Module 4 Drivers of Reactions - Summary

Dot point	Summary
Energy Changes in Chemical Reactions Inquiry question 4.1: What energy changes occur in chemical reactions?	
4.1.1	● conduct practical investigations to measure temperature changes in examples of endothermic and exothermic reactions, including: – combustion – dissociation of ionic substances in aqueous solution

Experiment: Temperature Changes in Endothermic and Exothermic Reactions
You are asked to conduct an experiment in which you measure the temperature change of two reactions:

1. Combustion of methane (CH_4) in excess oxygen.
2. Dissociation of sodium chloride (NaCl) in water.

a) Describe the process of measuring temperature changes in these reactions, including the necessary equipment and steps. **(3 marks)**

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b) For each reaction, predict whether it will be endothermic or exothermic, and explain why. **(4 marks)**

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c) How could you use the temperature change data to calculate the heat energy absorbed or released in each reaction? **(3 marks)**

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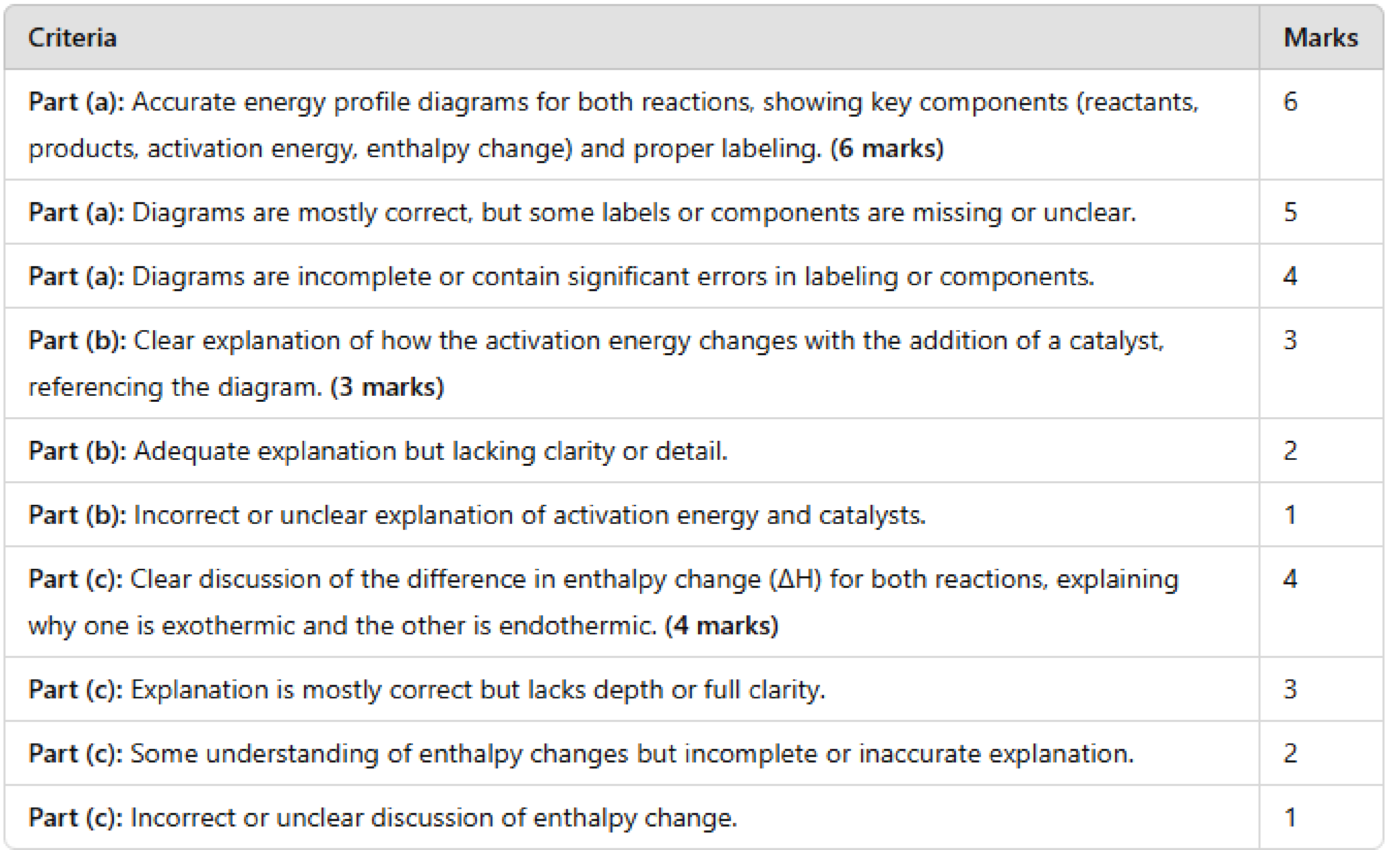

Criteria	Marks
Part (a): Accurate energy profile diagrams for both reactions, showing key components (reactants, products, activation energy, enthalpy change) and proper labeling. **(6 marks)**	6
Part (a): Diagrams are mostly correct, but some labels or components are missing or unclear.	5
Part (a): Diagrams are incomplete or contain significant errors in labeling or components.	4
Part (b): Clear explanation of how the activation energy changes with the addition of a catalyst, referencing the diagram. **(3 marks)**	3
Part (b): Adequate explanation but lacking clarity or detail.	2
Part (b): Incorrect or unclear explanation of activation energy and catalysts.	1
Part (c): Clear discussion of the difference in enthalpy change (ΔH) for both reactions, explaining why one is exothermic and the other is endothermic. **(4 marks)**	4
Part (c): Explanation is mostly correct but lacks depth or full clarity.	3
Part (c): Some understanding of enthalpy changes but incomplete or inaccurate explanation.	2
Part (c): Incorrect or unclear discussion of enthalpy change.	1

4.1.2	● investigate enthalpy changes in reactions using calorimetry and $q = mc\Delta T$ (heat capacity formula) to calculate, analyse and compare experimental results with reliable secondary-sourced data, and to explain any differences

In an experiment, you are tasked with investigating the enthalpy change of the neutralization reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH) using calorimetry.
The following data was collected:

- Mass of water: 150.0 g
- Initial temperature of water: 22.0°C
- Final temperature of water: 35.0°C
- Specific heat capacity of water: 4.18 J/g°C
- Heat released by the reaction: q (calculated using $q=mc\Delta T$)

a) Using the formula $q=mc\Delta T$, calculate the heat absorbed by the water in the calorimeter. Show all workings. **(3 marks)**

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b) Theoretical data for the enthalpy change of neutralization (ΔH) for the reaction between HCl and NaOH is -57.3 kJ/mol. Assuming the reaction occurs between 0.1 mol of each reactant, calculate the theoretical heat released during the reaction and compare it to your experimental results. **(4 marks)**

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c) Discuss at least two possible sources of error in the experiment and explain how these could affect the accuracy of your results. **(3 marks)**

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d) Explain why the heat capacity formula $q=mc\Delta T$ is used to calculate the enthalpy change and how it relates to the principles of calorimetry. **(2 marks)**

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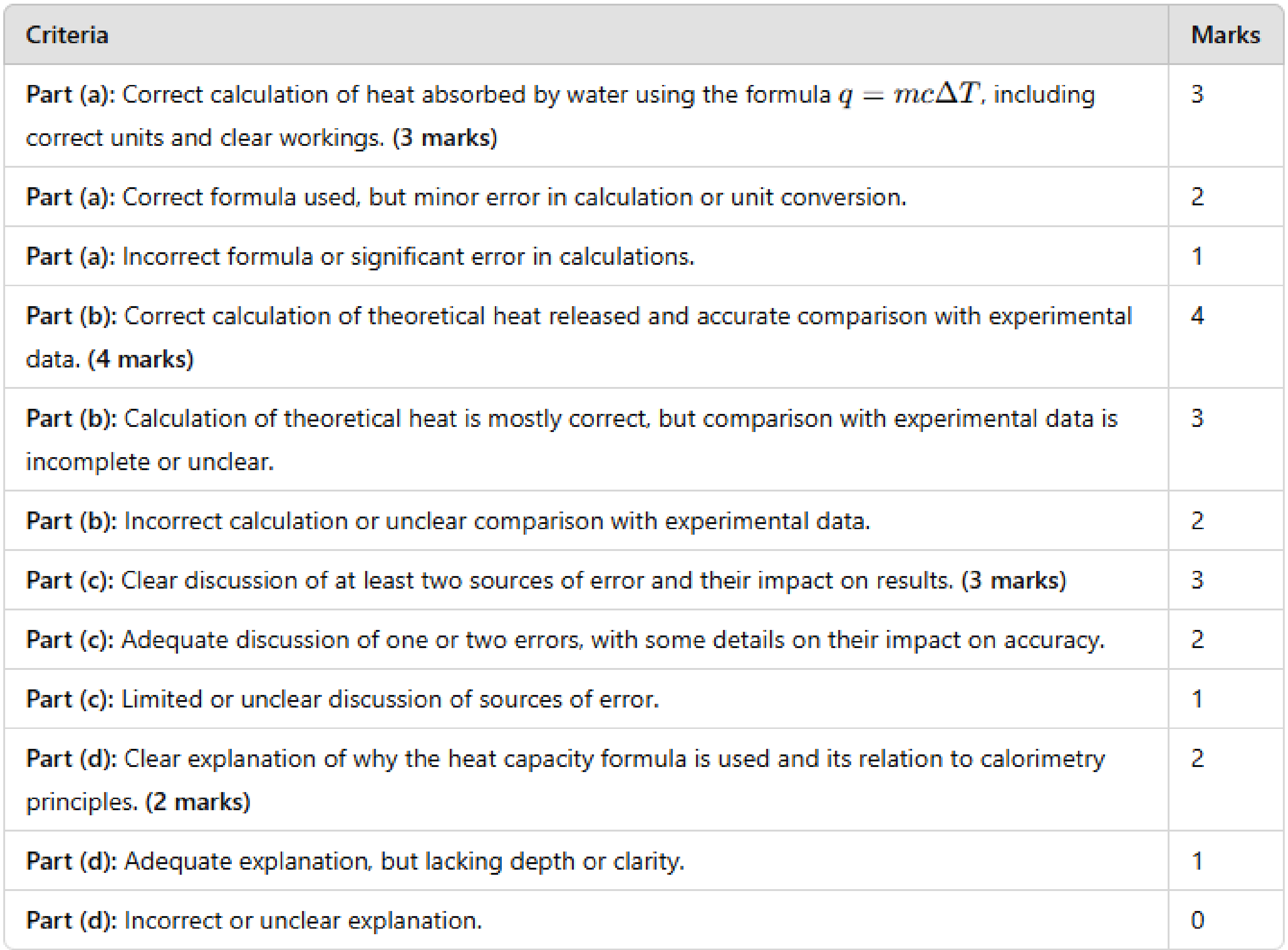

Criteria	Marks
Part (a): Correct calculation of heat absorbed by water using the formula $q = mc\Delta T$, including correct units and clear workings. **(3 marks)**	3
Part (a): Correct formula used, but minor error in calculation or unit conversion.	2
Part (a): Incorrect formula or significant error in calculations.	1
Part (b): Correct calculation of theoretical heat released and accurate comparison with experimental data. **(4 marks)**	4
Part (b): Calculation of theoretical heat is mostly correct, but comparison with experimental data is incomplete or unclear.	3
Part (b): Incorrect calculation or unclear comparison with experimental data.	2
Part (c): Clear discussion of at least two sources of error and their impact on results. **(3 marks)**	3
Part (c): Adequate discussion of one or two errors, with some details on their impact on accuracy.	2
Part (c): Limited or unclear discussion of sources of error.	1
Part (d): Clear explanation of why the heat capacity formula is used and its relation to calorimetry principles. **(2 marks)**	2
Part (d): Adequate explanation, but lacking depth or clarity.	1
Part (d): Incorrect or unclear explanation.	0

4.1.3	● construct energy profile diagrams to represent and analyse the enthalpy changes and activation energy associated with a chemical reaction

You are investigating two reactions:

1. The combustion of methane (CH_4), which is an exothermic reaction.
2. The decomposition of calcium carbonate ($CaCO_3$), which is endothermic and requires a catalyst to proceed at a reasonable rate.

a) Draw two separate energy profile diagrams:

1. For the exothermic combustion of methane, clearly showing the enthalpy change (ΔH) and activation energy (Ea).

2. For the endothermic decomposition of calcium carbonate with a catalyst, showing how the catalyst lowers the activation energy. Label all key components, including the reactants, products, activation energy, and enthalpy change. **(6 marks)**

b) Using the diagrams you have drawn, explain how the activation energy of the decomposition of calcium carbonate changes with the addition of a catalyst. **(3 marks)**

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c) Discuss the difference in the enthalpy change (ΔH) between the two reactions and explain why the combustion of methane is exothermic and the decomposition of calcium carbonate is endothermic. **(4 marks)**

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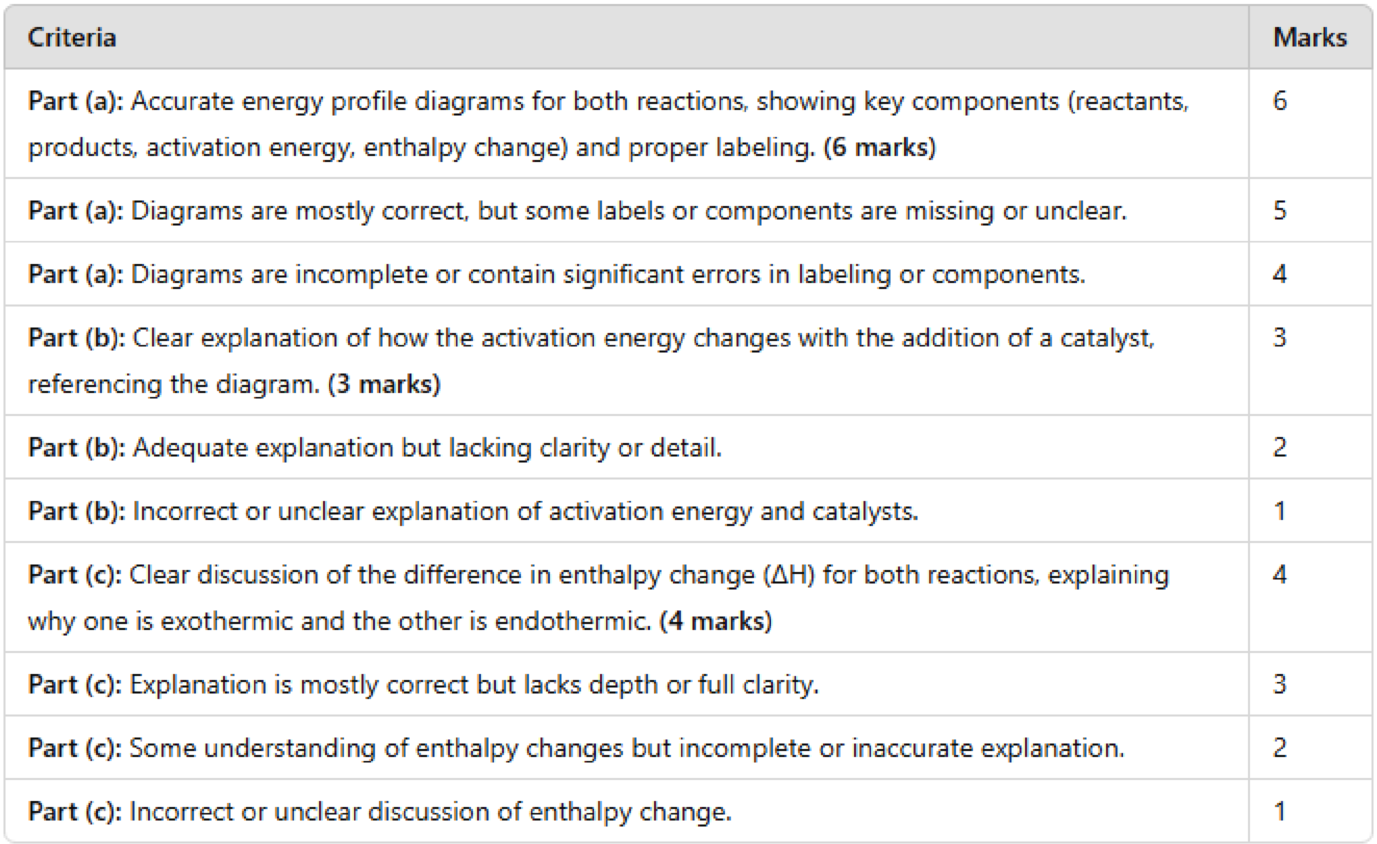

Criteria	Marks
Part (a): Accurate energy profile diagrams for both reactions, showing key components (reactants, products, activation energy, enthalpy change) and proper labeling. **(6 marks)**	6
Part (a): Diagrams are mostly correct, but some labels or components are missing or unclear.	5
Part (a): Diagrams are incomplete or contain significant errors in labeling or components.	4
Part (b): Clear explanation of how the activation energy changes with the addition of a catalyst, referencing the diagram. **(3 marks)**	3
Part (b): Adequate explanation but lacking clarity or detail.	2
Part (b): Incorrect or unclear explanation of activation energy and catalysts.	1
Part (c): Clear discussion of the difference in enthalpy change (ΔH) for both reactions, explaining why one is exothermic and the other is endothermic. **(4 marks)**	4
Part (c): Explanation is mostly correct but lacks depth or full clarity.	3
Part (c): Some understanding of enthalpy changes but incomplete or inaccurate explanation.	2
Part (c): Incorrect or unclear discussion of enthalpy change.	1

4.1.4	● model and analyse the role of catalysts in reactions

You are asked to investigate the role of a catalyst in the reaction between hydrogen peroxide (H_2O_2) and potassium iodide (KI), which produces iodine (I_2) and water (H_2O).

a) Draw a potential energy diagram for the reaction, both with and without the presence of a catalyst. Label all key components such as the activation energy, reactants, and products. **(4 marks)**

b) Explain the effect of a catalyst on the activation energy of the reaction. Use the potential energy diagram from part (a) to support your answer. **(3 marks)**

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c) In the context of the reaction above, describe how a catalyst speeds up the reaction without being consumed. **(3 marks)**

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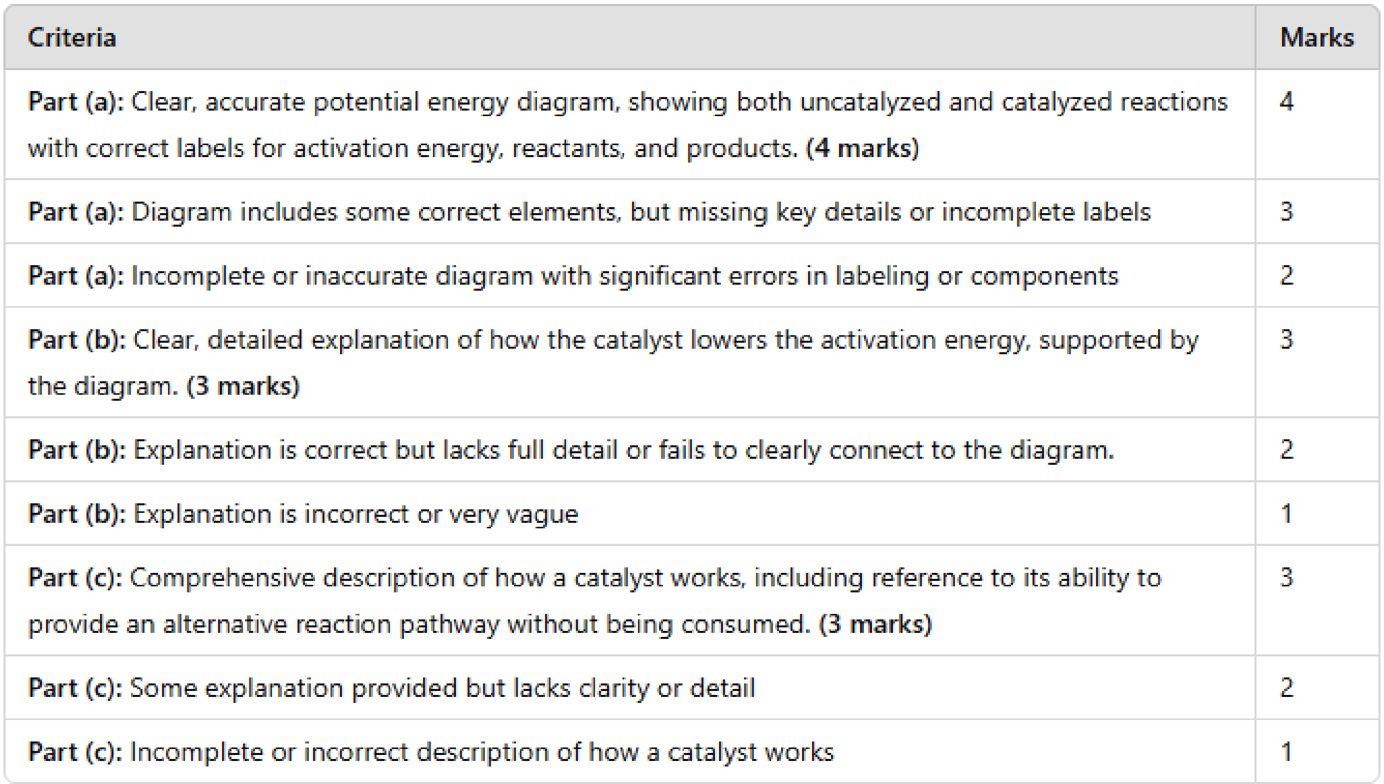

Criteria	Marks
Part (a): Clear, accurate potential energy diagram, showing both uncatalyzed and catalyzed reactions with correct labels for activation energy, reactants, and products. **(4 marks)**	4
Part (a): Diagram includes some correct elements, but missing key details or incomplete labels	3
Part (a): Incomplete or inaccurate diagram with significant errors in labeling or components	2
Part (b): Clear, detailed explanation of how the catalyst lowers the activation energy, supported by the diagram. **(3 marks)**	3
Part (b): Explanation is correct but lacks full detail or fails to clearly connect to the diagram.	2
Part (b): Explanation is incorrect or very vague	1
Part (c): Comprehensive description of how a catalyst works, including reference to its ability to provide an alternative reaction pathway without being consumed. **(3 marks)**	3
Part (c): Some explanation provided but lacks clarity or detail	2
Part (c): Incomplete or incorrect description of how a catalyst works	1

Enthalpy and Hess's Law
Inquiry question 4.2: How much energy does it take to break bonds, and how much is released when bonds are formed?

4.2.1	● explain the enthalpy changes in a reaction in terms of breaking and reforming bonds, and relate this to: – the law of conservation of energy

Explain the enthalpy changes that occur in a chemical reaction in terms of breaking and reforming bonds. Use the law of conservation of energy to relate these changes to the overall energy of the system. **(6 marks)**

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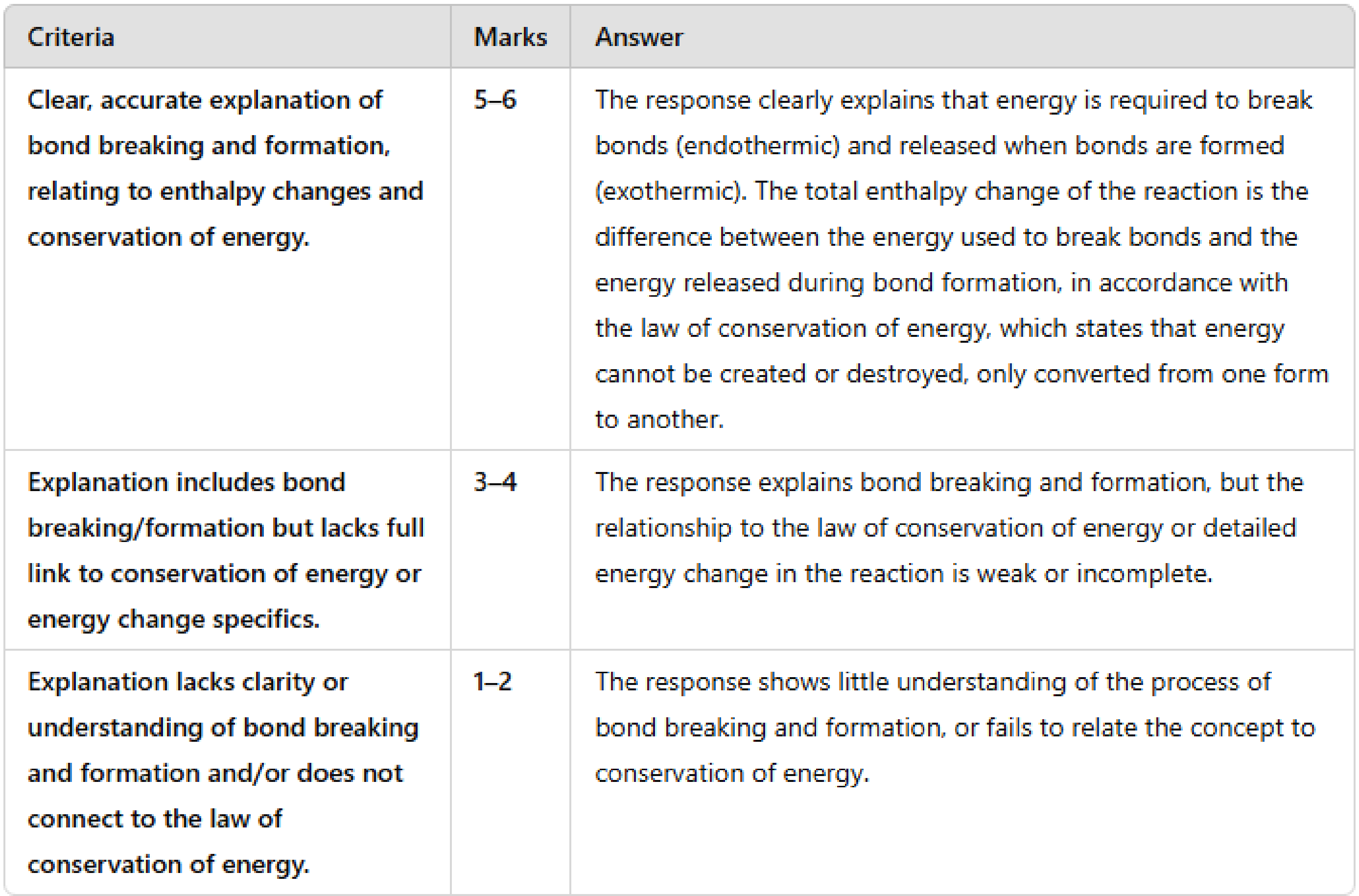

Criteria	Marks	Answer
Clear, accurate explanation of bond breaking and formation, relating to enthalpy changes and conservation of energy.	**5–6**	The response clearly explains that energy is required to break bonds (endothermic) and released when bonds are formed (exothermic). The total enthalpy change of the reaction is the difference between the energy used to break bonds and the energy released during bond formation, in accordance with the law of conservation of energy, which states that energy cannot be created or destroyed, only converted from one form to another.
Explanation includes bond breaking/formation but lacks full link to conservation of energy or energy change specifics.	**3–4**	The response explains bond breaking and formation, but the relationship to the law of conservation of energy or detailed energy change in the reaction is weak or incomplete.
Explanation lacks clarity or understanding of bond breaking and formation and/or does not connect to the law of conservation of energy.	**1–2**	The response shows little understanding of the process of bond breaking and formation, or fails to relate the concept to conservation of energy.

4.2.2	● investigate Hess’s Law in quantifying the enthalpy change for a stepped reaction using standard enthalpy change data and bond energy data, for example: – carbon reacting with oxygen to form carbon dioxide via carbon monoxide

Using Hess’s Law, calculate the enthalpy change for the following reaction (6 marks):

C(s) + 2H2(g) → CH4(g)

Given the following reactions and their standard enthalpy changes:

1. C(s) + O2(g) → CO2(g)   ΔH = -393.5 kJ/mol
2. 2H2(g) + O2(g) → 2H2O(l)   ΔH = −572.0 kJ/mol
3. CH4(g) + 2O2(g) → CO2(g) + 2H2O(l) ΔH = −890.3 kJ/mol

Using Hess’s Law, determine the enthalpy change for the reaction:

C(s) + 2H2(g) → CH4(g)

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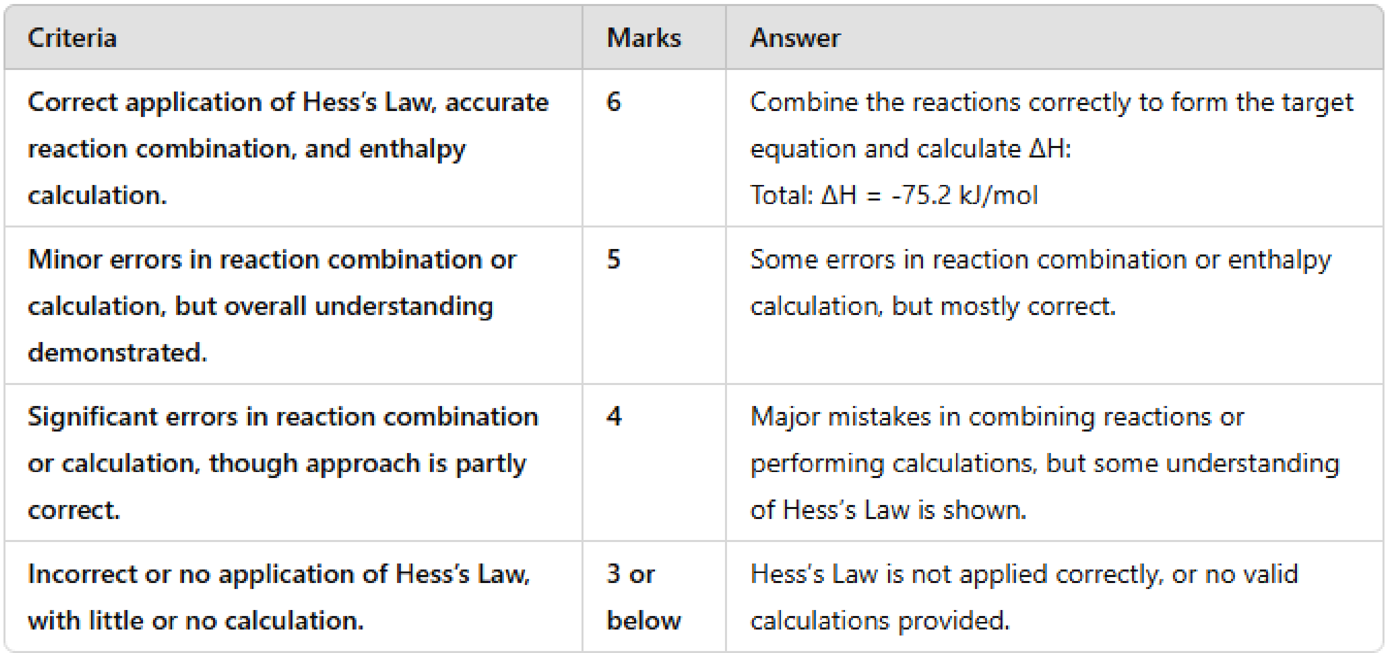

Criteria	Marks	Answer
Correct application of Hess's Law, accurate reaction combination, and enthalpy calculation.	**6**	Combine the reactions correctly to form the target equation and calculate ΔH: Total: ΔH = -75.2 kJ/mol
Minor errors in reaction combination or calculation, but overall understanding demonstrated.	**5**	Some errors in reaction combination or enthalpy calculation, but mostly correct.
Significant errors in reaction combination or calculation, though approach is partly correct.	**4**	Major mistakes in combining reactions or performing calculations, but some understanding of Hess's Law is shown.
Incorrect or no application of Hess's Law, with little or no calculation.	**3 or below**	Hess's Law is not applied correctly, or no valid calculations provided.

4.2.3	● apply Hess's Law to simple energy cycles and solve problems to quantify enthalpy changes within reactions, including but not limited to: – heat of combustion – enthalpy changes involved in photosynthesis – enthalpy changes involved in respiration

Use Hess's Law to calculate the enthalpy change (ΔH) for the following reaction:
C2H4(g) + 3O2(g) → 2CO2(g) + 2H2O(g)

Given the following reactions and their enthalpy changes (6 marks):

1. C2H4(g) + 3O2(g) → 2CO2(g) + 2H2O(l) ΔH=−1411kJ/mol
2. H2O(l) → H2O(g) ΔH=+44kJ/mol

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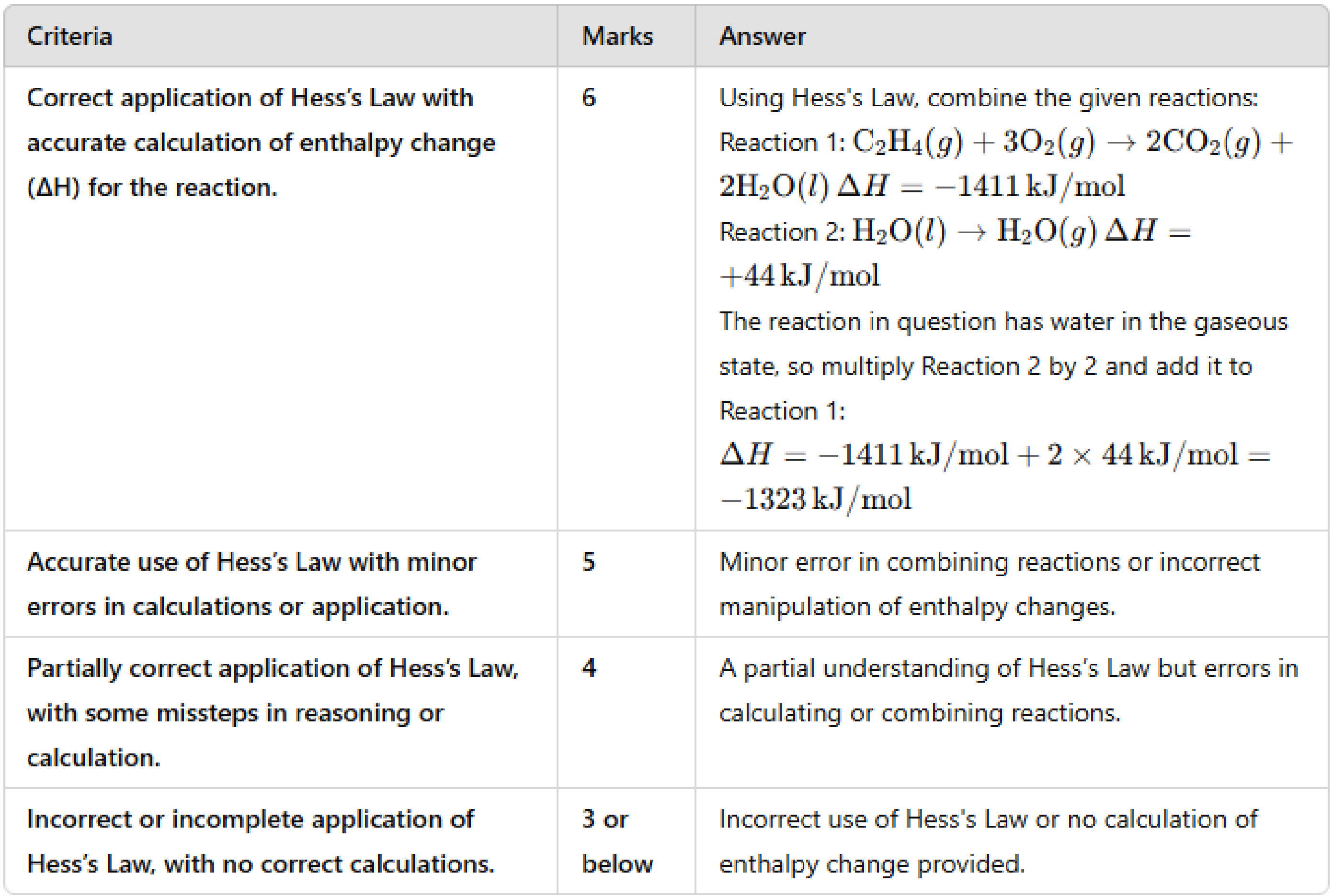

Criteria	Marks	Answer
Correct application of Hess's Law with accurate calculation of enthalpy change (ΔH) for the reaction.	6	Using Hess's Law, combine the given reactions: Reaction 1: $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)\ \Delta H = -1411\,\mathrm{kJ/mol}$ Reaction 2: $H_2O(l) \rightarrow H_2O(g)\ \Delta H = +44\,\mathrm{kJ/mol}$ The reaction in question has water in the gaseous state, so multiply Reaction 2 by 2 and add it to Reaction 1: $\Delta H = -1411\,\mathrm{kJ/mol} + 2 \times 44\,\mathrm{kJ/mol} = -1323\,\mathrm{kJ/mol}$
Accurate use of Hess's Law with minor errors in calculations or application.	5	Minor error in combining reactions or incorrect manipulation of enthalpy changes.
Partially correct application of Hess's Law, with some missteps in reasoning or calculation.	4	A partial understanding of Hess's Law but errors in calculating or combining reactions.
Incorrect or incomplete application of Hess's Law, with no correct calculations.	3 or below	Incorrect use of Hess's Law or no calculation of enthalpy change provided.

Entropy and Gibbs Free Energy
Inquiry question 4.3: How can enthalpy and entropy be used to explain reaction spontaneity?

4.3.1	• analyse the differences between entropy and enthalpy

a) Define the terms entropy and enthalpy. Explain their significance in the context of chemical reactions. **(4 marks)**

b) Discuss the key differences between entropy and enthalpy with respect to:

- The nature of the physical quantities (whether they are state functions, how they are measured, etc.)
- Their relationship to spontaneity and temperature changes. **(5 marks)**

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c) For a reaction to be spontaneous at higher temperatures, the contribution of entropy must be greater than the contribution of enthalpy. Using this information, explain why certain reactions are spontaneous at higher temperatures but not at lower temperatures. **(3 marks)**

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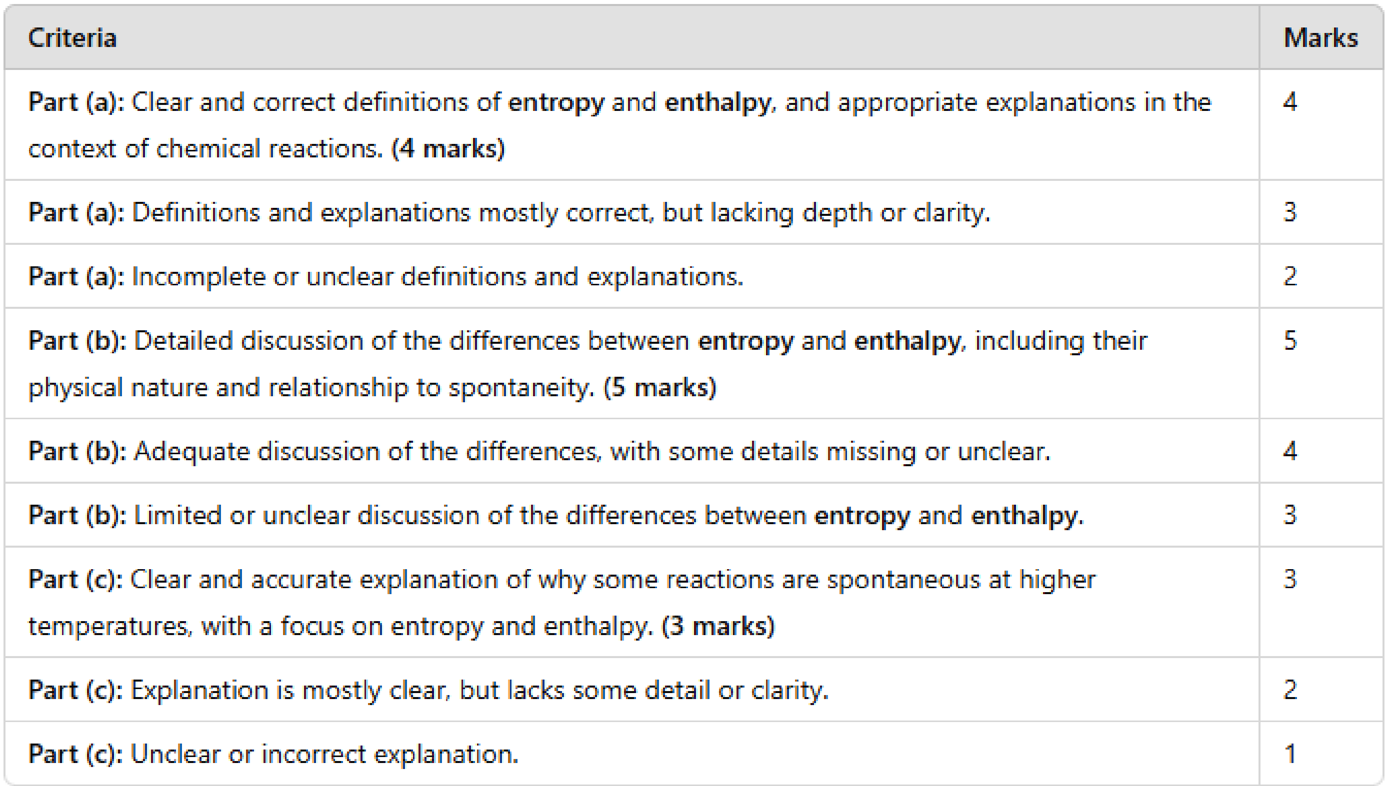

Criteria	Marks
Part (a): Clear and correct definitions of **entropy** and **enthalpy**, and appropriate explanations in the context of chemical reactions. **(4 marks)**	4
Part (a): Definitions and explanations mostly correct, but lacking depth or clarity.	3
Part (a): Incomplete or unclear definitions and explanations.	2
Part (b): Detailed discussion of the differences between **entropy** and **enthalpy**, including their physical nature and relationship to spontaneity. **(5 marks)**	5
Part (b): Adequate discussion of the differences, with some details missing or unclear.	4
Part (b): Limited or unclear discussion of the differences between **entropy** and **enthalpy**.	3
Part (c): Clear and accurate explanation of why some reactions are spontaneous at higher temperatures, with a focus on entropy and enthalpy. **(3 marks)**	3
Part (c): Explanation is mostly clear, but lacks some detail or clarity.	2
Part (c): Unclear or incorrect explanation.	1

4.3.2	● use modelling to illustrate entropy changes in reactions

a) Define entropy and explain how it relates to the disorder or randomness in a system. **(3 marks)**

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b) Use a model (e.g., a particle model, diagram, or example) to illustrate the change in entropy during a phase transition, such as the melting of a solid or the evaporation of a liquid. Describe how this model helps in understanding entropy changes. **(5 marks)**

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c) Consider the following reaction:

$$A\ (s) \rightarrow B\ (g)$$

Using the model, predict and explain the expected change in entropy during this reaction. Discuss how the states of the reactants and products affect the entropy change. **(4 marks)**

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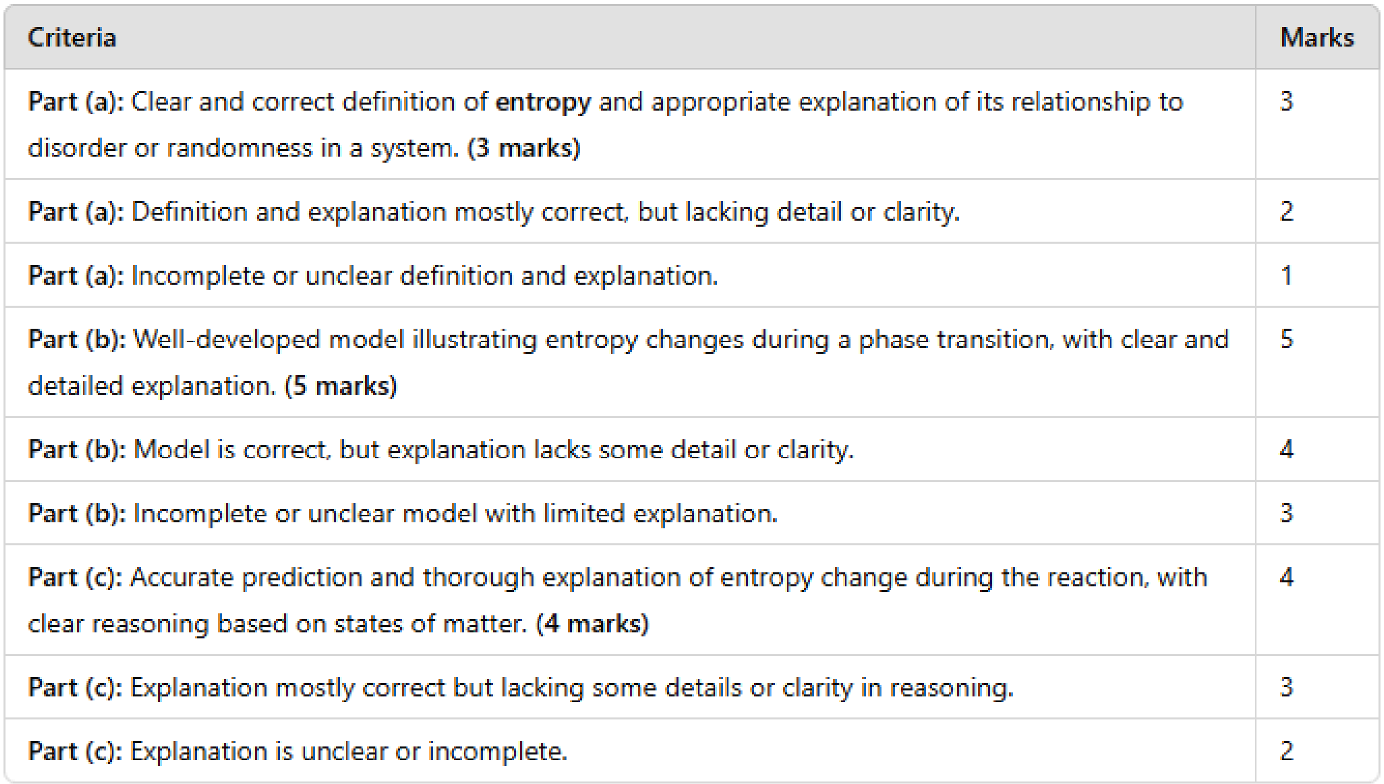
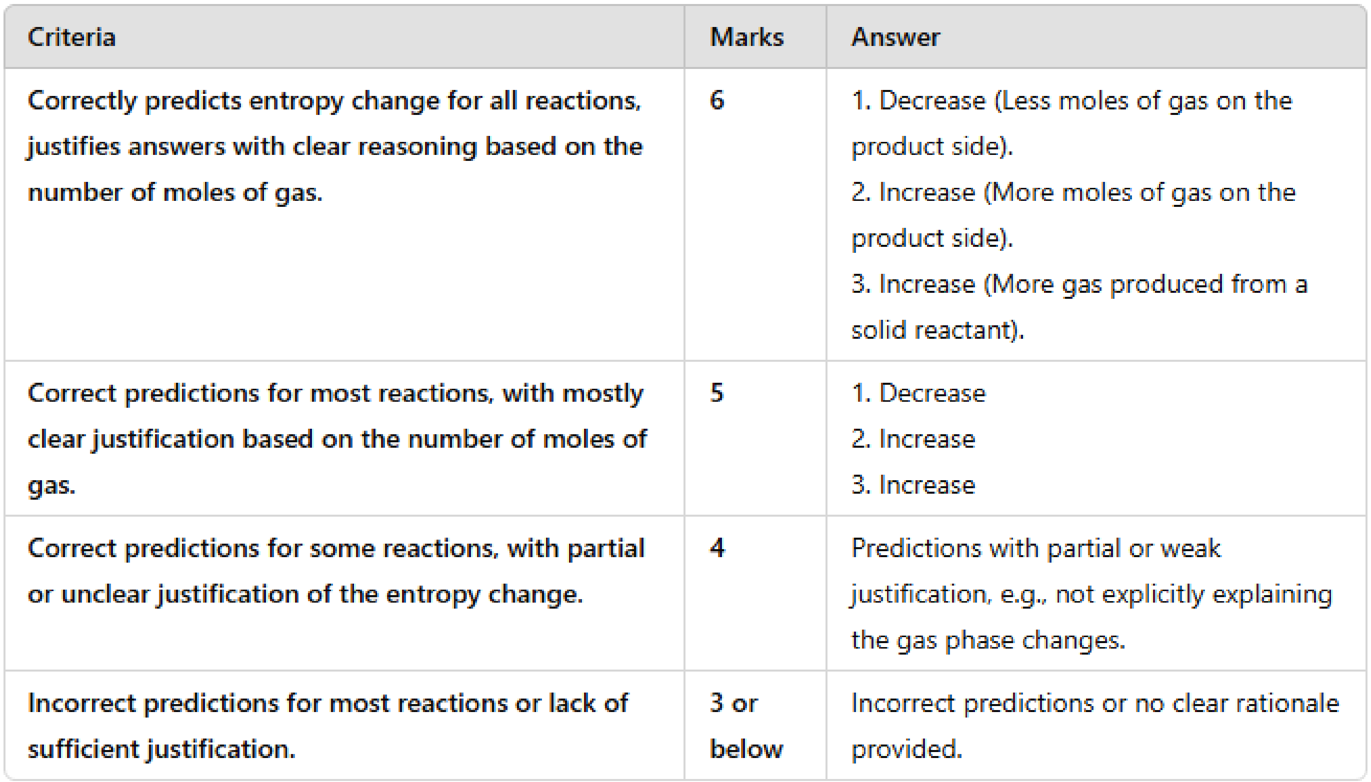


Criteria	Marks
Part (a): Clear and correct definition of **entropy** and appropriate explanation of its relationship to disorder or randomness in a system. **(3 marks)**	3
Part (a): Definition and explanation mostly correct, but lacking detail or clarity.	2
Part (a): Incomplete or unclear definition and explanation.	1
Part (b): Well-developed model illustrating entropy changes during a phase transition, with clear and detailed explanation. **(5 marks)**	5
Part (b): Model is correct, but explanation lacks some detail or clarity.	4
Part (b): Incomplete or unclear model with limited explanation.	3
Part (c): Accurate prediction and thorough explanation of entropy change during the reaction, with clear reasoning based on states of matter. **(4 marks)**	4
Part (c): Explanation mostly correct but lacking some details or clarity in reasoning.	3
Part (c): Explanation is unclear or incomplete.	2

4.3.3	● predict entropy changes from balanced chemical reactions to classify as increasing or decreasing entropy

Predict whether the entropy of the system will increase or decrease for the following chemical reactions. Justify your answers based on the changes in the number of moles of gaseous products and reactants. **(6 marks)**

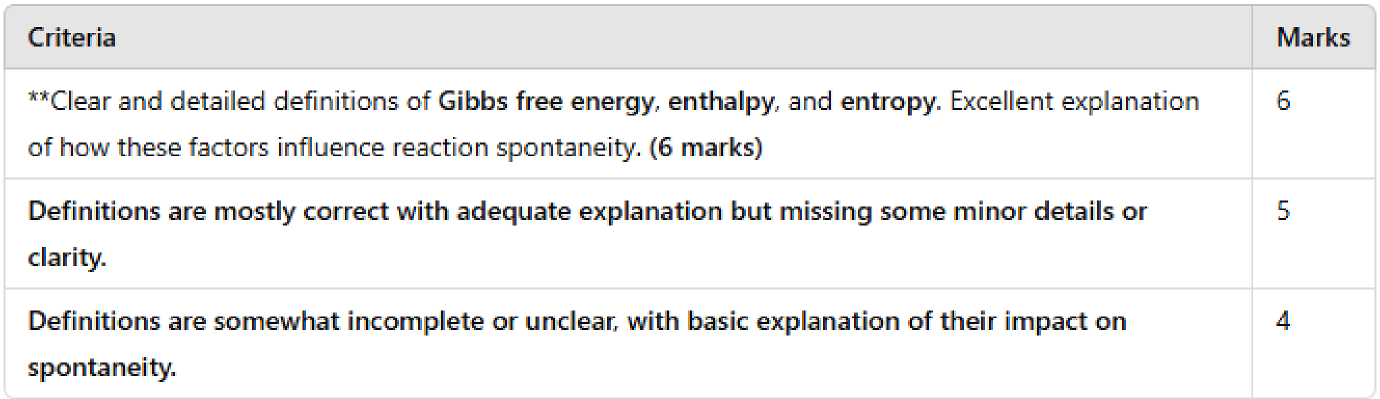
1. **N2(g) + 3H2(g) → 2NH3(g)**
2. **2NaCl(s) → 2Na(s) + Cl2(g)**
3. **CaCO3(s) → CaO(s) + CO2(g)**



Criteria	Marks	Answer
Correctly predicts entropy change for all reactions, justifies answers with clear reasoning based on the number of moles of gas.	6	1. Decrease (Less moles of gas on the product side). 2. Increase (More moles of gas on the product side). 3. Increase (More gas produced from a solid reactant).
Correct predictions for most reactions, with mostly clear justification based on the number of moles of gas.	5	1. Decrease 2. Increase 3. Increase
Correct predictions for some reactions, with partial or unclear justification of the entropy change.	4	Predictions with partial or weak justification, e.g., not explicitly explaining the gas phase changes.
Incorrect predictions for most reactions or lack of sufficient justification.	3 or below	Incorrect predictions or no clear rationale provided.

4.3.4	● explain reaction spontaneity using terminology, including: – Gibbs free energy – enthalpy – entropy

Define Gibbs free energy, enthalpy, and entropy. Explain how these quantities influence whether a reaction will be spontaneous or non-spontaneous at a given temperature. **(6 marks)**



Criteria	Marks
Clear and detailed definitions of **Gibbs free energy, **enthalpy**, and **entropy**. Excellent explanation of how these factors influence reaction spontaneity. **(6 marks)**	6
Definitions are mostly correct with adequate explanation but missing some minor details or clarity.	5
Definitions are somewhat incomplete or unclear, with basic explanation of their impact on spontaneity.	4

4.3.5	• solve problems using standard references and $\Delta G = \Delta H - T\Delta S$ (Gibbs free energy formula) to classify reactions as spontaneous or nonspontaneous

A reaction has an enthalpy change (ΔH) of +75 kJ/mol and an entropy change (ΔS) of 200 J/mol·K.

a) Calculate the Gibbs free energy change (ΔG) at 25°C and determine whether the reaction is spontaneous at this temperature. **(3 marks)**

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b) Predict whether increasing the temperature would make the reaction more or less spontaneous, justifying your answer. **(2 marks)**

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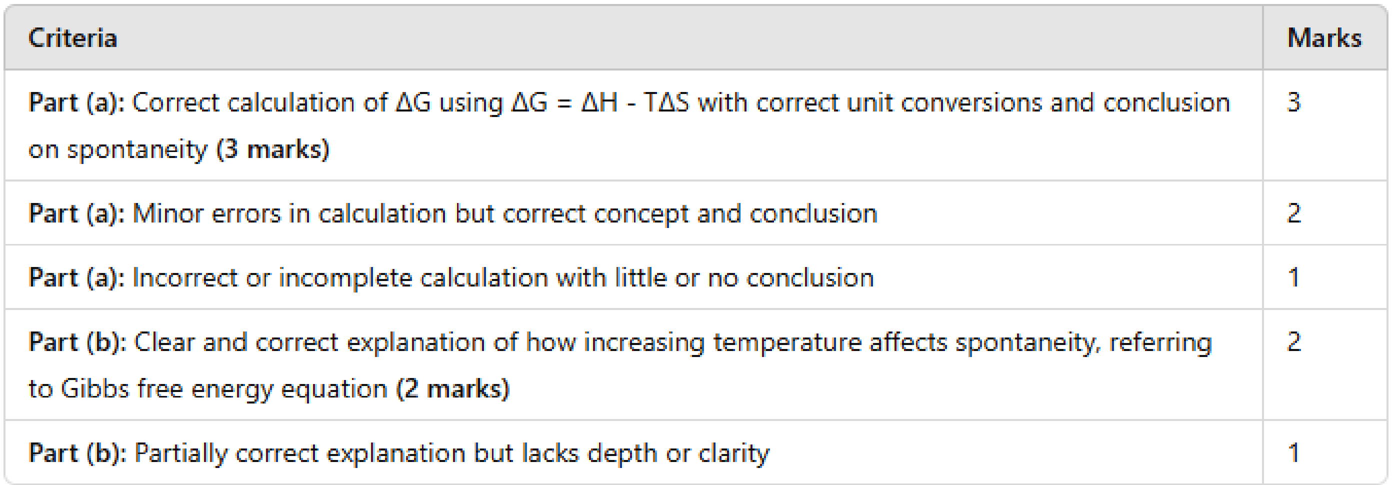

Criteria	Marks
Part (a): Correct calculation of ΔG using ΔG = ΔH - TΔS with correct unit conversions and conclusion on spontaneity **(3 marks)**	3
Part (a): Minor errors in calculation but correct concept and conclusion	2
Part (a): Incorrect or incomplete calculation with little or no conclusion	1
Part (b): Clear and correct explanation of how increasing temperature affects spontaneity, referring to Gibbs free energy equation **(2 marks)**	2
Part (b): Partially correct explanation but lacks depth or clarity	1

4.3.6	● predict the effect of temperature changes on spontaneity

Explain how temperature changes affect the spontaneity of a chemical reaction. In your response, refer to Gibbs free energy (ΔG) and the relationship between enthalpy (ΔH), entropy (ΔS), and temperature (T). **(4 marks)**

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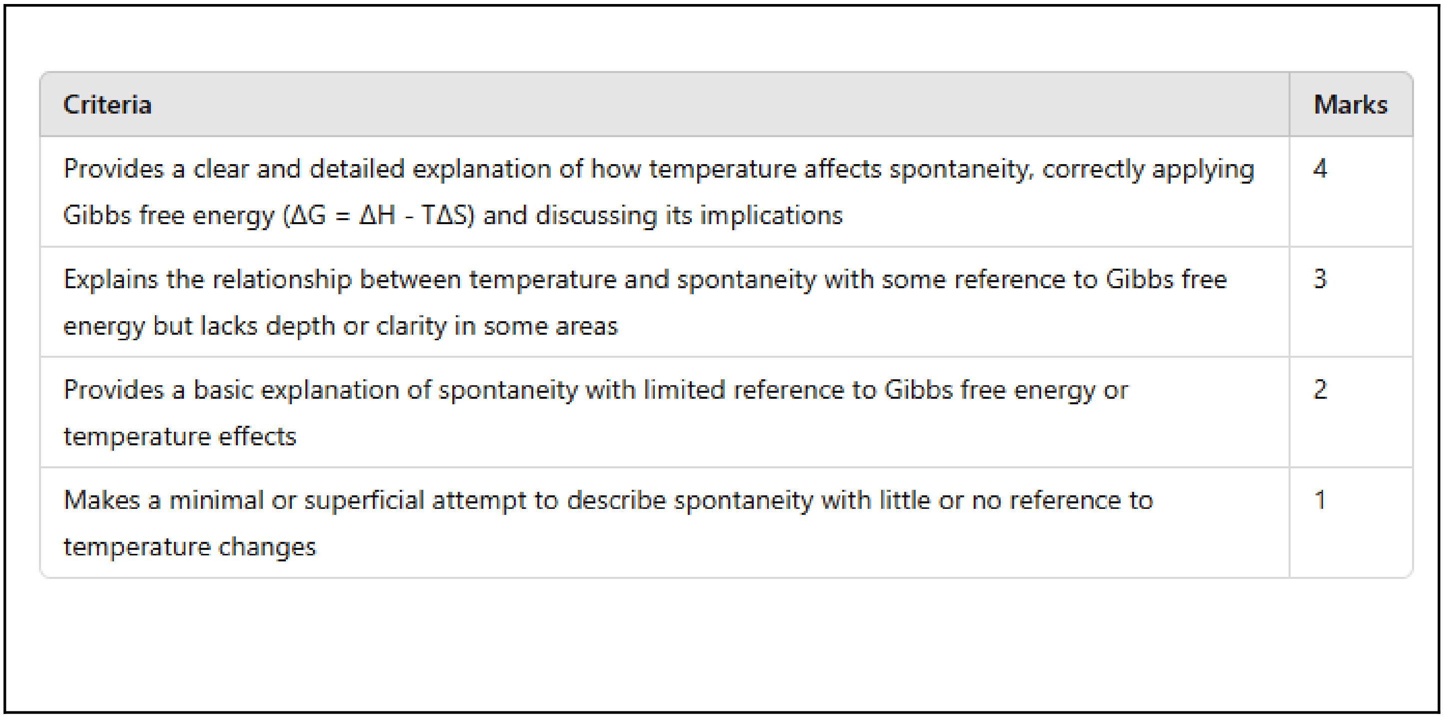

Criteria	Marks
Provides a clear and detailed explanation of how temperature affects spontaneity, correctly applying Gibbs free energy ($\Delta G = \Delta H - T\Delta S$) and discussing its implications	4
Explains the relationship between temperature and spontaneity with some reference to Gibbs free energy but lacks depth or clarity in some areas	3
Provides a basic explanation of spontaneity with limited reference to Gibbs free energy or temperature effects	2
Makes a minimal or superficial attempt to describe spontaneity with little or no reference to temperature changes	1