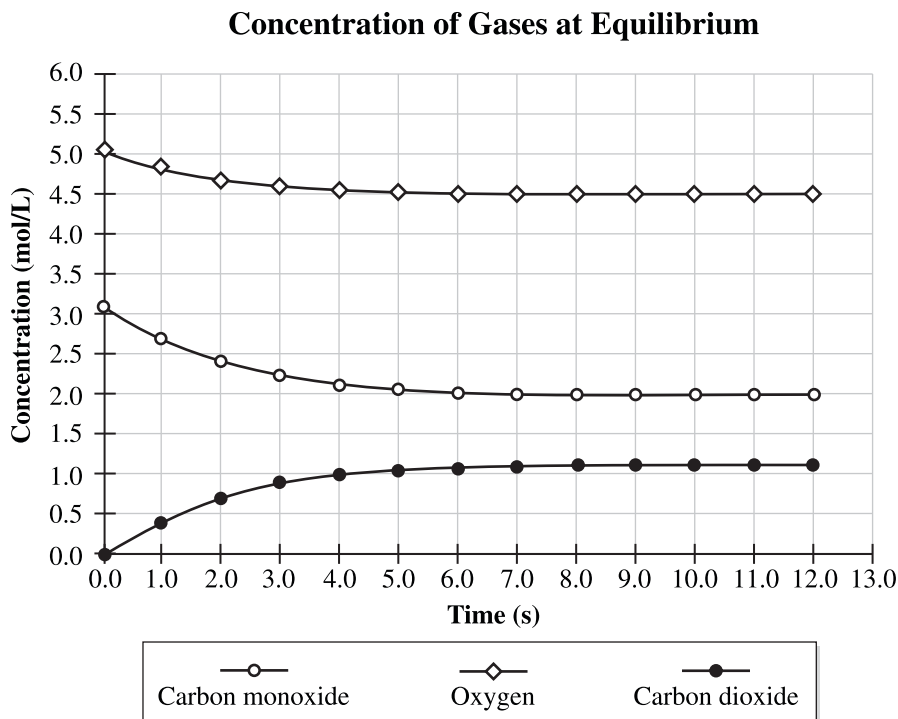
Question	Marks	Acceptable Response	Comments
12.a.	3	$\Delta H^{\circ}_{\text{lost}} = H_{\text{gained}}$ $\Delta H^{\circ} = mc\Delta T_{(\text{H}_2\text{O})} + mc\Delta T_{(\text{Al})}$ $= (0.250 \text{ kg})(4.19 \text{ kJ/kg}\cdot^{\circ}\text{C})(82.30-21.40)^{\circ}\text{C} + (0.010 \text{ 65 kg})(0.897 \text{ kJ/kg}\cdot^{\circ}\text{C})(82.30-21.40)^{\circ}\text{C}$ $= -64.374 \text{ 5 kJ}$ $n = \frac{m}{M} = \frac{3.89 \text{ g}}{46.08 \text{ g/mol}} = 0.084 \text{ 4 mol}$ $\Delta H^{\circ} = \frac{-64.37 \text{ kJ}}{0.084 \text{ 4 mol}}$ $= -763 \text{ kJ/mol}$	<ul style="list-style-type: none"> • 1 mark for method • 1 mark for substitution • 1 mark for correct answer in kJ/mol
12.b.	2	<p>Improvement</p> <ul style="list-style-type: none"> • a bomb calorimeter would limit heat loss to the surroundings • using a shield around the calorimeter and burner would limit heat loss to the surroundings • using a more efficient burner with better air flow would reduce incomplete combustion • suspending the can directly above the flame would eliminate heat loss to the iron stand and ring 	<ul style="list-style-type: none"> • 1 mark for improvement • 1 mark for explanation
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

Carbon monoxide gas and oxygen gas react to form carbon dioxide gas as represented by the equilibrium equation below.



A technician added carbon monoxide gas and oxygen gas to an empty flask. The technician then recorded the concentrations of each gas present in the flask until the reaction reached equilibrium at 500 K, as shown in the graph below.



Written Response—10% (5 marks for content, 1 mark for overall communication)

13. a. Write the equilibrium law expression, and **calculate** the value for the equilibrium constant at 500 K. **(3 marks)**
- b. Indicate whether the products or reactants are favoured in this reaction and **explain** your answer. **(2 marks)**

Question 13 – Analytic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Question	Marks	Acceptable Response	Comments
13.a.	3	$K_c = \frac{[\text{CO}_2(\text{g})]^2}{[\text{CO}(\text{g})]^2[\text{O}_2(\text{g})]}$ $K_c = \frac{(1.1)^2}{(2.0)^2(4.5)} = 6.7 \times 10^{-2}$ $= 6.7 \times 10^{-2}$	<ul style="list-style-type: none"> • 1 mark for equilibrium expression • 1 mark for selecting correct equilibrium equations • 1 mark for correct answer
13.b.	2	<p>The equilibrium favours the reactants because</p> <ul style="list-style-type: none"> • the K_c value, 6.7×10^{-2}, is less than 1 • there is a higher concentration of reactants than products present • at equilibrium, there is more than 50% of the initial concentrations <p>Note: The K_c value does not have to be restated here.</p>	<ul style="list-style-type: none"> • 1 mark for correct identification of shift consistent with K_c in 2.a. • 1 mark for rationale consistent with choice
	1	Communication—See Guide	Use Analytic Scoring Guide
		Total possible marks = 6	

Use the following information to answer the next question.

A student hypothesizes that if the concentration of nickel(II) ions is increased in a nickel–zinc voltaic cell, the potential difference of the cell will also increase.

Written Response—15%

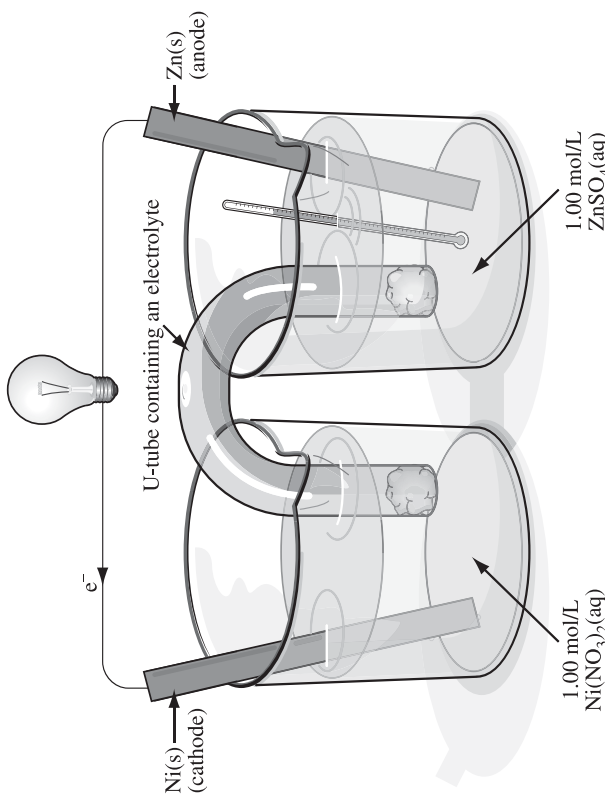
- 14.** **Design** an experiment that would allow you to test the student’s hypothesis using a nickel–zinc voltaic cell.

Your response should include

- a detailed procedure
- a labelled diagram of the nickel–zinc voltaic cell
- relevant balanced equation(s) and a potential difference calculation for your voltaic cell

Question 14 – Holistic Scoring Criteria

* Please note that these are only sample responses, and other variations of the response may also have received full marks.

Marks	Sample Response	Comments
5	<p>Variables: Manipulated – concentration of $\text{Ni}^{2+}(\text{aq})$ Responding – the cell potential (or cell voltage) Controlled – temperature, oxidizing and reducing agent used, cell set-up, and time the cell runs prior to measuring voltage</p> $\text{Ni}^{2+}(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{Ni}(\text{s}) + \text{Zn}^{2+}(\text{aq})$ $E^\circ_{\text{cell}} = -0.26 \text{ V} - (-0.76 \text{ V})$ $= +0.50 \text{ V}$  <p>*Or any other version of a working nickel-zinc voltaic cell.</p> <p>Procedure:</p> <ol style="list-style-type: none"> 1. Construct a voltaic cell, using the reagents given in the diagram. 2. Place a 100.0 mL sample of 1.0 mol/L $\text{Ni}(\text{NO}_3)_2(\text{aq})$ in the beaker containing the $\text{Ni}(\text{s})$ electrode. 3. Measure and record the cell potential using a voltmeter. 4. Repeat steps 1 to 3 using different concentrations of $\text{Ni}(\text{NO}_3)_2(\text{aq})$ solution. 	<p>Key Component</p> <ul style="list-style-type: none"> • valid experimental design or procedure that attempts to manipulate the concentration of $\text{Ni}^{2+}(\text{aq})$ in an electrochemical cell <p>Support Components</p> <ul style="list-style-type: none"> • detailed procedure • labelled nickel-zinc cell diagram • relevant balanced equation(s) and potential difference calculation

Question 14 – Holistic Split Scoring Guide

Score	Key–no Key Criteria
2 Key	The student has addressed the question asked by designing an experiment (procedure or design) involving a cell (voltaic or electrolytic, and not necessarily nickel-zinc) and has attempted to manipulate the concentration of nickel solution (or in the student’s understanding manipulated the concentration), and the student’s responding variable relates to measuring the cell potential.
0 No Key	The student has not addressed the question asked.

Score	Support
3 Very Good to Excellent	The student has provided good support for all of the bullets. The support may include a minor error/weakness in one of the support bullets.
2 Satisfactory to Good	The student has provided support for the majority of the bullets but not necessarily all of the bullets; the support provided may contain minor errors/weaknesses. There is more correct than incorrect support.
1 Minimal	The student has provided minimal support for one or more of the bullets, but there are many errors throughout. There is more incorrect than correct support.
0 Limited to No support	The student has not provided enough support to demonstrate more than a limited understanding. The support is either off topic or contains major errors throughout all of the bullets.

- Minor errors:
- Unbalanced equation
 - Method for calculating potential difference is correct, but the student has made a calculation error
 - Using a solution in the salt bridge that would precipitate
- Major errors:
- Electrolytic cell, or a voltaic cell other than nickel-zinc
 - Missing electrolyte or other major error in the cell diagram
 - Flawed experimental design, or procedure not provided