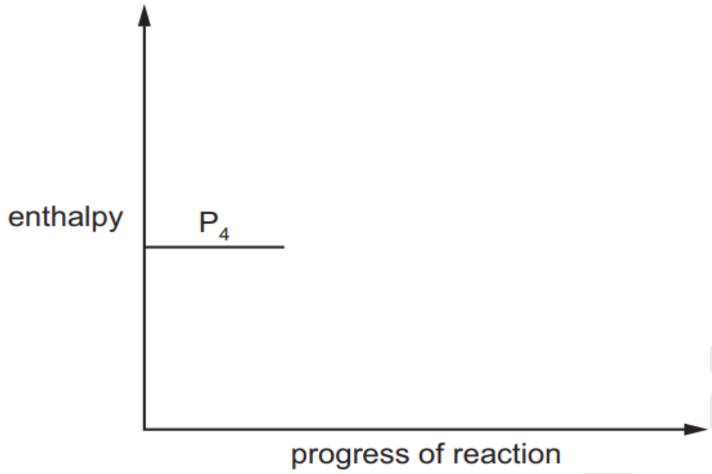
5.1 ENTHALPY CHANGE

Introduction

1. Red phosphorus (P) forms when white phosphorus (P_4) is exposed to sunlight.

$$\underset{\text{white}}{\tfrac{1}{4}P_4(s)} \rightarrow \underset{\text{red}}{P(s)} \qquad \Delta H = -17.6\,\text{kJ mol}^{-1}$$

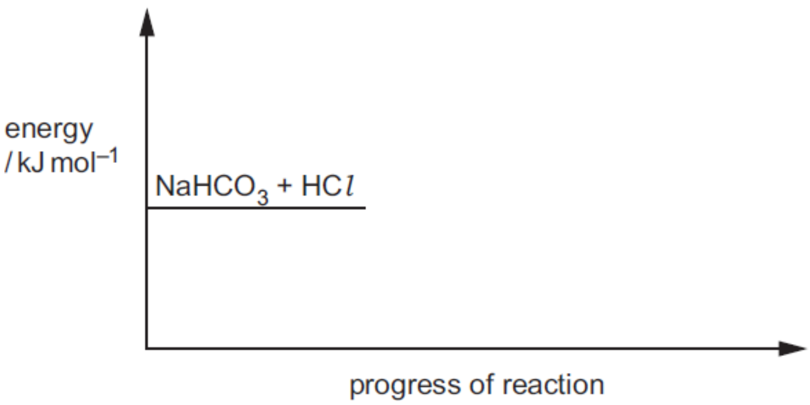
Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P_4).



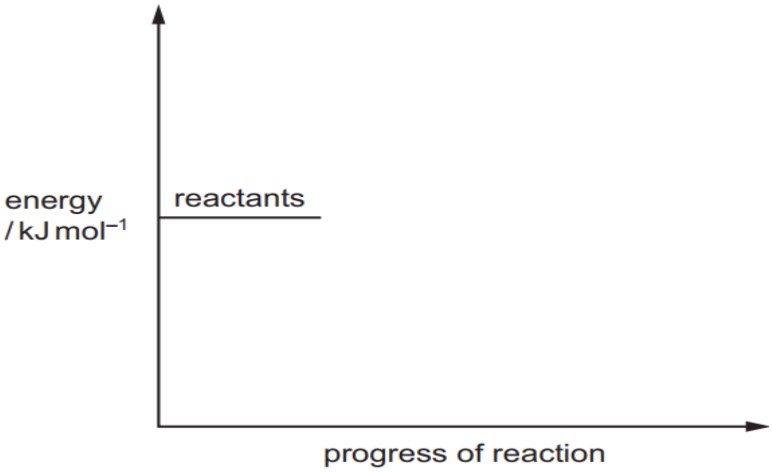
2. Separate samples of Na_2CO_3 and $NaHCO_3$ react with HCl (aq) to produce the same products, as shown in Table

reaction	equation	ΔH / kJ mol^{-1}
1	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	ΔH_1
2	$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$	$\Delta H_2 = +27.2$

Complete the reaction pathway diagram in Fig. 2.1 for reaction 2.
Label the diagram to show the enthalpy change, ΔH_2, and the activation energy, E_A.



3. Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride, $KrF_2(g)$.
$Kr(g) + F_2(g) \rightarrow KrF_2(g)$
activation energy for the reaction, $E_a = +385 kJmol^{-1}$
enthalpy change of formation of KrF_2, $\Delta H_f = +60.2 kJmol^{-1}$
(i) Use this information to complete the reaction profile diagram for the formation of KrF_2.
Label E_a and ΔH_f on the diagram.
Assume the reaction proceeds in one step. [2]



4. Magnesium, Mg, burns in oxygen, O_2.
The activation energy, $\mathbf{E}_a$, for this reaction is $+148 kJmol^{-1}$.
On the following figure:
● sketch a reaction pathway diagram for the reaction that occurs when Mg burns in O_2
● label the diagram to show the enthalpy change, $\Delta\mathbf{H}$, and the activation energy, $\mathbf{E}_a$, for the reaction.

5. Oxygen reacts readily with some metals, but each Group 2 metal requires strong heating to start the reaction with oxygen.
Suggest why strong heating is required to start these reactions. [1]

Standard enthalpy change of formation, ΔH_f

6. Nitric acid, HNO_3, can be made by reacting nitrogen dioxide with water.
   The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.
   $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(l) + NO(g)\ \Delta H_r$
   Explain what is meant by the term *enthalpy change of formation*. [2]

7. Define enthalpy change of formation. [2]
8. The standard enthalpy change of formation, $\Delta H_f^\ominus$, of H**I**(g) is 26.5kJmol^{-1}.
   Define the term standard enthalpy change of formation. [1]

9. The Haber process involves the reaction of N_2 and H_2 to form ammonia, NH_3.
   A catalyst is used, which allows the process to be carried out at a lower temperature and pressure.

   $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)\ \Delta H = -92\ \text{kJ mol}^{-1}$

   Use the information in **(c)** to complete Table 3.1.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
N_2	
H_2	
NH_3	

[2]

10. Write an equation to show the reaction for the standard enthalpy change of formation of H_2O.
    Include state symbols. [2]

11. When 3.645g of Mg(s) burns in excess N_2(g) to form Mg_3N_2(s), 23.05kJ of energy is released.
    Calculate the enthalpy change of formation, $\Delta \boldsymbol{H}_f$, of Mg_3N_2. Show your working.

$\Delta \boldsymbol{H}_f (Mg_3N_2)$ = ... [3]

Standard enthalpy change of combustion, ΔH_c

12. Define the enthalpy change of combustion. [2]

13. Explain what is meant by the term enthalpy change of combustion of sucrose. [2]

Standard enthalpy change of neutralisation, ΔH_{neut}

14. A neutralisation reaction occurs when NaOH(aq) is added to H_2SO_4(aq).
equation 1 $2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$
Define enthalpy change of neutralisation, ΔH_{neut}. [1]

15. Identify each of the following reactions as $\Delta H_f^{\ominus}$, $\Delta H_c^{\ominus}$ or $\Delta H_r^{\ominus}$

$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

$C(graphite) + O_2(g) \rightarrow CO_2(g)$

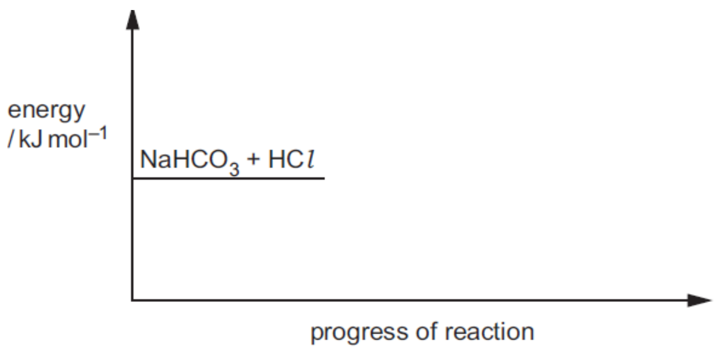
$HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$

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

16. Separate samples of Na_2CO_3 and $NaHCO_3$ react with HC*l* (aq) to produce the same products, as shown in Table.

reaction	equation	ΔH / kJ mol^{-1}
1	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	ΔH_1
2	$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$	$\Delta H_2 = +27.2$

Complete the reaction pathway diagram in Fig. 2.1 for reaction 2.
Label the diagram to show the enthalpy change, ΔH_2, and the activation energy, E_A.



Use of bond energies to calculate the enthalpy change of reaction, ΔH_r

17. Use equation **1** and the bond energy values in the following table to calculate the change in enthalpy, ΔH, for the thermal decomposition of 1 mole of HI(g). Show your working.
equation **1** $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ [2]

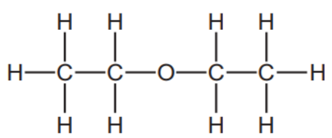
Bond	Bond energy, /$kJmol^{-1}$
H-H	436
I-I	151
H-I	299

18. In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4.
reaction 1 $C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$
Use the bond energy values in Table 4.1 to calculate the enthalpy change, ΔH_r, for reaction 1. (Ans = -50 $kJmol^{-1}$) [2]

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

19. When **G**, $C_4H_{10}O$, is heated, thermal decomposition occurs.
$C_4H_{10}O(g) \rightarrow C_2H_6(g) + CO(g) + CH_4(g)$ $\Delta H = -7.00 kJmol^{-1}$
G has following structure.

G



Calculate the bond energy of C≡O using the bond energy values in the following table and the enthalpy change, ΔH, for the thermal decomposition of *G*. Show your working.

bond	bond energy, /$kJmol^{-1}$
C–C	350
C–O (in *G*)	360
C–H	410

bond energy ($C\equiv O$) = ...(ans 1077)........ $kJmol^{-1}$ [2]

Measuring enthalpy changes

20. An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and H_2SO_4(aq).
100cm^3 of 1.00 moldm^{-3} NaOH(aq) is added to 75cm^3 of 1.00moldm^{-3} H_2SO_4(aq) in a polystyrene cup and stirred.
Results from the experiment are shown in following table.

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.
(ans: amount of H_2SO_4(aq) neutralised = 0.05 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 $Jg^{-1}K^{-1}$
- 1.00cm^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.

(Ans: ΔH_{neut} = -57057 units= J mol^{-1} or, 57.057 kJmol^{-1}) [3]

21. In an experiment, 50.0cm^3 of 2.00 moldm^{-3} NaOH(aq) is added to 60.0cm^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.

(ans; amount of H_2SO_4 neutralised = 0.05 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 –57.1kJmol^{-1}
- full dissociation of H_2SO_4(aq) occurs
- the specific heat capacity of the final solution is 4.18Jg^{-1}K^{-1}
- 1.00cm^3 of the final solution has a mass of 1.00g
- there is no heat loss to the surroundings
- the experiment takes place at constant pressure.

Show your working.

(Ans: theoretical maximum temperature = **33.8 °C**) [3]

22. Separate samples of Na_2CO_3 and $NaHCO_3$ react with HCl (aq) to produce the same products, as shown in Table

reaction	equation	ΔH/kJ mol^{-1}
1	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	ΔH_1
2	$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$	$\Delta H_2 = +27.2$

The value for ΔH_1 is determined by experiment using the following method.

- 50.0 cm^3 of 2.00 mol dm^{-3} HCl (aq) is added to a polystyrene cup.
- The initial temperature of the acid is recorded as 19.6 °C.
- 0.0400 mol of Na_2CO_3 is added and the mixture is stirred.
- All the solid Na_2CO_3 disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2 °C.

(i) Describe **one** other observation that shows the reaction is complete.

.... [1]

(i) Calculate the value of ΔH_1 in kJ mol^{-1}.
Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.
Show your working.

ΔH_1 = ... kJ mol^{-1} [3]

(iii) Thermal decomposition occurs when $NaHCO_3$ is heated.
reaction 3 $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$
Calculate the enthalpy change for reaction 3, ΔH_r, using the data in Table 2.1 and the value of ΔH_1 calculated in (ii).
(If you were unable to calculate a value for ΔH_1 in (ii), assume the enthalpy change is –38.4 kJ mol^{-1}. This is not the correct value.)

ΔH_r = ... kJ mol^{-1} [2]

23. Separate samples of Na_2CO_3 and $NaHCO_3$ react with HCl (aq) to produce the same products, as shown in Table

reaction	equation	ΔH / kJ mol^{-1}
1	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	ΔH_1
2	$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$	$\Delta H_2 = +27.2$

The value for ΔH_1 is determined by experiment using the following method.

• 50.0 cm^3 of 2.00 mol dm^{-3} HC*l* (aq) is added to a polystyrene cup.
• The initial temperature of the acid is recorded as 19.6 °C.
• 0.0400 mol of Na_2CO_3 is added and the mixture is stirred.
• All the solid Na_2CO_3 disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2 °C.
(i) Calculate the value of $\Delta H1$ in kJ mol^{-1}.
Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.
Show your working.

ΔH_1 = ... kJ mol^{-1} [3]

(ii) Thermal decomposition occurs when $NaHCO_3$ is heated.
reaction 3 2 $NaHCO_3 \rightarrow N_{a2}CO_3 + H_2O + CO_2$
Calculate the enthalpy change for reaction 3, ΔH_r, using the data in Table 2.1 and the value of ΔH_1 calculated in (b)(ii).
(If you were unable to calculate a value for ΔH_1 in (b)(ii), assume the enthalpy change is –38.4 kJ mol^{-1}. This is not the correct value.)

ΔHr = ... kJ mol^{-1}[2]

***... ***