

## SECTION 8 Chemical Reactions and Energy

## Multiple-Choice Questions

ASL10(l)\_08

Which of the following process is endothermic?

- A. Freezing of water  
 B. Condensation of steam  
 C. Reaction of  $\text{H}^+(\text{aq})$  with  $\text{OH}^-(\text{aq})$  to give  $\text{H}_2\text{O}(\text{l})$   
 D. Electrolysis of water

DSB11SP\_10

Which of the following reactions is endothermic?

- A.  $\text{Zn}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \longrightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu}(\text{s})$   
 B.  $\text{CaCO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \longrightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
 C.  $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \longrightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l})$   
 D.  $\text{C}_9\text{H}_{20}(\text{l}) \longrightarrow \text{C}_2\text{H}_6(\text{g}) + \text{C}_3\text{H}_8(\text{g}) + \text{C}_4\text{H}_8(\text{g})$

DSE11SP\_13

Standard enthalpy changes of several reactions, as denoted by x, y and z respectively, are listed in the table below.

Reaction	Standard enthalpy change / $\text{kJ mol}^{-1}$
$\text{C}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g})$	x
$\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \longrightarrow \text{H}_2\text{O}(\text{g})$	y
$\text{C}(\text{s}) + 2\text{H}_2(\text{g}) \longrightarrow \text{CH}_4(\text{g})$	z

For the reaction  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$ , which of the following is a reasonable estimate of its standard enthalpy change?

- A.  $x + y - z$   
 B.  $-x - y + z$   
 C.  $x + 2y - z$   
 D.  $-x - 2y - z$

DSE11SP\_19

In an experiment, 10.0 g of  $\text{KCl}(\text{s})$  was added to 100  $\text{cm}^3$  of water. The mixture was then stirred until all the  $\text{KCl}(\text{s})$  dissolved. The temperature of the mixture was found to drop by 5.5°C. What is the molar enthalpy change, in  $\text{kJ mol}^{-1}$ , of the dissolving process of  $\text{KCl}(\text{s})$  under the conditions of the experiment?

(Specific heat capacity of the mixture =  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ ; Density of water =  $1.0 \text{ g cm}^{-3}$ ;

Relative atomic masses: K = 39.1, Cl = 35.5)

- A. +2.31  
 B. +2.54  
 C. +17.23  
 D. +18.96



DSE15\_18

Which of the following combinations is / are correct?

Chemical reaction	Enthalpy change of reaction
(1) $2\text{H}_2\text{O}(l) \longrightarrow 2\text{H}_2(g) + \text{O}_2(g)$	Positive
(2) $2\text{CO}(g) + \text{O}_2(g) \longrightarrow 2\text{CO}_2(g)$	Positive
(3) $2\text{Na}(s) + 2\text{H}_2\text{O}(l) \longrightarrow 2\text{NaOH}(aq) + \text{H}_2(g)$	Negative

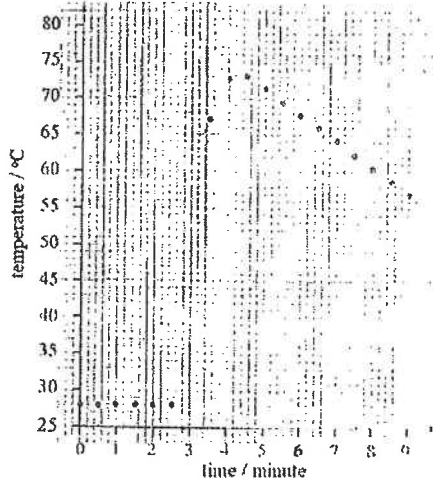
A. (1) only  
 B. (2) only  
 C. (1) and (3) only  
 D. (2) and (3) only

DSE16\_24

1 <sup>st</sup> statement	2 <sup>nd</sup> statement
The standard enthalpy change of formation of a compound must be negative value.	Under standard conditions, a compound must be energetically more stable than its constituent elements.

DSE17\_07

In an experiment for studying the enthalpy change of a reaction, the variation of the temperature of the content in the reaction container with time was plotted in a graph as shown below:  
 The reaction starts at the third minute. Which of the following combinations is correct?

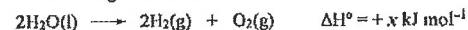


	The greatest temperature rise of the content	Enthalpy change of the reaction
A.	51 °C	negative
B.	45 °C	negative
C.	51 °C	positive
D.	45 °C	positive

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DSE18\_18

Consider the following information:



Which of the following statements is/are correct?

- (1) The standard enthalpy change of formation of  $\text{H}_2\text{O}(l)$  is  $-0.5x \text{ kJ mol}^{-1}$   
 (2) The standard enthalpy change of formation of  $\text{H}_2\text{O}(l)$  is  $+0.5x \text{ kJ mol}^{-1}$   
 (3) The standard enthalpy change of combustion of  $\text{H}_2(g)$  is  $-x \text{ kJ mol}^{-1}$
- A. (1) only  
 B. (2) only  
 C. (1) and (3) only  
 D. (2) and (3) only

DSE18\_22

Which of the following processes are endothermic?

- (1) Melting of wax  
 (2) Cracking of heavy oil  
 (3) Adding zinc powder to  $\text{CuSO}_4(aq)$
- A. (1) and (2) only  
 B. (1) and (3) only  
 C. (2) and (3) only  
 D. (1), (2) and (3)

DSE19\_09

It is given that:

Standard enthalpy change of formation of water =  $-286 \text{ kJ mol}^{-1}$

Standard enthalpy change of combustion of propane =  $-2222 \text{ kJ mol}^{-1}$

Standard enthalpy change of formation of carbon dioxide =  $-394 \text{ kJ mol}^{-1}$

What is the standard enthalpy change of formation of propane?

- A.  $-52 \text{ kJ mol}^{-1}$   
 B.  $-104 \text{ kJ mol}^{-1}$   
 C.  $+52 \text{ kJ mol}^{-1}$   
 D.  $+104 \text{ kJ mol}^{-1}$

DSE19\_22

Which of the following are exothermic?

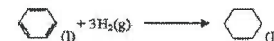
- (1) Thermal decomposition of mercury(II) oxide solid  
 (2) Dilution of concentrated sulphuric acid with water  
 (3) Reaction of magnesium ribbon with dilute hydrochloric acid
- A. (1) and (2) only  
 B. (1) and (3) only  
 C. (2) and (3) only  
 D. (1), (2) and (3)

DSE2020:

10. Refer to the standard enthalpy changes of combustion below :



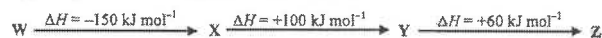
What is the standard enthalpy change of the following reaction ?



- A.  $-206 \text{ kJ mol}^{-1}$   
 B.  $-652 \text{ kJ mol}^{-1}$   
 C.  $+206 \text{ kJ mol}^{-1}$   
 D.  $+652 \text{ kJ mol}^{-1}$

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13. The enthalpy changes for some conversions are shown below :



Which of the following combinations is correct ?

	$W \rightarrow Z$	$Z \rightarrow X$
A.	exothermic	endothermic
B.	exothermic	exothermic
C.	endothermic	exothermic
D.	endothermic	endothermic

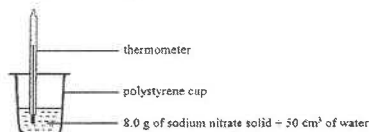
21. Which of the following statements are correct ?

- (1) The standard enthalpy change of formation of  $\text{NH}_3(\text{g})$  can be determined directly from experiment.  
 (2) The standard enthalpy change of combustion of  $\text{H}_2\text{NNH}_2(\text{l})$  is negative.  
 (3) The standard enthalpy change of formation of  $\text{N}_2(\text{g})$  is zero.

- A. (1) and (2) only  
 B. (1) and (3) only  
 C. (2) and (3) only  
 D. (1), (2) and (3)

DSE2021:

14. Based on the experimental set-up in the diagram below, after 8.0 g of sodium nitrate solid is completely dissolved in 50 cm<sup>3</sup> of water, the temperature drops by 6 °C.



Which of the following would give a drop of temperature by 3 °C under the same experimental conditions ?

- A. After 2.0 g of sodium nitrate solid is completely dissolved in 25 cm<sup>3</sup> of water.  
 B. After 4.0 g of sodium nitrate solid is completely dissolved in 100 cm<sup>3</sup> of water.  
 C. After 16.0 g of sodium nitrate solid is completely dissolved in 100 cm<sup>3</sup> of water.  
 D. After 24.0 g of sodium nitrate solid is completely dissolved in 75 cm<sup>3</sup> of water.
15. When 7.89 g of carbon monoxide gas burns completely, 80 kJ of heat is released. Under those experimental conditions, the enthalpy change of formation of carbon dioxide gas is  $-394 \text{ kJ mol}^{-1}$ . What is the enthalpy change of formation of carbon monoxide gas under the same experimental conditions ?

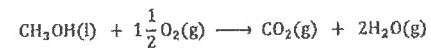
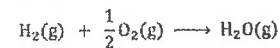
(Relative atomic masses : C = 12.0, O = 16.0)

- A.  $-678 \text{ kJ mol}^{-1}$   
 B.  $-474 \text{ kJ mol}^{-1}$   
 C.  $-314 \text{ kJ mol}^{-1}$   
 D.  $-110 \text{ kJ mol}^{-1}$

### Structural Questions

AL98(II)\_02c

Both  $\text{H}_2(\text{g})$  and  $\text{CH}_3\text{OH}(\text{l})$  are possible fuels for powering rockets. Their combustion reactions are show below.



- (i) For each of the above reactions, calculate the enthalpy change at 298 K, per kg of the fuel-oxygen mixture in the mole ratio as indicated in the stoichiometric equation. (3 marks)
- (ii) The effectiveness of a fuel can be estimated by dividing the enthalpy change per kg of the fuel-oxygen mixture in its combustion reaction by the average molar mass of the product(s) in g.

Deduce which of the above two fuels is more effective in powering rockets.

Note: You are provided with the following data at 298 K:

Compound	Molar mass / g	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{CO}_2(\text{g})$	44	-394
$\text{H}_2\text{O}(\text{g})$	18	-242
$\text{CH}_3\text{OH}(\text{l})$	32	-239

(3 marks)

AL99(I)\_07b

In an experiment to determine the enthalpy change of neutralization, a polystyrene foam cup was used as a calorimeter. When a solution of an acid was poured into a solution of an alkali in the calorimeter, the temperature rise was recorded by a thermometer which also served as a stirrer.

State THREE sources of error in the result obtained in such an experiment.

(2 marks)

ASL99(I)\_02

Consider the standard enthalpy changes of combustion,  $\Delta H_c^\circ$ , of the alkanols listed in the table below:

Alkanol	$\Delta H_c^\circ, 298 / \text{kJ mol}^{-1}$
$\text{CH}_3\text{OH}(\text{l})$	-726
$\text{CH}_3\text{CH}_2\text{OH}(\text{l})$	-1367
$\text{CH}_3(\text{CH}_2)_2\text{OH}(\text{l})$	-2017
$\text{CH}_3(\text{CH}_2)_3\text{OH}(\text{l})$	x

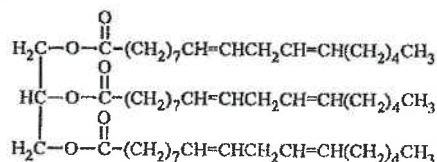
- (a) Explain why the combustion of  $\text{CH}_3\text{OH}(\text{l})$  is exothermic. (1 mark)
- (b) Estimate the value of x. Show how you arrive at your answer. (2 marks)

- (c) At 298 K, the standard enthalpy changes of formation of  $\text{CO}_2(\text{g})$  and  $\text{H}_2\text{O}(\text{l})$  are  $-393$  and  $-286 \text{ kJ mol}^{-1}$  respectively. Calculate the standard enthalpy change of formation of  $\text{CH}_3\text{OH}(\text{l})$  at 298K.

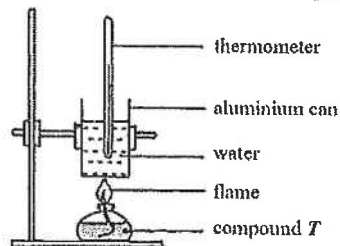
(3 marks)

ASL99(II)\_13 [Similar to DSE18\_06b]

Compound T is the main chemical constituent of a cooking oil. T has the following structural formula;



- (a) State all functional groups in T. (2 marks)
- (b) The enthalpy change of combustion of T can be determined using the set-up shown below:



When 2.30 g of T was burnt, the temperature of water of mass 250 g in the aluminium can was found to increase by  $20.5^\circ\text{C}$ .

- (i) Calculate the enthalpy change of combustion of T, in  $\text{kJ mol}^{-1}$ , under the conditions of the experiment. (Specific heat capacity of water =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ ; relative molecular mass of T = 878) (3 marks)
- (ii) Suggest TWO main sources of error in the experiment. (2 marks)

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ASL00(II)\_08

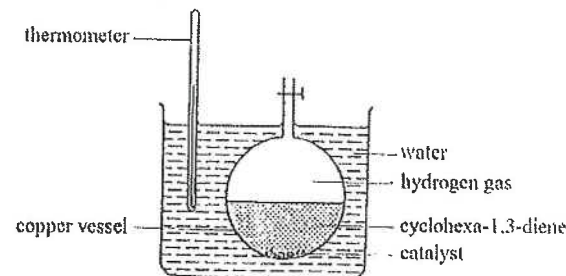
- (a) The standard enthalpy changes of combustion of cyclohexa-1,3-diene ( $\text{C}_6\text{H}_8$ ), cyclohexane ( $\text{C}_6\text{H}_{12}$ ) and hydrogen are as follows:

$$\Delta H^\circ_{\text{c},298} [\text{C}_6\text{H}_8(\text{l})] = -3584 \text{ kJ mol}^{-1}$$

$$\Delta H^\circ_{\text{c},298} [\text{C}_6\text{H}_{12}(\text{l})] = -3924 \text{ kJ mol}^{-1}$$

$$\Delta H^\circ_{\text{c},298} [\text{H}_2(\text{g})] = -286 \text{ kJ mol}^{-1}$$

- (i) With the help of a chemical equation, state the meaning of the standard enthalpy change of combustion of cyclohexane. (3 marks)
- (ii) Write a chemical equation to represent the complete hydrogenation of cyclohexa-1,3-diene. Hence, calculate the standard enthalpy change of hydrogenation of cyclohexa-1,3-diene. (3 marks)
- (b) In an experiment to determine the enthalpy change of hydrogenation of cyclohexa-1,3-diene, 0.10 mol of cyclohexa-1,3-diene was treated with excess hydrogen gas in the presence of a catalyst in a copper vessel. The vessel was immersed in 300.0 g of water. The diagram below shows the experimental set-up:



- (i) Name a catalyst suitable for the hydrogenation. (1 mark)
- (ii) It is necessary to shake the vessel vigorously during the experiment. Explain. (1 mark)
- (iii) Suggest TWO reasons why a copper vessel was used instead of a glass vessel. (2 marks)
- (iv) At the end of the experiment, the temperature of the water increased by  $16.5^\circ\text{C}$ . (I) Calculate the enthalpy change of hydrogenation of cyclohexa-1,3-diene, in  $\text{kJ mol}^{-1}$ , under the conditions of the experiment. (specific heat capacity of the water is  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ ) (3 marks)
- (II) State TWO assumptions in your calculation. (2 marks)

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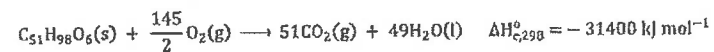
ASL01(II)\_09 [Similar to DSE15\_08]

(a) The table below lists the standard enthalpy changes of formation of three compounds:

Compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{C}_6\text{H}_{12}\text{O}_6(\text{s})$ (glucose)	-1274
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{l})$	-286

- (i) Calculate the standard enthalpy change of combustion of glucose. (3 marks)
- (ii) Calculate the theoretical amount of energy released when 10.0 g of glucose undergoes complete combustion. (2 marks)

(b) The thermochemical equation for the combustion of tripalmitin ( $\text{C}_{51}\text{H}_{98}\text{O}_6$ ) is given below:



Calculate the theoretical amount of energy released when 10.0 g of tripalmitin undergoes complete combustion. (2 marks)

(c) With reference to your answers in (a) and (b), suggest why plants store their energy mainly in the form of carbohydrates, whereas animals store their energy mainly in the form of fats (tripalmitin). (2 marks)

ASL02(II)\_08 [Similar to DSE17\_07]

(a) In an experiment to determine the enthalpy change of combustion of ethanol, a calorimeter containing 200.0 g of water was used. Burning 0.185 g of ethanol caused the temperature of the water in the calorimeter to rise by 6.0 °C.

- (i) Draw a labelled diagram of the set-up used in the experiment. (2 marks)
- (ii) Assuming that the heat capacity of the calorimeter is negligible, calculate the enthalpy change of combustion of ethanol, in  $\text{kJ mol}^{-1}$ , under the conditions of the experiment. (specific heat capacity of the mixture is  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ ) (3 marks)
- (iii) State TWO other assumptions made in your calculation. (2 marks)

(b) (i) Do you agree with the following statement? Explain your answer. 'The standard enthalpy change of formation of ethanol can be determined directly by experiment.' (1 mark)

(ii) The table below lists the standard enthalpy changes of combustion of three substances.

Substance	$\Delta H_{\text{c},298}^\circ / \text{kJ mol}^{-1}$
C(graphite)	-394
$\text{H}_2(\text{g})$	-286
$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-1368

Calculate the standard enthalpy change of formation of ethanol,  $\Delta H_f^\circ[\text{C}_2\text{H}_5\text{OH}(\text{l})]$ . (3 marks)

(c) The table below lists the standard enthalpy changes of neutralization of three acids with NaOH(aq).

Acid	$\Delta H_{\text{neutralization},298}^\circ / \text{kJ mol}^{-1}$
HCl(aq)	-57.3
$\text{HNO}_3(\text{aq})$	-57.3
$\text{CH}_3\text{CO}_2\text{H}(\text{aq})$	-55.2

Account for the following statements:

- (i) The standard enthalpy change of neutralization of HCl(aq) with NaOH(aq) is the same as that of  $\text{HNO}_3(\text{aq})$  with NaOH(aq). (2 marks)
- (ii) The standard enthalpy change of neutralization of HCl(aq) with NaOH(aq) is more negative than that of  $\text{CH}_3\text{CO}_2\text{H}(\text{aq})$  with NaOH(aq). (2 marks)

ASL03(II)\_09 [Same as DSE19\_08]

In a titrimetric experiment, 25.0  $\text{cm}^3$  of 2.0 M sodium hydroxide solutions was placed in a polystyrene foam cup and was titrated against hydrochloric acid. The experimental results are listed in the table below:

Volume of HCl(aq) added / $\text{cm}^3$	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0
Temperature of mixture / °C	25.8	30.0	34.4	38.8	39.8	38.2	36.6	35.0

- (a) Plot a graph to show the variation of the temperature of the mixture with the volume of HCl(aq) added. (3 marks)
- (b) (i) From your graph, determine the maximum temperature that could be attained by the mixture. (1 mark)
- (ii) Calculate the molarity of the HCl(aq) used. (2 marks)
- (c) Using your result in (b), calculate the enthalpy change of neutralization of NaOH(aq) with HCl(aq) under the conditions of the experiment. (You may assume that the density of the mixture is  $1.0 \text{ g cm}^{-3}$ , the specific heat capacity of the mixture is  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  and that the heat capacity of the polystyrene cup is negligible.) (3 marks)

## ASL04(II)\_10

In an experiment to determine the enthalpy change of hydration of  $\text{CuSO}_4(\text{s})$  indirectly, 0.025 mol of  $\text{CuSO}_4(\text{s})$  and 0.025 mol of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(\text{s})$  were dissolved separately in 50.0  $\text{cm}^3$  of deionized water in a polystyrene cup. The maximum change in temperature of each mixture was determined. The table below lists the results obtained:

The form of copper(II) sulphate(VI) used	Maximum change in temperature / $^{\circ}\text{C}$
$\text{CuSO}_4(\text{s})$	+7.7
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(\text{s})$	-1.7

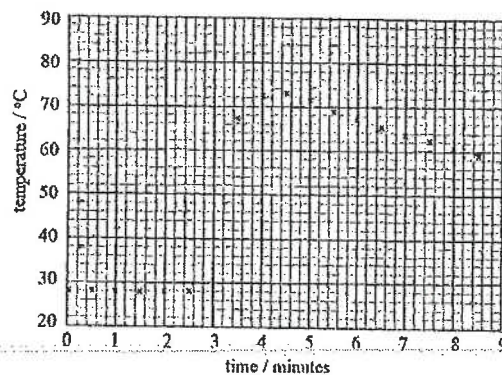
- (a) Calculate, under the condition of the experiment, the molar enthalpy change of solution of each of the following compounds.
- $\text{CuSO}_4(\text{s})$
  - $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(\text{s})$
- (You may assume that the copper(II) sulphate(VI) solution formed has a specific heat capacity of  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  and a density of  $1.0 \text{ g cm}^{-3}$ , and that the heat capacity of the polystyrene cup is negligible.)
- (b) From your results in (a), calculate the molar enthalpy change of hydration of  $\text{CuSO}_4(\text{s})$ .
- (c) Suggest why the enthalpy change of hydration of  $\text{CuSO}_4(\text{s})$  cannot be determined directly.

## ASL05(I)\_04

An experiment was carried out to determine the enthalpy change of the following reaction:



25.0  $\text{cm}^3$  of 1.00 M  $\text{CuSO}_4(\text{aq})$  was transferred to a polystyrene cup with negligible heat capacity, and the temperature of the solution was recorded every half minute for 2½ minutes. At precisely 3.0 minutes, 4.0 g of zinc powder was added to the cup. The mixture was stirred and its temperature was recorded for an additional 6 minutes. The graph below shows the plot of temperature against time.



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- (a) Show, by calculation, that  $\text{CuSO}_4$  is the limiting reactant. (2 marks)
- (b) Find, from the graph, the maximum temperature rise of the mixture. (You should show your working on the graph.) (2 marks)
- (c) Assuming that the specific heat capacity and the density of the mixture are  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  and  $1.0 \text{ g cm}^{-3}$  respectively, calculate the enthalpy change of this reaction, in  $\text{kJ mol}^{-1}$ . (3 marks)

## AL05(II)\_05

Most of the petroleum stock located on Earth is likely to be used up in 50 to 100 years if petroleum consumption is maintained at the current rate. With a view to cutting down petroleum consumption, some countries have adopted an alternative fuel for motor vehicles – gasoline which contains ethanol.

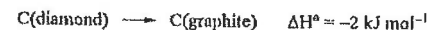
- (a) Based on the standard enthalpy changes of formation given below, calculate the standard enthalpy changes for the complete combustion of octane and ethanol respectively.

Compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{C}_8\text{H}_{18}(\text{l})$	-250
$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-278
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{l})$	-286

- (b) Assuming that gasoline contains only octane, compare the enthalpy change of combustion values, in  $\text{kJ g}^{-1}$ , of gasoline and an alternative fuel containing gasoline and 10% ethanol by mass. (4 marks)
- (c) Besides cutting down petroleum consumption, suggest one additional advantage of using the alternative fuel over using gasoline. (1 mark)

## AL06(I)\_02

Given:



Explain why the conversion of diamond into graphite will not occur spontaneously under normal condition.

(1 mark)

## ASL06(Q)\_06

When 10.0  $\text{cm}^3$  of ethyl ethanoate was mixed with 8.0  $\text{cm}^3$  of trichloromethane, the temperature of the mixture increased by 9.5  $^{\circ}\text{C}$ .

- (a) With the help of a diagram, showing the structures of the molecules, explain why the above mixing process is exothermic.

(2 marks)

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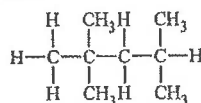
- (b) Based on the data given below, estimate by calculation the enthalpy change, in  $\text{kJ mol}^{-1}$ , for the above mixing process.

Compound	Molar mass	Density	Specific heat capacity
Ethyl ethanone	$88.0 \text{ g mol}^{-1}$	$0.90 \text{ g cm}^{-3}$	$1.92 \text{ J g}^{-1} \text{ K}^{-1}$
Trichloromethane	$119.5 \text{ g mol}^{-1}$	$1.49 \text{ g cm}^{-3}$	$0.97 \text{ J g}^{-1} \text{ K}^{-1}$

(3 marks)

ASL06(II)\_11

Compound *X* has the following structure:



Complete combustion of 1.0 g of *X* liberates 44.5 kJ at 298 K under atmospheric pressure.

- (a) Give the systematic name of *X*. (1 mark)
- (b) Calculate the standard enthalpy change of combustion of *X* at 298 K. (3 marks)
- (c) Calculate the standard enthalpy change of formation of *X* at 298 K. (3 marks)

Standard enthalpy change of formation of  $\text{CO}_2(\text{g})$  and  $\text{H}_2\text{O}(\text{l})$  at 298 K are  $-393.5 \text{ kJ mol}^{-1}$  and  $-285.8 \text{ kJ mol}^{-1}$  respectively.

AL08(II)\_01

The table below lists the **standard enthalpy change of formation of four compounds**.

Compound	$\Delta H_f^\circ, 298 / \text{kJ mol}^{-1}$
$\text{H}_2\text{O}(\text{l})$	-286
$\text{HCl}(\text{g})$	-92
$\text{SiO}_2(\text{s})$	-910
$\text{SiCl}_4(\text{l})$	-640

- (a) State the meaning of the term 'standard enthalpy change of formation of a compound'. (1 mark)
- (b)  $\text{SiCl}_4(\text{l})$  undergoes hydrolysis to give  $\text{SiO}_2(\text{s})$
- (i) Write the chemical equation for the hydrolysis. (1 mark)
- (ii) Using the above data, calculate the standard enthalpy change for the hydrolysis. State ONE assumption made in your calculation. (3 marks)

ASL09(II)\_01

Hydrolysis of protein gives a variety of amino acids, and alanine ( $\text{CH}_3\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$ ) is one of the amino acids commonly obtained.

- (a) In the human body, alanine undergoes biological oxidation to give carbon dioxide, water and urea ( $\text{CO}(\text{NH}_2)_2$ ). Write the chemical equation for this reaction. (1 mark)
- (b) When nitrogen-containing organic compounds are burnt in calorimetric experiments, the nitrogen they contained is transformed to nitrogen molecules. Write the chemical equation for the combustion of each of the following compounds in a calorimetric experiment:
- (i) Alanine (1 mark)
- (ii) Urea (1 mark)
- (c) Using the equations that you have given in (a) and (b), as well as the standard enthalpy change of combustion given in the table below:

Compound	$\Delta H_c^\circ, 298 / \text{kJ mol}^{-1}$
Alanine	-1577
Urea	-632

Calculate the energy, in kJ, that can be obtained from the biological oxidation of 1.00 g of alanine at 298 K.

(4 marks)

ASL10(II)\_07 [Similar to DSE14\_06]

The table below lists the **standard enthalpy change of formation of four compounds**.

Compound	$\Delta H_f^\circ, 298 / \text{kJ mol}^{-1}$
$\text{H}_2\text{O}(\text{l})$	-286
$\text{H}_2\text{O}_2(\text{l})$	-188
$\text{NH}_3(\text{g})$	-46
$\text{N}_2\text{H}_4(\text{l})$	+51

- (a) What is the meaning of the term 'standard enthalpy change of formation'? (1 mark)
- (b) Hydrazine ( $\text{N}_2\text{H}_4$ ) is a colorless liquid commonly used as a rocket fuel. It can be synthesized in a chemical process in which ammonia is oxidized by hydrogen peroxide to give hydrazine and water. For the oxidation of ammonia to hydrazine.
- (i) Write its chemical equation, and (1 mark)
- (ii) calculate its standard enthalpy change using the above thermochemical data. (2 marks)



(e) A student found the following information in a Material Safety Data Sheet (MSDS):

'Hydrazine is extremely explosive in the presence of oxidizing materials'

The student accounted for the phenomenon by the positive standard enthalpy change of formation of hydrazine. Is the student's explanation correct? Elaborate your answer.

(2 marks)

AL10(II)\_02

A flight of space shuttle requires the use of three propellants:

A **solid propellant**, which is a mixture of powder Al(s) and NH<sub>4</sub>ClO<sub>4</sub>(s), is used to power the rockets carrying the shuttle. Upon ignition, the solid propellant reacts to give Al<sub>2</sub>O<sub>3</sub>(s), AlCl<sub>3</sub>(s), NO(g) and H<sub>2</sub>O(g). This reaction provides energy for launching the rockets and the shuttle up to the upper atmosphere.

After the shuttle separates from the rockets, the shuttle is propelled into its designed orbit by a **cryogenic propellant**, which is a mixture of H<sub>2</sub>(l) and O<sub>2</sub>(l).

When the shuttle is in its orbit, a **hypergolic propellant**, of which the fuel is CH<sub>3</sub>NHNH<sub>2</sub>(l) and oxidant is N<sub>2</sub>O<sub>4</sub>(l), will provide energy for manoeuvring the shuttle. The fuel and oxidant react upon mixing, without ignition, to give CO<sub>2</sub>(g), H<sub>2</sub>O(g) and N<sub>2</sub>(g).

(a) Write the chemical equation for the reaction of

(i) Al(s) with NH<sub>4</sub>ClO<sub>4</sub>(s), and

(1 mark)

(ii) CH<sub>3</sub>NHNH<sub>2</sub>(l) with N<sub>2</sub>O<sub>4</sub>(l).

(1 mark)

(b) Given the following standard enthalpy change of formation, calculate the standard enthalpy change, at 298 K, of reaction (I) and that of reaction (II).

Compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
Al <sub>2</sub> O <sub>3</sub> (s)	-1676
AlCl <sub>3</sub> (s)	-704
CH <sub>3</sub> NHNH <sub>2</sub> (l)	+53
CO <sub>2</sub> (g)	-394
H <sub>2</sub> O(g)	-242
NH <sub>4</sub> ClO <sub>4</sub> (s)	-295
NO(g)	+90
N <sub>2</sub> O <sub>4</sub> (l)	-20

(4 marks)

(c) Suggest an advantage of using the solid propellant in powering the rockets.

(1 mark)

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(d) The cryogenic propellant is also used to produce electricity for use in the shuttle. Briefly describe the electrochemical process involved.

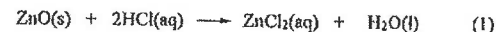
(2 marks)

(e) State an advantage of using the hypergolic propellant in manoeuvring the shuttle.

(1 mark)

AL11(II)\_03 [Similar to DSE16\_07]

The enthalpy change of formation  $\Delta H_f^\ominus$  of ZnO(s) can be determined indirectly from the enthalpy change of formation of H<sub>2</sub>O(l) and the enthalpy changes of reactions (1) and (2) below.

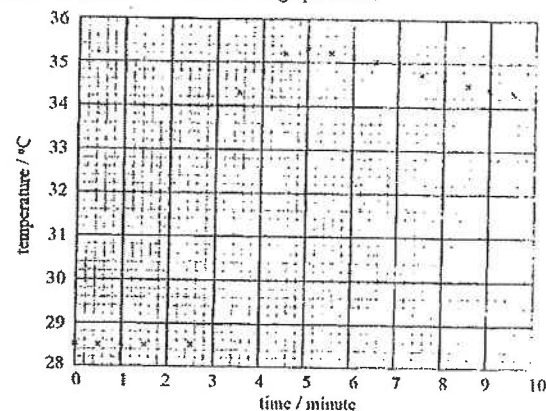


An experiment as outlined below was carried out to determine the enthalpy change of reaction (1):

25.0 cm<sup>3</sup> of 1.10 mol dm<sup>-3</sup> HCl(aq) was placed in an expanded polystyrene cup. The temperature of the acid in the cup was measured with a thermometer at half-minute intervals.

Right at the third minute, 0.75 g of ZnO(s) was added to the cup. The mixture in the cup was then stirred with the thermometer and its temperature was measured for an additional 7 minutes.

The recordings of temperature are shown in the graph below:



(a) (i) Deduce the greatest temperature change of the reaction mixture. (Show your working on the graph.)

(2 marks)

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(ii) Calculate the molar enthalpy change of reaction (1) under the conditions of the experiment. (Assume that the heat capacity of the expanded polystyrene cup is negligible, and that the specific heat capacity and density of the solutions are  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  and  $1.0 \text{ g cm}^{-3}$  respectively.)

(4 marks)

(b) Given that under the same conditions, the molar change of reaction (2) is  $-49 \text{ kJ}$ , and the molar enthalpy change of formation of  $\text{H}_2\text{O}(l)$  is  $-286 \text{ kJ}$ , calculate  $\Delta H_f$  of  $\text{ZnO}(s)$ .

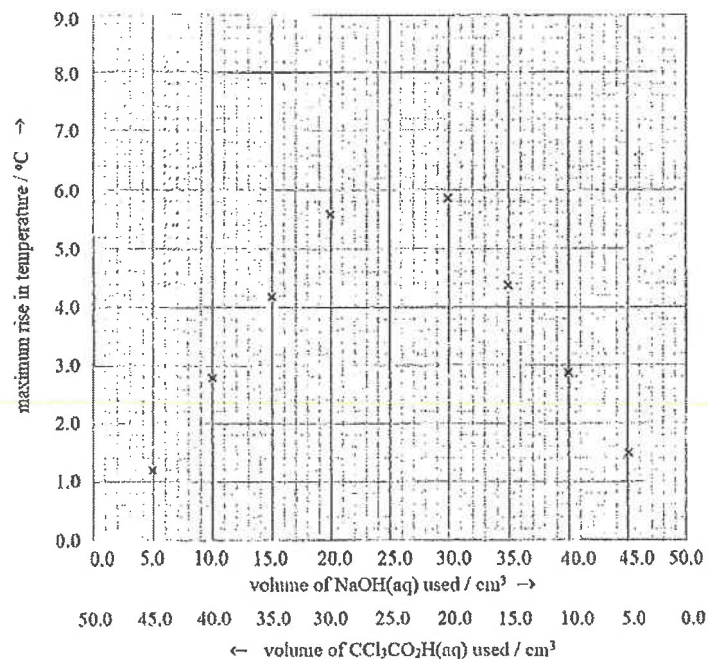
(3 marks)

AL13(H)\_09 (modified) [Similar to DSE19\_08]

An experiment was carried out to determine the enthalpy change of neutralization of  $\text{CCl}_3\text{CO}_2\text{H}(aq)$  with  $\text{NaOH}(aq)$ :



A sample of  $1.50 \text{ mol dm}^{-3}$   $\text{CCl}_3\text{CO}_2\text{H}(aq)$  and  $1.02 \text{ mol dm}^{-3}$   $\text{NaOH}(aq)$  were mixed in different volume ratios to give mixture of  $50.0 \text{ cm}^3$  in an expanded polystyrene cup. Each mixture was stirred and the highest temperature reached was recorded. The graph below shows the maximum rise in temperature for each of the reaction mixture.



(a) Assume that the density and specific heat capacity of all reaction mixtures are  $1.0 \text{ g cm}^{-3}$  and  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$  respectively, and the heat capacity of the expanded polystyrene cup is negligible. Calculate the enthalpy change of neutralization, in  $\text{kJ mol}^{-1}$ , of  $\text{CCl}_3\text{CO}_2\text{H}(aq)$  with  $\text{NaOH}(aq)$ .

(5 marks)

(b) Under the same experimental conditions, the enthalpy change of neutralization of  $\text{CH}_3\text{CO}_2\text{H}(aq)$  with  $\text{NaOH}(aq)$  was found to be  $-52 \text{ kJ mol}^{-1}$ . Explain why the two acids,  $\text{CCl}_3\text{CO}_2\text{H}(aq)$ , have different enthalpy changes of neutralization with  $\text{NaOH}(aq)$ .

(2 marks)

DSE11SP\_05

In an experiment to determine the enthalpy change of combustion of ethanol, a calorimeter containing  $200.0 \text{ g}$  of water was used. Burning  $0.185 \text{ g}$  of ethanol caused the temperature of the water in the calorimeter to rise by  $6.0 \text{ °C}$ .

(a) Draw a labelled diagram of the set-up used in the experiment.

(2 marks)

(b) Assuming that the heat capacity of the calorimeter is negligible, calculate the enthalpy change of combustion of ethanol, in  $\text{kJ mol}^{-1}$ , under the conditions of the experiment. (Specific heat capacity of water =  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ )

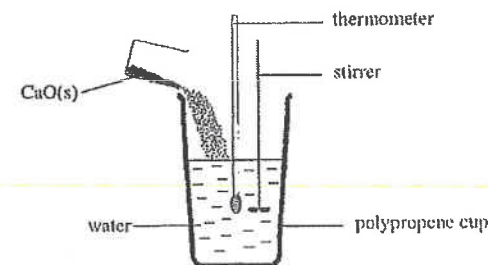
(3 marks)

(c) State ONE other assumption made in your calculation.

(1 mark)

DSE12PP\_07

(a) A student carried out an experiment to determine the enthalpy change of the reaction of calcium oxide with water. The set-up used is shown in the diagram below:



The experimental results are as follows:

Mass of $\text{CaO}(s)$ used	= $3.0 \text{ g}$
Volume of water in the cup	= $50.0 \text{ cm}^3$
Initial temperature of water in the cup	= $28.2 \text{ °C}$
Highest temperature attained by the $\text{Ca}(\text{OH})_2(aq)$ formed	= $46.7 \text{ °C}$

- (i) Calculate the enthalpy change, in  $\text{kJ mol}^{-1}$ , of the reaction of calcium oxide with water under the conditions of the experiment.

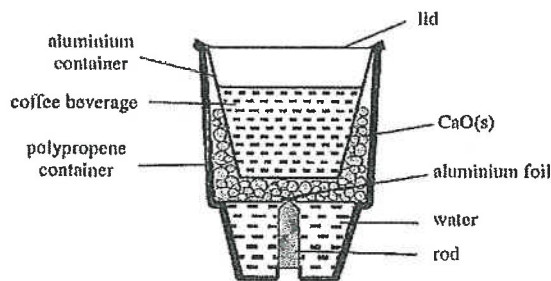
(Assume: density of water is  $1.0 \text{ g cm}^{-3}$  and specific heat capacity of the  $\text{Ca}(\text{OH})_2(\text{aq})$  formed is  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ ; the polypropene cup, thermometer and stirrer used all have negligible heat capacity.)

(4 marks)

- (ii) According to the literature,  $\Delta H^\circ$  for this reaction is  $-82.2 \text{ mol}^{-1}$ . Suggest ONE reasonable explanation for the discrepancy between the literature value and the value obtained in (i).

(1 mark)

- (b) The diagram below shows the design of a can of self-heating coffee beverage. When the bottom of the can is pushed, the rod will pierce the aluminium foil and cause mixing of the water and calcium oxide. The coffee beverage in the can will then be heated up.



- (i) With reference to the properties of the materials involved, explain why (I) a polypropene container is used to contain the calcium oxide, and

(II) an aluminium container is used to contain the coffee beverage.

(3 marks)

- (ii) Suggest ONE reasonable explanation for using calcium oxide in this type of self-heating beverage can.

(1 mark)

DSE12\_08

Potassium hydrogencarbonate ( $\text{KHCO}_3$ ) can be used to bake bread. Upon heating,  $\text{KHCO}_3$  decomposes into  $\text{K}_2\text{CO}_3$ ,  $\text{H}_2\text{O}$  and  $\text{CO}_2$ .

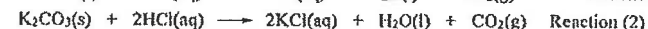
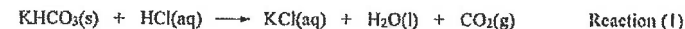
- (a) Explain the purpose of using  $\text{KHCO}_3$  in bread baking.

(1 mark)

- (b) Write the chemical equation for the decomposition of  $\text{KHCO}_3$  upon heating.

(1 mark)

- (c) The enthalpy change of decomposition of  $\text{KHCO}_3(\text{s})$  can be determined indirectly from the enthalpy change of the following two reactions:



In an experiment to determine the enthalpy change of Reaction (1), 3.39 g of  $\text{KHCO}_3(\text{s})$  was added to excess  $\text{HCl}(\text{aq})$  in an expanded polystyrene cup. The experimental data obtained are shown below:

Initial temperature of the reacting solution:	25.8 °C
Final temperature of the reacting solution:	20.2 °C
Mass of the resulting solution:	27.5 g
Specific heat capacity of the contents:	$4.3 \text{ J g}^{-1} \text{ K}^{-1}$
Molar mass of $\text{KHCO}_3$ :	100.1 g

- (i) Assuming that the heat capacity of the cup used is negligible, calculate the enthalpy change of Reaction (1) from the above data.

(2 marks)

- (ii) In another experiment performed under the same conditions, the enthalpy change of Reaction (2) was found to be  $-49.1 \text{ kJ mol}^{-1}$ . Calculate the enthalpy change of decomposition of  $\text{KHCO}_3(\text{s})$  under the experimental condition.

(2 marks)

- (d) According to the literature, the standard enthalpy change of formation of  $\text{K}_2\text{CO}_3(\text{s})$ ,  $\text{KHCO}_3(\text{s})$ ,  $\text{CO}_2(\text{g})$  and  $\text{H}_2\text{O}(\text{l})$  are as follows:

Compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{K}_2\text{CO}_3(\text{s})$	-1146
$\text{KHCO}_3(\text{s})$	-959
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{l})$	-286

- (i) Using the given information, calculate the standard enthalpy change of decomposition of  $\text{KHCO}_3(\text{s})$ .

(1 mark)

- (ii) Suggest why the answers obtained from (c)(ii) and d(i) are different.

(1 mark)

DSE14\_06 [Similar to ASL10(II)\_07]

Petrol is a commonly used motor car fuel. It can be obtained from petroleum by fractional distillation

(a) (iii) Octane (C<sub>8</sub>H<sub>18</sub>) is a component of petrol. Using octane as an example, state the meaning of the term 'standard enthalpy change of combustion' with the aid of a chemical equation.

(2 marks)

(b) Motor cars powered by petrol emit air pollutants such as nitrogen monoxide and carbon monoxide. Installing a certain device in motor cars can convert these two oxides to less harmful substances.

(i) Name this device.

(1 mark)

(ii) The equation for the reaction involved in the conversion is shown below:



The standard enthalpy changes of formation of NO(g), CO(g) and CO<sub>2</sub>(g) are as follows:

Compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
NO(g)	+90.3
CO(g)	-110.5
CO <sub>2</sub> (g)	-394.0

Calculate the standard enthalpy change of the above reaction.

(3 marks)

DSE15\_08 [Similar to ASL01(II)\_09]

Natural gas is an important energy source for electricity generation. It contains mainly methane (CH<sub>4</sub>).

(a) Write the general formula of the molecules in the homologous series that methane belongs to.

(1 mark)

(b) The combustion of methane is an exothermic reaction. Its chemical equation is shown below:



(i) Complete the table below by stating all the covalent bond(s) that are broken and formed during the combustion of methane.

Covalent bond(s) broken	
Covalent bond(s) formed	

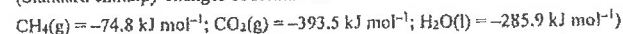
(2 marks)

(ii) Suggest why the combustion is exothermic in terms of the breaking and forming of covalent bonds.

(1 mark)

(iii) Calculate the standard enthalpy change of combustion of methane.

(Standard enthalpy changes of formation:



(2 marks)

(c) Some regions tend to generate electricity more by natural gas but less by coal. Give TWO reasons from environmental protection consideration.

(2 marks)

DSE16\_07 [Similar to AL11\_03]

The enthalpy change of formation of MgCO<sub>3</sub>(s) can be obtained using an indirect method. Firstly, the enthalpy change for the reaction of MgCO<sub>3</sub>(s) with H<sub>2</sub>SO<sub>4</sub>(aq), and that of Mg(s) with H<sub>2</sub>SO<sub>4</sub>(aq) are respectively determined experimentally. After that, the enthalpy change of formation of MgCO<sub>3</sub>(s) can be obtained through calculation with given enthalpy changes of formation of CO<sub>2</sub>(g) and H<sub>2</sub>O(l).

(a) According to definition, under which condition could that 'heat change' of a reaction be regarded as the 'enthalpy change'?

(1 mark)

(b) Explain why, instead of a direct method, an indirect method is used to obtain the enthalpy change of formation of MgCO<sub>3</sub>(s).

(1 mark)

(c) In order to determine experimentally the enthalpy change for the reaction of MgCO<sub>3</sub>(s) with H<sub>2</sub>SO<sub>4</sub>(aq), an accurate mass of MgCO<sub>3</sub>(s) was firstly allowed to react with excess H<sub>2</sub>SO<sub>4</sub>(aq) in a polystyrene foam cup. The maximum rise in temperature of the mixture was then found. After calculation, the enthalpy change for the reaction can be obtained.

(i) Suggest one possible error for the above experimental procedure.

(1 mark)

(ii) Explain whether the enthalpy change for the reaction of CaCO<sub>3</sub>(s) with H<sub>2</sub>SO<sub>4</sub>(aq) can be obtained using a similar experimental procedure.

(1 mark)

(d) Using the information given below, calculate the standard enthalpy change of formation of MgCO<sub>3</sub>(s).

	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
Standard enthalpy change for the reaction of MgCO <sub>3</sub> (s) with H <sub>2</sub> SO <sub>4</sub> (aq)	-50
Standard enthalpy change for the reaction of Mg(s) with H <sub>2</sub> SO <sub>4</sub> (aq)	-467
Standard enthalpy change of formation of CO <sub>2</sub> (g)	-394
Standard enthalpy change of formation of H <sub>2</sub> O(l)	-286

(3 marks)

DSE17\_07 [Similar to ASL02(II)\_08]

Ethyne is a gaseous hydrocarbon with molecular formula  $C_2H_2$ .

(a) Suggest why the enthalpy change of formation of  $C_2H_2(g)$  CANNOT be determined directly by experiment.

(1 mark)

(b) Hess's law can be used to find enthalpy changes which CANNOT be determined directly by experiment. State Hess's law.

(1 mark)

(c) Based on the enthalpy changes of combustion  $\Delta H_c$  of  $C_2H_2(g)$ , C(graphite) and  $H_2(g)$  to construct an enthalpy change cycle and applying Hess's law can give the enthalpy change of formation of  $C_2H_2(g)$ .

(i) Draw, with labels, this enthalpy change cycle.

(2 marks)

(ii) The standard enthalpy change of combustion  $\Delta H_c^\circ$  of  $C_2H_2(g)$ , C(graphite) and  $H_2(g)$  are given below:

	$\Delta H_c^\circ / \text{kJ mol}^{-1}$
$C_2H_2(g)$	-1300
C(graphite)	-394
$H_2(g)$	-286

(1) State the standard conditions for 'standard enthalpy change'.

(1 mark)

(2) Calculate the standard enthalpy change of formation of  $C_2H_2(g)$ .

(2 marks)

DSE18\_06 [Similar to ASL99(II)\_13, ASL09(II)\_01]

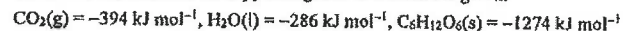
Energy exists in various forms.

(a) Glucose ( $C_6H_{12}O_6$ ) is one important energy source for living things.

(i) Write a chemical equation for the conversion of carbon dioxide gas and liquid water to solid glucose and oxygen gas.

(1 mark)

(ii) The following standard enthalpy changes of formation are given:



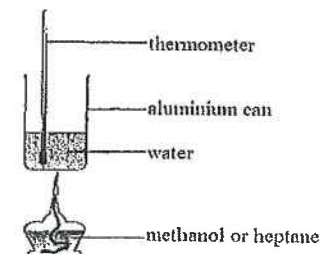
Calculate the standard enthalpy change of the conversion in (i) above.

(2 marks)

(iii) Green plants can convert carbon dioxide and water to glucose and oxygen. State the transformation of energy in this conversion.

(1 mark)

(b) Burning heptane ( $C_7H_{16}$ ) releases energy. The enthalpy change of combustion of heptane was determined using the set-up shown below:



Step (I): The aluminium can with a fixed mass of water was heated by burning methanol. The temperature of water increased by  $18.5^\circ\text{C}$  after  $1.58 \text{ g}$  of methanol was burnt.

Step (II): The aluminium can with the same mass of water in Step (I) was heated by burning heptane. The temperature of water increased by  $25.8^\circ\text{C}$  after  $1.02 \text{ g}$  of heptane was burnt.

(i) Given that, under the conditions of experiment, the enthalpy change of combustion of methanol is  $-715 \text{ kJ mol}^{-1}$ , calculate the enthalpy change of combustion of heptane, in  $\text{kJ mol}^{-1}$ , under the same conditions.

(Relative molecular masses: methanol = 32.0, heptane = 100.0)

(3 marks)

(ii) Besides the heat loss, suggest another source of error in the experiment.

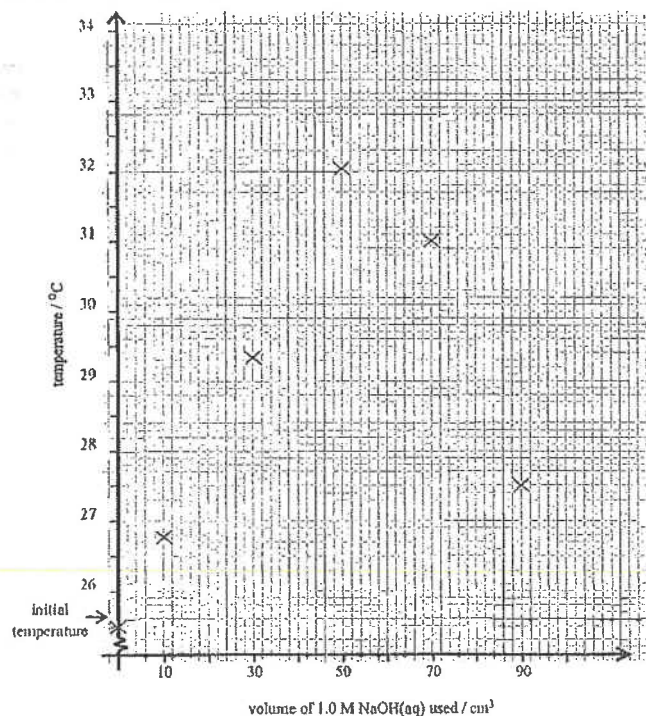
(1 mark)

DSE19\_08 [Same as ASL03(II)\_09, similar to AL13(II)\_09]

Several trials of an experiment were performed for determining the enthalpy change of neutralization for a reaction, for each trial, a total volume of 100.0 cm<sup>3</sup> of a solution was obtained from mixing specified volumes of a HCl(aq) and 1.0 M NaOH(aq) as shown below in an expanded polystyrene cup. The HCl(aq) and NaOH(aq) were kept at the same initial temperature before mixing.

Trial	1	2	3	4	5
Volume of the HCl(aq) used / cm <sup>3</sup>	90	70	50	30	10
Volume of the 1.0 M NaOH(aq) used / cm <sup>3</sup>	10	30	50	70	90

For each trial, the mixture was stirred and its maximum temperature reached was recorded. A graph of the maximum temperature reached for each trial is shown below:



(a) It is estimated from the graph that 58.0 cm<sup>3</sup> of NaOH(aq) (and 42.0 cm<sup>3</sup> of HCl(aq)) is required for obtaining the possible maximum temperature reached in the experiment. Show how this estimation can be done in the above graph.

(1 mark)

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(b) (i) Calculate the number of moles of NaOH(aq) reacted with HCl(aq) in (a). Hence, find the concentration of the HCl(aq). (2 marks)

(ii) Given that the initial temperature of the mixture for each trial is 25.5°C, calculate the enthalpy change of neutralisation of the reaction, in kJ mol<sup>-1</sup>.

(Density of the mixture = 1.00 g cm<sup>-3</sup>;

specific heat capacity of the mixture = 4.18 J g<sup>-1</sup> K<sup>-1</sup>;

heat capacity of the expanded polystyrene cup : negligible)

(2 marks)

(c) The one determined above is not the standard enthalpy change of neutralisation. What, then, is meant by the term 'standard enthalpy change of neutralisation'?

(1 mark)

DSE20\_05bii,iii

5. The molecular formula of an organic compound W is C<sub>4</sub>H<sub>8</sub>O<sub>4</sub>. It is soluble in water.

(a) When a piece of magnesium ribbon is placed into an aqueous solution of W, hydrogen gas evolves. According to this observation, suggest a functional group that W may contain.

(1 mark)

(b) It is known that one mole of W can completely react with two moles of NaOH.

(i) Draw TWO possible structures of W.

(ii) Consider the following thermochemical equation of a neutralisation reaction in standard conditions :

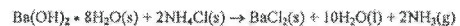


State the meaning of the term 'standard enthalpy change of neutralisation', and deduce the standard enthalpy change of neutralisation for this reaction in terms of y.

(iii) The standard enthalpy change of neutralisation between HCl(aq) and NaOH(aq) is -57.3 kJ mol<sup>-1</sup>. Explain whether the enthalpy change deduced in (ii) above should be more negative than, less negative than or equal to -57.3 kJ mol<sup>-1</sup>.

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7. An experiment is performed to study the following reaction :



- (a) When the two solid reactants are mixed and stirred in a conical flask, ammonia gas with a characteristic pungent smell is formed. Explain how ammonia gas can be tested.

(2 marks)

- (b)  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$  is an alkali. What is meant by the term 'alkali' ?

(1 mark)

- (c) The standard enthalpy change of formation of  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$  is  $-3345 \text{ kJ mol}^{-1}$ .

- (i) Write a thermochemical equation for the standard enthalpy change of formation of  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$ .

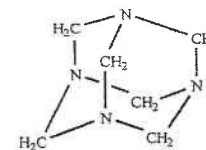
- (ii) Calculate the standard enthalpy change of the reaction between  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$  and  $\text{NH}_4\text{Cl}(\text{s})$ .

(Standard enthalpy changes of formation :

$\text{NH}_3(\text{g}) = -46 \text{ kJ mol}^{-1}$ ,  $\text{H}_2\text{O}(\text{l}) = -286 \text{ kJ mol}^{-1}$ ,  $\text{NH}_4\text{Cl}(\text{s}) = -314 \text{ kJ mol}^{-1}$ ,  
 $\text{BaCl}_2(\text{s}) = -859 \text{ kJ mol}^{-1}$ )

- (iii) Hence, explain whether the temperature of the mixture would increase, decrease or remain unchanged during the reaction.

5. Hexamine ( $\text{C}_6\text{H}_{12}\text{N}_4$ ) is the main component of a portable solid fuel. It is a solid under room conditions and its structure is shown below :

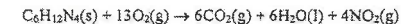


- (a) Suggest why the combustion of hexamine is exothermic in terms of the breaking and forming of covalent bonds.  
 (b) It is given that :

Compound	Standard enthalpy change of formation / $\text{kJ mol}^{-1}$
$\text{C}_6\text{H}_{12}\text{N}_4(\text{s})$	+123
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{l})$	-286
$\text{NO}_2(\text{g})$	+33

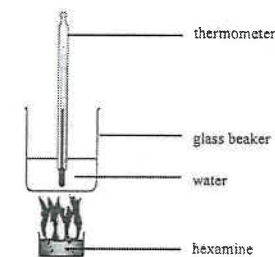
- (i) Write a thermochemical equation for the standard enthalpy change of formation of hexamine.

- (ii) Hexamine combusts as shown by the equation below :



Calculate the standard enthalpy change of combustion of hexamine.

5. (c) The following diagram shows an experimental set-up for determining the enthalpy change of combustion of hexamine under certain experimental conditions.



The data obtained are shown below :

Mass of hexamine combusted :	2.40 g
Mass of water :	600.0 g
Initial temperature of water :	23.5 °C
Final temperature of water :	47.5 °C
Molar mass of hexamine :	140.0 g
Specific heat capacity of water :	4.20 $\text{J g}^{-1} \text{K}^{-1}$

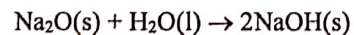
Assuming that the heat capacity of the glass beaker is negligible, calculate the enthalpy change of combustion of hexamine under these experimental conditions.

2022

14. The enthalpy changes of formation of some substances under certain conditions are shown below :

Substance	Enthalpy change of formation / $\text{kJ mol}^{-1}$
$\text{H}_2\text{O(l)}$	-286
$\text{Na}_2\text{O(s)}$	-414
$\text{NaOH(s)}$	-425

What is the enthalpy change of the following reaction under the same conditions ?



- A. +275  $\text{kJ mol}^{-1}$   
B. -150  $\text{kJ mol}^{-1}$   
C. -722  $\text{kJ mol}^{-1}$   
D. -1125  $\text{kJ mol}^{-1}$
21. Which of the following statements are correct ?
- (1) The standard enthalpy change of formation of graphite is zero.  
(2) The standard enthalpy change of combustion of carbon monoxide is a negative value.  
(3) The standard enthalpy change of formation of carbon monoxide is equal to the standard enthalpy change of combustion of graphite.
- A. (1) and (2) only  
B. (1) and (3) only  
C. (2) and (3) only  
D. (1), (2) and (3)



2022

7. (b) (ii) It is given that the enthalpy change of neutralisation is the enthalpy change when solutions of an acid and an alkali react together to produce one mole of water.

In the experiment, HCl(aq) is in excess. Calculate the enthalpy change of neutralisation between Ca(OH)<sub>2</sub>(s) and HCl(aq), in kJ mol<sup>-1</sup>, under the experimental conditions.

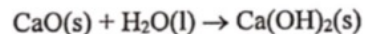
(Volume of the reaction mixture = 100.0 cm<sup>3</sup>;  
density of the reaction mixture = 1.00 g cm<sup>-3</sup>;  
specific heat capacity of the reaction mixture = 4.2 J g<sup>-1</sup> K<sup>-1</sup>;  
heat capacity of the expanded polystyrene cup : negligible)  
(Relative atomic masses : H = 1.0, O = 16.0, Cl = 35.5, Ca = 40.1)

(5 marks)

- (c) Standard enthalpy changes of neutralisation  $\Delta H_n^\circ$  for two reactions are given below :

	$\Delta H_n^\circ / \text{kJ mol}^{-1}$
Reaction between Ca(OH) <sub>2</sub> (s) and HCl(aq)	-58.6
Reaction between CaO(s) and HCl(aq)	-186.0

Calculate the standard enthalpy change of the following reaction.



### Marking Scheme

#### MCQ

ASL10(I)_08	D	DSE11SP_10	D	DSE11SP_13	C	DSE11SP_19	D
DSE12PP_05	C	DSE12PP_12	A	DSE12_07	A (56%)	DSE13_15	B (46%)
DSE13_18	A (58%)	DSE14_09	A (76%)	DSE15_12	C (66%)	DSE14_12	D (48%)
DSE15_18	C (68%)	DSE16_24	D (58%)	DSE17_07	A (45%)	DSE18_18	A (66%)
DSE18_22	A (72%)	DSE19_09	B	DSE19_22	C		

DSE20_10	A
DSE20_13	C
DSE20_21	C

### Structural Questions

AL98(II)\_02c

(i) (1) 
$$\Delta H = \frac{-242 \times 1000}{18} = -1.34 \times 10^4 \text{ kJ kg}^{-1} \quad [1]$$

(2) 
$$\Delta H^\circ_f[\text{CH}_3\text{OH}(l)] = \Delta H^\circ_f[\text{CO}_2(g)] + 2\Delta H^\circ_f[\text{H}_2\text{O}(l)] - \Delta H^\circ_f[\text{CH}_3\text{OH}(l)]$$
  

$$= -394 + 2(-242) - (-239) = -639 \text{ kJ mol}^{-1} \quad [1]$$

$$\Delta H = \frac{-639 \times 1000}{(32 + 1.5 \times 32)} = -8.0 \times 10^3 \text{ kJ kg}^{-1} \quad [1]$$

(ii) Effectiveness of fuel

(1): 
$$\frac{-1.34 \times 10^4}{18} = -744 \quad [1]$$

(2): 
$$\frac{-8 \times 10^3}{\frac{1}{3}(44 + 2 \times 18)} = -300 \quad [1]$$

Based on the above data,  $\text{H}_2(\text{g})$  is more effective fuel. [1]

AL99(I)\_07b

Any THREE of the following: [3]

- Heat loss to the surrounding
- The specific heat capacity of the reaction mixture equals to that of water
- The heat absorbed by the polystyrene foam cup / the thermometer is negligible
- The density of the solution is the same as that of water

ASL99(II)\_02

(a) As the energy released in forming bonds in products (C=O and O-H) larger than energy absorbed for breaking bonds in reactants (C-C, C-H, O-H and O=O) [1]

(b) The average enthalpy change for breaking 1 C=C and 2 C-H bonds  

$$= \frac{(1367 - 726) + (2017 - 1367)}{2} = 645.5 \text{ kJ mol}^{-1} \quad [1]$$

Value of  $x = -2017 + 645.5 = -2662.5 \text{ kJ mol}^{-1}$  [1]

(c) 
$$\text{CH}_3\text{OH}(l) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \quad [1]$$

$$\Delta H^\circ_{c, 298}[\text{CH}_3\text{OH}(l)] = \sum \Delta H^\circ_f[\text{product}] - \sum \Delta H^\circ_f[\text{reactant}]$$

$$-726 = (-393) + 2(-286) - \Delta H^\circ_{f, 298}[\text{CH}_3\text{OH}(l)] \quad [1]$$

$$\Delta H^\circ_{f, 298}[\text{CH}_3\text{OH}(l)] = -239 \text{ kJ mol}^{-1} \quad [1]$$

ASL99(II)\_13

- (a) Ester group [1]  
 C=C [1]
- (b) (i) Energy released =  $250 \times 4.18 \times 20.5 = 21422.56 \text{ J} = 21.4 \text{ kJ}$  [1]  
 Mole of compound T burnt =  $\frac{2.30}{878} = 2.62 \times 10^{-3}$  [1]  
 Enthalpy change of combustion =  $\frac{-21.4}{2.62 \times 10^{-3}} = -8178 \text{ kJ mol}^{-1}$  [1]
- (ii) Any TWO of the following [2]  
 Incomplete combustion of compound T  
 Heat lost to the surrounding  
 Heat absorbed by the aluminium can is non-negligible

ASL00(II)\_08

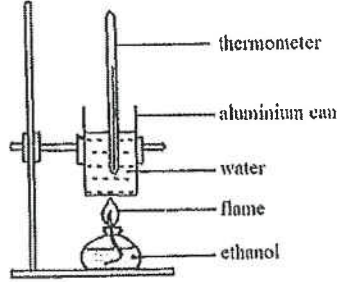
- (a) (i) An enthalpy change when 1 mol of cyclohexane is burnt completely in excess oxygen gas under the standard conditions. [1]  
 $\text{C}_6\text{H}_{12}(\text{s}) + 9\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$  [1]
- (ii)  $\text{C}_6\text{H}_6(\text{l}) + 2\text{H}_2(\text{g}) \rightarrow \text{C}_6\text{H}_{12}(\text{l})$  [1]  
 $\Delta H^\circ_{\text{rxn}} = \sum \Delta H^\circ_f[\text{reactant}] - \sum \Delta H^\circ_f[\text{product}]$  [1]  
 $= (-3584) + 2(-286) - (-3924)$  [1]  
 $= -232 \text{ kJ mol}^{-1}$  [1]
- (b) (i) Platinum / nickel [1]  
 (ii) To ensure that hydrogen gas well contact with cyclohexa-1,3-diene and catalyst for reaction. [1]  
 (iii) Copper is a better heat conductor than glass. [1]  
 Copper has a higher strength to withstand the high pressure built up by the hydrogen gas. [1]
- (iv) (I) Energy released =  $300 \times 4.2 \times 16.5 = 20790 \text{ J} = 20.79 \text{ kJ}$  [1]  
 Enthalpy change of hydrogenation =  $\frac{-20.79}{0.10} = -207.9 \text{ kJ mol}^{-1}$  [2]
- (II) Any TWO of the following: [2]  
 No heat lost to the surrounding  
 Hydrogenation of cyclohexa-1,3-diene is completed.  
 There is no evaporation of cyclohexa-1,3-diene or cyclohexane.

ASL01(II)\_09

- (a) (i)  $\text{C}_6\text{H}_{12}\text{O}_6(\text{s}) + 6\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$  [1]  
 $\Delta H^\circ_{\text{c}, 298}[\text{C}_6\text{H}_{12}\text{O}_6(\text{s})] = \sum \Delta H^\circ_f[\text{product}] - \sum \Delta H^\circ_f[\text{reactant}]$  [1]  
 $= 6(-394) + 6(-286) - (-1274)$  [1]  
 $= -2806 \text{ kJ mol}^{-1}$  [1]
- (ii) No. of mole of glucose =  $\frac{10}{180} = 0.0556$  [1]  
 Energy released =  $2806 \times 0.0556 = 156 \text{ kJ}$  [1]

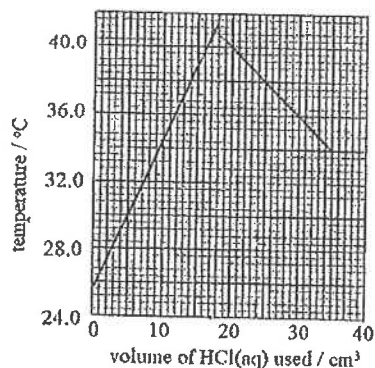
- (b) No. of mole of tripalmitin =  $\frac{10}{806} = 0.0124$  [1]  
 Energy released =  $31400 \times 0.0124 = 389 \text{ kJ}$  [1]
- (c) Under the same mass of carbohydrate and fat, carbohydrate provides less amount of energy to support the plant with lower metabolic rate, while fat provides larger amount of energy to support animal with higher metabolic rate. [1]

ASL02(II)\_08

- (a) (i) [2]
- 
- (ii) Energy liberated =  $200.0 \times 4.2 \times 6 = 5040$  [1]  
 Mole of ethanol used =  $\frac{0.185}{46} = 4.02 \times 10^{-3}$  [1]  
 Enthalpy change of combustion =  $\frac{-5040}{4.02 \times 10^{-3}} = -1253 \text{ kJ mol}^{-1}$  [1]
- (iii) There is no heat lost to the surrounding. [2]  
 Complete combustion of ethanol
- (b) (i) No. As the side products such as  $\text{CO}_2$  may form. [1]  
 (ii)  $2\text{C}(\text{graphite}) + 3\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{l})$  [1]  
 $\Delta H^\circ_{\text{f}, 298}[\text{C}_2\text{H}_5\text{OH}(\text{l})] = \sum \Delta H^\circ_{\text{f}}[\text{reactant}] - \sum \Delta H^\circ_{\text{f}}[\text{product}]$  [1]  
 $= 2(-394) + 3(-286) - (-1368)$  [1]  
 $= -278 \text{ kJ mol}^{-1}$  [1]
- (c) (i) Both HCl and  $\text{HNO}_3$  are monobasic and they are completely ionized in water. [1]  
 They neutralize with NaOH(aq) to give same amount of water molecule. [1]  
 (ii) HCl(aq) is a strong acid while  $\text{CH}_3\text{CO}_2\text{H}(\text{aq})$  is a weak acid. [1]  
 Part of heat released in the neutralization of  $\text{CH}_3\text{CO}_2\text{H}(\text{aq})$  with NaOH(aq) is absorbed for complete ionization of  $\text{CH}_3\text{CO}_2\text{H}(\text{aq})$ . [1]

ASL03(II)\_09

(a)



[3]

(b) (i) 40.7 °C

[1]

(ii) Volume of HCl(aq) required to reach the end-point = 17.3 cm<sup>3</sup>

[1]



$$\text{Concentration of HCl(aq)} = \frac{2.0 \times 25}{17.3} = 2.89 \text{ mol dm}^{-3}$$

[1]

(c) At the end-point of the titration, total volume of reaction mixture = 42.3 cm<sup>3</sup>

[1]

Temperature rise = 14.9 °C

$$\text{Energy liberated} = 42.3 \times 4.2 \times 14.9 = 2647 \text{ J}$$

[1]

$$\text{Enthalpy change of neutralization} = \frac{-2647}{2 \times 25 \times 10^{-3}} = -52.9 \text{ kJ mol}^{-1}$$

[1]

ASL04(II)\_10

(a) (1) Molar enthalpy change of solution of CuSO<sub>4</sub>(s)

$$= -\frac{50 \times 4.2 \times 7.7}{0.025}$$

[1]

$$= -64680 \text{ J} = -64.68 \text{ kJ}$$

[1]

(2) Molar enthalpy change of solution of CuSO<sub>4</sub>·5H<sub>2</sub>O(s)

$$= +\frac{50 \times 4.2 \times 1.7}{0.025}$$

[1]

$$= +14280 \text{ J} = +14.28 \text{ kJ}$$

[1]

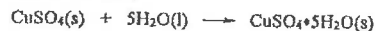
(b) CuSO<sub>4</sub>(s) + aq → CuSO<sub>4</sub>(aq)

$$\Delta H_1 = -64.68 \text{ kJ mol}^{-1}$$

CuSO<sub>4</sub>·5H<sub>2</sub>O(s) + aq → CuSO<sub>4</sub>(aq)

$$\Delta H_2 = +14.28 \text{ kJ mol}^{-1}$$

For the reaction,



$$\Delta H = \Delta H_1 - \Delta H_2 = -64.68 - (+14.28)$$

[1]

$$= -78.96 \text{ kJ mol}^{-1}$$

[1]

(c) It is difficult to measure the temperature of a solid.

[1]

ASL05(I)\_04

(a)

$$\text{no. of moles of Zn} = \frac{4.0}{65.4} = 0.061$$

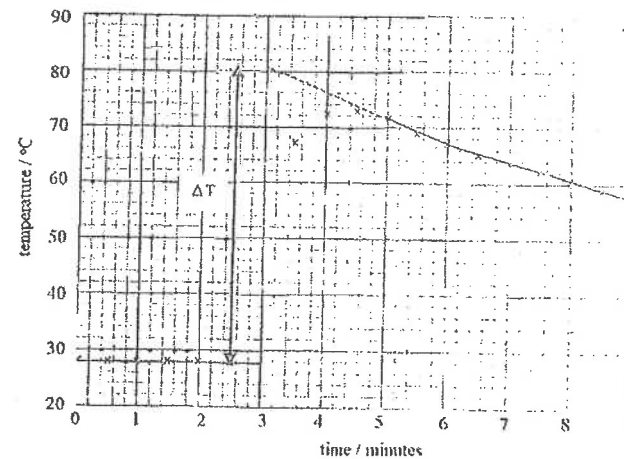
[1]

$$\text{no. of moles of Cu}^{2+}(\text{aq}) = 1.0 \times 25 \times 10^{-3} = 0.025$$

∴ CuSO<sub>4</sub>(aq) is the limiting reactant.

[1]

(b) Maximum temperature rise = 53 °C



[2]

(c) Heat evolved = 25 × 4.2 × 53 = 5565 J = 5.565 kJ

[1]

$$\Delta H = -\frac{5.565}{0.025}$$

[1]

$$= -222.6 \text{ kJ mol}^{-1}$$

[1]

AL05(II)\_05

(a) Complete combustion of octane:



Standard enthalpy change

$$= 8\Delta H_f^\circ[\text{CO}_2(\text{g})] + 9\Delta H_f^\circ[\text{H}_2\text{O}(\text{l})] - \Delta H_f^\circ[\text{C}_8\text{H}_{18}(\text{l})]$$

$$= 8(-394) + 9(-286) - (-250)$$

[1]

$$= -5476 \text{ kJ mol}^{-1}$$

[1]

Complete combustion of ethanol:



Standard enthalpy change

$$= 2\Delta H_f^\circ[\text{CO}_2(\text{g})] + 3\Delta H_f^\circ[\text{H}_2\text{O}(\text{l})] - \Delta H_f^\circ[\text{C}_2\text{H}_5\text{OH}(\text{l})]$$

$$= 2(-394) + 3(-286) - (-278)$$

[1]

$$= -1368 \text{ kJ mol}^{-1}$$

[1]

(b) Conversion of enthalpy changes of combustion from  $\text{kJ mol}^{-1}$  to  $\text{kJ g}^{-1}$  units

$$\text{For octane, } \Delta H_c^\ominus \text{ per g} = \frac{-5476}{114} = -48.0 \text{ kJ g}^{-1} \quad [1]$$

$$\text{For ethanol, } \Delta H_c^\ominus \text{ per g} = \frac{-1368}{46} = -29.7 \text{ kJ g}^{-1} \quad [1]$$

As the alternative fuel contains 90% octane & 10% ethanol, its enthalpy change of combustion

$$= (0.9)(-48.0) + (0.1)(-29.7) = -46.2 \text{ kJ g}^{-1} \quad [1]$$

For the same mass, the alternative fuel has a lower energy content. [1]

(c) Any one of the following: [1]

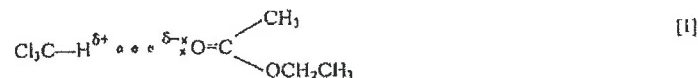
1. Ethanol is an oxygen-containing compound. It is easier for the alternative fuel to achieve complete combustion / less CO is produced / less particulates are formed / less air pollutants. [1]
2. Ethanol is a renewable energy source. It can be obtained from agricultural products. [1]
3. The cost for the production of ethanol is low in agricultural counties. [1]

AL06(I)\_02

The conversion of diamond to graphite has very high activation energy. The reaction is very slow under normal conditions. [1]

ASL06(I)\_06

(a) A stronger intermolecular force, hydrogen bond, is formed between trichloromethane and ethyl ethanoate molecules. Energy is released accordingly. [1]



(b) no. of mole of trichloromethane =  $\frac{8 \times 1.49}{119.5} = 0.0997$  [1]

$$\text{no. of mole of ethyl ethanoate} = \frac{10 \times 0.9}{88.0} = 0.1023$$

Trichloromethane is the limiting reactant.

$$\text{Heat given out} = 8 \times 1.49 \times 0.97 \times 9.5 + 10 \times 0.9 \times 1.92 \times 9.5 = 274.0 \quad [1]$$

$$\Delta H = \frac{-274.0}{0.0997} = -2748 \text{ J mol}^{-1} = -2.75 \text{ kJ mol}^{-1} \quad [1]$$

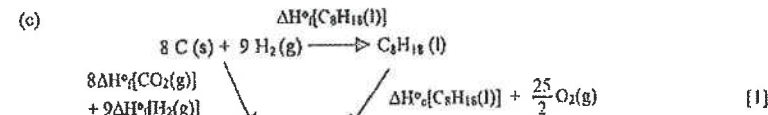
ASL06(II)\_11

(a) 2,2,4-trimethylpentane [1]

(b) Molar mass of X =  $12 \times 8 + 1 \times 18 = 114 \text{ g mol}^{-1}$  [1]

$$\text{no. of mole of X burnt} = \frac{1}{114} = 0.00877 \quad [1]$$

$$\Delta H_c^\ominus = -\frac{44.5}{0.00877} = -5074 \text{ kJ mol}^{-1} \quad [1]$$



$$\Delta H_f^\ominus[\text{C}_8\text{H}_{18}(\text{l})] + (-5074) = 8(-393.5) + 9(-285.8) \quad [1]$$

$$\Delta H_f^\ominus[\text{C}_8\text{H}_{18}(\text{l})] = -646 \text{ kJ mol}^{-1} \quad [1]$$

AL08(II)\_01

(a) The enthalpy change when 1 mol of the compound is formed from its constituent elements under standard conditions. [1]

(b) (i)  $\text{SiCl}_4(\text{l}) + 2\text{H}_2\text{O}(\text{l}) \longrightarrow \text{SiO}_2(\text{s}) + 4\text{HCl}(\text{g})$  [1]  
[NOT accept:  $\text{SiO}_2 \cdot 2\text{H}_2\text{O}$  as one of the products]

$$\begin{aligned} \text{(ii)} \quad &= \Delta H_f^\ominus[\text{SiO}_2(\text{s})] + 4\Delta H_f^\ominus[\text{HCl}(\text{g})] - \Delta H_f^\ominus[\text{SiCl}_4(\text{l})] - 2\Delta H_f^\ominus[\text{H}_2\text{O}(\text{l})] \\ &= (-910) + 4(-92) - (-640) - 2(-286) \end{aligned} \quad [1]$$

$$= -66 \text{ kJ mol}^{-1} \quad [1]$$

Any ONE of the following: [1]

1.  $\text{SiCl}_4(\text{l})$  is in excess / The hydrolysis gives  $\text{HCl}(\text{g})$  instead of  $\text{HCl}(\text{aq})$
2. The Hess' Law is followed. (NOT accept energy is conserved.)

ASL09(II)\_01

(a)  $2\text{CH}_3\text{CH}(\text{NH}_2)\text{CO}_2\text{H}(\text{s}) + 6\text{O}_2(\text{g}) \longrightarrow 5\text{CO}_2(\text{g}) + \text{CO}(\text{NH}_2)_2(\text{s}) + 5\text{H}_2\text{O}(\text{l})$  [1]

(b) (i)  $4\text{CH}_3\text{CH}(\text{NH}_2)\text{CO}_2\text{H}(\text{s}) + 15\text{O}_2(\text{g}) \longrightarrow 12\text{CO}_2(\text{g}) + 14\text{H}_2\text{O}(\text{l}) + 2\text{N}_2(\text{g})$  [1]

(ii)  $2\text{CO}(\text{NH}_2)_2(\text{s}) + 3\text{O}_2(\text{g}) \longrightarrow 2\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l}) + 2\text{N}_2(\text{g})$  [1]

(c) Enthalpy change for biological oxidation of alanine [1]  
 $= \frac{4\Delta H_c^\ominus[\text{alanine}] - 2\Delta H_c^\ominus[\text{urea}]}{4} = \frac{4(-1577) - 2(-632)}{4}$

$$= -1261 \text{ kJ mol}^{-1} \quad [1]$$

Molar mass of alanine = 89.0 g

Energy obtained from the biological oxidation of 1.00 g of alanine [1]

$$= \frac{-1261}{89} = -14.2 \text{ kJ} \quad [1]$$

## ASL10(II)\_07

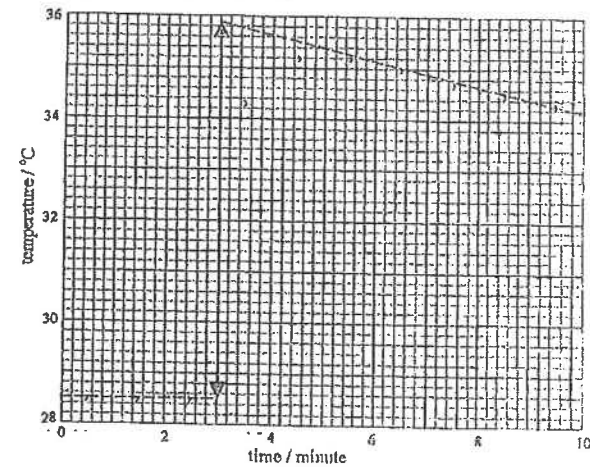
- (a) The enthalpy change when 1 mol of the compound is formed from its constituent elements under standard conditions. [1]
- (b) (i)  $2\text{NH}_3(\text{g}) + \text{H}_2\text{O}_2(\text{l}) \longrightarrow \text{N}_2\text{O}_4(\text{l}) + 2\text{H}_2\text{O}(\text{l})$  [1]  
 (ii)  $\Delta H^\circ = \Delta H_f^\circ[\text{N}_2\text{O}_4(\text{l})] + 2\Delta H_f^\circ[\text{H}_2\text{O}(\text{l})] - 2\Delta H_f^\circ[\text{NH}_3(\text{g})] - \Delta H_f^\circ[\text{H}_2\text{O}_2(\text{l})]$   
 $= +51 + 2(-286) - 2(-46) - (-188)$  [1]  
 $= -241 \text{ kJ mol}^{-1}$  [1]
- (c) No. The explosive property of hydrazine is due to the fact that the oxidation is very fast and there is evolution of a large volume of gases. [1]  
 The positive standard enthalpy change of formation hydrazine only means that it is unstable as compared to its constituent elements. [1]

## AL10(II)\_02

- (n) (i)  $3\text{Al}(\text{s}) + 3\text{NH}_4\text{ClO}_4(\text{s}) \longrightarrow \text{Al}_2\text{O}_3(\text{s}) + \text{AlCl}_3(\text{s}) + 3\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$  [1]  
 (ii)  $4\text{CH}_3\text{NHNH}_2(\text{l}) + 5\text{N}_2\text{O}_4(\text{l}) \longrightarrow 4\text{CO}_2(\text{g}) + 12\text{H}_2\text{O}(\text{g}) + 9\text{N}_2(\text{g})$  [1]  
 (i)  $\Delta H^\circ = \Delta H_f^\circ[\text{Al}_2\text{O}_3(\text{s})] + \Delta H_f^\circ[\text{AlCl}_3(\text{s})] + 3\Delta H_f^\circ[\text{NO}(\text{g})] + 6\Delta H_f^\circ[6\text{H}_2\text{O}(\text{g})]$   
 $- (3\Delta H_f^\circ[\text{Al}(\text{s})] + 3\Delta H_f^\circ[\text{NH}_4\text{ClO}_4(\text{s})])$   
 $= (-1676) + (-704) + 3(+90) + 6(-242) - 3(0) - 3(-295)$  [1]  
 $= -2677 \text{ kJ mol}^{-1}$  [1]
- (ii)  $\Delta H^\circ = 4\Delta H_f^\circ[\text{CO}_2(\text{g})] + 12\Delta H_f^\circ[\text{H}_2\text{O}(\text{g})] + 9\Delta H_f^\circ[\text{N}_2(\text{g})]$   
 $- (4\Delta H_f^\circ[\text{CH}_3\text{NHNH}_2(\text{l})] + 5\Delta H_f^\circ[\text{N}_2\text{O}_4(\text{l})])$   
 $= 4(-394) + 12(-242) - 4(+53) - 5(-20)$  [1]  
 $= -4592 \text{ kJ mol}^{-1}$  [1]
- (c) Any ONE of the following: [1]
- Al(s) and  $\text{NH}_4\text{ClO}_4(\text{s})$  react only upon ignition. The take-off of the shuttle and rockets can be easily controlled.
  - The solid propellant has a high power density, i.e. energy liberated per unit mass is great.
- (d) The cryogenic mixture acts as reacts in the  $\text{H}_2\text{-O}_2$  fuel cell. The chemical processes involved are:  
 Anode:  $2\text{H}_2(\text{g}) + 4\text{OH}^-(\text{aq}) \longrightarrow 4\text{H}_2\text{O}(\text{l}) + 4\text{e}^-$  [½]  
 Cathode:  $\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \longrightarrow 4\text{OH}^-(\text{aq})$  [½]  
 Overall:  $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O}(\text{l})$  [1]
- (e)  $\text{CH}_3\text{NHNH}_2(\text{l})$  reacts with  $\text{N}_2\text{O}_4(\text{l})$  on contact. The propulsion can easily be started and restarted. [1]

## AL11(II)\_03

- (a) (i)  $(35.9 - 28.5) = 7.4 \text{ }^\circ\text{C} / \text{K}$  [2]  
 (Accept answers from 7.3 to 7.5  $^\circ\text{C}$ )



(1 mark for answer; 1 mark for working shown on the graph)

Working on graph; either the two dotted lines OR only the solid line but take note that cannot exceed the indicated region.

If all lines are drawn with intersection, even beyond the region, accept as correct.

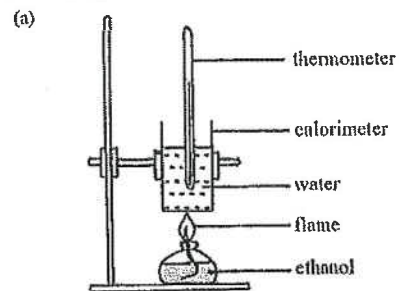
- (ii) No. of moles of  $\text{ZnO}(\text{s})$  used =  $\frac{0.75}{81.4} = 9.21 \times 10^{-3}$  [1]  
 No. of moles of  $\text{H}^+(\text{aq})$  present =  $1.1 \times 25 \times 10^{-3} = 2.75 \times 10^{-2}$   
 $\therefore \text{ZnO}(\text{s})$  is the limiting reactant.  
 Heat liberated =  $25.0 \times 4.2 \times 7.4 = 0.777 \text{ kJ}$  [1]  
 For reaction (1), molar enthalpy change  
 $= -\frac{0.777}{9.21 \times 10^{-3}} = -84.4 \text{ kJ (mol}^{-1}\text{)}$  [1]  
 (Acceptable range:  $-83.2$  to  $-85.5 \text{ kJ}$ )
- (b)  $\text{Zn}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g}) \longrightarrow \text{ZnO}(\text{s})$  [1]  
 $\Delta H_f[\text{ZnO}(\text{s})] = \Delta H_f(2) - \Delta H_f(1) + \Delta H_f[\text{H}_2\text{O}(\text{l})]$   
 $= -49 - (-84.4) + (-286)$  [1]  
 $= -250.6 \text{ kJ mol}^{-1}$  [1]  
 (Acceptable range:  $-252$  to  $-250 \text{ kJ mol}^{-1}$ )

## AL13(II)\_09 (modified)

- (a) From the graph, the volume ratio of NaOH(aq) : CCl<sub>3</sub>CO<sub>2</sub>H(aq) for complete neutralization = 25.5 : 24.5 [1]  
 (Accept volume ratio from 25.4 : 24.6 to 25.6 : 24.4)  
 No. of moles of NaOH (or CCl<sub>3</sub>CO<sub>2</sub>H) used =  $1.02 \times 25 \times 10^{-3}$  [1]  
 Maximum rise in temperature = 7.1 °C (Acceptable range: 7.0 to 7.2) [1]  
 Heat liberated =  $50 \times 4.2 \times 7.1$  [1]  

$$\Delta H = \frac{50 \times 4.2 \times 7.1}{1.02 \times 25.5 \times 10^{-3}} = -57.3 \text{ kJ mol}^{-1}$$
 [1]  
 (Acceptable range: -59.0 to -55.0)
- (b) The enthalpy change of neutralization of CCl<sub>3</sub>CO<sub>2</sub>H(aq) by NaOH(aq) is more negative (more exothermic) than that of CH<sub>3</sub>CO<sub>2</sub>H(aq) by NaOH(aq), i.e. CCl<sub>3</sub>CO<sub>2</sub>H is a stronger acid than CH<sub>3</sub>CO<sub>2</sub>H. [1]  
 Part of the heat is absorbed for complete ionization of CH<sub>3</sub>CO<sub>2</sub>H. [1]

## DSE11SP\_05



- (1 mark for an alcohol lamp containing some ethanol; 1 mark for a calorimeter containing some water.)
- (b) Heat released =  $200 \times 4.2 \times 6 = 5040 \text{ J} = 5.04 \text{ kJ}$  [1]  
 Moles of C<sub>2</sub>H<sub>5</sub>OH(l) burnt =  $\frac{0.185}{(12.0 \times 2 + 1.0 \times 6 + 16.0)} = 4.02 \times 10^{-3}$  [1]  
 Enthalpy change of combustion of C<sub>2</sub>H<sub>5</sub>OH(l) =  $\frac{-5.04}{4.02 \times 10^{-3}} = -1254 \text{ kJ mol}^{-1}$  [1]
- (c) No heat loss to the surroundings [1]  
 OR, The ethanol undergoes complete combustion

## DSE12PP\_07

- (a) (i) Moles of CaO(s) used =  $\frac{3.0}{40.1 + 16} = 0.053$  [1]  
 Heat liberated =  $53 \times 4.2 \times (46.7 - 28.2) = 4118 \text{ J} = 4.118 \text{ kJ}$  [1]  

$$\Delta H = \frac{-4.118}{0.053} = -77.0 \text{ kJ mol}^{-1}$$
 [1]  
 (Acceptable range: -72.6 to -77.0 kJ mol<sup>-1</sup>) [2]
- (ii) Any ONE of the following: [1]  
 - PP is not a perfect heat insulator; heat is lost to the surroundings.  
 - Some CaO(s) may have reacted with H<sub>2</sub>O(l) in air.  
 (Accept other reasonable answers.)
- (b) (i) (I) Any THREE of the following (at least 1 mark should be allocated to each part): [3]  
 - PP is a poor conductor of heat. Using PP container to hold CaO(s) will protect hands for skin burns.  
 - PP can withstand the high temperature caused by the reaction of CaO(s) with H<sub>2</sub>O(l).  
 (II) - Compounds of Al are non-toxic. They will not cause food poisoning.  
 - Al is a good conductor of heat. The heat liberated from the reaction of CaO(s) with H<sub>2</sub>O(l) can readily be transmitted to the coffee beverage.  
 - Aluminium is covered by a layer of unreactive Al<sub>2</sub>O<sub>3</sub>(s), which prevents the metal from corrosion.  
 (Accept other reasonable answers.)
- (ii) The reaction of CaO(s) and H<sub>2</sub>O(l) is highly exothermic, and CaO(s) is an inexpensive material. [1]  
 (Accept other reasonable answers.)

## DSE12\_08

- (a) CO<sub>2</sub> gas produced makes the bread rise / spongy / soft. [1]
- (b)  $\text{KHCO}_3(\text{s}) \longrightarrow \frac{1}{2}\text{K}_2\text{CO}_3(\text{s}) + \frac{1}{2}\text{H}_2\text{O}(\text{l}) + \frac{1}{2}\text{CO}_2(\text{g})$  [1]
- (c) (i)  $q = 27.5 \times 4.3 \times (25.8 - 20.2) = 662.2 \text{ J} = 0.6622 \text{ kJ}$  [1]  

$$\Delta H = \frac{+0.6622}{\frac{3.39}{39.1 + 1 + 12 + 16 \times 3}} = +19.6 \text{ kJ mol}^{-1} / +19.55 \text{ kJ mol}^{-1} / +19.5 \text{ kJ mol}^{-1}$$
 [1]

If the candidate omitted the "+" sign for the positive numbers, and the numerical answers are correct, deduct 1 mark only.

(ii)  $\Delta H = 19.6 - \left(-49.1 \times \frac{1}{2}\right)$  [1]  
 $= +44.15 \text{ kJ mol}^{-1}$  (Accept +44.1 to +44.2 kJ mol<sup>-1</sup>) [1]

If the candidate omitted the “+” sign for the positive numbers, and the numerical answers are correct, deduct 1 mark only.

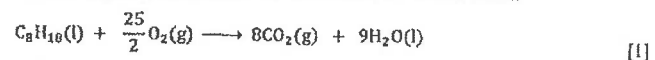
(d) (i)  $\Delta H = \frac{1}{2}[-1146 - 394 - 286 - (-959 \times 2)] = +46 \text{ kJ mol}^{-1}$  [1]

If the candidate omitted the “+” sign for the positive numbers, and the numerical answers are correct, deduct 1 mark only

(ii) Not performing the experiment in standard conditions. / Heat transfer with the surroundings. / The heat capacity of the container was neglected. [1]

#### DSE14\_06

(a) (iii) The enthalpy change when one mole of a compound (substance / octane) burns completely under standard conditions / 25 °C and 1 atm. [1]



(The equation should have correct state symbols)

(b) (i) Catalytic converter [1]

(ii)  $\Delta H^\circ = 2(-394) - 2(-110.5) - 2(90.3)$  [2]  
 $= -747.6 \text{ kJ mol}^{-1}$  (the answer should have correct sign and unit) [1]

#### DSE15\_08

(a)  $\text{C}_n\text{H}_{2n+2}$  [1]

(b) (i) Covalent bond(s) broken C-H and O=O [1]  
 Covalent bond(s) formed C=O and O-H [1]

(ii) (The total) Energy released in the bond forming process is larger than (the total) energy absorbed in the bond breaking process. [1]

(iii)  $\Delta H^\circ = \Delta H^\circ_f[\text{CO}_2(\text{g})] + 2\Delta H^\circ_f[\text{H}_2\text{O}(\text{l})] - \Delta H^\circ_f[\text{CH}_4(\text{g})]$  [1]  
 $= (-393.5) + 2(-285.9) - (-74.8)$  [1]  
 $= -890.5 \text{ kJ mol}^{-1}$  [1]

(c) - Natural gas burns (more) completely but coal does not. / [1]  
 Burning coal would produce soot / carbon monoxide but burning natural gas would not.

- Compared with natural gas, coal contains more impurities. / [1]  
 Burning coal would produce more pollutant, such as SO<sub>2</sub>, metal compound dust, NO<sub>2</sub>. (If the answer mentions pollutants, the answer should have a correct example of pollutant. NOT accept CO, soot.)

(Accept natural gas or methane in the answer only. NOT accept other gaseous fuel such as LPG)

#### DSE16\_07

(a) Constant pressure [1]  
 Do not accept answers like “1 atm”, “1 atm and 25°C”.

(b) It is very difficult for Mg(s), C(s) and O<sub>2</sub>(g) to react directly to form MgCO<sub>3</sub>(s). [1]

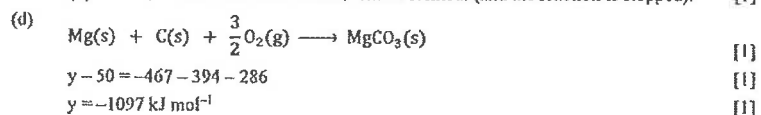
OR, MgCO<sub>3</sub>(s) cannot be formed from its elements.

OR, MgCO<sub>3</sub>(s) cannot be formed directly.

OR, There will be side products. / MgO will be formed. / CO<sub>2</sub> will be formed.

(c) (i) Heat loss to surrounding. / PS cup absorbs heat. / Thermometer absorbs heat [1]

(ii) No, because insoluble CaSO<sub>4</sub> will be formed. (and the reaction is stopped). [1]

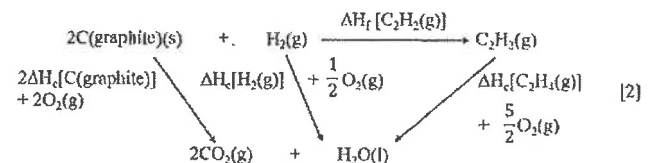


#### DSE17\_07

(a) The reaction between carbon and hydrogen does not only give ethyne. / There will be side reactions / side products will be formed. [1]  
 Carbon and hydrogen gas have no reaction at room conditions.

(b) The total enthalpy change of a chemical reaction is independent of the pathway [1]  
 between the initial and final states.

(c) (i)



(ii) (i) 298 K / 25 °C and 1 atm / 101 kPa / 101325 Nm<sup>-2</sup> [1]

(ii)  $\Delta H^\circ_f[\text{C}_2\text{H}_2(\text{g})] = 2 \times (-394) + (-286) - (-1300)$  [1]  
 $= +226 \text{ kJ mol}^{-1}$  [1]

Correct Unit. MUST show the positive sign.

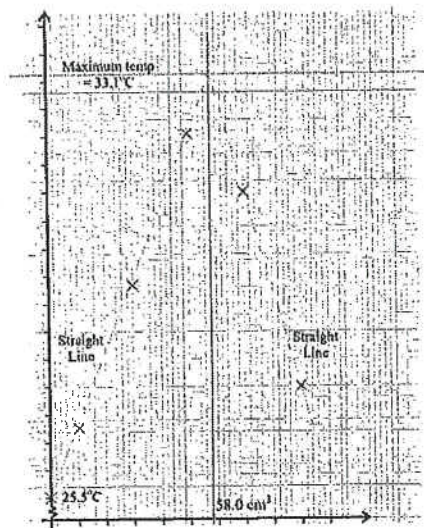


DSE18\_06

- (a) (i)  $6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(\text{s}) + 6\text{O}_2(\text{g})$  [1]  
 (ii)  $\Delta H = -1276 - 6 \times (-394 - 286) = +2806 \text{ kJ mol}^{-1}$  [2]  
 (Do not accept +2800, +2810  $\text{kJ mol}^{-1}$ )  
 (iii) Light / solar energy changes to chemical energy. [1]  
 (b) (i) Let C be the heat capacity of the calorimeter,  
 $-715 \times \frac{1.58}{32} = -C \times 18.5$  (1) [1]  
 $\Delta H \times \frac{1.02}{100} = -C \times 25.8$  (2) [1]  
 $\Delta H = -4826.8 \text{ kJ mol}^{-1}$  [1]  
 (Accept -4823 to -4831.1)  
 (ii) Incomplete combustion / some methanol or heptane evaporates. [1]

DSE19\_08

(a)



Drawing 2 best-fit slant straight lines to show how to obtain the possible maximum temperature using the volume of NaOH(aq) (58.0  $\text{cm}^3$ ).

- (b) (i) No. of moles of NaOH(aq) used =  $1.0 \times (58.0 + 1000) = 0.058 \text{ (mol)}$  [1]  
 $\therefore$  At equivalent point, no. of moles of NaOH(aq) used = No. of moles of HCl(aq) reacted  
 $\therefore$  No. of moles of HCl(aq) reacted = 0.058 (mol)  
 Concentration of HCl(aq) =  $0.058 + (42.0 \div 1000) = 1.38 \text{ mol dm}^{-3}$  [1]  
 OR 1.381 M

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- (ii) Energy released during the reaction = [1]  
 $100.0 \times 1.0 \times 4.18 \times (33.1 - 25.5) = 3176.8 \text{ J}$   
 Enthalpy change of neutralisation =  
 $-3176.8 \div (0.058 \times 1000) = -54.77 \text{ (kJ mol}^{-1}\text{)}$  [1]  
 OR  $-54.772 \div -54.8 \text{ (kJ mol}^{-1}\text{)}$   
 OR Energy released during the reaction  
 $= 100.0 \times 1.0 \times 4.18 \times (33.1 - 25.5) = 3177 \text{ J}$   
 Enthalpy change of neutralisation  
 $= -3177 + (0.058 \times 1000) = -54.776 \text{ (kJ mol}^{-1}\text{)}$   
 OR  $-54.78 \text{ (kJ mol}^{-1}\text{)}$   
 (c) The enthalpy change when an acid solution and a base / an alkali solution react together under standard conditions to produce 1 mole of water. [1]

DSE20\_05

5. (a) Carboxyl (group) /  $-\text{CO}_2\text{H}$  (group) /  $-\text{COOH}$  (group) /  $-\text{CO}_2\text{H}$  /  $-\text{COOH}$  /  $\text{CO}_2\text{H}$  /  $\text{COOH}$  1  
 (Not accept: acid / alkanic acid / organic acid /  $\text{COOH}$  /  $\text{CHO}_2$  /  $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$  / carboxylic acid group)  
 (b) (i)  $\text{HO}_2\text{CCH}_2\text{CH}_2\text{CO}_2\text{H}$  /  $\text{HOOCCH}_2\text{CH}_2\text{COOH}$  /  $(\text{CH}_2\text{COOH})_2$  1  
 (Not accept:  $\text{HOOCCH}_2\text{COOH}$ )  
 $\text{HO}_2\text{CCH}(\text{CH}_3)\text{CO}_2\text{H}$  /  $\text{HOOCCH}(\text{CH}_3)\text{COOH}$  1  
 $\text{HO}_2\text{CCH}_2\text{COOCH}_3$  /  $\text{HO}_2\text{CCH}_2\text{CO}_2\text{CH}_3$  (1)  
 (ii) \* The enthalpy change when solutions of an acid and an alkali / a base react together / neutralise under standard conditions to produce 1 mole of water. 1  
 (Accept:  $25^\circ\text{C}$  (298K) and one atmospheric pressure (760 mmHg, 103 kPa))  
 \* As indicated in the equation, the reaction produces 2 moles of water, hence  $v / 2$  represents the standard enthalpy change of neutralisation. 1  
 (Accept: No unit)  
 (iii) \* Less negative than  $-57.3 \text{ kJ mol}^{-1}$  1  
 \* W is a weak acid when compared with HCl(aq), energy / heat energy / heat is needed to ionise the hydrogen in the carboxyl /  $-\text{CO}_2\text{H}$  group. 1  
 / W is a weak(er) acid, energy / heat energy / heat is needed to ionise the hydrogen in the carboxyl /  $-\text{CO}_2\text{H}$  group.  
 (Accept: absorb energy to break the O-H bond in carboxyl group.)  
 (Not accept: dissociate)

DSE20\_07

7. (a) \* Put a moist red litmus paper / moist pH paper near the mouth of the conical flask. 1  
 \* Ammonia /  $\text{NH}_3$  gas dissolves in water to give  $\text{OH}^-$  ions / is alkaline which turn red litmus paper to blue / pH paper to blue. 1  
 \* Put a glass rod with conc. HCl / HCl(g) near the mouth of the conical flask. (1)  
 \* After reaction, (dense) white fumes containing  $\text{NH}_4\text{Cl}$ (s) is formed. (1)  
 \* Deliver the gas produced into water, then use a pH meter to measure the pH of the solution formed. (1)  
 \* Ammonia /  $\text{NH}_3$  gas dissolves in water to give  $\text{OH}^-$  ions / an alkaline solution with  $\text{pH} > 7$ . (1)  
 (b) Alkali is a water soluble substance reacts with an acid to give salt and water only. 1  
 / Alkali is a substance when dissolved in water to give hydroxide ions as the only anion.  
 / Alkali is a soluble base that reacts with an acid to give salt and water only.  
 (Not accept: alkali reacts with acid to give salt and water only.)  
 (Not accept: alkalis are water soluble base.)  
 (Not accept: alkali is a solution with  $[\text{OH}^-]$  higher than  $[\text{H}^+]$ .)  
 (c) (i)  $\text{Ba}(\text{s}) + 9\text{H}_2(\text{g}) + \text{SO}_2(\text{g}) \rightarrow \text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$   $\Delta H^\circ = -3345 \text{ kJ mol}^{-1}$  1  
 $\text{Ba}(\text{s}) + 9\text{H}_2(\text{g}) + \text{SO}_2(\text{g}) \rightarrow \text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$   $\Delta H = -3345 \text{ kJ mol}^{-1}$   
 (Not accept:  $\text{Ba}(\text{s}) + 9\text{H}_2(\text{g}) + \text{SO}_2(\text{g}) \rightarrow \text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$   $\Delta H < 0$ )  
 (Correct state symbols and unit)  
 (ii)  $\Delta H^\circ = (-859) + 10 \times (-286) + 2 \times (-46) - (-3345) - 2 \times (-314)$  1\*  
 $= +162 \text{ kJ mol}^{-1}$  (Show correct unit) 1  
 (Accept: +162.0  $\text{kJ mol}^{-1}$ )  
 (Not accept: "wrong unit", "missing unit", "no plus sign", etc.)  
 (iii) (As the reaction has  $\Delta H \geq 0$ ), the reaction is endothermic / absorbs heat, thus the temperature would decrease. 1