WJEC EDUQAS AS CHEMISTRY · COMPONENT 2

CHEMISTRY



EXAM QUESTION PACK

2.1 THERMOCHEMISTRY

SCORE	PERCENTAGE
/83	%

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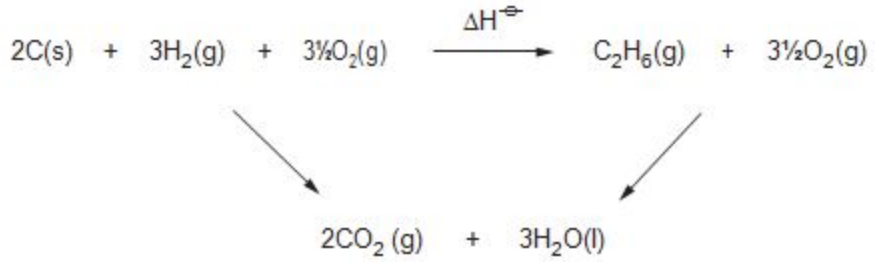
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1. Study the following energy cycle.



Use the values in the table below to calculate the enthalpy change of reaction, $\Delta H^{\ominus}$. [2]

Substance	Enthalpy change of combustion, $\Delta H_c^{\ominus}$ / kJ mol^{-1}
carbon	−394
hydrogen	−286
ethane	−1560

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

2.

(a) Ethanol, C_2H_5OH, is a liquid at room temperature. It is being increasingly used as a fuel.

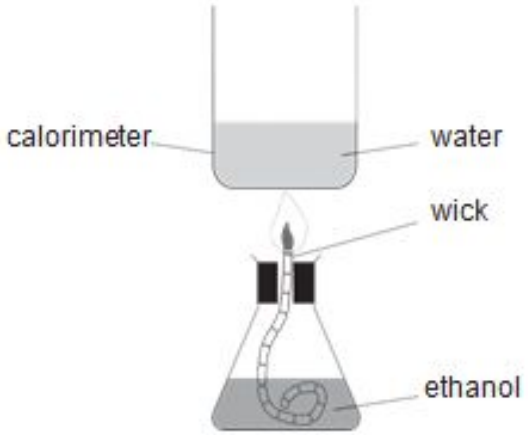
(i) Write the equation that represents the standard molar enthalpy change of formation (ΔH_f) of ethanol. [1]

(ii) Suggest why this enthalpy change cannot be measured directly. [1]

(b) Enthalpy changes of combustion can often be measured directly. The equation for the reaction which represents the enthalpy change of combustion (ΔH_c) of ethanol is as follows.

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

A student used the apparatus below to determine the enthalpy change of combustion of ethanol.



The student obtained the following results.

Mass of spirit burner + ethanol at start	= 72.27 g
Mass of spirit burner + ethanol after combustion	= 71.46 g
Temperature of water at start	= 21.5 °C
Temperature of water after combustion	= 75.5 °C
Volume of water in calorimeter	= 100 cm^3

The energy released in the experiment can be calculated using the formula

$$\text{energy released} = mc\Delta T$$

where m = mass of the water in grams (assume 1 cm^3 has a mass of 1 g)
c = 4.2 $Jg^{-1}°C^{-1}$
ΔT = change in temperature of the water

(i) Calculate the energy released in the experiment

[1]

Energy released = ... J

(ii) The enthalpy change of combustion of ethanol is defined as the energy change per mol of ethanol burned.

Use your answer to (i) to calculate the enthalpy change of combustion of ethanol.

Give your answer in kJ mol^{-1} and correct to **3 significant figures**. Include the sign.

[3]

(c) Another student did not carry out an experiment to find ΔH_c of ethanol. He looked up the literature value on a respected internet site.

How would you expect the numerical values obtained by the two students to differ? Explain your answer.

You may assume that both values were found under the same conditions of temperature and pressure.

[2]

(d) The students then used the apparatus from (b) to find the enthalpy change of combustion of higher relative molecular mass alcohols. They found that as the number of carbon atoms increased the value of the enthalpy change of combustion became more negative.

(i) Write the equation for the reaction which represents the enthalpy change of combustion of propanol, C_3H_7OH. [1]

(ii) In terms of bond strengths, explain why enthalpy changes of combustion are negative

[1]

(iii) Explain why the enthalpy change of combustion of propanol is more negative than that of ethanol

[1]

(e) Recent research has been carried out to find economic and environmentally friendly uses for waste straw and wood chippings.
The process of gasification involves the material being partly combusted at a temperature of about 700 °C to give a mixture consisting mainly of hydrogen and carbon monoxide but also some carbon dioxide.
Another approach has been to use enzyme catalysed reactions to change the waste material into glucose and then to ethanol.

Comment on the economic and environmental factors involved in both of these processes.

[4] QWC [2]

(Total 17)

3.

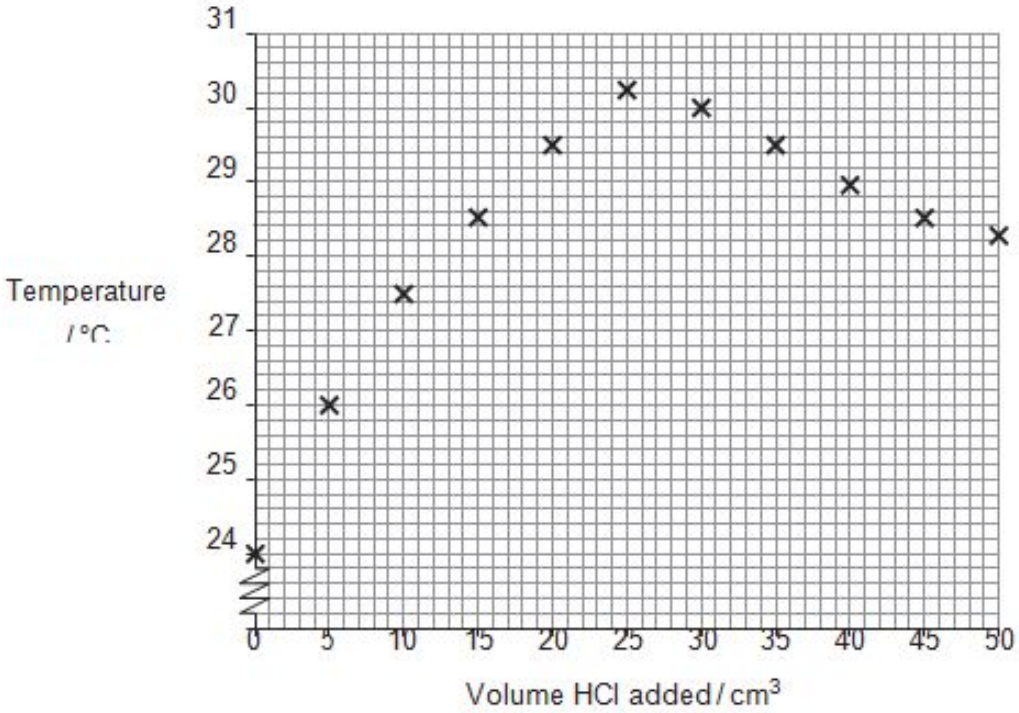
Zac was asked to measure the molar enthalpy change of neutralisation of sodium hydroxide by hydrochloric acid.

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

He was told to use the following method:

- Measure 25.0 cm^3 of sodium hydroxide solution of concentration 0.970 mol dm^{-3} into a polystyrene cup.
- Measure the temperature of the solution.
- Place the hydrochloric acid solution into a suitable container and measure the temperature of the solution.
- When the temperatures of both solutions are equal add 5.00 cm^3 of hydrochloric acid to the sodium hydroxide and stir.
- Measure the temperature of the mixture.
- Keep adding 5.00 cm^3 portions of hydrochloric acid, until 50.0 cm^3 have been added, stirring and measuring the temperature each time.

Zac's results are shown on the graph below.



(a) Suggest why it is important that the hydrochloric acid and the sodium hydroxide are at the same temperature.

[1]

(b) By drawing lines of best fit for both sets of points determine:

(i) the maximum temperature **change** [2]

Maximum temperature rise from the graph = ... °C

(ii) the volume of acid required to neutralise the sodium hydroxide. [1]

Volume of acid = ... cm^3

(c) Use your value from part *(b)*(ii) to calculate the concentration, in mol dm^{-3}, of the hydrochloric acid solution. [2]

Concentration = ... mol dm^{-3}

(d) Use **both** values from part *(b)* to calculate the heat given out during **this** experiment.

[Assume that the density of the solution is 1.00 g cm^{-3} and that its specific heat capacity is 4.18 J K^{-1} g^{-1}] [1]

Heat given out = ... J

(e) Calculate the molar enthalpy change, ΔH, for the reaction between sodium hydroxide and hydrochloric acid. [2]

ΔH = ... kJ mol^{-1}

(g) Explain why the temperature falls on continuing to add hydrochloric acid **after** the maximum temperature has been reached.

[2]

(h) The data book value for this molar enthalpy change of neutralisation is more exothermic than Zac's value

State the **main** reason for the difference between the values and suggest **one** change that would improve his result.

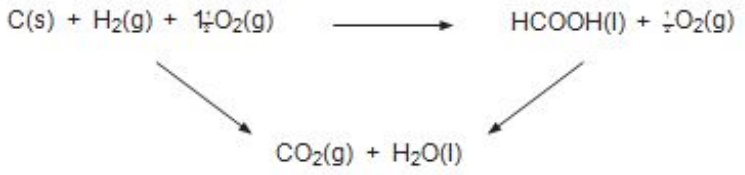
[2]

(Total 14)

4. Methanoic acid is the simplest carboxylic acid and occurs naturally, most notably in ant venom. It has a molar mass of 46.02 g mol^{-1}.

(a) State what is meant by *molar mass*. [1]

(b) Use the values in the table below to calculate the enthalpy change of formation for methanoic acid. [1]



Substance	Enthalpy change of combustion, $\Delta H_c^{\ominus}$ / kJ mol^{-1}
C	−394
H_2	−286
HCOOH	−263

5. *(a)* Nitrogen(I) oxide is a colourless gas that reacts with hydrogen to give nitrogen and water.

$$N_2O(g) + H_2(g) \longrightarrow N_2(g) + H_2O(l) \qquad \Delta H = -368 \text{ kJ mol}^{-1}$$

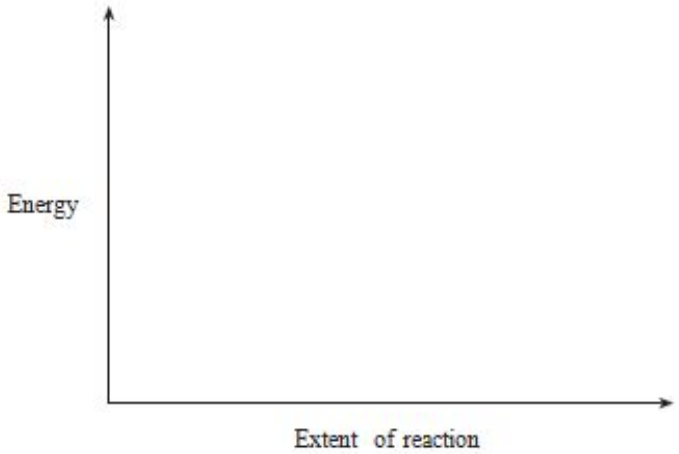
(i) State why the standard enthalpy of formation of both hydrogen and nitrogen gases is 0 kJ mol^{-1}. [1]

(ii) Calculate the standard enthalpy of formation of nitrogen(I) oxide in kJ mol^{-1}. (You should assume that the standard enthalpy of formation of water is –286kJ mol^{-1}) [2]

(b) A new method for producing phenol, C_6H_5OH, is by reacting benzene, C_6H_6, with nitrogen(I) oxide at 400 °C in the presence of a suitable catalyst.

$$C_6H_6 + N_2O \longrightarrow C_6H_5OH + N_2 \qquad \Delta H = -286 \text{ kJ mol}^{-1}$$

(i) Sketch the energy profiles for the catalysed and uncatalysed reactions using the axes shown below.
Label your profiles as *catalysed* and *uncatalysed*. [2]



(ii) A pilot-scale plant used 156 kg of benzene (M_r = 78) to produce phenol (M_r = 94).

I Calculate the number of moles of benzene used. [1]

Moles of benzene = ... mol

II The yield of phenol was 95 %. Using your answer to I and the equation below (or another suitable method), calculate the mass of phenol obtained. Show your working. [3]

$$C_6H_6 + N_2O \longrightarrow C_6H_5OH + N_2$$

(iii) Study the short account below, which gives more detail about this process.

The process to make phenol is carried out in the gas phase and uses a solid zeolite catalyst. The operating temperature is around 400 °C.

$$C_6H_6 + N_2O \longrightarrow C_6H_5OH + N_2 \qquad \Delta H = -286 \text{ kJ mol}^{-1}$$

The reactants are the hydrocarbon benzene and nitrogen(I) oxide, which is a potent greenhouse gas. The nitrogen(I) oxide is obtained from another process, where it is produced as an undesirable side product.

Use the account and the equation to comment on the environmental and *Green Chemistry* advantages of this process. A reference to the yield is not required. [4]
QWC [1]

Total [14]

6.

Callum and Carys wish to measure the enthalpy change of the reaction of aqueous copper(II) sulfate with zinc powder. The reaction that occurs is:

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

(a) Callum prepares copper(II) sulfate solution from hydrated copper(II) sulfate, $CuSO_4.5H_2O$.

(i) Calculate the relative molecular mass of hydrated copper(II) sulfate, $CuSO_4.5H_2O$. [1]

.....

.....

(ii) Callum measures a mass of hydrated copper(II) sulfate and uses this to make exactly 250.0 cm^3 of copper(II) sulfate solution of concentration 0.250 mol dm^{-3}.

I. Calculate the mass of hydrated copper(II) sulfate required to prepare this solution. [2]

.....

.....

.....

Mass of hydrated copper(II) sulfate = ... g

II. Describe, giving full practical details, how Callum should prepare the 250.0 cm^3 of copper(II) sulfate solution. [5]

QWC [1]

.....

.....

.....

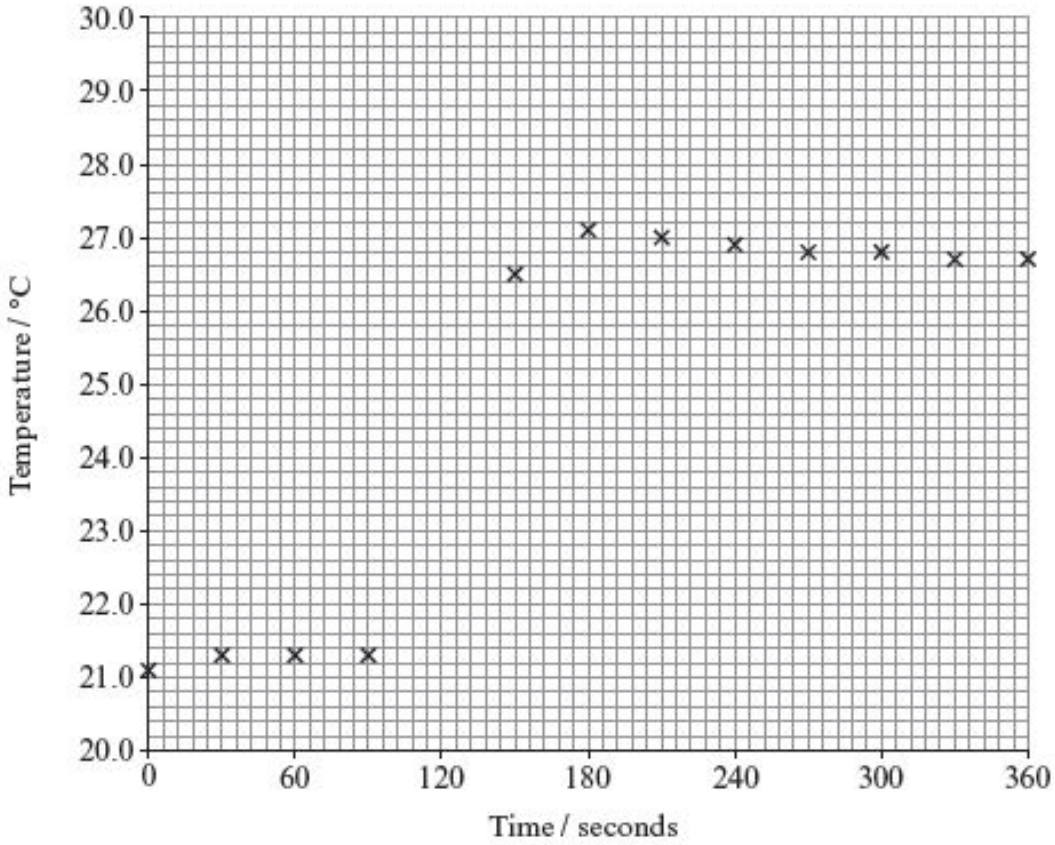
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(b) In order to measure the enthalpy change, Carys carried out the reaction between zinc powder and their copper(II) sulfate solution in an insulated vessel. She measured the temperature in the vessel at 30 second intervals, before, during and after the reaction. The zinc powder was added to the copper(II) sulfate solution at 120 seconds. The temperatures recorded were plotted on the graph below.



(i) Explain why zinc powder is used in this experiment rather than pieces of zinc metal. [2]

.....

.....

(ii) Draw lines to complete the graph, and use these to find the maximum temperature change.

Maximum temperature change ..... °C [2]

(iii) In this experiment, Carys used 50.00 cm^3 of the copper(II) sulfate solution prepared by Callum and added 0.400 g of zinc powder.

I. Calculate the number of moles of copper(II) sulfate present in this solution. [1]

.....

.....

II. The sample of zinc metal used contained 6.12×10^{-3} moles. State why this value, rather than the number of moles of copper(II) sulfate, is used to calculate the enthalpy change of the reaction. [1]

.....

.....

III. The enthalpy change can be calculated using the expression below.

$$\Delta H = -\frac{mc\Delta T}{n}$$

Where: m is the mass of the copper(II) sulfate solution (50 g)
ΔT is the change in temperature in °C
n is the number of moles of zinc
c is the specific heat capacity of the solution which equals 4.18 $J\,g^{-1}\,°C^{-1}$

Calculate the enthalpy change for the reaction in $kJ\,mol^{-1}$. [2]

.....

.....

.....

.....

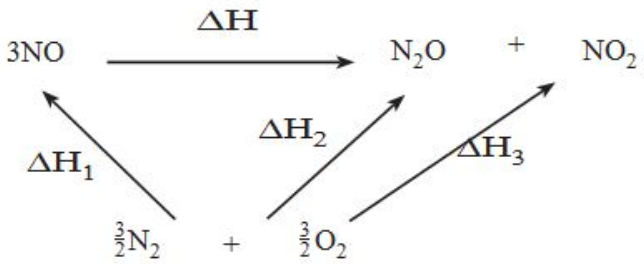
IV. Give a reason why the sign of the enthalpy value calculated is different from the sign of the temperature change measured. [1]

.....

.....

Total [18]

7. The energy cycle for a decomposition of nitrogen(II) oxide is shown below.

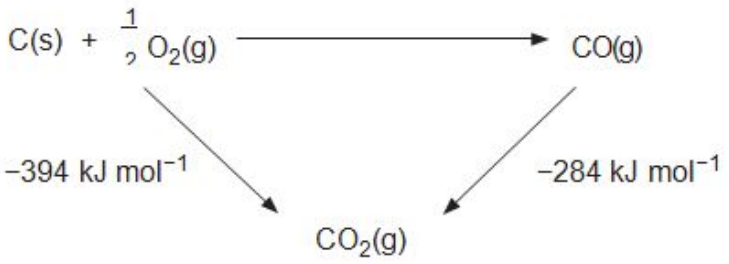


(a) Complete the equation to show ΔH in terms of ΔH_1, ΔH_2 and ΔH_3. [1]

ΔH = ...

(b) Write the chemical equation for the standard molar enthalpy change of formation of gaseous nitrogen(II) oxide, NO. [1]

Use the energy cycle to calculate the enthalpy change of formation of carbon monoxide. [1]



Enthalpy change of formation = ... kJ mol^{-1}

8. Jewels such as diamonds, rubies and emeralds are highly valued but are all closely related to much less precious materials.

(a) Emeralds are a form of the mineral beryl, with their green colour due to the impurities present.

A sample of beryl contains 10.04 % aluminium, 53.58 % oxygen and 31.35 % silicon by mass, with beryllium making up the remainder. Its molecular formula is $Al_2Be_xSi_6O_{18}$. Find the percentage by mass of beryllium in the compound and hence calculate the value of x in this formula. [3]

x = ...

(b) The most common form of carbon is graphite, however the element also exists in the form of diamond.

We can calculate the standard enthalpy change of reaction for making diamond from graphite using Hess' Law.

Reaction	Standard enthalpy change of reaction / kJ mol^{-1}
$C(diamond) + O_2(g) \rightarrow CO_2(g)$	–395.4
$C(graphite) + O_2(g) \rightarrow CO_2(g)$	–393.5

(i) State Hess' Law.

[1]

(ii) Use Hess' Law and the data in the table on page 4 to calculate the enthalpy change of the reaction below. [2]

$$C(graphite) \longrightarrow C(diamond)$$

Enthalpy change of reaction = ... kJ mol^{-1}

(iii) Kyran states that because diamond is an element, its enthalpy of formation under standard conditions must be zero.State whether Kyran is correct and give a reason to support your answer.

[1]

(iv) Most diamonds used in jewellery come from natural sources, but it is possible to produce diamonds artificially although these are rarely of gemstone quality.

(I) One proposed use of artificial diamond is to protect medical implants. To cover a particular implant, a volume of 2.08 cm^3 of diamond is needed. Calculate the mass of diamond required

[1]

[Density of diamond under standard conditions = 3.51 g cm^{-3}]

Mass of diamond = ... g

(II) The process of producing diamond from graphite has a yield of 93 %. Calculate the mass of graphite needed to make the diamond required.

[2]

Mass of graphite = ... g

(Total 10)

9.

The combustion of fossil fuels provides much of the energy we use today. Nonane, C_9H_{20}, is one of the compounds present in the fuel kerosene.

(a) (i) The equation for the combustion of nonane is given below.

$$C_9H_{20}(l) + 14\,O_2(g) \longrightarrow 9CO_2(g) + 10H_2O(l)$$

Use the values given in the table to calculate the standard enthalpy of combustion of nonane. [3]

Substance	Standard enthalpy of formation, $\Delta H_f^{\ominus}$ / kJ mol^{-1}
$C_9H_{20}(l)$	–275
$O_2(g)$	0
$CO_2(g)$	–394
$H_2O(l)$	–286

Standard enthalpy of combustion = ... kJ mol^{-1}

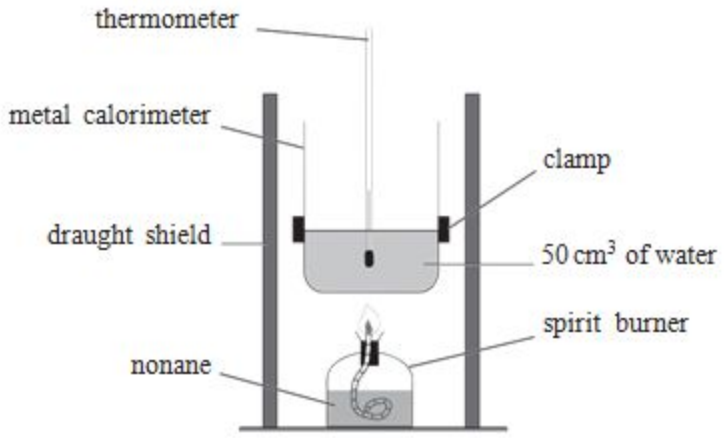
(ii) Standard enthalpy changes are measured under standard conditions. Give the standard conditions of temperature and pressure, including units for each.

[2]

Temperature .....

Pressure .....

(b) Iwan wished to confirm the value he had calculated for the enthalpy of combustion of nonane, and he used the apparatus below.



(i) Iwan measured the mass of the spirit burner at the start and end of the experiment and found that 0.20 g of nonane had been burned. Calculate the number of moles of nonane present in 0.20 g.

[2]

Number of moles = ... mol

(ii) During this experiment, the temperature of the water increased by 42.0 °C. Use the formula below to calculate the enthalpy change of combustion of nonane, in kJ mol^{-1}.

[2]

$$\Delta H = \frac{-mc\Delta T}{n}$$

m is the mass of water
c is the specific heat capacity of water which is 4.18 $J\,°C^{-1}g^{-1}$
ΔT is the temperature change in °C n is the number of moles of nonane

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

(iii) Give **one** reason why the experimental value that Iwan obtained differs from the theoretical value calculated in part *(a)*.

[1]

(Total 10)

3 (a) Otherwise a temperature change would occur on adding the acid which had nothing to do with the reaction [1]

(b) (i) Best fit lines (1)

Temperature rise = 6.4 °C (1)
(Take value from candidate's best fit lines) [2]

(ii) Volume of acid = 26.0 cm^3 [1]

[If no best fit lines award 0 in (i) and accept 25 cm^3 in (ii)]

(c) Moles acid = 0.02425 (1)

Conc acid = $\frac{0.02425}{0.026}$ = 0.933 mol dm^{-3} (1) [2]

(d) Heat = 51 × 4.18 x 6.4

= 1364 J [1]

(e) $\Delta H = -\frac{1364}{0.02425}$ (1)

= – 56.2 kJ mol^{-1} (1) [2]

(f) Pipette / burette [1]

(g) No further reaction occurs (1)

The excess acid cools the solution (1) [2]

(h) Heat / energy is lost to the environment (1)

Insulation is improved e.g. lid on the polystyrene cup (1) [2]

Total [14]

5 (a) (i) They are both elements in their standard states. [1]

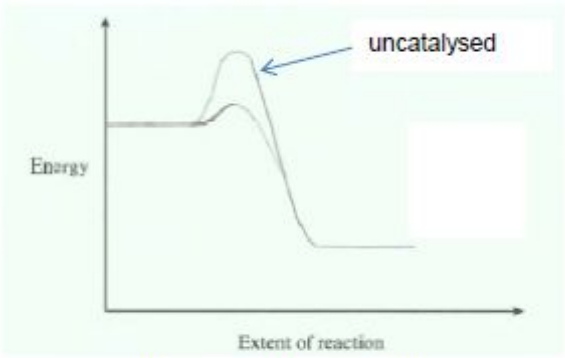
(ii) $\Delta H = \Sigma \Delta H_f$ products $- \Sigma \Delta H_f$ reactants (1)

$= (-286 + 0) - (-368 + 0)$

$= -286 + 368 = (+)82$ (kJ mol^{-1}) (1) [2]

or by a cycle where correct cycle drawn (1) correct answer (1)

(b) (i)



exothermic profile drawn (1)
uncatalysed / catalysed line labelled (1) [2]

(ii) I number of moles of benzene = 2000 [1]

II mole ratio is 1 : 1 (1)

$\therefore$ moles of phenol produced $= \frac{2000 \times 95}{100} = 1900$ (1)

mass $= M_r \times$ number of moles $= 94 \times 1900 = 178.6 / 179$ kg (1)

alternatively

78 (g / kg) of benzene gives 94 (g / kg) of phenol (1)

$\therefore$ 1 (g / kg) of benzene gives 94/78 (g / kg) of phenol
$\therefore$ 156 (kg) of benzene gives $94 \times 156/78$ (kg) of phenol = 188 (kg) (1)
but 95% yield $\therefore \frac{188 \times 95}{100} = 178.6 / 179$ (kg) (1) [3]

(iii) Look for at least four relevant positive points [4]

e.g.

- the process uses a (heterogeneous) catalyst, which can easily be separated from the gaseous products (thus saving energy)
- the only other product of the reaction is gaseous nitrogen, which is non-toxic / safe / not a harmful product
- the process uses nitrogen(I) oxide which is used up, rather than being released into the atmosphere from the other process (and causing global warming)
- the process is exothermic and the heat produced can be used elsewhere
- a relatively moderate operating temperature reduces overall costs
- high atom economy

Legibility of text; accuracy of spelling, punctuation and grammar;

clarity of meaning QWC [1]

6 (a) (i) M_r ($CuSO_4.5H_2O$) = 249.7 [1]

(ii) I. Moles of copper(II) sulfate

= 0.250 x 250/1000 = 6.25×10^{-2} moles (1)

Mass = 6.25×10^{-2} x 249.7 = 15.6 g (1) [2]

II. 1 mark each for:

- Weighing method
- Dissolve copper sulfate in a smaller volume of distilled water
- Transfer to 250.0 cm^3 volumetric / standard flask
- Use of funnel
- Wash funnel / glass rod / beaker with distilled water into volumetric flask
- Add distilled water up to mark
- Shake solution / mix thoroughly 5 max [5]

QWC: organisation of information clearly and coherently; use of specialist vocabulary where appropriate [1]

(b) (i) Powder has a greater surface area (1) so gives a higher rate of reaction (1) [2]

(ii) Extrapolate lines from start (level at 21.3°C) and end (through points at 180-270 seconds) (1)

Temperature rise = 6.0°C (Range 5.8-6.2°C) (1) [2]

(iii) I. Moles = 0.250 x 0.05 = 1.25×10^{-2} moles [1]

II. Zinc is the limiting reagent / Copper(II) sulfate is in excess [1]

III. $\Delta H = -(50) \times 4.18 \times 6.0 \div (6.12 \times 10^{-3})$ (1)

$\Delta H = -204902$ J mol^{-1}

$\Delta H = -205$ kJ mol^{-1} (1) [2]

IV. Enthalpy measures chemical energy, and as heat energy increases, chemical energy must decrease [1]

Total [18]

7 (a) $\Delta H = \Delta H_2 + \Delta H_3 - \Delta H_1$ [1]

(b) $\frac{1}{2}N_2(g) + \frac{1}{2}O_2(g) \rightarrow NO(g)$ state symbols requires [1]

enthalpy changes = –110 [1]

8 (a) percentage Be by mass = 5.03% (1)

division of percentage by A_r for Be and at least one other element as shown below (1)

Al 10.04 ÷ 27 = 0.3719 → 1.00

Be 5.03 ÷ 9.01 = 0.5583 → 1.50

O 53.58 ÷ 16 = 3.3488 → 9.00

Si 31.35 ÷ 28.1 = 1.1566 → 3.10

molecular formula = $Al_2Be_3O_{18}Si_6$ or x=3 (1) [3]

(b) (i) Hess' Law states that where a reaction can occur by more than one route the total enthalpy **change** for each route will be the same [1]

(ii) ΔH = –393.5 – (–395.4) (1) = +1.9 kJ mol^{-1} (1) [2]

(iii) Kyran is **incorrect** as diamond is not the **standard state** of carbon [1]

(iv) I mass of diamond = 7.30 g [1]

II mass of graphite = 7.30 ÷ (93/100) (1) = 7.85 g (1) [2]

Total [10]

9 (a) (i) $\Delta H = 9 \times (-394) + 10 \times (-286) - (-275)$ (1)

$= -6131$ kJ mol^{-1} (1) for correct value and (1) for correct sign **[3]**

(ii) temperature 298K, 25°C (1) pressure 1 atm, 101 kPa (1) **[2]**

(b) (i) $M_r = (9 \times 12) + (20 \times 1.01) = 128.2$ (1)

number of moles $= 1.56 \times 10^{-3}$ mol (1) **[2]**

(ii) $\Delta H = -50 \times 4.18 \times 42 \div 1.56 \times 10^{-3}$ (1)

$= -5626698$ J mol^{-1} $= -5627$ kJ mol^{-1} (1) **[2]**

(iii) heat loss to environment / incomplete combustion / not standard conditions **[1]**

Total [10]