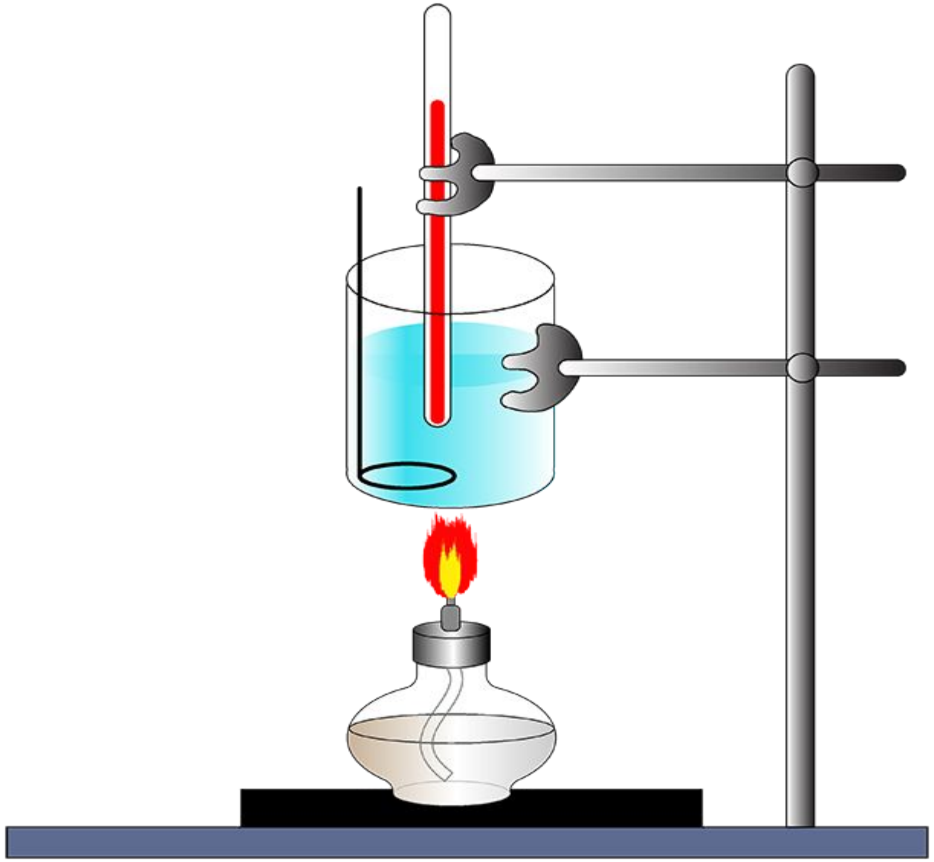
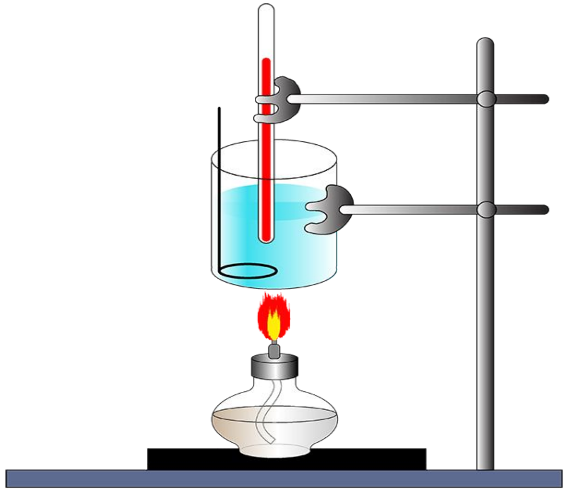
Determining an Enthalpy Change



Material Covered

Each exam board has a core practical related to enthalpy changes:

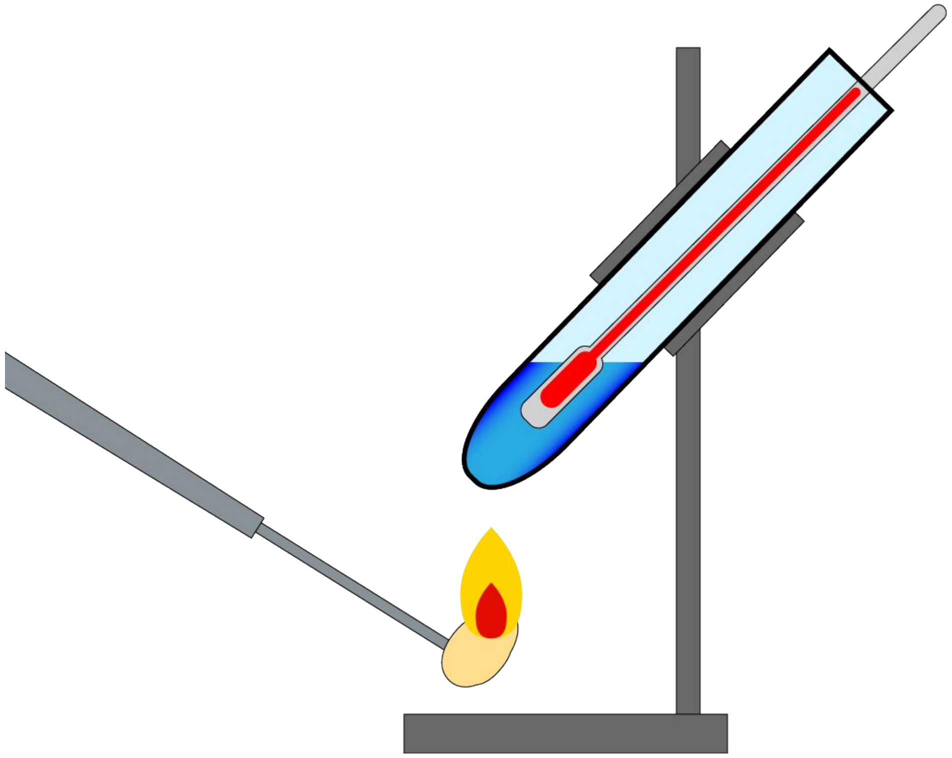
- **Edexcel** – to determine the enthalpy change of a reaction using Hess' law
- **AQA** – Measurement of an enthalpy change
- **OCR** – Enthalpy determination



Note that Edexcel is slightly different as it is more focused on Hess' law

From the specification:
"In order to develop their **practical skills**, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include a wide variety of **calorimetry experiments** involving **displacement** and **neutralisation** reactions, investigating the **enthalpy of combustion** of a homologous series of alcohols."

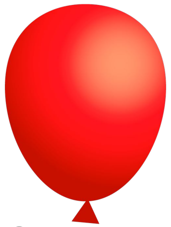
Enthalpy Changes



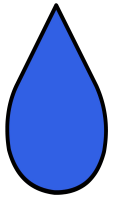
Standard Enthalpies

When measuring an **enthalpy change**, we use **standard conditions** to make our results **comparable** to other results and also **data book values**

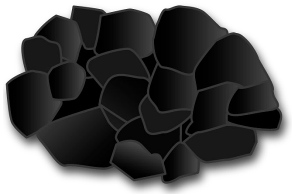
The **standard conditions** are:
Pressure:
Temperature:



Oxygen



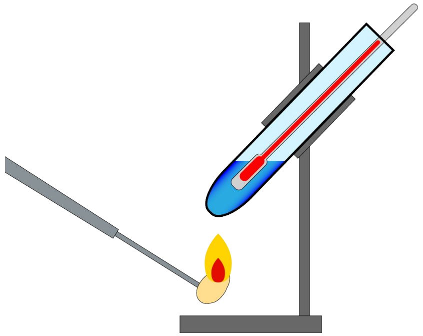
Water



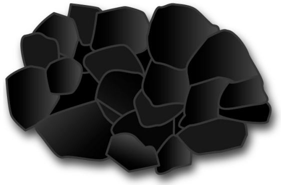
Carbon

Generally, we identify **standard molar enthalpy changes** for **reactions**

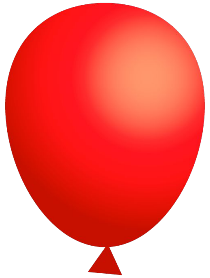
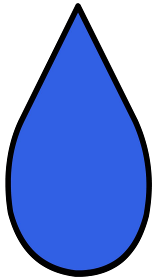
"**Standard**" means using **standard conditions** and with **reactants** and **products** in their **standard states** (the state an element/compound is in under standard conditions)

All the following **definitions** are defined **under standard conditions** (**ϴ**), with all **reactants** and **products** in their **standard states**:



Standard enthalpy change is the measure of **heat change** at **constant pressure**

Standard molar enthalpy of combustion is the **enthalpy change** when **one mole** of a substance is **completely burnt** in **oxygen**

Standard molar enthalpy of formation is the **enthalpy change** when **one mole** of a substance is **formed** from its **constituent elements** in their **standard states**

Exemplar Exam Question – Statement

1) Define standard molar enthalpy of formation, $\Delta_f H^{\ominus}$. **[1 mark]**

Command: simple recall of definition

Context: enthalpy of formation

Direction: state definition - use standard wording

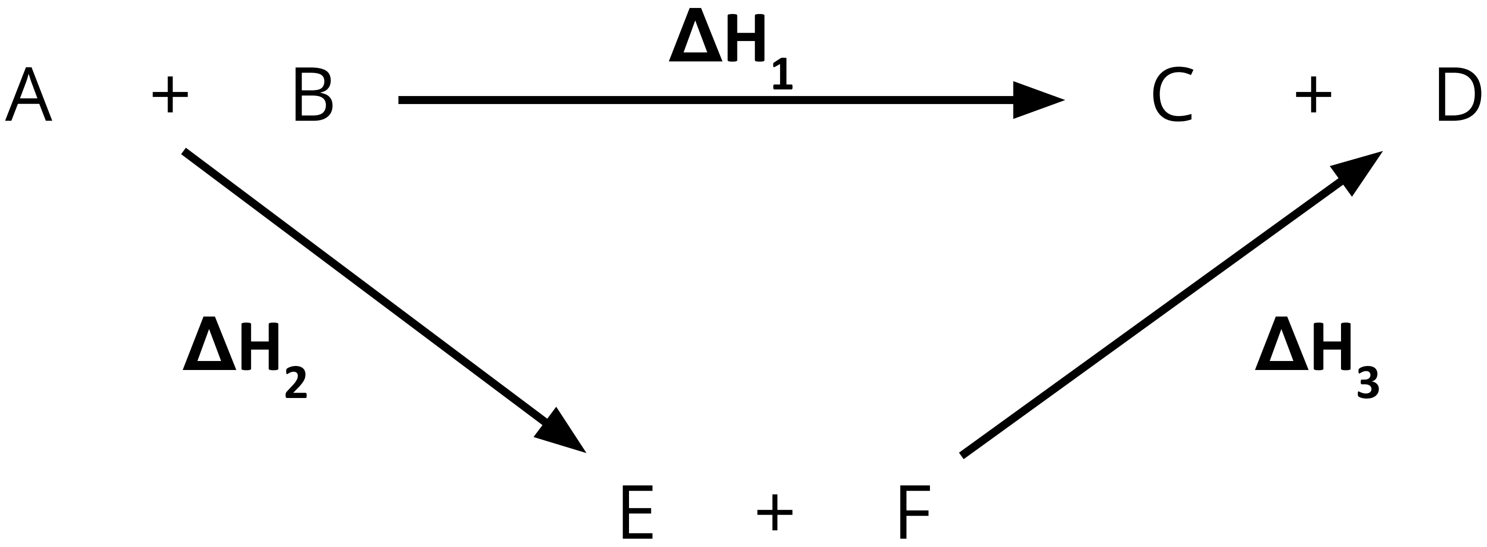
Exemplar Exam Question – Statement

1) Define standard molar enthalpy of formation, $\Delta_f H^{\ominus}$. **[1 mark]**

The enthalpy change when one mole of a substance is formed from
its constituent elements under standard conditions, with all
reactants and products in their standard states.

Hess' Law

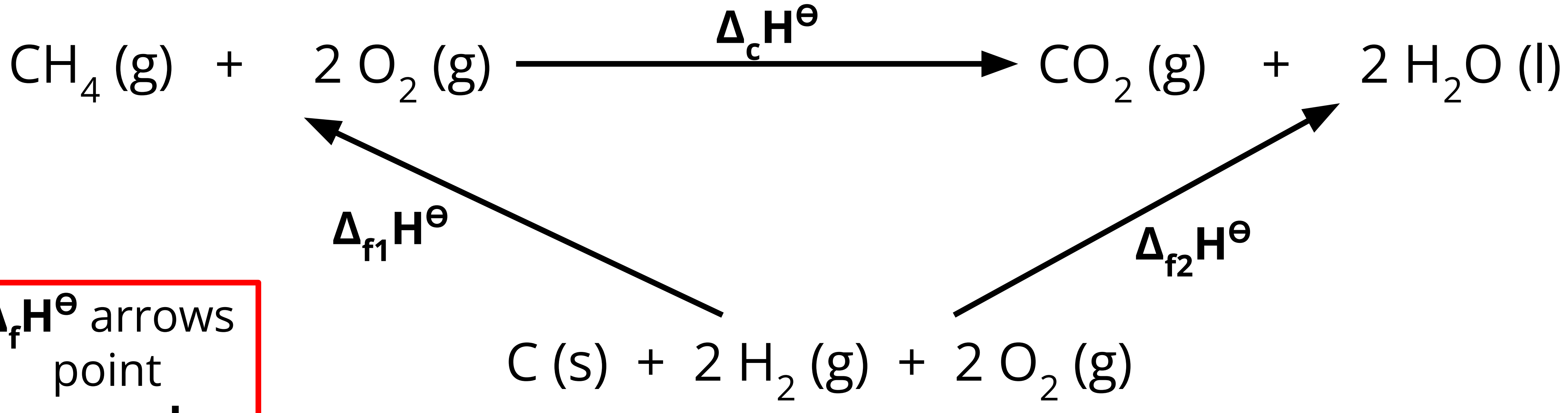
Hess' law states the **enthalpy change** for a chemical reaction is the **same**, **whatever route** is taken from reactants to products



Hess' Law - $\Delta_c H^\ominus$

A **Hess cycle** can be used to calculate **enthalpy changes of combustion $\Delta_c H^\ominus$ OR enthalpy changes of reaction**, **$\Delta_r H^\ominus$** using **$\Delta_f H^\ominus$** values

For example, for the **combustion of methane**:

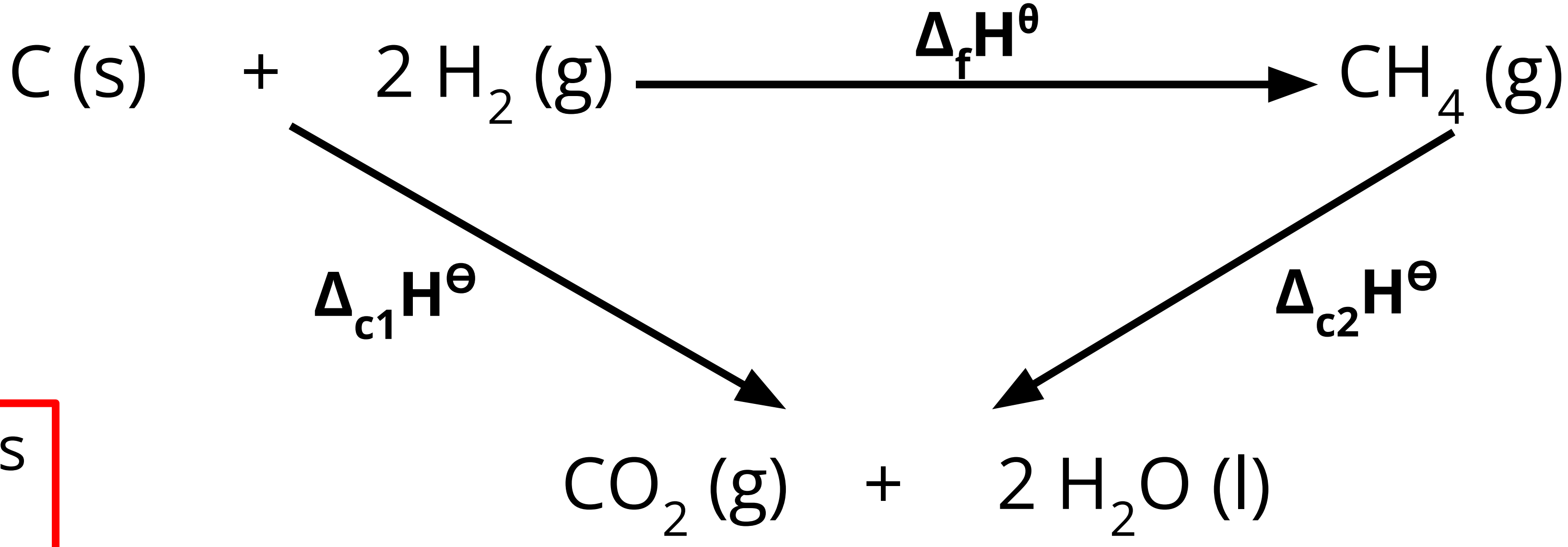


$\Delta_f H^\ominus$ arrows point **upwards**

Hess' Law - $\Delta_f H^\ominus$

A **Hess cycle** can also be used to calculate **enthalpy changes of formation**, $\mathbf{\Delta_f H^\ominus}$ using $\mathbf{\Delta_c H^\ominus}$ values

For example, for the **formation of methane**:



$\mathbf{\Delta_c H^\ominus}$ arrows point **downwards**

Exemplar Exam Question – Calculation

2) Ethanol is burned in a plentiful supply of oxygen.

$$C_2H_5OH\ (l) + 3\ O_2\ (g) \square\ 2\ CO_2\ (g) + 3\ H_2O\ (l)$$

We can draw Hess cycles to calculate the standard enthalpy change of combustion of ethanol using standard enthalpy changes of formation.

a) Draw the Hess cycle for this reaction. **[2 marks]**

Command: quick sketch of a Hess cycle

Direction: use correct states and arrows with labels in diagram

Context: $\Delta_c H^\ominus$ Hess cycles

Exemplar Exam Question – Calculation

2) Ethanol is burned in a plentiful supply of oxygen.

$$C_2H_5OH\ (l) + 3\ O_2\ (g) \rightarrow 2\ CO_2\ (g) + 3\ H_2O\ (l)$$

b) Using the data provided, calculate the enthalpy change of combustion of ethanol. **[2 marks]**

Context: calculations using $\Delta_c H^{\ominus}$ Hess cycles

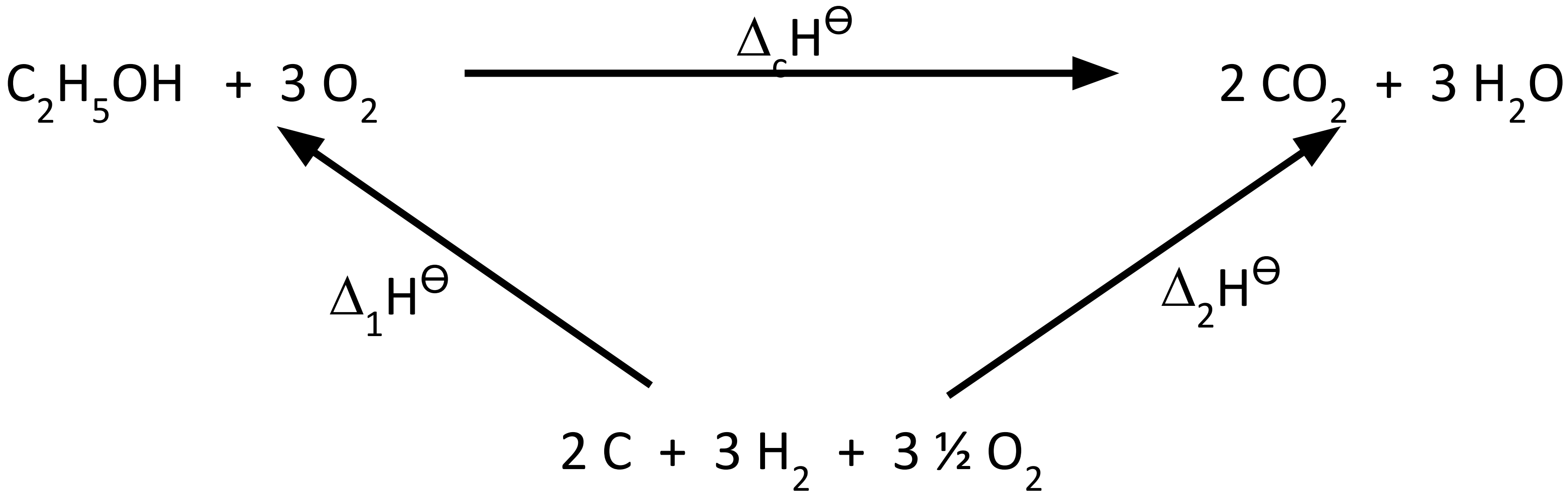
Command: show your full working

Direction: use the values in the table and correct signs in calculation

Molecule	$\Delta_f H^{\ominus}$ / kJ mol^{-1}
CO_2	-393.5
H_2O	-285.8
C_2H_5OH	-277.7

Exemplar Exam Question – Calculation

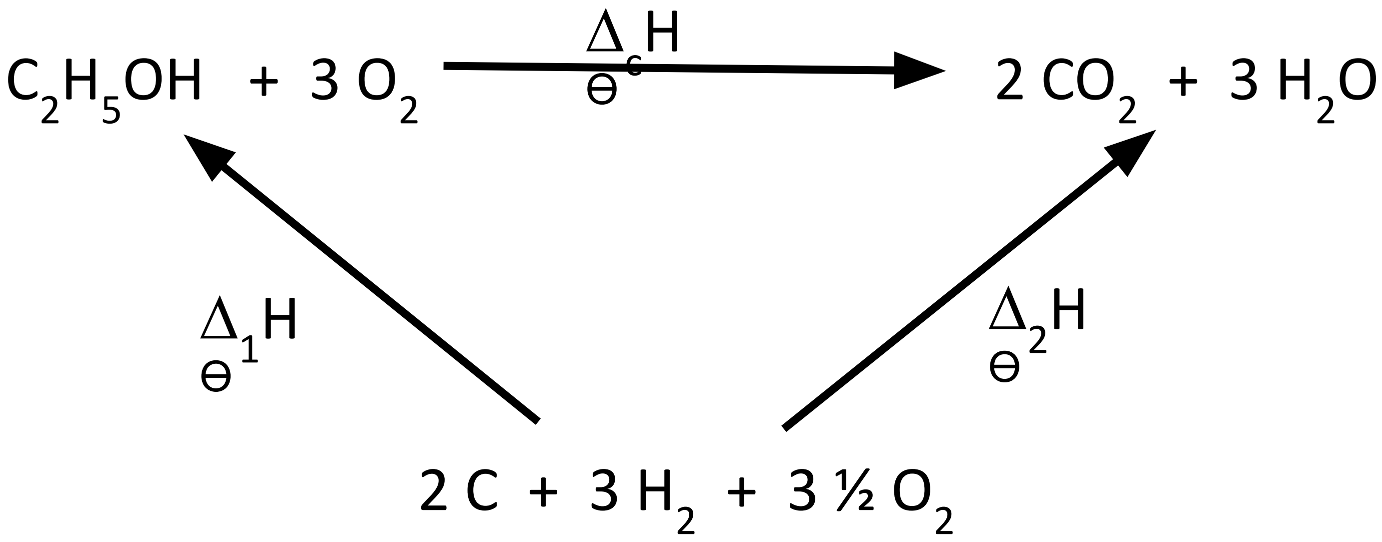
2) a) Draw the Hess cycle for this reaction. **[2 marks]**



Exemplar Exam Question – Calculation

2) b) Using the data provided, calculate the enthalpy change of combustion of ethanol. **[2 marks]**

Molecule	$\Delta_f H^\ominus$ / kJ mol^{-1}
CO_2	-393.5
H_2O	-285.8
C_2H_5OH	-277.7



$\Delta_c H^\ominus = -\Delta_1 H^\ominus + \Delta_2 H^\ominus$

$= -(-277.7) + [(2 \times -393.5) + (3 \times -285.8)]$

$= -1366.7$ kJ mol^{-1}

Exemplar Exam Question – Calculation

3) Respiration takes place in the mitochondria.

$$6O_2\ (g) + C_6H_{12}O_6\ (aq) \square\ 6CO_2\ (g) + 6H_2O\ (l)$$

We can draw Hess cycles to calculate the standard enthalpy change of reaction for respiration using standard enthalpy changes of combustion.

a) Draw the Hess cycle for this reaction. **[2 marks]**

Command: quick sketch of a Hess cycle

Direction: use correct states and arrows with labels in diagram

Context: $\Delta_c H^\ominus$ Hess cycles

Exemplar Exam Question – Calculation

3) Respiration takes place in the mitochondria.

$$6O_2\ (g) + C_6H_{12}O_6\ (aq)\square\ 6CO_2\ (g) + 6H_2O\ (l)$$

b) Using the data provided, calculate the enthalpy change of reaction for respiration. **[2 marks]**

Context: calculations using $\Delta_r H^\ominus$ Hess cycles

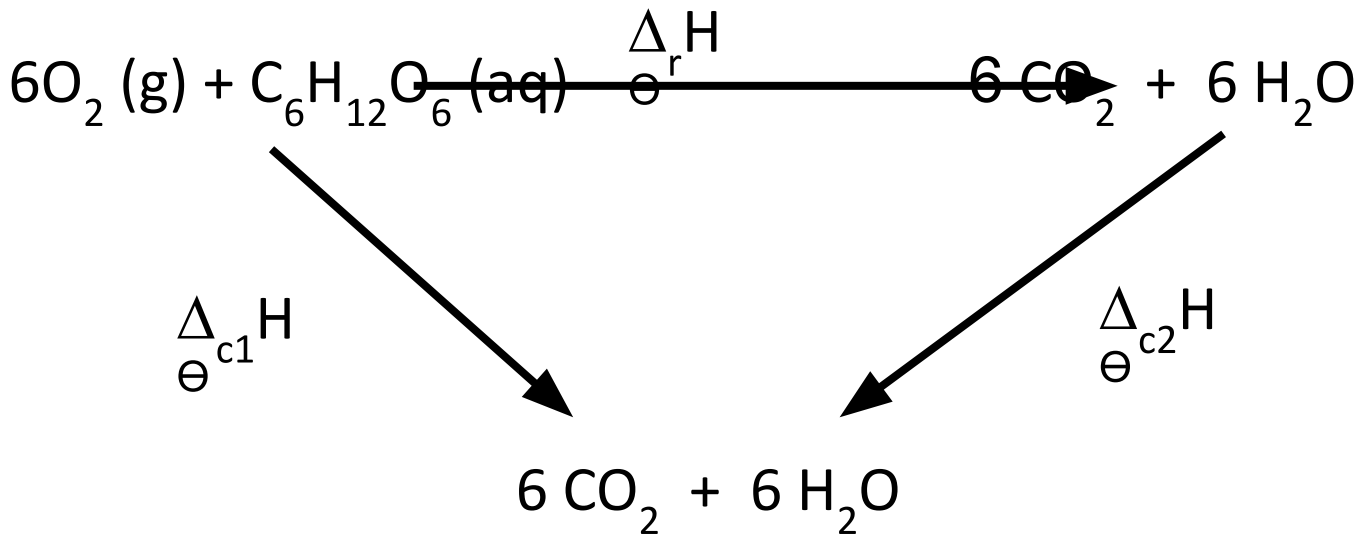
Command: show your full working

Molecule	$\Delta_c H^\ominus$ / kJ mol^{-1}
$C_6H_{12}O_6$	-2803

Direction: use the values in the table and correct signs in calculation

Exemplar Exam Question – Calculation

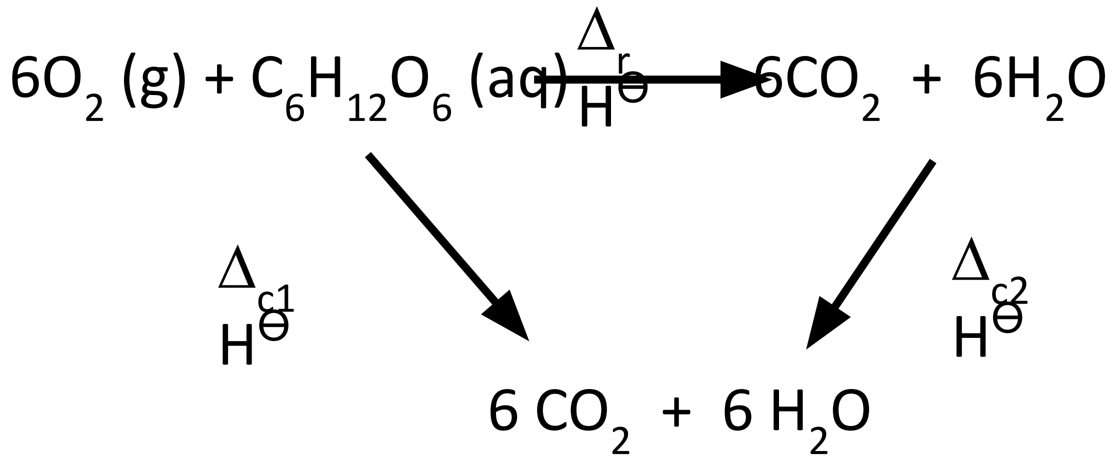
3) a) Draw the Hess cycle for this reaction. **[2 marks]**



Exemplar Exam Question – Calculation

3) b) Using the data provided, calculate the enthalpy change of combustion of ethanol. **[2 marks]**

Molecule	$\Delta_c H^\ominus$ / kJ mol^{-1}
$C_6H_{12}O_6$	-2803



$\Delta_r H^\ominus = +\Delta_{c1} H^\ominus - \Delta_{c2} H^\ominus$

$= -2803$ kJ mol^{-1}

Measuring Enthalpy Changes

The **standard enthalpy change of combustion, $\Delta_c H^\ominus$**, is the **enthalpy change** when **one mole** of a compound is **completely burnt in oxygen gas under standard conditions**

Combustion can be **complete** or **incomplete**:

- **<u>Complete</u> combustion** – occurs in a **plentiful** supply of **O_2**, producing only
- **<u>Incomplete</u> combustion** – occurs when there's a **limited supply** of **O_2**, producing **H_2O** but also can produce a mixture of

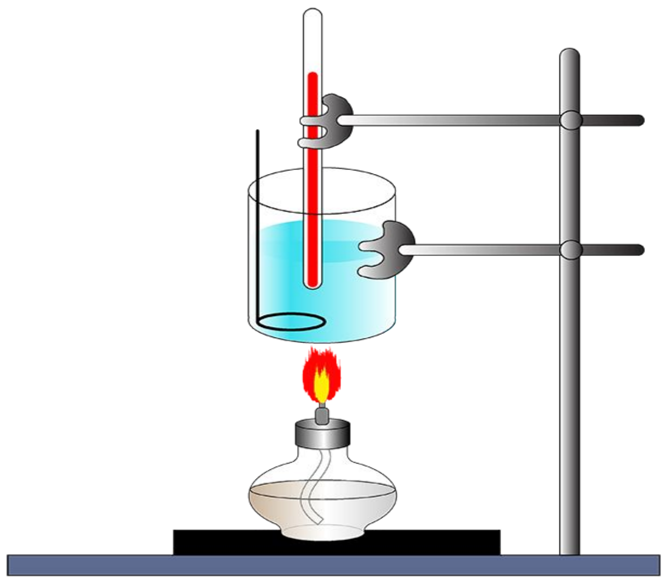
Carbon particulates cause a **dirty flame** and **CO** is a

A **plentiful supply** of **pure O_2** can be used to **ensure complete combustion**

Combustion Calorimetry

We can measure the approx. **enthalpy change** of **combustion** using a **calorimeter**

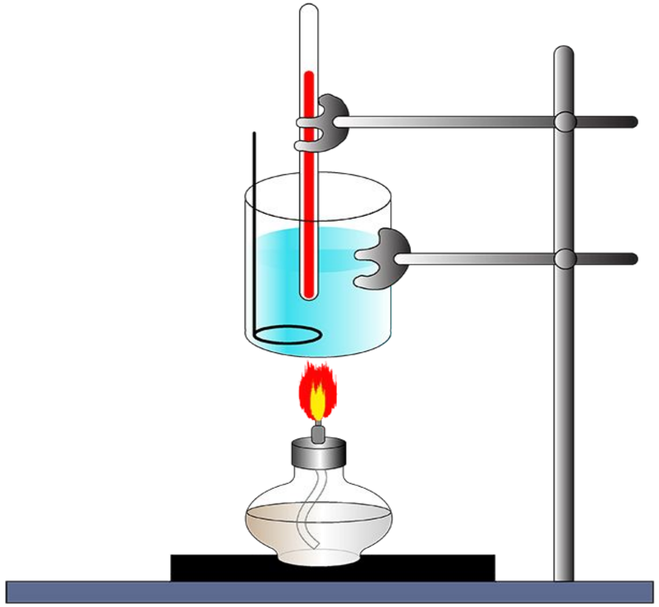
1. **Measure** an amount of **water** into a **calorimeter/beaker**
2. **Weigh** a **spirit burner** containing the **fuel**
3. **Measure** the **initial temperature** of the water
4. **Burn** the spirit burner to **heat** the **water**
5. After there has been a **reasonable temperature rise**, **stop heating** and **record** the **temperature** again
6. **Reweigh** the **spirit burner**
7. Use **$q = mc\Delta T$**



Ideally, the calorimeter should be **isolated** from the surroundings, so that **only** the **water absorbs** the **heat** given out by the fuel

Combustion Calorimetry

Experimental values for the enthalpy of combustion are usually **less exothermic** than the values found in **data books** (which are for ideal conditions), due to:



- **Heat loss** to surroundings from **spirit burner**, **wick**, **calorimeter**
- **Fuel loss** from **wick** and **burner** from
- **Water loss** by
- **Incomplete combustion** leaving **soot** on the **bottom** of **calorimeter**
- **Heat** used to **raise temperature** of **calorimeter itself**
- Reaction **not** occurring under

Neutralisation

Not required for AQA

The **standard enthalpy of neutralisation, $\Delta_{neut}H^{\ominus}$**, is the **enthalpy change** when an **acid** and **alkali react** to produce **1 mole** of **water under standard conditions**

When an **acid** and **alkali react** together in a **neutralisation** reaction, the general equation occurs:

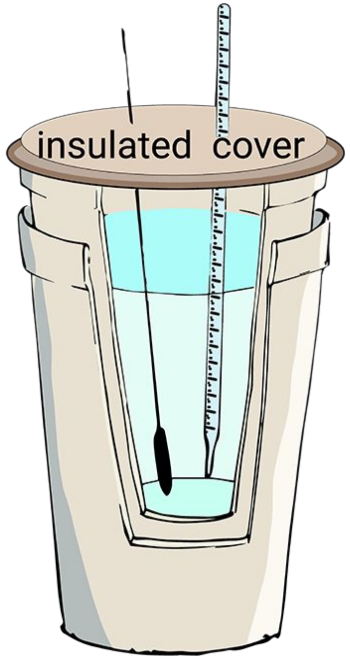
To find an **enthalpy change of neutralisation** for a reaction, we use the **quantities** in **moles** given by the **balanced equation** – neutralisation reactions in solution are

Neutralisation - Calorimetry

Not required for AQA

For a **neutralisation reaction**, the **enthalpy change** should be measured in a **different** way:

1. Place a **polystyrene cup** with a **thermometer** in a **glass beaker** to provide **support**
2. **Rinse** a **measuring cylinder** with the **acid**, **measure 25 cm^3** of the **acid**, and **transfer** to **cup**
3. **Stir** and **record** the **temperature**
4. **Rinse** another **measuring cylinder** with the **alkali**, **measure 25 cm^3** of the **alkali**
5. **Add** the **alkali** to the **acid**, **stir**, and **record** the **highest temperature** reached
6. Use **$q = mc\Delta T$**



A **polystyrene cup** is used because it **conducts less heat** than metals so **less heat** is **loss to surroundings**, it has a **lower specific heat capacity**, and it is **inert**

Exemplar Exam Question – Long Answer

4) Experimental values of combustion enthalpy change often differ to data book values. Explain why this might be the case and how a simple calorimetry experiment could be improved to give more accurate values. **[5 marks]**

Context: experimental vs data book standard enthalpy changes

Direction: what causes reduces accuracy is results for experimental values, how can we improve this

Command: more detailed response, why do we see these discrepancies, how can we reduce these

Exemplar Exam Question – Long Answer

4) Experimental values of combustion enthalpy changes often differ to data book values. Explain why this might be the case and how a simple calorimetry experiment could be improved to give more accurate values.
[5 marks]

Data book standard enthalpy change values are often higher than experimental values because the experiments aren't conducted under ideal conditions. Experimental values are easily affected by the following factors: heat loss to surroundings from spirit burner, wick, calorimeter; fuel loss by evaporation from wick, burner; water loss by evaporation.

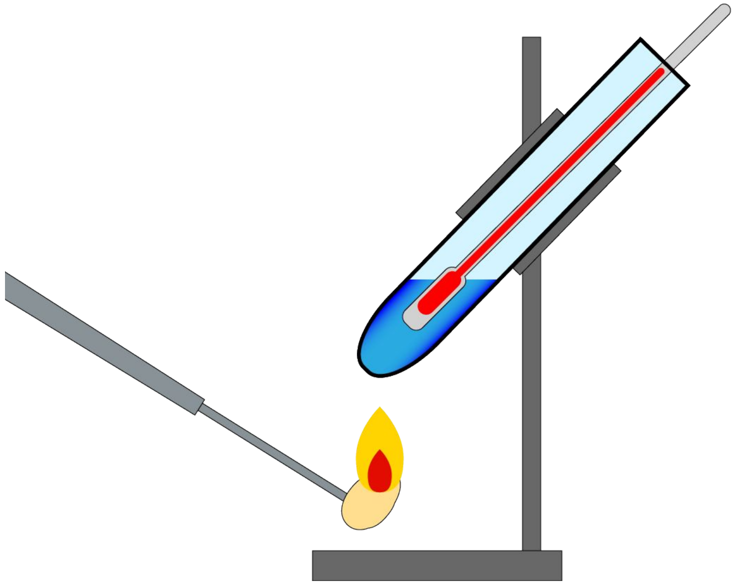
Exemplar Exam Question – Long Answer

These factors can be reduced by using a draught shield and lid to reduce heat loss to surroundings; minimise distance between flame and calorimeter; insulate the calorimeter and burner to reduce heat loss.

Heat Energy Transferred (q)

Temperature is related to the **average kinetic energy** of the **particles** in a system –

Heat is a measure of the **total energy** of all the **particles** in a system –



If **heat** is **absorbed** by a **liquid** (usually **water** or another **aqueous** solution), we can measure an associated **temperature change** and use this to determine the

Heat Energy Transferred (q)

The **heat energy transferred**, **q**, can be given as:

Where:
m = mass of substance being heated (g)
c = specific heat capacity of the substance (J g^{-1} K^{-1})
ΔT = change in temperature of the substance (in °C or K)

Specific heat capacity, **c**, is the **amount of heat energy** needed to **raise the temperature** of **1 g** of substance by **1 K**, with the units **J g^{-1} K^{-1}** – it is the **link** between **temperature** and **heat**

Exemplar Exam Question – Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^{0}C above its initial temperature.

a) The specific heat capacity of water is 4.18 J g^{-1} K^{-1}. Using the expression $q = mc\Delta T$, calculate the heat energy (q) absorbed by the sample of water used in this experiment. **[2 marks]**

Direction: use equations and any relevant data given

Context: $q = mc\Delta T$

Command: calculation showing full working

Exemplar Exam Question – Statement + Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^{0}C above its initial temperature.

b) Based on your answer to part a), write a balanced equation for the combustion of octane in these conditions. **[1 mark]**

Direction: know the products of each combustion type + balance your equation

Command: simple answer

Context: complete vs. incomplete combustion

Exemplar Exam Question – Statement + Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^0C above its initial temperature.

c) Assuming standard conditions, what is the standard molar enthalpy of combustion of octane? **[4 marks]**

Direction: use the relevant values given

Context: calculating $\Delta_c H^\ominus$

Command: calculation – show full working

Exemplar Exam Question – Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^{0}C above its initial temperature.

a) The specific heat capacity of water is 4.18 J g^{-1} K^{-1}. Using the expression $q = mc\Delta T$, calculate the heat energy (q) absorbed by the sample of water used in this experiment.

[2 marks]

m = mass of water = 0.500 L = 500 cm^3 = 500 g (water has a density of 1 g cm^{-3})

c = specific heat capacity of water = 4.18 J g^{-1} K^{-1}

ΔT = change in temperature of water = 24.9 ^{0}C

$q = mc\Delta T$

= (500 g) x (4.18 J g^{-1} K^{-1}) x (24.9 ^{0}C)

= <u>52,041 J</u>

Exemplar Exam Question – Statement + Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^{0}C above its initial temperature.

b) Based on your answer to part a), write a balanced equation for the combustion of octane in these conditions. **[1 mark]**

$$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$$

or

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

Exemplar Exam Question – Statement + Calculation

6) Octane is a fuel which is a liquid under standard conditions, where its density is 0.703 g cm^{-3}. In a calorimetry experiment, 2.00 cm^3 of octane in a spirit burner is burnt in pure oxygen. The spirit burner is below a beaker containing 0.500 L of water. The maximum temperature of the water during the experiment is 24.9 ^{0}C above its initial temperature.

c) Assuming standard conditions, what is the standard molar enthalpy of combustion of octane? **[4 marks]**

From part a), q = 52,041 J

Heat is given out from the system and into the surroundings so it is **negative**: 2cm^3 of octane burnt = -52.041 kJ

Exemplar Exam Question – Statement + Calculation

Mass of octane: mass = density x volume

$= (0.703 \text{ g cm}^{-3}) \times (2.00 \text{ cm}^3) = 1.406 \text{ g}$

Moles of octane: moles = mass / molar mass

$= 1.406 \text{ g} / [(8 \times 12) + (18 \times 1)] = (1.406 \text{ g}) / (114 \text{ g mol}^{-1})$

$= 0.0123 \text{ mol}$

Standard molar enthalpy of combustion of octane:

$\Delta_c H^\theta = (-52.041 \text{ kJ}) / (0.0123 \text{ mol})$

$= -4230.975\ldots = \underline{-4231 \text{ kJ mol}^{-1}}$

Mini Mock Paper

Mini Mock Paper

1) Enthalpy changes of formation, $\Delta_f H^\ominus$ of compounds are difficult to measure directly. However, we can use Hess' law to calculate a value for $\Delta_f H^\ominus$.

Use a Hess cycle to calculate the formation of ethanol, C_2H_5OH, using the data provided. **[4 marks]**

Molecule	ΔH^θ / kJ mol^{-1}
$\Delta_f H^\theta$ CO_2	-393.5
$\Delta_f H^\theta$ H_2O	-285.8
$\Delta_c H^\theta$ C_2H_5OH	-1366.7

Mini Mock Paper

2) An experiment is set up to determine the enthalpy change of combustion, $\Delta_c H^\ominus$, of butan-1-ol, C_4H_9OH.
Use the following data to calculate $\Delta_c H^\ominus$ in kJ mol^{-1}.

[5 marks]

Measurement	Reading
Mass of spirit burner + butan-1-ol before	65.20 g
Mass of spirit burner + butan-1-ol after	62.56 g
Initial temperature of water	20.4 ^{o}C
Final temperature of water	46.7 ^{o}C
Mass of water in calorimeter	100 g
Specific heat capacity of water	4.18 J g^{-1} K^{-1}

Mini Mock Paper

3) In an experiment to calculate the enthalpy of neutralisation between acids and alkalis a polystyrene cup is used instead of a metal container. Explain why this is the case. **[3 marks]**

Mini Mock Paper Answers

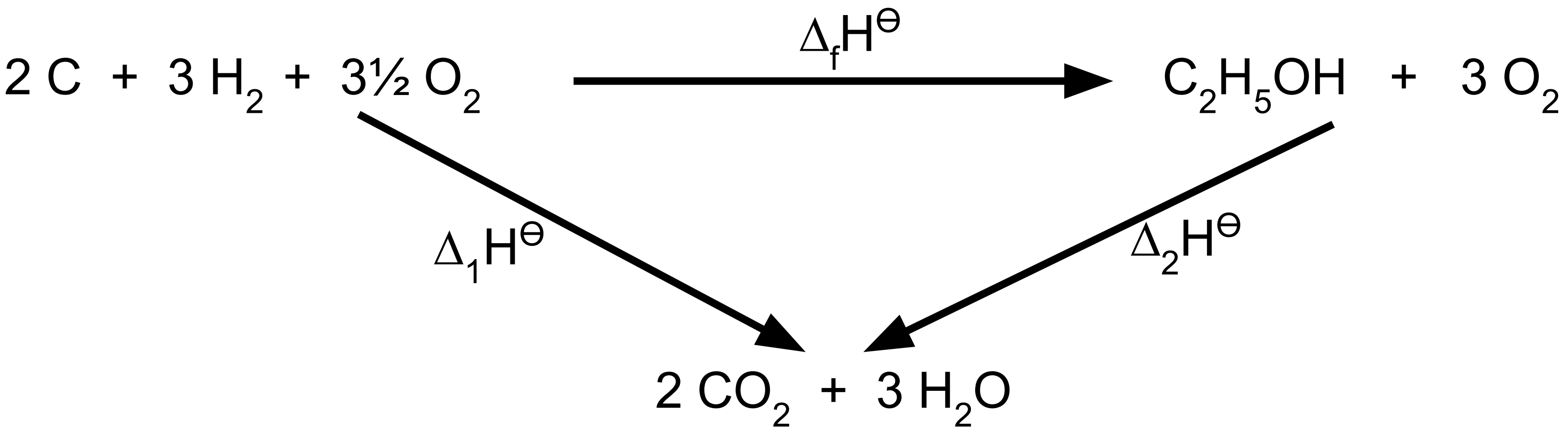
Mini Mock Paper

1) Enthalpy changes of formation, $\Delta_f H^{\ominus}$ of compounds are difficult to measure directly. However, we can use Hess' law to calculate a value for $\Delta_f H^{\ominus}$.

Use a Hess cycle to calculate the formation of ethanol, C_2H_5OH, using the data provided.

[4 marks]

Molecule	$\Delta_c H^{\ominus}$/ kJ mol^{-1}
C	-393.5
H_2	-285.8
C_2H_5OH	-1366.7



$\Delta_f H^{\ominus} = \Delta_1 H^{\ominus} - \Delta_2 H^{\ominus}$

$= [(2 \times -393.5) + (3 \times -285.8)] – (-1366.7)$

$= -277.7$ kJ mol^{-1}

Mini Mock Paper

2) An experiment is set up to determine the enthalpy change of combustion, $\Delta_c H^\ominus$, of butan-1-ol, C_4H_9OH.
Use the following data to calculate $\Delta_c H^\ominus$ in kJ mol^{-1}.

[5 marks]

Measurement	Reading
Mass of spirit burner + butan-1-ol before	65.20 g
Mass of spirit burner + butan-1-ol after	62.56 g
Initial temperature of water	20.4 ^oC
Final temperature of water	46.7 ^oC
Mass of water in calorimeter	100 g
Specific heat capacity of water	4.18 J g^{-1} K^{-1}

m = mass of water = 100 g
c = specific heat capacity of water = 4.18 J g^{-1} K^{-1}
ΔT = change in temperature of water = 46.7 – 20.4 = 26.3 ^oC

$q = mc\Delta T$
$= (100\text{ g}) \times (4.18\text{ J g}^{-1}\text{ K}^{-1}) \times (26.3\ ^oC)$
$= \underline{10{,}993.4\text{ J}}$

Mini Mock Paper

2) An experiment is set up to determine the enthalpy change of combustion, $\Delta_c H^\ominus$, of butan-1-ol, C_4H_9OH.
Use the following data to calculate $\Delta_c H^\ominus$ in kJ mol^{-1}.
[5 marks]

Measurement	Reading
Mass of spirit burner + butan-1-ol before	65.20 g
Mass of spirit burner + butan-1-ol after	62.56 g
Initial temperature of water	20.4 ^oC
Final temperature of water	46.7 ^oC
Mass of water in calorimeter	100 g
Specific heat capacity of water	4.18 J g^{-1} K^{-1}

Mass of butan-1-ol: 65.20 – 62.56 = 2.64 g

Moles of butan-1-ol: moles = mass / molar mass
= 2.64 g / [(4 x 12) + (10 x 1) + (1 x 16)] = (2.64 g) / (74.0 g mol^{-1})
= 0.0357 mol

Enthalpy change of combustion of butan-1-ol: -(10,993.4 J) / (0.0357 mol) = -307,938 J mol^{-1}

$\Delta_c H^\ominus$ = -<u>307.9 kJ mol^{-1}</u>

Mini Mock Paper

3) In an experiment to calculate the enthalpy of neutralisation between acids and alkalis a polystyrene cup is used instead of a metal container. Explain why this is the case. **[3 marks]**

Polystyrene conducts heat less well than metals and so less heat is lost to surroundings giving more accurate results.

Polystyrene has a lower specific heat capacity so absorbs less heat energy and less is lost to the surroundings.

Polystyrene is inert so will not react with the reactants.