



AS Level Chemistry

CHEMICAL ENERGETICS

9701-PAPER 2

2026 EDITION

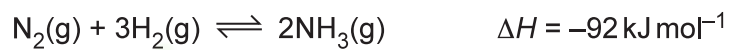
Q1 • Easy

9701/22/F/M/24/Q3(c)(i)

2 marks

(c) The Haber process involves the reaction of N_2 and H_2 to form ammonia, NH_3 .

A catalyst is used, which allows the process to be carried out at a lower temperature and pressure.



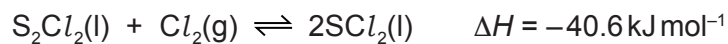
(i) Use the information in (c) to complete Table 3.1.

Table 3.1

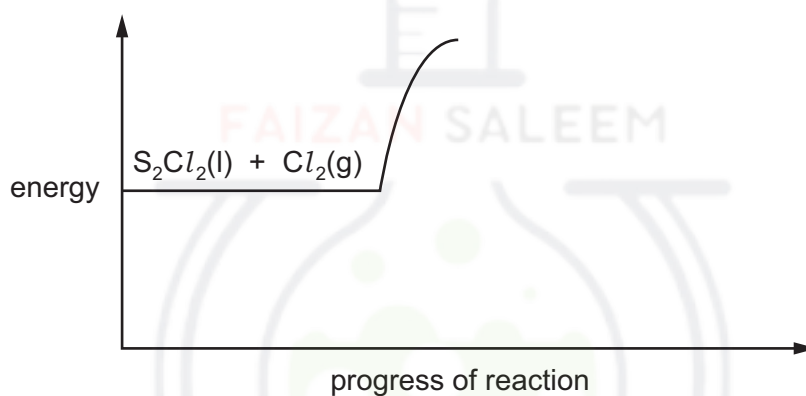
compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
N_2	
H_2	
NH_3	

[2]

(b) SCl_2 is formed in the following reaction.



- (ii) Complete and fully label the reaction pathway diagram for the reaction between S_2Cl_2 and Cl_2 . Include labels for activation energy, E_a , and enthalpy change of the forward reaction, ΔH .



ks

[2]

Q3 • Easy

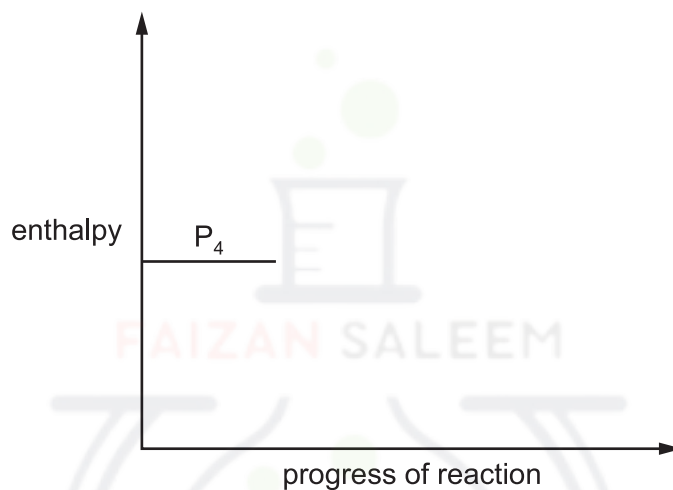
9701/21/O/N/21/Q3(a)(ii)

1 mark

(ii) Red phosphorus (P) forms when white phosphorus (P_4) is exposed to sunlight.



Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P_4).



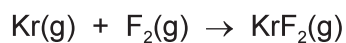
[1]

Q 4 • Hard

9701/22/F/M/21/Q1(c)(i)

2 marks

- (c) Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride, $\text{KrF}_2(\text{g})$.

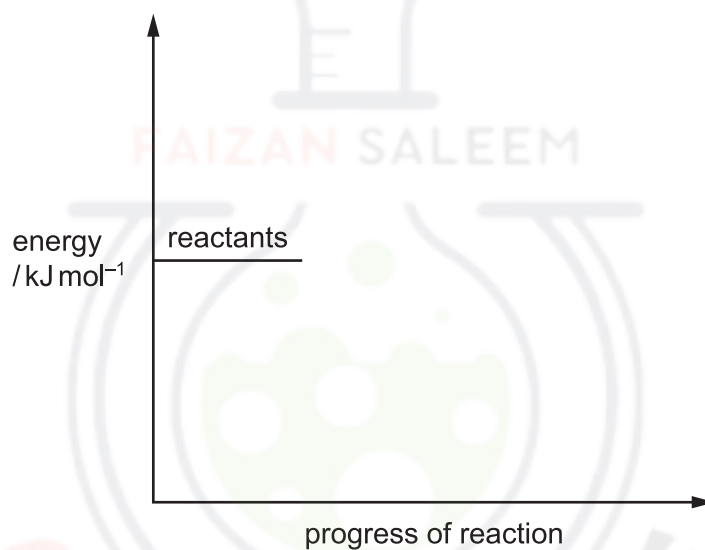


activation energy for the reaction, $E_a = +385 \text{ kJ mol}^{-1}$

enthalpy change of formation of KrF_2 , $\Delta H_f = +60.2 \text{ kJ mol}^{-1}$

- (i) Use this information to complete the reaction profile diagram for the formation of KrF_2 . Label E_a and ΔH_f on the diagram.

Assume the reaction proceeds in one step.



[2]

Q 5 • Easy

9701/22/O/N/21/Q1(b)

2 marks

(b) The standard enthalpy change of formation, $\Delta H_f^\ominus$, of HI(g) is +26.5 kJ mol⁻¹.

Define the term *standard enthalpy change of formation*.

.....

.....

..... [2]

Q 6 • Hard

9701/21/M/J/24/Q4(b)(i)

2 marks

(b) Iron is made when iron(III) oxide is heated with carbon monoxide, as shown by reaction 2.

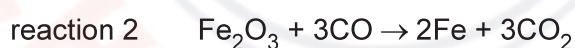


Table 4.1 shows enthalpy change of formation data measured at 298 K and 101 kPa.

Table 4.1

substance	equation	value for $\Delta H_f^\ominus$ / kJ mol ⁻¹
Fe ₂ O ₃		-824.2
CO		-110.5
CO ₂	$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	-393.5

(i) Complete Table 4.1 by adding equations with relevant state symbols to represent:

- standard enthalpy change of formation for Fe₂O₃
- standard enthalpy change of formation for CO.

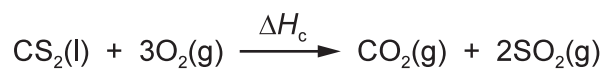
[2]

Q 7 • Easy

9701/21/O/N/21/Q1(b)(i)

2 marks

(b) The enthalpy change of combustion of $\text{CS}_2(\text{l})$ is represented by the following equation.



(i) Define *enthalpy change of combustion*.

.....

.....

..... [2]



Q 8 • Hard

9701/23/M/J/24/Q3(a)-(b)

4 marks

- 3 (a) Write an equation to show the reaction for the standard enthalpy change of formation of H_2O . Include state symbols.

..... [2]

- (b) Water is one of the products in the reaction of B_2O_3 and NH_3 , as shown in reaction 2.

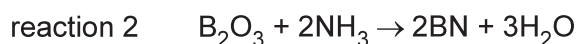


Table 3.1 shows information about the standard enthalpy change of formation, $\Delta H_f^\ominus$, of some substances.

Table 3.1

substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
B_2O_3	-1264
NH_3	-46
BN	-134
H_2O	-286

Calculate the enthalpy change, ΔH , for reaction 2 using the data from Table 3.1.

$\Delta H = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

Q 9 • Hard

9701/21/O/N/23/Q1(e)(ii)

2 marks

(e) $\text{POCl}_3(\text{g})$ forms when $\text{PCl}_3(\text{g})$ reacts with $\text{O}_2(\text{g})$.

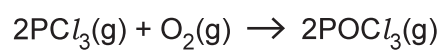


Table 1.3 gives some relevant data.

Table 1.3

process	value / kJ mol^{-1}
enthalpy change of formation of $\text{PCl}_3(\text{g})$	-289
enthalpy change of formation of $\text{POCl}_3(\text{g})$	-592
$\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$	+496

(ii) Calculate the bond energy of $\text{P}=\text{O}$ in POCl_3 using the data in Table 1.3.

Show your working.

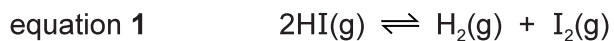
bond energy of $\text{P}=\text{O}$ = ... kJ mol^{-1}
[2]

Q 10 • Easy

9701/22/M/J/22/Q3(b)

2 marks

- 3 (a) 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.



- (b) Use equation 1 and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH , for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
H–H	436
I–I	151
H–I	299

$\Delta H = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

Q 11 • Hard

9701/22/M/J/25/Q3(c)

2 marks

(c) Hydrocarbon **Y** contains two C=C groups. There are no other functional groups present.

Y reacts with an excess of $\text{H}_2(\text{g})$ to produce hexane, C_6H_{14} .

Table 3.1

bond	energy / kJ mol^{-1}
C–C	350
C=C	610
$\text{C}\equiv\text{C}$	840
H–H	436
C–H	410

Use Table 3.1 to calculate the enthalpy change per mole of C_6H_{14} produced in this reaction.

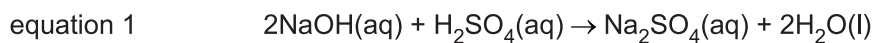
enthalpy change = ... kJ mol^{-1} [2]

Q 12 • Easy

9701/21/M/J/23/Q2(a)-(b)(ii)

6 marks

2 A neutralisation reaction occurs when NaOH(aq) is added to H₂SO₄(aq).



(a) Define enthalpy change of neutralisation, ΔH_{neut} .

.....

 [2]

(b) An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and H₂SO₄(aq).

100 cm³ of 1.00 mol dm⁻³ NaOH(aq) is added to 75 cm³ of 1.00 mol dm⁻³ H₂SO₄(aq) in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq)/°C	20.0
initial temperature of H ₂ SO ₄ (aq)/°C	20.0
maximum temperature of mixture/°C	27.8

(i) Use equation 1 to calculate the amount, in mol, of H₂SO₄(aq) that is neutralised in the experiment.

amount of H₂SO₄(aq) neutralised = ... mol [1]

(ii) Calculate ΔH_{neut} using the results in Table 2.1. Include units in your answer.

Assume that:

- the specific heat capacity of the final solution is 4.18 J g⁻¹ K⁻¹
- 1.00 cm³ of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- full dissociation of H₂SO₄(aq) occurs
- the experiment takes place at constant pressure.

Show your working.

ΔH_{neut} = ... units [3]

Q 13 • Hard

9701/22/M/J/24/Q2(b)(ii)

3 marks

- 2 Separate samples of Na_2CO_3 and NaHCO_3 react with $\text{HCl}(\text{aq})$ to produce the same products, as shown in Table 2.1.

Table 2.1

reaction	equation	$\Delta H / \text{kJ mol}^{-1}$
1	$\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	ΔH_1
2	$\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	$\Delta H_2 = +27.2$

- (b) The value for ΔH_1 is determined by experiment using the following method.

- 50.0 cm^3 of 2.00 mol dm^{-3} $\text{HCl}(\text{aq})$ is added to a polystyrene cup.
- The initial temperature of the acid is recorded as 19.6°C .
- 0.0400 mol of Na_2CO_3 is added and the mixture is stirred.
- All the solid Na_2CO_3 disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2°C .

- (ii) Calculate the value of ΔH_1 in kJ mol^{-1} .

Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.

Show your working.

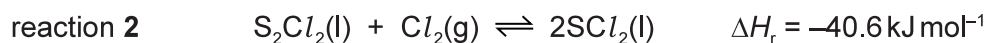
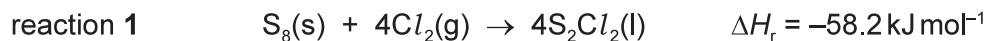
$\Delta H_1 = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

Q 14• Easy

9701/21/O/N/22/Q3(d)(ii)

2 marks

- (d) Sulfur, S_8 , reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2 . SCl_2 forms when sulfur reacts with an excess of chlorine.



- (ii) Calculate the enthalpy change of formation, ΔH_f , of $SCl_2(l)$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $SCl_2(l)$, $\Delta H_f = \dots\dots\dots \text{ kJ mol}^{-1}$
[2]

Q 15 • Hard

9701/22/M/J/24/Q2(b)(iii)

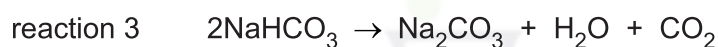
2 marks

- 2 Separate samples of Na_2CO_3 and NaHCO_3 react with $\text{HCl}(\text{aq})$ to produce the same products, as shown in Table 2.1.

Table 2.1

reaction	equation	$\Delta H / \text{kJ mol}^{-1}$
1	$\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	ΔH_1
2	$\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	$\Delta H_2 = +27.2$

- (iii) Thermal decomposition occurs when NaHCO_3 is heated.



Calculate the enthalpy change for reaction 3, ΔH_r , using the data in Table 2.1 and the value of ΔH_1 calculated in (b)(ii).

(If you were unable to calculate a value for ΔH_1 in (b)(ii), assume the enthalpy change is $-38.4 \text{ kJ mol}^{-1}$. This is **not** the correct value.)

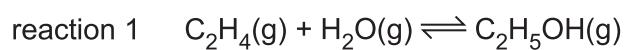
$\Delta H_r = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

Q 16 • Easy

9701/22/M/J/23/Q4(a)

2 marks

- 4 In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4 .



- (a) Use the bond energy values in Table 4.1 to calculate the enthalpy change, ΔH_r , for reaction 1.

Table 4.1

bond	bond energy / kJ mol^{-1}
C–C	350
C=C	610
C≡C	840
C–H	410
C–O	360
C=O	740
O–H	460

$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

Q 17 • Hard

9701/23/M/J/22/Q3(a)(ii)

2 marks

- 3 **G** belongs to a group of compounds called ethers.

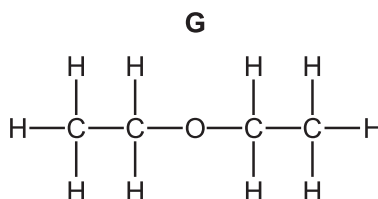
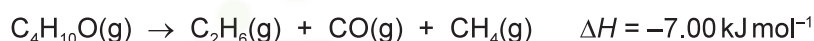


Fig. 3.1

- (a) When **G**, $C_4H_{10}O$, is heated, thermal decomposition occurs.



- (i) The atoms in a molecule of CO are held together by a triple covalent bond. One of these bonds is a coordinate (dative covalent) bond.

Draw a dot-and-cross diagram to show the arrangement of outer electrons in a CO molecule.

Use • to represent electrons from an oxygen atom.

Use × to represent electrons from a carbon atom.

[1]

- (ii) Calculate the bond energy of $C\equiv O$ using the bond energy values in Table 3.1 and the enthalpy change, ΔH , for the thermal decomposition of **G**. Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
C—C	350
C—O (in G)	360
C—H	410

bond energy ($C\equiv O$) = ... kJ mol^{-1}
[2]

Q1 • Easy

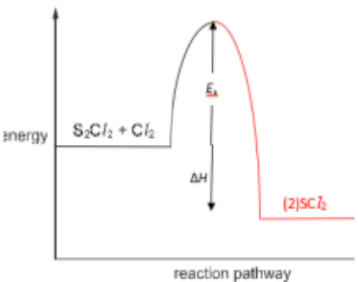
9701/22/F/M/24/Q3(c)(i)

2 marks

3(c)(i)	0 for both ΔH_f° of N_2 and H_2	1
	–46 for ΔH_f° of NH_3	1

Q 2 • Hard

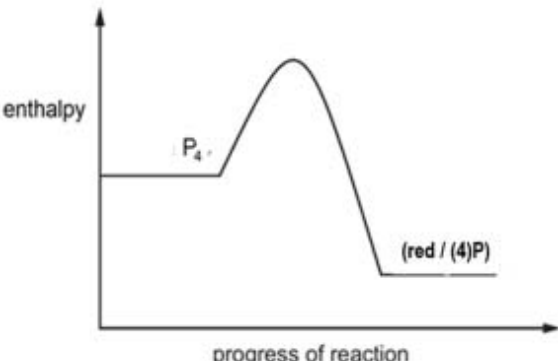
9701/22/O/N/18

2(b)(ii)	 M1 profile for exothermic reaction [1] M2 identification of ΔH and E_a [1]	2
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Q 3 • Easy

9701/21/O/N/21/Q3(a)(ii)

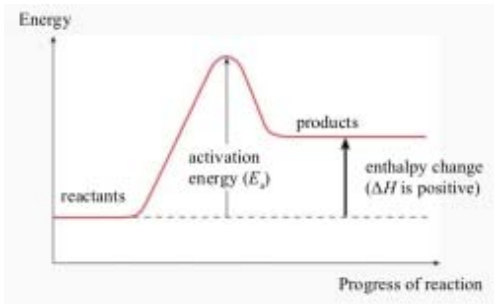
1 mark

3(a)(ii)		1
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Q 4 • Hard

9701/22/F/M/21/Q1(c)(i)

2 marks

1(c)(i)	 M1: end higher than start AND 'hill' for E_a M2: E_a AND ΔH labelled	2
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Q 5 • Easy

9701/22/O/N/21/Q1(b)

2 marks

1(b)	(enthalpy / energy change) when one mole of a compound is formed from its elements in their standard states	2
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Q 6 • Hard

9701/21/M/J/24/Q4(b)(i)

2 marks

4(b)(i)	<table border="1"> <thead> <tr> <th></th><th>equation for reaction</th><th>$\Delta_f H^\circ$</th></tr> </thead> <tbody> <tr> <td>Fe_2O_3</td><td>$2\text{Fe (s)} + \frac{3}{2}\text{O}_2\text{(g)} \rightarrow \text{Fe}_2\text{O}_3\text{(s)}$</td><td>-824.2</td></tr> <tr> <td>CO</td><td>$\text{C (s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO (g)}$</td><td>-110.5</td></tr> <tr> <td>CO_2</td><td>$\text{C (s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$</td><td>-393.5</td></tr> </tbody> </table>		equation for reaction	$\Delta_f H^\circ$	Fe_2O_3	$2\text{Fe (s)} + \frac{3}{2}\text{O}_2\text{(g)} \rightarrow \text{Fe}_2\text{O}_3\text{(s)}$	-824.2	CO	$\text{C (s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO (g)}$	-110.5	CO_2	$\text{C (s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	-393.5	2
	equation for reaction	$\Delta_f H^\circ$												
Fe_2O_3	$2\text{Fe (s)} + \frac{3}{2}\text{O}_2\text{(g)} \rightarrow \text{Fe}_2\text{O}_3\text{(s)}$	-824.2												
CO	$\text{C (s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO (g)}$	-110.5												
CO_2	$\text{C (s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	-393.5												

Q 7 • Easy

9701/21/O/N/21/Q1(b)(i)

2 marks

1(b)(i)	M1 (enthalpy/energy change when) 1 mole of a compound M2 burns/combusts/reacts in excess oxygen/O_2 OR completely burns/ completely combusts/completely reacts in oxygen/O_2	2
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Q 8 • Hard

9701/23/M/J/24/Q3(a)-(b)

4 marks

3(a)	$\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O(l)}$ M1 correct equation only M2 correct state symbols based on this equation	2
3(b)	$\Delta H = -(-1264) - (2 \times -46) + (2 \times -134) + (3 \times -286) = (+)230 \text{ kJ mol}^{-1}$ M1 correct expression in terms of all 4 enthalpy changes of formation AND correct stoichiometry (as described in given equation) M2 correct calculation based on figures given	2

Q 9 • Hard

9701/21/O/N/23/Q1(e)(ii)

2 marks

1(e)(ii)	$2(-592) = 2(-289) + (496) - 2(\text{P}=\text{O})$ OR $(2) \text{P}=\text{O} = 2(-289) + (496) + 2(592)$	1
	$E_{\text{P}=\text{O}} = \frac{1}{2}(1102) = +551 \text{ (kJ mol}^{-1}\text{)}$	1

Q 10 • Easy

9701/22/M/J/22/Q3(b)

2 marks

3(b)	evaluation, to give a value, based on calculation using: - all three correct bond energies [$\text{HI} = 299$, $\text{H}_2 = 436$, $\text{I}_2 = 151$] - correct use of stoichiometry to calculate ΔH for 1 mol HI $x = 1$ and $y = \frac{1}{2}$ - calculate a value for ΔH correctly i.e. $x(299) - y(436 + 151)$ $\Delta H = (+)5.5 \text{ kJ mol}^{-1}$	2
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Q 11 • Hard

9701/22/M/J/25/Q3(c)

2 marks

3(c)	method 1 – breaking all bonds in molecules $(2 \times 610) + (2 \times 436) + (10 \times 410) + (3 \times 350) - (14 \times 410) - (5 \times 350)$ - energy involved when all bonds are broken = (7242) - energy involved when all bonds are made = (7490) - energy to break bonds – energy to make bonds $= (7242 - 7490) = -248$ method 2 – ignore any bonds that do not change from reactants to products $(2 \times 610) + (2 \times 436) - (4 \times 410) - (2 \times 350)$ - energy involved when all bonds are broken = (2092) - energy involved when all bonds are made = (2340) - energy to break bonds – energy to make bonds $(2092 - 2340) = -248$	2
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Q 12 • Easy

9701/21/M/J/23/Q2(a)-(b)(ii)

6 marks

2(a)	M1 (enthalpy change) when 1 mole of water is formed M2 from an (aqueous) acid and an alkali / (aqueous) base	2
2(b)(i)	0.05 mol	1
2(b)(ii)	M1 correct volume and correct temperature change M2 calculation to calculate Q based on M1 volume and temp and $Q = mc\Delta T$ $Q = mc\Delta T = 175 \times 4.18 \times (27.8 - 20) = (-)5705.7$ M3 energy change when 0.1 mol H₂O is made with appropriate unit and sign $\Delta H = M2 / 0.1 = -57.1 \text{ kJ mol}^{-1}$ OR $-57100 \text{ J mol}^{-1}$	3

Q 13 • Hard

9701/22/M/J/24/Q2(b)(ii)

3 marks

2(b)(ii)	M1 calculate Q from $= 50 \times 4.18 \times (26.2 - 19.6) = 1379.4$ M2 Use M1 to find energy change when 1 mol Na₂CO₃ / 2 mol HCl reacts $M1 \div 0.04 = 34485$ M3 express Q as $\Delta H_{(1)}$ in $\text{kJ mol}^{-1} = -(\text{value for M2}) \div 1000$ $= -34.5 \text{ kJ mol}^{-1}$ Alternative method M1 evidence of use $Q = mc\Delta T = 50 \times 4.18 / 1000 \times (26.2 - 19.6) = 1.3794$ M2 Use M1 to find energy change when 1 mol Na₂CO₃ / 2 mol HCl reacts $M1 \div 0.04 = 34.485$ M3 express Q as $\Delta H_{(1)}$ in $\text{kJ mol}^{-1} = -(\text{value for M2})$ (expressed in kJ) $= -34.5 \text{ kJ mol}^{-1}$	3
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Q 14 • Easy

9701/21/O/N/22/Q3(d)(ii)

2 marks

3(d)(ii)	Correct use of enthalpy values / correct direction / use of arrows (with or without an energy cycle) M1 $(-58.2) + (-40.6)$ OR (-98.8) M2 $(-58.2 + 4(-40.6) = 8\Delta H_f)$ Correct calculation and correct stoichiometry $\Delta H_f = -27.6 \text{ (kJ mol}^{-1}\text{)}$	2
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Q 15 • Hard

9701/22/M/J/24/Q2(b)(iii)

2 marks

2(b)(iii)	Using answer from 2(b)(ii) $(\Rightarrow) 2\Delta H_2 - (\Delta H_1)$ $(\Rightarrow) 2 \times 27.2 - (2b(ii))$ $2 \times 27.2 - (-34.50) = (+) 88.9 \text{ kJ mol}^{-1}$ All three correct (2 marks) or two correct (1 mark): $(27.2) - (-34.5)$ OR $(27.2) - (2b(ii))$ 2×27.2 and $1 \times 2b(ii)$ - calculate correctly their expression Using alternative value of $\Delta H_1 = -38.4 \text{ kJ mol}^{-1}$ $\Delta H_r = (+)92.8 \text{ kJ mol}^{-1} = 2 \text{ marks}$	2
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Q 16 • Easy

9701/22/M/J/23/Q4(a)

2 marks

4(a)	Method 1 - identification of number and type of bonds when all are broken $2\text{O-H} + 4\text{C-H} + \text{C}=\text{C}$ OR $(2 \times 460) + (4 \times 410) + 610$ - Identification of number and type of bonds when all are made $\text{O-H} + 5\text{C-H} + \text{C-C} + \text{C-O}$ OR $(460 + (5 \times 410) + 350 + 360)$ - calculation of energy to break bonds – energy to make bonds $3170 - 3220 = -50 \text{ (kJ mol}^{-1}\text{)}$ Two correct for one mark, three correct for two marks. OR Method 2 - identification of number and type of relevant bonds broken (including the new C-H only) $2\text{O-H} + \text{C}=\text{C}$ OR $(2 \times 460) + 610$ - identification of number and type of relevant bonds made (including the new C-H only) $\text{O-H} + \text{C-H} + \text{C-C} + \text{C-O}$ OR $(460 + 410 + 350 + 360)$ - calculation using energy to break bonds – energy to make bonds $1530 - 1580 = -50 \text{ (kJ mol}^{-1}\text{)}$ Two correct for one mark, three correct for two marks.	2
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Q 17 • Hard

9701/23/M/J/22/Q3(a)(ii)

2 marks

3(a)(ii)	M1 expression OR value derived from using all bond energy values and ΔH correctly, ignoring stoichiometry $-7 = (n350 + m360 + p410) - (q410 + r350 + s\text{C}\equiv\text{O})$. M2 correct calculation based on correct expression AND stoichiometry $[-7 = 2(350) + 2(360) + 10(410) - 10(410) - 350 - x] = (+)1077 \text{ kJ mol}^{-1}$	2
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