Q1.

In Europe, some of the glucose from crops is fermented to produce ethanol.

Use of a carbon-neutral fuel leads to no net emissions of carbon dioxide to the atmosphere.

(a) The ethanol produced by fermentation of glucose may be regarded as a carbon-neutral fuel.

Justify this statement. Include the relevant chemical equations in your answer.

(4)

Coffee beans from South America are exported to Europe in an outer layer called silverskin.

The waste silverskin can be fermented to produce a solution containing propanone, ethanol and butan-1-ol.

(b) Suggest why ethanol produced in Europe using silverskin from South America is less likely to be carbon-neutral than ethanol produced from crops grown in Europe.

(1)

(c) **Table 1** shows the enthalpies of combustion of the three fuels from the fermentation of silverskin.

Table 1

Fuel	**Standard enthalpy of combustion / kJ mol^{-1}**	**Energy released per mole of CO_2 produced / kJ**
ethanol, $C_2H_5OH(l)$	–1371	
butan-1-ol, $C_4H_9OH(l)$	–2673	
propanone, $C_3H_6O(l)$	–1786	

One way to measure a fuel's environmental impact is to measure the amount of energy released per mole of CO_2 produced.

Complete **Table 1**.

Use your answers to deduce the fuel with the lowest environmental impact by this measure.

____

____

(2)

(d) A student investigated the combustion of propanone (C_3H_6O) using calorimetry.

A copper calorimeter containing water was heated by the complete combustion of some propanone. The student did not record the final temperature of the water.

Table 2 shows the student's results.

Table 2

Mass of propanone burned / g	1.18
Mass of water / g	260
Initial temperature of water / °C	22.3
Final temperature of water / °C	Not recorded

Use the results in **Table 2** to calculate a value for final temperature of the water in the experiment. Assume that no heat was lost in the experiment and that the heat capacity of the calorimeter is negligible.

For propanone, enthalpy of combustion = –1786 kJ mol^{-1}

For water, specific heat capacity = 4.18 J g^{-1} K^{-1}

Final temperature of water ________________ °C

(4)

(e) Butan-1-ol can be added to petrol for cars.

An equation for the complete combustion of gaseous butan-1-ol is shown.

$$C_4H_9OH(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 5\ H_2O(g) \quad \Delta H = -2504\ kJ\ mol^{-1}$$

Table 3 shows some mean bond enthalpy data.

Table 3

Bond	C=O	C–H	C–O	O–H	O=O
Mean bond enthalpy / kJ mol^{-1}	805	412	360	463	496

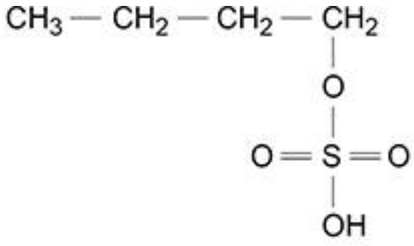
Use these data to calculate a value for the mean C–C bond enthalpy in gaseous butan-1-ol.

C–C bond enthalpy _______________ kJ mol^{-1}

(3)

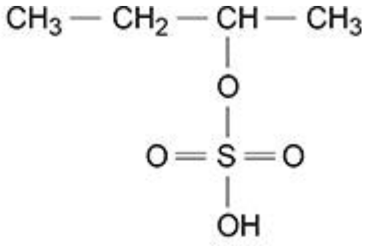
Butan-1-ol can be manufactured by reacting steam with but-1-ene in the presence of the catalyst, concentrated sulfuric acid.

In the first part of this process, but-1-ene reacts with concentrated sulfuric acid to form compounds **W** and **X**.



$CH_3-CH_2-CH_2-CH_2-O-S(=O)_2-OH$

Compound **W**



$CH_3-CH_2-CH(-O-S(=O)_2-OH)-CH_3$

Compound **X**

Butan-1-ol is then made from compound **W**.

(f) Name and outline a mechanism to show the conversion of but-1-ene into compound **W** in the first part of this process.

Name of mechanism ____

Outline of mechanism

(5)

(g) There is a very low yield of butan-1-ol from but-1-ene in this manufacturing process.

Explain why.

____

____

____

____

(2)
(Total 21 marks)

Q2.

A value for enthalpy of solution can be determined in two ways:

- from a cycle, using lattice enthalpy and enthalpies of hydration
- from the results of a calorimetry experiment.

(a) Define the term enthalpy of lattice dissociation.

____

____

____

____

(2)

(b) The enthalpy of solution for ammonium nitrate is the enthalpy change for the reaction shown.

$$NH_4NO_3(s) + aq \rightarrow NH_4^+(aq) + NO_3^-(aq) \qquad \Delta H = +26 \text{ kJ mol}^{-1}$$

Table 1

	$NH_4^+(g)$	$NO_3^-(g)$
Enthalpy of hydration $\Delta_{hyd}H$ / kJ mol^{-1}	−307	−314

Draw a suitably labelled cycle and use it, with data from **Table 1**, to calculate the enthalpy of lattice dissociation for ammonium nitrate.

Enthalpy of lattice dissociation _______________ kJ mol^{-1}

(3)

(c) A student does an experiment to determine a value for the enthalpy of solution for ammonium nitrate.

The student uses this method.

- Measure 25.0 cm^3 of distilled water in a measuring cylinder.
- Pour the water into a beaker.
- Record the temperature of the water in the beaker.
- Add 4.00 g of solid NH_4NO_3 to the water in the beaker.
- Stir the solution and record the lowest temperature reached.

Table 2 shows the student's results.

Table 2

Initial temperature / °C	20.2
Lowest temperature / °C	12.2

Calculate the enthalpy of solution, in kJ mol^{-1}, for ammonium nitrate in this experiment.

Assume that the specific heat capacity of the solution, $c = 4.18$ J K^{-1} g^{-1}

Assume that the density of the solution = 1.00 g cm^{-3}

Enthalpy of solution _______________ kJ mol^{-1}

(3)

(d) The uncertainty in each of the temperature readings from the thermometer used in this experiment is ±0.1°C

Calculate the percentage uncertainty in the temperature change in this experiment.

Percentage uncertainty ____________________

(1)

(e) Suggest a change to the student's method, using the same apparatus, that would reduce the percentage uncertainty in the temperature change.

Give a reason for your answer.

Change ____

____

Reason ____

____

(2)

(f) Another student obtained a value of +15 kJ mol^{-1} using the same method.

Suggest the main reason for the difference between this experimental value for the enthalpy of solution and the correct value of +26 kJ mol^{-1}

____

____

(1)

(g) **Table 3** shows some entropy data at 298 K

Table 3

	Entropy *S* / J K^{-1} mol^{-1}
$NH_4NO_3(s)$	151
$NH_4^+(aq)$	113
$NO_3^-(aq)$	146

Calculate a value for the Gibbs free-energy change (ΔG), at 298 K, for the reaction when ammonium nitrate dissolves in water.

$$NH_4NO_3(s) + aq \rightarrow NH_4^+(aq) + NO_3^-(aq) \qquad \Delta H = +26 \text{ kJ mol}^{-1}$$

Use data from **Table 3** and the value of ΔH from the equation.
Assume for the solvent, water, that the entropy change, $\Delta S = 0$

Explain what the calculated value of ΔG indicates about the feasibility of this reaction at 298 K

ΔG ________________ kJ mol^{-1}

Explanation ____

____

____

(4)

(h) Ammonium nitrate decomposes as shown.

$$NH_4NO_3(s) \rightarrow N_2(g) + \frac{1}{2} O_2(g) + 2\ H_2O(g) \qquad \Delta H = +123 \text{ kJ mol}^{-1}$$

The entropy change (ΔS) for this reaction is +144 J K^{-1} mol^{-1}

Calculate the temperature at which this reaction becomes feasible.

Temperature _______________ K

(2)

(Total 18 marks)

Q3.

This question is about combustion.

(a) State the meaning of the term standard enthalpy of combustion.

____

____

____

____

(2)

(b) A student does an experiment to determine the enthalpy of combustion of propan-1-ol ($CH_3CH_2CH_2OH$, $M_r = 60.0$).
Combustion of 0.497 g of propan-1-ol increases the temperature of 150 g of water from 21.2 °C to 35.1 °C

Calculate a value, in kJ mol^{-1}, for the enthalpy of combustion of propan-1-ol in this experiment.

The specific heat capacity of water is 4.18 J K^{-1} g^{-1}

Enthalpy of combustion _______________ kJ mol^{-1}

(3)

(c) The enthalpy of combustion determined experimentally is less exothermic than that calculated using enthalpies of formation.

Give **one** possible reason for this, other than heat loss.

____

____

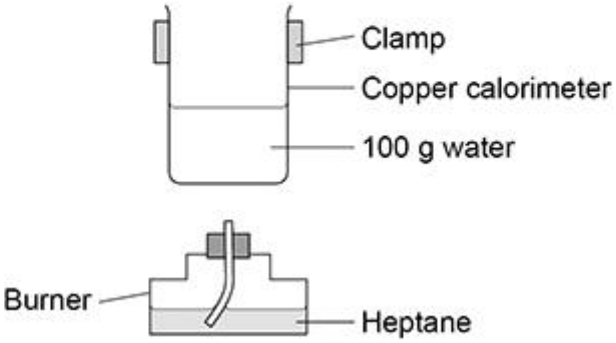
(1)

(Total 6 marks)

Q4.

A student does an experiment to determine a value for the enthalpy of combustion of heptane.

The figure below shows some of the apparatus used.



(a) Design a table to record all the readings necessary to determine an experimental value for the enthalpy of combustion for heptane in this experiment.

(2)

(b) The student considered using a glass beaker on a tripod and gauze instead of the clamped copper calorimeter.

Suggest **two** disadvantages of using a glass beaker on a tripod and gauze.

Disadvantage 1 ____

____

Disadvantage 2 ____

____

(2)

(c) Suggest **two** reasons why the value of enthalpy of combustion from this experiment is less exothermic than a data book value.

Reason 1 ____

____

Reason 2 ____

____

(2)

(d) Suggest **one** addition to this apparatus that would improve the accuracy of the enthalpy value obtained.

____

____

(1)

(Total 7 marks)

Q5.

This question is about enthalpy changes.

(a) State the meaning of the term enthalpy change as applied to a chemical reaction.

____

____

(1)

(b) A student determines the enthalpy change for the reaction between calcium carbonate and hydrochloric acid.

$$CaCO_3(s) + 2\ HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

The student follows this method:

- measure out 50 cm^3 of 1.00 mol dm^{-3} aqueous hydrochloric acid using a measuring cylinder and pour the acid into a 100 cm^3 glass beaker
- weigh out 2.50 g of solid calcium carbonate on a watch glass and tip the solid into the acid
- stir the mixture with a thermometer
- record the maximum temperature reached.

The student uses the data to determine a value for the enthalpy change.

Explain how the experimental method and use of apparatus can be improved to provide more accurate data.

Describe how this data from the improved method can be used to determine an accurate value for the temperature change.

____

____

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____

____

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____

____

(6)

(c) In a different experiment 50.0 cm^3 of 0.500 mol dm^{-3} aqueous hydrochloric acid are reacted with 50.0 cm^3 of 0.500 mol dm^{-3} aqueous sodium hydroxide.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta H = -57.1 \text{ kJ mol}^{-1}$$

The initial temperature of each solution is 18.5 °C

Calculate the maximum final temperature of the reaction mixture.

Assume that the specific heat capacity of the reaction mixture, $c = 4.18$ J K^{-1} g^{-1}

Assume that the density of the reaction mixture = 1.00 g cm^{-3}

Final temperature _______________ °C

(5)

(d) Suggest how, without changing the apparatus, the experiment in part (c) could be improved to reduce the percentage uncertainty in the temperature change.

(1)

(Total 13 marks)

Q1.

(a) **M1** $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ 1

M2 $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Allow C_2H_6O for ethanol formula 1

M3 $2C_2H_5OH + 6O_2 \rightarrow 4CO_2 + 6H_2O$

M1/2/3 *allow multiples*

M3 $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ 1

M4 explains with reference to relevant equations that formation of $C_6H_{12}O_6$ takes in $6CO_2$ and fermentation and combustion of ethanol gives out $6CO_2$

M4 *depends on having appropriate equations in* ***M1/2/3*** *showing 6 CO_2 in and out* 1

(b) transport (from South America to Europe) produces CO_2 / has C emissions / has larger C footprint

Process to separate ethanol from propanone and butan-1-ol produces CO_2 / has C emissions / has larger C footprint 1

(c) **M1** 685.5 (686), 668(.25), 595(.33…) in third column of table

M1 *ignore any minus sign on values* 1

M2 depends on their answer to **M1** − must be the compound giving most energy per mole of CO_2 released (correct **M1** would give ethanol)

M2 *need evidence of attempt to calculate energy released per C atom (i.e. per mole of CO_2 formed)* 1

(d) **M1** amount propanone = $\frac{1.18}{58.0}$(= 0.0203 mol) 1

M2 q = **M1** × 1786 (= 36.3 kJ = 36300 J) 1

M3 ΔT (= $\frac{q}{mc} = \frac{\text{M2 (in J)}}{260 \times 4.18}$) = 33.4 (°C) (allow 32.8-33.4)

M3 *ignore sign* 1

M4 final temperature = (22.3 + **M3**) = 55.7 (°C) (allow 55-596)

M4 *must show a temperature rise* 1

Correct answer scores 4 marks

Allow ECF at each stage

(e) **M1** correctly showing how many of which types of bonds are broken / made
(broken) 3(C-C) + 9(C-H) + (C-O) + (O-H) + 6(O=O)
(made) 8(C=O) + 10(O-H)

M1 *could show broken as:*
3(C-C) + 9(412) + (360) + (463) + 6(496)
or 7507 + 3(C-C)

and, could show made as
8(805) + 10(463)
or 11070

1

M2 (bonds broken) − (bonds made) = −2504
7507 + 3(C-C) − 11070 = −2504
3(C–C) = 1059

*Allow ECF from **M1** to **M2***

*Ignore incorrect number of C-C bonds in **M1/2**, but should be 3 for **M3***

1

M3 (C–C) = $\frac{M2}{3}$ = 353 (kJ mol^{-1})

*Allow ECF from **M2** to **M3** (if **M2** is negative value, then ignore sign for **M3**)*

1

Correct answer scores 3 marks;

265 scores 2 marks if from 4(C-C) bonds

1188 scores 2 marks (not included −2504)

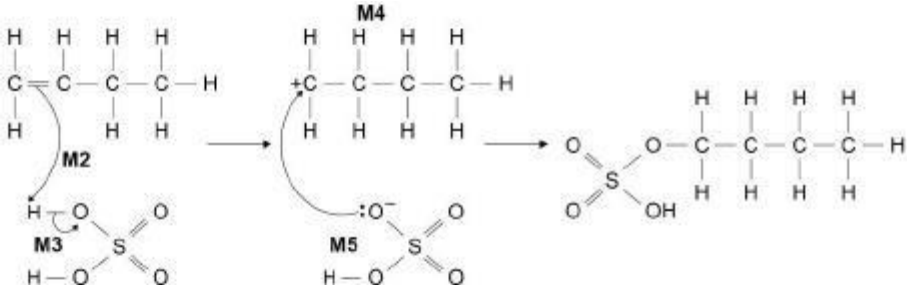
2022 scores 2 marks (using (made − broken))

−353 scores 2 marks

±834 scores 2 marks (use of C-O in CO_2)

±836 scores 1 marks (use of C-O in CO_2 and using (made − broken))

(f) **M1** electrophilic addition



1

M2 must show an arrow from the double bond towards the H atom of the H_2SO_4 molecule

***M2** ignore partial negative charges on the double bond*

1

M3 must show the breaking of the H-O bond in H_2SO_4

***M3** penalise incorrect partial charges on the H–O bond and penalise formal charges*

1

M4 is for the structure of the correct carbocation

*Penalise **M4** if there is a bond drawn to the positive charge*

1

M5 must show an arrow from the lone pair of electrons on the correct oxygen of HSO_4^- towards the positively charged atom of <u>their</u> carbocation drawn

1

*All arrows are double-headed. Penalise one mark from the total for **2-5** if half headed arrows are used*

Do not penalise the "correct" use of "sticks"

Penalise only once in any part of the mechanism for a line and two dots to show a bond

*For **M2 / 3**, the full structure of H_2SO_4 does not need to be shown, but the key features for the mechanism should be shown and the formula must be correct. Penalise only once in **M2 / 3** an incorrect but genuine attempt at the structure of sulfuric acid*

***Max 3 of 4 marks (M2-5)** for wrong organic reactant or wrong carbocation (ignore structure of product)*

*If attack is shown from C=C to H^+ rather than H_2SO_4, then allow **M2** but not **M3***

*For **M5**, credit attack on a partially positively charged carbocation structure, but penalise **M4** for the structure of the carbocation*

*For **M5**, the full structure of HSO_4^- is not essential, but attack must come from a lone pair on an individual oxygen on HSO_4^-, but the – sign could by anywhere on the ion (eg :OSO_3H^-)*

(g) **M1** formed from less stable carbocation

***M1** must be clear that it is the stability of the carbocation that matters rather than the stability of the alcohol*

1

M2 formed from primary rather than secondary carbocation

***M2** allow 1 mark for primary carbocation is less stable than secondary carbocation even if not clear that product is formed from a carbocation (but must be clear that the alcohols are not the carbocations)*

1

[21]

Q2.

(a) The enthalpy change / ΔH when one mole of a (solid) ionic compound

***Ignore** standard states / conditions*

***Allow** heat change at constant pressure when...*

***Ignore** heat change (alone) / energy change*

1

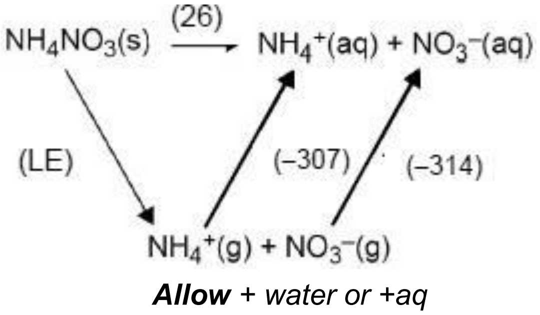
dissociates (fully) into gaseous ions

***M2 Allow** suitable equation with state symbols for ions*

***Not** one mole of gaseous ions*

1

(b)



***Allow** + water or +aq*

M1 = cycle (3 'corners' with formulae and state symbols and suitable arrows)

***Allow** equivalent Born-Haber style energy cycle*

***Not** ecf to M2 and M3 from incorrect cycle*

1

LE = 26 + 307 + 314

M2 = working e.g. 26 = LE − 307 − 314

= (+)647

1

M3 = answer (+)647 gets 3/3 if M1 given or 2/3 if not
−647 = 2/3 if M1 given or 1/3 if not
+595 / −595 = 2/3 if M1 given or 1/3 if not
−621/+621 = 1/3 if M1 given
***Not** ecf for M3 from incorrect expression in M2*

1

(c) ($q = mc\Delta T$ =) 25.0 × 4.18 × (20.2 − 12.2) **OR** 25.0 × 4.18 × 8
(= 836 (J) or 0.836 (kJ))

***Not** if m = 29*

***Ignore** sign of q*

1

4.00 g NH_4NO_3 = 4.00/80 **OR** 0.0500 mol

1

$\Delta H^{\⦵}$soln = 836/0.05 = 16720 = (+)16.7(2) kJ mol^{-1}

***Allow** ecf from M1 and/or from M2*

–16.7(2) = 2/3

+19.4 = 2/3 (using m = 29 in M1)

−19.4 = 1/3

+2.68 = 2/3

−2.68 = 1/3

+587 or +588 = 2/3

−587 or −588 = 1/3

***Allow** 2 sig figs or more*

1

(d) (2 × 0.1/8) × 100 = 2.5%

***Allow** ecf from ΔT in (c)*

1

(e) use a larger mass/amount of NH_4NO_3 / solid

Marking points are independent

***Allow** smaller volume of water / less water*

***Allow** use more NH_4NO_3*

***Not** larger volume of water*

***Ignore** higher concentration (of NH_4NO_3)*

***Ignore** any references to changing apparatus e.g. insulation*

1

so temperature change/decrease is greater
OR final temperature is lower

***Allow** temperature increase is greater*

***Not** final temperature is higherr*

1

(f) heat gain (from the surroundings) / incomplete dissolvingg

***Allow** incomplete reaction*

***Allow** thermal energy gain*

Not *heat loss*
Ignore *energy gain*
Ignore *references to mistakes in method*

1

(g) ΔS = (113 + 146) − 151 = +108 (J K^{-1} mol^{-1})

1

$\Delta G = \Delta H - T\Delta S$ **OR** 26 − (298 × 108 × 10^{-3})

Allow *ecf 26 − (298 × M1 × 10^{-3})*
Allow *ecf 26 − (298 × M1)*
Allow M2 *for 26000 − (298 × 108)*
Allow M2 *for 26 − (298 × 108)*

1

ΔG = −6.184 / −6.18 / −6.2

−32158 = ***M1*** *and* ***M2***
−32.2 = ***M1*** *and* ***M2***
−6184 = ***M1*** *and* ***M2***
(+)58.2 = ***M2*** *and* ***M3*** *(ecf if −108 for M1)*

1

negative value for ΔG indicates reaction is feasible/spontaneous

Allow *positive value for ΔG indicates reaction is NOT feasible/spontaneous*
Allow *< 0 or > 0 as appropriate*
M4 *is standalone*

1

(h) Converting ΔH into J **OR** ΔS into kJ

1

($T = \Delta H / \Delta S$ = 123/144 × 10^{-3} **OR** 123000/144) = 854(.1666666) (K)

0.854 (K) = 1/2
0.00117 (K) = 1/2 (calculation upside down)
2SF minimum

1

[18]

Q3.

(a) Enthalpy change when one mole of a substance burns completely in oxygen

Allow heat energy change / allow fully combust

1

With all substances in their standard states (at stated temperature and 100kPa)

1

(b) q = m c ΔT = 150 × 4.18 × 13.9 = 8715.3 J

1

n(propan-1-ol)= $\frac{0.497}{60.0}$ = 0.00828 mol

1

ΔH = $-\frac{8.7153}{0.00828}$ = −1050 kJ mol^{-1}

M3 = – M1×10^{-3}/M2

Minimum of 2 sf needed

Must be negative

1

(c) Incomplete combustion

Evaporation of fuel

Experiment not completed under standard conditions

1

[6]

Q4.

(a)

	Temp/ °C		Mass /g
Initial		Burner before	
Final		Burner after	
(ΔT)		(Mass heptane burned)	

M1 for Temperature data including units

M2 for Burner mass data including units If either unit missing MAX 1

M1
M2

(b) Any two from:

Glass is a poorer conductor than copper

M1

Tripod and gauze would reduce heat transfer

Tripod and gauze would have a fixed height above the flame

Heat capacity of metal is less than glass or vice versa

M2

(c) Heat loss to surroundings or to copper/calorimeter

M1

Incomplete combustion

M2

(d) Use a wind shield (to reduce heat loss)

Allow use a lid

Insulate the sides of the calorimeter

1

[7]

Q5.

(a) Heat energy change at constant pressure

1

(b)

This question is marked using Levels of Response.	
Level 3: All stages are covered and the explanation of each stage is generally correct and virtually complete. Answer is well structured with no repetition or irrelevant points. Accurate and clear expression of ideas with no errors in use of technical terms.	5-6 marks
Level 2: All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete. Answer shows some attempt at structure. Ideas are expressed with reasonable clarity with, perhaps, some repetition or some irrelevant points. Some minor errors in use of technical terms.	3-4 marks
Level 1: Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete. Answer includes isolated statements but these are not presented in a logical order or show some confusion. Answer may contain valid points which are not clearly linked to an argument structure. Errors in the use of technical terms.	1-2 marks
Level 0: Insufficient correct chemistry to gain a mark.	0 marks

Indicative Chemistry

Stage 1: Apparatus
1a. Use a burette/pipette (instead of a measuring cylinder)
1b. Use a polystyrene cup (instead of a beaker) / insulate beaker
1c. Reweigh the watchglass after adding the solid 1d: Use powdered solid

Stage 2: Temperature Measurements
2a. Measure and record the initial temperature of the solution for a few minutes before addition
2b. Measure and record the temperature after the addition at regular intervals (eg each minute) for 8+ minutes/until a trend is observed

Stage 3: Temperature Determination
3a. Plot a graph of temperature against time
3b. Extrapolate to the point of addition
3c. Determine ΔT at the point of addition

6

(c) n(HCl) or n(NaOH) = 50 x 0.500 / 1000 = 0.025 moles

1

$q = -\Delta H \times n = 57.1 \times 0.025 = 1.4275$ kJ

M2 *= 57.1 ×* ***M1***

1

$\Delta T = q/mc$

1

ΔT = (1.4275 x 1000) / (100 x 4.18) = 3.4(2) °C

__M4__ = (__M2__ × 1000) / (100 × 4.18)

1

Final Temperature = 18.5 + 3.4 = 21.9 °C

__M5__ = __M4__ + 18.5 (but final temperature must be higher than 18.5 °C)

1

(d) Increase the concentration of the solutions

1

[13]