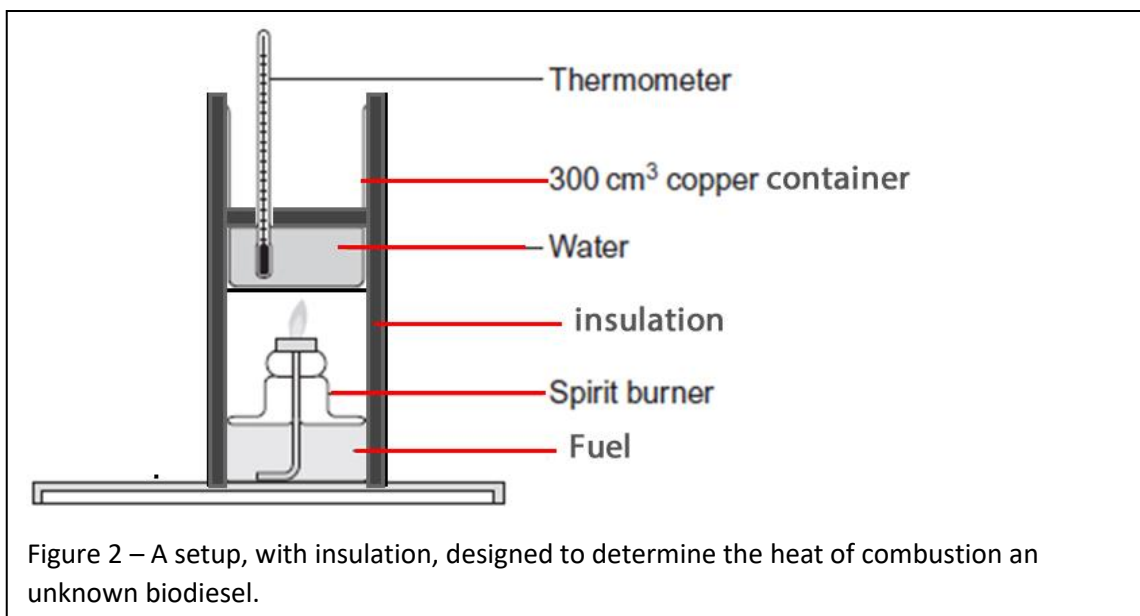
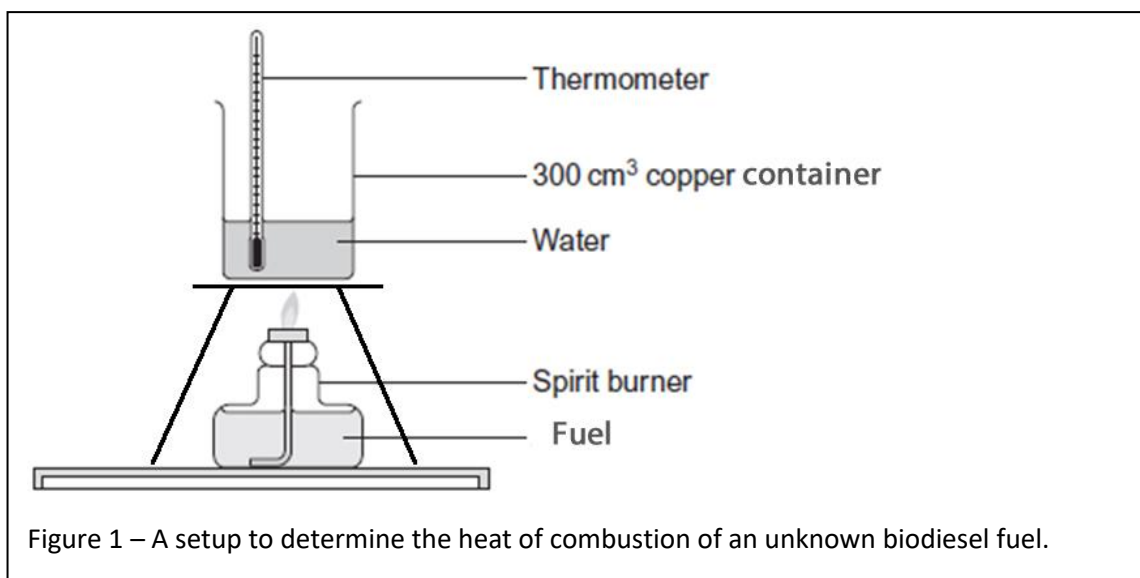


## Molar heat of combustion of a fuel.



Shown above are the experimental setups of two individual groups assigned the task of determining the heat of combustion in kJ/g of an unknown biodiesel. The table below shows the results of three groups. The mass of biodiesel for each group at each trial is also give in the table below.

Trial	Group 1		Group 2		Group 3	
	$\Delta T$ ( $^{\circ}\text{C}$ )	Mass of biodiesel (g)	$\Delta T$ ( $^{\circ}\text{C}$ )	Mass of biodiesel (g)	$\Delta T$ ( $^{\circ}\text{C}$ )	Mass of biodiesel (g)
1	33.5	3.0	25.5	3.00	38.9	3.0
2	41.4	3.0	24.6	3.00	38.6	3.0
3	35.6	3.0	25.4	3.00	37.8	3.0
4	29.8	3.0	25.2	3.00	37.9	3.0
5	30.2	3.0	24.9	3.00	37.7	3.0

Using the information presented above and given that the literature value for the heat of combustion of the biodiesel is 7130 J/g, answer the questions below.

- Given the volume of water used was consistently 150 mL for each trial calculate the average heat of combustion, for each group. Assume density of water is 1.00 g/mL. Show all calculations and give each answer to the right number of significant figures.

Group 1

*Step 1 – Assume all data is relevant, find the average  $\Delta T$*

$\Rightarrow (33.5 + 41.4 + 35.6 + 29.8 + 30.2) / 5 = 34.1 \text{ }^\circ\text{C}$  ----- 1 mark

*Step 2 – find the energy absorbed by the water*

$\Rightarrow 4.18 \text{ j/g}^\circ\text{C} \times 150\text{g} \times 34.1 \text{ }^\circ\text{C} = 21.38 \text{ kJ}$  ----- 1 mark

*Step 3 – find the energy per gram of the fuel.*

$\Rightarrow 21.38 \text{ kJ} / 3.0 \text{ g} = 7.1 \text{ kJ/g}$  ----- 1 mark correct answer and sig figs

Group 2

*Step 1 – Assume all data is relevant and find the average  $\Delta T$ .*

$\Rightarrow (25.5 + 24.6 + 25.4 + 25.2 + 24.9) / 5 = 25.1 \text{ }^\circ\text{C}$  ----- 1 mark

*Step 2 – find the energy absorbed by the water*

$\Rightarrow 4.18 \text{ j/g}^\circ\text{C} \times 150\text{g} \times 25.12 \text{ }^\circ\text{C} = 15.75 \text{ kJ}$  ----- 1 mark

*Step 3 – find the energy per gram of the fuel.*

$\Rightarrow 15.75 \text{ kJ} / 3.00 \text{ g} = 5.25 \text{ kJ/g}$  ----- 1 mark correct answer and sig figs

Group 3

*Step 1 – Assume all data is relevant and find the average  $\Delta T$*

$\Rightarrow (38.9 + 38.6 + 37.8 + 37.9 + 37.7) / 5 = 38.2 \text{ }^\circ\text{C}$  ----- 1 mark

*Step 2 – find the energy absorbed by the water*

$\Rightarrow 4.18 \text{ j/g}^\circ\text{C} \times 150\text{g} \times 38.2 \text{ }^\circ\text{C} = 24.0 \text{ kJ}$  ----- 1 mark

*Step 3 – find the energy per gram of the fuel.*

$\Rightarrow 24.90 \text{ kJ} / 3.00 \text{ g} = 8.0 \text{ kJ/g}$  ----- 1 mark correct answer and sig figs

- Complete the table below to describe each group's data . Circle two appropriate responses.

Group	Accuracy	Validity	Precision
1	High accuracy Low accuracy	More valid Less valid	High precision Low precision
2	High accuracy Low accuracy	More valid Less valid	High precision Low precision
3	High accuracy Low accuracy	More valid Less valid	High precision Low precision

*Group 1 has results that lack precision but when averaged out are closer to the real value than groups 2 and 3, hence, the results have higher accuracy. Since group 1 used the*

*uninsulated apparatus a greater proportion of the energy given off by the fuel was able to be lost by the water to the environment and hence give a lower measurable temperature increase than expected. This makes the results less valid as they represent a lower proportion of the energy released. Results lack precision as the highest and lowest recordings of  $\Delta T$  differ by  $11.6\text{ }^{\circ}\text{C}$  (41.4 to 29.8).*

*Groups 2 and 3 produce results that give a less accurate value when compared to the known energy density of the fuel. The fact that groups 2 and 3 selected the apparatus which had high insulation means the results obtained are more valid than group 1. Group 2 and 3, however, have results with the highest precision out of the three groups, where the highest and lowest recording of group 2 differ by only  $0.9\text{ }^{\circ}\text{C}$  and those of group 3 differ by  $1.2\text{ }^{\circ}\text{C}$ .*

3. Suggest a type of error present in each of the three group's investigation that would lead to the results obtained by each group. Give an example of such an error and suggest how this error would lead to the results obtained by each group.

#### Group 1

*Random error. ---- 1 mark*

*Any plausible random error that will cause fluctuations in the results.*

*eg The apparatus was set up in a drafty part of the room where irregular and inconsistent convection currents would cause a varying degree of heat loss from the water. ---- 1mark*

#### Group 2

*Systematic error ---- 1 mark*

*Since the results are more precise than group 1 it must be a consistent error hence systematic.*

*Any plausible systematic error that would lead to an underestimation of the energy density of the fuel.*

*Any plausible suggestion with an explanation as to how it would impact the results.*

*eg The limited supply of oxygen in the ignition chamber would lead to incomplete oxidation and hence lead to the release of less energy. ---- 1 mark*

*Human error that is consistently applied can become a systematic error*

*eg. The amount of water placed in the beaker was greater than 150g by a consistent amount for each trial hence giving a lower  $\Delta T$  as the energy produced heats up larger volume of water.*

*Badly calibrated thermometer was not accepted as taking the difference in temperature would eliminate this error.*

*It is important for students to note that a human error is one which occurs when the procedure is not followed either through carelessness of the person conducting the experiment or through a lack of training in the use of equipment or calculation of results. A human error, however, consistently applied can be a systematic error. This is exemplified when a burette is read with a consistent parallax error due to the operator not adhering to the correct procedure in reading the burette.*

#### Group 3

*Systematic error ---- 1 mark*

*Since the results are more precise than group 1 it must be a consistent error hence systematic.*

*Any plausible systematic error that would lead to an overestimation of the energy density of the fuel.*

*eg adding less water is human error as the experimenter failed to adhere to the procedure, however, wince this error is consistently applied across all the trials it becomes a systematic error. The water in the beaker was less than 150 g by a consistent amount during each trial. This would increase the  $\Delta T$  as the energy produced by 3.0 grams of water heats up a smaller volume of water hence raising the temperature of the water by a greater amount. ---- 1 mark*  
*Badly calibrated thermometer was not accepted as the difference in temperature would eliminate this error.*

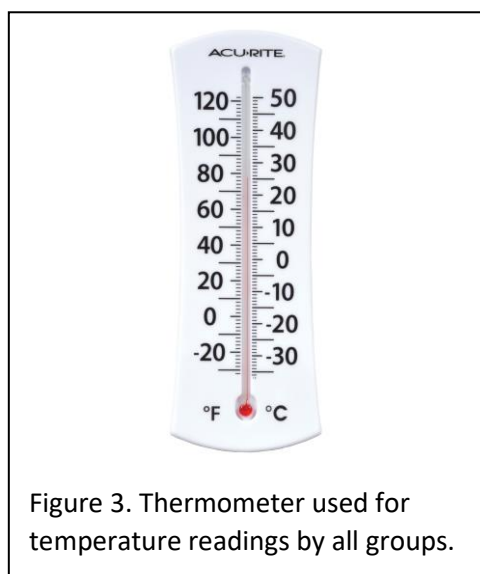
4. What is the resolution of the electronic scale used by each group?

Group 1 \_\_\_\_\_ *0.1g* \_\_\_\_\_ -----1 mark

Group 2 \_\_\_\_\_ *0.01g* \_\_\_\_\_ -----1 mark

Group 3 \_\_\_\_\_ *0.1g* \_\_\_\_\_ -----1 mark

*Resolution is the smallest gradation on an instrument display that a value can be read to without needing the experimenter to guess or make a judgement on the final digit of the value.*



5. Consider the thermometer shown in fig. 3.

a. Determine the resolution of this instrument.

*1.0 °C ----- 1 mark*

b. With reference to the temperature readings from group 1, describe the difference between the terms **precision** and **resolution**.

*When a quantity is measured under the same conditions precise results are achieved when there is little variance between each result. In other words the results are repeatable and differ little from a given value. ---- 1 mark*

The temperature readings (33.5, 41.4, 35.6, 29.8, 30.2) show variability, ranging from 41.4 to 29.2 a range of 12.2 °C. Hence precision is not high.

---- 1 mark reference to data

Resolution on the other hand refers to the smallest increment a measuring device can be read to without the operator having to judge the final digit. The smallest gradation on the thermometer is 0.1 °C so its resolution is 0.1°C. ---- 1 mark

6. Name one limitation of the setup shown in figure 2, above and state how this limitation will impact the final result.

---- 1 mark for any plausible limitation

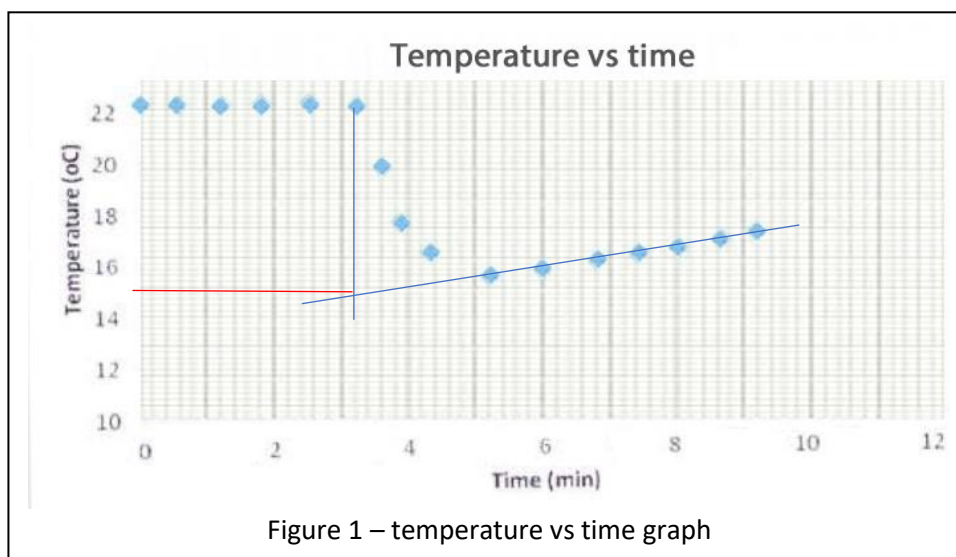
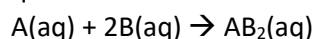
---- 1 mark for accurate impact on final calculation.

Eg. Limited amount of oxygen present in the combustion chamber of the well-insulated device (fig 2) leads to incomplete combustion hence releasing a limited amount of the energy potential of the fuel hence a lower energy density is calculated.

Hence only small amounts of fuel can be burnt in the limited oxygen environment.

Eg. The thermometer used has a resolution of 0.1 °C and hence small changes in temperature when minute amounts of fuel samples are burnt, may not be accurately detected and resolved.

7. A reaction is represented by the equation shown below.



50.0 mL of 0.500 M A solution is mixed with 50.0 mL of a 1.00 M B solution in a solution calorimeter. The temperature of the water was measured over time and recorded in the graph in fig 1.

- a. Using the graph in fig 1, calculate the change in temperature( $\Delta T$ ) of the water in the beaker. 1 mark

*Reading from the graph we get  $22.2\text{ }^{\circ}\text{C} - 14.9\text{ }^{\circ}\text{C} = 7.3\text{ }^{\circ}\text{C}$*

*Margin for error is allowed .  $7.0 - 7.4$*

- b. Indicate if energy is absorbed or released by the reaction and calculate the amount of heat energy, in kJ, involved.

*Energy is absorbed ----- 1 mark*

*$E = 4.18\text{ J/g}^{\circ}\text{C} \times 100\text{g} \times 7.3\text{ }^{\circ}\text{C} = 3.1\text{ kJ}$  ----- 1 mark*

- c. What is assumed in calculating the amount of energy in b. above?

*Either*

*The density of the resulting 100 mL solution is 1g/mL because the solutions are not pure water and so solutes will influence the density of the solution.*

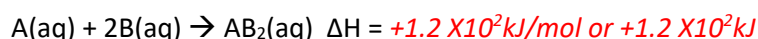
*or*

*that solution has a heat capacity equivalent to pure water ( $4.18\text{ J/g}^{\circ}\text{C}$ ) . Again solutions are not pure water and solutes can impact the heat capacity of water ----- 1 mark*

*Do not accept "We assume that all the energy is absorbed by the water" as the extrapolation of the temperature time graph is an attempt to account for the lost energy in terms of  $\Delta T$ .*

*Do not accept "we assume that the heat capacity of pure water is  $4.18\text{ }^{\circ}\text{C}$  or the density of water is 1g/mL" as these are facts stated in the data book.*

- d. Calculate the  $\Delta H$  of the reaction below.



*Step 1 find the limiting reactant*

$$\Rightarrow n_A = 0.0500 \times 0.500 = 0.0250$$

$$\Rightarrow n_B = 0.0500 \times 1 = 0.0500$$

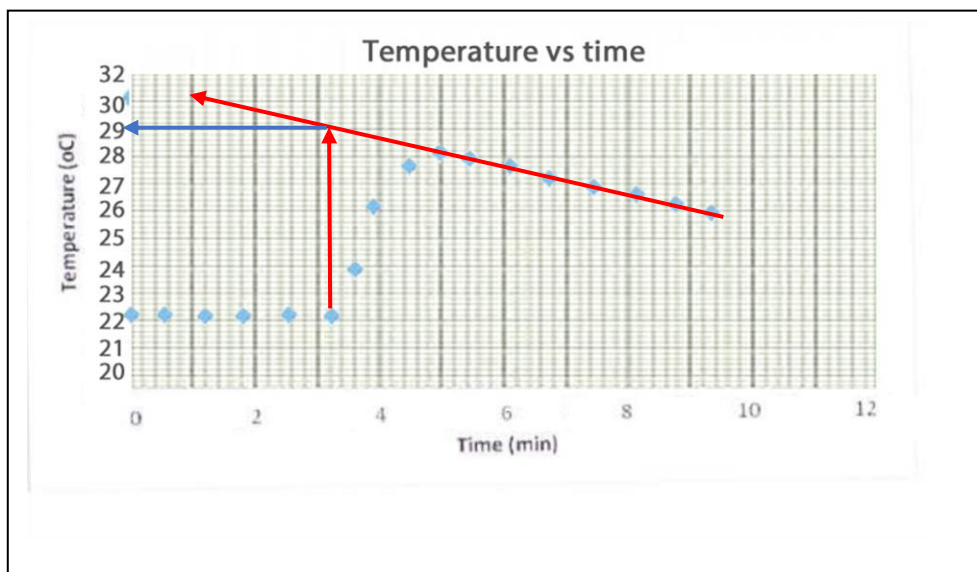
*Reactants are in the right ratio*

*Step 2 find the kJ/mol using the mol of A*

$$\Rightarrow 3.1\text{ kJ} / 0.0250\text{ mol} = 124\text{ kJ} \Rightarrow 1.2 \times 10^2 \text{ kJ/mol} \quad \text{---- 1 mark}$$

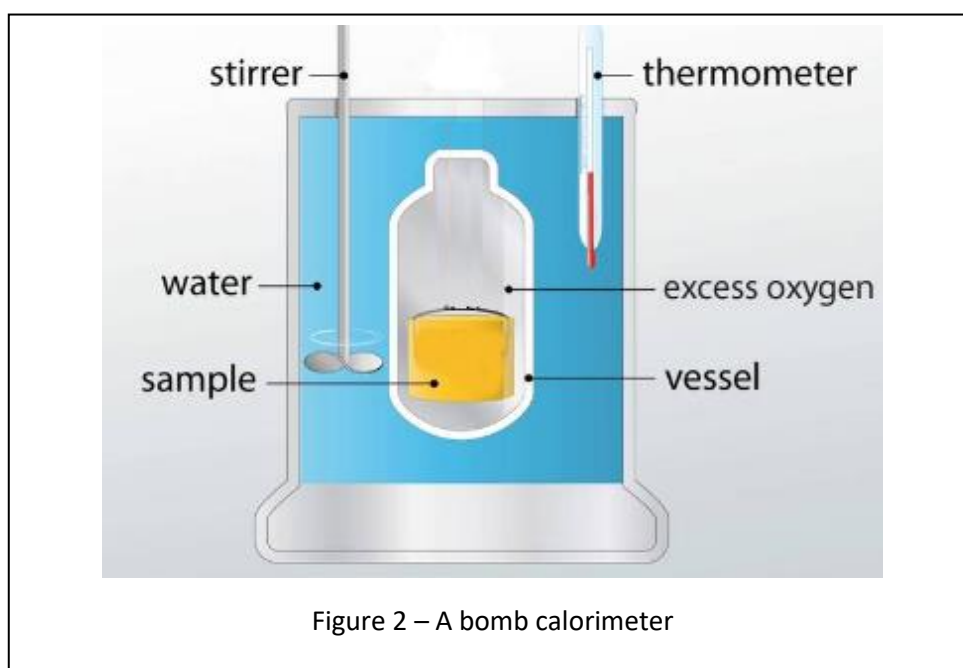
*Step 3 find  $\Delta H = + 1.2 \times 10^2 \text{ kJ/mol}$  ----- 1 mark*

8.

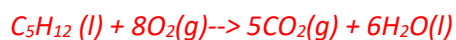


A bomb calorimeter is an instrument designed to measure the heat of combustion of different substances as shown in fig 2. Energy is measured indirectly by measuring the change in temperature of a given mass of water.

A mass of  $8.44 \times 10^{-2}$  grams of liquid pentane was placed in the combustion chamber and ignited. The temperature of the 150.0 grams of water was then recorded at regular intervals and plotted on the graph shown in fig 3.



- a. Using the graph in fig 3 obtain the temperature change ( $\Delta T$ ) of the water.  
*29.0 - 22.2 = 6.8 (range 6.7-8.0)*
- b. Give the balanced chemical equation for the complete combustion of pentane at SLC.



--- 1 mark correct states

--- 1 mark correct formulas

- c. Calculate the  $\Delta H$  for the equation given as the answer to question b. above.

*Step 1 – Find the energy released*

$$\Rightarrow E = 4.18 \text{ J/g}^\circ\text{C} \times 150\text{g} \times 6.8^\circ\text{C} = 4.264 \text{ kJ} \quad \text{---- 1 mark}$$

*Step 2 – find the mol of pentane*

$$\Rightarrow 0.0844 / 72.0 = 0.00117 \text{ mol} \quad \text{---- 1 mark}$$

*Step 3 – find the molar heat of combustion*

$$\Rightarrow 4.264 / 0.00117 = 3644 \text{ kJ/mol} \quad \text{---- 1 mark}$$

*Step 4 – Find the  $\Delta H$*

$$\Rightarrow C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l) \quad \Delta H = -3644 \text{ kJ or } -3644 \text{ kJ/mol} \quad \text{---- 1 mark}$$

*Since the equation shows one mole of pentane reacting, the  $\Delta H$  is therefore written as the molar heat of combustion with a negative sign.*

- d. One experimenter accidentally placed 180 grams of water instead of 150 grams in the bomb calorimeter.

- i. How does this impact the calculated  $\Delta H$  for the reaction? Circle the correct response below. 1 mark

No change

Gives a higher  $\Delta H$

Gives a lower  $\Delta H$

- ii. What type of error is this?

*Human error*

- e. The analogue thermometer used to obtain the temperature readings is shown in fig 4.

- i. What is the resolution of the data.

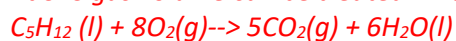
*1°C*

- ii. If the initial temperature of the water was recorded using a digital thermometer to 22.65 °C what would be the reading that should be recorded using the analogue thermometer shown in fig 4?

*23 °C*

- f. What is the volume of  $CO_2$  produced if 400 litres of oxygen gas reacts with excess liquid pentane at SLC.

*At SLC gas volume can be treated in ratios exactly as we would treat mol.*



*\Rightarrow The ratio between oxygen gas and carbon dioxide is 8 : 5*

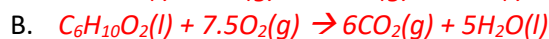
---- 1 mark

*\Rightarrow so 400 litres of  $O_2$  gas will produce  $5/8 \times 400$  litres of  $CO_2 \Rightarrow 250 \text{ L}$*

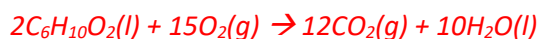
---- 1 mark



9. Two organic acids, **Compound A** (C<sub>6</sub>H<sub>12</sub>O<sub>2</sub>) and **Compound B** (C<sub>6</sub>H<sub>10</sub>O<sub>2</sub>), undergo complete combustion, at SLC.
- a. Write the balanced chemical equations for the combustion of both compounds. 3 marks



Or



---- 1 mark for correct states in each equation (water and organic acid as a liquids)

---- 1 mark for balanced equations

---- 1 mark for correct formulae in both equations

- b. Consider the following bond energies, found in the data book in tables 10 and 11.

**Bond Energies:**

C-H: 414 kJ/mol

C-C: 346 kJ/mol

C=O: 804 kJ/mol

C-O: 358 kJ/mol

O-H: 463 kJ/mol

O=O: 498 kJ/mol

- i. Using the balanced chemical equations provided in question a, above, and the bond energies listed, identify the acid with the highest molar heat of combustion and give an explanation to justify your answer.

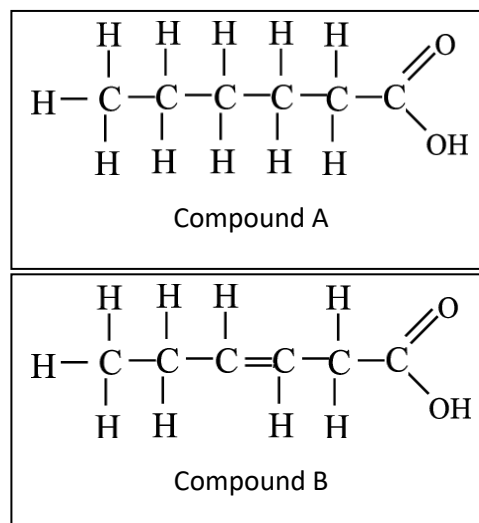
---- 1 mark Compound A has the highest molar heat of combustion

---- 1 mark reference to difference in bonds and bond energies of reactants.

Compound A has 2 more C-H bonds (414 kJ/mol) than compound B and produces 2 more O-H bonds (463 kJ/mol) than compound B  
Compound A reacts with 0.5 mol more of O<sub>2</sub> than compound B

Compound B has a C=C bond (614 kJ/mol) in place of a C-C (346 kJ/mol).

---- 1 mark for referencing the extra 2 O-H (463 kJ/mol) bonds as products for compound A.



- ii. Calculate the molar heat of combustion ( $\Delta H$ ), kJ/mol, of acid A. 2 marks

$11 \times C-H = 11 \times 414 \text{ kJ/mol} = 4554 \text{ kJ/mol}$

$5 \times C-C = 5 \times 346 \text{ kJ/mol} = 1730 \text{ kJ/mol}$

$1 \times C-O = 1 \times 358 \text{ kJ/mol} = 358 \text{ kJ/mol}$

$1 \times O-H = 1 \times 463 \text{ kJ/mol} = 463 \text{ kJ/mol}$

$1 \times C=O = 1 \times 804 \text{ kJ/mol} = 804 \text{ kJ/mol}$

$8 \times O=O = 8 \times 498 \text{ kJ/mol} = 3984 \text{ kJ/mol}$

Total energy needed to break reactant bonds = 11893 kJ/mol

*Energy released during bond formation*

*12 X C=O = 12 X 804 = 9648 kJ/mol*

*12 X O-H = 12 X 463 = 5556 kJ/mol*

*Total energy released = 15204 kJ/mol*

*$\Delta H = 11893 - 15204 = -3311$  kJ/mol*

- iii. Explain the difference in molar heat of combustion of both acids in terms of oxidation states.

***Compound A*** ( $C_6H_{12}O_2$ ) and ***Compound B*** ( $C_6H_{10}O_2$ ),

*Carbon in compound A has an oxidation state of -1.3 whilst carbon in compound B has an oxidation state of -1. ----- 1 mark*

*Hence compound B is already partially oxidised ----- 1 mark*