5.2 Hess's Law

Mark Schemes

Course	DP IB Chemistry
Section	5. Energetics / Thermochemistry
Topic	5.2 Hess's Law
Difficulty	Medium

To be used by all students preparing for DP IB Chemistry HL
Students of other boards may also find this useful

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The correct answer is **B** because:

- The **standard enthalpy of formation** ($\Delta H_f^\ominus$) is the enthalpy change when one mole of a compound is formed from its elements under standard conditions. The reactants and products must be in their standard states.
- For elements in the standard state, the enthalpy of formation is zero
  - Therefore, O_2 is zero
- **Equation;** $\Delta H = \sum \Delta H_f(products) - \sum \Delta H_f(reactants)$
- **Known quantities:**
  - Reactants; $4NH_3 = (4 \times (-46.1))$, $5O_2 = 0$
  - Products; $4NO = ((4 \times 90.3)$, $6H_2O = (6 \times (-241.8))$
- **Substitution into the equation:**
  - $\Delta H = ((4 \times 90.3) + (6 \times (-241.8)) - (4 \times (-46.1))$

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The correct answer is **A**

- The **standard enthalpy of formation** ($\Delta H_f^\ominus$) is the enthalpy change when one mole of a compound is formed from its elements under standard conditions.
  The reactants and products must be in their standard states.
- Elements in the standard state have an $\Delta H_f^\ominus$ of zero; therefore, C and Ti are zero
- **Equation;** $\Delta H = \sum \Delta H_f(products) - \sum \Delta H_f(reactants)$
- **Known quantities:**
  - Reactants; $TiO_2 = -890$, $2C = (2 \times 0)$
  - Products; $2CO = (2 \times -110.5)$, $Ti = 0$
- **Substitution into the equation:**
  - $\Delta H = -221 - (-890) = -221 + 890 = +669 kJ\,mol^{-1}$

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The correct answer is **B** because:

- The **standard enthalpy of formation** ($\Delta H_f^{\ominus}$) is the enthalpy change when one mole of a compound is formed from its elements under standard conditions.
  The reactants and products must be in their standard states.
- Elements in the standard state have an of zero; therefore, O_2 is zero
- **Equation;** $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$
- **Formula:** $\Delta H = \sum \Delta H_f(products) - \sum \Delta H_f(reactants)$
- **Known quantities:**
  - Products; $2CO_2 = (2 \times \mathbf{a})$, $3H_2O = (3 \times \mathbf{b})$
  - Reactants; $C_2H_5OH = \mathbf{c}$, $3O_2 = (3 \times 0)$
- **Substitution into the equation:**
  - $\Delta H = 2a + 3b - c$ kJ mol^{-1}

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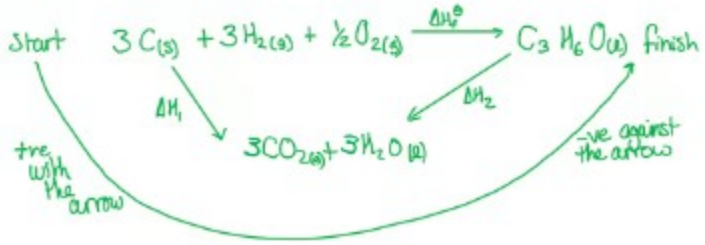
The correct answer is **B** because:

- Hess's law states that the overall enthalpy change will be the same regardless of the route taken
- Draw the cycle to make it easier to see the processes



- ΔH_1 is made from two components, the combustion of carbon(x) x 3 moles, and the combustion of hydrogen gas(y) x 3 moles
  - $\Delta H_1 = 3x + 3y$
- ΔH_2 is subtracted because the enthalpy change is in the opposite direction to the arrow
  - $\Delta H_2 = z$
- **Calculate ΔH_f**
  - $\Delta H_f = \Delta H_1 - \Delta H_2$
  - $\Delta H_f = 3x + 3y - z$

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The correct answer is **C** because:

- The elements that are missing from the Hess cycle need to be in their standard states
  - Carbon is monoatomic and solid: C (s)
  - Hydrogen is diatomic and gaseous: H_2 (g)
  - Oxygen is diatomic and gaseous: O_2 (g)
    - $C(s) + H_2(g) + O_2(g)$
- The elements also need to balance the two equations:
  - Elements $\rightarrow C_2H_4(g) + 3O_2(g)$
  - Elements $\rightarrow 2CO_2(g) + 2H_2O(g)$
    - $2C(s) + 2H_2(g) + 3O_2(g)$

A is incorrect as	the carbon is shown as gaseous
B is incorrect as	the elements are correct but they are not balanced for the cycle
D is incorrect as	the carbon is shown as diatomic

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The correct answer is **B** because:

- The enthalpy of combustion is the energy required to **burn / combust one mole** of a substance completely in oxygen
  - Therefore, only arrow *P* represents the enthalpy of combustion
- The enthalpy of formation is the energy required to **form one mole** of a compound from its elements in their standard states
  - Therefore, only arrow *Q* represents the enthalpy of formation
- The enthalpy of reaction is the enthalpy change when reactants in their standard states change to products in their standard states
  - This can be true for any arrow in the diagram

A is incorrect as	arrows *R* and *S* represents the enthalpy of reaction **not** combustion because the enthalpy of combustion is the energy required to burn / combust **one mole of a reactant**
C is incorrect as	arrows *R* and *S* cannot be enthalpy of combustion or formation because they do not agree with the **one mole** part of the definitions
D is incorrect as	arrows *R* and *S* represents the enthalpy of reaction **not** formation because the enthalpy of formation is to form **one mole of product**

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The correct answer is **C** because:

- Statement 1 is incorrect
  - This is the symbol that would be given to the enthalpy change for the conversion of graphite to diamond and this is the one that we are calculating
- Statement 2 is correct
  - Both graphite and diamond can combust / react with oxygen to form carbon dioxide
- Statement 3 is correct
  - When graphite and diamond react to form carbon dioxide, this is also the formation of carbon dioxide

A, **B** & **D** are incorrect as	statement I is incorrect

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The correct answer is **D** because:

- Hess's Law states that the enthalpy change for any chemical reaction is independent of the route taken, providing that the starting and final conditions, reactants and products are the same
  - Therefore, statements I, II and III are correct

A, **B** & **C** are incorrect as	statements I, II and III are all correct

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The correct answer is **D** because:

- Arrow 1 can be labelled as:
  - Either $\Delta H^{\ominus}_{r}$ because it is the reaction in question
  - Or $\Delta H^{\ominus}_{hyd}$ because it is the hydration of anhydrous copper sulfate as stated in the question
- Arrows 2 and 3 must have the same label as they are forming the same aqueous products
  - The aqueous products will be in solution, so these arrows are $\Delta H^{\ominus}_{sol}$

A is incorrect as	the solution, $\Delta H^{\ominus}_{sol}$, and hydration, $\Delta H^{\ominus}_{hyd}$, labels are the wrong way around
B is incorrect as	arrows 2 and 3 should be $\Delta H^{\ominus}_{sol}$
C is incorrect as	arrows 2 and 3 should have the same $\Delta H^{\ominus}_{sol}$ label

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The correct answer is **A** because:

- Anhydrous copper(II) sulfate is typically a powder which makes it difficult to accurately measure the temperature

B is incorrect as	the reaction between anhydrous copper sulfate is relatively quick
C is incorrect as	the reaction simply requires the addition of water. The reverse reaction has high energy requirements as heat is needed to remove the water of crystallisation
D is incorrect as	the reaction between anhydrous copper sulfate is exothermic