5.2 Hess's law

Name: _____ Class: _____ Date: _____ **Total: 20 marks**

KEY WORDS hess's law • energy cycle • enthalpy change • enthalpy change of formation • exothermic

Objective

Build the skills to answer exam questions on **Hess's law** – constructing **energy cycles** and calculating enthalpy changes from formation and combustion data.

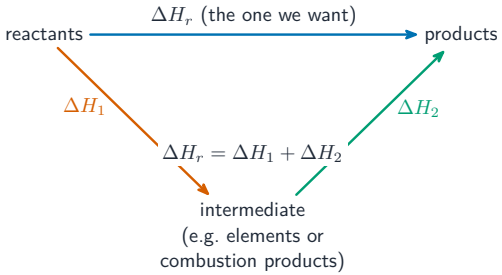
You must be able to:

- state Hess's law and construct simple energy cycles
- calculate an enthalpy change that cannot be measured directly
- use formation or combustion data (and bond energies) in a cycle

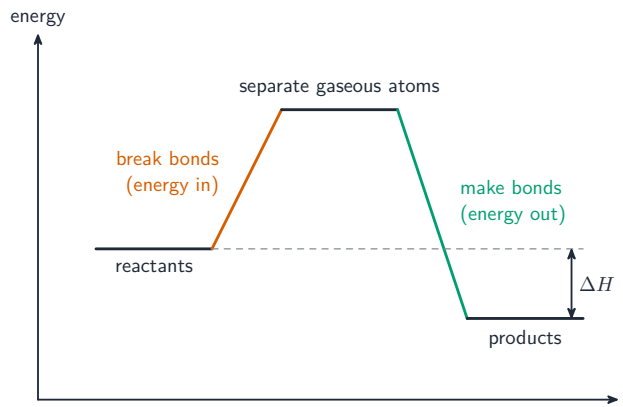
1 Key knowledge and worked examples

■ Hess's law

Hess's law: the total enthalpy change is the same whatever the route from reactants to products (energy is conserved).



The direct route equals the indirect route: $\Delta H_r = \Delta H_1 + \Delta H_2$



Bond energies feed an enthalpy (Hess) cycle

■ Using formation data

$$\Delta H_r = \sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$$

Example. $CaCO_3 \rightarrow CaO + CO_2$ (ΔH_f / kJ mol^{-1}: $CaCO_3$ −1207, CaO −635, CO_2 −394): $\Delta H_r = (-635 - 394) - (-1207) = +178$ kJ mol^{-1}.

■ Using combustion data

$$\Delta H_r = \sum \Delta H_c(\text{reactants}) - \sum \Delta H_c(\text{products})$$

2 Practice

2.1 State **Hess's law**. [1]

2.2 Give **one** reason Hess's law is useful (something it lets you find). [1]

3 Exam-style questions

3.1 Hess's law is a consequence of: [1]

☐ **A** the conservation of mass
B the conservation of energy
C the ideal gas equation
D Avogadro's law

3.2 ΔH_r from formation data is calculated as: [1]

- [ ] **A** $\sum \Delta H_f(\text{reactants}) - \sum \Delta H_f(\text{products})$
B $\sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$
C $\sum \Delta H_c(\text{products}) - \sum \Delta H_c(\text{reactants})$
D $mc\Delta T$

3.3 For $C_2H_4 + H_2 \rightarrow C_2H_6$, use ΔH_f (kJ mol^{-1}: C_2H_4 +52, C_2H_6 −85, H_2 0) to calculate ΔH_r. [3]

3.4 Explain why Hess's law allows the enthalpy change of formation of a compound to be found even when the reaction cannot be carried out directly. [2]

3.5 Use the standard enthalpy changes of formation below.

Compound	$\Delta H_f^\ominus$ **/ kJ mol^{-1}**
$CH_3OH(l)$	−239
$CO_2(g)$	−394
$H_2O(l)$	−286

(a) Write the equation for the complete combustion of methanol, then construct an energy cycle through the elements and use it to calculate $\Delta H_c^\ominus$ for methanol. [5]

(b) Explain why $\Delta H_f^\ominus$ of $O_2(g)$ is zero. [2]

(c) A school laboratory obtains −690 kJ mol^{-1}. State whether that is more or less exothermic than your answer, and give one reason for the difference. [2]

(d) State the principle that allows this calculation even though methanol is never actually burned along the route you drew. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the total enthalpy change of a reaction is the same regardless of the route taken

2.2

- e.g. it lets you find an enthalpy change that cannot be measured directly / calculate ΔH_r from formation or combustion data

3.1 B

- Hess's law follows from the conservation of energy

3.2 B

- $\sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$

3.3

- $\Delta H_r = \Delta H_f(C_2H_6) - [\Delta H_f(C_2H_4) + \Delta H_f(H_2)] = -85 - (52 + 0) = -137 \text{ kJ mol}^{-1}$

3.4

- an indirect route (e.g. via combustion or formation of the elements) can be measured; by Hess's law the sum of the indirect steps equals the direct (unmeasurable) enthalpy change

3.5

(a)

- $CH_3OH(l) + 1\frac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$. The cycle runs from the elements up to the reactants and up to the products, so $\Delta H_c = \sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants})$; $= [(-394) + 2(-286)] - [(-239) + 0] = -966 + 239 = -727 \text{ kJ mol}^{-1}$

(b)

- By definition the standard enthalpy of formation of an **element in its standard state** is zero – forming it from itself is no change at all

(c)

- Less exothermic; heat escapes to the surroundings, so less energy appears to have been released per mole burned

(d)

- Hess's law: the enthalpy change of a reaction is independent of the route taken, provided the initial and final states are the same