Chemical energetics – 2023 AS Chemistry 9701

1. Nov/2023/Paper_ 9701/11/No.9

Which statement about enthalpy changes is correct?

A Enthalpy changes of reaction are always negative.

B Enthalpy changes of combustion are always positive.

C Enthalpy changes of formation are always positive.

D Enthalpy changes of neutralisation are always negative.

2. Nov/2023/Paper_ 9701/11/No.10

What is the definition of standard enthalpy change of neutralisation, $\Delta H^{\ominus}_{neut}$?

A $\Delta H^{\ominus}_{r}$ when one mole of an aqueous acid is neutralised by an aqueous alkali

B $\Delta H^{\ominus}_{r}$ when one mole of an aqueous alkali is neutralised by an aqueous acid

C $\Delta H^{\ominus}_{r}$ when one mole of an aqueous acid is neutralised by one mole of an aqueous alkali

D $\Delta H^{\ominus}_{r}$ when an aqueous acid and an aqueous alkali react together to produce one mole of water

3. Nov/2023/Paper_ 9701/12/No.11

Nitric acid is made industrially by the oxidation of ammonia. The overall equation for the process is shown.

equation 1 $\quad NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$

The process happens in three stages. The equations and enthalpy changes for these stages are given.

stage 1	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$	$\Delta H = -904\,kJ\,mol^{-1}$
stage 2	$2NO + O_2 \rightarrow 2NO_2$	$\Delta H = -114\,kJ\,mol^{-1}$
stage 3	$4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$	$\Delta H = -348\,kJ\,mol^{-1}$

What is the enthalpy change of the process shown in equation 1?

A $-1480\,kJ\,mol^{-1}$

B $-370\,kJ\,mol^{-1}$

C $-341.5\,kJ\,mol^{-1}$

D $+82\,kJ\,mol^{-1}$

(e) The structure of glucose, $C_6H_{12}O_6$, is shown in Fig. 3.2.

glucose

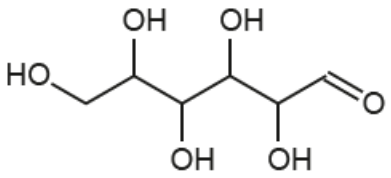


Fig. 3.2

(i) Complete Table 3.1 to identify the number of primary, secondary and tertiary alcohol groups present in the structure shown in Fig. 3.2.

Table 3.1

type of alcohol group	primary	secondary	tertiary
number of groups			

[1]

(ii) Separate samples of aqueous glucose are tested with the reagents shown in Table 3.2.

Complete Table 3.2 with the observation for each reaction.

Write "no reaction" if applicable.

Table 3.2

reagent and conditions	observation with glucose
acidified $KMnO_4(aq)$ and warm	
Fehling's reagent and warm	
alkaline $I_2(aq)$ and warm	

[3]

(iii) There are many structural isomers of $C_6H_{12}O_6$.

Define structural isomers.

.....

..... [1]

5. Nov/2023/Paper_ 9701/21/No.3(b)

Compounds **C** and **D** are alkenes with the same molecular formula, C_5H_{10}.

Fig. 4.1

(b) The mass spectrum of **C** shows a molecular ion peak at *m/e* = 70. This peak has a relative intensity of 48.7.

The relative intensity of the [M+1] peak is 2.7.

Show that this information is consistent with the molecular formula of **C**.

[2]

6. Nov/2023/Paper_ 9701/22/No.3(b)

Phosphoric(V) acid, H_3PO_4, is used in both inorganic and organic reactions.

(b) H_3PO_4 is also formed in the process shown in reaction 1.

reaction 1 $\quad 4H_3PO_3 \rightarrow 3H_3PO_4 + PH_3$

Table 3.1 shows some relevant thermodynamic data.

Table 3.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
H_3PO_3	–972
H_3PO_4	–1281
PH_3	+9

(i) Define enthalpy change of formation.

.....

.....

..... [2]

(ii) Use the data in Table 3.1 to calculate the enthalpy change, ΔH_r, of reaction 1.

ΔH_r = ... kJ mol^{-1}
[2]

(iii) Explain why reaction 1 is a disproportionation reaction.

Explain your reasoning with reference to relevant oxidation numbers.

.....

.....

..... [2]

7. June/2023/Paper_9701/11/No.5

Calcium carbide, CaC_2, reacts with water, as shown. The data below the equation show, in kJ mol^{-1}, the standard enthalpies of formation of the compounds involved.

$CaC_2(s)$	+	$H_2O(l)$	→	$CaO(s)$	+	$C_2H_2(g)$
–60		–286		–635		+228

What is the standard enthalpy change of the reaction shown?

A –753 kJ mol^{-1}

B –61 kJ mol^{-1}

C +61 kJ mol^{-1}

D +753 kJ mol^{-1}

8. June/2023/Paper_9701/12/No.9

A student mixed 25.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid with an equal volume of 4.00 mol dm^{-3} sodium hydroxide. The initial temperature of both solutions was 15.0 °C. The maximum temperature recorded was 30.0 °C. The heat capacity of the final solution can be assumed to be 4.18 J K^{-1} g^{-1} and the density of this solution can be assumed to be 1.00 g cm^{-3}.

Using these results, what is the enthalpy change of neutralisation of hydrochloric acid?

A –62.7 kJ mol^{-1}

B –31.4 kJ mol^{-1}

C –15.7 kJ mol^{-1}

D –3.14 kJ mol^{-1}

9. June/2023/Paper_9701/12/No.10

Nitrogen monoxide is rapidly oxidised to nitrogen dioxide.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Nitrogen dioxide can then dimerise to form dinitrogen tetroxide.

$$2NO_2(g) \rightarrow N_2O_4(g) \qquad \Delta H^{\ominus} = -58\,kJ\,mol^{-1}$$

$$\Delta H_f^{\ominus}NO = +91\,kJ\,mol^{-1} \text{ and } \Delta H_f^{\ominus}NO_2 = +34\,kJ\,mol^{-1}$$

What is the value of the standard enthalpy change for the reaction shown?

$$2NO(g) + O_2(g) \rightarrow N_2O_4(g)$$

A $+56\,kJ\,mol^{-1}$ **B** $-1\,kJ\,mol^{-1}$ **C** $-115\,kJ\,mol^{-1}$ **D** $-172\,kJ\,mol^{-1}$

10. June/2023/Paper_9701/13/No.10

Which equation represents the reaction whose standard enthalpy change is the standard enthalpy change of formation of water?

A $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

B $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$

C $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

D $2H(g) + O(g) \rightarrow H_2O(l)$

11. June/2023/Paper_9701/13/No.12

The enthalpy change for neutralisation of $HNO_3(aq)$ with NaOH(aq) is $-57.0\,kJ\,mol^{-1}$.

In an experiment, $20.0\,cm^3$ of $4.00\,mol\,dm^{-3}$ HNO_3 is mixed with $30.0\,cm^3$ of $2.00\,mol\,dm^{-3}$ NaOH in an insulated container. The initial temperature of both solutions is 25.0 °C.

It can be assumed that the heat capacity of the product mixture is $4.2\,J\,cm^{-3}\,°C^{-1}$ and that there are no heat losses.

What is the maximum final temperature of the mixture?

A 41.3 °C **B** 44.0 °C **C** 46.7 °C **D** 52.1 °C

12. June/2023/Paper_9701/13/No.13

Some bond energies are listed.

bond	bond energy / kJ mol^{-1}
H–H	436
O–H	463
O–O	146
O=O	496

One mole of hydrogen reacts with oxygen to give water vapour.

Using the bond energy data, what is the value for the enthalpy change of this reaction?

A +221 kJ mol^{-1}

B +6 kJ mol^{-1}

C –242 kJ mol^{-1}

D –417 kJ mol^{-1}

13. June/2023/Paper_9701/21/No.2

A neutralisation reaction occurs when NaOH(aq) is added to $H_2SO_4(aq)$.

equation 1 $\quad 2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

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

.....

.....

..... [2]

(b) An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and $H_2SO_4(aq)$.

$100\,cm^3$ of $1.00\,mol\,dm^{-3}$ NaOH(aq) is added to $75\,cm^3$ of $1.00\,mol\,dm^{-3}$ $H_2SO_4(aq)$ in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq) / °C	20.0
initial temperature of $H_2SO_4(aq)$ / °C	20.0
maximum temperature of mixture / °C	27.8

(i) Use equation 1 to calculate the amount, in mol, of $H_2SO_4(aq)$ that is neutralised in the experiment.

amount of $H_2SO_4(aq)$ neutralised = ... mol [1]

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

Assume that:

- the specific heat capacity of the final solution is $4.18\,J\,g^{-1}\,K^{-1}$
- $1.00\,cm^3$ of the final solution has a mass of $1.00\,g$
- there is no heat loss to the surroundings
- full dissociation of $H_2SO_4(aq)$ occurs
- the experiment takes place at constant pressure.

Show your working.

ΔH_{neut} = ... units .....
[3]

(c) **(i)** Complete the equation for the reaction that occurs when a solution of $Ba(OH)_2$ is added to aqueous sulfuric acid. Include state symbols.

..... $H_2SO_4(aq)$ + ...$Ba(OH)_2(aq)$ → .....

[2]

(ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

.....

..... [1]

[Total: 9]

14. June/2023/Paper_9701/22/No.4

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

reaction 1 $C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$

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

Table 4.1

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

ΔH_r = ... kJ mol^{-1} [2]

(b) Reaction 1 reaches equilibrium at constant temperature and pressure.

Deduce what effect increasing the pressure will have on the amount of ethanol in the new equilibrium mixture. Use Le Chatelier's principle to explain your answer.

effect of increasing pressure .....

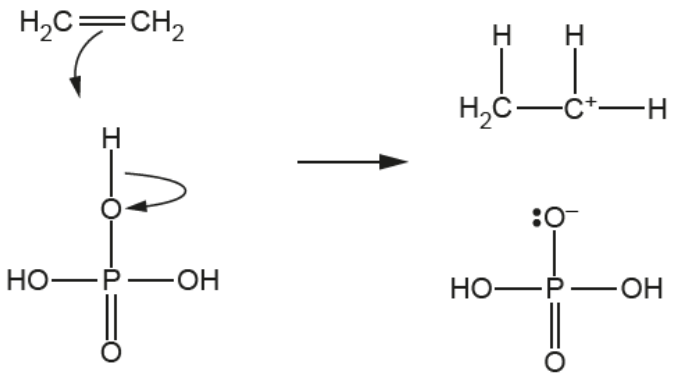
explanation .....

.....

[2]

(c) The mechanism for reaction 1 can be described in three steps. Steps 1 and 2 for reaction 1 are shown in Fig. 4.1.

step 1



step 2

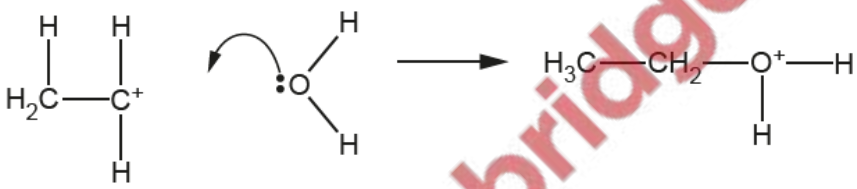


Fig. 4.1

(i) Describe the behaviour of H_3PO_4 in step 1 in Fig. 4.1. Explain your answer.

.....

..... [1]

(ii) Identify the species that behaves as an electrophile in step 2 in Fig. 4.1. Explain your answer.

.....

..... [1]

(iii) Complete Fig. 4.2 to show the mechanism for step 3 of reaction 1. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

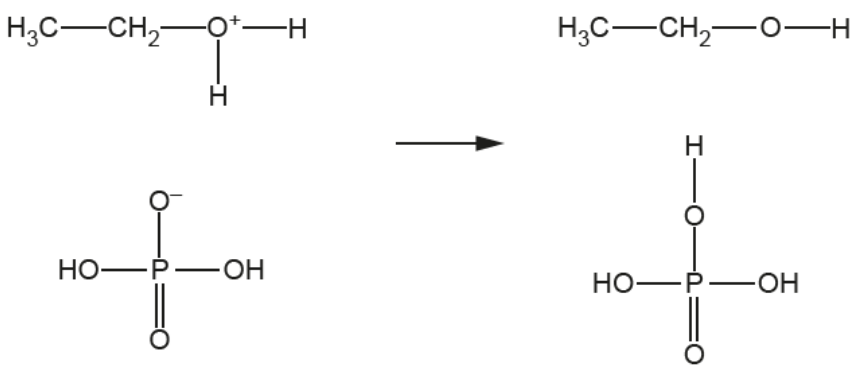


Fig. 4.2

[2]

(iv) Describe how a catalyst affects a reaction. Explain your answer.

.....

..... [2]

(v) Use Fig. 4.1 and Fig. 4.2 to justify why H_3PO_4 is described as a catalyst in reaction 1.

.....

..... [1]

(vi) Propene also reacts with steam. A mixture of organic products is produced.

Explain why propan-2-ol is produced in the higher yield.

.....

.....

..... [2]

(d) Describe the covalent bonds present between the carbon atoms in an ethene molecule by completing Table 4.2.

Table 4.2

	sigma (σ)	pi (π)
type of orbitals involved in bond		
how the orbitals overlap		

[2]

[Total: 15]

15. June/2023/Paper_9701/23/No.3

A neutralisation reaction occurs when NaOH(aq) is added to $H_2SO_4(aq)$.

equation 1 $\quad 2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

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

.....

.....

..... [2]

(b) In an experiment, 50.0 cm^3 of 2.00 mol dm^{-3} NaOH(aq) is added to 60.0 cm^3 of 1.00 mol dm^{-3} $H_2SO_4(aq)$ in a polystyrene cup and stirred. Both solutions have a temperature of 21.4 °C before mixing. The maximum temperature of the mixture is measured.

(i) Use equation 1 to calculate the amount, in mol, of $H_2SO_4(aq)$ that is neutralised in the experiment.

amount of H_2SO_4 neutralised = ... mol [1]

(ii) Calculate the theoretical maximum temperature of the mixture in this experiment.

Assume that:

- enthalpy change of neutralisation, ΔH_{neut}, of NaOH(aq) and $H_2SO_4(aq)$ is –57.1 kJ mol^{-1}
- full dissociation of $H_2SO_4(aq)$ occurs
- the specific heat capacity of the final solution is 4.18 J g^{-1} K^{-1}
- 1.00 cm^3 of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- the experiment takes place at constant pressure.

Show your working.

theoretical maximum temperature = ... °C [3]

(c) The enthalpy change of neutralisation of $CH_3COOH(aq)$ and $NaOH(aq)$ is $-55.2\,kJ\,mol^{-1}$.

(i) Complete the equation for the reaction.

.....CH_3COOH + ...$NaOH \rightarrow$ ..... [1]

(ii) Values for the enthalpy change of neutralisation, ΔH_{neut}, are shown in Table 3.1.

Table 3.1

reagents	ΔH_{neut} / kJ mol^{-1}
NaOH + HC*l*	–57.1
NaOH + CH_3COOH	–55.2

Suggest why the value for ΔH_{neut} of the weak acid, CH_3COOH, reacting with NaOH is different to the value obtained using the strong acid, HC*l*. Assume that the values are determined under the same conditions.

.....

..... [1]

[Total: 8]

16. March/2023/Paper_9701/12/No.10

The equation for a chemical reaction is shown. All substances are in their standard states.

$$XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$$

Which statement describes the standard enthalpy change of reaction for this reaction?

A the enthalpy change when a total of one mole of products is produced

B the enthalpy change when a total of one mole of reactants is reacted

C the enthalpy change when one mole of water reacts

D the enthalpy change when six moles of hydrogen fluoride are produced

17. March/2023/Paper_9701/12/No.16

The table shows bond energies for some diatomic molecules. Deuterium, D, is an isotope of hydrogen.

bond	energy / kJ mol^{-1}
F–F	158
C*l*–C*l*	242
Br–Br	193
I–I	151
H–H	436
D–D	442

Which statements are correct?

1 Diatomic molecules have exact values for their bond energies, which are always positive.

2 The trend in Group 7 bond energies can be explained by the variation in instantaneous dipole–induced dipole (id–id) forces.

3 A value for the enthalpy change for the reaction between deuterium and chlorine can be calculated using these data alone.

A 1 only **B** 1 and 2 only **C** 1 and 3 only **D** 2 and 3 only

18. March/2023/Paper_9701/22/No.3(d)

(d) The reaction of ethene, C_2H_4, with a 1:1 mixture of CO and H_2 is shown in equation 1.

equation 1 $\quad C_2H_4(g) + CO(g) + H_2(g) \rightleftharpoons CH_3CH_2CHO(g)$

At atmospheric pressure a cobalt-based catalyst is used in this reaction.

(i) State and explain the effect of using a catalyst on this reaction.

.....

.....

.....

..... [2]

(ii) Explain why the yield of $CH_3CH_2CHO(g)$ increases when the overall pressure of the reaction mixture is increased.

.....

..... [1]

(iii) Use the information in Table 3.2 to calculate the enthalpy change, ΔH_r, of the reaction in equation 1.

equation 1 $\quad C_2H_4(g) + CO(g) + H_2(g) \rightleftharpoons CH_3CH_2CHO(g)$

Table 3.2

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$C_2H_4(g)$	+52
$CO(g)$	–111
$CH_3CH_2CHO(g)$	–187

ΔH_r = ... kJ mol^{-1} [2]

(iv) The reaction mixture is cooled to collect CH_3CH_2CHO as a liquid.

Identify all types of van der Waals' forces that are present between molecules of CH_3CH_2CHO.

.....

..... [1]