Calibration of a calorimeter using a neutralisation reaction (Solutions with second-hand data)

Objective:

To calibrate a solution calorimeter by determining its heat capacity using the neutralisation reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH).

Prior knowledge: H^+(aq) + OH^- (aq) → H_2O(l) ΔH = -57.1 kJ/mol

Materials:

- 1 M HCl solution (50 mL)
- 1 M NaOH solution (50 mL)
- A 100 mL solution calorimeter
- 2 X Thermometers 0 – 100ºC
- Measuring cylinder (50 mL)
- Stirring rod
- Stopwatch or timer

Procedure:

Step 1 -   Measure 50 mL of 1 M HCl using a measuring cylinder and pour it into the dry calorimeter. Make sure the thermometer is already placed on the lead of the calorimeter.

 -    Measure 50 mL of 1 M NaOH using a separate measuring cylinder.

Step 2 -   Allow both solutions to reach the same temperature. Record the initial temperature of both the HCl solution in the calorimeter and the NaOH in the measuring cylinder.

Step 3 -   Quickly add the 50 mL of NaOH solution to the HCl in the calorimeter and immediately seal the calorimeter with the lid and thermometer inserted and stir gently for 20 seconds.

Step 4 -   Record the temperature of the water every 30 seconds for 5 minutes. Record your results in an appropriate table.

Step 5 -   Accurately plot the temperature vs time graph for the set of results.

Data Collection:

Trial/time (sec)	0	30	60	90	120	150	180	210	240	270	300
(°C)	22.00	22.00	25.20	26.50	27.00	27.20	27.10	27.00	26.90	26.85	26.80
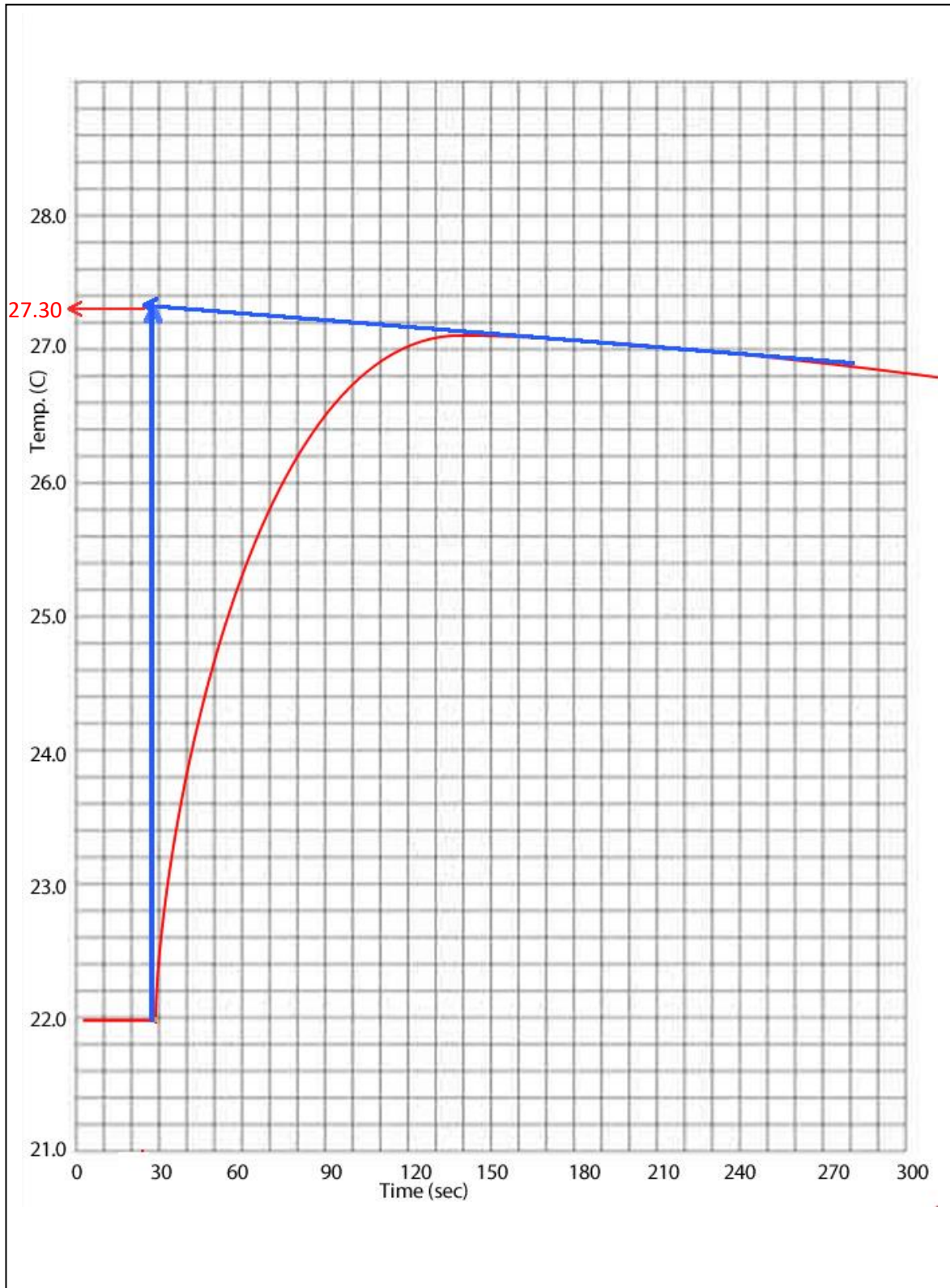
Calculations:

1. Using the graph drawn, determine the ΔT for each trial.

    Students should be able to extrapolate to derive the ΔT.
    27.3 - 22.00 = 5.30 °C.

2. **Determine the heat energy, in kJ, released by the reaction**

Step 1 Determine the mol of the limiting reactant
=> both reactants are in the exact stoichiometric ratio , hence
=> n_{HCl} = C X V = 1.00 X 0.050 = 0.050 mol
Step 2 calculate the energy released using the stoichiometry of the thermochemical reaction given.
=> 0.050 X 57.1 kJ = 2.86 kJ

3. **Calculate the calibration factor C_f of the Calorimeter**

    => C_f = 2.86 / 5.3 °C = 0.54 kJ/°C

Questions:

1. **Why is it important to ensure that both solutions are at the same initial temperature before mixing?**

   Avoiding Heat Transfer Between Solutions so that the temperature change is only influenced by the amount of energy released by the reaction. If the solutions are at different temperatures, heat will flow between them before the reaction even starts. This will affect the final temperature of the mixture, complicating the calculations for the heat released by the neutralization reaction. Ensuring both solutions start at the same temperature minimizes this extra heat transfer. What assumptions are made when calculating the C_f?

2. **Consider the theoretical reaction A + B → C. If the temperature change is 6.5°C when 0.10 mol of A completely reacts with excess B, calculate the ΔH of the reaction.**

   Energy released = 0.54 kJ/°C X 6.5 °C = 3.5 kJ
   Energy released per mol of A = 3.5 kJ /0.1 = 350 kJ/mol
   *A + B → C ΔH = -350kJ or -350 kJ/mol*

3. **What is the purpose of calibrating the calorimeter before measuring the ΔH of a reaction?**

   A calibration factor accounts for the heat loss to the environment and for the energy absorbed by the actual calorimeter itself with all its components, such as heating coil, stirrer, metal container and lid. Hence the results for the ΔH are more valid when using a calibration factor than using the formula Q =4.18 X mass X ΔT, which assumes 100% of the energy released was absorbed by the water.

1. **An unrelated solution calorimeter with 100g of water was calibrated and its C_f was found to be 0.55 kJ/°C. A temperature rise of 6.3 degrees was observed when 0.10 mol of compound B reacted fully with excess reactant G according to the equation below.**
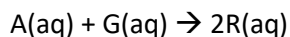
    A(aq) + G(aq) → 2R(aq)

    Two calculations were performed to obtain the ΔH of the reaction above. These calculations are shown below.

    Calculation 1

    Energy released = 0.55kJ/°C X 6.3 °C = 3.5 kJ

    Energy per mol of A = 3.5 kJ/0.1 =35 kJ/mol

    A(aq) + G(aq) → 2R(aq) **ΔH = - 35kJ**

    The second calculation was performed using Q = 4.18 X mass X ΔT

    a.   **Complete the working out for calculation 2.**

    Calculation 2

    Energy released = *4.18 X 100 X 6.3 = 2.6 kJ*

    Energy per mol of A = *26 kJ/mol*

    ΔH = *-26 kJ*

    b.   **Explain the difference between the two calculation and suggest, with a reason which calculation has greater validity.**

    Calculation 2 assumes all the energy released was absorbed by the water and reflected in the temperature change of 6.3 °C. A great deal of the energy was released into the environment, probably due to poor insulation and hence not registered as a temperature increase of the water. The ΔH = -26 kJ is therefore lower than that calculated with the calibration factor which does take into account energy loss. For this reason calculation 1 is more valid.

2. **Explain how important is it that the total volume of water or solution in the solution calorimeter remains constant after it has being calibrated.**

    Once the calorimeter is calibrated, it's important that the volume of water doesn't change. For example, if the volume of water increases, the temperature change (ΔT) will be smaller because more water is being heated with the same amount of energy. This is based on the formula ΔT = Energy / (4.18 × mass of water). So, if the mass of water increases, ΔT will decrease. As a result, the energy calculations (Cf × ΔT) will give a lower value for the energy released or absorbed, leading to inaccurate results

Determination of the ΔH of an exothermic reaction.

Background

A reaction commonly used to heat cans of soup or self-heating meals is the exothermic reaction between calcium oxide (quicklime) and water. This reaction produces calcium hydroxide according the equation given below.

$$CaO \text{ (s)} + H_2O \text{ (l)} \rightarrow Ca(OH)_2 \text{ (aq)} \quad \Delta = ?$$
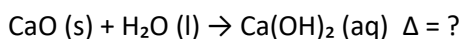
This reaction is highly exothermic and can raise the temperature of the surrounding liquid or food contents, making it ideal for self-heating food packaging.

Aim: **To Measure ΔH of the Reaction between calcium oxide and water using a calibrated solution calorimeter.**

Materials:

- Approximately 2 grams of calcium oxide (quicklime)

- 50 mL of distilled water

- 100 mL solution calorimeter (which was previously calibrated)

- 1 X Thermometer (0-100 °C)

- Stirring rod

- Balance (± 0.01 g)

- Graduated cylinder (50 mL)

Procedure:

Step 1 - Weigh approximately 2.00 g of calcium oxide and record its mass.

Step 2 - Measure 50.0 g of distilled water at room temperature, using the electronic balance and pour it into the calorimeter.
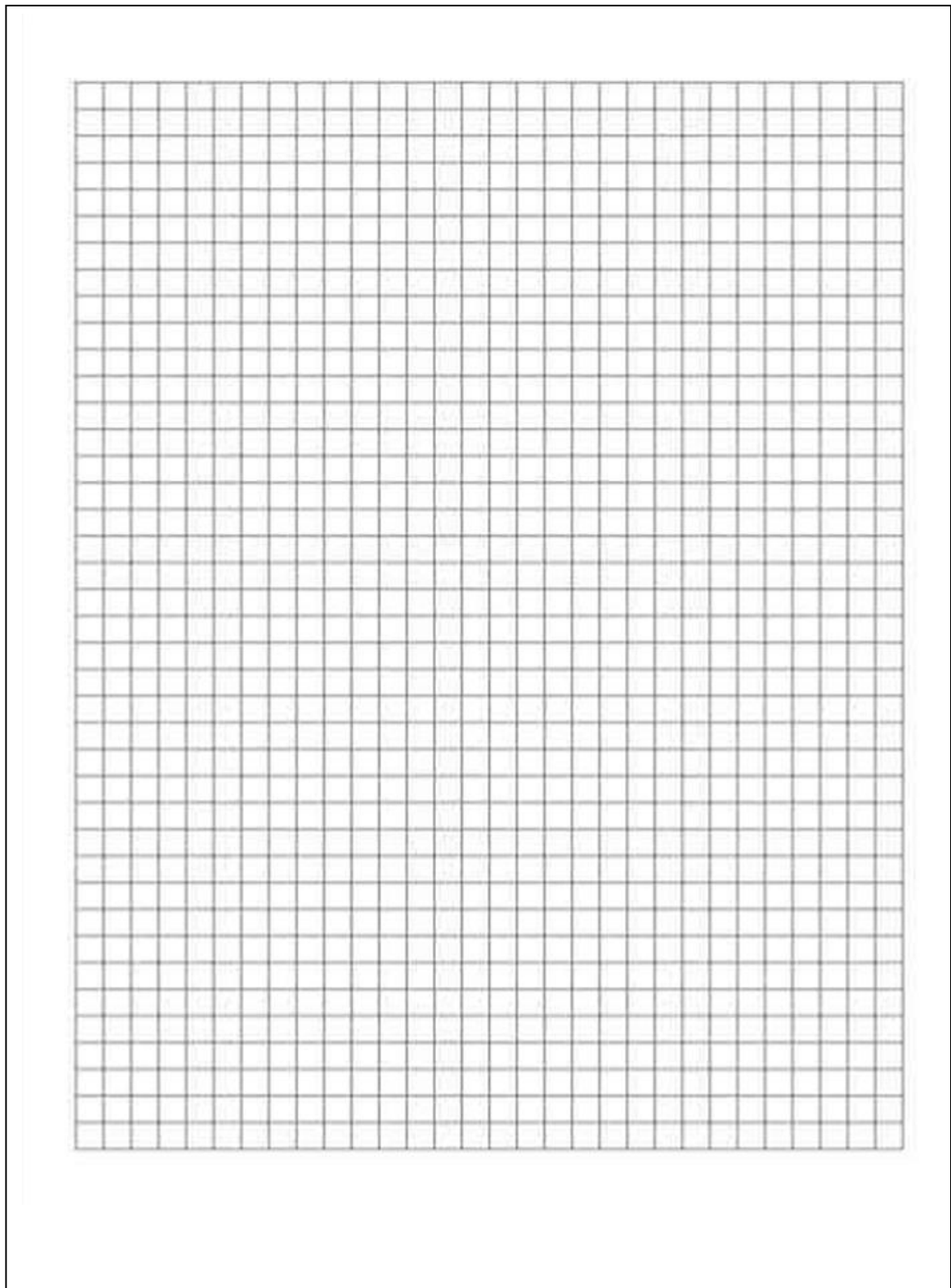
Step 3 - Record the initial temperature of the water.

Step 4 - Add the calcium oxide to the water in the calorimeter, quickly seal the lid, and stir the mixture gently.

Step 5 - Record the temperature every 30 seconds for five minutes.

Step 6 – Graph the results and use the graph to obtain the ΔT of the water.

Data Collection:

Trial/time(sec)	0	30	60	90	120	150	180	210	240	270	300
(°C)											

1. **Using the graph of temperature vs time, determine the ΔT.**
   Using hypothetical data. ΔT = 4.3⁰C

2. **Calculate the mol of calcium oxide reacted .** Molar mass of CaO (56.08 g/mol)
   => 2.00 / 56.08 = 0.0357 mol

3. Calculate the amount of energy released by the mol of CaO calculated in question 2 above.

   => C_f X ΔT = 0.54 kJ/⁰C X 4.3 °C = 2.3 kJ (2 sig figs)

4. Calculate the **ΔH** of the reaction CaO (s) + H_2O (l) → $Ca(OH)_2$ (aq) Δ = ?

   2.3 kJ / 0.0357 mol = 65 kJ/mol
   => ΔH = -65 kJ (2 sig figs) negative sign must be shown.

Questions

1. What is the resolution of the data?

    0.01g

_____

2. What assumptions are made in this calorimetry experiment if the calorimeter was well stirred?
    A valid assumption such as:

    - *all the calcium oxide reacts completely with water to form calcium hydroxide.*

    - *reaction between calcium oxide and water is the sole reaction contributing to the observed temperature change.*

3. Why is calcium oxide used in self-heating cans and not anhydrous copper sulfate, which also reacts exothermically with water?

$$CuSO_4 \ (s) \ + 5H_2O \ (l) \rightarrow CuSO_4 \cdot 5H_2O \ (s) \ \ \Delta H = -11.7kJ/mol$$

    Any plausible suggestion that differentiates the two reactions with reference to ΔH and heavy metal toxicity, such as:
    - *The heat released is much lower than that of calcium oxide, making it less effective for heating.*

    - *Since the ΔH for the reaction between CaO and H_2O is higher than that of the hydration of $CuSO_4$, less CaO can be used in compact compartments to quickly and efficiently heat food or beverages when water is added. The CaO reaction produces sufficient heat in a short time to achieve the desired temperature increase.*
    - *Anhydrous copper sulfate's lower heat output and toxicity, heavy metal, would make it impractical and unsafe for use in such applications*

4. If 1.80 g of calcium oxide is mixed with 50 mL of distilled water in a new calorimeter whose C_f has been calculated at 0.500 kJ/°C, calculate the enthalpy change (ΔH) in kJ/mol if the temperature of the water increased by 4.6 °C.

    Step 1 Calculate the energy released.

    => Q = ΔT X C_f = 4.6 X 0.500 = 2.3 kJ

    Step 2 Calculate the mol of CaO
    => 1.80 / 56.1 = 0.0321
    Step 3 – find ΔH => -2.3/0.0321 = -72kJ 0r -72kJ/mol.

5. Provide one plausible suggestion, that can be implemented in the school laboratory, as to how the validity of the results could be improved? Your answer should not include performing more trials.

    Any plausible suggestion with a valid explanation such as:

    - *Use a larger volume of water, say from 10 mL to 100 mL, in the calorimeter. Since a larger water mass reduces the relative effect of heat loss to the surroundings, as a greater proportion of the released heat is absorbed by the water.*

    - *Ensure constant stirring until all the calcium oxide (CaO) is fully dissolved and reacted with the water. Incomplete reactions may lead to underestimating the total heat released, as not all of the reactants have participated in the reaction. Stirring ensures maximum contact between CaO and water, leading to complete reaction and accurate results.*

    - *Use boiled or distilled water. This will remove gases from the water, such as CO_2, which could react with the CaO to form insoluble $CaCO_3$.*

    - *Allow the solid CaO and water to stand at room temperature until they are both at the same temperature.is at the same temperature as the water. If the CaO is at a different temperature, for example cooler or warmer than the water, it can artificially influence the observed temperature change (ΔT). For example, a colder CaO sample would absorb some heat from the water, leading to an underestimation of the heat released by the reaction. Ensuring both reactants are at the same starting temperature increases the validity of the measured ΔT.*