Higher Chemistry: Unit 2 – Chemical Changes and Structure

Revision of Calculations – Energy Calculations

Learning Outcomes

The lesson will help you revise the following topics

1. Enthalpy of Combustion
2. Hess's Law
3. Bond Enthalpy

Success Criteria

You will have been successful in this lesson if you:

1. Read the summary given (do not copy these notes – you already have notes for this)
2. Watch the links provided
3. Complete questions provided
4. EXTENSION: There is a further reading section to help you gain more depth of understanding for this section. There are also suggested questions for you to try from the blue book of revision questions.

If you have any questions about the content of this lesson, you should ask your class teacher either through your class MS team or via email. The teams will be monitored through the week and someone will get back to you as soon as they can.

Links to Prior Knowledge

You may wish to revise the following to help you understand this lesson:

Higher chemistry – Chemistry in Society – Chemical Energy

You may wish to have a copy of the data booklet handy for this lesson. Download or print a copy of the Higher Chemistry Data Booklet from MS Teams or the SQA website - https://www.sqa.org.uk/sqa/files_ccc/ChemistryDataBooklet_NewH_AH-Sep2016.pdf

You do not need to copy the notes below. You will have been given notes on these topics by your teacher. Have those notes to hand and use these worked examples to help refresh your memory of how to answer the calculations shown.

WATCH – Miss Adam's Chemistry YouTube channel

Miss Adam's Chemistry YouTube channel has videos explaining all of the parts of the chemistry higher course: For a recorded lesson on the following calculations, watch the videos below:

1. Enthalpy of Combustion - https://youtu.be/bh-TJVGPkdI
2. Hess's Law - https://youtu.be/y1odUs75JXc
3. Bond Enthalpy - https://youtu.be/gZsbdVRbacw

Chemical Energy Calculations

For each of the following topics you should:

1. Read through your notes on the topic and the worked examples given by your teacher
2. Follow through the worked examples
3. Try the rest of the questions and check your answers

1. Enthalpy of Combustion

WORKED EXAMPLE:

Calculating Energy Change Using Enthalpy Values from data booklet

Calculate the energy released when 4 g of methanol (CH_3OH) is burned.

Enthalpy of Combustion = -726kJmol^{-1}

1 mole → 726 kJ

32g → 726 kJ

1g → $\frac{726}{32}$

4 g → $\frac{726}{32}$ x 4 = 90.75kJ

Finding the enthalpy of combustion through experimentation

100 cm^3 of water was heated by 25 ^oC by burning 0.35 g of propanol. Calculate the enthalpy of combustion of propanol.

Step 1: Calculate energy released in the experiment:

$E_h = c \times m \times \Delta T$ $100cm^3 = 100g = 0.1kg$

$= 4.18 \times 0.2 \times 25$

$= 10.45$ kJ

10.45 kJ of energy released by **0.35g of propanol**

Enthalpy of Combustion is energy change for **1 mole (60g)**

Step2: energy released for 1 mole (Scale up to 1 mole)

0.35g $\rightarrow$ 10.45 kJ

1g $\rightarrow$ $\frac{10.45}{0.35}$

60 g $\rightarrow$ $\frac{10.45}{0.35} \times 60 = -1791$ kJ mol^{-1}

Now try the practice questions below.

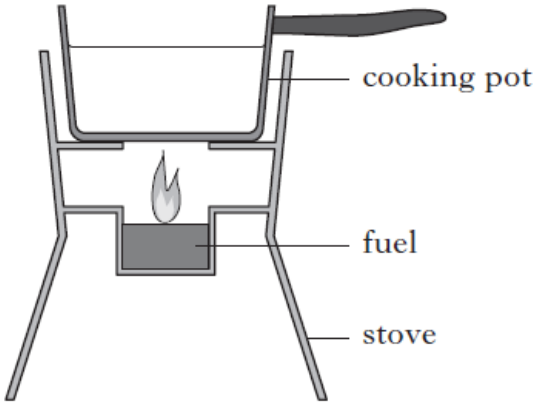
Enthalpy of Combustion

1. Calculate the energy released (E_h) when 0.25 moles of benzene is burned. (You will have to use the enthalpy of combustion of benzene in the data booklet).

2. Calculate the energy released (E_h) when 7.13g of methane is burned. (You will have to use the enthalpy of combustion of methane in the data booklet).

3. 0.19g of methanol was burned and heated 100cm^3 of water by 17^oC. Calculate the enthalpy of combustion of methanol.

4. Ethanol C_2H_5OH, can be used as a fuel in some camping stoves.



The enthalpy of combustion of ethanol is – 1367 kJ mol^{-1}.

Using this value, calculate the mass of ethanol required to raise the temperature of 500 g of water from 18^0C to 100^0C.

5. Flameless heaters are used by mountain climbers to heat food and drinks. The chemical reaction in a flameless heater releases 45 kJ of energy.

If 200 g of water is heated using this heater, calculate the rise in temperature of the water, in °C.

6. Calculate the temperature increase if 3.75 litres of water was heated by burning 0.25 moles of butane?

2. Hess's Law

WORKED EXAMPLE:

In industry butan-2-ol is produced by the hydration of but-2-ene.

$C_4H_8(g) + H_2O(g) \rightarrow C_4H_{10}O(g)$ **TARGET EQUATION (ΔHT)**

but-2-ene butan-2-ol

The enthalpy values for the following reactions are:

$4C(s) + 4H_2(g) \rightarrow C_4H_8(g)$	$\Delta H = -7{\cdot}1$ kJ mol^{-1}	**ΔH1**
$4C(s) + 5H_2(g) + O_2(g) \rightarrow C_4H_{10}O(g)$	$\Delta H = -292{\cdot}8$ kJ mol^{-1}	**ΔH2**
$H_2(g) + O_2(g) \rightarrow H_2O(g)$	$\Delta H = -241{\cdot}8$ kJ mol^{-1}	**ΔH3**

Using the data above, calculate the enthalpy change, in kJ mol^{-1}, for the production of butan-2-ol by hydration of but-2-ene.

STEP 1 - For each reaction you must decide whether to reverse, multiply or keep the same so that they can combine to form the target equation, ΔHT.

It helps to name the reactions…. ΔH1, ΔH2 (see above)

$4C(s) + 4H_2(g) \rightarrow C_4H_8(g)$	**ΔH1 - Reverse (C_4H_8 on left in ΔHT)**
$4C(s) + 5H_2(g) + O_2(g) \rightarrow C_4H_{10}O(g)$	**ΔH2 - Keep the same ($C_4H_{10}O$ on right in ΔHT)**
$H_2(g) + O_2(g) \rightarrow H_2O(g)$	**ΔH3 - Reverse (H_2O on left in ΔHT)**

STEP 2 - Add the enthalpies together with multiples and subtractions as decided

ΔHT = Reserve ΔH1 + ΔH2 + Reverse ΔH3

= (+7.1) + (-292.8) + (+241.8)

= 7.1 – 292.8 + 241.8 **= -43.9 kJ mol^{-1}**

Now try the practice questions below.

Hess' Law Practice Calculations

1. Below is the equation for the of formation of carbon monoxide

   $C_{(s)} + \frac{1}{2}O_{2\,(g)} \rightarrow CO_{(g)}$

   Calculate the enthalpy of formation of carbon monoxide using the following information:

   $C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)}$ $\Delta H = -394\ kJmol^{-1}$

   $CO_{(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow CO_{2\,(g)}$ $\Delta H = -284\ kJmol^{-1}$

2. Calculate the enthalpy change for the following reaction

   $C_{(s)} + 2H_{2\,(g)} \rightarrow CH_{4(g)}$

   Using the following information:

   $C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)}$ $\Delta H = -394\ kJmol^{-1}$

   $H_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow H_2O_{(l)}$ $\Delta H = -286\ kJmol^{-1}$

   $CH_{4(g)} + 2\,O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\,H_2O_{(l)}$ $\Delta H = -891\ kJmol^{-1}$

3. The reaction for the enthalpy of formation of propan-1-ol is

   $3C_{(s)} + 4\,H_{2\,(g)} + \frac{1}{2}\,O_{2\,(g)} \rightarrow C_3H_7OH_{(l)}$

   Calculate the enthalpy of the above reaction using the enthalpies of combustion of carbon, hydrogen and propan-1-ol:

   $C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)}$ $\Delta H = -394\ kJmol^{-1}$

   $H_{2\,(g)} + \frac{1}{2}\,O_{2\,(g)} \rightarrow H_2O_{(l)}$ $\Delta H = -286\ kJmol^{-1}$

   $C_3H_7OH_{(g)} + 4\frac{1}{2}O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + 4\,H_2O_{(l)}$ $\Delta H = -2020\ kJmol^{-1}$

4. $C_6H_4(OH)_{2\,(aq)} + H_2O_{2\,(aq)} \rightarrow C_6H_4O_{2\,(aq)} + 2H_2O_{(l)}$

Use the following data to calculate the enthalpy change, in kJ mol^{-1}, for the above reaction.

$C_6H_4(OH)_{2(aq)}$	$\rightarrow$ $C_6H_4O_{2\,(aq)}$ +	$H_{2\,(g)}$	ΔH_1 = +177.4 kJ mol
$H_{2(g)} + O_{2(g)}$	$\rightarrow$ $H_2O_{2\,(aq)}$		ΔH_2 = - 191.2 kJ mol^{-1}
$H_{2\,(g)} + \frac{1}{2}O_{2\,(g)}$	$\rightarrow$ $H_2O_{\,(g)}$		ΔH_3 = - 241.8 kJ mol^{-1}
$H_2O_{\,(g)}$	$\rightarrow$ $H_2O_{\,(l)}$		ΔH_4 = - 43.8 kJ mol^{-1}

5. $C(s) + H_2(g) + O_2(g) \rightarrow HCOOH(\ell)$ $\Delta H = a$

$HCOOH(\ell) + \frac{1}{2}O_2(g) \rightarrow CO_2(g) + H_2O(\ell)$ $\Delta H = b$

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = c$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta H = d$

What is the relationship between a, b, c and d?

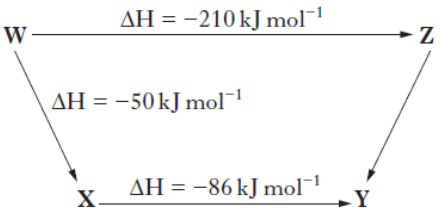
A $a = c + d - b$

B $a = b - c - d$

C $a = -b - c - d$

D $a = c + b + d$

6. Consider the reaction pathway shown below.



According to Hess's Law, the ΔH value, kJ mol^{-1}, for reaction **Z** to **Y** is

A +74

B −74

C +346

D −346.

7.

$C(graphite) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -394\,kJ\,mol^{-1}$

$C(diamond) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -395\,kJ\,mol^{-1}$

What is the enthalpy change, in $kJ\,mol^{-1}$, for the conversion of one mole of graphite into one mole of diamond?

A −789

B −1

C +1

D +789

8.

$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(\ell) \quad \Delta H_1$

$CH_3CHO(\ell) + 2½O_2(g) \rightarrow 2CO_2(g) + 2H_2O(\ell) \quad \Delta H_2$

$2O_3(g) \rightarrow 3O_2(g) \quad \Delta H_3$

The enthalpy change equal to $\Delta H_1 - \Delta H_2 + ½\Delta H_3$ is associated with the reaction

A $C_2H_4(g) + ½O_2(g) \rightarrow CH_3CHO(\ell)$

B $C_2H_4(g) + O_3(g) \rightarrow CH_3CHO(\ell) + O_2(g)$

C $C_2H_4(g) + 2O_3(g) \rightarrow CH_3CHO(\ell) + 2½O_2(g)$

D $C_2H_4(g) + 2½O_2(g) + CH_3CHO(\ell) + O_3(g) \rightarrow 4CO_2(g) + 4H_2O(\ell)$

5. Bond Enthalpy

WORKED EXAMPLE:

Use bond enthalpies from the Data Booklet to calculate the enthalpy change, in kJ, for the reaction.

Step 1 – Make a table with two columns BOND BREAKING and BOND FORMING

BOND BREAKING (ALWAYS POSITIVE)	BOND FORMING (ALWAYS NEGATIVE)
3 x C-Cl: 3 x 338 = 1014 1 x C-H: 1 x 412 = 412 2 x H-F: 2 x 570 = 1140 **(ENERGY IN) TOTAL = 2566**	1 x C-Cl: 1 x -338 = -338 1 x C-H: 1 x -412 = -412 2 x C-F: 2 x -484 = -968 2 x H-Cl: 2 x -432 = -864 **(ENERGY OUT) TOTAL = - 2582**

Step 2 – Add the totals together – NOTE: bond forming is ALWAYS NEGATIVE

ΔH = bond breaking + bond forming

ΔH = 2566 + (-2582) = **- 16 kJ**

Now try the practice questions below.

Bond Enthalpy Practice Calculations

1. Calculate the enthalpy change for the following reaction using bond enthalpies:

   $H_2\,(g) + Cl_2\,(g) \rightarrow 2HCl\,(g)$

2. The following reaction occurs in the Haber Process:

   $N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)}$

   Using bond enthalpies from the data booklet, calculate the enthalpy change in kJ mol^{-1}, for this reaction.

3. Chloromethane can be produced by the reaction of methane with chlorine

   $CH_4\,(g) + Cl_2\,(g) \rightarrow CH_3Cl(g) + HCl\,(g)$

   Using bond enthalpies from the data booklet, calculate the enthalpy change in kJ mol^{-1}, for this reaction.

4. $C_2H_4\,(g) + H_2O(g) \rightleftharpoons C_2H_3OH(g)$

   Using bond enthalpies from the data booklet, calculate the enthalpy change in kJ mol^{-1}, for this reaction.

5. In the presence of bright light, hydrogen and chlorine react explosively. One step in the reaction is shown below:

   $H_2\,(g) + Cl\,(g) \rightarrow 2HCl\,(g) + H\,(g)$

   The enthalpy change for this step can be represented as

   A (H-H bond enthalpy) + (Cl-Cl bond enthalpy)
   B (H-H bond enthalpy) − (Cl-Cl bond enthalpy)
   C (H-H bond enthalpy) + (H-Cl bond enthalpy)
   D (H-H bond enthalpy) − (H-Cl bond enthalpy).

Answers to the exercises above can be found at the end of this document

Learning Outcomes

You should have now revised:

1. Enthalpy of Combustion
2. Hess's Law
3. Bond Enthalpy

Further Reading

To learn more about this topic, try the following online resources:

BBC Bitesize: https://www.bbc.co.uk/bitesize/guides/z8p72hv/revision/1

Read prevision pages (optional) and **TRY THE END TOPIC TEST**

Scholar: Log in through GLOW

Higher Chemistry → Chemistry in Society → Topic 6: Chemical energy

Read through the exercises and **TRY THE END TOPIC TEST**

Evans2 chem web: https://www.evans2chemweb.co.uk/login/index.php#

Username: snhs password: giffnock

Select any teacher → revision material → CfE Higher → Unit 3: Chemistry in Society → Chemical Energy

EXTENSION WORK

Use the online learning link above if you would like to extend your knowledge on this topic. For more practise questions, use your Revision Questions for Higher Chemistry "Blue book":

Enthalpy of combustion	page 96
Hess's Law	page 98
Bond enthalpy	page 102

Check your answers to the exercises above

Enthalpy of Combustion - ANSWERS

1. 907 kJ mol^{-1}
2. 397 kJ mol^{-1}
3. Eh = 7.11kJ, Enthalpy of Combustion = -1197 kJ mol^{-1}
4. Eh = 171 kJ, m = 5.8 g
5. 54 °C
6. Eh = 719 kJ, ΔT = 46 °C

Hess's Law - ANSWERS

1. -110 $kJmol^{-1}$
2. -75 $kJmol^{-1}$
3. -306 $kJmol^{-1}$
6. - 202 $kJmol^{-1}$
7. A
8. A
9. C
10. B

Bond Enthalpy - ANSWERS

1. -185 kJ
2. -75 kJ
3. -115 kJ
4. -45 kJ mol^{-1}
5. D