Chemistry 30

2010 Released Formative Assessment Materials

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Introduction

The recent changes to the design of the Chemistry 30 Diploma Examination involved a removal of written-response items. At the time of this decision, several examinations had already been developed with the Part A written-response section. This document contains these written-response items and the scoring guides from those examinations.

The items here are intended to continue 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, 2007.*

Use the following information to answer the first question.

Methane gas can be produced in a laboratory by reacting carbon disulfide, $CS_2(g)$, and hydrogen gas, as represented by the equation below.

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

The initial concentrations that are placed into an empty flask at a temperature of 90.0 °C are 0.175 mol/L $CS_2(g)$ and 0.310 mol/L $H_2(g)$. When equilibrium is established, 0.125 mol/L $CS_2(g)$ 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 equilibrium constant for the reaction at 90.0 °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	$$\begin{array}{lcccc} & CS_2(g) \; + & 4\,H_2(g) \; \rightleftharpoons & CH_4(g) \; + & 2\,H_2S(g) \\ \text{initial} & 0.175 \text{ mol/L} & 0.310 \text{ mol/L} & 0 & 0 \\ \text{change} & -0.050 \text{ mol/L} & -\frac{4}{1}(0.050 \text{ mol/L}) & +\frac{1}{1}(0.050 \text{ mol/L}) & +\frac{2}{1}(0.050 \text{ mol/L}) \\ \hline \text{equilibrium} & 0.125 \text{ mol/L} & 0.110 \text{ mol/L} & 0.050 \text{ mol/L} & 0.100 \text{ mol/L} \end{array}$$ The concentration of $H_2(g)$ = 0.110 mol/L (3 significant digits contained in the original data) **Note:** Also allow 0.11 mol/L (0.050 may be considered original data)	• 1 mark for correct change in concentration (can be implied) • 1 mark for correct mole ratio for $H_2(g)$ • 1 mark for correct answer (consistent with change and mole ratio) for $H_2(g)$
1.b.	2	$$K_c = \frac{[CH_4(g)][H_2S(g)]^2}{[CS_2(g)][H_2(g)]^4} = \frac{(0.050 \text{ mol/L})(0.100 \text{ mol/L})^2}{(0.125 \text{ mol/L})(0.110 \text{ mol/L})^4} = 27.3$$ (3 significant digits contained in the original data) **Note:** Also allow 27 (0.050 may be considered original data)	• 1 mark for equilibrium law expression • 1 mark for correct answer consistent with the concentrations obtained in part 1a
	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 cell potential.

(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 variations using other reducing agents may also have received full marks.*

Question	Marks	Sample Response	Comments
2.a.	3	Reduction Half-Reactions: $MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^-(aq) \rightleftharpoons Mn^{2+}(aq) + 4\,H_2O(l)$ $E° = +1.51$ V $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $E° = -0.77$ V net $MnO_4^-(aq) + 8\,H^+(aq) + 5\,Fe^{2+}(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$ $E°_{cell} = +1.51\text{ V} - 0.77\text{ V}$ $= +0.74\text{ V}$	• 1 mark for suitable reducing agent • 1 mark for balanced net ionic equation • 1 mark for cell potential consistent with net ionic equation
2.b.	2	Oxidizing agent is acidified $KMnO_4(aq)$ (or $MnO_4^-(aq)$). Reducing agent is Fe(s). Electrons are transferred from the iron strip to the oxidizing agent, $MnO_4^-(aq)$ (or $MnO_4^-(aq) + H^+(aq)$). **or** The iron strip is oxidized (mass decreases) by the $MnO_4^-(aq)$ solution. (The iron metal reacted.)	• 1 mark for identifying $MnO_4^-(aq) + H^+(aq)$ as OA, and Fe(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	$C_3H_8(g) + 5\,O_2(g) \rightarrow 3\,CO_2(g) + 4\,H_2O(g)$ $\Delta H° = [4\text{ mol}(-241.8\text{ kJ/mol}) + 3\text{ mol}(-393.5\text{ kJ/mol})] - [1\text{ mol}(-103.8\text{ kJ/mol}) + 0\text{ kJ}]$ $\Delta H° = -2\,043.9\text{ kJ}$ $C_8H_{18}(l) + \frac{25}{2}O_2(g) \rightarrow 8\,CO_2(g) + 9\,H_2O(g)$ $\Delta H° = [9\text{ mol}(-241.8\text{ kJ/mol}) + 8\text{ mol}(-393.5\text{ kJ/mol})] - [1\text{ mol}(-250.1\text{ kJ/mol}) + 0\text{ kJ}]$ $\Delta H° = -5\,074.1\text{ kJ}$ $C_2H_5OH(l) + 3\,O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(g)$ $\Delta H° = [3\text{ mol}(-241.8\text{ kJ/mol}) + 2\text{ mol}(-393.5\text{ kJ/mol})] - [1\text{ mol}(-277.6\text{ kJ/mol}) + 0\text{ kJ}]$ $\Delta H° = -1\,234.8\text{ kJ}$ $C_3H_8(g)$ $\frac{3\text{ mol }CO_2(g)}{2\,043.9\text{ kJ}} = 1.47 \times 10^{-3}\ \frac{\text{mol }CO_2(g)}{\text{kJ}}$ $C_8H_{18}(g)$ $\frac{8\text{ mol }CO_2(g)}{5\,074.1\text{ kJ}} = 1.58 \times 10^{-3}\ \frac{\text{mol }CO_2(g)}{\text{kJ}}$ $C_2H_5OH(l)$ $\frac{2\text{ mol }CO_2(g)}{1\,234.8\text{ kJ}} = 1.62 \times 10^{-3}\ \frac{\text{mol }CO_2(g)}{\text{kJ}}$ $C_3H_8(g)$ produces the least amount of $CO_2(g)$ per 1 kJ of energy. **Note:** Also acceptable is kJ/mol $CO_2(g)$ comparison.	*Key Components* • a comparison in terms of energy and $CO_2(g)$ for each fuel *Supports* • balanced combustion equations including enthalpy calculations • calculation for moles of $CO_2(g)$ 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.

$$2\,H^{+}(aq) + 2\,e^{-} \rightarrow H_2(g)$$

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	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ $2H^+(aq) + 2e^- \rightarrow H_2(g)$ ――――――――――― $Cu(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2(g)$	1 mark each for • correct oxidation half-reaction • valid net redox reaction (consistent)
4.b.	3	$n_{e^-} = \dfrac{(3.00\ C/s)(48.0\ h)(3600\ s/h)}{9.65 \times 10^4\ C/mol} = 5.37\ mol$ $n_{Cu} = \frac{1}{2} n_{e^-} = 2.69\ mol$ $m_{Cu} = 2.69\ mol(63.55\ g/mol) = 171\ g$ $\Delta m_{anode} = 400\ g - 171\ g = 229\ g$	1 mark each for • 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 for the ionization of the unknown acid solution 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	$HA(aq) + H_2O(l) \rightleftharpoons A^-(aq) + H_3O^+(aq)$ **or** $HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$ $K_a = \frac{[H_3O^+(aq)][A^-(aq)]}{[HA(aq)]}$	• 1 mark for balanced equation • 1 mark for K_a expression
5.b.	3	Initial pH = 2.25 $[H_3O^+(aq)] = [A^-(aq)] = 10^{-pH}$ $= 5.6 \times 10^{-3}$ mol/L $K_a = \frac{(5.6 \times 10^{-3}\ \text{mol/L})^2}{(0.176\ \text{mol/L} - 5.6 \times 10^{-3}\ \text{mol/L})} = 1.9 \times 10^{-4}$ **Properties** • weak acid • only partially ionizes in water • most of the acid does not dissociate • proton donor • monoprotic • $[H_3O^+(aq)]$ is less than [HA(aq)] • when titrated with a strong base, pH at equivalence point is above 7 • low conductivity • sour taste	• 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
	6	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.

Equation I $2\,NO(g) + 3\,H_2(g) \xrightarrow{\text{catalyst}} 2\,NH_3(g) + O_2(g)$

Equation II $4\,NH_3(g) + 6\,NO(g) \xrightarrow{\text{catalyst}} 5\,N_2(g) + 6\,H_2O(g)$

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 energy.

Your response should include

- enthalpy calculations per mole of nitrogen monoxide gas for each reaction
- potential energy 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.*

<table>
<tr><th>Marks</th><th>Sample Response</th><th>Comments</th></tr>
<tr>
<td>5</td>
<td>

Calculations

$\Delta H^\circ = \sum n\Delta_f H^\circ(\text{products}) - \sum n\Delta_f H^\circ(\text{reactants})$

Equation 1

$2\ NO(g) + 3\ H_2(g) \xrightarrow{\text{catalyst}} 2\ NH_3(g) + O_2(g)$

$\Delta H^\circ = [(2\ mol)(-45.9\ kJ/mol) + 0\ kJ)] - [(2\ mol)(+91.3\ kJ/mol) + 0\ kJ)]$

$= -274.4\ kJ/2\ mol = -137.2\ kJ/mol\ of\ NO(g)$

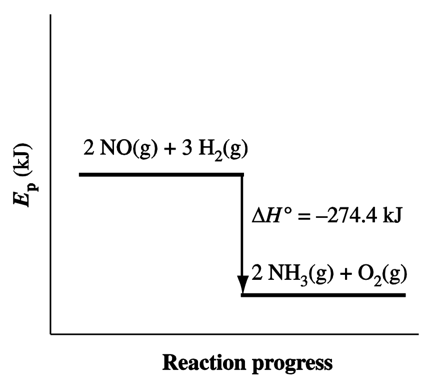
Equation 2

$4\ NH_3(g) + 6\ NO(g) \xrightarrow{\text{catalyst}} 5\ N_2(g) + 6\ H_2O(g)$

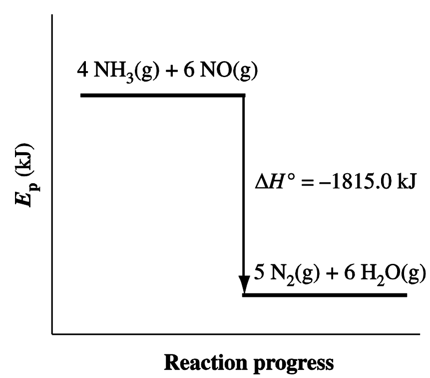
$\Delta H^\circ = [0\ kJ + (6\ mol)(-241.8\ kJ/mol)] - [(4\ mol)(-45.9\ kJ/mol) + (6\ mol)(+91.3\ kJ/mol)]$

$= -1\ 815.0\ kJ/6\ mol = -302.5\ kJ/mol\ of\ NO(g)$

Equation 1



Equation 2



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

</td>
<td>

Key Component:

- a comparison between each reaction is made in terms of energy (kJ or kJ/mol)

Support:

- enthalpy change calculations (kJ/mol of NO(g))
- potential energy diagrams consistent with calculations
- explanation and identification of a similarity **and** a difference

</td>
</tr>
</table>

Question 6 – Holistic Split Scoring Guide

Score	Key–No Key Criteria
2 **Key**	The student has addressed the question by making a comparison between the two reactions in terms of energy (reasonable approach to enthalpy change or molar enthalpy change). **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.
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.

I	$2\,NO_2(g) \rightarrow 2\,NO(g) + O_2(g)$	
II	$N_2(g) + O_2(g) \rightarrow 2\,NO(g)$	$\Delta H° = +182.6$ kJ

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

7. **a.** **Determine** the enthalpy change for reaction I, and **sketch** a potential energy 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.

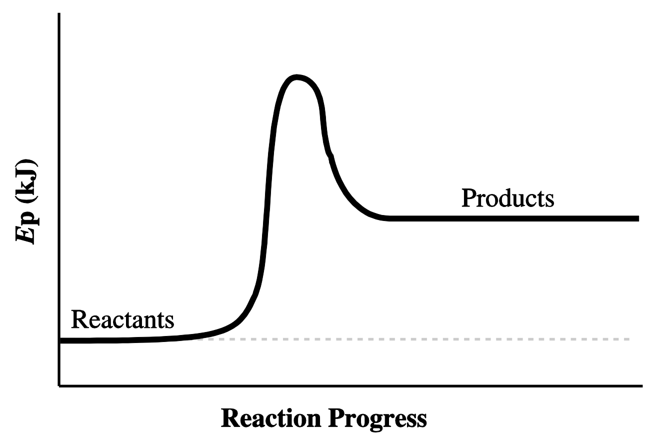
(2 marks)

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.*

<table>
<tr><th>Question</th><th>Marks</th><th>Acceptable Response</th><th>Comments</th></tr>
<tr><td>7.a.</td><td>3</td><td>

$\Delta H^\circ = \sum n\Delta_f H^\circ(\text{products}) - \sum n\Delta_f H^\circ(\text{reactants})$
$\Delta H^\circ_1 = [(2\ \text{mol})(+91.3\ \text{kJ/mol}) + 0\ \text{kJ}] - [(2\ \text{mol})(+33.2\ \text{kJ/mol})]$
$= +116.2\ \text{kJ}$

Energy Diagram


Note:
• The activation energy barrier does not need to be included on the energy diagram.
• The terms reaction progress, reaction coordinate, reaction, or time may be used to label the x-axis.
• A title is not required.</td>
<td>• 1 mark for correct method to calculate enthalpy change
• 1 mark for correct answer, including the sign (consistent with method)
• 1 mark for potential energy diagram (correct or consistent with answer)</td></tr>
</table>

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	**Similarities:** (**Note:** This is the correct response if the response to question **1.a**. is correct.) • 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. **Differences:** • 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. **(If in part (a) student shows an exothermic reaction)** **Differences:** • Reaction II absorbs energy; reaction I releases energy (consistent with diagram). • Reaction I is exothermic; reaction II is endothermic (consistent with $\Delta H°$). • 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 $\Delta H°$).	• 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 K_a value of acetic 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 acetic acid.

Your response should include

- a detailed procedure
- a definition for the term K_a
- a relevant equilibrium 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	**Procedure:** **1.** Obtain three 100.00 mL beakers, and fill each beaker with 50.0 mL of 0.100 mol/L acetic acid solution. **2.** Using three water baths at different temperatures, warm or cool, place one beaker of acetic acid in each water bath. **3.** Measure and record the temperature of each acetic acid solution. **4.** Using a pH meter, measure and record the pH of each acid sample **Note:** This can also be done by titration to determine hydronium ion concentration at the half equivalence point. **Variables:** (may be implied) controlled – same acid, concentration of acid, amount of acid manipulated – temperature of acetic acid solution responding – pH of the acetic acid solution K_a is a measure of the extent to which an acid ionizes. **Expressions and Formulas:** $CH_3COOH(aq) + H_2O(l) \rightarrow H_3O^+(aq) + CH_3COO^-(aq)$ $K_a = \frac{[H_3O^+(aq)][A^-(aq)]}{[HA(aq)]}$ (The ionization equation may be implied if the equilibrium expression is correct.) $[H_3O^+(aq)] = [CH_3COO^-(aq)] = 10^{-pH}$	*Key Component:* • 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) *Support:* • definition of K_a • details of procedure, (identifying the manipulated, responding and controlled variables, may be implied) • relevant equation(s) and formula(s)
		Total Possible Marks = 5	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.

$$Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(s) + 3\,CO_2(g)$$

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

Step I	$3\,Fe_2O_3(s) + CO(g) \rightarrow 2\,Fe_3O_4(s) + CO_2(g)$	$\Delta H^\circ = -47.2$ kJ
Step II	$Fe_3O_4(s) + CO(g) \rightarrow 3\,FeO(s) + CO_2(g)$	$\Delta H^\circ = +19.4$ kJ
Step III	$FeO(s) + CO(g) \rightarrow Fe(s) + CO_2(g)$	$\Delta H^\circ = -11.0$ kJ

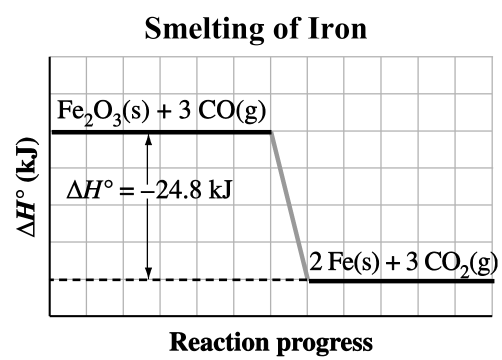
Written Response—10% (5 marks for content, 1 mark for overall communication)

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 energy 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.*

<table>
<tr><th>Question</th><th>Marks</th><th>Sample Response</th><th>Comments</th></tr>
<tr><td>9.a.</td><td>3</td><td>
$Fe_2O_3(s) + \frac{1}{3}CO(g) \rightarrow \frac{2}{3}Fe_3O_4(s) + \frac{1}{3}CO_2(g) \quad \Delta H° = \frac{1}{3}(-47.2\ kJ)$
$\frac{2}{3}Fe_3O_4(s) + \frac{2}{3}CO(g) \rightarrow 2\,FeO(s) + \frac{2}{3}CO_2(g) \quad \Delta H° = \frac{2}{3}(+19.4\ kJ)$
$2\,FeO(s) + 2\,CO(g) \rightarrow 2\,Fe(s) + 2\,CO_2(g) \quad \Delta H° = 2(-11.0\ kJ)$
$Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(s) + 3\,CO_2(g) \quad \Delta H° = -24.8\ kJ$
or
$\Delta H° = \sum n\Delta_f H°_{(products)} - \sum n\Delta_f H°_{(reactants)}$
$= [(2\ mol)(0\ kJ/mol) + (3\ mol)(-393.5\ kJ/mol)]$
$- [(1\ mol)(-824.2\ kJ/mol) + (3\ mol)(-110.5\ kJ/mol)]$
$= -24.8\ kJ$
$Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(s) + 3\,CO_2(g) + 24.8\ kJ$
</td><td>• 1 mark for correct method
• 1 mark for correct answer
• 1 mark for energy term on side of equation consistent with calculation</td></tr>
<tr><td>9.b.</td><td>2</td><td>
Note: Vertical axis can be labelled $\Delta H°$, E_p, or energy. Horizontal axis can be labelled Reaction progress, Reaction coordinate, Reaction, or Time.
Note: A title is not required, and neither is the enthalpy change ($\Delta H°$).


</td><td>• 1 mark for labels (must include x- and y-axes and identification of reactants and products)
• 1 mark for shape of energy diagram consistent with enthalpy calculation</td></tr>
<tr><td></td><td>1</td><td>Communication—See Guide</td><td>Use Analytic Scoring Guide</td></tr>
<tr><td></td><td></td><td>Total possible marks = 6</td><td></td></tr>
</table>

Use the following information to answer the next question.

Dinitrogen tetraoxide 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.

$$N_2O_4(g) \rightleftharpoons 2\,NO_2(g) \qquad \Delta H° = +55.3 \text{ kJ}$$

A technician placed a sample of $N_2O_4(g)$ 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 $N_2O_4(g)$ 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 $NO_2(g)$ 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	Sample Response	Comments
10.a.	3	$N_2O_4(g) \rightleftharpoons 2\,NO_2(g)$ $K_c = \frac{[NO_2(g)]^2}{[N_2O_4(g)]}$ $[NO_2(g)] = \sqrt{K_c[N_2O_4(g)]}$ $= \sqrt{(5.40 \times 10^{-3})(3.00 \times 10^{-1}\ \text{mol/L})}$ $= 4.02 \times 10^{-2}\ \text{mol/L}$ mol of $NO_2(g) = (4.02 \times 10^{-2}\ \text{mol/L})(2.00\ \text{L}) = 8.05 \times 10^{-2}$ mol	• 1 mark for correct K_c expression/ method • 1 mark for correct concentration of $NO_2(g)$ • 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 $NO_2(g)$ increases, and the concentration of $N_2O_4(g)$ decreases, and $K_c = \frac{[\text{products}]}{[\text{reactants}]}$.	• 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%

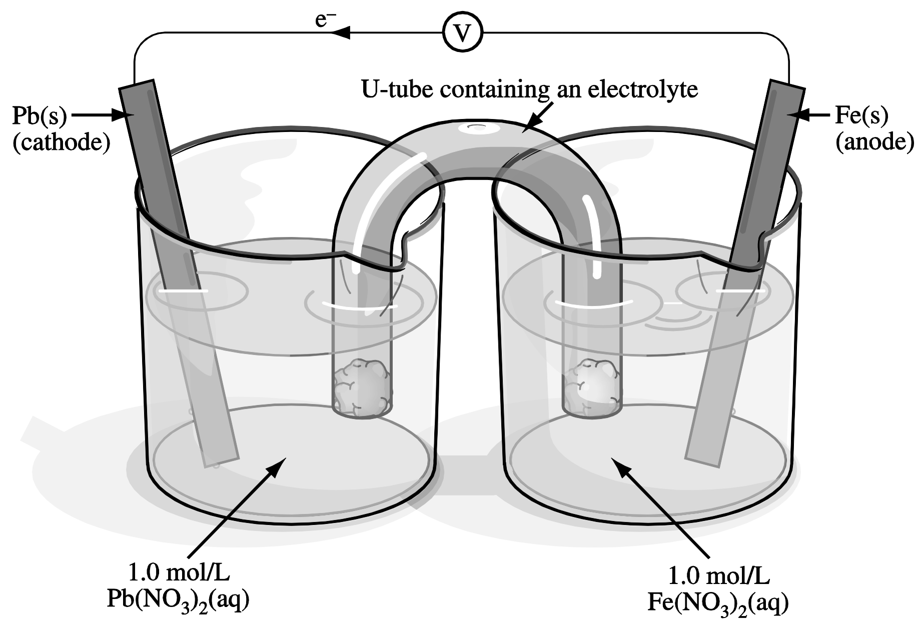
11. **Design** an experiment that would allow you to test the student's hypothesis using a lead–iron voltaic cell.

Your response should include

- a detailed procedure
- a labelled diagram of the lead–iron voltaic cell
- relevant balanced equation(s) and an $E°_{cell}$ 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	**Procedure:** 1. Construct a voltaic cell, using the reagents given in the diagram. 2. Place 100.0 mL of 1.0 mol/L $Pb(NO_3)_2(aq)$ in the beaker containing the Pb(s) electrode and 100.0 mL of 1.0 mol/L $Fe(NO_3)_2(aq)$ in the beaker containing the Fe(s) electrode. 3. Measure and record the cell potential using a voltmeter after the cell operates for 5 minutes. 4. Repeat steps 1 to 3 using different masses of Fe(s) for the iron electrode. **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. Note: The variables can be implied in the procedure. **Diagram:**  * Or any other version of a working lead–iron voltaic cell **Equation and Calculation** $Pb^{2+}(aq) + Fe(s) \rightarrow Pb(s) + Fe^{2+}(aq)$ $E^\circ_{cell} = -0.13\ V - (-0.45\ V) = +0.32\ V$	*Key Components* • experimental design or procedure that attempts to manipulate the mass of Fe(s) in an electrochemical cell, and measure cell potential *Support Components* • detailed procedure • labelled lead–iron voltaic cell diagram • relevant balanced equation(s) and E°_{cell} 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 cell potential 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.

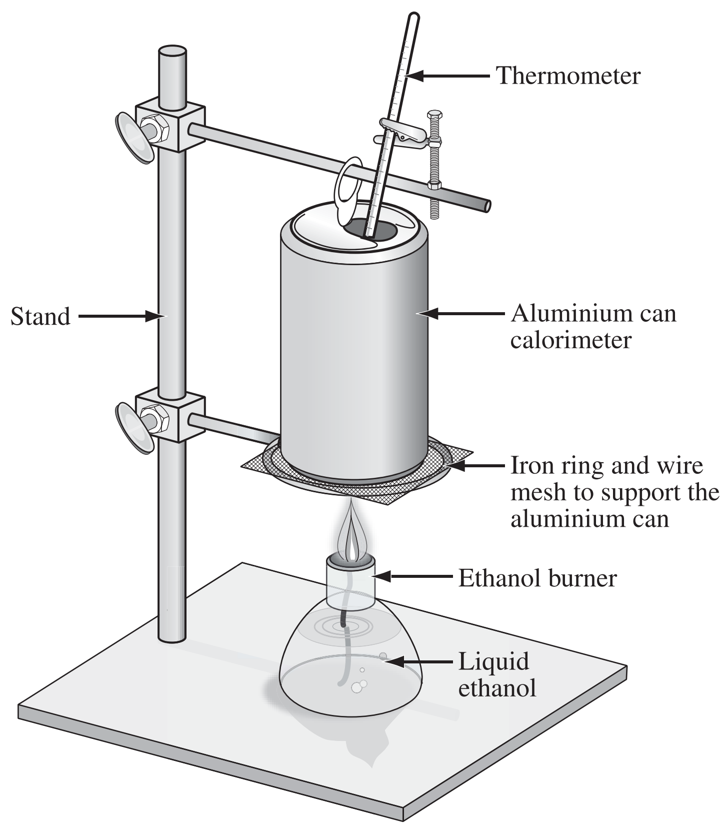
A student performs a calorimetry experiment to determine the molar enthalpy of combustion of ethanol. The student uses an aluminium can as a calorimeter. The combustion of liquid ethanol produces gaseous products, as represented by the equation below.

$$C_2H_5OH(l) + 3\,O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(g)$$

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.*

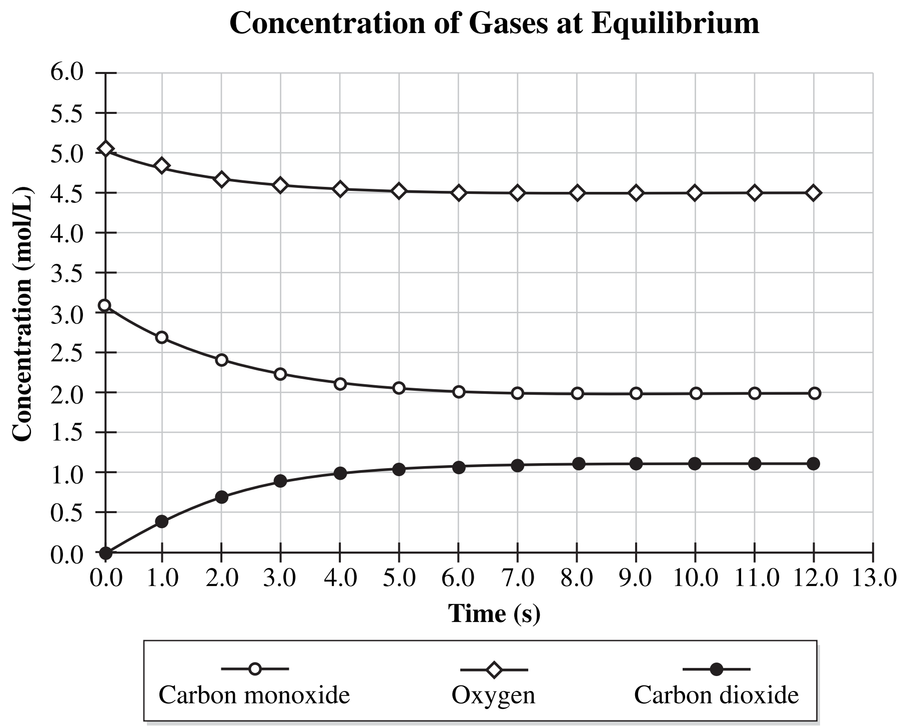
Question	Marks	Sample Response	Comments
12.a.	3	$\Delta H°_{lost} = H_{gained}$ $\Delta H° = mc\Delta t_{(H_2O)} + mc\Delta t_{(Al)}$ $= (0.250\ kg)(4.19\ kJ/kg{\bullet}°C)(82.30–21.40)°C + (0.010\ 65\ kg)(0.897\ kJ/kg{\bullet}°C)(82.30–21.40)°C$ $= –64.374\ 5\ kJ$ $n = \frac{m}{M} = \frac{3.89\ g}{46.08\ g/mol} = 0.084\ 4\ mol$ $\Delta H° = \frac{–64.37\ kJ}{0.084\ 4\ mol}$ $= –763\ kJ/mol$	• 1 mark for method • 1 mark for substitution • 1 mark for correct answer in kJ/mol
12.b.	2	**Improvement** • 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	• 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.

$$2\,CO(g) + O_2(g) \rightleftharpoons 2\,CO_2(g)$$

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	Sample Response	Comments
13.a.	3	$K_c = \frac{[CO_2(g)]^2}{[CO(g)]^2[O_2(g)]}$ $K_c = \frac{(1.1)^2}{(2.0)^2(4.5)} = 6.7 \times 10^{-2}$ $= 6.7 \times 10^{-2}$	• 1 mark for equilibrium expression • 1 mark for selecting correct equilibrium equations • 1 mark for correct answer
13.b.	2	The equilibrium favours the reactants because • 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 **Note:** The K_c value does not have to be restated here.	• 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 an $E°_{cell}$ calculation for your voltaic cell

Question 14 – Holistic Scoring Criteria

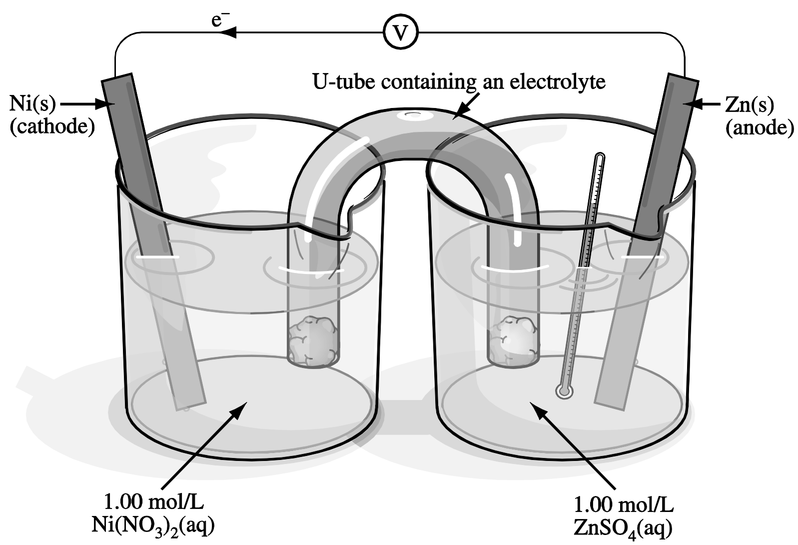
** Please note that these are only sample responses, and other variations of the response may also have received full marks.*

<table>
<tr><th>Marks</th><th>Sample Response</th><th>Comments</th></tr>
<tr>
<td>5</td>
<td>

Variables: Manipulated – concentration of $Ni^{2+}(aq)$
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

$Ni^{2+}(aq) + Zn(s) \rightarrow Ni(s) + Zn^{2+}(aq)$

$E^\circ_{net} = -0.26\ V - (-0.76\ V)$
$= +0.50\ V$



*Or any other version of a working nickel-zinc voltaic cell.

Procedure:

1. Construct a voltaic cell, using the reagents given in the diagram.
2. Place a 100.0 mL sample of 1.0 mol/L $Ni(NO_3)_2(aq)$ in the beaker containing the Ni(s) electrode.
3. Measure and record the cell potential using a voltmeter.
4. Repeat steps 1 to 3 using different concentrations of $Ni(NO_3)_2(aq)$ solution.

</td>
<td>

Key Components

- valid experimental design or procedure that attempts to manipulate the concentration of $Ni^{2+}(aq)$ in an electrochemical cell

Support Components

- detailed procedure
- labelled nickel-zinc cell diagram
- relevant balanced equation(s) and E°_{cell} calculation

</td>
</tr>
</table>

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 cell potential 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