PROSPERITY ACADEMY

AS CHEMISTRY 9701

Crash Course

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CHEMICAL ENERGETICS

COMPLETE NOTES

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Enthalpy Changes:-

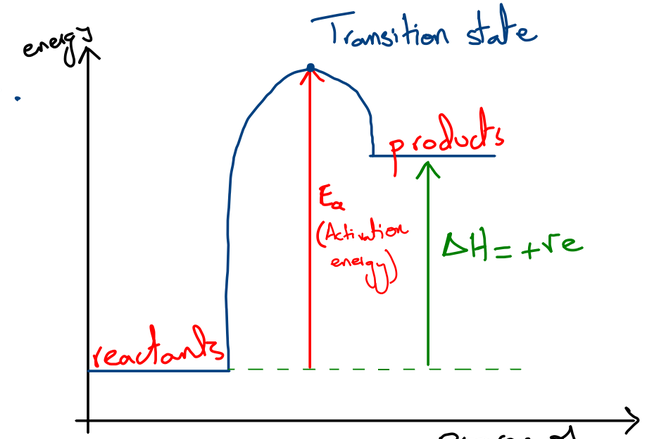
Enthalpy is the total heat energy content of a system.

Enthalpy change:- Change in heat energy content of a system measured at constant pressure.

2 types of reactions:-

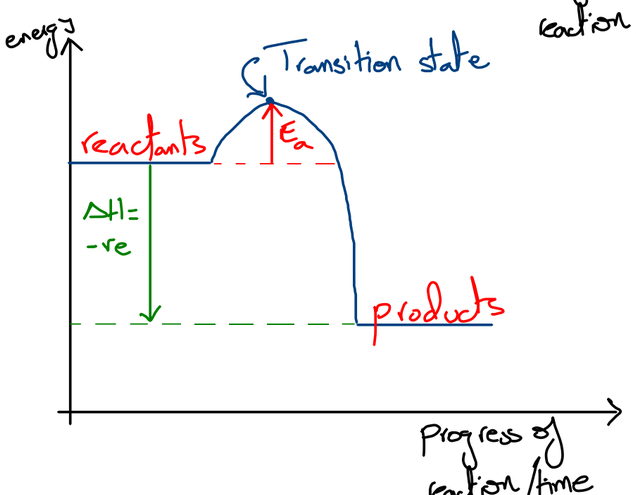
Endothermic reaction:- A reaction which absorbs heat energy from the surroundings.

- ΔH = $E_{products} - E_{reactants}$ = +ve
- All bond breaking is endothermic
- Examples:- Thermal decomposition and photosynthesis



Exothermic reaction:- A reaction in which heat energy is released to the surroundings.

- ΔH = $E_{products} - E_{reactants}$ = -ve
- All bond making is exothermic
- Examples:- Combustion and neutralization

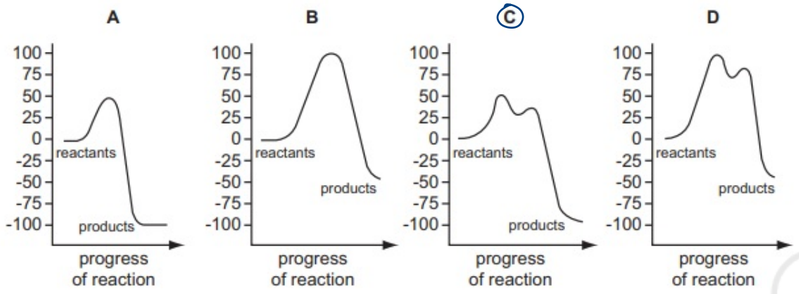


2 An exothermic chemical reaction proceeds by two stages.

reactants —(stage 1)→ intermediate —(stage 2)→ products

The activation energy of stage 1 is 50 kJ mol^{-1}. The overall enthalpy change of reaction is −100 kJ mol^{-1}.

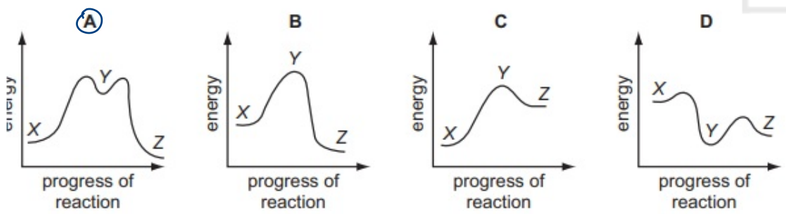
Which diagram represents the reaction pathway for this reaction?



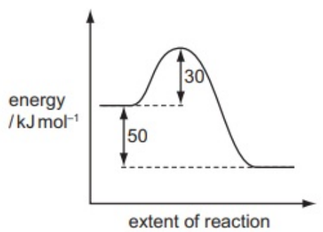
3 In the conversion of compound *X* into compound *Z*, it was found that the reaction proceeded by way of compound *Y*, which could be isolated. The following steps were involved.

$X \rightarrow Y$; ΔH, positive
$Y \rightarrow Z$; ΔH, negative

Which reaction profile fits these data?



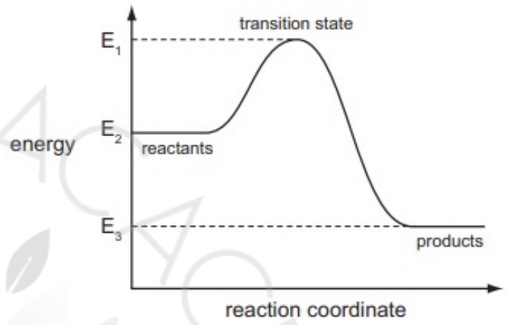
48 The reaction pathway for a reversible reaction is shown below.



Which statement is correct?

A The activation energy of the reverse reaction is +80 kJ mol^{-1}.
B The enthalpy change for the forward reaction is +30 kJ mol^{-1}.
C The enthalpy change for the forward reaction is +50 kJ mol^{-1}.
D The enthalpy change for the reverse reaction is +30 kJ mol^{-1}.

4 The reaction pathway diagram below illustrates the energies of reactants, products and the transition state of a reaction.

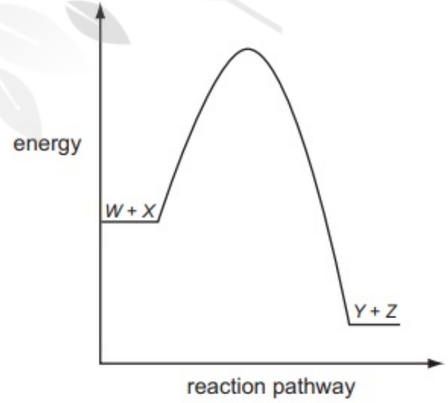


Which expression represents the activation energy of the forward reaction?

A $E_1 - E_2$ **B** $E_1 - E_3$ **C** $E_2 - E_3$ **D** $(E_1 - E_2) - (E_2 - E_3)$

5 The diagram represents the reaction pathway for the following reaction.

$W(g) + X(g) \rightarrow Y(g) + Z(g)$



What statement can be made about the reverse reaction, $Y(g) + Z(g) \rightarrow W(g) + X(g)$?

A It will have a larger activation energy and a positive ΔH.
B It will have a larger activation energy and a negative ΔH.
C It will have a smaller activation energy and a positive ΔH.
D It will have a smaller activation energy and a negative ΔH.

Standard Conditions:-

To compare ΔH for different reactions, we calculate ΔH under standard conditions ($\Delta H^{\ominus}$)

1) Temperature of 25°C (298 K)
2) A pressure of 1 atm (1.013×10^5 Pa)
3) The concentration of any solution must be 1 mol dm^{-3}
4) All chemicals must be in their preferred states at these conditions.

1) Standard enthalpy change of reaction, $\Delta H^{\ominus}_r$: Amount of energy released or absorbed when the molar quantities of reactants as given in the chemical equation react completely to form products under standard conditions.

e.g. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\quad \Delta H^{\ominus}_r = -92$ KJ

$2N_2(g) + 6H_2(g) \rightleftharpoons 4NH_3(g)$ $\quad \Delta H^{\ominus}_r = -184$ KJ

2) Standard enthalpy change of formation, $\Delta H_f^\ominus$: Amount of heat energy absorbed or released when 1 mole of a compound is formed from its constituent elements, under standard conditions.

$Na_{(s)} + \frac{1}{2}Cl_{2(g)} \longrightarrow NaCl_{(s)}$ $\quad \Delta H_f^\ominus = -41 \text{ KJ mol}^{-1}$

$C_{(graphite)} + O_{2(g)} \longrightarrow CO_{2(g)}$ $\quad \Delta H_f^\ominus = -394 \text{ KJ mol}^{-1}$ per mole of product

↳ graphite is used as state of carbon as it is most stable

$\frac{1}{2}H_{2(g)} + \frac{1}{2}Br_{2(g)} \longrightarrow HBr_{(g)}$ $\quad \Delta H_f^\ominus = -36 \text{ KJ mol}^{-1}$

* $\Delta H_f^\ominus$ of an element is always zero! $O_{2(g)} \longrightarrow O_{2(g)}$ $\quad \Delta H_f^\ominus = 0$

3) Standard enthalpy change of combustion, $\Delta H_c^\ominus$: Amount of heat energy released when 1 mole of a substance is completely burned in oxygen under standard conditions.

$CH_{4(g)} + 2O_{2(g)} \longrightarrow CO_{2(g)} + 2H_2O_{(l)}$ $\quad \Delta H_c^\ominus = -890 \text{ KJ mol}^{-1}$

$C_{(graphite)} + O_{2(g)} \longrightarrow CO_{2(g)}$ $\quad \Delta H_c^\ominus = -394 \text{ KJ mol}^{-1}$ per mole of substance burned

Q. What would happen if incomplete combustion occured?
$\Delta H_c^\ominus$ would be less negative (less exothermic)

Q. What would happen if steam was formed instead in reaction 1?
$\Delta H_c^\ominus$ would be less negative (less exothermic) as hydrogen bonds would not be made (Bond formation is exothermic)

4) Standard enthalpy change of neutralization, $\Delta H^{\ominus}_n$: Amount of heat energy released when solutions of acid and alkali react together to form 1 mole of water under standard conditions.

e.g. $NaOH_{(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(s)} + H_2O_{(l)}$ $\quad \Delta H^{\ominus}_n = -57\ KJ\,mol^{-1}$ per mole of water

ionic equation: $Na^+ + OH^- + H^+ + Cl^- \longrightarrow Na^+ + Cl^- + H_2O$

$\Rightarrow OH^-_{(aq)} + H^+_{(aq)} \longrightarrow H_2O_{(l)}$ $\quad \Delta H^{\ominus}_n = -57\ KJ\,mol^{-1}$

e.g. $\frac{1}{2}H_2SO_{4(aq)} + KOH_{(aq)} \longrightarrow H_2O_{(l)} + \frac{1}{2}K_2SO_{4(aq)}$ $\quad \Delta H^{\ominus}_n = -57\ KJ\,mol^{-1}$

ionic: $H^+ + \frac{1}{2}SO_4^{2-} + K^+ + OH^- \longrightarrow H_2O + K^+ + \frac{1}{2}SO_4^{2-}$

$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$ $\quad \Delta H^{\ominus}_n = -57\ KJ\,mol^{-1}$

- All neutralizations involving a strong acid and alkali have $\Delta H^{\ominus}_n = -57\ KJ\,mol^{-1}$
- All neutralizations involving a weak acid and/or weak alkali have $\Delta H^{\ominus}_n$ slightly lower than $-57\ KJ\,mol^{-1}$
  - ↳ some energy is required to complete the ionization.

1 For which equation is the enthalpy change correctly described as an enthalpy change of formation?

A $2NO(g) \rightarrow N_2(g) + O_2(g)$

B $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

C $H_2O(l) + NaCl(s) \rightarrow NaCl(aq)$

D $K(s) + Mn(s) + 2O_2(g) \rightarrow KMnO_4(s)$

16 Hydrazine, N_2H_4, is widely used as a rocket fuel because it reacts with oxygen as shown, producing 'environmentally friendly' gases.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g) \qquad \Delta H = -534\,kJ\,mol^{-1}$$

Despite its use as a rocket fuel, hydrazine does not burn spontaneously in oxygen.

Which statement explains why hydrazine does **not** burn spontaneously?

A Hydrazine is a liquid.

B The activation energy is too high.

C The N≡N bond is very strong.

D The reaction is exothermic.

17 Skiers trapped by snowstorms use heat packs to keep warm. The heat may be generated by the reaction below.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s) \quad ; \quad \Delta H^{\ominus} = \frac{-1648\,kJ}{2} = -824\,kJ\,mol^{-1}$$

$2Fe(s) + 1.5O_2(g) \rightarrow Fe_2O_3(s)$

What is the standard enthalpy change of formation of iron(III) oxide?

A $0\,kJ\,mol^{-1}$

B $-824\,kJ\,mol^{-1}$

C $-1648\,kJ\,mol^{-1}$

D $-3296\,kJ\,mol^{-1}$

40 The equation for a reaction is shown.

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)\ ;\ \Delta H = x\,kJ\,mol^{-1}$$

Which pair of descriptions is fully correct for this reaction?

	type(s) of enthalpy change	value of x
A	formation only	positive
B	formation only	negative
C	combustion, formation	positive
D	combustion, formation	negative

61 Which reaction has an enthalpy change equal to the standard enthalpy change of formation of propane?

A $3C(g) + 4H_2(g) \rightarrow C_3H_8(g)$

B $3C(g) + 8H(g) \rightarrow C_3H_8(g)$

C $3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$

D $3C(s) + 4H_2(g) \rightarrow C_3H_8(l)$

Calorimetry :- Finding enthalpy of neutralization

50g
50.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid was placed in a polystyrene cup and its temperature was found to be 21.5 °C.

50g
50.0 cm^3 of 1.00 mol dm^{-3} sodium hydroxide (at the same temperature) was added to the cup.

The reaction mixture was stirred with the thermometer and the highest temperature was found to be 28.0 °C.

$$HCl + NaOH \longrightarrow H_2O + NaCl$$

n HCl = $1 \times 50 \times 10^{-3}$ = 0.05 moles n of water = 0.05 moles

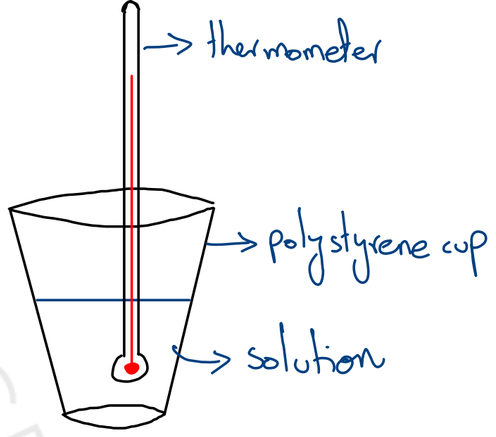
n NaOH = $1 \times 50 \times 10^{-3}$ = 0.05 moles

$Q = mc\Delta\theta$

$= 100 \times 4.18 \times (28 - 21.5) = 2717$ J

$\Delta H_n = (2717 \times 10^{-3}) / 0.05 = 54.34 \simeq \boxed{-54.3\ KJ\ mol^{-1}}$

Apparatus :-



Q. How can we reduce heat losses?
- Use a lid
- Insulate polystyrene cup (Use 2 or 3 cups)

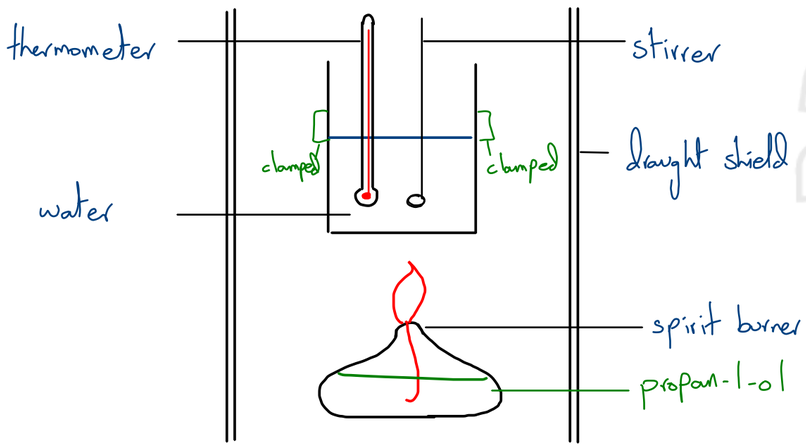
Q. Suggest reasons for why your value may not be accurate?
1) Heat loss to surroundings 2) Precision of thermometer is limiting
3) Initial temperature is non standard 4) Assumed $c = 4.18\ Jg^{-1}K^{-1}$

- It takes 4.18 J of energy to raise the temperature of 1g of pure water by 1°C or 1 K. ($c = 4.18\ Jg^{-1}K^{-1}$)
- Heat absorbed by water : $Q = mc\Delta\theta$ (↳ change in temp; ↳ mass)
- $1cm^3$ of solution has 1g of mass
- $\Delta H = Q \times 10^{-3} / \text{no. of moles}$
  - $\times 10^{-3}$ to convert to KJ
  - no. of moles: for $\Delta H^{\ominus}_n$ = n of water; for $\Delta H^{\ominus}_c$ = n of substance burned

- Put - / + as per required.

Calorimetry :- Finding enthalpy of combustion

Q. A spirit burner filled with propan-1-ol is measured to have a mass of 86.27g. The apparatus is setup as shown below. The heat from the spirit burner is used to raise the temperature of water in a beaker which has a mass of 100g. The starting temperature of the water was 20.2°C and the ending temperature was 30.9°C. The spirit burner was reweighed to have a mass of 86.06g. Calculate the ΔH_c of propan-1-ol.



$Q = mc\Delta\theta$

$= 100\,(4.18)(30.9 - 20.2) = 4472.6\ J$

$\Delta H = 4472.6 \times 10^{-3} / \frac{0.21}{60}$

$\Delta H_c = 1277.88$

$= -1280\ kJ\,mol^{-1}$

propan-1-ol = $CH_3CH_2CH_2OH$

$M_r = 60$

mass = 86.27 - 86.06

= 0.21g

$n = \frac{0.21}{60}$

Q. The correct value for $\Delta H_c^{\theta}\ CH_3CH_2CH_2OH$ is $-2021\ kJ\,mol^{-1}$. Suggest reasons for why your value is so different.

1) Heat losses
2) Incomplete combustion of fuel
3) Small mass of fuel has high percentage error
4) Precision of thermometer is limiting
5) Non standard conditions
6) Assumed $c = 4.18\ J\,g^{-1}\,K^{-1}$

8 50 cm^3 of 2.50 mol dm^{-3} hydrochloric acid was placed in a polystyrene beaker of negligible heat capacity. Its temperature was recorded and then 50 cm^3 of 2.50 mol dm^{-3} NaOH at the same temperature was quickly added, with stirring. The temperature rose by 17 °C.

The resulting solution may be considered to have a specific heat capacity of 4.2 J g^{-1} K^{-1}.

What is an approximate value for the molar enthalpy change of neutralisation of hydrochloric acid and sodium hydroxide from this experiment?

A $\frac{-(50 \times 4.2 \times 17)}{(0.050 \times 2.5)}$ J mol^{-1}

B $\frac{-(50 \times 4.2 \times 17)}{(0.10 \times 2.5)}$ J mol^{-1}

C $\frac{-(100 \times 4.2 \times 17)}{(0.050 \times 2.5)}$ J mol^{-1}

D $\frac{-(100 \times 4.2 \times 17)}{(50 \times 2.5)}$ J mol^{-1}

9 In a calorimetric experiment 1.60 g of a fuel is burnt. 45 % of the energy released is absorbed by 200 g of water whose temperature rises from 18 °C to 66 °C. The specific heat capacity of water is 4.2 J g^{-1} K^{-1}.

What is the total energy released per gram of fuel burnt?

A 25 200 J **B** 56 000 J **C** 89 600 J **D** 143 360 J

50 A student mixed 25 cm^3 of 0.10 mol dm^{-3} sodium hydroxide solution with 25 cm^3 of 0.10 mol dm^{-3} hydrochloric acid and noted a temperature rise of 2.5 °C.

What is the enthalpy change of the reaction per mole of NaOH?

A −209 kJ mol^{-1}

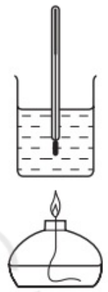
B −104.5 kJ mol^{-1}

C −209 J mol^{-1}

D −522.5 J mol^{-1}

55 A student carried out an experiment to determine the enthalpy change for the combustion of methanol.

The following results were obtained by the student.



start temperature of the water	20 °C
final temperature of the water	53 °C
mass of alcohol burner before burning	259.65 g
mass of alcohol burner after burning	259.15 g
mass of glass beaker plus water	150.00 g
mass of glass beaker	50.00 g

How much of the heat energy produced by the burning of methanol went into the water?

A 209 J **B** 13 794 J **C** 20 691 J **D** 22 154 J

56 A student mixed 25.0 cm^3 of 0.350 mol dm^{-3} sodium hydroxide solution with 25.0 cm^3 of 0.350 mol dm^{-3} hydrochloric acid. The temperature rose by 2.50 °C. Assume that no heat was lost to the surroundings.

The final mixture had a specific heat capacity of 4.20 J cm^{-3} K^{-1}.

What is the molar enthalpy change for the reaction?

A −150 kJ mol^{-1}

B −60.0 kJ mol^{-1}

C −30.0 kJ mol^{-1}

D −0.150 kJ mol^{-1}

Hess' law :- The enthalpy change of a reaction is independant of the path taken, provided all measurements are made under the same conditions.

↳ Derived from first law of thermodynamics → energy cannot be created or destroyed, it can only be converted from one form to the other.

- Helpful to determine enthalpy changes for reactions that cannot be performed in the laboratory.

6 Hydrazine reacts with oxygen according to the following equation.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

(i) Use the data in the table to calculate the standard enthalpy change of this reaction.

compound	$\Delta H_f^\ominus$/kJ mol^{-1}
$N_2H_4(l)$	50.6
$H_2O(g)$	−241.8

$N_2H_4 + O_2 \xrightarrow{\Delta H_1} N_2 + 2H_2O$

$\Delta H_2 = 50.6$ ↑ ↓ $\Delta H_3 = (-241.8) \times 2$

$N_2 + 2H_2 + O_2$

$\Delta H_1 = -50.6 + (2 \times -241.8) = -534.2$

$\Delta H^\ominus$ = ... -534.2 ..... kJ mol^{-1}

(ii) Although the above reaction is highly exothermic, hydrazine does not burn spontaneously in oxygen.
Suggest a reason for this.

The reaction has a high activation energy

(iii) Suggest why using hydrazine as a rocket fuel could be regarded as being 'environmentally friendly'.

It produces nitrogen and water which are not hazardous.

[4]

5 Alkanes such as methane, CH_4, undergo few chemical reactions. Methane will, however, react with chlorine but not with iodine.

Relevant standard enthalpy changes of formation for the reaction of methane with chlorine to form chloromethane, CH_3Cl, are given below.

	$\Delta H_f^\ominus$/kJ mol^{-1}
CH_4	−75
CH_3Cl	−82
HCl	−92

(a) (i) Use the data to calculate $\Delta H^\ominus_{reaction}$ for the formation of CH_3Cl.

$CH_4 + Cl_2 \xrightarrow{\Delta H_1} CH_3Cl + HCl$

$\Delta H_2 = -75$ ↑ ↓ $\Delta H_3 = -82 - 92$

$C + 2H_2 + Cl_2$

$\Delta H_1 = +75 + (-82 - 92) = -99$ KJ

4 Urea, $CO(NH_2)_2$, is a naturally occurring substance which can be hydrolysed with water to form ammonia according to the following equation.

$$H_2O(l) + CO(NH_2)_2(aq) \longrightarrow CO_2(aq) + 2NH_3(aq)$$

The standard enthalpy changes of formation of water, urea, carbon dioxide and ammonia (in aqueous solution) are given below.

compound	$\Delta H_f^{\ominus}$/kJ mol^{-1}
$H_2O(l)$	−287.0
$CO(NH_2)_2(aq)$	−320.5
$CO_2(aq)$	−414.5
$NH_3(aq)$	−81.0

Use these data to calculate the standard enthalpy change for the hydrolysis of urea.

ΔH_1

$H_2O(l) + CO(NH_2)_2(aq) \longrightarrow CO_2(aq) + 2NH_3(aq)$

$\Delta H_2 = -287 - 320.5$

$\Delta H_3 = -414.5 + 2(-81)$

$H_2 + O_2 + C + N_2$

$\Delta H_1 = -\Delta H_2 + \Delta H_3$

$= -(-287 - 320.5) + (-414.5 + 2(-81))$

$\Delta H_1 = +31\ KJ\,mol^{-1}$

14 Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation $C(graphite) + O_2(g) \longrightarrow CO_2(g)$

definition Energy released or absorbed (in this case: its release) when 1 mole of CO_2 is made from Carbon and oxygen under standard conditions. [3]

(b) Relevant $\Delta H_f^{\ominus}$ values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^{\ominus}$/kJ mol^{-1}
$CO_2(g)$	−394
$CH_3OH(g)$	−201
$H_2O(g)$	−242

(i) Use these values to calculate $\Delta H^{\ominus}_{reaction}$ for this synthesis of methanol.

Include a sign in your answer.

ΔH_1

$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$

$\Delta H_2 = -394$

$\Delta H_3 = -201 - 242$

$C + O_2 + 3H_2$

$\Delta H_1 = -\Delta H_2 + \Delta H_3 = -49$

$\Delta H^{\ominus}_{reaction} = -49$ kJ mol^{-1}

(ii) Suggest **one** possible environmental advantage of this reaction. Explain your answer.

CO_2 gas is removed which is a greenhouse gas

[5]

8 Ethanol, C_2H_5OH, is a most important industrial chemical and is used as a solvent, a fuel and an intermediate in large scale organic synthesis.

Ethanol is prepared industrially by the reaction of ethene and steam in the presence of a catalyst.

$$C_2H_4(g) + H_2O(g) \longrightarrow C_2H_5OH(g)$$

The standard enthalpy change of the reaction can be determined by using the standard enthalpy changes of combustion, $\Delta H_c^{\ominus}$, at 298 K.

	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
$C_2H_4(g)$	–1411
$C_2H_5OH(l)$	–1367

(a) Calculate the standard enthalpy change for the following reaction.

$$C_2H_4(g) + H_2O(l) \longrightarrow C_2H_5OH(l)$$

ΔH_1

$\Delta H_2 = -1411$ $+3O_2$ $+3O_2$ $\Delta H_3 = -1367$

$2CO_2 + 3H_2O$

$\Delta H_1 = \Delta H_2 - \Delta H_3 = -1411 + 1367 = -44$

$= -44$ KJ mol^{-1}

[2]

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant $\Delta H_c^{\ominus}$ values for this reaction are given in the table below.

compound	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
CO(g)	–283
$H_2(g)$	–286
$CH_3OH(g)$	–726

(b) Use these values to calculate $\Delta H_{reaction}^{\ominus}$ for the synthesis of methanol, using the following equation. Include a sign in your answer.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

ΔH_1

$\Delta H_2 = -283$ $+\frac{3}{2}O_2$ $+\frac{3}{2}O_2$ $\Delta H = -726$

$+2(-286)$

$CO_2 + 2H_2O$

$\Delta H_1 = -283 + 2(-286) + 726 = -129$

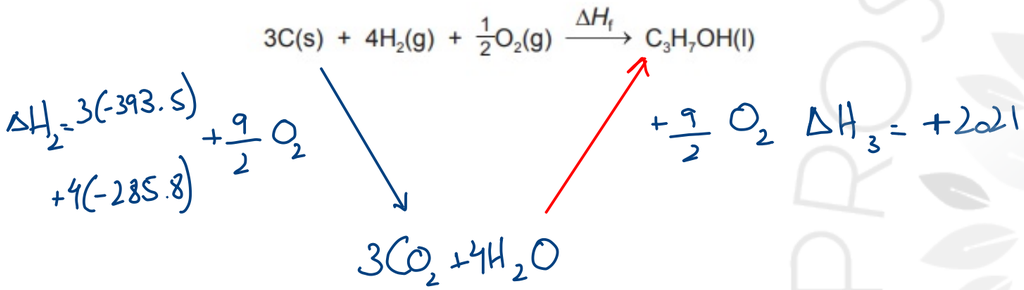
$\Delta H_{reaction}^{\ominus}$ = -129 kJ mol^{-1}

[3]

The table gives some enthalpy change of combustion values.

substance	enthalpy change of combustion / kJ mol^{-1}
C(s)	–393.5
$H_2(g)$	–285.8
$C_3H_7OH(l)$	–2021.0

(i) Construct a labelled energy cycle to show how these values could be used to calculate the enthalpy change of formation of $C_3H_7OH(l)$, ΔH_f.



(ii) Calculate the enthalpy change of formation, ΔH_f, of $C_3H_7OH(l)$.

$\Delta H_f = 3(-393.5) + 4(-285.8) + 2021$

$= -302.7$

ΔH_f = ... -302.7 ..... kJ mol^{-1} [2]

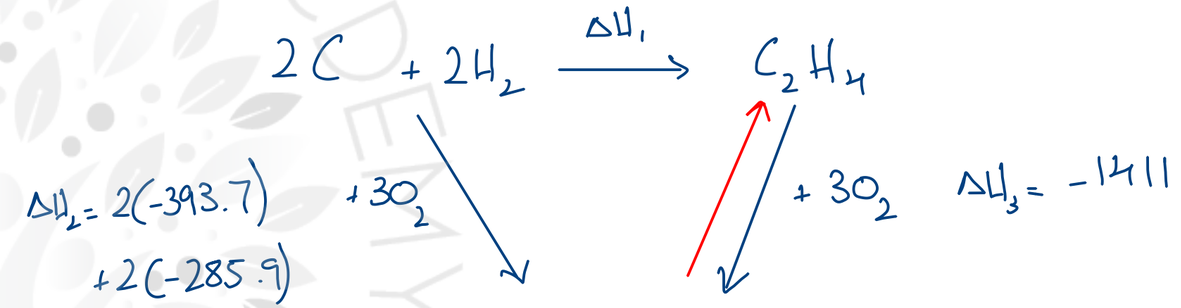
9 Carbon, hydrogen and ethene each burn exothermically in an excess of air.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H_c^{\ominus} = -393.7\,kJ\,mol^{-1}$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\quad \Delta H_c^{\ominus} = -285.9\,kJ\,mol^{-1}$

$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$ $\quad \Delta H_c^{\ominus} = -1411.0\,kJ\,mol^{-1}$

Use the data to calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, in kJ mol^{-1}, of ethene at 298 K.



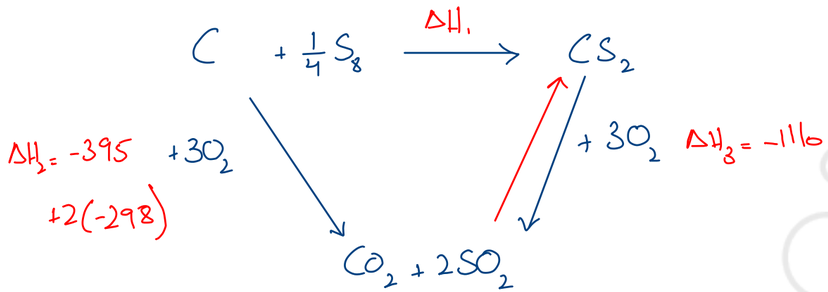
$\Delta H_1 = 2(-393.7) + 2(-285.9) + 1411 = +51.8\ kJ\ mol^{-1}$

10 Calculate the standard enthalpy change of formation of CS_2 from the following data. Include a sign in your answer.

standard enthalpy change of combustion of CS_2 = $-1110\,kJ\,mol^{-1}$

standard enthalpy change of formation of CO_2 = $-395\,kJ\,mol^{-1}$

standard enthalpy change of formation of SO_2 = $-298\,kJ\,mol^{-1}$

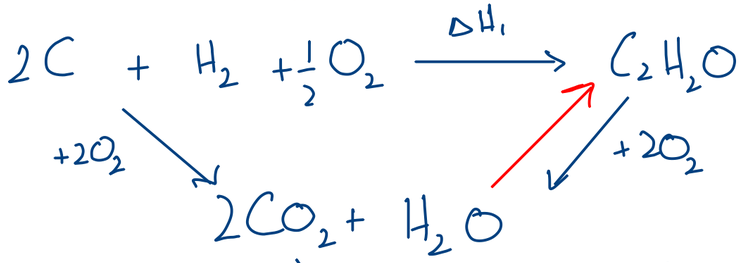


$\Delta H_1 = -395 + 2(-298) + 1110 = +119 \quad KJ\,mol^{-1}$

11 Ketene, C_2H_2O, is a member of a class of unsaturated organic compounds that is widely used in pharmaceutical research for the synthesis of organic compounds.

Use the data below to calculate the standard enthalpy change of formation of ketene.

	$\Delta H^{\ominus}$/kJ mol^{-1}
standard enthalpy change of formation of CO_2	−395
standard enthalpy change of combustion of H_2	−286
standard enthalpy change of combustion of $CH_2{=}C{=}O$	−1028



$\Delta H_1 = 2(-395) - 286 + 1028 = -48\ KJ\,mol^{-1}$

7 The standard enthalpy change of combustion of C_2H_2, $\Delta H_c^{\ominus}$, is $-1300\,kJ\,mol^{-1}$ at 298 K.

Values of relevant standard enthalpy changes of formation, $\Delta H_f^{\ominus}$, measured at 298 K, are given in the table.

substance	$\Delta H_f^{\ominus}$/kJ mol^{-1}
$CO_2(g)$	−394
$H_2O(l)$	−286

(i) Write balanced equations, with state symbols, that represent

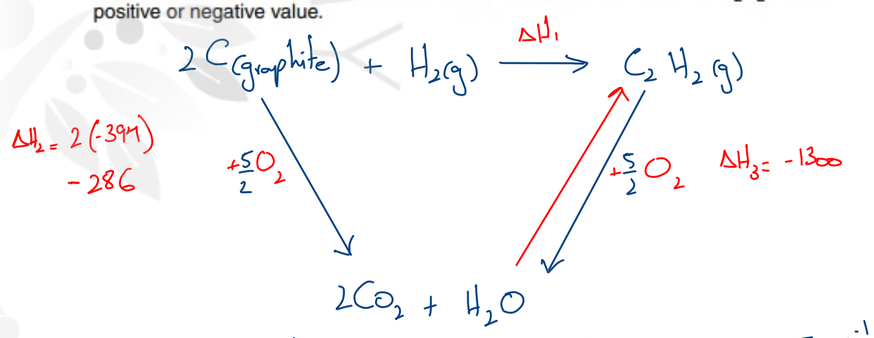
the standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, of C_2H_2, and

$C_2H_2(g) + \frac{5}{2}O_2 \longrightarrow 2CO_2 + H_2O$

the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of C_2H_2.

$2C_{(graphite)} + H_2(g) \longrightarrow C_2H_2(g)$

(ii) Use the data above and your answer to **(i)** to calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of C_2H_2.
Show clearly whether the standard enthalpy change of formation of C_2H_2 has a positive or negative value.



$\Delta H_1 = 2(-394) - 286 + 1300 = 226 \rightarrow +226\ KJ\,mol^{-1}$

Calculating enthalpy changes using bond energies:-

- Bond formation is exothermic ($\Delta H = -ve$)
- Bond breaking is endothermic ($\Delta H = +ve$)

$\Delta H = E_{reactants} - E_{products}$

C-H = 416 C≡C = 840 O=O = 496 C=O = 805 O-H = 460

3 **(d)** The equation for the complete combustion of ethyne is given below.
Use appropriate bond energy data from the *Data Booklet* to calculate a value for the enthalpy change of combustion of ethyne.

$$C_2H_2(g) + 5/2\,O_2(g) \rightarrow 2CO_2(g) + H_2O(g)$$

$H-C\equiv C-H + \frac{5}{2}\,O=O \rightarrow 2\,O=C=O + H-O-H$

$2(C-H) + 1(C\equiv C) + \frac{5}{2}(O=O) \rightarrow 4(C=O) + 2(O-H)$

$= 2(416) + 840 + \frac{5}{2}(496) - 4(805) - 2(460)$

$= -1240\ kJ\ mol^{-1}$

[3]

(e) The value for the standard enthalpy change of combustion of ethyne is $-1300\,kJ\,mol^{-1}$.

(ii) Explain why your answer to **(d)** does not have the same value as the standard enthalpy change of combustion.

- Average bond enthalpies
- In standard state, H_2O is liquid so hydrogen bonds have not been accounted in calculation.

[3]

35 The standard enthalpy change for the reaction

$$2NF_3(g) \rightarrow 2N(g) + 6F(g) \qquad \text{is } \Delta H^{\ominus} = +1668\,kJ$$

What is the bond energy of the N–F bond?

A $-556\,kJ\,mol^{-1}$
B $-278\,kJ\,mol^{-1}$
C $+278\,kJ\,mol^{-1}$
D $+556\,kJ\,mol^{-1}$

$2\left(F-\underset{F}{N}-F\right) \rightarrow 2N + 6F$

$6(N-F) = 1668$

$N-F = +278$

11 Methanol may be prepared by the reaction between carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

The relevant average bond energies are given below.

$E(C\equiv O)$	$1077\,kJ\,mol^{-1}$
$E(C-O)$	$360\,kJ\,mol^{-1}$
$E(C-H)$	$410\,kJ\,mol^{-1}$
$E(H-H)$	$436\,kJ\,mol^{-1}$
$E(O-H)$	$460\,kJ\,mol^{-1}$

$(C\equiv O) + 2(H-H) \rightarrow H-\underset{H}{\overset{H}{C}}-O-H$

$= 1077 + 2(436) - 3(416) - 360 - 460$

$= -101\ kJ\,mol^{-1}$

What is the enthalpy change of this reaction?

A $-537\,kJ\,mol^{-1}$
B $-101\,kJ\,mol^{-1}$
C $+101\,kJ\,mol^{-1}$
D $+537\,kJ\,mol^{-1}$

C-H = 410 I-I = 151 C-I = 240 H-I = 299

(ii) The corresponding reaction with iodine does **not** take place.

Use bond energy data from the *Data Booklet* to calculate a 'theoretical value' for $\Delta H_{reaction}$ for the following equation.

$$CH_4 + I_2 \rightarrow CH_3I + HI$$

$H-\underset{H}{\overset{H}{C}}-H + I-I \rightarrow H-\underset{H}{\overset{H}{C}}-I + H-I$

$4(C-H) + (I-I) \rightarrow 3(C-H) + (C-I) + (H-I)$

$= 4(416) + 151 - 3(416) - 240 - 299$

$= +22\ kJ\ mol^{-1}$

(iii) Suggest why this reaction does **not** in fact occur.

High activation energy.

[5]