Cambridge Assessment International Education

Teaching Pack

Determing the enthalpy change for the thermal decompostion of $KHCO_3$

Cambridge International AS & A Level Chemistry 9701

Version 1.0

Cambridge Pathway

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Briefing lesson

Planning lesson

Lab lesson

Debriefing lesson

Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

Important note
Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.

This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 3 (Advanced Practical Skills) or Paper 5 (Planning, Analysis and Evaluation).

This is one of a range of *Teaching Packs* and each pack is based on one experiment. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson reinforces the key concepts, relevant skills, knowledge and understanding linked to the experiment.

↓

Planning lesson (1 hour*)
This lesson focuses on planning an experiment.
It ends with a demonstration video of the experiment.

↓

Lab lesson (1 hour*)
This lesson focuses on carrying out the experiment including the collection and recording of observations, measurements and estimates.

↓

Debriefing lesson (1 hour*)
This lesson focuses on the analysis and interpretation of data.
This includes making conclusions, evaluating methods and the quality of data and how improvements could be made.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this pack you will find lesson plans, worksheets and teacher resource sheets.

Experiment: Determining the enthalpy change for the thermal decomposition of $KHCO_3$

This *Teaching Pack* focuses on a decomposition experiment.

The enthalpy change of a thermal decomposition reaction cannot be measured as the reaction mixture is heated as the experiment is carried out. In this experiment you will carry out two reactions and use Hess' Law to calculate the enthalpy change of decomposition of $KHCO_3$.

This experiment has links to the following syllabus content (see syllabus for detail):

- 5.2 Hess' Law, including Born-Haber Cycles

The experiment covers the following experimental skills, as listed in **AO3: Experimental skills and investigations:**

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret data to reach conclusions
- evaluate methods and quality of data and suggest improvements.

Prior knowledge

Knowledge from the following syllabus topic is useful for this experiment.

- 5.1 Enthalpy Change, ΔH

Briefing lesson: Hess' Law

Resources	• Worksheet A • Worksheet B
Learning objectives	By the end of the lesson: • ***all*** learners should be able to write enthalpy cycles • ***most*** learners should be able to give examples of when an enthalpy cycle is required • ***some*** learners will be able to determine unknown enthalpy changes when given data of other reactions in the enthalpy cycle.

Timings	Activity
10 min	**Starter/Introduction** Learners complete a ΔH calculation (Worksheet A) using $mc\Delta T$. Go through the answer with them – lead to the idea that we cannot always measure ΔH. *Get ideas from learners as to why not.* (For example, if heating the reaction would affect the results.)
10 min	**Main lesson** Ask learners if you could measure the enthalpy change of a thermal decomposition. Lead to the idea that because you are heating it, the results would be affected.
15 min	Define Hess' Law and explain that we can use different reaction pathways to get to the answer. Draw a Hess cycle on the board describing a thermal decomposition (use $KHCO_3$). Show the reactions for ΔH_1 and ΔH_2.
20 min	Give learners Worksheet B so that they can practice drawing Hess' Law cycles and calculations.
5 min	**Plenary** Ask learners for a list of examples of when they could measure enthalpy change directly (e.g. combustion) and when they cannot and have to use an enthalpy cycle.

Planning lesson: Calorimetry

Resources	• Image of calorimetry experiment • Written enthalpy reaction cycle for $KHCO_3$ that students will complete during practical in next lesson • Hess' Law experiment video • Worksheet C (if required)

Learning objectives	By the end of the lesson: • ***all*** learners should be able to plan a calorimetry experiment • ***most*** learners should be able to plan what they would need to measure to calculate ΔH of a thermal decomposition reaction • ***some*** learners will be able to discuss problems with calorimetry.

Timings	Activity
5 min	**Starter/Introduction** Ask learners to look at the picture of the calorimetry set-up. Discuss what errors can happen during the experiment (e.g. heat loss to surroundings, thermometer making experiment unstable); what do we need to consider when setting up the experiment?
10 min 25 min 15 min	**Main lesson** Learners should write a quick plan for an experiment that would measure a temperature change caused by combustion (e.g. spirit burner, beaker of water above, measure temperature change of water). Ask the question: is calculating ΔH from this experiment possible? (*yes*) What would we need to measure to calculate ΔH? (*mass of spirit as well as temperature change and mass of water*). Lead to $KHCO_3$. Can we measure the enthalpy change for the thermal decomposition of potassium hydrogen carbonate? (*no, as we have to provide heat when doing thermal decomposition reaction*). Show learners the enthalpy cycle of $KHCO_3$ with HCl. What could we do instead? (*measure the other two reactions*). Ask learners to plan an experiment (that will be completed next lesson) to find the enthalpy changes of the other two reactions in the cycle. The plan should include safety rules, an equipment list and masses of chemicals used. How can learners minimise heat loss and any other errors? Give out Worksheet C, which provides prompts, if required. Now watch the Hess' Law experiment video. After watching the video ask learners to look at their plan to see what, if anything, they have missed. Learners add any extra bits or change any mistakes.
5 min	**Plenary** Learners write out how they will calculate the enthalpy change of thermal decomposition based on the results they will get. Compare with another learner. Ask learners to revise the enthalpy cycle for $KHCO_3$ and HCl for homework.

Lab lesson: Investigating enthalpy change

Resources

- *Teacher walkthrough* video
- Experimental equipment
- Teacher notes
- Experimental method (if needed)

Learning objectives

By the end of the lesson:

- ***all*** learners should be able to carry out a calorimetry experiment
- ***most*** learners should be able to collect results in order to calculate $Q = mc\Delta T$
- ***some*** learners will be able to calculate enthalpy change from their results.

Timings	Activity
5 min	**Starter/Introduction** Learners write out the enthalpy cycle for $KHCO_3$ and HCl from memory.
40 min	**Main lesson** Learners carry out practical – if there is time, and enough chemicals, learners can repeat the experiment to get three sets of results, in order to calculate an average. **Safety** Circulate the classroom at all times during the experiment so that you can make sure that your learners are safe and that the data they are collecting is accurate.
10 min	Learners need to calculate Q using the equation $Q = mc\Delta T$ for the two reactions. Learners also need to calculate the energy per mole of reactant. From these values, learners can then calculate the enthalpy change for the thermal decomposition reaction using Hess' Law (if learners are unsure of how to do this, replay the experiment video focusing on the calculation steps). Get learners to check each other's calculations.
5 min	**Plenary** Ask learners what the most difficult part of the practical was, leading to ideas about errors. This will be discussed further in the next lesson.

Teacher notes

Watch the Hess' Law video (*Teacher Walkthrough* version) and read these notes.

Each group will require:

- access to 2 mol dm^{-3} HCl
- potassium hydrogen carbonate
- potassium carbonate
- a polystyrene cup
- a cardboard lid, with a hole
- a thermometer
- a clamp stand with boss and clamp
- a mass balance
- a measuring cylinder capable of measuring 20 cm^3
- a spatula
- a weighing boat.

Safety

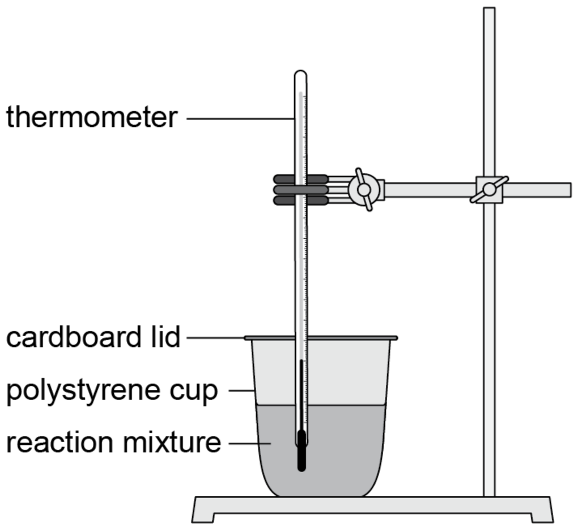
The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Substance	Hazard	First aid
Hydrochloric acid [2 mol dm^{-3} solution]	 GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Potassium hydrogen carbonate	Low hazard	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor.

Substance	Hazard	First aid
		Spilt on skin or clothing: remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.
Potassium carbonate	 GHS07 (*moderate hazard* **MH**)	**In the eye:** rinse thoroughly with plenty of water for at least 15 min and consult a doctor. **Swallowed:** wash out the mouth with water. Do not induce vomiting. Never give anything by mouth to an unconscious person. Consult a doctor. **If inhaled:** move person into fresh air. If not breathing, give artificial respiration. Consult a doctor. **Spilt on skin or clothing:** remove contaminated clothing and shoes immediately and rinse. Wash off the skin with plenty of water. Consult a doctor.

Experiment set-up



Teacher method

This is your version of the method for this experiment that accompanies the *Teacher walkthrough* video. Do not share this method with learners.

Before you begin

Plan how you will group your learners during the experiment session.

Think about:

- the number of groups you will need (group size 2–4 learners)
- the amount of equipment/chemicals required
- If you would like them to repeat the experiment.

Experiment

Walk around the learners during the experiment in case they encounter any difficulties.

Steps	Notes
1. Learners should collect the equipment they require from the front of the class.	*Remind learners that the thermometer makes the calorimeter unsteady and so a clamp stand is a good idea.*
2. They should find a space in the classroom where the equipment can be assembled safely.	
3. Make sure your learners can switch on the equipment they are using	*Remind learners to zero the mass balance.*
4. Learners should measure out 20 cm^3 of HCl and approximately 3.5 g of $KHCO_3$. They should pour the acid into the polystyrene cup and measure the initial temperature	*The HCl is an irritant, so learners should be wearing goggles.*
5. Learners should add the $KHCO_3$ and record the lowest temperature reached	
6. Students should then repeat the experiment with K_2CO_3.	

Clean-up

After the experiment learners should:

- clean all glassware
- tidy up their work space
- ensure any spillages have been mopped up
- return all equipment and any unused chemicals to you.

Alternative methods

If you do not have access to the required equipment or the suggested method would not work for your class, here are some possible alternatives that you could use

- Complete the practical as a demonstration
- Instead of using $KHCO_3$ and K_2CO_3 you can use $CaCO_3$ and CaO with HCl.

Debriefing lesson: Calorimetry analysis

Resources	• Worksheets D and E
Learning objectives	By the end of the lesson: • ***all*** learners should be able to analyse their method for the calorimetry experiment • ***most*** learners should be able to use experimental data to calculate enthalpy changes • ***some*** learners will be able to plan experiments based on unfamiliar reaction cycles.

Timings	Activity
5 min	**Starter/Introduction** Ask learners the biggest source of error in the experiment they completed (they are likely to say either heat loss or difficulty in ensuring they read the maximum or minimum temperature change).
10 min	**Main lesson** Ask learners to discuss how errors could be minimised. Ideas could be: *further insulation to prevent heat loss* or *a temperature logger for the max. or min. temperature so they cannot be missed*. Provide suitable feedback on learners' responses.
25 min	Ask learners if they were able to calculate the enthalpy change of thermal decomposition based on their experiment. If not, go through how to do this (can use Hess' Law experiment video for guidance). Give learners Worksheet D which provides further examples of Hess' Law calculations from experimental data. Learners should peer review the answers.
15 min	Give Learners Worksheet E showing an unfamiliar reaction cycle. Ask them to write a brief plan for the unknown reaction. Ask them what they may need to consider (e.g. state symbols, safety rules, etc.).
5 min	**Plenary** Reinforce the calorimetry experiment by drawing with learners a labelled diagram of the experimental set-up.

Worksheets and answers

	Worksheet	Answers
For use in *Briefing lesson*:		
A: $Q = mc\Delta T$ question	**15**	**21**
B: Hess' Law questions	**16**	**22**
For use in *Planning lesson*:		
C: Experiment planning	**18**	**24**
For use in *Debriefing lesson*:		
D: Experimental calculations	**19**	**25**
E: Experimental plan	**20**	**27**

Worksheet A: $Q = mc\Delta T$

Complete the following questions.

For all the questions assume that the densities and specific heat capacities of the solutions are the same as pure water.

$$\rho = 1.0 \text{ g cm}^{-3} \text{ and } c = 4.18 \text{ J g}^{-1} \text{K}^{-1}$$

1. Zinc will displace copper from copper(II) sulfate solution according to the following equation:

$$CuSO_4(aq) + Zn(s) \rightarrow Cu(s) + ZnSO_4(aq)$$

If an excess of zinc powder is added to 50 cm^3 of 1.0 mol dm^{-3} copper(II) sulfate, the temperature increases by 6.3 °C. Calculate the enthalpy change for the reaction.

2. Magnesium will also displace copper from copper(II) sulfate solution. If an excess of magnesium is added to 100 cm^3 of 1.0 mol dm^{-3} copper(II) sulfate, the temperature increases by 46.3 °C.

(a) Calculate the molar enthalpy change for the reaction.
(b) Calculate the minimum quantity of magnesium required to ensure the copper(II) sulfate completely reacts.

Worksheet B: Hess' Law questions

Complete the following questions. A worked example is provided to help you.

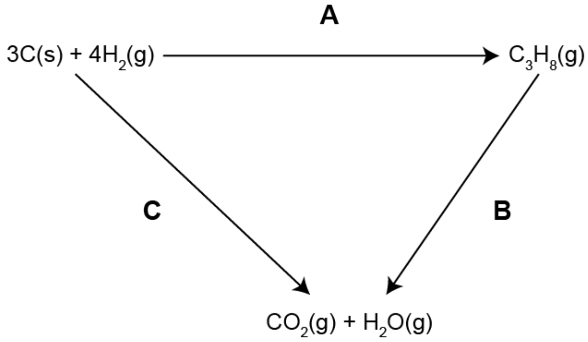
Worked example

The equation for the formation of propane is:

$$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$$

The enthalpy change cannot be measured directly, however the enthalpy changes of the combustion reactions of the reactants and products can be measured directly. The combustion reactions produce CO_2 and H_2O.

First, construct an enthalpy cycle between the reactants, products and their combustion products.



The enthalpy change of the combustion of the reactants, **C**, is −2326 kJ mol^{-1}. The enthalpy change of the combustion of the products, **B,** is −2202 kJ mol^{-1}.

To work out the unknown enthalpy change, **A**:

A + B = C **so** C – B = A

Therefore:

$$(-2326) - (-2202) = \mathbf{-124\ kJ\ mol^{-1}}$$

1. The equation for the formation of pentane is: $5C(s) + 6H_2(g) \rightarrow C_5H_{12}(g)$
   (a) Construct an enthalpy cycle between the reactants, products and their combustion products.
   (b) Calculate the unknown enthalpy change for the formation of pentane. The enthalpy change of the combustion of the reactants is −3686 kJ mol^{-1}. The enthalpy change of the combustion of the products is −3509 kJ mol^{-1}.

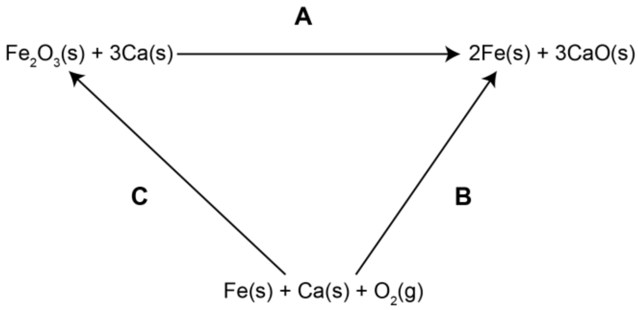
2. The equation for the decomposition of $NaHCO_3$ is: $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$
   (a) Construct an enthalpy cycle between the reactants, products and their products from the reaction with HCl.
   (b) Calculate the unknown enthalpy change for the decomposition of $NaHCO_3$. The enthalpy change of the reaction of $NaHCO_3$ with HCl is +28 kJ mol^{-1}. The enthalpy change of the reaction of Na_2CO_3 with HCl is −26 kJ mol^{-}. (Remember to take into consideration the number of moles reacting in each reaction.)

Worksheet B: Hess' Law questions, continued

3. The equation for the decomposition of $CaCO_3$ is: $CaCO_3 \rightarrow CaO + CO_2$
   (a) Construct an enthalpy cycle between the reactants, products and their products from the reaction with HC*l*.
   (b) Calculate the enthalpy change for the decomposition of $CaCO_3$. The enthalpy change of the reaction of $CaCO_3$ with HC*l* is +38 kJ mol^{-1}. The enthalpy change of the reaction of CaO with HC*l* is −77 kJ mol^{-1}.

4. The equation for the formation of butane is: $4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$
   (a) Construct an enthalpy cycle between the reactants, products and their combustion products.
   (b) Calculate the unknown enthalpy change for the formation of butane.The enthalpy change of the combustion of the reactants is −3006 kJ mol^{-1}. The enthalpy change of the combustion of the products is −2877 kJ mol^{-1}.

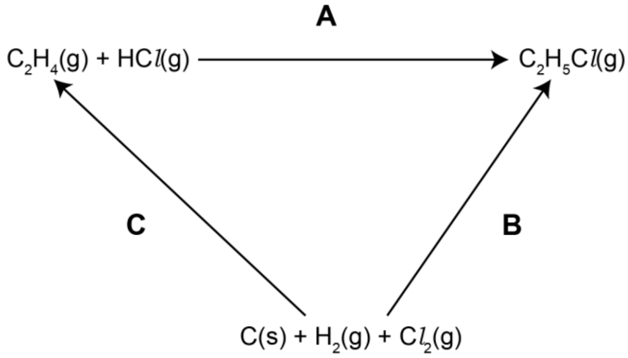
5. An enthalpy cycle is shown below.



   Calculate **A** if **B** is −1905 kJ mol^{-1} and **C** is −824 kJ mol^{-1}.

6. The equation for the decomposition of $KHCO_3$ is: $2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$
   (a) Construct an enthalpy cycle between the reactants, products and their products from the reaction with HC*l*.
   (b) Calculate the unknown enthalpy change for the decomposition of $KHCO_3$. The enthalpy change of the reaction of $KHCO_3$ with HC*l* is +29.4 kJ mol^{-1}. The enthalpy change of the reaction of K_2CO_3 with HC*l* is −33.4 kJ mol^{-1}. (Remember to take into consideration the number of moles reacting in each reaction.)

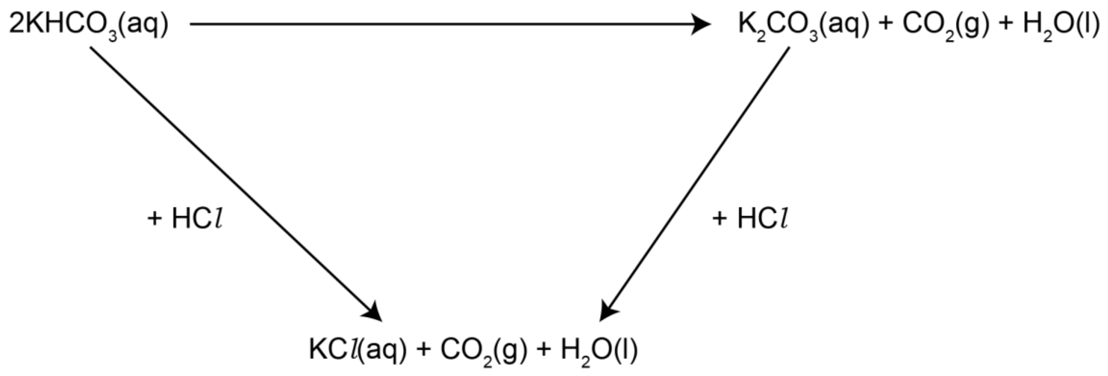
7. An enthalpy cycle is shown below.



   Calculate **A** if **B** is −1222 kJ mol^{-1} and **C** is −624 kJ mol^{-1}.

Worksheet C: Experiment planning

Use this worksheet to help you plan the experiment to find the enthalpy change of the thermal decomposition of $KHCO_3$.



Your plan should include the following sections.

- Equipment needed
- Method
  - Be specific; include masses and volumes of chemicals you will use.
- Safety
  - Do you know if any of the chemicals are irritants?
- Errors
  - What could go wrong; how could you minimise this?
- Diagram of experimental set-up

Write your plan in your lab book.

Worksheet D: Experiment calculations

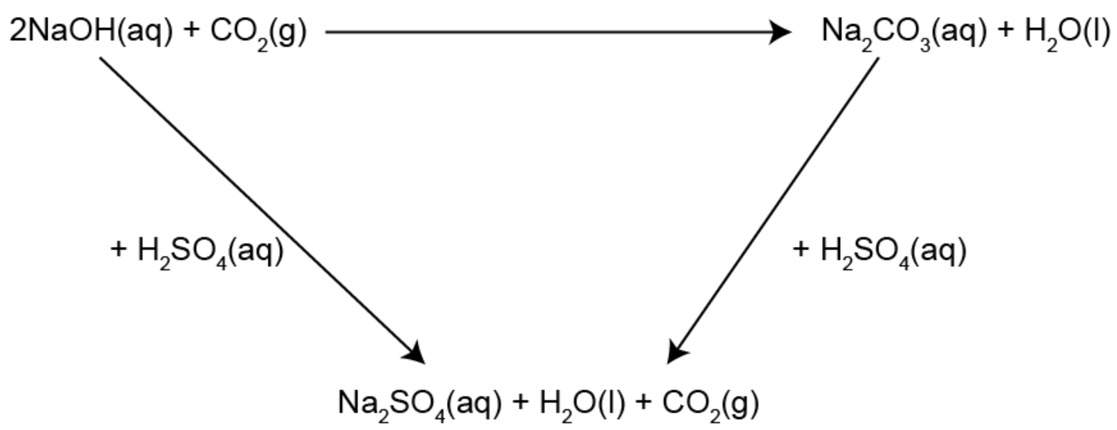
Complete the following questions

1.
   (a) Sodium hydroxide and carbon dioxide react together to produce sodium carbonate and water. Write the balanced symbol equation.
   (b) The enthalpy change for this reaction cannot be measured in the laboratory, however, both sodium carbonate and sodium hydroxide react with sulfuric acid. Write balanced symbol equations for these reactions.
   (c) Draw an enthalpy cycle for these reactions.
   (d) 25 cm^3 of 2 mol dm^{-3} sodium hydroxide was added to 25 cm^3 of 1 mol dm^{-3} sulfuric acid. The temperature increased by 11 °C. Calculate the energy transferred per mole of sodium hydroxide during this reaction; assume the density of the liquid is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.18 J g^{-1} K^{-1}.
   (e) 25 cm^3 of 1 mol dm^{-3} sodium carbonate was added to 25 cm^3 of 1 mol dm^{-3} sulfuric acid. The temperature increased by 4 °C. Calculate the energy transferred per mole of sodium carbonate during this reaction; assume the density of the liquid is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.18 J g^{-1} K^{-1}.
   (f) Calculate the enthalpy change of the reaction between sodium carbonate and carbon dioxide.
   (g) Suggest reasons why the experimental temperature rise might be less than the literature value for this experiment.

2.
   (a) Sodium hydrogen carbonate decomposes to produce sodium carbonate, carbon dioxide and water. Write the balanced symbol equation.
   (b) The enthalpy change for this reaction cannot be measured in the laboratory, however, both sodium carbonate and sodium hydrogen carbonate react with hydrochloric acid. Write balanced symbol equations for these reactions.
   (c) Draw an enthalpy cycle for these reactions.
   (d) 3 g of sodium hydrogen carbonate was added to 25 cm^3 of 1 mol dm^{-3} hydrochloric acid. The temperature decreased by 2 °C. Calculate the energy transferred per mole of sodium hydrogen carbonate during this reaction; assume the density of the liquid is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.18 J g^{-1} K^{-1}.
   (e) 3 g of sodium carbonate was added to 25 cm^3 of 1 mol dm^{-3} hydrochloric acid. The temperature increased by 7 °C. Calculate the energy transferred per mole of sodium carbonate during this reaction; assume the density of the liquid is 1.0 g cm^{-3} and the specific heat capacity of the solution is 4.18 J g^{-1} K^{-1}.
   (f) Calculate the enthalpy change of the decomposition of sodium hydrogen carbonate.

Worksheet E: Experimental plan

Here is a reaction cycle for the addition of carbon dioxide to sodium hydroxide.



Write an experimental plan for this reaction cycle in your lab book.

You should include the following sections in your plan.

- Equipment needed
- Method
  - Be specific; include volumes and concentrations of chemicals you will use.
- Safety
  - Do you know if any of the chemicals are irritants?
- Errors
  - What could go wrong; how could you minimise this?
- Diagram of experimental set-up

Also include a sentence on why the use of state symbols is important when drawing reaction cycles.

Worksheet A: Answers

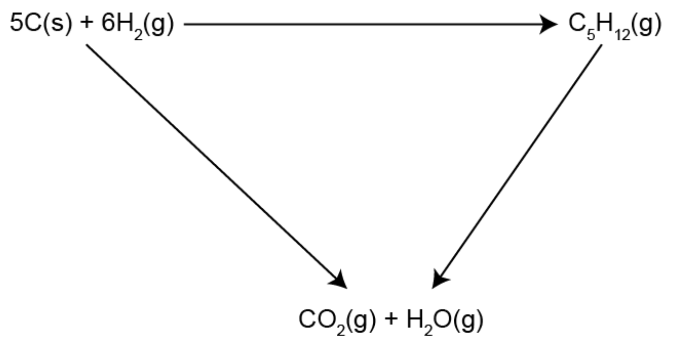
1. -26.3 kJ mol^{-1}

2. (a) -193.5 kJ mol^{-1} (b) 2.43 g

Worksheet B: Answers

1.

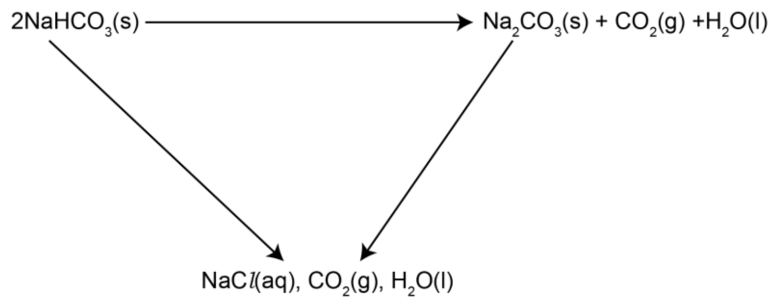
(a)



(b) −177 kJ mol^{-1}

2.

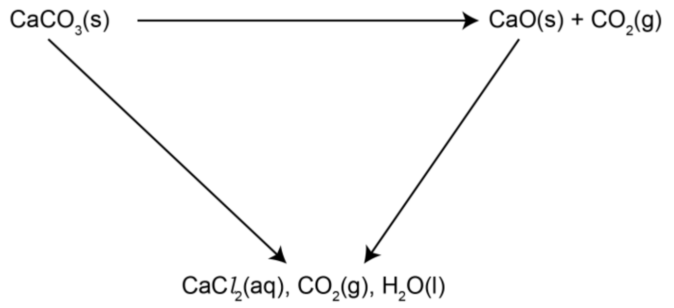
(a)



(b) +82 kJ mol^{-1}

3.

(a)

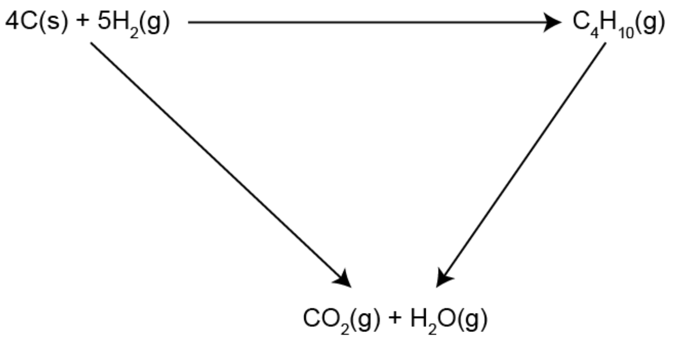


(b) +115 kJ mol^{-1}

Worksheet B: Answers, continued

4.

(a)

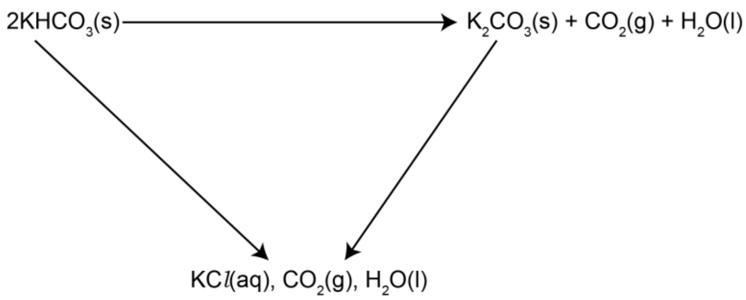


(b) –129 kJ mol^{-1}

5. –1081 kJ mol^{-1}

6.

(a)



(b) +92.2 kJ mol^{-1}

7. –598 kJ mol^{-1}

Worksheet C: Answers

Equipment needed

- *HCl*
- *potassium hydrogen carbonate*
- *potassium carbonate*
- *a polystyrene cup, with a cardboard lid*
- *a thermometer*
- *a clamp stand with boss and clamp*
- *a mass balance*
- *a measuring cylinder capable of measuring 20 cm^3*
- *a spatula*
- *a weighing boat*

Method

- *Set up the polystyrene cup with a thermometer clamped above it.*
- *Measure out 20 cm^3 of HCl and approximately 3.5 g of $KHCO_3$. Pour the acid into the polystyrene cup and measure the initial temperature.*
- *Add the $KHCO_3$ and record the temperature.*
- *Repeat the experiment with K_2CO_3.*

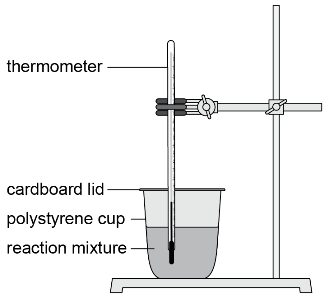
Safety

- *Wear goggles.*
- *Wash any spills on skin with plenty of water.*

Errors

- *Heat loss, ensure there is a lid over the reaction vessel.*
- *Could miss the lowest / highest temperature, ensure you are watching at all times. Could use a datalogger instead.*

Diagram of experimental set-up



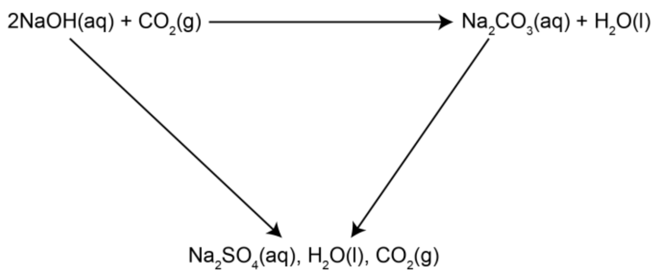
Worksheet D: Answers

1. (a) $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

   (b) $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

   $Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$

   (c)



   (d) $50 \times 4.18 \times 11 = 2299$ J

   moles of sodium hydroxide = $2 \times 0.025 = 0.05$

   per mole = 2299/0.05 = 45 980 J mol^{-1}

   $\Delta H = -45.98$ kJ mol^{-1}

   (e) $50 \times 4.18 \times 4 = 836$ J

   moles of sodium carbonate = $1 \times 0.025 = 0.025$

   per mole = 836/0.025 = 33 440 J mol^{-1}

   $\Delta H = -33.44$ kJ mol^{-1}

   (f) $2(-45.98) - (-33.44) = -58.52$ kJ mol^{-1}

   (g) Suggestions could include heat loss to surroundings, heat loss to polystyrene cup, experiment not stirred correctly.

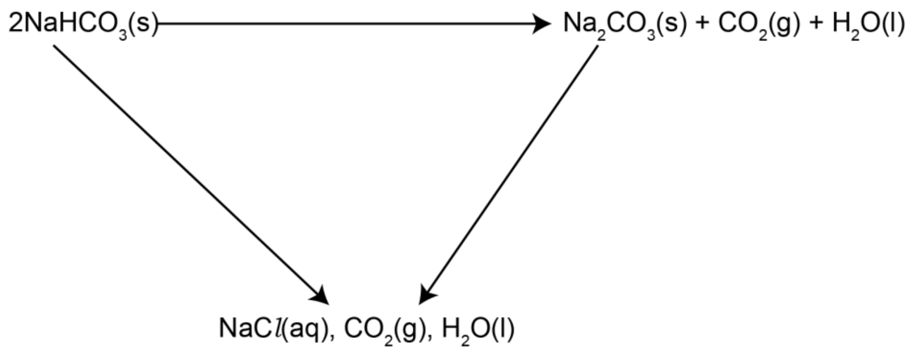
Worksheet D: Answers, continued

2. (a) $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

   (b) $NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$

   $Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$

   (c)



   (d) +5.85 kJ mol^{-1}

   (e) –25.85 kJ mol^{-1}

   (f) +37.55 kJ mol^{-1}

Worksheet E: Answers

Equipment needed

- H_2SO_4
- sodium carbonate solution
- sodium hydroxide solution
- a polystyrene cup, with a cardboard lid
- a thermometer
- a clamp stand with boss and clamp
- a measuring cylinder capable of measuring 20 cm^3

Method

- Set up the polystyrene cup with a thermometer clamped above it.
- Measure out 20–50 cm^3 of 0.5–2 mol dm^{-3} H_2SO_4 and 20–50 cm^3 of 0.5–2 mol dm^{-3} Na_2CO_3.
- Pour the acid into the polystyrene cup and measure the initial temperature.
- Add the Na_2CO_3 and record the temperature.
- Repeat the experiment with NaOH.

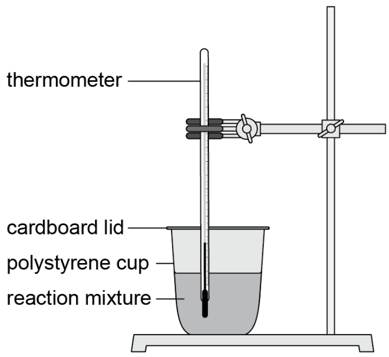
Safety

- Wear goggles.
- Wash any spills on skin with plenty of water.

Errors

- Heat loss, ensure there is a lid over the reaction vessel.
- Could miss the lowest/highest temperature, ensure you are watching at all times. Could use a datalogger instead.

Diagram of experimental set-up



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