AS / A LEVEL CHEMISTRY

Hess's law and enthalpy cycles

1. Hess's law
2. Enthalpy cycles
   a) Enthalpy change of reaction from enthalpy changes of formation
   b) Enthalpy change of formation from enthalpy changes of combustion
3. Exam style questions
4. Summary

CONSERVATION OF ENERGY

Conserving energy of Conservation of Energy states that ‘energy cannot be created or destroyed’. This is called the **First Law of Thermodynamics.** This law also applies to chemical reactions.

- The total energy of the chemicals and their surroundings must remain constant.

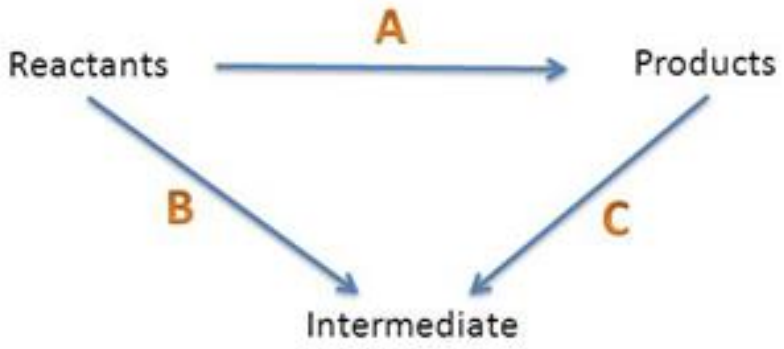
- In 1840 Germain Hess applied the Law of Conservation of Energy to enthalpy changes.

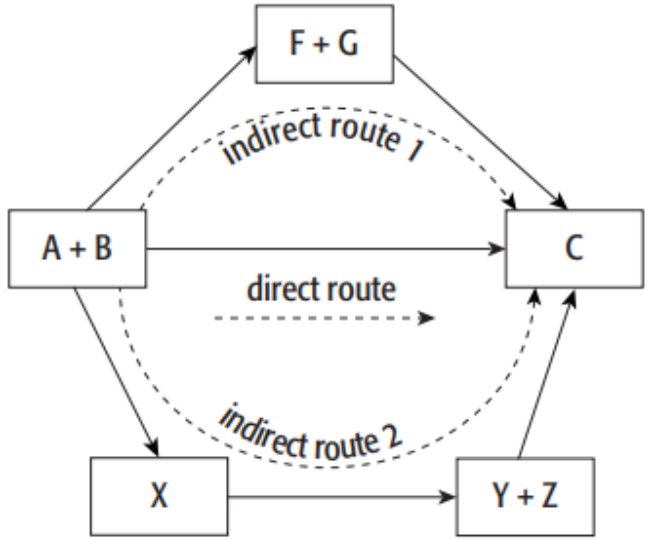
Germain Henri Hess
1802 – 1850
Russian Chemist

HESS'S LAW

Hess's law states that:

"the total enthalpy change in a chemical reaction is independent of the route by which the chemical reaction takes place as long as the initial and final conditions are the same".

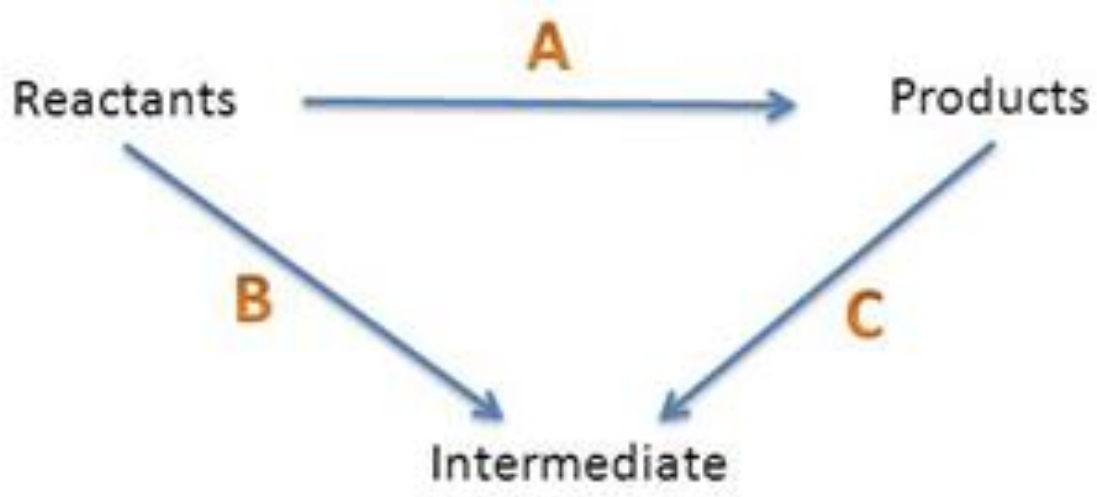




We can use Hess's law to calculate enthalpy changes that cannot be found by experiments using calorimetry.

ENTHALPY CYCLES

- The enthalpy change of a reaction cannot always be directly measured.
- We can use enthalpy cycles to help us to indirectly calculate the enthalpy change
- An enthalpy cycle is a pictorial representation showing the alternative routes of reaction between reactants and products.



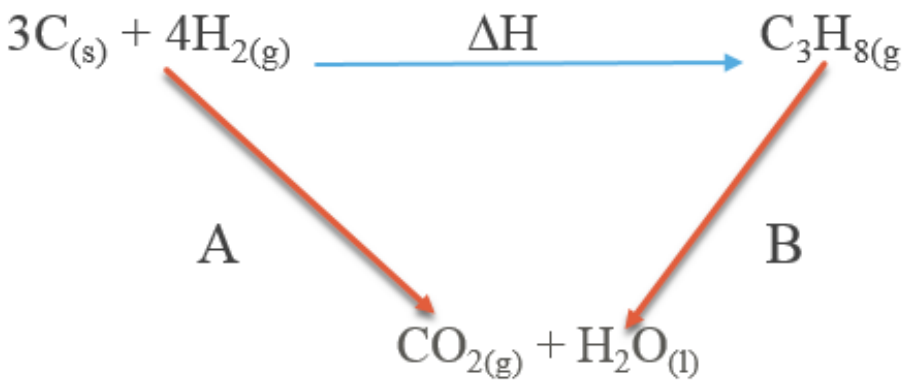
- Enthalpy cycles are triangular
  - In each corner there should be the same number of each atom
    - As well as energy, matter is also conserved
  - The sides of the triangle are arrows

ENTHALPY CYCLES EXAMPLE: COMBUSTION

- We can use the enthalpy changes of combustion to find the enthalpy change of the reaction.

$$3C_{(s)} + 4H_{2(g)} \longrightarrow C_3H_{8(g)}$$

- Carbon and Hydrogen can be combusted to form carbon dioxide and water
- Propane can be combusted to form carbon dioxide and water



	ΔH^0_c, (kJ*mol^{-})
$C_3H_{8(g)}$	-2220
$C_{(s)}$	-394
$H_{2(g)}$	-286

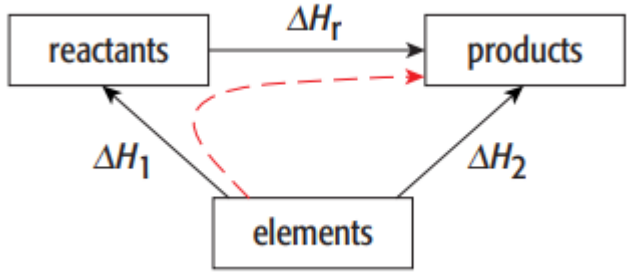
- ΔH + B = A

$$\Delta H = A\text{-}B$$

- Calculating A:
- Calculating B:
- ΔH = (A-B) =

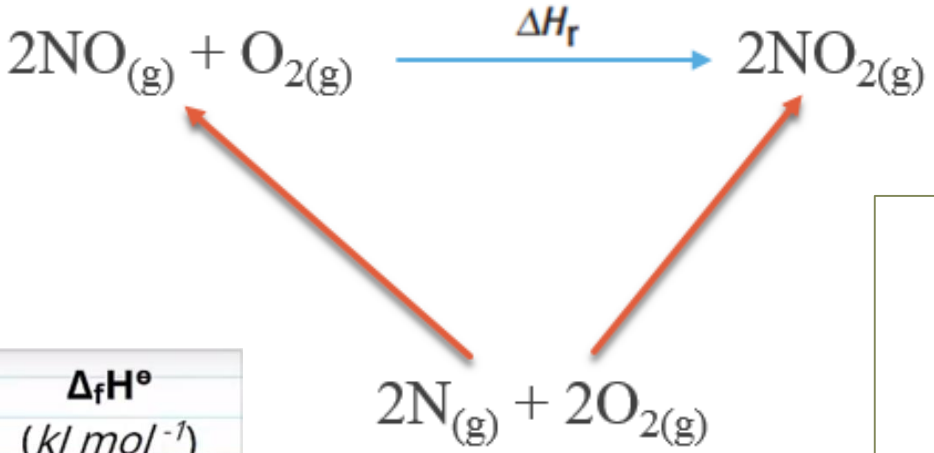
ENTHALPY CYCLES EXAMPLE: FORMATION

- We can use the enthalpy changes of formation to find the enthalpy change of the reaction.



E.g. $2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$

- Nitrogen monoxide and oxygen can be made from nitrogen and oxygen
- Nitrogen dioxide can be formed from nitrogen and oxygen



Substance	$\Delta_f H^\ominus$ ($kJ\ mol^{-1}$)
$NO_{(g)}$	+90
$NO_{2(g)}$	+33

- **Calculating A:**
- **Calculating B:**
- **ΔH = (B-A) =**

EXAM STYLE QUESTION

Q1. This question is about the extraction of metals.

(a) Manganese can be extracted from Mn_2O_3 by reduction with carbon monoxide at high temperature.

(i) Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

	$Mn_2O_3(s)$	$CO(g)$	$Mn(s)$	$CO_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−971	−111	0	−394

$$Mn_2O_3(s) + 3CO(g) \longrightarrow 2Mn(s) + 3CO_2(g)$$

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(3)

(ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

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(1)

EXAM STYLE QUESTION

Q7. (a) Define the term *standard molar enthalpy of formation*, $\Delta H_f^{\ominus}$.

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(3)

(b) State Hess's law.

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(1)

(c) Propanone, CH_3COCH_3, burns in oxygen as shown by the equation

$$CH_3COCH_3(l) + 4\,O_2(g) \rightarrow 3H_2O(l) + 3CO_2(g)$$

Use the data given below to calculate the standard enthalpy of combustion of propanone.

	$CO_2(g)$	$H_2O(l)$	$CH_3COCH_3(l)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–394	–286	–248

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(Total 7 marks)

SUMMARY

Q10. (a) What is the meaning of the term *enthalpy change*?

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(b) (i) Define the term *standard enthalpy of formation* of a compound.

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(ii) Write an equation, including state symbols, for the formation from its elements of solid sodium sulphate, Na_2SO_4.

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(5)

(c) State Hess's Law.

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(1)

(d) Some standard enthalpy changes are difficult to measure directly but can be determined from standard enthalpies of combustion.
Maleic acid, $C_4H_4O_4$, reacts with oxygen to form carbon dioxide and water as shown by the following equation.

$$C_4H_4O_4(s) + 3O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l)$$

Use the standard enthalpy of combustion data given below to calculate a value for the standard enthalpy change for the following reaction.

$$4C(s) + 2H_2(g) + 2O_2(g) \rightarrow C_4H_4O_4(s)$$

	$C_4H_4O_4(s)$	C(s)	$H_2(g)$
$\Delta H_c^\ominus$ / kJ mol^{-1}	–1356	–393.5	–285.8

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(3)

(Total 11 marks)

EXAM STYLE QUESTION

Q4. Use the information below to answer this question.

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H^{\ominus} = -394 \text{ kJ mol}^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H^{\ominus} = -286 \text{ kJ mol}^{-1}$$

$$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g) \qquad \Delta H^{\ominus} = -126 \text{ kJ mol}^{-1}$$

The standard enthalpy of combustion of butane, in kJ mol^{-1}, is

A −2880

B −2590

C −806

D −554

(Total 1 mark)