Section A

Q1 Hess's Law can be used to calculate the average C-H bond energy in methane.

$\Delta H^{\ominus}_{at}$ = standard enthalpy change of atomisation

$\Delta H^{\ominus}_{f}$ = standard enthalpy change of formation

$\Delta H^{\ominus}_{c}$ = standard enthalpy change of combustion

Which data values are needed in order to perform the calculation?

A $\Delta H^{\ominus}_{at}$ (C), $\Delta H^{\ominus}_{at}$ (H), $\Delta H^{\ominus}_{f}$ (CH_4)

B $\Delta H^{\ominus}_{c}$ (C), $\Delta H^{\ominus}_{c}$ (H_2), $\Delta H^{\ominus}_{c}$ (CH_4)

C $\Delta H^{\ominus}_{c}$ (C), $\Delta H^{\ominus}_{c}$ (H_2), $\Delta H^{\ominus}_{f}$ (CH_4)

D $\Delta H^{\ominus}_{f}$ (CH_4) only, as $\Delta H^{\ominus}_{f}$ (C), and $\Delta H^{\ominus}_{f}$ (H_2), are defined as zero

Q2 The standard enthalpy changes of formation of HCl and HI are –92 kJ mol^{-1} and +26 kJ mol^{-1} respectively. Which statement is most important in explaining this difference?
A Chlorine is more electronegative than iodine.
B The activation energy for the $H_2 + Cl_2$ reaction is much less than that for the $H_2 + I_2$ reaction.
C The bond energy of HI is smaller than the bond energy of HCl.
D The bond energy of I_2 is smaller than the bond energy of Cl_2.

Q3 Methanol may be prepared by the reaction between carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

The relevant average bond energies are given below.

E(C≡O) 1077 kJ mol^{-1}
E(C–O) 360 kJ mol^{-1}
E(C–H) 410 kJ mol^{-1}
E(H–H) 436 kJ mol^{-1}
E(O–H) 460 kJ mol^{-1}

What is the enthalpy change of this reaction?
A –537 kJ mol^{-1} B –101 kJ mol^{-1} C +101 kJ mol^{-1} D +537 kJ mol^{-1}

Q4 Use of the Data Booklet is relevant to this question.
The enthalpy change of formation, ΔH_f, of hydrated calcium ions is the enthalpy change of the
following reaction.

$$Ca(s) + aq - 2e^- \rightarrow Ca^{2+}(aq)$$

The following enthalpy changes are not quoted in the Data Booklet.

$$Ca(s) \rightarrow Ca(g) \quad \Delta H_a = 177 \text{ kJ mol}^{-1}$$

$$Ca^{2+}(g) + aq \rightarrow Ca^{2+}(aq) \quad \Delta H_{hyd} = -1565 \text{ kJ mol}^{-1}$$

What is the enthalpy change of formation of hydrated calcium ions?
A –1388 kJ mol^{-1} B –798 kJ mol^{-1} C –238 kJ mol^{-1} D +352 kJ mol^{-1}

Q5 The first stage in the industrial production of nitric acid from ammonia can be represented by the following equation.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

Using the following standard enthalpy change of formation data, what is the value of the standard enthalpy change, ΔH_o, for this reaction?

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$NH_3(g)$	–46.1
NO(g)	+90.3
$H_2O(g)$	–241.8

A +905.2 kJ mol^{-1} B –105.4 kJ mol^{-1} C –905.2 kJ mol^{-1} D –1274.0 kJ mol^{-1}

Q6 Red lead oxide, Pb_3O_4, is used in metal priming paints. It can be made by heating PbO in air.

$$6PbO(s) + O_2(g) \rightarrow 2Pb_3O_4(s)$$

Which two values are needed to calculate the enthalpy change for this reaction?
A enthalpy change of combustion of lead and enthalpy change of formation of Pb_3O_4
B enthalpy change of combustion of PbO and enthalpy change of formation of Pb_3O_4
C enthalpy change of formation of PbO and enthalpy change of atomisation of O_2
D enthalpy change of formation of PbO and enthalpy change of formation of Pb_3O_4

Q7 Which equation represents the standard enthalpy change of atomisation of bromine?
A $Br_2(l) \rightarrow 2Br(g)$
B $Br_2(g) \rightarrow 2Br(g)$
C $\frac{1}{2} Br_2(l) \rightarrow Br(g)$
D $\frac{1}{2} Br_2(g) \rightarrow Br(g)$

Q8 For which equation is the enthalpy change correctly described as an enthalpy change of formation?
A $2NO(g) \rightarrow N_2(g) + O_2(g)$
B $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$
C $H_2O(l) + NaCl(s) \rightarrow NaCl(aq)$
D $K(s) + Mn(s) + 2O_2(g) \rightarrow KMnO_4(s)$

Q9 Given $CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$ $\Delta H_o = –283$ kJ mol^{-1}
$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H_o = –286$ kJ mol^{-1}
$H_2O(g) \rightarrow H_2O(l)$ $\Delta H_o = –44$ kJ mol^{-1}
what is the change in enthalpy, ΔH_o, for the following reaction?

$$CO_2(g) + H_2(g) \rightarrow CO(g) + H_2O(g)$$

A –525 kJ mol^{-1} B –41 kJ mol^{-1} C +41 kJ mol^{-1} D +525 kJ mol^{-1}

Q10 Given $S(s) + O_2(g) \rightarrow SO_2(g)$, $\Delta H^o_f = –297$ kJ mol^{-1}
and $S(s) + 3/2\ O_2(g) \rightarrow SO_3(g)$ $\Delta H^o_f = –395$ kJ mol^{-1}
what is the enthalpy change of reaction, ΔH^o, of $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$?
A –196 kJ mol^{-1}
B –98 kJ mol^{-1}
C +98 kJ mol^{-1}
D +196 kJ mol^{-1}

Q11 The table shows the enthalpy change of neutralisation per mole of water formed, ΔH, for various acids and bases.

acid	base	ΔH / kJ mol^{-1}
hydrochloric acid	sodium hydroxide	–57.0
P	sodium hydroxide	–54.0
hydrochloric acid	Q	–52.0
nitric acid	R	–57.0

	P	Q	R
A	ethanoic acid	ammonia	potassium hydroxide
B	ethanoic acid	sodium hydroxide	ammonia
C	sulphuric acid	ammonia	potassium hydroxide
D	sulphuric acid	sodium hydroxide	ammonia

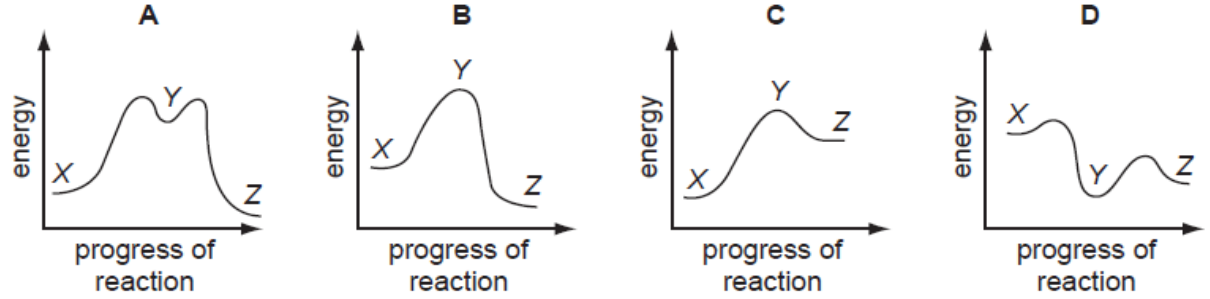
Q12 Titanium occurs naturally as the mineral rutile, TiO_2. One possible method of extraction of titanium is to reduce the rutile by heating with carbon.

$$TiO_2(s) + 2C(s) \rightarrow Ti(s) + 2CO(g)$$

The standard enthalpy changes of formation of $TiO_2(s)$ and $CO(g)$ are –940 kJ mol^{-1} and –110 kJ mol^{-1} respectively.
What is the standard enthalpy change of this reaction?
A –830 kJ mol^{-1}
B –720 kJ mol^{-1}
C +720 kJ mol^{-1}
D +830 kJ mol^{-1}

Q13 Which reaction has an enthalpy change equal to the standard enthalpy change of formation of propane?
A $3C(g) + 4H_2(g) \rightarrow C_3H_8(g)$
B $3C(g) + 8H(g) \rightarrow C_3H_8(g)$
C $3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$
D $3C(s) + 4H_2(g) \rightarrow C_3H_8(l)$

Q14 In the conversion of compound X into compound Z, it was found that the reaction proceeded by way of compound Y, which could be isolated. The following steps were involved.
$X \rightarrow Y$; ΔH, positive $Y \rightarrow Z$; ΔH, negative
Which reaction profile fits these data?



Q15 Some bond energy values are listed below.

bond	bond energy / kJ mol^{-1}
C–H	410
C–*Cl*	340
Cl–*Cl*	244
Br–Br	193

These bond energy values relate to the following four reactions.

P $Br_2 \rightarrow 2Br$
Q $2Cl \rightarrow Cl_2$
R $CH_3 + Cl \rightarrow CH_3Cl$
S $CH_4 \rightarrow CH_3 + H$

What is the order of enthalpy changes of these reactions from most negative to most positive?
A P → Q → R → S
B Q → R → S → P
C R → Q → P → S
D S → P → Q → R

Q16 Given the following enthalpy changes,

$$I_2(g) + 3Cl_2(g) \rightarrow 2ICl_3(s) \qquad \Delta H^{\ominus} = -214\,kJ\,mol^{-1}$$

$$I_2(s) \rightarrow I_2(g) \qquad \Delta H^{\ominus} = +38\,kJ\,mol^{-1}$$

What is the standard enthalpy change of formation of iodine trichloride, $ICl_3(s)$?
A +176 kJ mol^{-1}
B –88 kJ mol^{-1}
C –176 kJ mol^{-1}
D –214 kJ mol^{-1}

Q17 Hydrogen peroxide slowly decomposes into water and oxygen. The enthalpy change of reaction can be calculated using standard enthalpies of formation.

$$\Delta H_f^{\ominus}(\text{hydrogen peroxide(l)}) = -187.8\,kJ\,mol^{-1}$$

$$\Delta H_f^{\ominus}(\text{water(l)}) = -285.8\,kJ\,mol^{-1}$$

Using a Hess cycle, what is the enthalpy change of reaction for this decomposition?

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$$

A +98 kJ mol^{-1}
B −98 kJ mol^{-1}
C −196 kJ mol^{-1}
D −947.2 kJ mol^{-1}

Q18 For which equation does the enthalpy change correspond to the enthalpy change of atomization of iodine?
A ½ $I_2(s) \rightarrow I(s)$
B ½ $I_2(s) \rightarrow I(g)$
C $I_2(g) \rightarrow 2I(g)$
D $I_2(s) \rightarrow 2I(g)$

Q19 Titanium occurs naturally as the mineral rutile, TiO_2. One possible method of extraction of titanium is to reduce the rutile by heating with carbon.

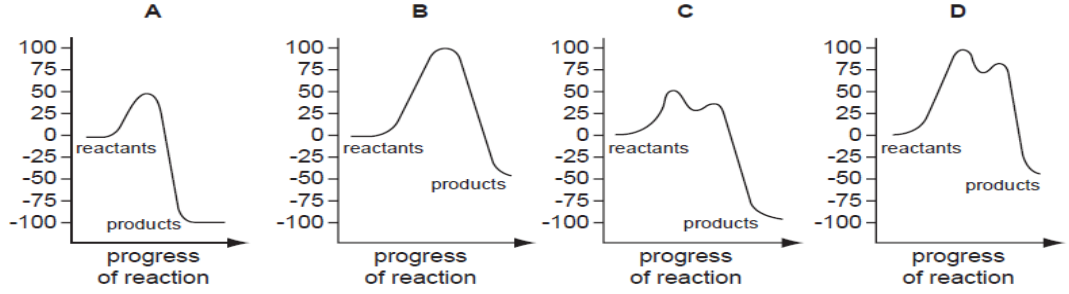
$$TiO_2(s) + 2C(s) \rightarrow Ti(s) + 2CO(g)$$

The standard enthalpy changes of formation of $TiO_2(s)$ and CO(g) are –940 kJ mol^{-1} and –110 kJ mol^{-1} respectively. What is the standard enthalpy change of this reaction?
A –830 kJ mol^{-1}
B –720 kJ mol^{-1}
C +720 kJ mol^{-1}
D +830 kJ mol^{-1}

Q20 An exothermic chemical reaction proceeds by two stages.

reactants —(stage 1)→ intermediate —(stage 2)→ products

The activation energy of stage 1 is 50 kJ mol^{-1}. The overall enthalpy change of reaction is –100 kJ mol^{-1}. Which diagram represents the reaction pathway for this reaction?



Q21 Skiers trapped by snowstorms use heat packs to keep warm. The heat may be generated by the reaction below.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s) \; ; \; \Delta H^O = -1648 \text{ kJ}$$

What is the standard enthalpy change of formation of iron(III) oxide?

A 0 kJ mol^{-1}

B –824 kJ mol^{-1}

C –1648 kJ mol^{-1}

D –3296 kJ mol^{-1}

Q22 Iodine trichloride, ICl_3, is made by reacting iodine with chlorine.

$$I_2(s) + Cl_2(g) \rightarrow 2ICl(s) \; ; \; \Delta H^o = +14 \text{ kJ mol}^{-1}$$

$$ICl(s) + Cl_2(g) \rightarrow ICl_3(s) \; ; \; \Delta H^o = -88 \text{ kJ mol}^{-1}$$

By using the data above, what is the enthalpy change of the formation for solid iodine trichloride?

A –60 kJ mol^{-1}

B –74 kJ mol^{-1}

C –81 kJ mol^{-1}

D –162 kJ mol^{-1}

Q23 Use of the Data Booklet is relevant to this question.

A reaction which causes the presence of oxides of nitrogen in car exhausts is the formation of NO.

$$N_2 + O_2 \rightarrow 2NO \; \Delta H = +180 \text{ kJ mol}^{-1}$$

What is the bond energy in kJ mol^{-1} of the bond between the atoms in NO?

A 655 B 835 C 1310 D 1670

Q24 In the table below,

- '+' means that this type of standard enthalpy change can only have positive values,
- '–' means that this type of standard enthalpy change can only have negative values,
- '+ / –' means that either positive or negative values are possible.

Which row is correct?

	atomisation	formation	solution
A	+	+	+/–
B	+	+/–	+/–
C	–	+/–	–
D	–	–	+

Q25 A student calculated the standard enthalpy change of formation of ethane, C_2H_6, using a method based on standard enthalpy changes of combustion.

He used correct values for the standard enthalpy change of combustion of ethane (–1560 kJ mol^{-1}) and hydrogen (–286 kJ mol^{-1}) but he used an incorrect value for the standard enthalpy change of combustion of carbon. He then performed his calculation correctly. His final answer was –158 kJ mol^{-1}.

What did he use for the standard enthalpy change of combustion of carbon?

A –1432 kJ mol^{-1} B –860 kJ mol^{-1} C –430 kJ mol^{-1} D –272 kJ mol^{-1}

Q26 Which process could be used to calculate the bond energy for the covalent bond X-Y by dividing its ΔH by n?

A $XY_n(g) \rightarrow X(g) + nY(g)$

B $2XY_n(g) \rightarrow 2XY_{n-1}(g) + Y_2(g)$

C $Y(g) + XY_{n-1}(g) \rightarrow XY_n(g)$

D $nXY(g) \rightarrow nX(g) + \frac{n}{2}Y_2(g)$

Section B

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

Q27 Which of the enthalpy changes of the following reactions can only be obtained by application of Hess' Law?
1 The hydration of anhydrous copper sulphate to form crystals of $CuSO_4.5H_2O$.
2 The formation of methane from its elements.
3 The combustion of glucose, $C_6H_{12}O_6$.

Q28 Sodium ions can be formed from sodium atoms.
$Na(s) \rightarrow Na^+(g)$
Which quantities are required to calculate the enthalpy change of formation of gaseous sodium ions?
1 enthalpy change of atomisation of sodium
2 first ionisation energy of sodium
3 enthalpy change of formation of sodium

Q29 For which reactions does the value of ΔH_o represent both a standard enthalpy change of combustion and a standard enthalpy change of formation?
1 $C(s) + O_2(g) \rightarrow CO_2(g)$
2 $2C(s) + O_2(g) \rightarrow 2CO(g)$
3 $CO(g) + 1/2\ O_2(g) \rightarrow CO_2(g)$

1. A
2. C
3. B
4. D
5. C
6. D
7. C
8. D
9. C
10. A
11. A
12. C
13. C
14. A
15. C
16. B
17. C
18. D
19. C
20. C
21. B
22. C
23. A
24. B
25. C
26. A
27. B
28. B
29. D

Q1 **(a)**The equation for the complete combustion of ethyne is given below. Use appropriate bond energy data from the *Data Booklet* to calculate a value for the enthalpy change of combustion of ethyne.

$$C_2H_2(g) + 5/2O_2(g) \rightarrow 2CO_2(g) + H_2O(g)$$

(b) The value for the standard enthalpy change of combustion of ethyne is –1300 kJ mol^{-1}.
(i) Define the term *standard enthalpy change of combustion*.

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(ii) Explain why your answer to **(d)** does not have the same value as the standard enthalpy change of combustion.

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(June 2006)

Q2 **(a)** Define the term *standard enthalpy change of formation*, $\ominus\Delta H_f$.

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(b) Hydrazine reacts with oxygen according to the following equation.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

(i) Use the data in the table to calculate the standard enthalpy change of this reaction.

compound	ΔH_f /kJ mol^{-1}
$N_2H_4(l)$	50.6
$H_2O(g)$	–241.8

ΔH = ... kJ mol^{-1}

(ii) Although the above reaction is highly exothermic, hydrazine does not burn spontaneously in oxygen. Suggest a reason for this.

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(June 2010 P23)

Q3 Fluoroethane, CH_3CH_2F, has been used as a refrigerant. It may be made by reacting ethene with hydrogen fluoride.You are to calculate a value for the C–F bond energy in fluoroethane.

(a) Use relevant bond energies from the *Data Booklet*, and the equation below to calculate a value for the bond energy of the C–F bond.

$$CH_2 = CH_2(g) + HF(g) \rightarrow CH_3CH_2F(g) \qquad \Delta H^{\ominus} = -73\,kJ\,mol^{-1}$$

C–F bond energy = ... kJ mol^{-1}

(June 2011 P22)

Q4 Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation .....

definition .....

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(b) Relevant $\Delta H_f^{\ominus}$ values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$CO_2(g)$	–394
$CH_3OH(g)$	–201
$H_2O(g)$	–242

Use these values to calculate standard enthalpy change of reaction for this synthesis of methanol. Include a sign in your answer.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

(June 2012 P21)

Q5 (a)Explain the term *standard enthalpy change of formation*, ΔH_f

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(b) Calculate the standard enthalpy change of formation of CS_2 from the following data.

standard enthalpy change of formation of SO_2 = $-298\,kJ\,mol^{-1}$

standard enthalpy change of formation of CO_2 = $-395\,kJ\,mol^{-1}$

standard enthalpy change of combustion of CS_2 = $-1110\,kJ\,mol^{-1}$

(NOV 2005)

Q6 Carbon, hydrogen and ethene each burn exothermically in an excess of air.

Use the data to calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, in $kJ\,mol^{-1}$, of ethene at 298 K.

$$2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$$

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H_c^{\ominus} = -393.7\,kJ\,mol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H_c^{\ominus} = -285.9\,kJ\,mol^{-1}$$

$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l) \qquad \Delta H_c^{\ominus} = -1411.0\,kJ\,mol^{-1}$$

(Nov 2007)

Q7 Use the data below to calculate the standard enthalpy change of formation of ketene.

	$\Delta H^{\ominus}$/kJ mol^{-1}
standard enthalpy change of formation of CO_2	–395
standard enthalpy change of combustion of H_2	–286
standard enthalpy change of combustion of CH_2=C=O	–1028

(NOV 2008)

Q8When 0.47 g of **E** was completely burnt in air, the heat produced raised the temperature of 200 g of water by 27.5 °C. Assume no heat losses occurred during this experiment.
The standard enthalpy change of combustion of **E** is –2059 kJ mol^{-1}.
(a) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

(b) Use the data above and your answer to **(i)** to calculate the relative molecular mass, M_r, of **E**.

(Nov10 P21)

Q9 **(a)** Relevant standard enthalpy changes of formation for the reaction of methane with chlorine to form chloromethane, CH_3Cl, are given below.

	$\Delta H_f^{\ominus}$/kJ mol^{-1}
CH_4	–75
CH_3Cl	–82
HCl	–92

Use the data to calculate enthalpy change of reaction for the formation of CH_3Cl.

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

(b) Use bond energy data from the *Data Booklet* to calculate a 'theoretical value' for $\Delta H_{reaction}$ for the following equation.

$$CH_4 + I_2 \rightarrow CH_3I + HI$$

(NOV 2009 P21)

Q10 For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate, $KHCO_3$, the enthalpy change of reaction cannot be measured directly.In such cases, the use of Hess' Law enables the enthalpy change of reaction to be calculated from the enthalpy changes of other reactions.

(a) State Hess' Law.

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In order to determine the enthalpy change for the thermal decomposition of potassium hydrogencarbonate, two separate experiments were carried out.

experiment 1

30.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (an excess) was placed in a conical flask and the temperature recorded as 21.0 °C.

When 0.0200 mol of potassium carbonate, K_2CO_3, was added to the acid and the mixture stirred with a thermometer, the maximum temperature recorded was 26.2 °C.

(b)(i) Construct a balanced equation for this reaction.

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(ii) Calculate the quantity of heat produced in **experiment 1**, stating your units.
Use relevant data from the *Data Booklet* and assume that all solutions have the same specific heat capacity as water.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of K_2CO_3.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(iv) Explain why the hydrochloric acid must be in an excess.

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experiment 2
The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate, $KHCO_3$.
All other conditions were the same.
In the second experiment, the temperature fell from 21.0 °C to 17.3 °C.
(c)(i) Construct a balanced equation for this reaction.

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(ii) Calculate the quantity of heat absorbed in **experiment 2**.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of $KHCO_3$.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(d) When $KHCO_3$ is heated, it decomposes into K_2CO_3, CO_2 and H_2O.

$$2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$$

Use Hess' Law and your answers to **(b)(iii)** and **(c)(iii)** to calculate the enthalpy change for this reaction.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(NOV 2009 P21)