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VCE Chemistry ¾
Calorimetry [0.3]
Workshop Solutions

Section A: Recap

Learning Objective: [1.4.1] - Calculate Calibration Factor via Electrical and Chemical Calibration $(\boldsymbol{CF = E/\Delta T})$

- Calorimeters are used to minimise heat loss.
- Heat is transferred directly to water.

Electrical Calibration	Chemical Calibration
$\boxed{\boldsymbol{E = VIt}}$	$\boxed{\boldsymbol{E = \Delta H \times n}}$

Learning Objective: [1.4.2] - Apply Calibration Factor to Find Energy Released $(\boldsymbol{E = CF \times \Delta T})$

- Calorimetry Calculation Steps:

1. Find ___energy___ (chemical/electrical) ($E = VIt$ or $E = \Delta H \times n$).
2. ___Find Calibration Factor $\left(CF = \frac{E}{\Delta T}\right)$___.
3. ___Use Calibration Factor $(E = CF \times \Delta T)$___.
4. ___Find the change in enthalpy $\left(\Delta H = \frac{q}{m}\right)$___.

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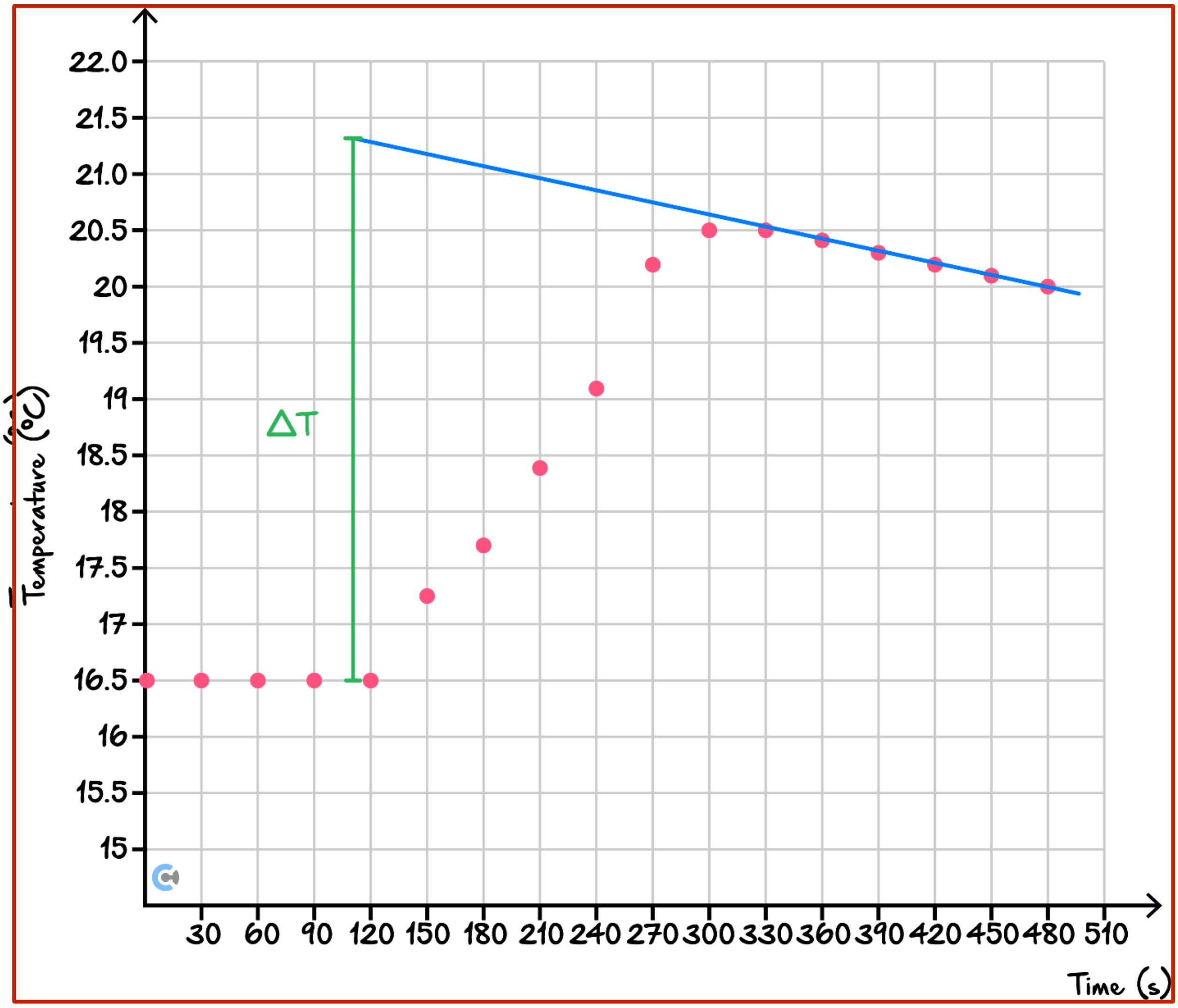
Learning Objective: [1.4.3] – Apply Temperature – Time Graphs to Calorimetry

- Find ΔT by __ extrapolating backwards __.
- For the following temperature-time graph, the change in temperature is as labelled:



- If the calorimeter has poor insulation, it has a [higher] / [lower] calibration factor.

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Question 1 Walkthrough.

A solution calorimeter was calibrated by reacting 0.053 mol of nitric acid (HNO_3) $\Delta H = -21.30\ kJ/g$ at 20.00°C. The temperature of the water in the calorimeter increased to 23.50°C during the calibration.

This calorimeter was then used to determine the heat content of a sample of Doritos. 25.00 g of Doritos were reacted in the calorimeter and the temperature of the water in the calorimeter rose by 4.9°C. Calculate the energy content of the Doritos in $kJ\ g^{-1}$.

$$m(HNO_3) = n \times M_r = 0.053 \times (1+14+48)$$

$$= 3.34g$$

$$q = \Delta H \times m = 21.3 kJ/g \times 3.34g$$

$$= 71.1 kJ$$

$$CF = \frac{E}{\Delta T} = \frac{71.1 kJ}{3.5°C} = 20.3 kJ/°C$$

$$E = CF \times \Delta T = 20.3 kJ/°C \times 4.9°C = 99.6 kJ$$

$$\Delta H = \frac{q}{m} = \frac{99.6 kJ}{25g} = 3.98 kJ/g$$

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Section B: Warm Up (10 Marks)

INSTRUCTION: 10 Marks. 7 Minutes Writing.

Question 2 (1 mark)

A bomb calorimeter was calibrated using a constant current of 3.40 A for 5.00 minutes. The voltage was 3.85 V. The temperature increased from 19.5°C to 22.1°C.

What is the calibration factor?

1.510×10^3 J / °C

Question 3 (3 marks)

A magnesium strip which weighs 30.0 g is added to excess cadmium nitrate, which reacts according to the following reaction:

$$\mathrm{Cd(NO_3)_2(aq) + Mg(s) \rightarrow Mg(NO_3)_2(aq) + Cd(s)} \quad \Delta H = -105\ kJ/mol$$

Given that the temperature of the system increases from 32.6°C to 39.1°C, find the calibration factor in $kJ/$°C.

$$n(Mg) = \frac{m}{M_r} = \frac{30\,g}{24.3\,g/mol} = 1.235\,mol$$

$$q = \Delta H \times n = 105\,kJ/mol \times 1.235\,mol$$
$$= 129.6\,kJ$$

$$CF = \frac{E}{\Delta T} = \frac{129.6\,kJ}{(39.1-32.6)°C} = 19.94\,kJ/°C$$

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Question 4 (2 marks)

Given that the calibration factor of a particular calorimeter is 369.0 $J/°C$, find the energy content of a 1.40 g biscuit in kJ/g, which happens to increase the temperature of the same calorimeter from 15.7°C to 23.2°C.

$$q = CF \times \Delta T = 369 J/°C \times (23.2 - 15.7)°C$$
$$= 2768 J$$
$$\Delta H = \frac{q}{m} = \frac{2.768 kJ}{1.40 g} = \underline{1.97 kJ/g}$$

Question 5 (1 mark)

A bomb calorimeter is calibrated by burning 1.05 g of benzoic acid (molar mass of 122 $g\ mol^{-1}$) and (ΔH_c of 3227 $kJ\ mol^{-1}$). If the temperature rose by 3.45°C, the calibration factor of the calorimeter in kJ °C^{-1} is:

A. 0.137

B. 8.05

C. 27.1

D. 95.9

Answer: B

Explanation:

n = m/M = 1.05 / 122 = 0.00861 mol
1 mol → 3227 kJ, so 0.00861 mol → 0.00861 x 3227 = 27.8 kJ
3.45 °C → 27.8 kJ so, 1°C → 27.8/3.45 = 8.05 kJ°C^{-1}

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Question 6 (3 marks)

A solution calorimeter containing 200 mL of water at SLC is calibrated by passing a 4.00 A current through the instrument for 5.20 minutes, at a potential difference of 2.25 V. The temperature of the water in the calorimeter rises to 31.80°C.

a. Calculate the calibration factor for the calorimeter and water in $J/°C$. (1 mark)

$$E = VIt = 2.25 \times 4 \times 5.2 \times 60 = 2808\,J$$

$$CF = \frac{E}{\Delta T} = \frac{2808\,J}{(31.8 - 25)°C} = \underline{413\,J/°C}$$

b. A piece of garlic of mass 1.20 g was reacted in the calibrated solution calorimeter.

If the temperature of the water increased from 20.00°C to 24.80°C, calculate the energy content of the garlic in $kJ\ g^{-1}$. (2 marks)

$$E = CF \times \Delta T = 413\,J/°C \times 4.8°C = 1982\,J$$
$$= 1.982\,kJ$$

$$\Delta H = \frac{E}{m} = \frac{1.982\,kJ}{1.20\,g} = \underline{1.65\,kJ/g}$$

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Section C: Ramping Up (6 Marks)

INSTRUCTION: 6 Marks. 5 Minutes Writing.

The following information applies to the three questions that follow.

The energy content of peanuts in a particular sample was investigated using two different methods.

- Method 1: A peanut was weighed and set alight. The burning peanut was then held close to a flask containing 25.0 g of water. The temperature of the water increased by 14.2°C by burning 0.113 g of the peanut.
- Method 2: 0.238 g of crushed peanuts were burnt in a bomb calorimeter to produce an increase in the temperature of 6.35°C. The energy content of the peanuts was calculated to be 23.1 $kJ\ g^{-1}$.

Question 7 (1 mark)

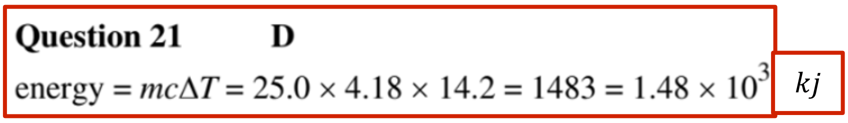
How many joules of energy were used to heat the water in the method 1?

A. 8.49 kJ

B. 1.67×10^2 kJ

C. 1.06×10^3 kJ

D. 1.48×10^3 kJ



Question 21 **D**

energy = $mc\Delta T = 25.0 \times 4.18 \times 14.2 = 1483 = 1.48 \times 10^3$ *kj*

Question 8 (1 mark)

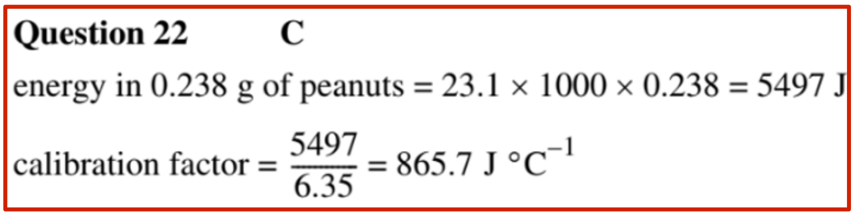
What is the calibration factor (in $J\ °C^{-1}$) of the bomb calorimeter used in the method 2?

A. 86.6

B. 616

C. 866

D. 925



Question 22 **C**

energy in 0.238 g of peanuts = $23.1 \times 1000 \times 0.238 = 5497$ J

calibration factor = $\frac{5497}{6.35} = 865.7\ \text{J °C}^{-1}$

Question 9 (1 mark)

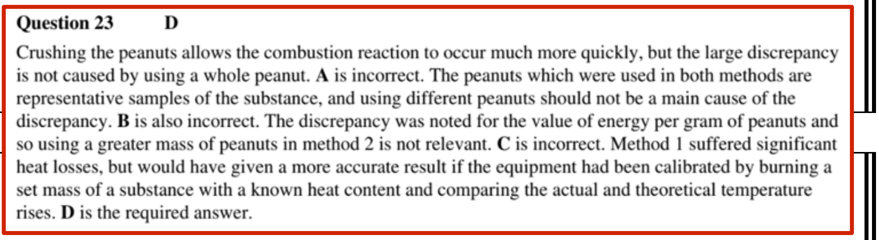
Method 2 produced a much higher value for the energy content per gram of peanuts than the method 1. What is the main reason for this discrepancy?

A. The peanut used in the method 1 was not crushed.

B. Method 2 used different peanuts to method 1.

C. A greater mass of peanuts was used in method 2.

D. Method 1 did not use any calibration.

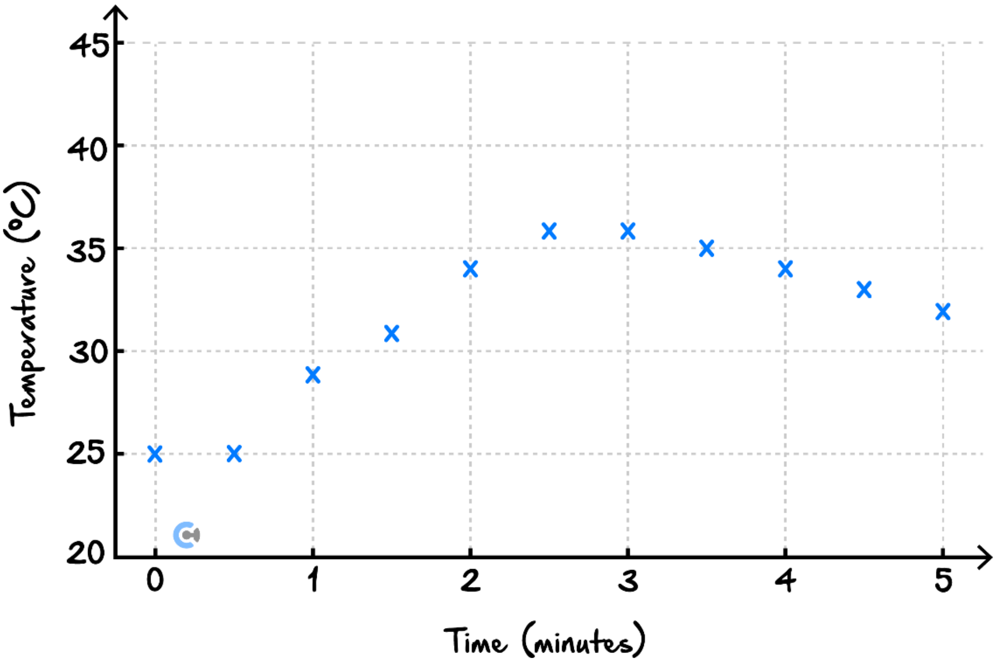


Question 23 **D**

Crushing the peanuts allows the combustion reaction to occur much more quickly, but the large discrepancy is not caused by using a whole peanut. **A** is incorrect. The peanuts which were used in both methods are representative samples of the substance, and using different peanuts should not be a main cause of the discrepancy. **B** is also incorrect. The discrepancy was noted for the value of energy per gram of peanuts and so using a greater mass of peanuts in method 2 is not relevant. **C** is incorrect. Method 1 suffered significant heat losses, but would have given a more accurate result if the equipment had been calibrated by burning a set mass of a substance with a known heat content and comparing the actual and theoretical temperature rises. **D** is the required answer.

Question 10 (3 marks)

To more accurately find the calibration factor of a calorimeter, Jayden plots the following temperature-time graph. He reacts with some nitrogen dioxide (NO_2), which is known to have a change in enthalpy of $-15.29\ kJ/g$. Find the calibration factor, if 2.00 mol of nitrogen dioxide is reacted.



$\Delta T = 40 - 25 = 15°C$

$m(NO_2) = n \times M_r = 2 \times (14+32) = 92\ g$

$q = \Delta H \times m = 15.29\ kJ/g \times 92g = 1406.7\ kJ$

$CF = \frac{E}{\Delta T} = \frac{1406.7\ kJ}{15°C} = 93.8\ kJ/°C$

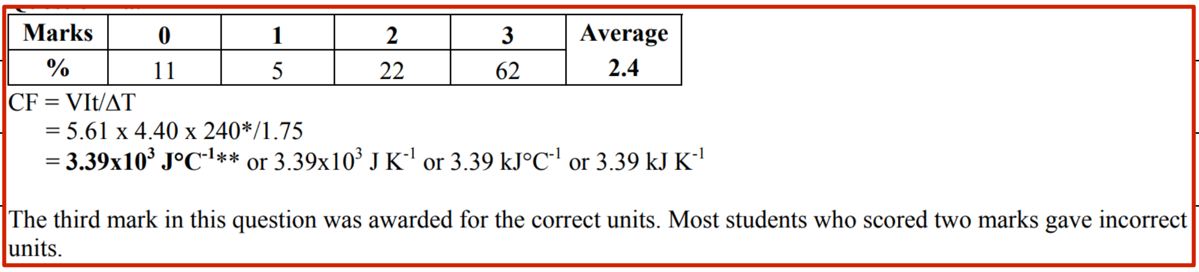
Section D: Getting Trickier I (8 Marks)

INSTRUCTION: 8 Marks. 7 Minutes Writing.

Question 11 (8 marks)

Methyl palmitate, $C_{17}H_{34}O_2$, is a component of one type of biochemical fuel. It is a liquid at room temperature. The molar enthalpy of combustion of methyl palmitate was determined using a bomb calorimeter. The calorimeter was calibrated by passing a current of 4.40 amperes at a potential difference of 5.61 volts through an electric heater for 240 seconds. The temperature of the calorimeter rose by 1.75°C.

a. Calculate the calibration factor of the calorimeter. Include the units of the calibration factor with your answer. (3 marks)



Marks	0	1	2	3	Average
%	11	5	22	62	**2.4**

CF = VIt/ΔT

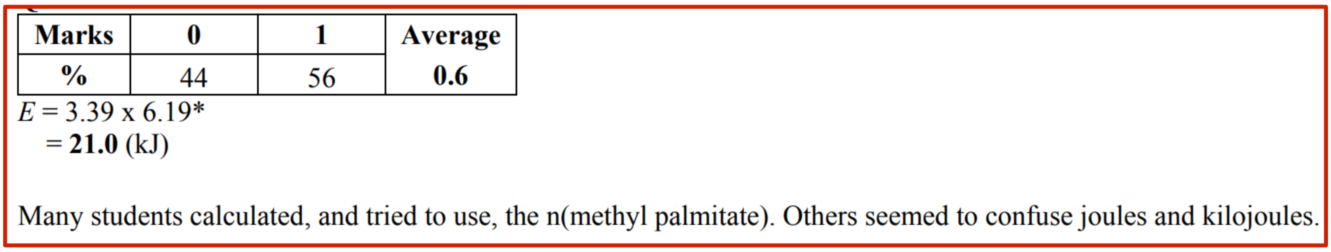
$= 5.61 \times 4.40 \times 240^{*}/1.75$

$= \mathbf{3.39\times10^{3}\ J°C^{-1}}$** or 3.39×10^{3} J K^{-1} or 3.39 kJ°C^{-1} or 3.39 kJ K^{-1}

The third mark in this question was awarded for the correct units. Most students who scored two marks gave incorrect units.

A 0.529 g sample of methyl palmitate was then burned in excess oxygen in the calorimeter and the temperature rose by a further 6.19°C. The molar mass of methyl palmitate is 270 $g\ mol^{-1}$.

b. Calculate the amount of energy, in kJ, absorbed by the calorimeter when the sample of methyl palmitate was burned. (1 mark)



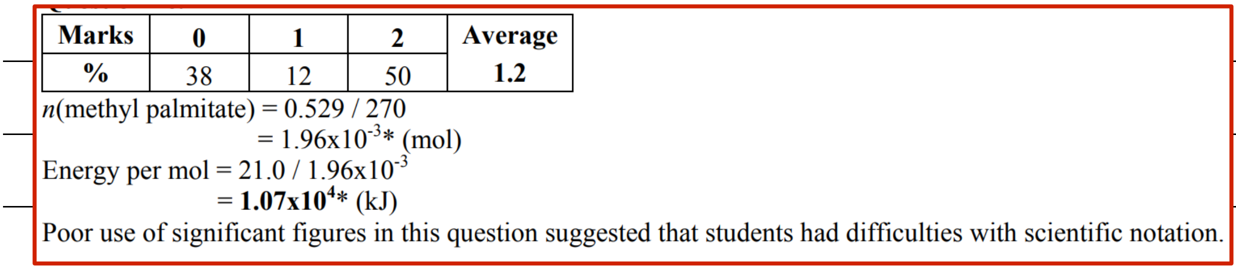
Marks	0	1	Average
%	44	56	**0.6**

$E = 3.39 \times 6.19^{*}$

$= \mathbf{21.0}$ (kJ)

Many students calculated, and tried to use, the n(methyl palmitate). Others seemed to confuse joules and kilojoules.

c. Calculate the amount of energy released, in kJ by the combustion of 1.00 mol of methyl palmitate. (2 marks)



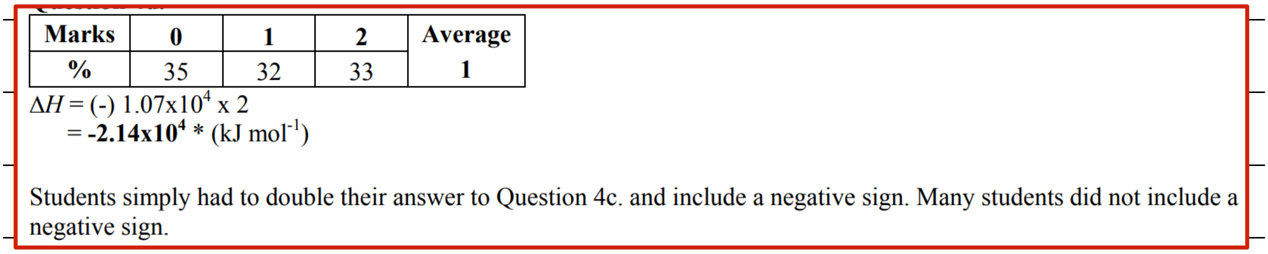
Marks	**0**	**1**	**2**	**Average**
%	38	12	50	**1.2**

n(methyl palmitate) = 0.529 / 270
= 1.96x10^{-3}* (mol)
Energy per mol = 21.0 / 1.96x10^{-3}
= **1.07x10^{4}*** (kJ)
Poor use of significant figures in this question suggested that students had difficulties with scientific notation.

d. The balanced equation for the combustion of liquid methyl palmitate in excess oxygen is:

$$2C_{17}H_{34}O_2(l) + 49O_2(g) \rightarrow 34CO_2(g) + 34H_2O(l)$$

Write the value of ΔH for this reaction, in $kJ\ mol^{-1}$. (2 marks)



Marks	**0**	**1**	**2**	**Average**
%	35	32	33	**1**

ΔH = (-) 1.07x10^{4} x 2
= **-2.14x10^{4}** * (kJ mol^{-1})

Students simply had to double their answer to Question 4c. and include a negative sign. Many students did not include a negative sign.

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Section E: Getting Trickier II (8 Marks)

INSTRUCTION: 8 Marks. 8 Minutes Writing.

Question 12 (1 mark)

The reaction between solutions of hydrochloric acid and sodium hydroxide can be represented by the following equation:

$$\mathrm{HCl(aq)} + \mathrm{NaOH(aq)} \rightarrow \mathrm{NaCl(aq)} + \mathrm{H_2O(l)} \quad \Delta H = -56\ kJ\ mol^{-1}$$

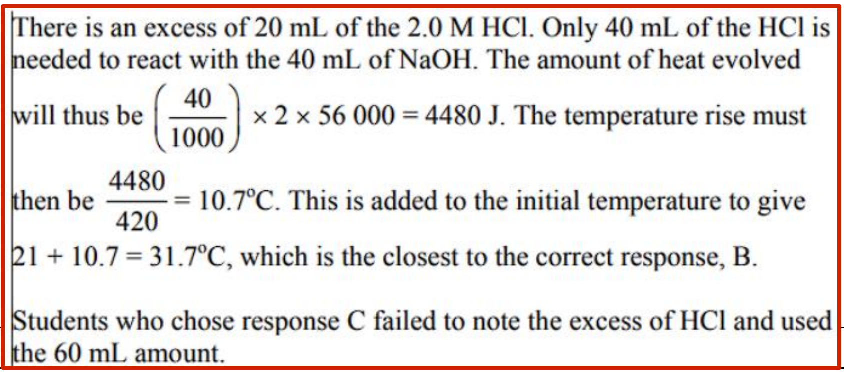
60.0 mL of 2.0 M HCl, at 21°C, is mixed with 40.0 mL of 2.0 M NaOH, also at 21°C, in a well-insulated calorimeter. The calibration factor for the calorimeter and contents is 420 $J\ K^{-1}$. The final temperature, in °C, of the resultant solution in the calorimeter would be closest to:

A. 11

B. 32

C. 37

D. 52



There is an excess of 20 mL of the 2.0 M HCl. Only 40 mL of the HCl is needed to react with the 40 mL of NaOH. The amount of heat evolved will thus be $\left(\frac{40}{1000}\right) \times 2 \times 56\ 000 = 4480$ J. The temperature rise must then be $\frac{4480}{420} = 10.7$°C. This is added to the initial temperature to give $21 + 10.7 = 31.7$°C, which is the closest to the correct response, B.

Students who chose response C failed to note the excess of HCl and used the 60 mL amount.

Question 13 (7 marks)

Angela loves playing around with some chemicals, and tries dissolving sulphuric acid into water. Below is the equation which represents what occurs:

$$\mathrm{H_2SO_4(s)} \rightarrow \mathrm{H_2SO_4(aq)} \qquad \Delta H = +75\ kJ/mol$$

a. When starting at 38.0°C, a sample of 8.30 g of sulphuric acid is dissolved into water. Given that the calibration factor is known to be 350 $J/$°C, find the expected final temperature of the water. (3 marks)

$n(H_2SO_4) = \frac{m}{M_r} = \frac{8.30}{2+32.1+64} = 0.0846 mol$

$q = \Delta H \times n = 75 kJ/mol \times 0.0846 mol$

$= 6.346 kJ$

$= 6346 J.$

$CF = \frac{q}{\Delta T} \quad \Delta T = \frac{q}{CF} = \frac{6346 J}{350 J/°C} = 18.1°C$

$T_f = 38.0 - 18.1 = \underline{19.9°C}$

Another reaction that involves sulphuric acid has excess lead (Pb) added to it, which reacts in the following manner:

$$H_2SO_4(aq) + Pb(s) \rightarrow PbSO_4(aq) + H_2(g)$$

The reaction is known to be exothermic, which produces 22.0 *L* of hydrogen gas at SLC.

b. Given that the reaction begins at 15.0°C, find the change in enthalpy of the reaction, which indicates the energy produced for every 1.00 *g* of lead. (4 marks)

$n(H_2) = \frac{V}{V_m} = \frac{22}{24.8} = 0.887\,mol$

$n(Pb) = n(H_2) = 0.887\,mol$

$m(Pb) = 183.8\,g$

$E = CF \times \Delta T = 350\,J/°C \times 10°C = 3500\,kJ$

$\Delta H = \frac{q}{m} = \frac{3500\,kJ}{183.8\,g} = \underline{19.0\,kJ/g}$

Let's take a ***BREAK!***

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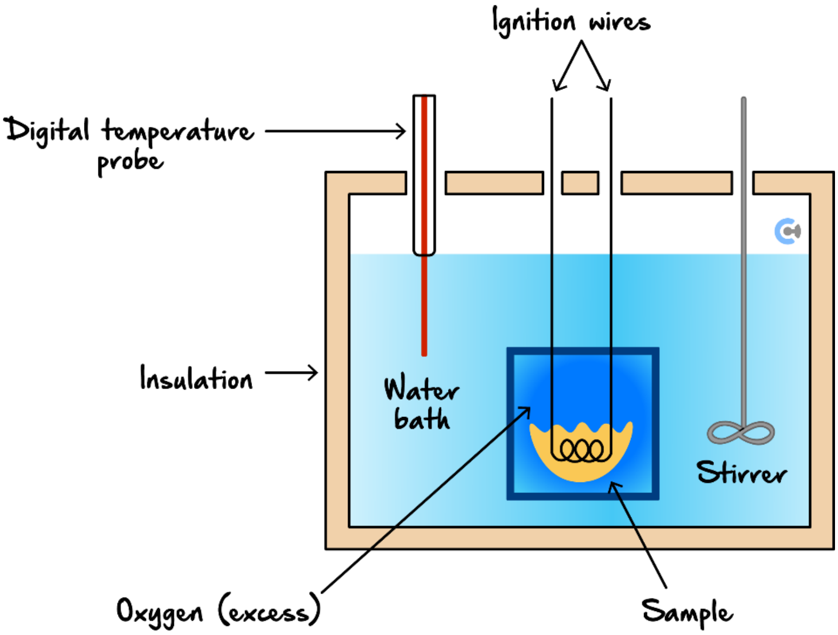
Section F: VCAA-Level Questions I (12 Marks)

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

Question 14 (12 marks)

Inspired from VCAA Chemistry Exam 2022
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2022/2022chem-w.pdf#page=27

The energy content of food can be determined experimentally using a bomb calorimeter similar to the one shown in the diagram below.



a. The calorimeter is first chemically calibrated by burning 8.30 g of ethyne which causes the temperature which is originally at 23.3°C to rise by 63.3°C. Write out the thermochemical equation for the combustion of ethyne and hence or otherwise calculate the calibration factor of this calorimeter. Ethyne has a molar heat of combustion of $-1300\ kJ/mol$. (3 marks)

$$C_2H_2(g) + \frac{5}{2}O_2(g) \rightarrow 2CO_2(g) + H_2O(l) \qquad \Delta H = -1300\ kJ/mol$$

$$E = \Delta H_c \times m$$
$$= (49.9)(8.30) = 414\ kJ$$

$$C.F = \frac{E}{\Delta T} = \frac{414}{(63.3)} = 6.54\ kJ/°C$$

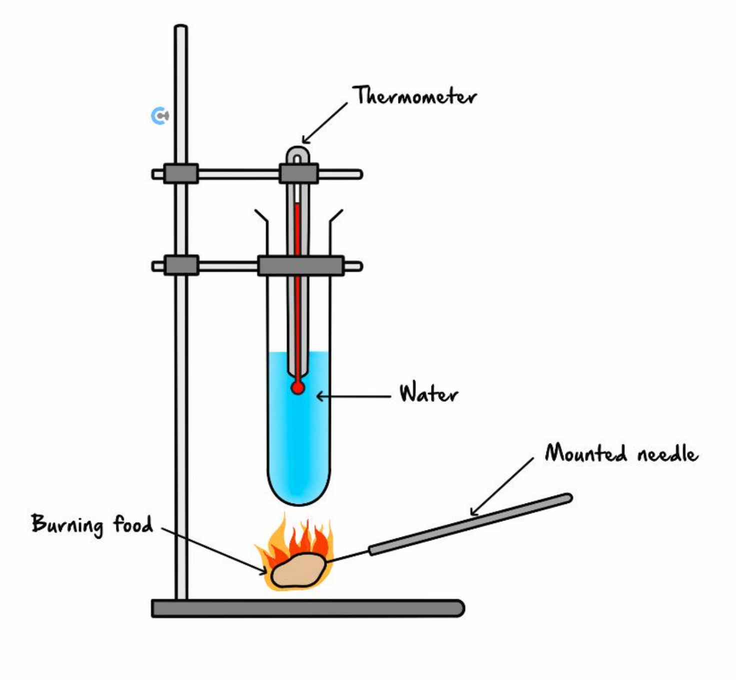
A 1.50 g sample of air-popped popcorn is placed in the bomb calorimeter. The initial temperature of the water is 22.2°C and the final temperature is 25.7°C. Assume that the air-popped popcorn is fully combusted.

b. Using the calibration factor provided, calculate the energy released by the air-popped popcorn in kilojoules per gram. (2 marks)

$$E = C.F \times \Delta T = (6.54)(25.7 - 22.2) = 22.9\ kJ$$

$$E_{content} = \frac{E}{m} = \frac{22.9}{1.50} = 15.3\ kJ/g$$

To test the impact of using a calorimeter, a 0.89 g of popcorn is burned below a test-tube water, as shown below, till food of mass 0.12 g are left.



c. Water of mass 60.00 g is heated from 20.8°C to 46.1°C. Calculate the experimental energy content from this method. (2 marks)

$$q = mc\Delta T = (60.00)(4.18)(46.1 - 20.8) = 6.35\ kJ$$

$$E_c = \frac{q}{\Delta m} = \frac{6.35}{(0.89 - 0.12)} = 8.24\ kJ/g$$

d. Compare the two results from **part b.** and **part c**. Provide two different reasons to explain this difference. (3 marks)

The energy content of the popcorn is calculated to be 15.3 kJ/g using a calorimeter, which is almost double the energy content calculated by using the method in **part b**.

This is due to a significant amount of heat being lost to the environment instead of heating the water in **part b.**, as well as not all of the food being burned in **part b.**, as this food may contain higher-than-average energy from the burned food.

e. Describe 2 ways to improve the methodology used in **part c.,** apart from using a calorimeter. (2 marks)

Answers include:
"Stirring the water to evenly distribute energy, bring the food as close to the test tube as possible or enclosing the apparatus in a small box to minimise heat being lost to the environment."

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Section G: Multiple Choice Questions (7 Marks)

INSTRUCTION: 7 Marks. 7 Minutes Writing.

Question 15 (1 mark)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=10

A food chemist conducted an experiment in a bomb calorimeter to determine the energy content, in joules per gram, of a muesli bar. A 3.95 g sample of the muesli bar was combusted in the calorimeter, and the temperature of the water rose by 16.7°C. The calibration factor of the calorimeter was previously determined to be $4780\ J\ °\mathrm{C}^{-1}$.

The energy content of the muesli bar is:

A. $3.51 \times 10^2\ kJ\ g^{-1}$

B. $2.02 \times 10^4\ J\ g^{-1}$

C. $3.51 \times 10^0\ kJ\ g^{-1}$

D. $2.02 \times 10\ J\ \ g^{-1}$

Energy from sample $= CF \times \Delta T$
$= 4780\ J\ °\mathrm{C}^{-1} \times 16.7°\mathrm{C}$
$= 7.98 \times 10^4\ J$

Energy content $= 7.98 \times 10^4\ J\ /\ 3.95\ g$
$= 2.02 \times 10^4\ J\ g^{-1}$

Question 16 (1 mark)

A foam cup calorimeter containing 100 mL of water is calibrated by passing an electric current through a small heater placed in the solution.

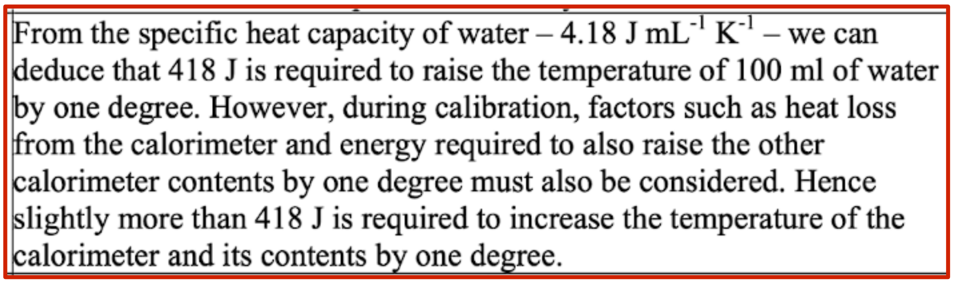
Assuming that all measurements are accurate, which one of the following is the most likely calibration factor (in $J\ °\mathrm{C}^{-1}$) for the calorimeter and contents?

A. 120

B. 240

C. 480

D. 960



From the specific heat capacity of water – 4.18 J mL^{-1} K^{-1} – we can deduce that 418 J is required to raise the temperature of 100 ml of water by one degree. However, during calibration, factors such as heat loss from the calorimeter and energy required to also raise the other calorimeter contents by one degree must also be considered. Hence slightly more than 418 J is required to increase the temperature of the calorimeter and its contents by one degree.

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Question 17 (1 mark)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/NHT/2021chem-nht-w.pdf#page=3

Ammonium nitrate, NH_4NO_3, can be used in chemical cold packs that are often found in first-aid kits.

A calorimeter was electrically calibrated using $100\ mL$ of pure water and was then used to determine the molar heat of the solution of NH_4NO_3.

If the water was replaced prior to the determination of the molar heat of the solution and, instead of $100\ mL$, only $90\ mL$ was added to the calorimeter, the molar heat of the solution determined would be:

A. Lower due to the temperature change being smaller.

B. Lower due to the temperature change being greater.

C. Higher due to the temperature change being smaller.

D. Higher due to the temperature change being greater.

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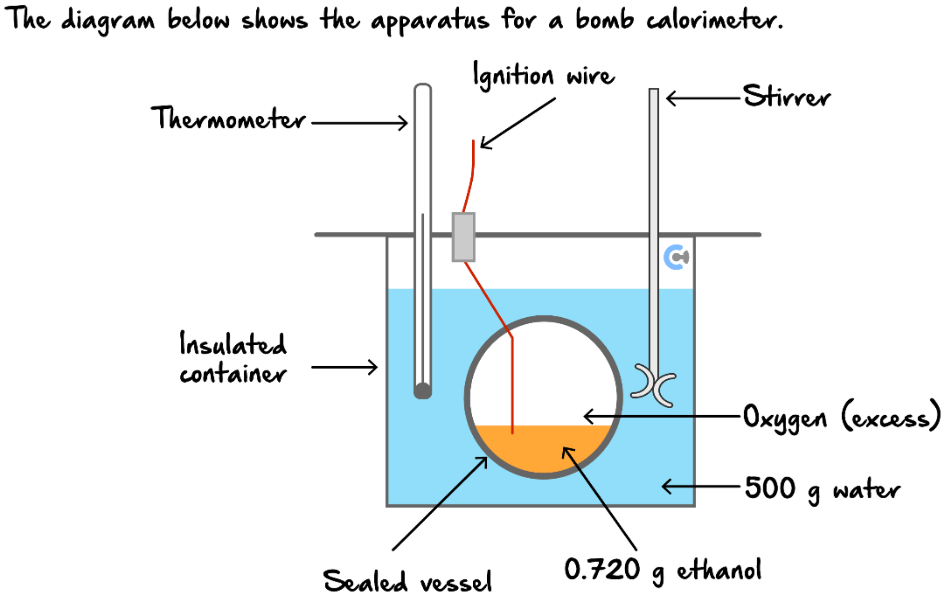
Question 18 (1 mark)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/NHT/2021chem-nht-w.pdf#page=9

The diagram below shows the apparatus for a bomb calorimeter.



The bomb calorimeter containing 500 g of water was chemically calibrated by combusting 0.720 g of ethanol with an excess of oxygen. The increase in temperature was found to be 22.0°C.

Which one of the following best explains these results?

A. The stirrer was not working.

B. The calorimeter actually contained 450 g of water.

C. The temperature in the calorimeter was still rising after the final temperature was noted.

D. Some of the ethanol evaporated after it was weighed but before it was added to the calorimeter.

Energy from ethanol = 0.720 g x 29.6 kJ g^{-1} = 21.3 kJ

Expected ΔT for 500 g of water = 21.3x10^3 / (4.18 x 500) = 10.2 °C

Best explanation was that the **stirrer was not working**.

Whilst a higher ΔT would be expected for 450 g, it would not be as high as 22 °C.

If ethanol had escaped the ΔT would be smaller not greater.

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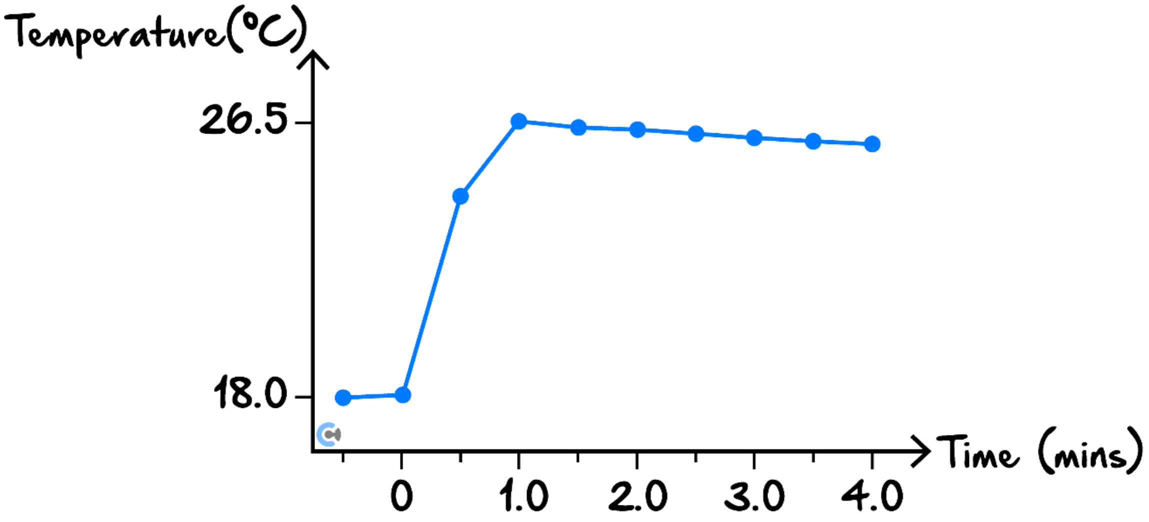
Question 19 (1 mark)

A temperature-time graph from a solution calorimetry experiment is shown below.



Which one of the following statements related to the graph is incorrect?

A. The calorimeter is poorly insulated and lost heat to the surroundings.

B. The graph depicts a reaction which has a negative enthalpy change.

C. After 4.0 minutes the graph will plateau at a constant value.

D. Before mixing, the temperature of the reactant solutions was 18.0°C.

Space for Personal Notes

The following information applies to the two questions that follow

Inspired from VCAA Chemistry Exam 2 2007
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2007chem2.pdf#page=8

A chemist used bomb calorimetry to measure the enthalpy change (ΔH) for the combustion of butane.

Question 20 (1 mark)

The calibration factor (CF) of the calorimeter was determined by measuring the temperature rise (ΔT_1) that occurred when a known amount of charge (Q) was passed through the heating element in the calorimeter at a measured voltage (V).

The CF, in J °C^{-1}, is:

A. Q

B. $\frac{\Delta T_1}{Q \times V}$

C. $V \times Q \times \Delta T_1$

D. $\frac{V \times Q}{\Delta T_1}$

Question 21 (1 mark)

In the calorimeter (calibration factor, CF), $n\ mol$ of butane was then burnt, and the resulting temperature rise (ΔT_2) was measured.

The ΔH, in $J\ mol^{-1}$, for the reaction,

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

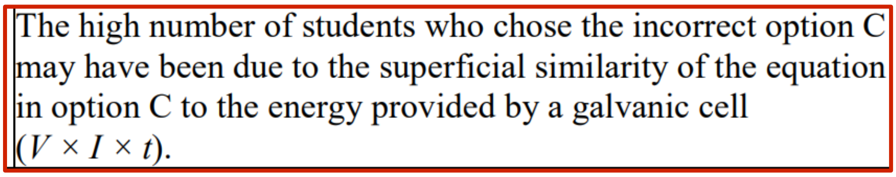
is:

A. $2 \times CF \times \Delta T_2 \times n$

B. $\frac{2 \times CF \times \Delta T_2}{n}$

C. $\frac{CF \times \Delta T_2}{2 \times n}$

D. $\frac{CF \times \Delta T_2}{n}$



The high number of students who chose the incorrect option C may have been due to the superficial similarity of the equation in option C to the energy provided by a galvanic cell ($V \times I \times t$).

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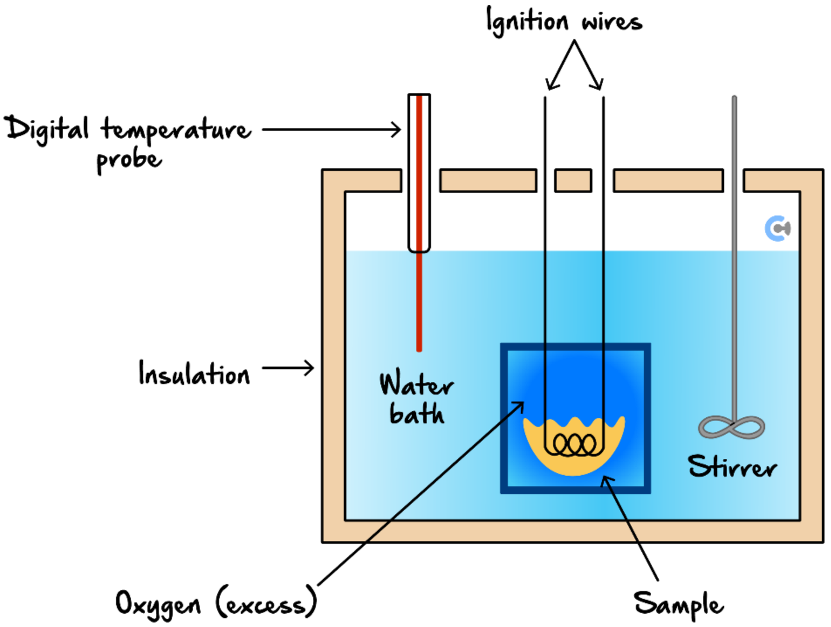
Section H: VCAA-Level Questions II (12 Marks)

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

Question 22 (12 marks)

Inspired from VCAA Chemistry NHT Exam 2018
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2018/nht/2018chem-nht-w.pdf#page=26

The energy content of foods can be determined using a bomb calorimeter similar to the one shown in the diagram below.



The calibration factor for the bomb calorimeter is initially determined by burning a known amount of naphthalene, $C_{10}H_8$.

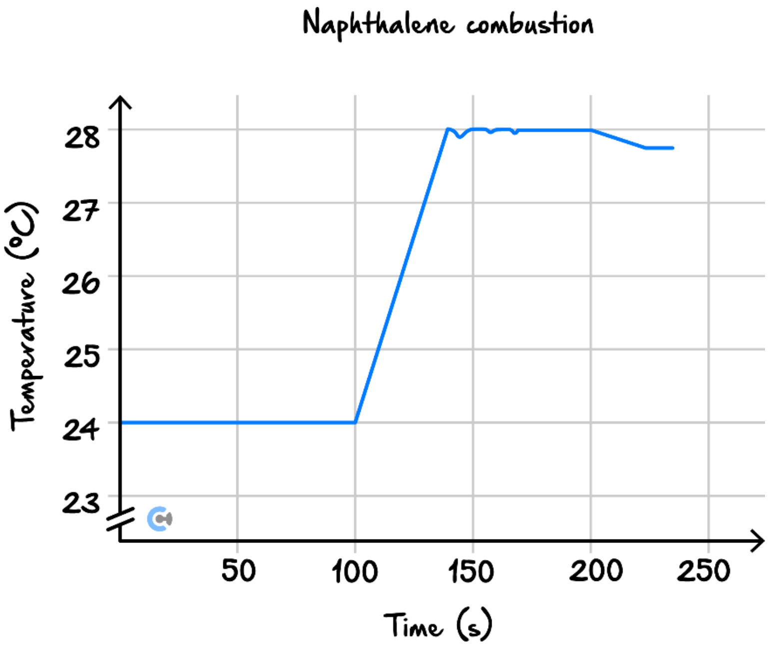
The combustion reaction for $C_{10}H_8$ is shown below:

$$C_{10}H_8\ (s) + 12O_2\ (g) \rightarrow 10CO_2\ (g) + 4H_2O\ (l) \qquad \Delta H = -5133\ kJ\ mol^{-1}$$

Data for the calibration of the bomb calorimeter

mass of $C_{10}H_8$	0.212 g
mass of water	300 g

The graph produced by the digital temperature probe in the bomb calorimeter is shown below.



a.

i. Use the data in the graph above to calculate the calibration factor for the bomb calorimeter. (3 marks)

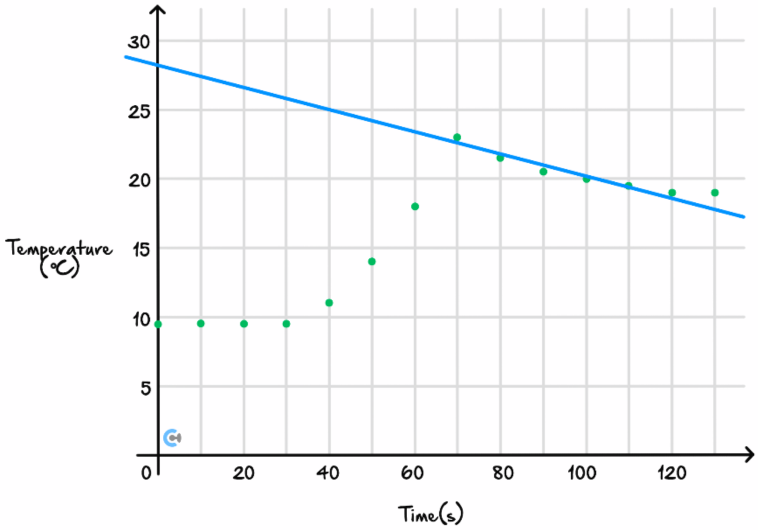
$$n(C_{10}H_8) = 0.212/128 = 0.001656\, mol$$
$$E \text{ released} = 0.001656 \times 5133 = 8.502\, kJ$$
$$CF = E\ /\ \Delta T = 8.502\ /\ 4.0 \text{ (from graph)} = 2.13\, kJ\ °\text{C}^{-1}$$

ii. If the calorimeter was to be electrically calibrated instead, calculate the current that would need to be run through if a voltage of 5.00 V was provided for 5.21 s leading to a temperature difference of 23.1℃. (1 mark)

$$C.F = \frac{VIt}{\Delta T}$$
$$I = \frac{C.F\Delta T}{Vt} = \frac{(2.13 \times 10^3)(23.1)}{(5.00)(5.21)} = 1.88\, A$$

b. Electrical calibration is now taken place in a different calorimeter with a voltage of 83.1 V and a current of 59.3 A running through the electric heater.

i. Draw the line of the best fit across the appropriate interval on the below temperature vs time graph. (1 mark)



ii. What is the change in temperature used in the calibration factor calculations for this calorimeter? (1 mark)

should be around 14-18°C, but to one decimal place.

For sample calculations it is 16.3.

iii. Is this ΔT measured the same way as for **part a.**? Explain why there's a difference and explain how the method for measuring ΔT in **part a.** and **b.** works. (3 marks)

No, ΔT is measured directly between the maximum temperature and minimum temperature in **part a**. due to negligible heat loss. As there is significant heat loss in the calorimeter in **part b.**, a line of best fit is drawn for the impact of heat loss which allows the maximum possible temperature to be seen at the instant the current is turned on, while ΔT is then calculated as the difference between the minimum temperature and the potential maximum temperature.

iv. Calculate the calibration factor for this calorimeter. (1 mark)

$$C.F = \frac{VIt}{\Delta T} = \frac{(83.1)(59.3)(40.0)}{16.3} = 1.21 \times 10^4\ J/°C = 12.1\ kJ/°C$$

c. Explain the difference between the calibration factors of the two calorimeters in **parts a.** and **b.**, Calorimeter A and Calorimeter B respectively and thus how they are made. (2 marks)

The two calorimeters are different and thus have different levels of insulation against heat loss. Calorimeter A has a lower $C.F.$ and is thus well insulated due to requiring less energy to heat up the water. Calorimeter B has a higher $C.F.$ and is thus relatively poor insulated as more energy is required to heat up water as more energy is lost.

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Section I: Summary

What have we learnt today?

TIPS

Pitfalls

Section J: Extension Questions (19 Marks)

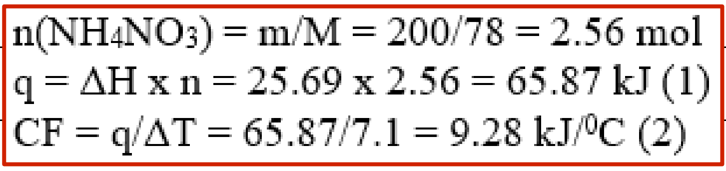
Question 23 (19 marks)

Students in a VCE ¾ Chemistry class have been studying the energy released by different foods that can be used by the body. One of their practicals involves various methods of determining the energy content of a jellybean in kJ/g, which is almost entirely comprised of pure glucose.

a. The first method explored is by using a calorimeter. It is calibrated chemically in which 200 g of ammonium nitrate, NH_4NO_3, is dissolved in the water according to the following thermochemical equation:

$$NH_4NO_3(s) \rightarrow NH_4NO_3(aq) \qquad \Delta H = +25.69\ kJ/mol$$

Given that the water's temperature decreased by 7.10°C, calculate the calibration factor for this calorimeter in $kJ/°C$. (2 marks)

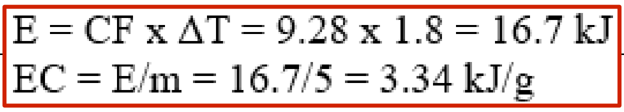


$n(NH_4NO_3) = m/M = 200/78 = 2.56$ mol

$q = \Delta H \times n = 25.69 \times 2.56 = 65.87$ kJ (1)

$CF = q/\Delta T = 65.87/7.1 = 9.28$ kJ/^{0}C (2)

b. A jellybean is then combusted in the calorimeter, and it is found that a 5.00 g jellybean raised the water's temperature by 1.8°C. Calculate its energy content in kJ/g. (2 marks)



$E = CF \times \Delta T = 9.28 \times 1.8 = 16.7$ kJ

$EC = E/m = 16.7/5 = 3.34$ kJ/g

c.

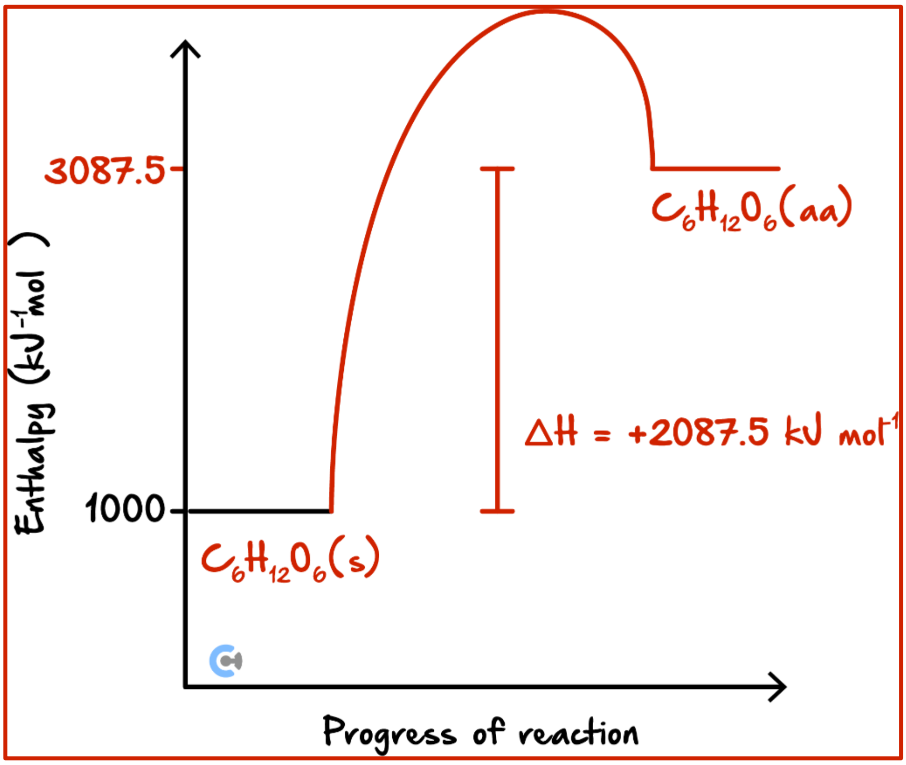
i. Briefly explain why the above experiment would technically not be feasible in a solution calorimeter. (1 mark)

Because combustion cannot occur in solution; that's what bomb calorimeters are for

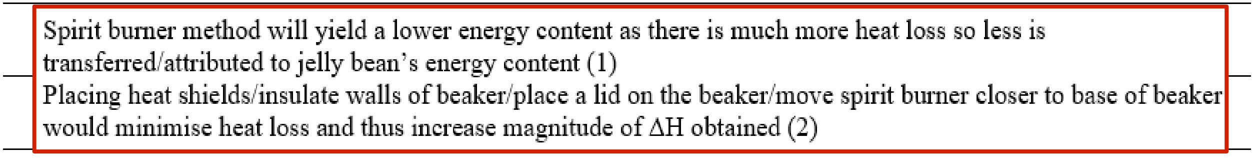
ii. In a **different experiment in the same solution calorimeter**, a jellybean is placed and begins to dissolve, and the energy changes from this process are analysed. Assuming all of the jellybeans is glucose, $C_6H_{12}O_6$, if a 4.00 *g* jellybean changed the water's temperature from 28.0°C to 23.0°C, write the thermochemical equation for this dissolution. (3 marks)

n(glucose) = m/M = 4/180 = 0.02 mol
E = CF x ΔT = 9.28 x 5 = 46.4 kJ (1)
ΔH = q/n = 46.4/0.02 = +2087.5 kJ/mol (2)
$C_6H_{12}O_6(s) \rightarrow C_6H_{12}O_6(aq)$ ΔH = +2087.5 kJ/mol (3)

iii. Hence, draw the energy profile diagram for the dissolution of glucose in water on the axes below, based on the information in **part c. ii.** Ensure to label your reactants, products and change in enthalpy value. (2 marks)



d. The second method explored is by combusting melted (liquid) jellybean in a spirit burner to heat up a sample of water to determine its energy content. Explain an expected difference in the values obtained for the jellybean's energy content and suggest a modification aimed at minimising this discrepancy. (2 marks)



Spirit burner method will yield a lower energy content as there is much more heat loss so less is transferred/attributed to jelly bean's energy content (1)

Placing heat shields/insulate walls of beaker/place a lid on the beaker/move spirit burner closer to base of beaker would minimise heat loss and thus increase magnitude of ΔH obtained (2)

e.

i. A sprinter typically consumes foods high in glucose ($C_6H_{12}O_6$), such as jellybeans, before a race for a burst of energy. Given that glucose's molar heat of combustion is $-2880\ kJ/mol$ at SLC, and a runner would like $50.0\ kJ$ of energy, how big of a jellybean, in g, which is 80% glucose, would they wish to consume? (3 marks)

ΔH(glucose) = 2880 kJ/mol = 16 kJ/g (divide by M(glucose) = 180 g/mol);
m(glucose) = q/ΔH = 50/16 = 3.125 g
m(jellybean) = 3.125/0.8 = 3.9 g

ii. Which of the following is true regarding the size of jellybean that would be consumed by a runner in the subcontinent where temperatures are greater than 25°C, assuming they would also need $50.0\ kJ$ of energy before a race? (1 mark)

A. A smaller jellybean would be consumed if the molar heat of combustion of glucose were lower in the subcontinent.

B. An identical jellybean would be consumed, as the molar heat of combustion of glucose is constant.

C. If the molar heat of combustion were greater in the subcontinent, a larger jellybean would be consumed.

D. None of the above.

iii. In a typical running season, a sprinter would need $450\ g$ of jellybeans. Using this information, and relevant information in **part e. i.,** write the thermochemical equation of the complete combustion of glucose in jellybeans **with stoichiometric ratios which match those of a sprinter's seasonal needs**. (3 marks)

m(glucose) = 0.8 x 450 = 360 g; n(glucose) = m/M = 360/180 = 2 mol (1)
$2C_6H_{12}O_6(s) + 12O_2(g) \rightarrow 12CO_2(g) + 12H_2O(l)$ ΔH = - 5760 kJ (2 marks for correct coefficients and states and ΔH value and sign with kJ as the unit)

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