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VCE Chemistry ¾
Calorimetry [1.4]
Homework Solutions

Homework Outline:

Section A: Compulsory Questions (27 Marks)

Sub-Section [1.4.1]: Calculate Calibration Factor via Electrical & Chemical Calibration ($CF = \frac{E}{\Delta T}$)

Question 1 (2 marks)

Andrew runs 340 J of electrical energy through a solution calorimeter. He notes that the temperature of the solution increases by 1.5°C.

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

$CF = \frac{340}{1.5}$

$= 226.7\ J/°C$

$\approx 2.3 \times 10^2\ J/°C$

b. Calculate the calibration factor for the calorimeter in $kJ/°C$. (1 mark)

$\frac{226.7}{1000} = 0.23\ kJ/°C$

Question 2 (3 marks)

A solution calorimeter containing 150 mL of water is being calibrated.

a. 2.00 A of current is passed through the instrument for 2.50 minutes, at a voltage of 2.30 V. Calculate the energy passing through the calorimeter. (1 mark)

$E_{elec} = VIt = 2.3 \times 2 \times 2.5 \times 60 = 690\ J$

b. The temperature of water in the calorimeter changes from 34.5°C to 36.5°C. Calculate the calibration factor for the calorimeter. (2 marks)

$\Delta T = 36.4 - 34.5 = 1.9°C$

$CF = \frac{E}{\Delta T} = \frac{690}{1.9} = 363.16\ J/°C$

$\approx 363\ J/°C$

Question 3 (3 marks)

A solution calorimeter is calibrated by using the following reaction, whereby 100.0 mL of 1.00 M HCl and excess NaOH are added to the calorimeter at 28.0°C, according to the following reaction:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta H = -57.3\ kJ/mol$$

It is found that the final temperature of the calorimeter is 36.3°C. Find the calibration factor of the calorimeter in $J/°C$.

$n(HCl) = 1 \times 0.1$

$= 0.1\ mol$

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

$\therefore q = 57.3 \times 0.1$

$= 5.73\ kJ$

$\Delta T = 36.3 - 28 = 8.3°C$

$\therefore CF = \frac{5730}{8.3} = 690.367\ J/°C$

$\approx 690\ J/°C$

Space for Personal Notes

Sub-Section [1.4.2]: Apply Calibration Factor To Find Energy Released ($E = CF \times \Delta T$)

Question 4 (4 marks)

A calorimeter is known to have a calibration factor of 43.6 $J/°C$. Calculate the energy released, in J, in each of the following circumstances:

a. If there is a temperature change of 2.5°C. (1 mark)

$E = 43.6 \times 2.5$

$= 109\ J$

$\approx 1.1 \times 10^2\ J$

b. If there is a temperature change of 6.75°C. (1 mark)

$E = 43.6 \times 6.75$

$\approx 294\ J$

c. If the temperature changes from 49.6°C to 54.5°C. (2 marks)

$\Delta T = 54.5 - 49.6$

$= 4.9°C$

$\therefore E = 4.9 \times 43.6$

$= 214\ J$

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Question 5

Chloe is using a solution calorimeter which has a known calibration factor of 42.1 $J/°C$, which contains 200.5 ml of an unknown solution. During an experiment, she notes that when a chicken drumstick is added to the calorimeter, the thermometer changes from 31.4°C to 44°C.

a. Find the energy released by the drumstick in kJ.

$CF = \frac{E}{\Delta T}$

$\therefore E = 42.1 \times 12.6$

$= 530.46 J$

$\approx 0.53 kJ$

b. Chloe knows that the drumstick weighs 15.2 g. Calculate the energy content of the drumstick in kJ/g.

$EC = \frac{0.53}{15.2}$

$= 0.0349\ kJ/g$

$\approx 3.49 \times 10^{-2}\ kJ/g$

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Question 6 (4 marks)

A solution calorimeter was calibrated by the passage of 5.40 A for 12.20 minutes at a voltage of 10.15 V. The temperature of the water in the calorimeter changed from 22.4°C to 31.5°C during the calibration. This calorimeter was then used to determine the heat content of a sample of potato crisps. 5.00 g of potato crisps was reacted in the calorimeter, causing the temperature of the water in the calorimeter to rise by 15.2°C. Calculate the energy content of the potato crisps in kJ/g.

Calibration:

$\Delta T = 31.5 - 22.4$

$= 9.1°C$

$\therefore CF = \frac{5.4 \times 12.2 \times 60 \times 10.15}{9.1}$

$CF = 4408.89 \ J/°C$

Test:

$\therefore E = CF \times \Delta T$

$= 4408.89 \times 15.2$

$= 67015.128 \ J$

$\therefore E.C = \frac{67.015}{5}$

$= 13.4 \ kJ/g$

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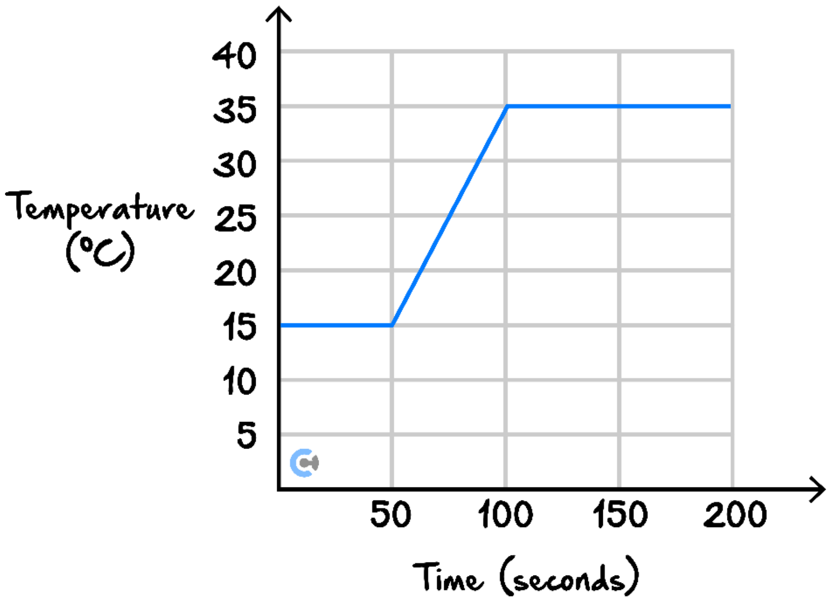
Sub-Section [1.4.3]: Apply Temperature-Time Graphs To Calorimetry

Question 7 (2 marks)

Sam is experimenting with the following calorimeter. At 50 seconds, the calorimeter is turned on, and at 100 seconds it is switched off.



a. Using the graph, find the temperature change of the calorimeter. (1 mark)

20°C

b. Given that 150 *J* of energy was released during the calibration, find the calibration factor of the calorimeter. (1 mark)

$$CF = \frac{150}{20}$$
$$= 7.5\ J/°C$$

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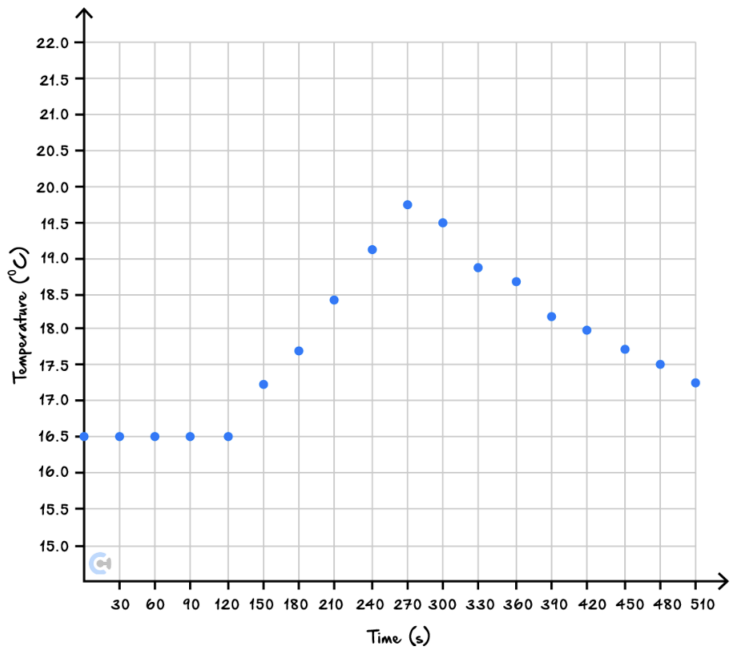
Question 8 (4 marks)

A bomb calorimeter is calibrated by passing through 2.70 A and a voltage of 5.10 V. The electric heater is turned on at $t = 120\ s$ and turned off at $t = 270\ s$. A graph highlighting this calibration is shown below:



a. Calculate the energy released in the calorimeter during calibration. (2 marks)

$E = VIt$

$= 5.1 \times 2.7 \times (270 - 120) \times 60$

$= 51030\ J$

$\approx 51.0\ kJ$

b. Using the graph provided, calculate the temperature change during the calibration. (1 mark)

$\Delta T = 19.75 - 16.5$

$= 3.25°C$

c. Calculate the calibration factor of the bomb calorimeter in $kJ/°C$. (1 mark)

$CF = \frac{51}{3.25}$

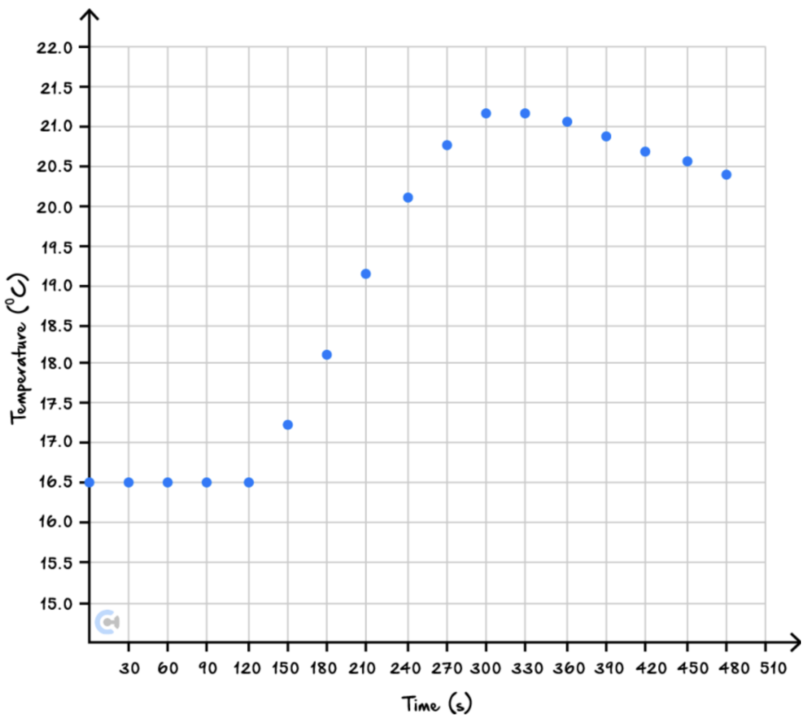
$= 15.7\ kJ/°C$

Question 9 (5 marks)

A sample of 4.25 g hydrogen peroxide (H_2O_2) placed in a solution calorimeter filled with 150 mL of water at 25°C, decomposes in the solution. The thermochemical reaction is shown below:

$$2H_2O_2 \rightarrow 2H_2O + O_2 \quad \Delta H = -196.6\ kJ/mol$$

The calibration is graphed on a temperature vs time graph which is shown below:



a. Calculate the calibration factor for this calorimeter, in $kJ/°C$. (3 marks)

$n(H_2O_2) = \frac{4.25}{2+32}$

$= 0.125\ mol$

$\therefore \Delta H = \frac{E}{n}$

$\therefore E = 196.6 \times \frac{0.125}{2}$

$= 12.2875\ kJ$

$\therefore CF = \frac{12.2875}{21.25 - 16.5}$

$= 2.59\ kJ/°C$

b. Is the calorimeter well-insulated or poorly insulated? Justify your answer. (2 marks)

No (1).
There is a drop in the temperature of the solution after the calorimeter is switched off, indicating that heat is being lost to the environment. This suggests that insulation is poor (2).

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Sub-Section: The 'Final Boss'

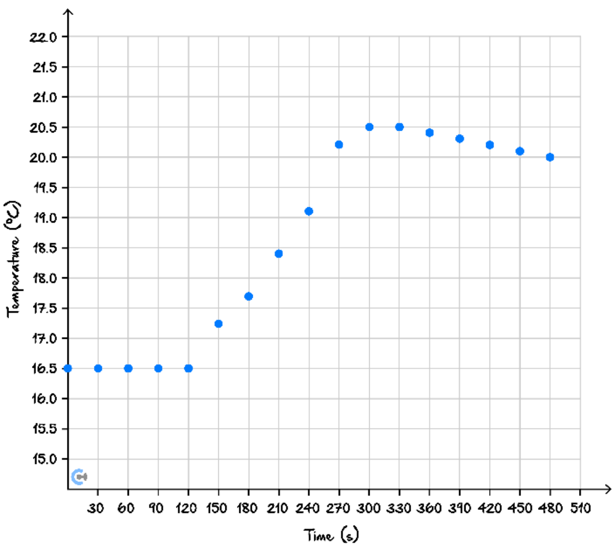
Question 10

A bomb calorimeter is used to measure the energy released during the combustion of a sample of a hydrocarbon fuel. The fuel undergoes combustion in excess oxygen, and the reaction is:

$$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g) \quad \Delta H = -9840\ kJ/mol$$

The bomb calorimeter is initially calibrated by heating an unknown solution, where the electrical input energy is measured and the temperature change is recorded. During the initial calibration, 3.50 A of current is passed through the calorimeter at 5.25 V. The calorimeter body has a heat capacity of 0.150 $kJ/°C$ and it is known that an additional 2.9 kJ of heat energy was absorbed by the water compartment.

The temperature-time graph below was graphed during the calibration of the calorimeter:



a. Consider the calibration of the calorimeter.

i. Calculate the energy input into the calorimeter.

Energy input:

$E = VIt$

$= 5.25 \times 3.5 \times 180$

$= 3.308\ kJ$

ii. Calculate the total energy absorbed by the calorimeter.

Total energy:

Absorbed by calorimeter body: $E = 0.15 \times 4 = 0.6$ kJ

$\therefore E_T = 0.6 + 2.4 = 3.0$ kJ

iii. Hence, calculate the calibration factor of the calorimeter.

$$CF = \frac{3}{4} = 0.75 \text{ kJ}/^\circ C$$

iv. Describe and justify the discrepancy between your answer for **part a. i.** and **part a. ii.**

The energy input is larger than the total energy absorbed by the calorimeter (1). Energy could be lost to the environment as thermal energy (2).

b. Following the calibration, 15.0 g of the fuel is combusted in the presence of 0.0256 kg of oxygen gas. If the calorimeter was initially at 141.0°C, calculate the final temperature of the calorimeter.

$n(C_8H_{18}) = \frac{15}{114} = 0.1316 \text{ mol}$

$n(O_2) = \frac{25.6}{32} = 0.8 \text{ mol}$

Ratios:

$n(C_8H_{18}) = \frac{0.1316}{2} = 0.0658 \text{ mol}$

$n(O_2) = \frac{0.8}{25} = 0.032 \text{ mol}$

∴ oxygen is limiting reagent.

$\therefore E = 9840 \times \frac{0.8}{25} = 314.88 \text{ kJ}$

$CF = 0.75 \text{ kJ/°C}$

$\therefore \Delta T = \frac{314.88}{0.75} = 419.85°C$

$\therefore T_f = 419.85 + 141 = 560.84 \approx 561°C$

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Section B: Supplementary Questions (56 Marks)

Sub-Section [1.4.1]: Calculate Calibration Factor via Electrical & Chemical Calibration ($CF = \frac{E}{\Delta T}$)

Question 11 (2 marks)

Jamie passes 410 J of electrical energy through a solution calorimeter. The temperature rise of the solution is recorded as 1.8°C.

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

$CF = \frac{E}{\Delta T}$

$CF = \frac{410}{1.8}$

$= 227.78\ J/°C \approx 2.3 \times 10^2\ J/°C$

b. Convert this calibration factor into $kJ/°C$. (1 mark)

$\frac{227.78}{1000}$

$= 0.23\ kJ/°C$

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Question 12 (3 marks)

Angela is experimenting with a solution calorimeter containing 250 mL of water. She applies 3.50 mA of current through the instrument for 1.50 hours, whilst voltage remains at 1.50 V. Interestingly, she finds that the temperature of the water changes from 24.2°C to 24.5°C. Calculate the calibration factor of the calorimeter in $kJ/°C$.

$E = VIt$

$= 1.5 \times 3.5 \times 10^{-3} \times 1.5 \times 60 \times 60$

$= 28.35 J$

$\approx 0.02835 kJ$

$\therefore CF = \frac{E}{\Delta T}$

$CF = \frac{0.02835}{24.5 - 24.2}$

$= 0.0945$

$\approx 9.45 \times 10^{-2} kJ/°C$

Question 13 (3 marks)

A solution calorimeter is calibrated using 120.0 mL of 1.00 M H_2SO_4 mixed with excess KOH at an initial temperature of 26.0°C. The reaction is as follows:

$$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l) \quad \Delta H = -114.0\ kJ/mol$$

The final temperature of the calorimeter is 35.0°C. Calculate the calorimeter's calibration factor in $J/°C$.

$n(H_2SO_4) = 0.12 \times 1$

$= 0.12\ mol$

$\therefore E = 114 \times 0.12$

$= 13.68 kJ$

$\therefore CF = \frac{13.68 \times 10^3}{35 - 26}$

$= 1.52 \times 10^3 J/°C$

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Question 14 (10 marks)

A calorimeter containing 200 mL of water is calibrated using both electrical and chemical methods.

A current of 3.00 A flows through the calorimeter for 5.00 minutes at a voltage of 4.50 V. There is an increase of 8.15°C in the temperature.

a. Calculate the energy transferred into the calorimeter. (1 mark)

$E = 3.00 \times 4.50 \times 300 = 4.05\ kJ$

b. Calculate the electrical calibration factor. (2 marks)

$CF = \frac{4.05}{8.15}$

$= 0.4969\ J/°C$

$\approx 0.497\ kJ/°C$

Next, 50.0 mL of 1.00 M H_2SO_4 is reacted with 50.0 mL of 3.00 M KOH in the calorimeter.

The reaction is:

$$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l) \quad \Delta H = -56.0\ kJ/mol.$$

The temperature rises from 25.0°C to 33.5°C.

c. Calculate the chemical calibration factor. (3 marks)

$n(H_2SO_4) = 1 \times 0.05 = 0.05\ mol$

$n(KOH) = 3 \times 0.05 = 0.15\ mol$

$n(H_2SO_4) : n(KOH) = 1 : 2$

$\therefore$ $n(H_2SO_4)$ is the limiting reactant.

$\therefore E = 0.05 \times 56 = 2.8\ kJ$

$\therefore CF = \frac{2.8}{33.5 - 25} = 0.329\ kJ/°C$

d. Compare the electrical and chemical calibration factor and make a conclusion on which calibration method is more efficient. (2 marks)

The electrical calibration method is more efficient than the chemical method (1). This is because the calibration value of the electrical method is higher, meaning that to change the temperature in the calorimeter by 1°C, less energy is required than using chemical calibration (2), making it more efficient.

e. Combine the calibration results from both methods to calculate an average calibration factor for the calorimeter in $kJ/°C$. (2 marks)

$$CF_{(average)} = \frac{0.329 + 0.427}{2} = 0.378 \text{ kJ/°C}$$

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Sub-Section [1.4.2]: Apply Calibration Factor To Find Energy Released ($E = CF \times \Delta T$)

Question 15 (3 marks)

A calorimeter has a known calibration factor of 51.5 $J/°C$. Calculate the energy released, in J, in the following cases:

a. If the temperature change is 3.0°C. (1 mark)

$$CF = \frac{E}{\Delta T}$$

$$E = 51.5 \times 3 = 1.55 \times 10^2 \, J$$

b. If the temperature change is 7.0°C. (1 mark)

$$CF = \frac{E}{\Delta T}$$

$$E = 51.5 \times 7 = 3.61 \times 10^2 \, J$$

c. If the temperature increases from 45.5°C to 53.0°C. (1 mark)

$$CF = \frac{E}{\Delta T}$$

$$E = 51.5 \times (53 - 45.5) = 3.86 \times 10^2 \, J$$

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Question 16 (3 marks)

Liam uses a calorimeter with a calibration factor of 40.5 $J/°C$ and fills it with 250.0 mL of an unknown solution. During an experiment, when a piece of steak is placed into the calorimeter, the temperature rises from 30.0°C to 43.5°C.

a. Calculate the energy released by the steak in kJ. (2 marks)

$CF = \frac{E}{\Delta T}$

$\therefore E = 40.5 \times (43.5 - 30)$

$= 546.75\ J$

$\approx 0.547\ kJ$

b. Given that the steak weighs 20.0 g, compute its energy content in kJ/g. (1 mark)

$E.C = \frac{0.54675}{20}$

$= 0.0273\ kJ/g$

$\approx 2.73 \times 10^{-2}\ kJ/g$

Question 17 (4 marks)

A solution calorimeter was calibrated by applying a current of 6.00 A for 10.00 minutes at a voltage of 12.00 V. During calibration, the water's temperature increased from 20.5°C to 30.0°C. This calorimeter was later used to determine the heat content of a sample of cereal. A 4.00 g cereal sample caused the temperature to increase by 14.0°C. Calculate the energy content of the cereal in kJ/g.

Callibration:

$E = VIt$

$= 12 \times 6 \times 10 \times 60$

$= 43200\ J$

$\therefore CF = \frac{43.2}{30 - 20.5}$

$= 4.547\ kJ/°C$

Cereal:

$E = 14 \times 4.547$

$= 63.66\ kJ$

$\therefore E.C = \frac{63.66}{4}$

$= 15.9\ kJ/g$

Question 18 (7 marks)

A complex calorimeter has a calibration factor of 45.0 $J/°C$. The calorimeter has two compartments: a water and an unknown aqueous solution compartment. During an experiment:

- A 300 mL aqueous solution experiences a temperature increase from 23.0°C to 42.0°C when a 12.0 g sample of fuel is burned.
- At the same time, a 150 mL water compartment in the calorimeter increases in temperature by 3.50°C.
- The calorimeter itself has a heat capacity of 200.0 $J/°C$ and its temperature also rises from 23.0°C to 42.0°C.

a. Calculate the total energy released by the fuel. (4 marks)

Heat absorbed by solution:

$CF = 45.0\ J/°C$

$\therefore E = 45.0 \times (42 - 23)$

$= 855.0\ J$

$= 0.855\ kJ$

Heat absorbed by water:

$q = mc\Delta T$

$q = 150 \times 4.18 \times 3.5$

$= 2.195\ kJ$

Heat absorbed by calorimeter:

$E = 200 \times 19$

$= 3800\ J$

$= 3.8\ kJ$

$\therefore$ Total energy

$= 0.855 + 3.8 + 2.195$

$= 6.85\ kJ$

b. Determine the energy content of the fuel in kJ/g. (1 mark)

$$\frac{6.85}{12} = 0.571\ kJ/g$$

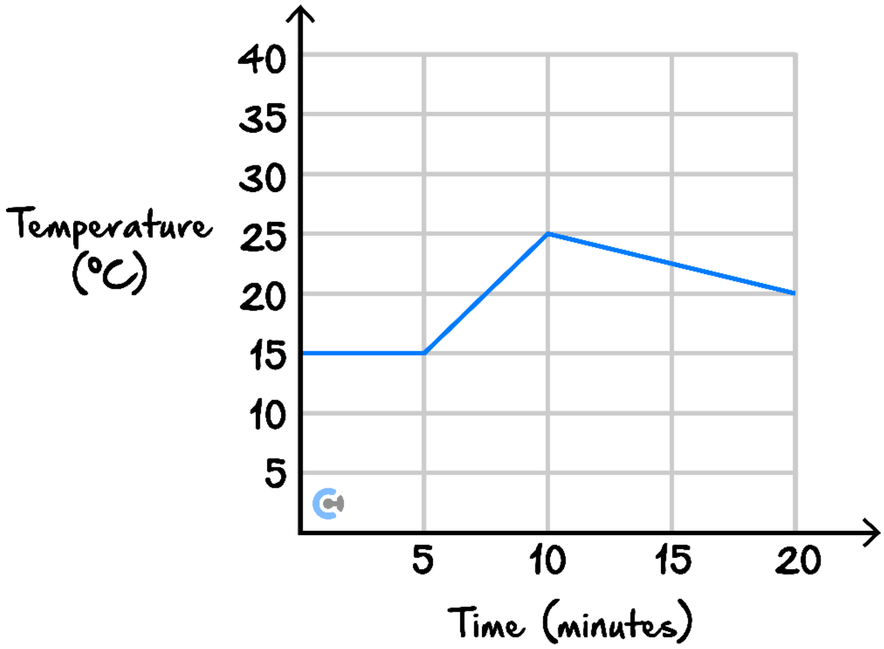
c. Sally, when analysing the calorimeter, notices that the temperature of the solution is not evenly distributed. She notices that closer to the centre, the solution is quite warm but cooler towards the peripheries. Suggest and justify an improvement that could be made to the calorimeter. (2 marks)

A stirrer (1).
This will help to disperse the thermal energy throughout the solution (2).

Sub-Section [1.4.3]: Apply Temperature-Time Graphs To Calorimetry

Question 19 (2 marks)

Alex is experimenting with a calorimeter. It is turned on at 5 minutes and switched off at 10 minutes.



a. From the graph, determine the temperature change in the calorimeter when it is turned on. (1 mark)

10°C

b. If 180 J of energy was released during calibration, calculate the calorimeter's calibration factor. (1 mark)

$$CF = \frac{180}{10} = 18\ J/°C$$

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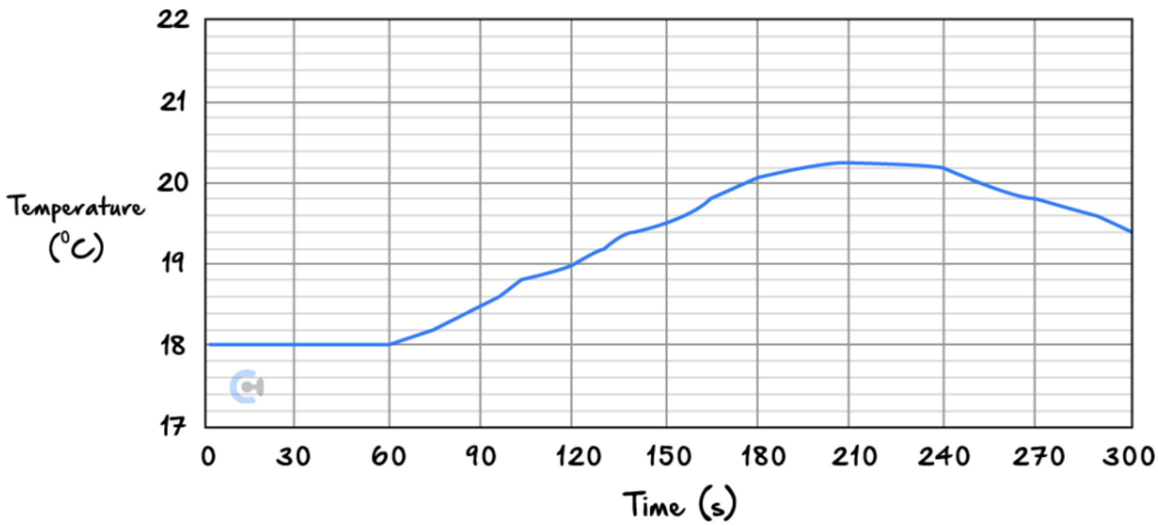
Question 20 (3 marks)

A calorimeter is calibrated with a current of 3.00 A and a voltage of 6.00 V. The heater operates from $t = 60.0$ seconds.



a. Predict when the heater in the calorimeter is turned off.

At roughly 210 seconds.

b. Determine the energy released during the calibration process. (2 marks)

$E = VIt$

$= 3 \times 6 \times (210 - 60)$

$= 2700\ J$

$= 2.70 \times 10^3\ J$

c. Using the graph, compute the temperature change during calibration.

$20.25 - 18 = 2.25°C$

d. Calculate the calorimeter's calibration factor in $kJ/°C$. (1 mark)

$CF = \frac{2.7}{2.25}$

$\rightarrow 1.20\ kJ/°C$

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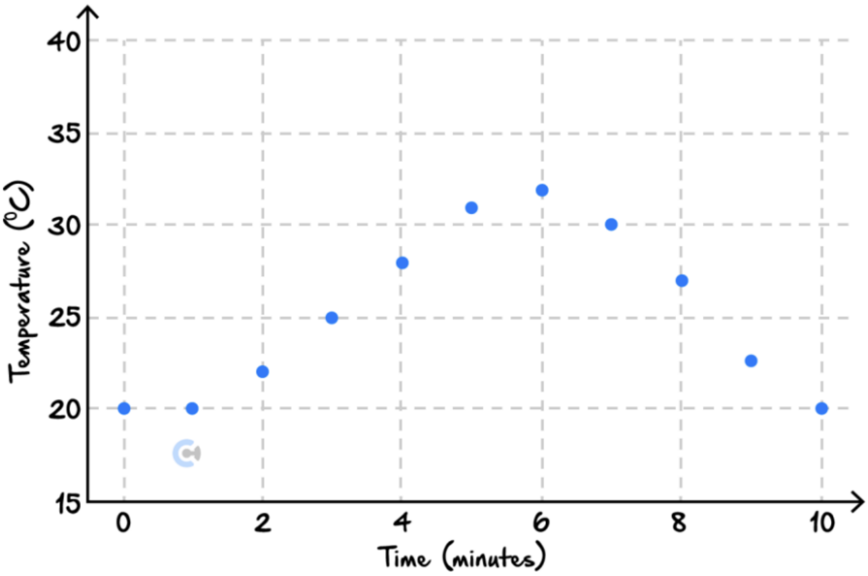
Question 21 (7 marks)

A 5.00 g sample of glucose is dissolved in water and reacts with oxygen in a calorimeter containing 200 mL of water at an initial temperature of 24°C. The reaction is as follows:

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \qquad \Delta H = -2800\ kJ/mol$$

The temperature-time graph for this reaction is provided:



When the reaction is completed, the temperature of the calorimeter is 45°C.

a. Determine the calibration factor for this calorimeter in $kJ/°C$. (3 marks)

$n(C_6H_{12}O_6) = \frac{5}{180}$

$= 0.02778\ mol$

$\therefore E = 0.02778 \times 2800$

$= 77.78\ kJ$

$\therefore CF = \frac{77.78}{45 - 24}$

$= 3.7\ kJ/°C$

b. Emma claims that "*based on the graph, it is evident that the calorimeter is poorly designed to conserve energy*." Evaluate this claim. (2 marks)

Emma is right (1). There is a drop in the temperature of the solution after the calorimeter is switched off, indicating that heat is being lost to the environment. This suggests that the device is poorly designed to conserve energy (2).

c. Suggest 2 ways in which the design of the calorimeter could be improved. (2 marks)

- Better insulation around the sides of the calorimeter.
- Ensuring a lid is present at the opening of the calorimeter, and that this lid is properly sealed.

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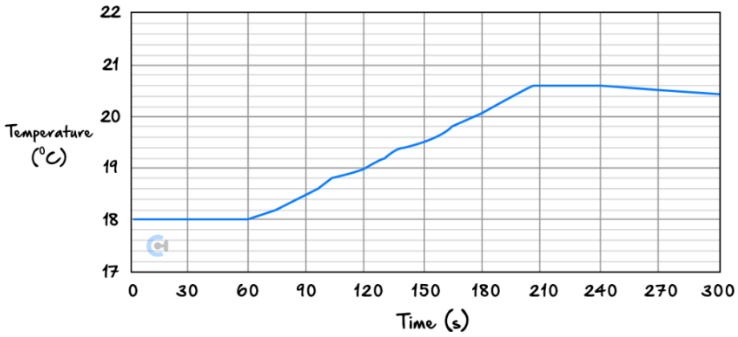
Question 22 (9 marks)

A bomb calorimeter is calibrated by passing a current of 3.50 A at a voltage of 6.20 V for 150 seconds.



a. From the temperature-time graph provided, determine the calorimeter's calibration factor in $kJ/°C$. (3 marks)

$E = VIt$

$= 3.5 \times 6.2 \times 150$

$= 3255\ J$

$\therefore CF = \frac{E}{\Delta T}$

$= \frac{3255}{20.6 - 18}$

$= 1251.92\ J/°C$

$= 1.25\ kJ/°C$

The calorimeter is then used to analyse the combustion of a 2.00 g sample of fuel, which increases the calorimeter's temperature by 15.5°C. During this combustion, it is noted that:

- A separate 100 mL water compartment outside the calorimeter absorbs 4.00 kJ of heat.
- The calorimeter itself has a heat capacity of 200 $J/°C$, which also absorbs heat during combustion.

b. Calculate the total energy released by the fuel. (3 marks)

Calorimeter:

$E = CF \times \Delta T$

$= 1.25 \times 15.5$

$= 19.375\ kJ$

Water Heat:

$E = 4\ kJ$

Calorimeter structure:

$E = 0.2 \times 15.5$

$= 3.10\ kJ$

Total energy:

$E_T = 3.1 + 19.375 + 4$

$= 26.475\ kJ$

$\approx 26.5\ kJ$

c. Calculate the energy content of the fuel in kJ/g. (1 mark)

$\therefore E.C = \frac{26.475}{2}$

$= 13.2375\ kJ/g$

$\approx 13.2\ kJ/g$

d. Explain whether this calorimeter has good or poor insulation. (2 marks)

Yes, the calorimeter has good insultation (1).
There is a minimal drop in the temperature of the solution after the calorimeter is switched off, indicating that minimal heat is being lost to the environment. This suggests that the insulation is good (2).

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