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VCE Chemistry ¾
Gas Calculations & Stoichiometry [0.2]
Workshop Solutions

Section A: Recap

Definition

[1.3.1] - Identify Changes to Minimise Heat Loss & Calculate Percentage Efficiency

- **Percentage Efficiency:**

$$\% \, eff = \frac{Experimental}{Theoretical} = \frac{output}{input}$$

- When finding theoretical ΔH from experimental ΔH, **[multiply] / [divide]** by percentage efficiency.
- Systematic error links to **[accuracy] / [precision]** is how close to true value.
- Random error links to **[accuracy] / [precision]** which is how spread the data is.
- To minimise heat loss:
  - Place the beaker closer to the spirit burner.
  - Add a lid.
  - Use heat shield to wrap the spirit burner - beaker.
  - Use an insulator on the outside of the can.

$$x = \frac{y}{z}$$

- Direct Proportionality: $x \propto y$
  - If x doubles, y doubles
- Inverse Proportionality: $x \propto \frac{1}{z}$
  - If x doubles, z halves.

Definition

[1.3.2] - Apply $n = \frac{V}{V_m}$ to Calculate Volumes of Gas at SLC

- Gas Law at SLC Equation/Formula: $n = \frac{V}{V_m}$
- Molar Volume at SLC Value: $24.8 \; L/mol$

Definition

[1.3.3] - Apply $m-m, m-v, v-v$ Stoichiometry to Calculation Questions with Equations

- Stoichiometry calculations are done using the coefficients as $\frac{unknown}{known}$.
- Mass-Volume Stoichiometry Steps
  1. Find the moles of substance using: $n = \frac{m}{M_r}$.
  2. Find the moles of other substances using stoichiometric ratios.
  3. Find the volume of other substances using $V = n \times V_m$.
- Volume-Volume Stoichiometry Conditions:
  - Constant temperature.
  - Constant pressure.
  - Both substances are gas.

Question 1 (2 marks) **Walkthrough.**

When an acid is split on baking soda, the following reaction can occur.

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$$

Given that 10.0 L of carbon dioxide was observed to be formed, find the mass of hydrochloric acid which must have reacted.

$n(CO_2) = \frac{V}{V_m} = \frac{10}{24.8} = 0.403$ mol

$n(\text{HCl}) = 2 \times n(CO_2) = 2 \times 0.403 = 0.806\ mol$
$m(\text{HCl}) = n \times M = 0.806 \times (1 + 35.5)$
$= 29.4\ g$

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Definition

[1.3.4] - Identify Limiting Reagents

- Finding limiting reagents steps:
  1. Find amount (mol) of each reactant.
  2. Divide each reactant by stoichiometric ratio.
  3. Limiting reagent has less amount.
- When finding the amount of products formed, the amount (in moles) of the **[limiting reagent]** / **[excess reagent]** is used.
- Amount of excess reagent left over:

$$n(excess)_{leftover} = n(excess)_{initial} - n(excess)_{reacted}$$

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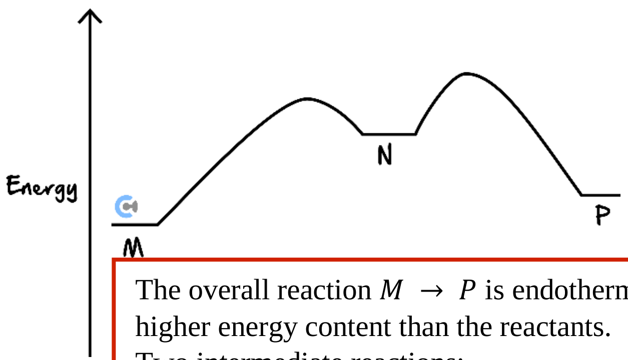
Section B: Warm Up (11 Marks)

INSTRUCTION: 11 Marks. 8 Minutes Writing.

Question 2 (1 mark)

The following energy profile shows the results obtained during an enzyme-catalysed reaction. Each stage of the the reaction is labelled: *M* represents the initial reactants, *N* represents a stable intermediate and *P* represents the final products.



The overall reaction $M \rightarrow P$ is endothermic – the products have a higher energy content than the reactants.
Two intermediate reactions:
$M \rightarrow N$ is endothermic.
$N \rightarrow P$ is exothermic – the product has a lower energy content.

Which one of the following statements is

A. The energy change from *M* to *N* is endothermic and the energy change from *N* to *P* is endothermic.

B. The energy change from *M* to *P* is exothermic and the energy change from *N* to *P* is exothermic.

C. The energy change from *M* to *N* is endothermic and the energy change from *M to P* is exothermic.

D. The energy change from *N* to *P* is exothermic and the energy change from *M* to *P* is endothermic.

Question 3 (2 marks)

For the following two scenarios, assume everything occurs at SLC.

a. Find the mass (g) of 3.00 L of nitrogen gas (N_2). (1 mark)

a. Find the mass (g) of 3.00 L of nitrogen gas (N_2). (1 mark)

$n(N_2) = \frac{3.00}{24.8} = 0.125 \text{ mol}$ $m(N_2) = 0.125 \times 28$
$= 3.5 g$

b. Find the volume that 30.0 g of ozone (O_3) occupies. (1 mark)

$n(O_3) = \frac{m}{M} = \frac{30}{48} = 0.625\ mol$

$V(O_3) = 15.5\ L$

Question 4 (2 marks)

Given the following equation:

$$C_6H_{14}(l) + \frac{19}{2}O_2(g) \rightarrow 6CO_2\ (g) + 7H_2O(l)$$

If 27.8 g of hexane were available, what volume of carbon dioxide (CO_2) would be evolved at SLC?

$$n(hex) = \frac{m}{M}$$
$$= 27.8/86.0 = 0.323\ mol\ (1)$$
$$n(steam) = 6n(hex) = 6 \times 0.323 = 1.94\ mol\ (2)$$
$$V(steam) = n \times V_m = 1.94 \times 24.8 = 48.1\ L\ (3)$$

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The following information applies to the three questions that follow.

Butane is a significant component of LPG. The equation for the complete combustion of butane is:

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$

Question 5 (1 mark)

The energy, in kJ, released from the combustion of 2.00 g of butane will be:

A. 49.7

B. 58.0

C. 5760

D. 99.3

Option D is correct. The data book quotes the combustion figure for butane to be 2880 $kJ\ mol^{-1}$.
The heat of combustion per gram will be $= \frac{2880}{58} \times 2 = 99.4\ kJg^{-1}$.
Option B is incorrect as this figure is the molar mass of butane.
Option C is incorrect as it gives the energy per 2 $moles$, not per 2 $grams$.
Option A is incorrect as it gives the energy per 1 $gram$.

Question 6 (1 mark)

The mass, in g, of O_2 gas required for the complete combustion of 2.16 g of butane will be:

A. 3.87

B. 7.75

C. 15.49

D. 14.04

Option B is correct: $n(\text{butane}) = \frac{2.16}{58} = 0.037\ mol$
$n(O_2) = \frac{13}{2} \times n(\text{butane}) = \frac{13 \times 0.037}{2} = 0.242\ mol$
mass $O_2 = 0.242 \times 32 = 7.75\ g$
Option A is incorrect as the figure does not take into account that oxygen gas exists as O_2.
Option C is incorrect as the figure is double the correct answer.
Option D is incorrect. It uses a mass ratio rather than a mole ratio.

Question 7 (1 mark)

The volume, in L, of CO_2 gas produced from the complete combustion of 2.16 g of butane at SLC will be:

A. 24.8

B. 0.918

C. 3.69

D. 0.148

Option C is correct. $n(CO_2) = 4 \times n(C_4H_{10})$.
$V = nV_m = 0.037 \times 4 \times 24.8 = 3.67\ L$.
Option A is incorrect as it assumes one mole of CO_2
Option B is incorrect as it forgets to use mole ratios.
Option D is incorrect as it only computes the number of moles of CO_2 as $4 \times n(\text{butane})$ and ignores volume.

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Question 8 (2 marks)

Find the amount of energy released when 28.3 L of propane (C_3H_8) is combusted at SLC.

$n(C_3H_8) = \frac{V}{V_m} = \frac{28.3}{24.8} = 1.14 \text{ mol}$

$q(C_3H_8) = \Delta H \times n = 2533 \text{ kJ}$

Question 9 (1 mark)

A reaction has the energy profile diagram shown below.

Which of the following represents the energy profile of the reverse reaction?

	Final product energy ($kJ\ mol^{-1}$)	ΔH ($kJ\ mol^{-1}$)
A.	40	+10
B.	50	+10
C.	50	−10
D.	40	−10

Section C: Ramping Up (12 Marks)

INSTRUCTION: 12 Marks. 9 Minutes Writing.

Question 10 (1 mark)

One form of incomplete combustion of methane is shown by the following equation:

$$4CH_4(g) + 5O_2(g) \rightarrow 2CO(g) + 8H_2O + 2C(s)$$

If 100 mL of methane fuel was burnt at SLC, what volume, in L, of carbon monoxide would be produced under the same conditions?

A. 0.500

B. 0.0500

C. 2.48

D. 50

Question 11 (8 marks)

a. Write a balanced thermochemical equation for the complete combustion of propane at SLC. (2 marks)

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)\ \Delta H = -2220\ kJ/mol$

b. Calculate the energy released by the combustion of 0.450 mol of propane. (2 marks)

Use ration of $\frac{energy}{mole}$ from the Data Book and second balanced equation:

$\frac{2220}{1.00} = \frac{x}{0.450}$ (1 mark)

$x = \frac{2220 \times 0.450}{1.00} = 999\ kJ$ (1 mark)

c. Calculate the volume of carbon dioxide, measured at SLC, produced for every 100 kJ of energy released. (2 marks)

Use ratio of $\frac{volume\ CO_2\ in\ L}{energy}$ from the Data Book and second balanced equation

$\frac{3\times24.8}{2220}=\frac{y}{100}$ (1 mark)

$y=\frac{3\times24.8\times100}{2220}=3.35\ L$ (1 mark)

d. Calculate the energy released when 2.50 g of water is produced. (2 marks)

$n(H_2O)=\frac{2.5}{18}=0.14$

$n(C_3H_8)=\frac{0.14}{3}$

$q=\frac{0.14}{3}\times2220$

$=77.1\ kJ$

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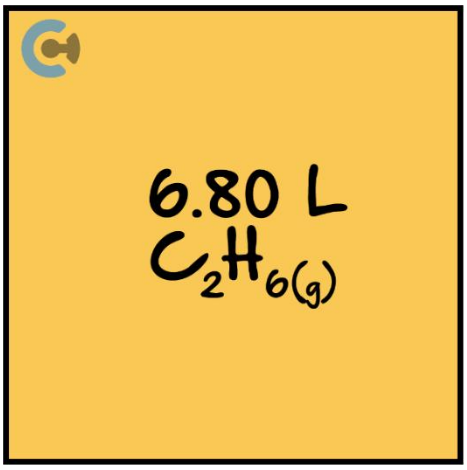
Question 12 (3 marks)

A container can occupy exactly 6.80 L of ethane gas at SLC.



The balanced thermochemical equation for the incomplete combustion of ethane gas is provided below:

$$2C_2H_6(g) + 5O_2(g) \rightarrow 4CO(g) + 6H_2O(l) \quad \Delta H = -2135\ kJ$$

a. Find the amount of energy that can be released if all of the ethane were to be combusted. (2 marks)

$n(C_2H_6) = \frac{V}{V_m} = \frac{6.8}{24.8} = 0.274\ mol$

$\Delta H = 1067.5\ kJ/mol$

$q(C_2H_6) = \Delta H \times n = 1067.5 \times 0.274 = 293\ kJ$

b. Find the volume of carbon dioxide produced at SLC, if all of the ethane gas is combusted. (1 mark)

13.60 L (volume-volume stoich)

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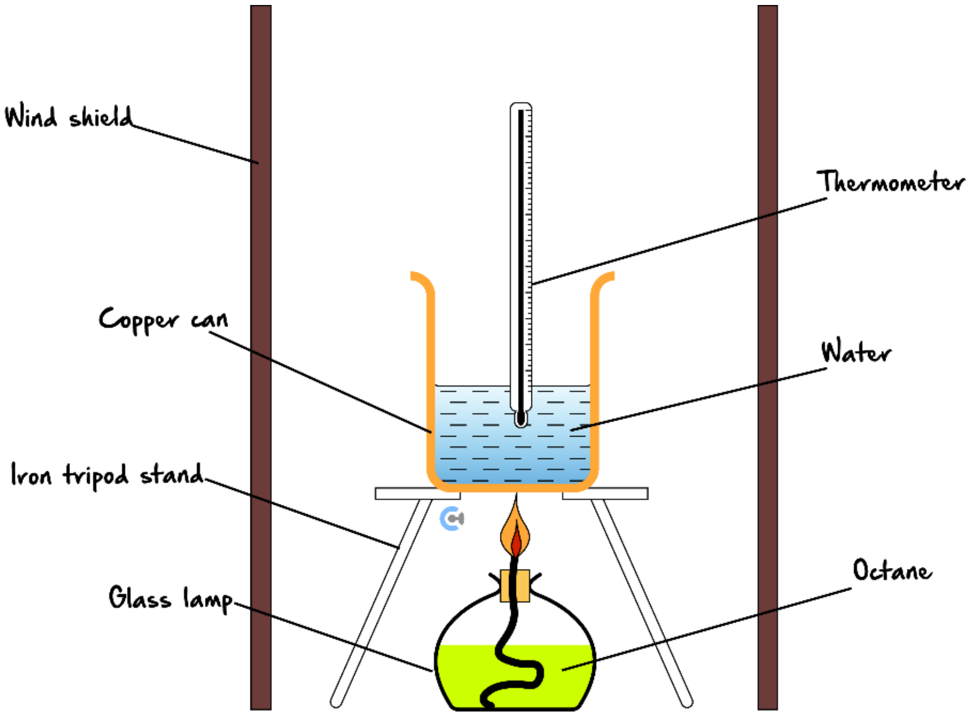
Section D: Getting Trickier I (9 Marks)

INSTRUCTION: 9 Marks. 7 Minutes Writing.

Question 13 (9 marks)

A sample of octane in a spirit burner which initially weighs $137.15\ g$ undergoes complete combustion.
After the combustion is complete, it is found that the spirit burner weighs $136.04\ g$. The heat energy released is used to heat $225\ mL$ of water at SLC. The temperature of the water rises to $45.20°C$. The following setup is used.



It is known that there is 40.0% energy loss to the surroundings.

a. Calculate the experimental heat of combustion of octane in kJ/mol. (4 marks)

$q = mC\Delta T$
$= 225 \times 4.18 \times 20.2$
$= 18.9981\ kJ$

$n(C_8H_{18}) = \frac{1.10}{96+18} = 0.009736\ mol$

$\Delta H = -\frac{18.9981}{0.009736}$
$= 1951.2\ kJ/mol$

$\frac{1951.2}{0.6} = -3252\ \frac{kJ}{mol}$

b. Find the volume of gases that are produced during this combustion at SLC. (2 marks)

olume of gases that are produced during this combustion at SLC. (2 marks)

$C_{18}H_{18} \rightarrow 18CO_2 \rightarrow V(CO_2) = 4.31\text{ L}$

$n(CO_2) = 0.1737\text{ mol}$

c. Explain one feature of the setup, and how it improves the accuracy of the experiment. (1 mark)

Windshield – minimises heat loss to the surrounding, which can be caused by convection currents in the wind.

d. It turns out the thermometer has accidentally lent on the side of the beaker of water. Explain how this will affect the calculated heat of combustion. (2 marks)

↑heat to thermometer = ↑ΔT = ↑q

= ↑ΔH

∴ overestimated ΔH_c.

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Section E: Getting Trickier II (8 Marks)

INSTRUCTION: 8 Marks. 7 Minutes Writing.

Question 14 (8 marks)

Nishad likes to have a barbecue in the summer and thus connects his natural gas supply from his house (which contains methane) to his grill to cook his meat.

a. Write the thermochemical equation for the complete combustion of methane. (2 marks)

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)\ \Delta H = -890\ kJ/mol$

b. As he burns the methane fuel at SLC, he finds that it produces 1.00 L of water. Find the volume of methane that he must have used. (4 marks)

$n(H_2O) = \frac{1000}{18} = 55.56$ mol

$n(CH_4) = \frac{55.56}{2} = 27.78$ mol

$V(CH_4) = 27.78 \times 24.8 = 688.89$ L

$= 689$ L

c. In another instance, he has a methane canister of 10.0 L volume at SLC. However, Eshani takes his methane canister and changes it to STP, Standard Temperature & Pressure (0°C & 100 kPa), whereby the molar volume at these conditions is $V_m = 22.4\ L/mol$. Find the volume that the methane will occupy at STP. (2 marks)

SLC: $n(CH_4) = \frac{V}{V_m} = \frac{10}{24.8} = 0.403$ mol

STP: $V(CH_4) = n \times V_m = 0.403\ mol \times 22.4\ L/mol$

$= 9.03$ L

NOTE: When you are given volume in (L), there are two types of volume:

- Liquid volume - use density ($d = \frac{m}{V}$).
- Gas volume - use molar volume ($n = \frac{V}{V_m}$).

Let's take a BREAK!

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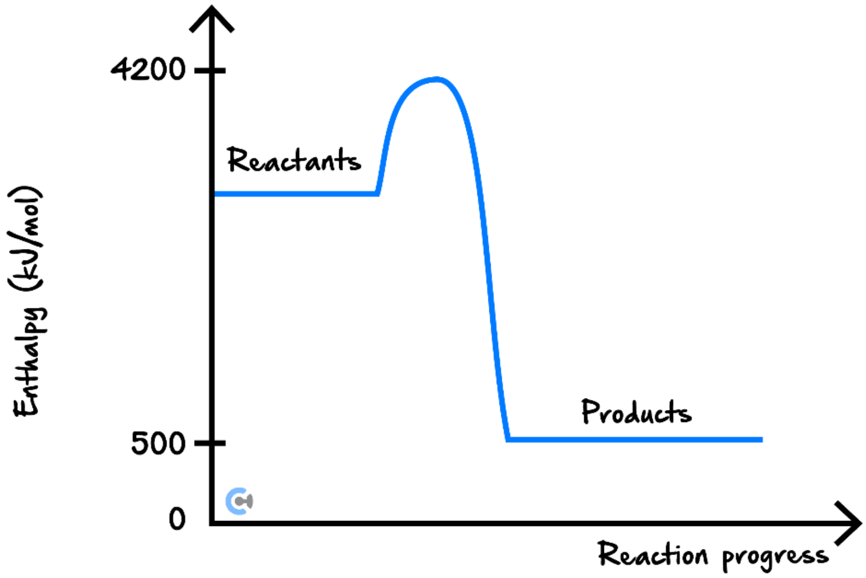
Section F: VCAA-Level Questions I (12 Marks)

INSTRUCTION: 12 Marks. 30 Seconds Reading. 11 Minutes Writing.

Question 15 (12 marks)

David and Jason like playing with dimethylpropane (C_5H_{12}), which is a highly volatile substance that can easily switch between liquid and gaseous states at SLC.

a. The energy profile diagram for the incomplete combustion of dimethylpropane, where carbon monoxide is the only carbon product at SLC is shown below:



i. Given that the activation energy for this reaction is $+400\ kJ/mol$, find the change in enthalpy (ΔH) for the reverse reaction. (1 mark)

$+3300\ kJ/mol$

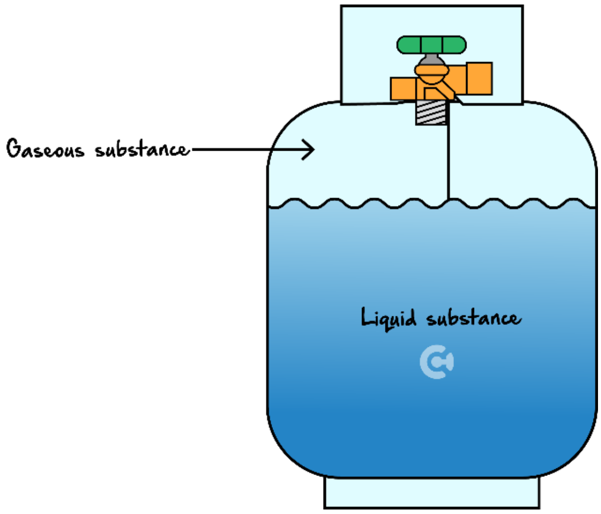
ii. Write a balanced thermochemical equation for the incomplete combustion of dimethylpropane liquid, where carbon monoxide is the only carbon product at SLC. (2 marks)

$C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)\ \ \Delta H = -3300\ kJ/mol$

iii. If the dimethylpropane were to completely combust instead, explain whether the heat of combustion is likely to be higher or lower at SLC. (3 marks)

Higher - during incomplete combustion, there is still some chemical energy in the fuel which can be released in thermal energy. Complete combustion releases all of the thermal energy the fuel can release, thereby resulting in a higher heat of combustion during complete combustion.

It is found that at SLC when dimethylpropane is placed into a 23.00 L canister, the following phenomena arise, where there is a gaseous and liquid dimethylpropane substance present.



b. At SLC, it is found that half of the volume of the canister is liquid, and half of the canister is gaseous. Given that the density of liquid dimethylpropane is 627 g/L.

i. Find the mass of the liquid dimethylpropane. (1 mark)

liquid
$V(C_5H_{12}) = 50\% \times 23.0L = 11.5L$
$m(C_5H_{12}) = d \times v = 627 g/L \times 11.5L = 7210.5g$

ii. Find the overall mass, in kilograms, Z of dimethylpropane present. (3 marks)

gaseous
$n(C_5H_{12}) = \frac{V}{V_m} = \frac{11.5}{24.8} = 0.464 mol$
$m(C_5H_{12}) = n \times M = 0.464 \times (60+12)$
$= 33.39g$
$m(total) = 7210.5g + 33.39g = 7243.9g = 7.24kg$

iii. Find the amount of energy released in MJ when this amount of dimethylpropane is incompletely combusted according to the thermochemical equation constructed in **part a. ii**. (2 marks)

$n(C_5H_{12}) = \frac{m}{M} = \frac{7243.9g}{60+12} = 100.61 mol$

$q(C_5H_{12}) = \Delta H \times n = 3300 kJ/mol \times 100.61 mol$

$= 332011 kJ$

$= 332 MJ$

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Section G: Multiple Choice Questions (7 Marks)

INSTRUCTION: 7 Marks. 7 Minutes Writing.

Question 16 (1 mark)

0.50 mol of ethane, C_2H_6, and 100.0 g of air that is 22.0% m/m oxygen, O_2, are injected into a combustion chamber.

The equation of the combustion of ethane is $C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$.

If complete combustion takes place, which reactant is in excess and by how much?

	Reactant in excess	Amount of reactant in excess
A.	C_2H_6	0.25 mol
B.	C_2H_6	0.30 mol
C.	O_2	12 g
D.	O_2	97 g

Question 17 (1 mark)

Inspired from VCAA Chemistry Exam 2014
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2014/2014chem-amd-w.pdf#page=12

Large deposits of methane hydrate have been discovered deep under the sediment on the ocean floor. It has been suggested that methane hydrate deposits could be commercially mined to provide a clean fuel once the trapped methane is extracted.
Methane hydrate has a complex structure. The simplified formula for methane hydrate is $CH_4.6H_2O$.
The amount of energy released by the complete combustion of methane extracted from a 0.50 kg sample of methane hydrate at SLC is:

A. $3.59 \times 10^3\ kJ$

B. $7.17 \times 10^3\ kJ$

C. $2.78 \times 10^4\ kJ$

D. $2.15 \times 10^4\ kJ$

$0.5\ mol\ CH_4.6H_2O \rightarrow 0.5\ mol\ CH_4 + 3\ mol\ H_2O$

$n(CH_4)$ extracted $= n(CH_4.6H_2O)$

$= \frac{m(CH_4.6H_2O)}{M(CH_4.6H_2O)}$

$= \frac{0.50\times10^3}{16.0+6\times18.0}\ g\ mol^{-1}$

$= \frac{0.50\times10^3}{124.0}$

$= 4.03\ mol$

$E = 4.03\ mol \times 890\ kJ/mol = 3588.7\ kJ$

Question 18 (1 mark)

Inspired from VCAA Chemistry Exam 2019
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2019/NHT/2019chem-nht-w.pdf#page=11

A student aims to calculate the theoretical amount of energy available to the body from cellular respiration using oxygen gas, O_2, retained by the body in a normal breath.
In this calculation, the student assumes that:

- the energy released at normal body temperature is the same as that released at standard laboratory conditions (SLC)
- 19.6 mL of O_2 is retained by the body in a normal breath.

A balanced thermochemical equation for cellular respiration, with glucose as the primary reactant, is shown below.

$$2C_6H_{12}O_6 + 12O_2 \rightarrow 12CO_2 + 12H_2O \quad \Delta H = -5632\ kJ$$

The theoretical amount of energy produced through cellular respiration from the O_2 retained by the body in a normal breath would be:

A. 4.4 kJ

B. $3.7 \times 10^{-1}\ kJ$

C. $7.4 \times 10^{-1}\ kJ$

D. $3.7 \times 10^{2}\ kJ$

$n(O_2) = 19.6 \times 10^{-3}/24.8 = 7.90 \times 10^{-4}\ mol$
Energy released per mol O_2 reacting = $\frac{5632}{12}$
Energy released = $7.90 \times 10^{-4} \times (\frac{5632}{12})$
$= 0.37\ kJ$

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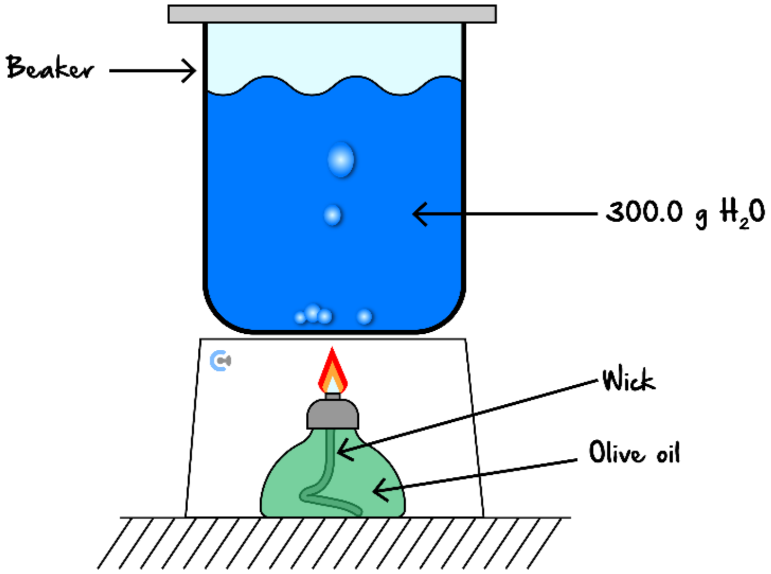
Question 19 (1 mark)

Inspired from VCAA Chemistry Exam 2017
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2017/2017chem-w.pdf#page=11

A sample of olive oil with a wick in a jar is ignited and used to heat a beaker containing 300.0 g of water, H_2O. The relevant data for the experiment is included in the table below:



Data:

Initial temperature (H_2O)	22.0°C
ΔH (olive oil)	$38.0\ kJ\ g^{-1}$
Total energy lost to the environment	$25.0\ kJ$

After complete combustion of 2.95 g of olive oil, the final temperature of the water, in degrees Celsius, would be:

A. 111.4

B. 89.4

C. 69.5

D. 91.5

Space for Personal Notes

Question 20 (1 mark)

Two identical flasks, A and B, contain, respectively, 5.0 g of N_2 gas and 14.4 g of an unknown gas. The gases in both flasks are at standard conditions (SLC).

The gas in flask B is:

A. H_2

B. SO_2

C. HBr

D. C_4H_{10}

Since the flasks are identical, i.e. the same volume, and the temperature and pressure conditions are the same, both flasks must contain the same number of mole of gas.

$n(N_2) = 5.0/28.0$
$= 0.179$ mol

$n(\text{unknown}) = 14.4/M(\text{unknown}) \rightarrow 0.179 = 14.4/M(\text{unknown})$

$M(\text{unknown}) = 14.4/0.179$
$= 80.6 \text{ g mol}^{-1}$

$M(H_2) = 2.0 \text{ g mol}^{-1}$; $M(SO_2) = 96.1 \text{ g mol}^{-1}$

$M(HBr) = 80.9 \text{ g mol}^{-1}$

$M(C_4H_{10}) = 58.0 \text{ g mol}^{-1}$

Question 21 (1 mark)

1 L of octane has a mass of 703 g at SLC. The efficiency of the reaction when undergoes combustion in the petrol engine of a car is 25.0%.

What volume of octane stored in a petrol tank at SLC is required to produce 528 MJ of usable energy in a combustion engine?

A. 3.92 L

B. 11.8 L

C. 15.7 L

D. 62.7 L

Question 22 (1 mark)

Which of the following fuels is expected to produce the most energy if 2.05 mol of it is burned in excess oxygen?

A. Methane (CH_4)

B. Ethanol (C_2H_5OH)

C. Propane (C_3H_8)

D. Methanol (CH_3OH)

Section H: VCAA-Level Questions II (12 Marks)

INSTRUCTION: 12 Marks. 30 Seconds Reading. 11 Minutes Writing.

Question 23 (1 mark)

Inspired from VCAA 2024 Sample exam
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/chemistry-sample-w.pdf

A similar fuel cell is used in a school laboratory and operates for 3.00 hours at a constant current. The equation for the overall reaction in this fuel cell is:

$$O_2(g) + 2H_2(g) \rightarrow 2H_2O(l)$$

Under SLC, a total of 375 mL of oxygen and 490 mL of hydrogen was pumped through the fuel cell.

a. Determine which chemical is the limiting reagent. (1 mark)

Hydrogen gas

b. Calculate the volume, in litres, of the unreacted gas. (2 marks)

$V(O_2 \text{ reacted}) = 0.5 \times V(H_2) = 245\ mL$
$V(O_2 \text{ left over}) = 375 - 245 = 130\ mL$
$= 0.130\ L$

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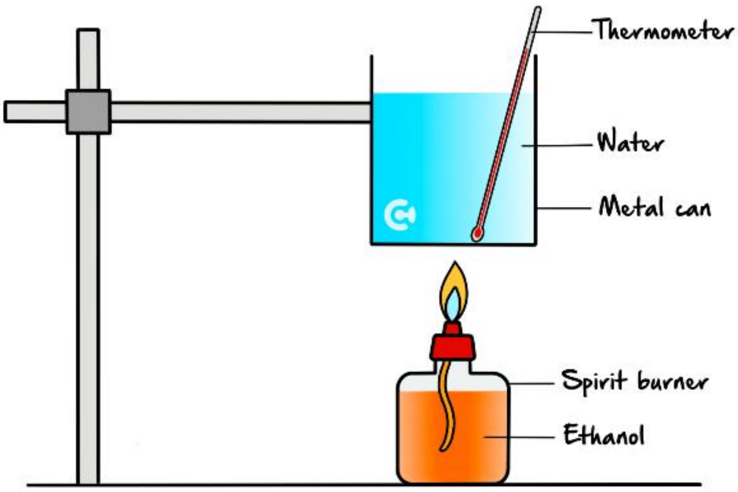
Question 24 (11 marks)

A series of experiments were conducted to determine the heat of combustion of ethanol using the equipment shown in the diagram below.



The results of the experiments are shown in the table below:

	Experiment 1	**Experiment 2**	**Experiment 3**	**Experiment 4**
Mass of water in metal can (g)	75.4	74.8	76.4	78.1
Mass of burner and ethanol before burning (g)	127.34	127.11	123.88	125.94
Mass of burner and ethanol after burning (g)	126.86	126.52	123.37	125.22
Temperature of water before heating (°C)	18.0	35.0	50.0	65.0
Temperature of water after heating (°C)	36.1	53.2	66.4	75.1

a. Using the results from experiment 1, calculate the heat of combustion of ethanol in kJ/mol. (3 marks)

$$m(ethanol) = 127.34 - 126.86 = 0.48\ g$$
$$n(ethanol) = \frac{0.48}{46} = 0.0104\ mol$$
$$q = mc\Delta T$$
$$q = 75.4 \times 4.18 \times (36.1 - 18.0) = 5704.6\ J = 5.705\ kJ$$
$$\Delta H = \frac{q}{n} = \frac{5.705}{0.0104} = -546.69 \frac{kJ}{mol} = -5.5 \times 10^2\ kJ/mol$$

b. The theoretical heat of combustion of the fuel is $\Delta H = -2017.7\ kJ/mol$.
Find the percentage efficiency of experiment 1 and give reasoning which accounts for this difference in heat of combustion. (3 marks)

$$\text{eff} = \frac{547}{2017.7} = 27.3\%$$

c. Suggest why a metal can is used instead of a Pyrex (heat-proof glass) beaker. (1 mark)

Heat can be transferred more efficiently to the can and hence the water in the vessel if it is a metal can, given metal has a much higher heat conductivity compared to glass.

d. State and explain two ways in which the accuracy can be improved in this experiment. (2 marks)

Accuracy can be improved by minimising heat loss to the environment. This can be minimised by placing the spirit burner closer to the flame/adding a lid to the metal can/covering the spirit burner to metal can opening with a reflective foil.

e. In experiments 2-4, the water was not allowed to cool back down to room temperature and was instead used and heated almost immediately again. Explain how this might affect the results obtained. (2 marks)

By not allowing the water to cool back down to room temperature, it results in the water temperature increasing higher and higher for each experiment. At higher temperatures, the experimental setup is likely to cool down faster, resulting in more heat loss in the later experiments which decreases the heat of combustion obtained for these later values.

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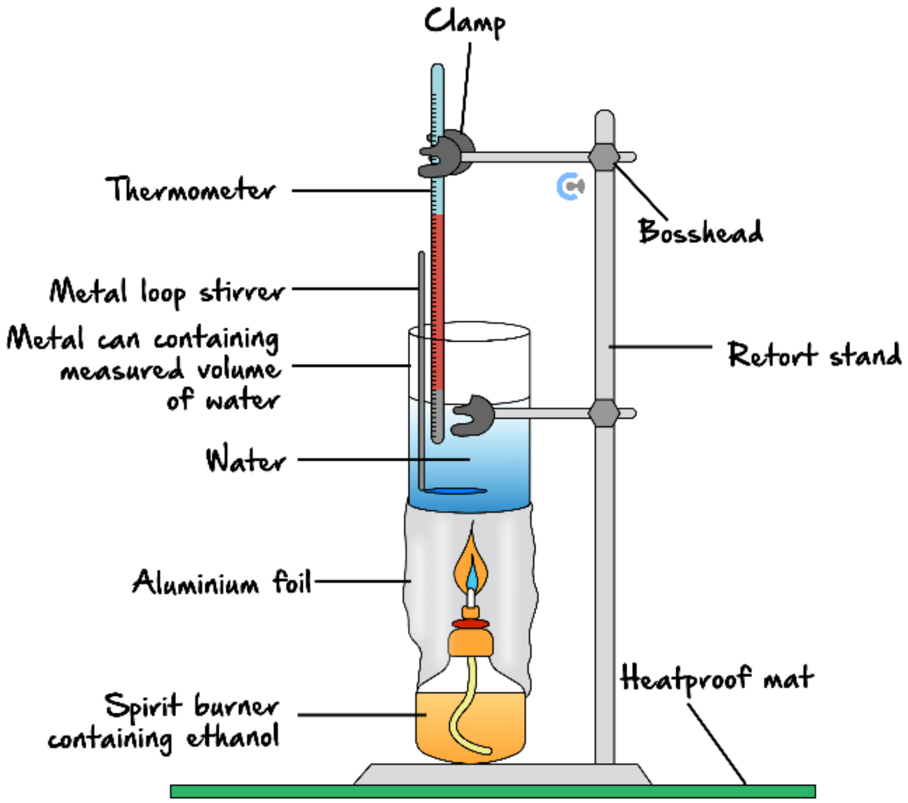
Section I: Extension Questions (25 Marks)

Question 25 (9 marks)

Eunise and Atharva decide to investigate the heat of combustion of ethanol by using the following setup.



Atharva wants to increase how precise their results are and decides to use aluminium foil and wrap the opening between the flame and the beaker of water as shown above.

a. Comment on how this change will affect the accuracy and precision of the results. (4 marks)

Accuracy - aluminium foil will minimise the amount of heat loss to the environment, which increases the amount of energy absorbed by the water. This reduces the effect of systematic error, thereby increasing accuracy.

Precision - by using aluminium foil, the amount of heat loss is more uniform as heat transferred is more controlled, reducing the effect of random error. This increases precision of results.

b. Compare the difference in the heat of combustion obtained by using the aluminium foil compared to without using the aluminium foil. (2 marks)

Delta H will be higher when using aluminium foil.

It reduces heat loss to the surrounding environment, which increases the heat transfer to the water. This increases the delta H as the energy content of ethanol is measured to be higher.

Eunise suggests that instead of using aluminium foil to wrap the opening, they should use a plastic covering instead as plastic is an insulator.

c. Evaluate the use of Atharva's aluminium foil and Eunise's plastic covering, discussing the advantages of using both materials. (3 marks)

Aluminium foil - aluminium foil is reflective, and thereby reflects thermal radiation (heat loss) back into the water, which thereby minimises heat loss.
It is also a conductor of heat, which helps transfer the heat via conduction from the spirit burner to the beaker of water.

Eunise's plastic covering is an insulator and will help reduce heat loss to the surrounding.

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Question 26 (9 marks)

Stearic acid is a fatty acid that occurs naturally in animal and plant fats. One of the products of the transesterification of these fats is a biofuel with the molecular formula $C_{19}H_{38}O_2$.

The energy content of this biofuel is 12.4 $kcal\ g^{-1}$.

a. Write a balanced equation for the complete combustion of this biofuel where the products are measured at 25°C. (1 mark)

$$2C_{19}H_{38}O_2(l) + 55O_2(g) \rightarrow 38CO_2(g) + 38H_2O(l) \text{ or}$$

$$C_{19}H_{38}O_2(l) + \frac{55}{2}O_2(g) \rightarrow 19CO_2(g) + 19H_2O(l)$$

b. Given one calorie (cal) is equivalent to 4.18 J, determine ΔH, in $kJ\ mol^{-1}$, for the equation in **part a.** (2 marks)

Energy content biodiesel $= 12.4\ kcal\ g^{-1} \times 4.18\ kJ\ kcal^{-1}$

$= 51.83\ kJ\ g^{-1}$

$M(C_{19}H_{38}O_2) = 19 \times 12.0 + 38 \times 1.0 + 2 \times 16.0 = 298\ g\ mol^{-1}$

Energy per mol $= 51.83\ kJ\ g^{-1} \times 298\ g\ mol^{-1}$

$= 1.35 \times 10^4\ kJ\ mol^{-1}$

So, for the equation

$C_{19}H_{38}O_2(l) + 27.5O_2(g) \rightarrow 19CO_2(g) + 19H_2O(l);\ \Delta H = -1.35 \times 10^4\ kJ\ mol^{-1}$

or for equation

$2C_{19}H_{38}O_2(l) + 55O_2(g) \rightarrow 38CO_2(g) + 38H_2O(l);\ \Delta H = -1.35 \times 10^4\ kJ\ mol^{-1}$

c. If the volume of carbon dioxide produced from the consumption of one kilogram of this biofuel was collected and stored in a container at 25.0°C and 100 kPa, what would be the capacity of this container in L? (2 marks)

$n(biodiesel) = 1000g/298g\ mol^{-1}$

$= 3.36\ mol$

$n(CO_2) = 19 \times 3.36$

$= 63.8\ mol$

$V(CO_2) = n \times V_m = 63.8 \times 24.8$

$= 1581.2\ L$

d. What volume of liquid octane, in litres, has the same energy content as fifty litres of this biodiesel? Hence, do you think octane is the principal component of petrodiesel given petrodiesel is more energy efficient than biodiesel? (4 marks)
[Densities: Octane 0.703 $g\ mL^{-1}$; Methyl stearate 0.850 $g\ mL^{-1}$.]

$$m(biodiesel) = d(biodiesel) \times V$$
$$= 0.850 \times 10^3\ g\ L^{-1} \times 50.0\ L$$
$$= 4.25 \times 10^4\ g$$

Energy content of 50.0 L biodiesel = $4.25 \times 10^4\ g \times 51.83\ kJ\ g^{-1}$ (part (b))
$= 2.203 \times 10^6$ kJ

Energy content octane= 47.9 $kJ\ g^{-1}$ (Data Book Table 11)

$m(octane)\ required = energy\ required\ /\ energy\ per\ gram$

$= energy\ content\ of\ biodiesel\ /\ energy\ per\ gram\ octane$

$= \frac{2.203\times10^6\ \text{kJ}}{47.9} kJ\ g^{-1}$

$= 4.599 \times 10^4\ g$.

$V(octane) = \frac{m}{d} = \frac{4.599\times10^4}{0.703\ g} mL^{-1}$.

$= 6.54 \times 10^4\ mL$.

$= 65.4\ L$.

Therefore, no, octane is not main component of petrodiesel as it is less energy efficient than methyl sterate (more L for same energy)

Question 27 (7 marks)

A student wishes to investigate liquid pentane (C_5H_{12}) and determine its molar heat of combustion. As such, they combust pentane in a spirit burner and use the pentane to heat 150 g of water. The temperature of the water rises from 26.0°C to 61.2°C.

a. Find the energy absorbed by the water in kilojoules. (1 mark)

$q = mc\Delta T = 150 \times 4.18 \times (61.2 - 26) = 22070.4\ \text{J} = 22.1\ kJ$

b. Write a balanced chemical equation for the complete combustion of pentane. (1 mark)

$C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$

c. Given that 2.23 L of CO_2 is produced at 100 kPa and 25°C when the pentane was combusted, determine the heat of combustion of pentane in kJ/g and kJ/mol. (4 marks)

$$n(CO_2) = \frac{V}{V_m} = 2.23/24.8 = 0.08992\,mol$$

$$n(pentane) = \frac{1}{5} \times n(CO_2) = 0.01798\,mol.$$

$$m(pentane) = n \times M_r = 0.01798 \times (5 \times 12 + 12) = 1.295\,g.$$

$$\Delta H = \frac{q}{m} = -\frac{22.1}{1.295} = -17.05\frac{kJ}{g} = -1227.2\frac{kJ}{mol}$$

d. Calculate the volume of steam produced at these same conditions. (1 mark)

0 L – there is no steam produced at SLC

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