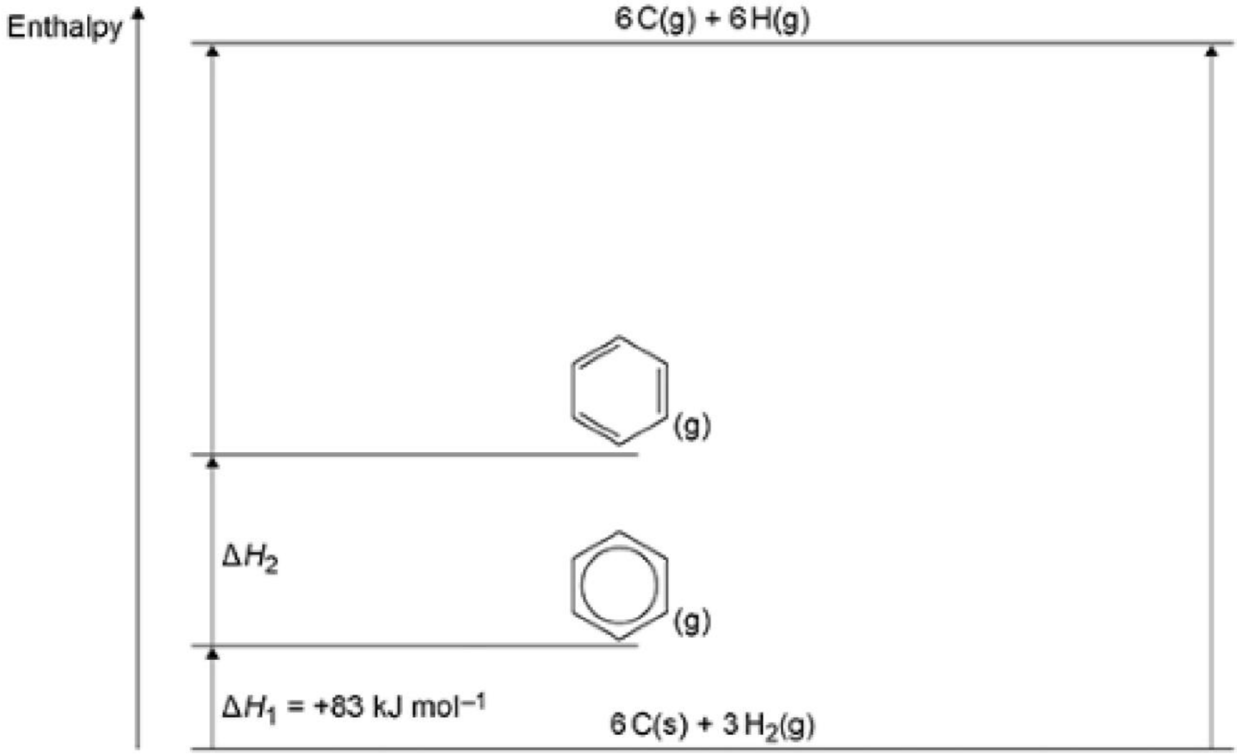
Question - 01

Kekulé suggested this structure for benzene. 

Benzene is now represented by this structure. 

Figure 1 shows the relative stability of  compared to .

Figure 1



(a) Use **Figure 1** and the data shown in the table below to calculate ΔH_2

	ΔH / kJ mol^{-1}
Enthalpy of atomisation for carbon	+715
Enthalpy of atomisation for hydrogen	+218
Bond enthalpy (C–C)	+348
Bond enthalpy (C=C)	+612
Bond enthalpy (C–H)	+412

ΔH_2 ________________ kJ mol^{-1}

(3)

(b) Explain, in terms of structure and bonding, why 

is more thermodynamically stable than 

____

____

____

(1)

(c) A mixture of concentrated nitric acid and concentrated sulfuric acid reacts with benzene.

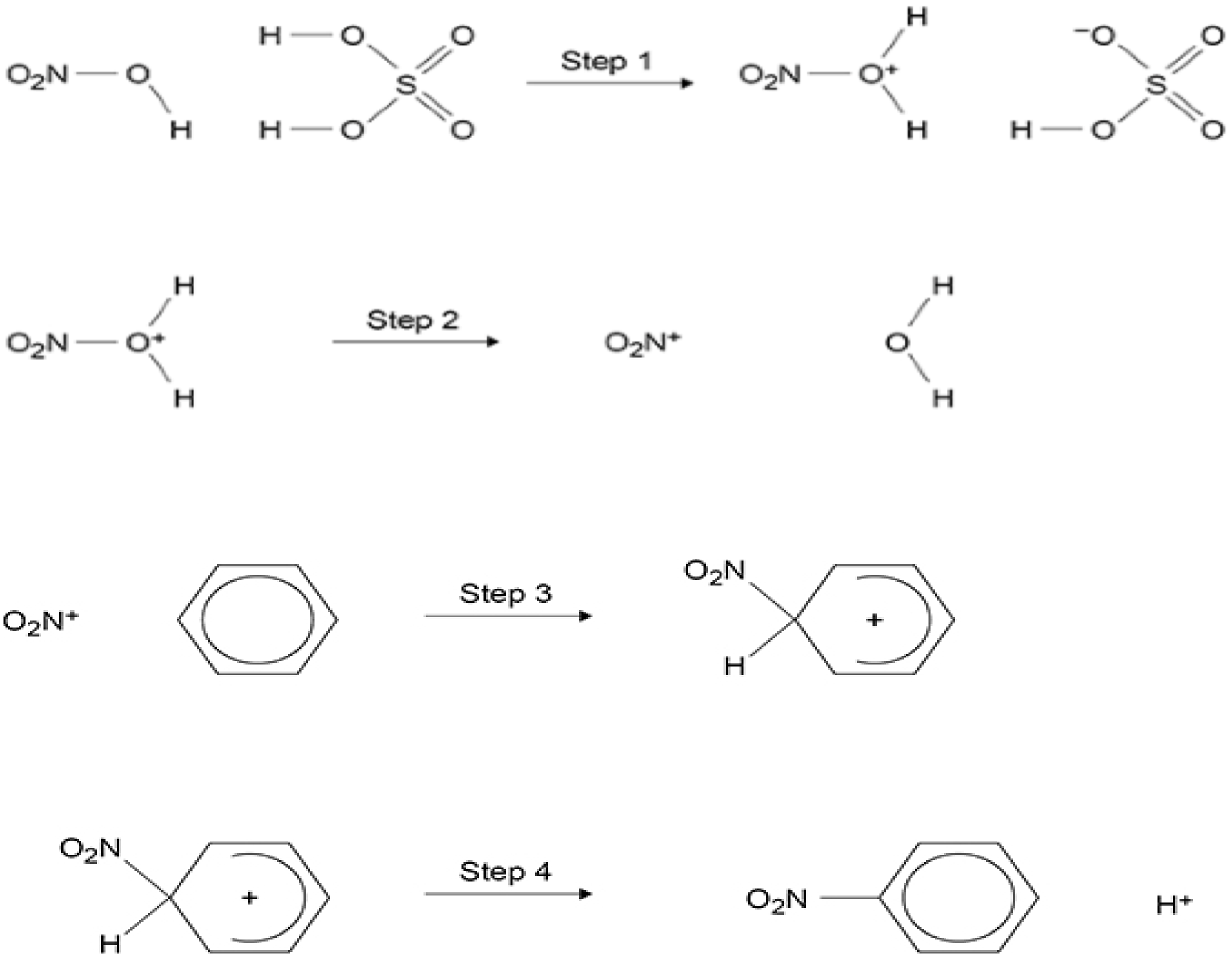
Figure 2 shows the incomplete mechanism for this reaction.

Name the mechanism.

Complete the mechanism in **Figure 2** by adding
- any lone pairs of electrons involved in each step
- **two** curly arrows in step **1**
- a curly arrow in step **2**
- a curly arrow in step **3**
- a curly arrow in step **4**.

Name of mechanism ____

Figure 2



(5)

(a) $(3 \times 612) + (3 \times 348) + (6 \times 412) = 5352$

For LHS

M1

$(6 \times 715) + (6 \times 218) = 5598$

For RHS

M2

$\Delta H_2 = M2 - M1 - 83 = +163\ \text{kJ mol}^{-1}$

M3

(b) (π) electrons delocalised

1

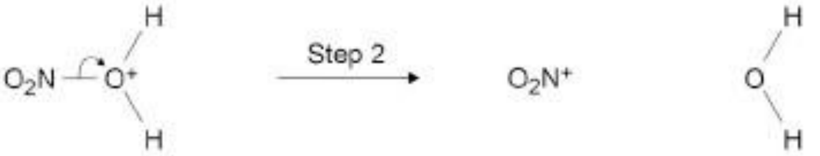
(c) M1 Electrophilic substitution

1

M2 for a lone pair and two curly arrows

1

M3 for a curly arrow from the bond to the O



1

M4 for a curly arrow from inside the hexagon to the N or + on the N

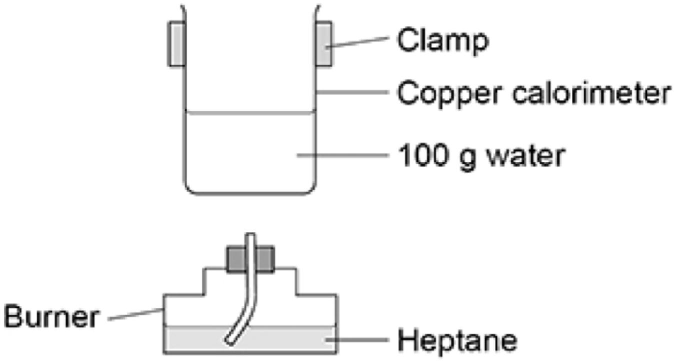
1

M5 curly arrow from the bond back into the hexagon

1

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)

(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

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.

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

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)

(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

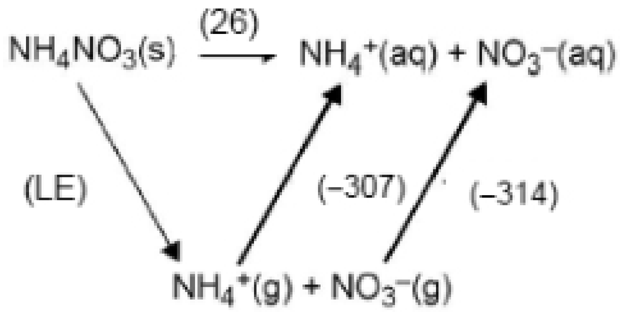
dissociates (fully) into gaseous ions

***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

$\Delta H^{\ominus}_{soln}$ = 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)

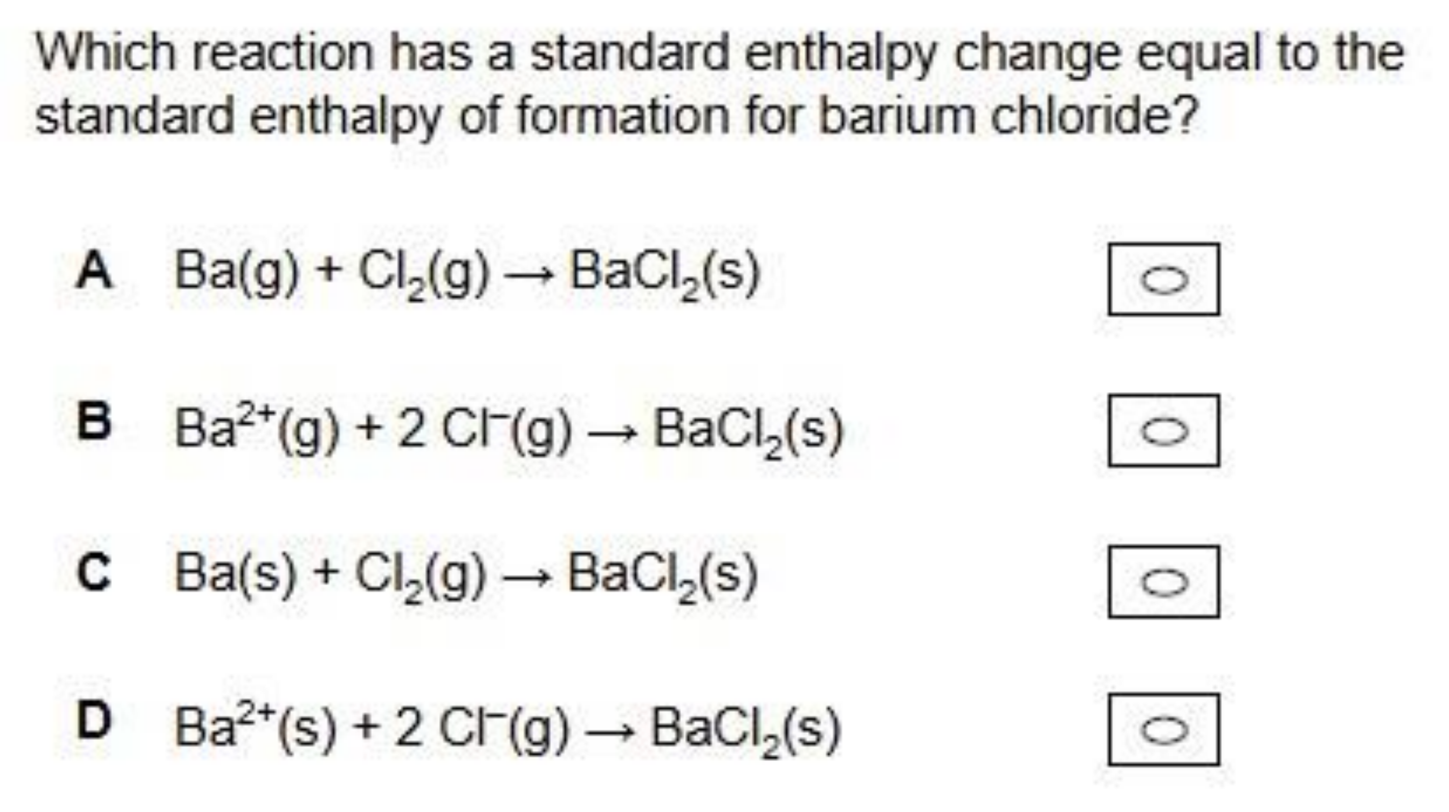
0.854 (K) = 1/2

0.00117 (K) = 1/2 (calculation upside down)

2SF minimum

1

Question - 04



Which reaction has a standard enthalpy change equal to the standard enthalpy of formation for barium chloride?

A $Ba(g) + Cl_2(g) \rightarrow BaCl_2(s)$ ○

B $Ba^{2+}(g) + 2\,Cl^{-}(g) \rightarrow BaCl_2(s)$ ○

C $Ba(s) + Cl_2(g) \rightarrow BaCl_2(s)$ ○

D $Ba^{2+}(s) + 2\,Cl^{-}(g) \rightarrow BaCl_2(s)$ ○

C

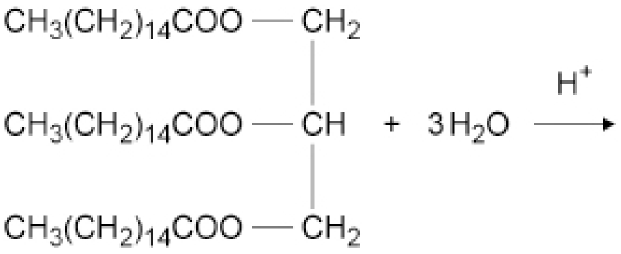
$$Ba(s) + Cl_2(g) \rightarrow BaCl_2(s)$$

Question - 05

This question is about biofuels.

Palmitic acid, $CH_3(CH_2)_{14}COOH$, can be made by hydrolysis of the triester in palm oil under acidic conditions.
Palmitic acid can be used as a biofuel.

(a) Complete the equation for the hydrolysis of the triester in palm oil under acidic conditions.



$$\begin{array}{l} CH_3(CH_2)_{14}COO - CH_2 \\ \qquad\qquad\qquad\quad\;\; | \\ CH_3(CH_2)_{14}COO - CH \quad + \quad 3H_2O \xrightarrow{H^+} \\ \qquad\qquad\qquad\quad\;\; | \\ CH_3(CH_2)_{14}COO - CH_2 \end{array}$$

(2)

(b) Palmitic acid burns in air.

In a calorimetry experiment, combustion of 387 mg of palmitic acid increases the temperature of 0.150 kg of water from 23.9 °C to 37.5 °C

Calculate a value, in kJ mol^{-1}, for the enthalpy of combustion of palmitic acid in this experiment.
Give your answer to the appropriate number of significant figures.

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

Enthalpy of combustion ____________________ kJ mol^{-1}

(5)

(c) State how the value calculated in part (b) is likely to differ from data book values.

Give one reason, other than heat loss, for this difference.

Difference ____

Reason ____

____

(2)

(d) A sample of a different biofuel, made from sewage sludge, is found to contain 37.08% carbon, 5.15% hydrogen and 24.72% oxygen by mass.
The rest of the sample is sulfur.

Calculate the empirical formula of this biofuel.

Empirical formula ____________________

(3)

(e) Complete combustion of the biofuel made from sewage sludge produces the greenhouse gas carbon dioxide.

Suggest **one** other possible environmental problem with the complete combustion of this biofuel.

State the formula of the pollutant responsible for this problem.

Environmental problem ____

____

Formula ____

(2)

(f) Ethanol is a biofuel that can be produced by the fermentation of glucose.

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

Glucose has the structural formula shown.

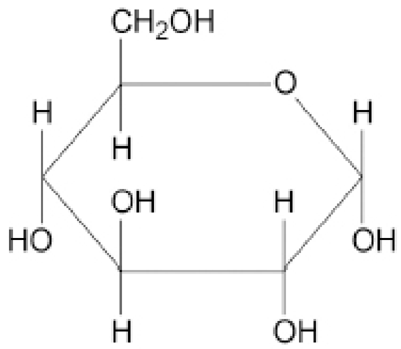


Table 1 shows some mean bond enthalpy values.

Table 1

	C–H	**C–C**	**C–O**	**C=O**	**O–H**
Mean bond enthalpy / kJ mol^{-1}	412	348	360	805	463

Use the equation and the data in **Table 1** to calculate an approximate value of Δ*H* for the fermentation of glucose. For this calculation you should assume that all the substances are in the gaseous state.

ΔH ____________________ $kJ\ mol^{-1}$

(3)

(g) The carbon dioxide produced from fermentation can be reacted with steam to make more ethanol.

The equation for this reaction is

$$2\ CO_2(g) + 3\ H_2O(g) \rightarrow C_2H_5OH(g) + 3\ O_2(g)$$

Table 2 shows some standard enthalpies of formation.

Table 2

	$CO_2(g)$	$O_2(g)$	$C_2H_5OH(g)$	$H_2O(g)$
$\Delta fH^{\ominus}$ / kJ mol^{-1}	–394	0	–235	–242

Use the data in **Table 2** to calculate a standard enthalpy change value for this reaction.

Standard enthalpy change ____________________ $kJ\ mol^{-1}$

(2)

(a) M1 3 $CH_3(CH_2)_{14}COOH$

M2 $CH_2(OH)CH(OH)CH_2OH$

Penalise additional product(s) once

2

(b) M1 $M_r = 256$

M2 $n(CH_3(CH_2)_{14}COOH) = \frac{0.387}{M1} = 1.51 \times 10^{-3}$

M3 $Q = 150 \times 4.18 \times 13.6 = 8527.2$ (J)

M4 $\Delta H = \frac{M3}{M2} \div 1000 = (-)5641$

M5 $\Delta H = -5640$ kJ mol^{-1}

Must be negative and 3sf (allow ecf on M4)

5

(c) M1 Less exothermic

Allow Less negative (value) / Lower

M2 Incomplete combustion

Allow products of incomplete combustion

2

(d)

		C 37.08	H 5.15	O 24.72	S M1 = 33.05
M2	$\div A_r$	= 3.09	= 5.15	= 1.55	= 1.030
	÷ smallest	= 3	= 5	= 1.50	= 1
M3	Empirical formula = $C_6H_{10}O_3S_2$				

M1 % S = 33.05
M2 Calculation of moles
M3 Ratio of moles AND Empirical Formula
If no Sulfur used ecf for M2 and M3
M2 3.09 : 5.15 : 1.55
M3 $C_6H_{10}O_3$

3

(e) M1 Acid rain

Allow smog

M2 SO_2

Allow NO_x

2

(f) M1 Bonds broken = 9459 kJ mol^{-1}

(5C-C + 7C-O + 7C-H + 5O-H)

Allow if they cancel the common bonds

M1 4233

M2 Bonds formed = 9682 kJ mol^{-1}

(2C-C + 10C-H + 2C-O + 2O-H + 4C=O)

M2 4456

M3 ΔH = M1 - M2 = -223 kJ mol^{-1}

M3 can be awarded as ecf from their M1 and M2

3

(g) M1 ΔH = -235 - (2 × -394) - (3 × -242)

M2 = +1279 kJ mol^{-1}

If no sign assume positive

2