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VCE Chemistry ¾
Energy Calculations & Delta H [1.2]
Workbook

Outline:

Learning Objectives:

- ☐ **CH34 [1.2.1]** - Apply $q = \Delta H \times n$ to energy released.
- ☐ **CH34 [1.2.2]** - Apply ΔH in kJ/mol, kJ/g and kJ/mL to energy calculations.
- ☐ **CH34 [1.2.3]** - Apply $q = mc\Delta T$ to find energy absorbed.
- ☐ **CH34 [1.2.4]** - Calculate ΔH experimentally.

Section A: Energy Calculations

Sub-Section: Moles & Molar Mass Recap

Discussion: What is a mole?

Moles (n)

- **Definition:** A unit of measurement for the ____________________ of substance which is present!
- One mole is equivalent to 6.02×10^{23} particles!

SI Unit	Formulae
mol	$n = \frac{m}{M}$

TIP: Think about one mole in a similar way to **one dozen – it simply groups amounts of substances together!**

- $1 \text{ dozen} = 12$ | $2 \text{ dozen} = 24$
- $1\ mol = 6.02 \times 10^{23}$ | $2\ mol = 1.20 \times 10^{24}$

REMINDER: The molar mass of substances (M) can be found by using the periodic table which can be found on **page 14 of the databook, item 17**.

Extension: Avogadro's Number

- Avogadro's Number (N_A) can be found on **page 4 of the databook, item 3.**
- It is a **constant** that indicates the number of particles present in one mole of a substance.
- **Value:**

$$N_A = 6.02 \times 10^{23}\ mol^{-1}$$

- **Formulae**:

$$n = \frac{N}{N_A}$$

  - N - Moles
  - N - Number of particles
  - N_A - Avogadro's Number
- This formula and idea is mainly a Chemistry $\frac{1}{2}$ concept, and is **not tested** in Chemistry $\frac{3}{4}$!

Question 1

If there is 10.0 g of carbon dioxide, calculate the amount (mol) of carbon dioxide present.

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Question 2

Jeremy finds 8.10 mol of sulphuric acid (H_2SO_4) in a beaker of water. Find the mass of sulphuric acid present.

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Sub-Section: Change in Enthalpy Values (kJ/mol)

What do changes in enthalpy values actually mean?

Exploration: Change in Enthalpy (ΔH) Values in kJ/mol

- **Example:** Methane

$$\Delta H = -890\ kJ/mol$$

- It means that for every **one mole** of methane combusted, ____________ of heat energy is released.
- How much heat energy is released when **two moles** of methane is combusted?
- **Operations:**
- **Formulae:**
- **Formulae Rearranged:**

Definition

Change in Enthalpy (ΔH) Values in kJ/mol

- **Definition:** Provides the amount of energy released/absorbed during a chemical reaction **per mole**.
- **SI Units:**

$$kJ/mol$$

- **Formulae:**

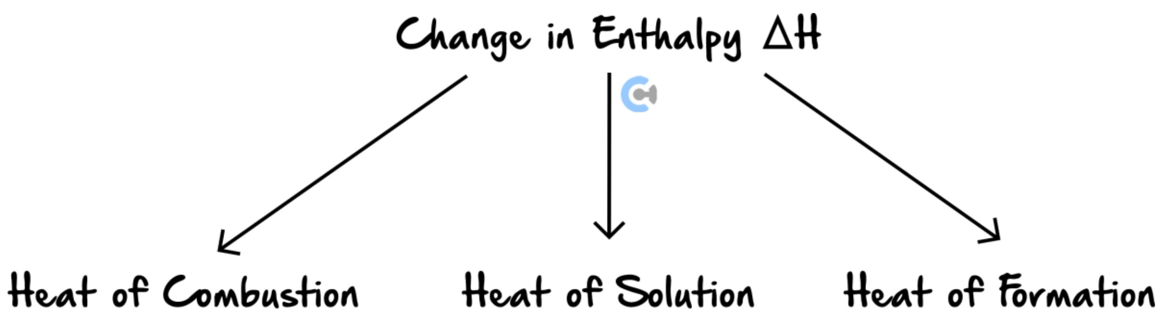
$$\Delta H = \frac{q}{n}$$

  - q - Energy (kJ)
  - n - Moles (mol)
  - ΔH - Change in enthalpy value (kJ/mol)
- **Alternative Name**: **Heat of combustion** (only if it is a combustion reaction).

NOTE: This formula can be found on **page 3 of the databook, item 2.**

Extension: Heat of Combustion vs Change in Enthalpy

- Change in enthalpy ΔH is the umbrella term:



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Misconception

"$\Delta H = \frac{q}{n}$ *is the same as* $\Delta h = \frac{Q}{N}$"

TRUTH: The sentence case of each symbol matters!

- For instance:
  - N refers to the **number** of molecules rather than the amount (mol).
  - Q refers to electric charge (C) rather than energy (kJ).

Question 3 Walkthrough.

How much energy is released when 3.40 mol of methanol (CH_3OH) is combusted?

TIP: The units for ΔH values are kJ/mol, and as such, the formula for the ΔH value is the same as its units!

$$\Delta H = \frac{kJ}{mol} = \frac{q}{n}$$

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<u>REMINDER</u>: For organic chemistry, the following prefixes correspond to the following number of carbons.

Longest Carbon Chain Length	Prefix
1	
2	
3	
4	
5	
6	
7	
8	

Question 4

Rachael is investigating the amount of energy released by some fuels she finds in her garage.

a. How much energy is released when 0.296 mol of butane is combusted completely?

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b. Find the heat of combustion of decane ($C_{10}H_{22}$) in kJ/mol, given that 0.841 mol of decane releases 3500 kJ of energy.

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TIP: First rearrange the 'raw' equation with the symbols before plugging the numbers in - this helps reduce the clutter of the working out!

REMINDER: Include the **negative sign (–)** when finding the heat of combustion of fuels!

Question 5

4.30 kJ of energy was released when an amount of ethanol was burnt in an unlimited supply of oxygen. Find the amount of ethanol that was burnt.

Question 6 Additional Question.

10.70 kJ of energy was released when carbon undergoes complete combustion. Find the amount, in mol, of carbon that was burnt.

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Sub-Section: Linking Molar Mass and Change in Enthalpy (kJ/mol)

What if the mass of a substance is provided instead?

Question 7 Walkthrough.

Find the energy released when 25.0 g of octane is completely combusted at SLC.

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Writing Numerical Working Out

- **Steps:**
  1. Write the raw formula, with the substance in brackets.
  2. Write numbers plugged in.
  3. Write an answer.
- **Example:**

$$n(C_8H_{18}) = \frac{m}{Mr} = \frac{25.0\ g}{(8 \times 12 + 18)\,g/mol} = 0.219\ mol$$

$$q = \Delta H \times n = 5470\frac{kJ}{mol} \times 0.219\ mol$$
$$= 1199\ kJ = 1.20 \times 10^3\ kJ$$

Your Turn!

Question 8

Find the energy released when 17.70 g of methane is completely combusted at SLC.

Question 9

Find the mass, in grams, of the propane completely combusted to release 2650 kJ of energy.

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Question 10 Additional Question.

When a sample of 8.50 g of pentane is combusted, 239 kJ of energy is measured to be released. Find the heat of combustion, in kJ/mol.

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Sub-Section: Change in Enthalpy Values (kJ/g)

Context

- There is another type of change in enthalpy (ΔH) values: one in kJ/mol and one in kJ/g.
- This is found **on page 11 of the databook, items 14 and 15.**

NOTE: The blended fuels and biofuels will be covered in detail later!

Exploration: Change in Enthalpy (ΔH) Values in kJ/g

- **Example:** Bioethanol

$$\Delta H = -29.7\ kJ/g$$

- It means that for every **one gram** of bioethanol combusted, ___________ of heat energy is released.
- How much heat energy is released when **two grams** of bioethanol is combusted?

- **Formulae:**

- **Formulae Rearranged:**

$$\Delta H = \frac{q}{m}$$

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Change in Enthalpy (ΔH) Values in kJ/g

- **Definition:** Provides the amount of energy released/absorbed during a chemical reaction **per gram**.
- **SI Units:**

$$kJ/g$$

- **Formulae:**

$$\Delta H = \frac{q}{m}$$

NOTE: Heat of Combustion v/s Molar Heat of Combustion

	Heat of Combustion	Molar Heat of Combustion
Units		
Formulae		

ALSO NOTE: Only the equation for molar heat of combustion is provided in the databook!

TIP: Look at the units of the ΔH (either kJ/mol or kJ/g) to see which formula to use.

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Let's look at a question together!

Question 11 Walkthrough.

Natural gas is tested in various ways, to find the amount of energy it releases.

a. Find the amount of thermal energy released upon combustion of 6.50 g of natural gas.

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b. Natural gas is compared to hydrogen gas, whereby 6.50 g of hydrogen gas is combusted. Find the amount of energy, in kilojoules, that is released during this process.

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NOTE: Look at the databook for what formula you use!

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Your Turn!

Question 12

a. Calculate the amount of energy released when 23.0 g of bioethanol undergoes complete combustion.

b. Calculate the amount of energy released when 150.0 g of methanol undergoes complete combustion.

Question 13

Find the mass, in kilograms, of diesel required to release 3.00×10^6 kJ of energy.

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Question 14 Additional Question.

Calculate the amount of energy released when $5.82\ g$ of methane is combusted at $100°C$, given that the molar heat of combustion of methane at this temperature is $-844\ kJ/mol$.

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NOTE: Sometimes, the question may provide their own heat of combustion as the fuel may be combusted at different conditions ($100°C$ rather than at SLC as specified). When this happens, **you must use the heat of combustion value provided.**

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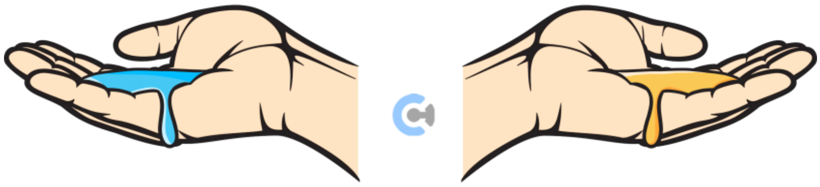
Sub-Section: Density of Fuels

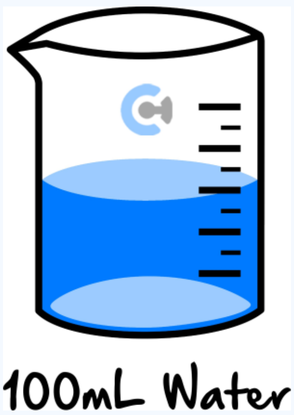
Discussion: If you grab a hand full of water compared to a hand full of honey, what differences do you expect to see?



- Difference is their ____________________________!

Exploration: Density

- Consider water and octane:

	Water (H_2O)	Octane (C_8H_{18})
Volume		
Mass		

- Different substances have different **density**, which corresponds to how much **mass** of the fuel is occupied in the same ________________.

- In every $100\ mL$ volume of each substance,

	Water (H_2O)	Octane (C_8H_{18})
Mass / $100\ mL$		
Mass / $1\ mL$ (Density)		

- **Density Formulae:**

Density (d)

- **Definition:** How tightly a material is packed closely together, which links its **mass** to its **volume** occupied.

SI Unit	Formulae
g/mL	$d = \frac{m}{V}$

NOTE: The density formula is not provided on the databook!

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Let's look at a question together!

Question 15 Walkthrough.

Given that the density of octane is 0.703 g/mL, find the amount of energy released if 25.0 L of octane is combusted.

NOTE: If required, density will be provided in the question!

Your Turn!

Question 16

The density of ethanol is 0.790 g/mL. A vial which contains 1.50 L of ethanol is completely combusted.

a. Find the mass, in grams, of ethanol which is present.

b. Calculate the theoretical energy that will be evolved if the $1.50\ L$ vial is completely combusted.

Question 17 Additional Question.

The density of petrol is $0.756\ g/mL$. When a sample of petrol is completely combusted, it releases $200\ kJ$ of energy.

Calculate the volume, in mL, of petrol which must have been combusted.

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Sub-Section: Change in Enthalpy Values (kJ/mL)

Change in Enthalpy (ΔH) Values in kJ/mL

- **Definition:** Provides the amount of energy released/absorbed during a chemical reaction **per** mL.
- **SI Units:**

$$kJ/mL$$

- **Formulae:**

$$\Delta H = \frac{q}{V}$$

Question 18

Kerosene is used for cooking and lighting in houses. A sample of 10.50 L of kerosene is completely combusted. Calculate the amount of energy released, in megajoules.

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Question 19

Using item 14 of the databook, find the density of diesel.

Question 20 Additional Question.

Petrol is used in cars. For a car to move 50 km, 175 MJ of energy must be released by the fuel. Find the volume of petrol, in litres, required for this to occur.

Key Takeaways

- ☑ To convert between mass and moles, $n = \frac{m}{Mr}$.
- ☑ To find energy released by a fuel, use the Data Book, and the formula $q = \Delta H \times n$.
- ☑ The heat of combustion ΔH value can be calculated in the following ways:

ΔH (kJ/mol)	ΔH (kJ/g)	ΔH (kJ/mL)
$\Delta H = \frac{q}{n}$	$\Delta H = \frac{q}{m}$	$\Delta H = \frac{q}{V}$

- ☑ Density is used to convert between mass and volume: $d = \frac{m}{V}$

Section B: Calculating Thermal Energy Released

Sub-Section: Introduction to Thermal Energy Released

While we can now calculate how much heat is released, how do we measure the amount of heat energy released?

Discussion: How can we measure 'heat'?

- How do we **measure 'heat'**?

Instrumentation	Measures

- How do we **measure heat energy**?

NOTE: We usually try to heat up ______________!

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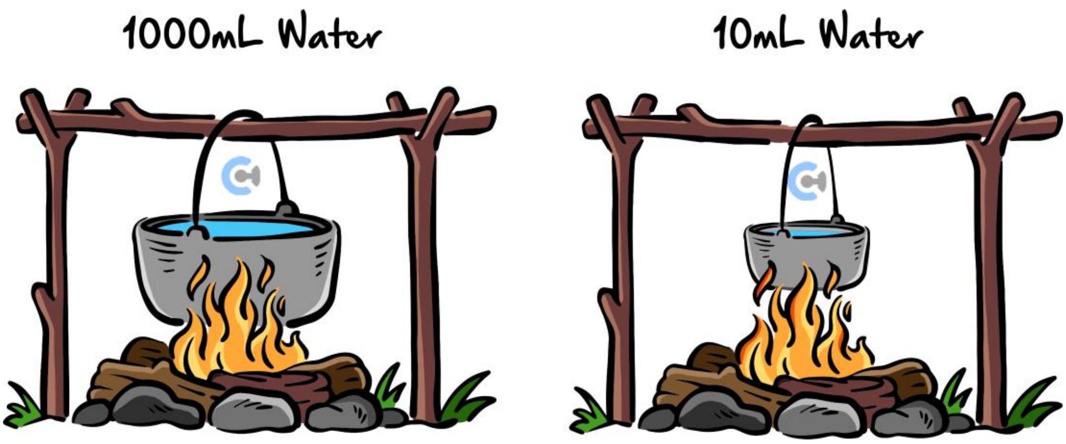
Why can't we just measure the change in temperature to find the heat energy released?

Exploration: Thermal Energy v/s Temperature

- Imagine burning a massive pot of water with $1000\ mL$ of water vs a tiny pot of water with $10\ mL$ of water:



- Which pot boils quicker?

- Main factor affecting the amount of thermal energy absorbed by the pot?

- The thermal energy absorbed can then be calculated.

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Sub-Section: Specific Heat Capacity

Specific Heat Capacity of Water

$$4.18\ J\ g^{-1}\ °C^{-1}$$

What does this mean?

Exploration: Specific Heat Capacity

- It means that $4.18\ J$ of energy is required to increase the temperature of $1\ g$ water by $1°C$.
  - How much energy is required to heat up $2\ g$ of water by $1°C$?
  - How much energy is required to heat up $2\ g$ of water by $2°C$?
- Formula:

$$q = mc\Delta T$$

Misconception

"Both "T" and "t" can be used to denote temperature"

TRUTH: They mean different things!

- 'T' refers to ______________________________.
- 't' refers to ______________________________.
- Make sure to write T when looking at the specific heat capacity formula!

NOTE: To convert from degrees Celsius (°C) to Kelvin (K), we simply add 273!

$$K = C + 273$$

ALSO NOTE: This can also be found on **page 5 of the databook** under '**unit conversions**'.

Exploration: For the specific heat capacity formula, do we use degrees Celsius (°C) or Kelvin (K)?

Initial Temperature: 35°C	Final Temperature: 40°C	Change in Temperature: 5°C
Initial Temperature:	Final Temperature:	Change in Temperature:

- This is because it is the ____________________ in temperature rather than the absolute value of the temperature!
- As such, ______________ Kelvin (K) or degrees Celsius (°C) can be used!

Specific Heat Capacity

- **Definition**: The amount of heat that must be added to one unit of mass of the substance to cause an increase of one unit in temperature.
- **Specific Heat Capacity of Water:**

$$4.18\ J\ g^{-1}\ °C^{-1}$$

- **Formula:**

$$q = mc\Delta T$$

- **Change in Temperature Measured in:**

°C or K

Let's look at some questions together!

Question 21 Walkthrough.

A sample of burning food is used to heat 130 g of water. Calculate the heat energy, in kilojoules, that has been transferred, if the temperature of the water increases from 18.5°C to 44.0°C.

Your Turn!

Question 22

a. Calculate the heat energy, in kJ, needed to increase the temperature of 500 g of water by 15°C.

b. If 19.5 kJ of energy caused a pot of water to increase in temperature from 18.0°C to 46.2°C, find the volume of water that was present.

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Question 23 Additional Question.

Calculate the heat energy, in kJ, required to heat up a bottle containing 250 mL of water from 25°C to 42°C.

Key Takeaway

- To measure the energy absorbed by water, it can be calculated by $q = mc\Delta T$, whereby the specific heat capacity of water is $\mathbf{4.18\ J\ g^{-1}\ °C^{-1}}$.

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Section C: Experimentally Obtaining Heat of Combustion

Context

- We've covered how to obtain the heat of combustion (ΔH) value by using the following equation:

$$\Delta H = \frac{q}{n}$$

- But how do we get the energy (q) and the amount of fuel (n) in real life?

Active Recall: What is a thermochemical equation?

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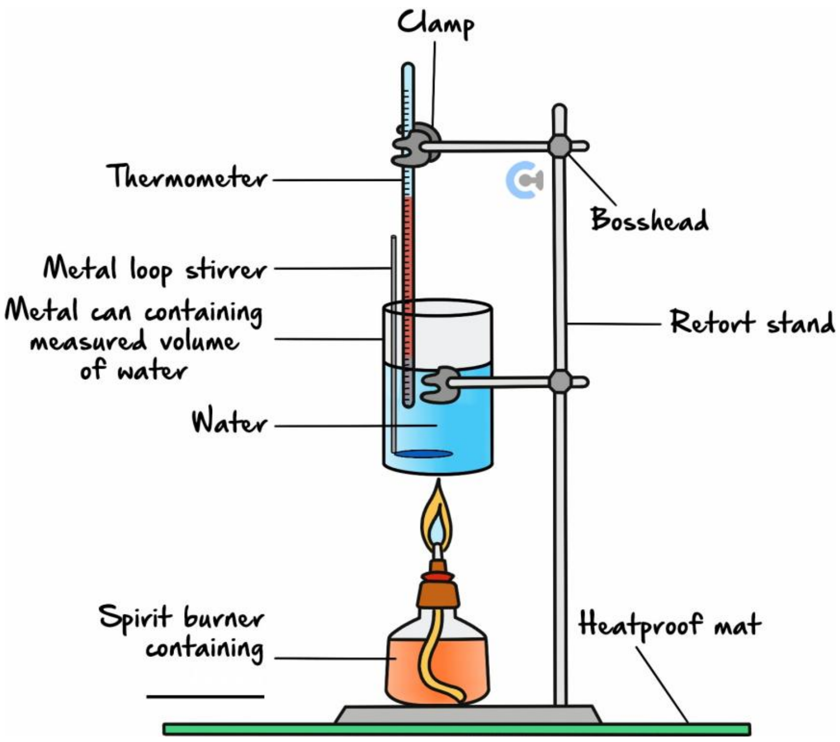
Sub-Section: Experimental Setup & Energy Calculation

Exploration: Experimental Setup to Obtain Heat of Combustion

- Setup:



$$\Delta H = \frac{q}{n}$$

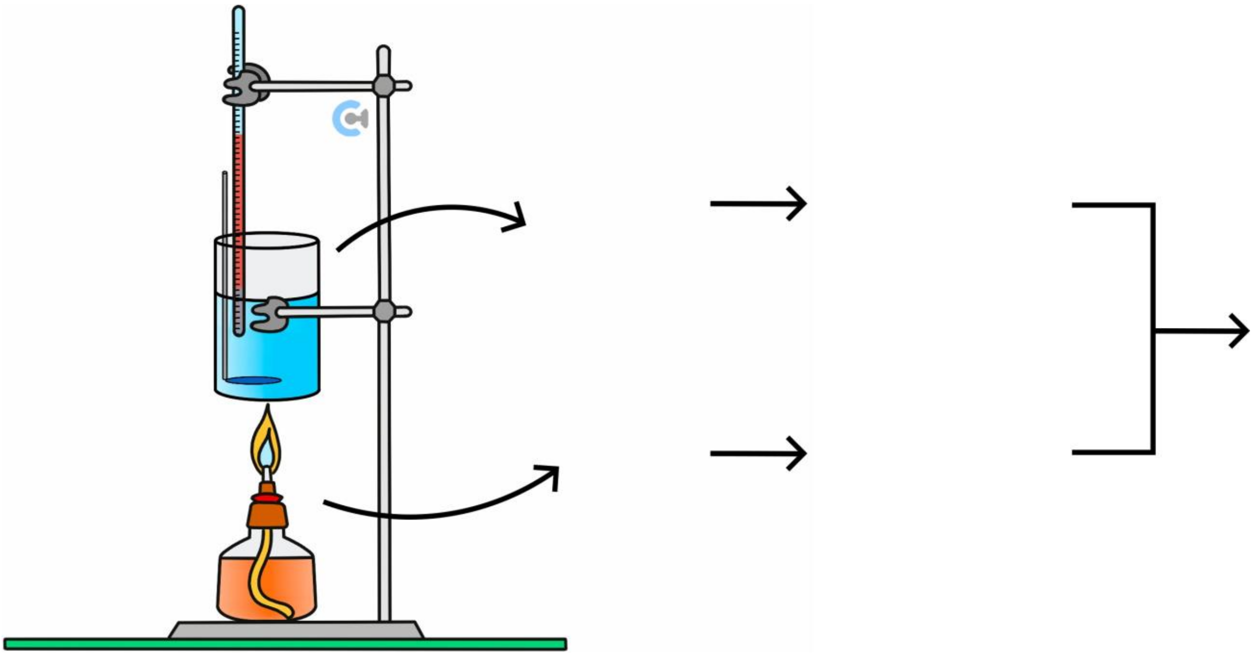
- How do we find the amount (mol) of the fuel which is combusted? (**Hint:** Imagine we only burn the fuel in the spirit burner for $20\ s$. How do we measure the amount of fuel that has combusted?)
  - ____
  - ____

- As the fuel is combusted, it releases thermal energy. Where does this thermal energy go?

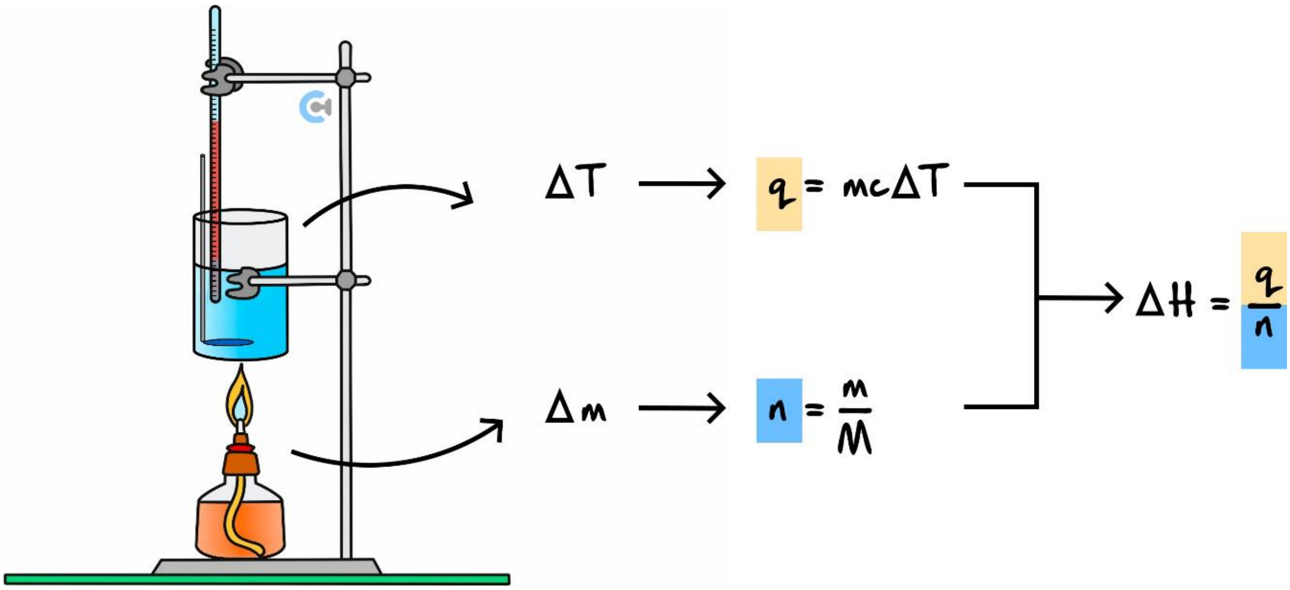
- As the water absorbs thermal energy, what happens to its temperature? **[increases]/[decreases]**

- How do we find the energy absorbed by the water?
  - ______________________________
  - ______________________________

- Whole process visualised:



Calculating Experimental Heat of Combustion



Let's look at some questions together!

Question 24 Walkthrough.

A sample of $5.47\ g$ of methanol (CH_3OH) undergoes complete combustion in a spirit burner. By the end of the experiment, there is $1.92\ g$ of methanol left. The heat energy released is used to heat $100\ mL$ of water. The temperature of the water rises from 20.24°C to 37.65°C.

Calculate the heat of combustion of methanol in kJ/mol.

TIPS

- Sometimes it's easier to start the question by writing the final equation that will be used ($\Delta H = \frac{q}{n}$ in this case) and then **work backwards**!
- Drawing a diagram may help visualise the scenario at hand!

NOTE: The question will usually be broken up into smaller parts!

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Recall!

Active Recall: What are the steps to find ΔH experimentally?

1. ________________________________

2. ________________________________

3. ________________________________

Your Turn!

Question 25 (3 marks)

A student used a spirit burner that contained heptane (C_7H_{16}) to heat a metal canister with 300 mL of water.

Initial mass of spirit burner (g)	Final mass of spirit burner (g)
293.02	291.20

a. Find the amount of heptane (mol) which has been combusted.

____

____

b. The temperature of the water is measured to increase from 35°C to 53°C. Find the amount of energy absorbed by the water.

____

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c. Hence or otherwise, find the heat of combustion heptane.

<u>**REMINDER**</u>: When asked for the heat of combustion, be sure to include the negative sign (–)!

Question 26

A chemistry student dissolves 4.51 g of sodium hydroxide in 100.0 mL of water at 19.5°C (in a calorimeter cup). As the sodium hydroxide dissolves, the temperature of the surrounding water increases to 31.7°C. Determine the heat of the solution (ΔH) of sodium hydroxide in J/g.

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Question 27 Additional Question.

A chemistry student ignites a sample of 1.50 g of carbon at SLC, and is used to heat 300 mL of water up. At the end, it is found that 0.380 g of carbon is left over. Given that the final temperature is 54.3°C, find the heat of combustion in kilojoules per mole.

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Contour Check

Learning Objective: [1.2.1] – Apply $q = \Delta H \times n$ to energy released

Key Takeaways

- ☐ To convert between mass and moles, ______________.
- ☐ To find energy released by a fuel, use the Data Book, and the formula ________________.

Learning Objective: [1.2.2] – Apply ΔH in kJ/mol, kJ/g and kJ/mL to energy calculations

Key Takeaways

- ☐ The heat of combustion ΔH value can be calculated the following ways:

$\Delta H\ (kJ/mol)$	$\Delta H\ (kJ/g)$	$\Delta H\ (kJ/mL)$

- ☐ Density is used to convert between mass and volume: ______________

Learning Objective: [1.2.3] – Apply $q = mcAT$ to find energy absorbed

Study Design

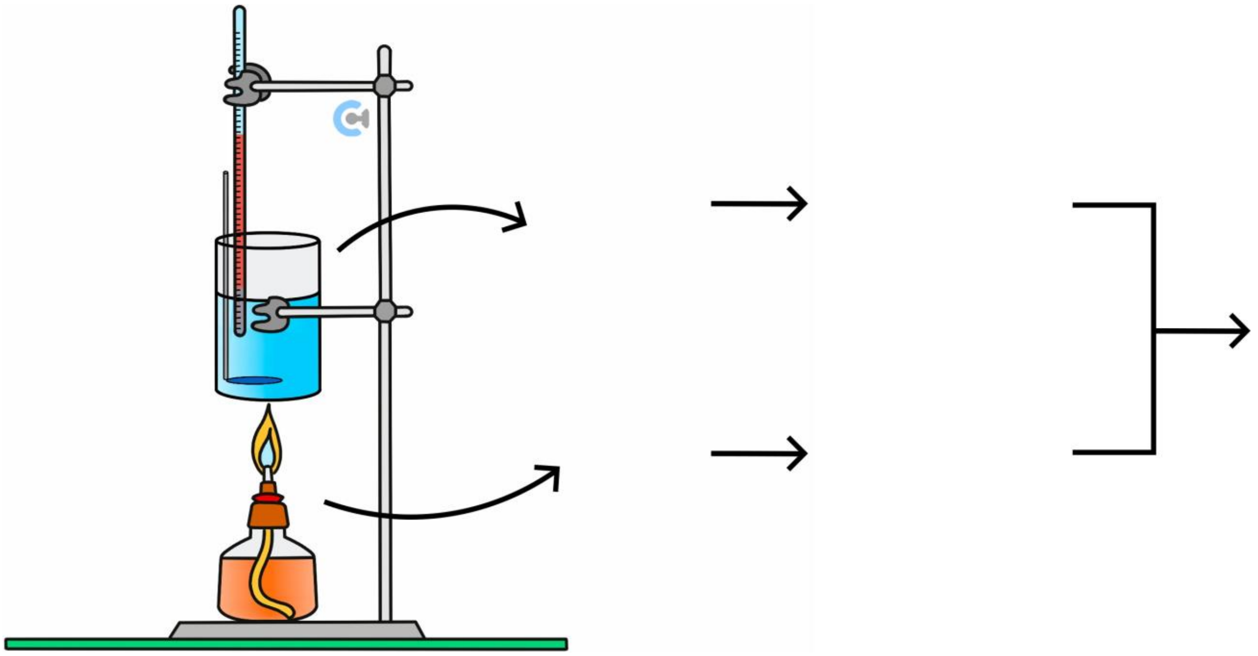
The use of specific heat capacity of water to approximate the quantity of heat energy released during the combustion of a known mass of fuel and food.

Key Takeaway

- ☐ To measure the energy absorbed by water, it can be calculated by ________________, whereby the specific heat capacity of water is ____________________.

Learning Objective: [1.2.4] - Calculate ΔH experimentally

Key Takeaway



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