Hess' Law

1. $N_2(g) + 2O_2(g) \rightarrow 2NO_2(g) \quad \Delta H = +88\,kJ$
$N_2(g) + 2O_2(g) \rightarrow N_2O_4(g) \quad \Delta H = +10\,kJ$

The enthalpy change for the reaction

$$2NO_2(g) \rightarrow N_2O_4(g)$$

will be

A +98 kJ

B +78 kJ

C −78 kJ

D −98 kJ.

2. $S(s) + H_2(g) \rightarrow H_2S(g) \quad \Delta H = a$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell) \quad \Delta H = b$

$S(s) + O_2(g) \rightarrow SO_2(g) \quad \Delta H = c$

$H_2S(g) + 1\frac{1}{2}O_2(g) \rightarrow H_2O(\ell) + SO_2(g) \quad \Delta H = d$

What is the relationship between a, b, c and d?

A a = b + c − d

B a = d − b − c

C a = b − c − d

D a = d + c − b

3. Given the equations

$Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g) \quad \Delta H = a\ J\ mol^{-1}$

$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g) \quad \Delta H = b\ J\ mol^{-1}$

$Mg(s) + Zn^{2+}(aq) \rightarrow Mg^{2+}(aq) + Zn(s) \quad \Delta H = c\ J\ mol^{-1}$

then, according to Hess's Law

A c = a − b

B c = a + b

C c = b − a

D c = − b − a.

4. $C(s) + H_2(g) + O_2(g) \rightarrow HCOOH(\ell) \quad \Delta H = a$

$HCOOH(\ell) + {}^1/_2O_2(g) \rightarrow CO_2(g) + H_2O(\ell) \quad \Delta H = b$

$C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = c$

$H_2(g) + {}^1/_2O_2(g) \rightarrow H_2O(\ell) \quad \Delta H = d$

What is the relationship between a, b, c and d?

A a = c + d − b

B a = b − c − d

C a = −b − c − d

D a = c + b + d

5. Excess iron was added to 100 cm^3 of 1·0 mol l^{-1} copper(II) sulphate solution releasing 3·1 kJ of energy.

$Fe(s) + CuSO_4(aq) \rightarrow Cu(s) + FeSO_4(aq)$

What is the enthalpy change, in kJ mol^{-1} for the above reaction?

A −0·31

B −3·1

C −31

D −310

6. $C(graphite) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -394\,kJ\,mol^{-1}$

$C(diamond) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -395\,kJ\,mol^{-1}$

What is the enthalpy change, in kJ mol^{-1}, for the conversion of one mole of graphite into one mole of diamond?

A −789

B −1

C +1

D +789

Hess' Law

7. $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(\ell)$ ΔH_1

$CH_3CHO(\ell) + 2\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 2H_2O(\ell)$ ΔH_2

$2O_3(g) \rightarrow 3O_2(g)$ ΔH_3

The enthalpy change equal to $\Delta H_1 - \Delta H_2 + \frac{1}{2}\Delta H_3$ is associated with the reaction

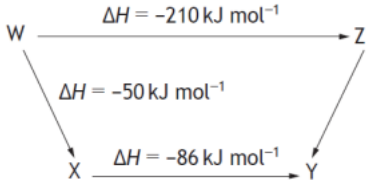
A $C_2H_4(g) + \frac{1}{2}O_2(g) \rightarrow CH_3CHO(\ell)$

B $C_2H_4(g) + O_3(g) \rightarrow CH_3CHO(\ell) + O_2(g)$

C $C_2H_4(g) + 2O_3(g) \rightarrow CH_3CHO(\ell) + 2\frac{1}{2}O_2(g)$

D $C_2H_4(g) + 2\frac{1}{2}O_2(g) + CH_3CHO(\ell) + O_3(g) \rightarrow 4CO_2(g) + 4H_2O(\ell)$

8. Consider the reaction pathway shown below.



According to Hess's Law, the ΔH value, in kJ mol^{-1}, for reaction Z to Y is

A +74

B −74

C +346

D −346.

9. What is the relationship between enthalpies p, q, r and s?

$S(s) + H_2(g) \rightarrow H_2S(g)$ $\Delta H = p$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta H = q$

$S(s) + O_2(g) \rightarrow SO_2(g)$ $\Delta H = r$

$H_2S(g) + 1\frac{1}{2}O_2(g) \rightarrow H_2O(\ell) + SO_2(g)$ $\Delta H = s$

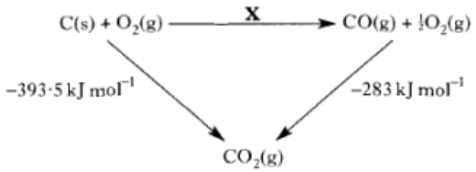
A $p = q + r - s$

B $p = s - q - r$

C $p = q - r - s$

D $p = s + r - q$

10. Consider the reaction pathway shown.



According to Hess's Law, what is the enthalpy change for reaction **X**?

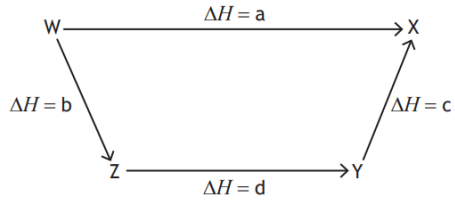
A +110·5 kJ mol^{-1}

B −110·5 kJ mol^{-1}

C −676·5 kJ mol^{-1}

D +676·5 kJ mol^{-1}

11. Consider the reaction pathway shown below.



According to Hess's Law

A $b = a - c - d$

B $b = a + c + d$

C $b = d - c + a$

D $b = d + c - a$.

Hess' Law

1. Silicon hydride, SiH_4, can be formed by reacting silicon with hydrogen.

$$Si(s) + 2H_2(g) \rightarrow SiH_4(g)$$

Calculate the enthalpy change, in kJ mol^{-1}, for this reaction using the following information.

$$SiH_4(g) + 2O_2(g) \rightarrow SiO_2(s) + 2H_2O(\ell) \quad \Delta H = -1517 \text{ kJ mol}^{-1}$$
$$Si(s) + O_2(g) \rightarrow SiO_2(s) \quad \Delta H = -911 \text{ kJ mol}^{-1}$$
$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(\ell) \quad \Delta H = -286 \text{ kJ mol}^{-1}$$

2. In the United States Space Shuttle, dinitrogen tetroxide was reacted with methylhydrazine.

$$4CH_3NHNH_2(\ell) + 5N_2O_4(\ell) \rightarrow 4CO_2(g) + 12H_2O(g) + 9N_2(g)$$

Calculate the enthalpy of this reaction, in kJ, by using the data shown below. **2** **2**

$$C(s) + 3H_2(g) + N_2(g) \rightarrow CH_3NHNH_2(\ell) \quad \Delta H = +54 \text{ kJ mol}^{-1}$$
$$N_2(g) + 2O_2(g) \rightarrow N_2O_4(\ell) \quad \Delta H = -20 \text{ kJ mol}^{-1}$$
$$C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H = -394 \text{ kJ mol}^{-1}$$
$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(\ell) \quad \Delta H = -286 \text{ kJ mol}^{-1}$$
$$H_2O(l) \rightarrow H_2O(g) \quad \Delta H = +41 \text{ kJ mol}^{-1}$$

Hess' Law

3. Carbon monoxide can be produced by the reaction of methane and steam.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H = -283\ kJ\,mol^{-1}$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$ $\quad \Delta H = -286\ kJ\,mol^{-1}$

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ $\quad \Delta H = -891\ kJ\,mol^{-1}$

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

2

4 Carbon tetrachloride, CCl_4, is prepared by the reaction of chlorine gas, Cl_2, with methane, CH_4.

$$CH_4(g) + 4Cl_2(g) \rightarrow CCl_4(g) + 4HCl(g)$$

Calculate the enthalpy change, in $kJ\,mol^{-1}$, for this reaction using the following information. **2**

$C(s) + 2H_2(g) \rightarrow CH_4(g)$ $\quad \Delta H = -75\ kJ\,mol^{-1}$

$C(s) + 2Cl_2(g) \rightarrow CCl_4(g)$ $\quad \Delta H = -98\ kJ\,mol^{-1}$

$\frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g) \rightarrow HCl(g)$ $\quad \Delta H = -92\ kJ\,mol^{-1}$

Hess' Law

5 Hess's Law can be used to calculate the enthalpy change for reactions that do not normally take place, such as the formation of propyne from its elements.

$$3C(s) \quad + \quad 2H_2(g) \quad \rightarrow \quad C_3H_4(g)$$

Calculate the enthalpy change, in kJ mol^{-1}, for this reaction using the following information. **2**

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = -394 \text{ kJ mol}^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(\ell) \qquad \Delta H = -286 \text{ kJ mol}^{-1}$$

$$C_3H_4(g) + 4O_2(g) \rightarrow 3CO_2(g) + 2H_2O(\ell) \qquad \Delta H = -1939 \text{ kJ mol}^{-1}$$

6.

6 Another reaction that produces sulfur dioxide gas involves combustion of carbon disulfide in the reaction shown.

$$CS_2(\ell) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$$

Calculate the enthalpy change, in kJ mol^{-1}, for this reaction using the following information. **2**

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = -393{\cdot}5 \text{ kJ mol}^{-1}$$

$$S(s) + O_2(g) \rightarrow SO_2(g) \qquad \Delta H = -296{\cdot}8 \text{ kJ mol}^{-1}$$

$$C(s) + 2S(s) \rightarrow CS_2(\ell) \qquad \Delta H = +87{\cdot}9 \text{ kJ mol}^{-1}$$

Hess' Law

7 Calcium hydroxide solution can be formed by adding calcium metal to excess water.

Solid calcium hydroxide would form if the exact molar ratio of calcium to water is used. The equation for the reaction is

$$Ca(s) + 2H_2O(\ell) \rightarrow Ca(OH)_2(s) + H_2(g)$$

Calculate the enthalpy change, in kJ mol^{-1}, for the reaction above by using the data shown below.

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta H = -286$ kJ mol^{-1}

$Ca(s) + O_2(g) + H_2(g) \rightarrow Ca(OH)_2(s)$ $\Delta H = -986$ kJ mol^{-1} **2**

6.

8 The equation for the combustion of diborane is shown below.

$$B_2H_6(g) + 3O_2(g) \rightarrow B_2O_3(s) + 3H_2O(\ell)$$

Calculate the enthalpy of combustion of diborane (B_2H_6) in kJ mol^{-1}, using the following data.

$2B(s) + 3H_2(g) \rightarrow B_2H_6(g)$ $\Delta H = 36$ kJ mol^{-1}

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta H = -286$ kJ mol^{-1}

$2B(s) + 1\frac{1}{2}O_2(g) \rightarrow B_2O_3(s)$ $\Delta H = -1274$ kJ mol^{-1}

Hess' Law

9. Mobile phones are being developed that can be powered by methanol.

Methanol can be made by a two-stage process.

In the first stage, methane is reacted with steam to produce a mixture of carbon monoxide and hydrogen.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

Use the data below to calculate the enthalpy change, in kJ mol^{-1}, for the forward reaction.

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H = -283\ \text{kJ mol}^{-1}$

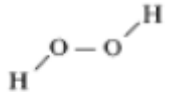
$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$ $\quad \Delta H = -242\ \text{kJ mol}^{-1}$

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ $\quad \Delta H = -803\ \text{kJ mol}^{-1}$

Show your working clearly.

10. Hydrogen peroxide has a high viscosity.

The structure of hydrogen peroxide is shown below.



Hydrogen peroxide may be prepared from its elements.

The equation for the reaction is:

$$H_2(g) + O_2(g) \longrightarrow H_2O_2(\ell)$$

Calculate the enthalpy change, in kJ mol^{-1}, for the above reaction using the enthalpy of combustion of hydrogen from the data booklet and the enthalpy change for the following reaction.

$$H_2O_2(\ell) \longrightarrow \tfrac{1}{2}O_2(g) + H_2O(\ell) \qquad \Delta H = -98\ \text{kJ mol}^{-1}$$

Show your working clearly.

Hess' Law

11 When in danger, bombardier beetles can fire a hot, toxic mixture of chemicals at the attacker.

This mixture contains quinone, $C_6H_4O_2$, a compound that is formed by the reaction of hydroquinone, $C_6H_4(OH)_2$, with hydrogen peroxide, H_2O_2. The reaction is catalysed by an enzyme called catalase.

The equation for the overall reaction is:

$$C_6H_4(OH)_2(aq) + H_2O_2(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(\ell)$$

Use the following data to calculate the enthalpy change, in kJ mol^{-1}, for the above reaction.

$$C_6H_4(OH)_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g) \qquad \Delta H = +177{\cdot}4\,kJ\ mol^{-1}$$

$$H_2(g) + O_2(g) \rightarrow H_2O_2(aq) \qquad \Delta H = -191{\cdot}2\,kJ\ mol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(g) \qquad \Delta H = -241{\cdot}8\,kJ\ mol^{-1}$$

$$H_2O(g) \rightarrow H_2O(\ell) \qquad \Delta H = -43{\cdot}8\,kJ\ mol^{-1}$$

Show your working clearly.

12 If more water is used the calcium hydroxide is produced as a solution instead of as a solid.

The equation for the reaction is:

$$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$$

Using the following data, calculate the enthalpy change, in kJ mol^{-1}, for this reaction.

$$Ca(s) + \tfrac{1}{2}O_2(g) \rightarrow CaO(s) \qquad \Delta H = -635\,kJ\ mol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(\ell) \qquad \Delta H = -286\,kJ\ mol^{-1}$$

$$Ca(s) + O_2(g) + H_2(g) \rightarrow Ca(OH)_2(s) \qquad \Delta H = -986\,kJ\ mol^{-1}$$

$$Ca(OH)_2(s) \rightarrow Ca(OH)_2(aq) \qquad \Delta H = -82\,kJ\ mol^{-1}$$

Show your working clearly.

Hess' Law

13 Vinegar is a dilute solution of ethanoic acid.

Hess's Law can be used to calculate the enthalpy change for the formation of ethanoic acid from its elements.

$$2C(s)\ (\text{graphite}) + 2H_2(g) + O_2(g) \rightarrow CH_3COOH(\ell)$$

Calculate the enthalpy change for the above reaction, in kJ mol^{-1}, using information from the data booklet and the following data.

$$CH_3COOH(\ell) + 2O_2(g) \rightarrow 2CO_2(g) + 2H_2O(\ell) \qquad \Delta H = -876\,kJ\ mol^{-1}$$

Show your working clearly.

14 Enthalpy changes can also be calculated using Hess's Law.

The enthalpy of formation for pentan-1-ol is shown below.

$$5C(s) + 6H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_5H_{11}OH(\ell) \qquad \Delta H = -354\,kJ\ mol^{-1}$$

Using this value, and the enthalpies of combustion of carbon and hydrogen from the data booklet, calculate the enthalpy of combustion of pentan-1-ol, in kJ mol^{-1}.

Hess' Law

15 Silane, silicon hydride, is formed in the reaction of silicon with hydrogen.

$$Si(s) + 2H_2(g) \rightarrow \underset{\text{silane}}{SiH_4(g)}$$

The enthalpy change for this reaction is called the enthalpy of formation of silane.

The combustion of silane gives silicon dioxide and water.

$SiH_4(g) + 2O_2(g) \rightarrow SiO_2(s) + 2H_2O(\ell) \quad \Delta H = -1517\,kJ\,mol^{-1}$

The enthalpy of combustion of silicon is $-911\,kJ\,mol^{-1}$.

Use this information and the enthalpy of combustion of hydrogen in the data booklet to calculate the enthalpy of formation of silane, in $kJ\,mol^{-1}$.

Show your working clearly.

16 The enthalpy of formation of glycerol is the enthalpy change for the reaction:

$$\underset{\text{(graphite)}}{3C(s)} + 4H_2(g) + 1\tfrac{1}{2}O_2(g) \rightarrow C_3H_8O_3(\ell)$$

Calculate the enthalpy of formation of glycerol, in $kJ\,mol^{-1}$, using information from the data booklet and the following data.

$C_3H_8O_3(\ell) + 3\tfrac{1}{2}O_2(g) \rightarrow 3CO_2(g) + 4H_2O(\ell) \quad \Delta H = -1654\,kJ\,mol^{-1}$

Show your working clearly.

Hess' Law

17 The overall equation for the Solvay process is

$$CaCO_3(s) + 2NaCl(aq) \rightarrow Na_2CO_3(aq) + CaCl_2(aq)$$

This reaction has to occur in a series of steps because calcium carbonate and sodium chloride do not react directly together.

The equations involved in the Solvay process are shown.

$CaCO_3(s) \rightarrow CO_2(g) + CaO(s)$ $\Delta H = +178\,kJ\,mol^{-1}$

$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$ $\Delta H = -65\,kJ\,mol^{-1}$

$NaCl(aq) + NH_3(aq) + CO_2(g) + H_2O(\ell) \rightarrow NaHCO_3(s) + NH_4Cl(aq)$ $\Delta H = -79\,kJ\,mol^{-1}$

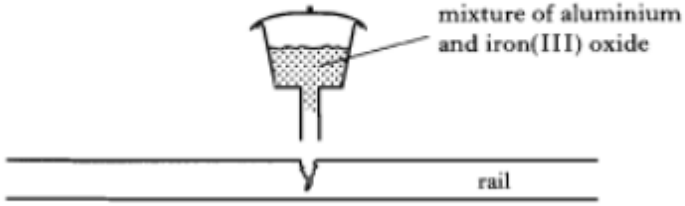
$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(\ell) + CO_2(g)$ $\Delta H = +85\,kJ\,mol^{-1}$

$Ca(OH)_2(aq) + 2NH_4Cl(aq) \rightarrow CaCl_2(aq) + 2H_2O(\ell) + 2NH_3(aq)$ $\Delta H = -20\,kJ\,mol^{-1}$

Calculate the enthalpy change, in $kJ\,mol^{-1}$, for the overall reaction in the Solvay process.

18 The Thermite Process involves the reaction between aluminium and iron(III) oxide to produce iron and aluminium oxide.

This highly exothermic reaction, which generates so much heat that the temperature of the mixture rises to around 3000 °C, is used for repairing cracked railway lines as shown in the diagram below.



(*a*) Suggest why this process is suitable for repairing cracked railway lines.

(*b*) The enthalpy changes for the formation of one mole of aluminium oxide and one mole of iron(III) oxide are shown below.

$2Al(s) + 1\frac{1}{2}O_2(g) \longrightarrow Al_2O_3(s)$ $\Delta H = -1676\,kJ\,mol^{-1}$

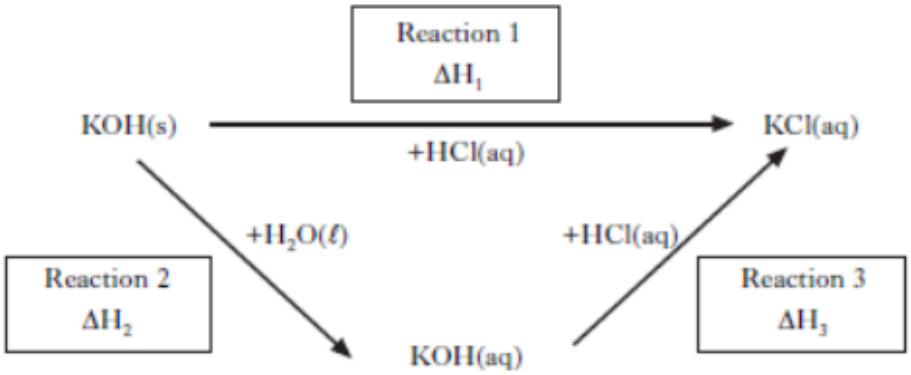
$2Fe(s) + 1\frac{1}{2}O_2(g) \longrightarrow Fe_2O_3(s)$ $\Delta H = -825\,kJ\,mol^{-1}$

Use the above information to calculate the enthalpy change for the reaction:

$$2Al(s) + Fe_2O_3(s) \longrightarrow Al_2O_3(s) + 2Fe(s)$$

Hess' Law

19 (*a*) Hess's Law can be verified using the reactions summarised below.



(i) Complete the list of measurements that would have to be carried out in order to determine the enthalpy change for Reaction 2.

Reaction 2

1. Using a measuring cylinder, measure out 25 cm^3 of water into a polystyrene cup.
2.
3. Weigh out accurately about 1·2 *g* of potassium hydroxide and add it to the water, with stirring, until all the solid dissolves.
4.

(ii) Why was the reaction carried out in a polystyrene cup?

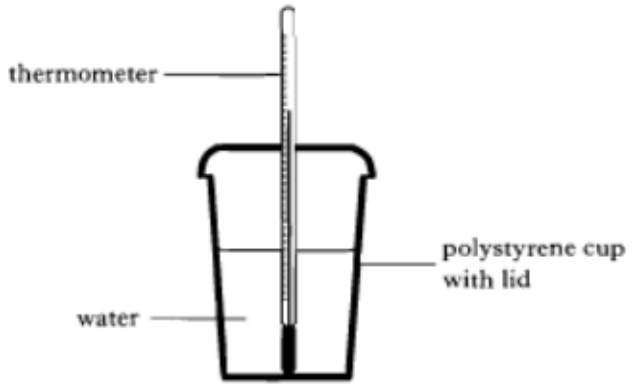
(iii) A student found that 1·08 kJ of energy was **released** when 1·2 *g* of potassium hydroxide was dissolved completely in water.

Calculate the enthalpy change for this reaction.

(b) State Hess's Law.

Hess' Law

20 The following apparatus can be used to determine the enthalpy of solution of a substance. (The enthalpy of solution is the energy change when 1 mole dissolves completely.)



(*a*) Why was the experiment carried out in a polystyrene cup with a lid?

(*b*) In an experiment to find the enthalpy of solution of potassium hydroxide, KOH, a student added 3·6 g of the solid to the water in the polystyrene cup and measured the temperature rise. From this, it was calculated that the heat energy produced in the reaction was 3·5 kJ.

Use this information to calculate the enthalpy of solution of potassium hydroxide.

Show your working clearly.

Hess' Law

1. C
2. A.
3. A
4. A
5. C
6. C
7. B
8. A
9. A
10. B
11. A

1.

Desired equation	$Si + 2H_2 \rightarrow SiH_4$	
❶	$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$	ΔH=-1517 kJ mol^{-1}
❷	$Si + O_2 \rightarrow SiO_2$	ΔH= -911 kJ mol^{-1}
❸	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	ΔH= -286 kJ mol^{-1}
❶x-1	$SiO_2 + 2H_2O \rightarrow SiH_4 + 2O_2$	ΔH=+1517 kJ mol^{-1}
❷	$Si + O_2 \rightarrow SiO_2$	ΔH= -911 kJ mol^{-1}
❸x2	$2H_2 + O_2 \rightarrow 2H_2O$	ΔH= -572 kJ mol^{-1}
add	$Si + 2H_2 \rightarrow SiH_4$	ΔH= +34 kJ mol^{-1}

2.

❶	$C_{(s)} + 3H_{2(g)} + N_{2(g)} \rightarrow CH_3NHNH_{2(l)}$	ΔH=+54 kJ mol^{-1}
❷	$N_{2(g)} + 2O_{2(g)} \rightarrow N_2O_{4(g)}$	ΔH=-20 kJ mol^{-1}
❸	$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$	ΔH=-394 kJ mol^{-1}
❹	$H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$	ΔH=-286 kJ mol^{-1}
❺	$H_2O_{(l)} \rightarrow H_2O_{(g)}$	ΔH=+41 kJ mol^{-1}
❶x-4	$4CH_3NHNH_{2(l)} \rightarrow 4C_{(s)} + 12H_{2(g)} + 4N_{2(g)}$	ΔH=-216 kJ mol^{-1}
❷x-5	$5N_2O_{4(g)} \rightarrow 5N_{2(g)} + 10O_{2(g)}$	ΔH=+100 kJ mol^{-1}
❸x4	$4C_{(s)} + 4O_{2(g)} \rightarrow 4CO_{2(g)}$	ΔH=-1576 kJ mol^{-1}
❹x12	$12H_{2(g)} + 6O_{2(g)} \rightarrow 12H_2O_{(l)}$	ΔH=-3432 kJ mol^{-1}
❺x12	$12H_2O_{(l)} \rightarrow 12H_2O_{(g)}$	ΔH=+492 kJ mol^{-1}
add	$5N_2O_{4(g)} + 4CH_3NHNH_{2(l)} \rightarrow 4CO_{2(g)} + 12H_2O_{(g)} + 9N_{2(g)}$	ΔH=-4632 kJ mol^{-1}

3.

❶	$CO + \frac{1}{2}O_2 \rightarrow CO_2$	ΔH=-283 kJ mol^{-1}
❷	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	ΔH=-286 kJ mol^{-1}
❸	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	ΔH=-891 kJ mol^{-1}
❶x-1	$CO_2 \rightarrow CO + \frac{1}{2}O_2$	ΔH=+283 kJ mol^{-1}
❷X-3	$3H_2O \rightarrow 3H_2 + 1\frac{1}{2}O_2$	ΔH=+858 kJ mol^{-1}
❸	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	ΔH=-891 kJ mol^{-1}
Add ❶'+❷+❸	$CH_4 + H_2O \rightarrow CO + 3H_2$	ΔH=+250 kJ mol^{-1}

Hess' Law

4.

❶	C	+	$2H_2$	→	CH_4			ΔH=-75 kJ mol^{-1}
❷	C	+	$2Cl_2$	→	CCl_4			ΔH=-98 kJ mol^{-1}
❸	$\frac{1}{2}H_2$	+	$\frac{1}{2}Cl_2$	→	HCl			ΔH=-92 kJ mol^{-1}
❶x-1			CH_4	→	C	+	$2H_2$	ΔH=+75 kJ mol^{-1}
❷	C	+	$2Cl_2$	→	CCl_4			ΔH=-98 kJ mol^{-1}
❸x4	$2H_2$	+	$2Cl_2$	→	$4HCl$			ΔH=-368 kJ mol^{-1}
Add ❶'+❷+❸'	CH_4	+	$4Cl_2$	→	CCl_4	+	$4HCl$	ΔH=-391 kJ mol^{-1}

5.

❶	C	+	O_2	→	CO_2			ΔH=-394 kJ mol^{-1}
❷	H_2	+	$\frac{1}{2}O_2$	→	H_2O			ΔH=-286 kJ mol^{-1}
❸	C_3H_4	+	$4O_2$	→	$3CO_2$	+	$2H_2O$	ΔH=-1939 kJ mol^{-1}
❶x3	$3C$	+	~~$3O_2$~~	→	~~$3CO_2$~~			ΔH=-1182 kJ
❷x2	$2H_2$	+	~~O_2~~	→	~~$2H_2O$~~			ΔH=-572 kJ
❸x-1	~~$3CO_2$~~	+	~~$2H_2O$~~	→	C_3H_4	+	~~$4O_2$~~	ΔH=+1939 kJ
Add ❶'+❷'+❸'	$3C$	+	$2H_2$	→	C_3H_4			ΔH=+185 kJ mol^{-1}

6.

❶	$C + O_2 \rightarrow CO_2$	ΔH= -393.5 kJ mol^{-1}	
❷	$S + O_2 \rightarrow SO_2$	ΔH= -296.8 kJ mol^{-1}	
❸	$C + 2S \rightarrow CS_2$	ΔH= +87.9 kJ mol^{-1}	
❶	$C + O_2 \rightarrow CO_2$	ΔH= -393.5 kJ	
❷x2	$2S + 2O_2 \rightarrow 2SO_2$	ΔH= -593.6 kJ	
❸x-1	$CS_2 \rightarrow C + 2S$	ΔH= -87.9 kJ	
Add ❶+❷'+❸'	$CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$	ΔH= -1075 kJ mol^{-1}	

7.

❶	H_2	+	$\frac{1}{2}O_2$			→	H_2O		ΔH=-286 kJ mol^{-1}
❷	Ca	+	O_2	+	H_2	→	$Ca(OH)_2$		ΔH=-986 kJ mol^{-1}
❶x-2	$2H_2O$	+				→	$2H_2$	+ O_2	ΔH=+572 kJ mol^{-1}
❷	Ca	+	O_2	+	H_2	→	$Ca(OH)_2$		ΔH=-986 kJ mol^{-1}
Add ❶'+❷	Ca	+	$2H_2O$			→	$Ca(OH)_2$	+ H_2	ΔH=-414 kJ mol^{-1}

8.

❶	$2B + 3H_2 \rightarrow B_2H_6$	ΔH= +36 kJ mol^{-1}	
❷	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	ΔH= -236 kJ mol^{-1}	
❸	$2B + 1\frac{1}{2}O_2 \rightarrow B_2O_3$	ΔH= -1274 kJ mol^{-1}	
❶x-1	$B_2H_6 \rightarrow 2B + 3H_2$	ΔH= -36 kJ mol^{-1}	
❷x3	$3H_2 + 1\frac{1}{2}O_2 \rightarrow 3H_2O$	ΔH= -858 kJ mol^{-1}	
❸	$2B + 1\frac{1}{2}O_2 \rightarrow B_2O_3$	Δ H= -1274 kJ mol^{-1}	
Add ❶'+❷'+❸	$B_2H_6 + 3O_2 \rightarrow B_2O_3 + 3H_2O$	ΔH= -2168 kJ mol^{-1}	

9. 283 + 242 -803 = -278.

10. -286 + 98 = -188

11 177.4 + 191.2 + (2 x -241.8) + (2 x -43.8) = -202.6 kJ mol^{-1}

12 635 + 286 -986 -82 = -147 kJ mol^{-1}

13 -788 - 572 + 876 = -484 kJ mol^{-1}

14 -3300

15 34

16 -1182 -1144 +1654 = -672

Hess' Law

17

20 kJ mol^{-1}

$CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$

❶ $CaCO_3 \rightarrow CO_2 + CaO$ $\Delta H=+178kJ$

❷ $CaO + H_2O \rightarrow Ca(OH)_2$ $\Delta H=-65kJ$

❸ $NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl$ $\Delta H=-79kJ$

❹ $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$ $\Delta H=+85kJ$

❺ $Ca(OH)_2 + 2NH_4Cl \rightarrow CaCl_2 + 2H_2O + 2NH_3$ $\Delta H=-20kJ$

❶ $CaCO_3 \rightarrow CO_2 + CaO$ $\Delta H=+178kJ$

❷ $CaO + H_2O \rightarrow Ca(OH)_2$ $\Delta H=-65kJ$

❸x2 $2NaCl + 2NH_3 + 2CO_2 + 2H_2O \rightarrow 2NaHCO_3 + 2NH_4Cl$ $\Delta H=-158kJ$

❹ $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$ $\Delta H=+85kJ$

❺ $Ca(OH)_2 + 2NH_4Cl \rightarrow CaCl_2 + 2H_2O + 2NH_3$ $\Delta H=-20kJ$

add $CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$ $\Delta H=+20kJ$

18. a) The molten iron flows into the crack.
b) -1676 + 825 = -851 kJ mol^{-1}

19. a) i) Measure the temperature of the water.
ii) To prevent heat loss to the surroundings
iii) -50.5 kJ mol^{-1}
b) The enthalpy change is independent of the route taken.

20. a) To prevent heat loss to the surroundings.
b) -54.5 kJ mol^{-1}