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SENIOR FIVE TERM 2

TOPIC 2/3: Thermochemistry

Topic competency: The learner analyses the trends and periodic properties of elements, to explain and predict the reactivity and properties of elements in the Periodic Table.

Energy changes

In most chemical reactions there is an associated energy change, shown by the evolution of heat in an exothermic reaction /process or by absorption of heat in an endothermic reaction. It is generally possible to measure what the change is, even though it may not be possible to determine the absolute energy levels before and after the change.

Heat changes at constant volume are known as **internal energy change (ΔU)** while those at constant pressure are known as **enthalpy changes (ΔH)**. If no volume change is involved $\Delta H = \Delta U$, but with a volume change, the difference between ΔH and ΔU arises because work is involved in expansion or contraction. For practical purposes, these heat changes are used interchangeably.

Heat absorbed or liberated in a reaction varies with the quantities of the reactants, the temperature and pressure at which a reaction is carried out.

Standard enthalpy changes

These are enthalpy changes when molar quantities are considered at 298K and 1 atmospheres.

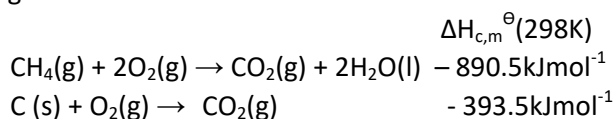
Standard molar enthalpy changes are then symbolized by $\Delta H_m^\ominus(298K)$ but the simpler symbol, ΔH , may be used. ΔH has negative value (heat evolved) for exothermic reaction and positive value for endothermic reaction. In thermodynamic, each enthalpy change is given a name specifying the initial and final energy level states as follows:

(a) Enthalpy of combustions

The standard molar enthalpy of combustion of a substance is the enthalpy changes when 1 mole of it is completely burn in oxygen under standard conditions.

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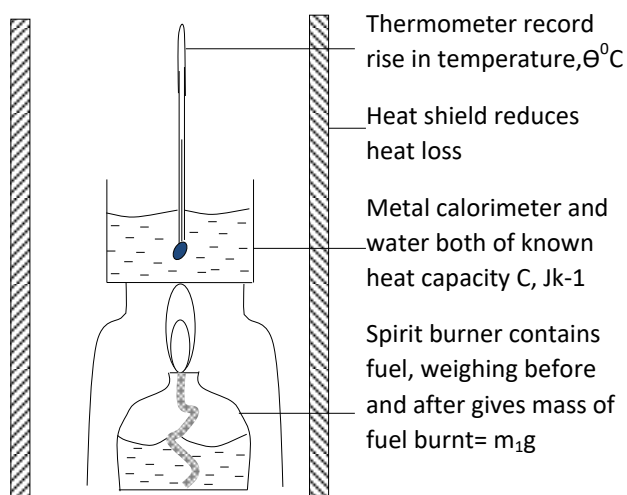
E.g.



Note that at 298K and 1 atmosphere, methane is a gas while carbon dioxide is a solid.

Experimental method for finding enthalpy of combustion a liquid fuel

The figure below shows a simple method for obtaining approximate value for the enthalpy of combustion of a fuel



Calculations

Assumption

Heat produced by combusting fuel = heat gained by water

Heat gained by calorimeter and water = $C\theta$ joules

It implies that

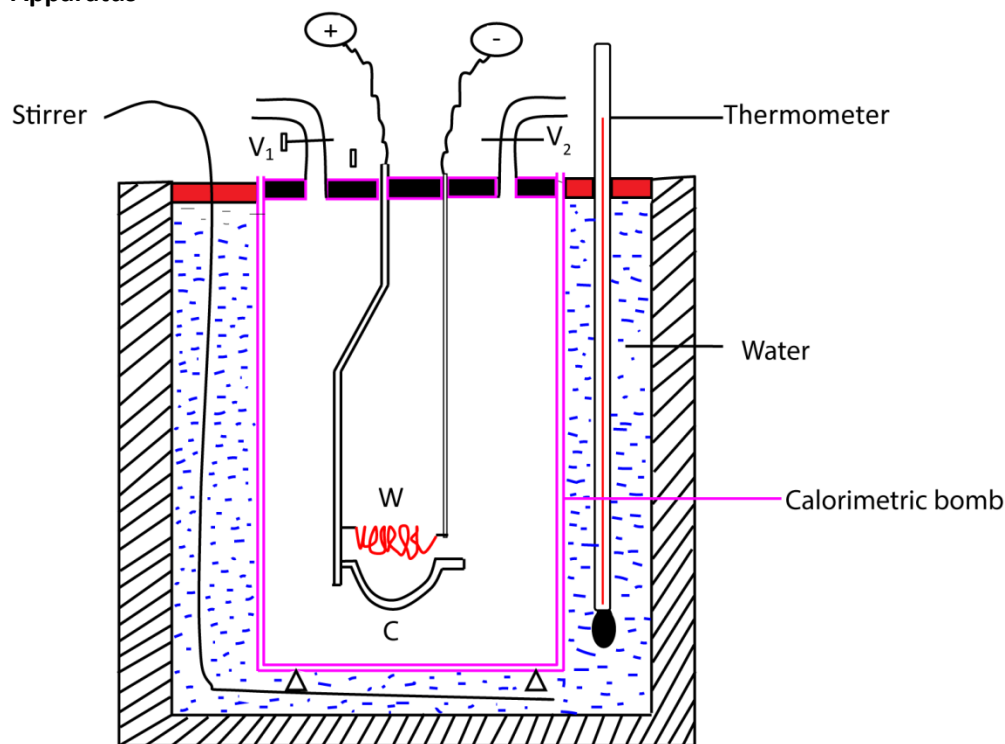
$m_1\text{g}$ of fuel produce = $C\theta$ joules

$M_r \text{ g}$ (molecular mass of substance) produce = $\frac{M_r C \theta}{m_1} \text{ joulesmol}^{-1}$

Experimental method for finding enthalpy of combustion using a calorimetric bomb.

This method is suitable for determination of enthalpy of combustion of carbon, Sulphur or sugar but can be used on a liquid fuel

Apparatus



Procedure

1. A known mass, m_1 g, of a substance is placed in a platinum crucible, C.
2. The bomb is filled with oxygen at a pressure of about 20 atmospheres and immersed in a known mass (m_w g) of water which is kept stirred.
3. The substance is ignited by passing an electric current through a small coil of iron wire, W.
4. The rise in temperature (θ) of water is read to 0.01°C with an accurate thermometer.

Calculation

Heat produced by burning m_1 g of substance = heat gained by m_w g of water
= $m_w \times 4.2 \times \theta$
where 4.2 is specific heat capacity of water

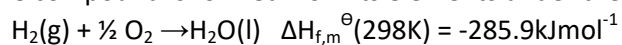
Therefore, enthalpy of combustion
of a substance

$$= \frac{4.2m_w\theta M_r}{m_1}$$

where, M_r is the relative molecular mass of the substance.

(b) Enthalpy of formation of compounds

The standard molar enthalpy of formation of a compound is the enthalpy change when 1 mole of the compound is formed from its elements under the standard conditions. e.g.

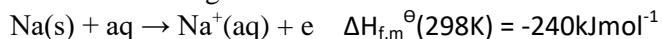


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Since there is no energy change in formation of an element under standard conditions; the standard enthalpies of all pure elements in their standard states is zero

(c) Enthalpy of formation of hydrated ions;

This refers to enthalpy change of the formations of 1mole of hydrated ions from an element in its standard state. e.g.



The figures are usually quoted on arbitrary scale on which the enthalpy of formation of $\text{H}^+(\text{aq})$ is taken to be zero. i.e.

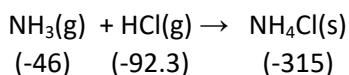


(d) Enthalpy of reaction

It is enthalpy change when 1mole of a substance is formed from its reactants at standard conditions. Tabulated values of the standard enthalpies of formation of compounds and or hydrated ions can be used to calculate the standard enthalpy change for any reaction

$$\left\{ \begin{array}{l} \text{Standard} \\ \text{enthalpy} \\ \text{change of a} \\ \text{reaction} \end{array} \right\} = \left\{ \begin{array}{l} \text{Sum of} \\ \text{standard} \\ \text{enthalpies of} \\ \text{formation of} \\ \text{product} \end{array} \right\} - \left\{ \begin{array}{l} \text{Sum of} \\ \text{standard} \\ \text{enthalpies of} \\ \text{formation of} \\ \text{reactants} \end{array} \right\}$$

Typical examples



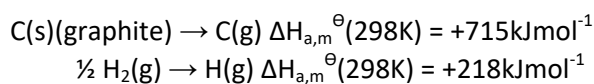
$$\Delta H_{r,m}^\ominus(298\text{K}) = -315 - (-46 + -92.3) = -177\text{kJmol}^{-1}$$

The negative sign means that reaction is exothermic.

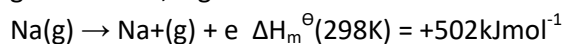
The standard enthalpy depends only on the difference between the standard enthalpy of the reactants and the products and not on the route by which the reaction occurs.

The ideal is embodied in Hess's law, which state that, "if a reaction take place by more than one route, the overall change in enthalpy is the same whichever route is followed" or "enthalpy change of a reaction is independent of the route followed to the product".

- (e) **Enthalpy of atomization:** refers to the enthalpy change for the formation of 1mole of gaseous atoms from an element in its standard state

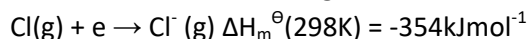


- (f) **Enthalpy of ionization:** refers to enthalpy change for conversion of gaseous atoms into free gaseous ions, e.g.



Factors affecting magnitude of ionization energy

- (i) **Size of an atom:** Small atoms have strong attraction to outer electrons leading to high ionization energy.
 - (ii) **Electronegativity:** highly electronegative atoms have high attraction to valence electrons causing high ionization energy.
 - (iii) **Electropositivity:** highly electropositive atoms have low attraction to valence electrons leading low ionization energy.
- (g) **Enthalpy of electron affinity:** refers to the enthalpy change for formation of free gaseous anions from 1mole of free gaseous atoms.

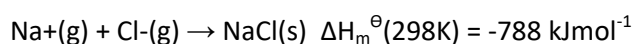


Factors affecting magnitude of electron affinity

- (i) **Size of an atom:** Small atoms have strong attraction to outer electrons leading to high negative electron affinity.
- (ii) **Electronegativity:** highly electronegative atoms have high attraction to valence electron causing high negative electron affinity
- (iii) **Electropositivity:** highly electropositive atoms have low attraction to valence electrons leading high positive electron affinity.

(h) Lattice enthalpy

This is the name given to the enthalpy change for the reaction in which 1mole of crystalline solid is formed from its component ions in the gaseous phase.



Factors affecting the magnitude of lattice energy

- (i) **Size of the ion;** small ions have strong interionic attraction causing high lattice energy
- (ii) **Charge on the ions:** ions with big charge have strong interionic attraction leading to high lattice energy.

(i) Enthalpy of solution

This refers to the enthalpy change for the formation of an infinitely dilute solution of 1 mole of salt.



Factors affecting the magnitude of enthalpy of solution

Enthalpy of solution = lattice energy (+ve) + sum of hydration energy of ions (-ve)

When the lattice energy exceeds the sum of hydration energies of the ions, the enthalpy of solution is positive (endothermic) and the salt is insoluble.

When the lattice energy is less than the sum of hydration energies of the ions, the enthalpy of solution is negative (exothermic) and the salt is soluble.

(j) Enthalpy of hydration

This refers to the enthalpy change when 1mole of gaseous ions is hydrated. e.g.

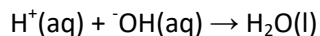


Factors affecting the magnitude of hydration energy

- (i) **Size of the ion:** small ions have strong attraction to water molecules leading to high hydration energy.
- (ii) **Charge on the ions:** ions with high big charge have a strong attraction to water molecules leading to high enthalpy of hydration.

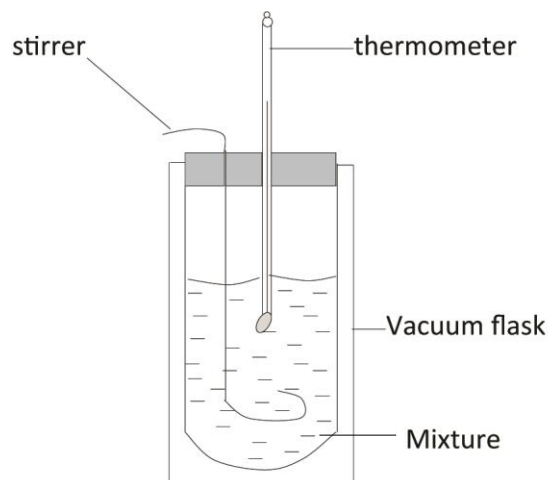
(k) Enthalpy of neutralization

This refers to enthalpy change for the formation 1 mole of water is formed from hydrogen and hydroxide ions



Measurement of standard enthalpy of neutralization

The heat released when a known amount of water is formed is found by measuring the temperature produced in a calorimeter and its contents.



A neutralization reaction is carried out in the calorimeter of known heat capacity, C .

Known volume of standard acid ($v \text{ cm}^3$) and alkali ($v \text{ cm}^3$) are added to calorimeter, and temperature change $\theta^\circ\text{C}$ is noted.

The number of moles of water formed, X moles, is calculated

Calculations

Assumptions:

- (i) The density of water = density of solution = 1gcm^{-3} .
- (ii) Specific heat of solution = specific heat capacity of water = $c \text{ Jg}^{-1}\text{K}^{-1}$
- (iii) Heat given out on neutralization = Heat received by water + calorimeter of capacity, C .

Thus, heat given out = $C\theta + (v+v)c\theta$

Thus X mole of water formed produce $= (C\theta + 2vc\theta)\text{J}$

1mole of water produced requires $= \frac{(C\theta + 2vc\theta)}{X} \text{ Jmol}^{-1}$

Example 1

250 cm^3 of 0.40M were added to 250cm^3 of 0.40M HCl in the calorimeter heat capacity of 90 J K^{-1} . The temperature of the two solutions was 17.5°C and rose to 20.1°C

Calculate the enthalpy of neutralization assuming that the specific heat capacities of solution are the same as that of water = $4.180\text{J g}^{-1} \text{ K}^{-1}$.

Calculation

Temperature change $\theta = 20.1 - 17.5 = 2.6^\circ\text{C}$

Heat liberated $= (C\theta + 2vc\theta)$
 $= 90 \times 2.6 + (250 + 250) \times 4.180 \times 2.6$

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$$= 5668\text{J}$$

Moles of water formed = moles of NaOH

$$= \frac{250 \times 0.40}{1000}$$

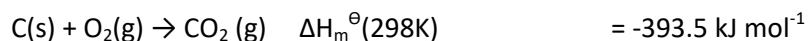
$$= 0.1\text{mole}$$

Molar heat of formation of water $= \frac{5668}{0.1} = -56680\text{Jmol}^{-1}$.

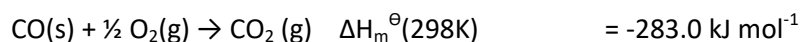
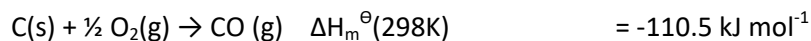
The negative sign signifies that heat is liberated.

Enthalpy diagrams

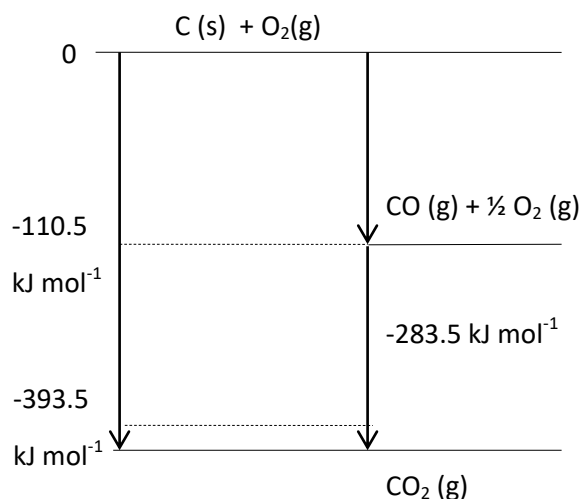
These are constructed by application of Hess's law: that states "enthalpy change of a reaction is independent of the route followed to the product." For instance, the enthalpy change for conversion of carbon into carbon dioxide is the same whether it is carried out in one step;



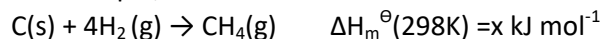
Or two steps



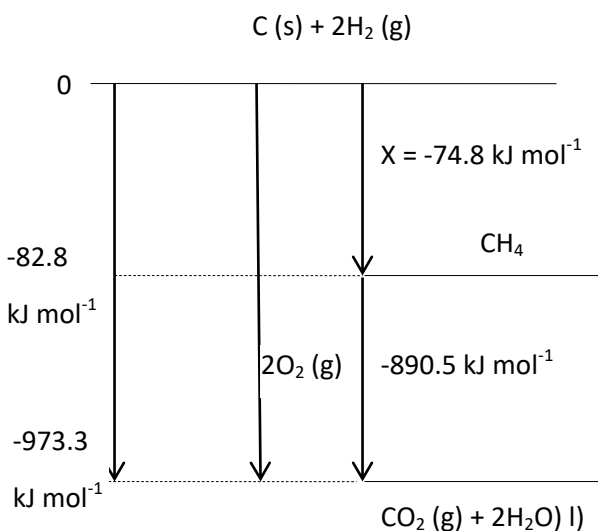
The relationship between various enthalpy changes is conveniently summarized in an enthalpy diagram below.



Such diagrams are used to obtain values for enthalpy changes that cannot be measured directly. The enthalpy of formation of methane cannot be measured directly since carbon and hydrogen do not react for example;



The enthalpies of combustion of carbon ($-393.5 \text{ kJ mol}^{-1}$), hydrogen ($-289.9 \text{ kJ mol}^{-1}$) and methane ($-890.5 \text{ kJ mol}^{-1}$) can however be measured and the required enthalpy of formation is obtained from them ($X = -82.8 \text{ kJ mol}^{-1}$) as summarized in figure below:



$$\begin{aligned} \text{i.e. } X + (-890.5) &= -393.5 + 2(-289.9) \\ &= -82.8 \text{ kJ mol}^{-1} \end{aligned}$$

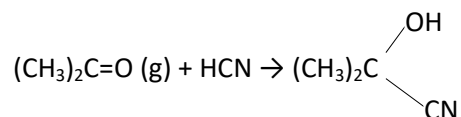
Standard enthalpy for a reaction from average standard bond enthalpies

When the standard enthalpy for a reaction cannot be measured, approximate value can be obtained by using average standard bond enthalpies. During reaction energy must be supplied to break bonds in the reactants and energy is given out when the bonds in the product form.

The Standard enthalpy of reaction	=	sum of the average bond of reactants	-	sum of the average bond of products
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Example2

Calculate the standard enthalpy change the reaction



Mean standard enthalpies are C=O = 743, C-H = 412; C-O = 360, C-C = 348, H-O = 463.

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Method

Bond broken	One	C=O	ΔH^θ	743 kJ mol ⁻¹
	one	C-H	ΔH^θ	412 kJ mol ⁻¹
Total energy absorbed				1155 kJ mol ⁻¹

Bond formed	One	C-O	ΔH^θ	360 kJ mol ⁻¹
	One	O-H	ΔH^θ	463 kJ mol ⁻¹
	one	C-C	ΔH^θ	4348 kJ mol ⁻¹
Total energy produced				1171 kJ mol ⁻¹

$$\begin{aligned} \text{Standard enthalpy of reaction} &= 1155 - 1171 \\ &= -16 \text{ kJ mol}^{-1}. \end{aligned}$$

Exercise

1. (a) The thermo energy changes for some process are shown in the table below

Process	Energy (kJmol ⁻¹)
Atomization of calcium	+178
First ionization energy of calcium	+590
Second ionization energy of calcium	+1146
Formation of calcium fluoride	-1220
Electron affinity of fluorine	-328
Bond dissociation energy of fluorine	+242.7

- (i) Calculate the lattice energy of calcium fluoride crystal. (02marks)
 (ii) Determine the enthalpy of solution of calcium fluoride
 [enthalpy of hydration of Ca²⁺ and F⁻ ion are -1587 and - 515 kJmol⁻¹ respectively]
 (b) (i) state the effect of temperature on solubility of calcium fluoride (01mark)
 (ii) give a reason for your answer

2. (a) Define standard enthalpy of formation (01mark)
 (b) some thermochemical data for calcium, calcium chloride and chlorine are given below.

	Energy (kJmol ⁻¹)
Formation of calcium chloride	-763
Atomization of chlorine	+121
Atomization of calcium	+193
First ionization energy of calcium	+590

Second ionization energy of calcium +1145

Electron affinity of chlorine -348

(i) Draw an energy diagram for formation of solid calcium chloride (04marks)

(ii) Calculate the lattice energy of calcium chloride. (2 ½ marks)

(c) If calcium formed a chloride in which calcium was in oxidation state of +1, would it be more or less stable than calcium chloride? Explain your answer. (03marks)

(d) (i) Calculate the enthalpy of solution of calcium chloride [enthalpies of hydration of Ca^{2+} and Cl^- are -1689.6 and - 383.7 kJmol^{-1} respectively] (2 ½ marks)

(ii) comment on the solubility of calcium chloride. (01mark)

(e) (i) State two factors that can affect the magnitude of hydration energy. (02marks)

(ii) Explain how the factors you have stated in (e)(i) affect hydration energy. (04marks)

3. (a) State

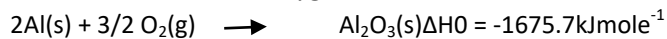
(i) What is meant by the term **first ionization energy**. (01marks)

(ii) Two factors that determine the value of the first ionization energy and explain how the factors affect the value of the first ionization energy

(b) (i) Define the term **first electron affinity**. (01mark)

(ii) Explain why the first electron affinity of oxygen is exothermic process while the second electron affinity is endothermic process

(c) Aluminium reacts with oxygen to form aluminium oxide according to the following equation



Some thermodynamic data of aluminium and oxygen are given below

(c)	Enthalpy of atomization of oxygen	=	+249 kJmol^{-1}
	Enthalpy of atomization of aluminium	=	+324 kJmol^{-1}
	First ionization of aluminium	=	+578.0 kJmol^{-1}
	Second ionization of aluminium	=	+1817.0 kJmol^{-1}
	Third ionization of aluminium	=	+2745.0 kJmol^{-1}
	First electron affinity for oxygen	=	-141.4 kJmol^{-1}
	second electron affinity for oxygen	=	+844.0 kJmol^{-1}
(i)	Draw an energy level diagram for the formation of aluminium oxide		5marks
(ii)	Calculate the lattice energy of aluminium III oxide		2 ½ marks
(iii)	Comment on the value of the lattice energy in (c)(ii)		1 ½ marks

4. The energy changes that take place during the formation barium chloride are shown below

Process	$\Delta H^\theta / \text{kJmol}^{-1}$
$\text{Ba}(s) \xrightarrow{\text{A}} \text{Ba}(g)$	+176
$\text{Ba}(g) \xrightarrow{\text{B}} \text{Ba}^{2+}(g) + 2e$	+1480

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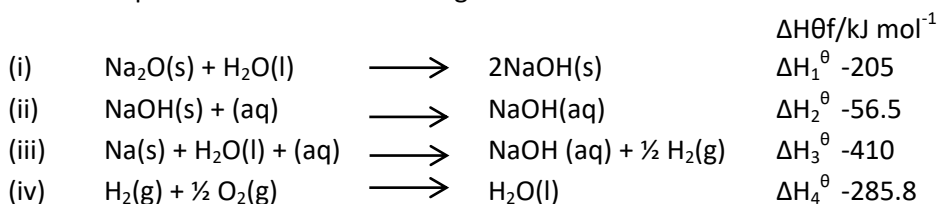
$\text{Cl}_2(\text{g})$	$\xrightarrow{\text{C}}$	$2\text{Cl}(\text{g})$	+224
$\text{Cl}(\text{g}) + \text{e}^-$	$\xrightarrow{\text{D}}$	$\text{Cl}^-(\text{g})$	-364
$\text{Ba}^{2+}(\text{g}) + 2\text{Cl}^-(\text{g})$	$\xrightarrow{\text{E}}$	$\text{BaCl}_2(\text{s})$	-2018

- (a) Name energy changes for the processes: A, B, C, D, and E.
 (b) Calculate the standard enthalpy of formation of barium chloride (03marks)
5. (a) Describe an experiment that can be carried out to determine the enthalpy of solution of sodium chloride (09marks)
 (b) In an experiment to determine the enthalpy of anhydrous copper (II) sulphate by indirect method. 4.0g of anhydrous salt was added to 50.0g of water and the temperature of water rose 8.0°C.
 When 4.0g of the hydrated salts was added to 50.0g of water, the temperature of water dropped by 0.90C.
 [Specific heat capacity of solution = 4.2Jg⁻¹K⁻¹; Cu = 64, S = 32, O = 16, H = 1]

Calculate the enthalpy of solution of

- (i) Anhydrous copper (II) sulphate (3marks)
 (ii) Hydrate copper (II) sulphate- 5-water
- (c) (i) State which one of two copper salt in (a) is more soluble in water and explain your answer.
 (ii) determine the enthalpy of hydration copper (II) sulphate (02marks)
6. Enthalpy of formation of phosphorus trichloride is -306kJmol⁻¹ and enthalpy of atomization of phosphorus and chlorine are +314 and 242kJmol⁻¹ respectively. Calculate the average bond energy of the P-Cl bond.

7. The enthalpies of some reactions are given below



Calculate enthalpy of formation of sodium oxide from its elements (4marks)

- 8 (a) (i) Define the **enthalpy of solution** (1mark)
 (ii) State the energy terms that determine the magnitude and the sign of the enthalpy of solution of ionic salt.
 (iii) Describe an experiment that can be of used to determine the enthalpy of solution
- (b) Some thermochemical data of copper, copper (II) chloride and chlorine are given below:

Enthalpy of formation of copper chloride	-220 kJmol ⁻¹
Enthalpy of sublimation of Cu	+338.3 kJmol ⁻¹

First ionization of copper	+745 kJmol ⁻¹
Second ionization of copper	+1954 kJmol ⁻¹
Electron affinity for chlorine	-364 kJmol ⁻¹
Bond dissociation energy of chlorine	+121 kJmol ⁻¹

- (i) Draw an energy level diagram which can be used to determine the lattice energy of copper (II) chloride. (4marks)
- (ii) The hydration energy of copper (II) chloride is -2883.9 kJmol⁻¹. Determine the enthalpy of solution of copper (II) chloride. (3marks)
- (iii) Comment on the solubility of copper (II) chloride. (1mark)

9. (a) Define the following terms:

- (i) Hydration energy
(ii) Lattice energy
(iii) Enthalpy of solution

(b) State two factors which can affect the magnitude of lattice energy and explain how they affect the lattice energy.

(c) Some thermochemical data are given below

The standard enthalpy of formation of CaCl ₂ (s)	=	-795 kJmol ⁻¹
The standard enthalpy of atomization of calcium		+177kJmol ⁻¹
The first ionization of calcium	=	+590kJmol ⁻¹
The second ionization of calcium	=	+1100kJmol ⁻¹
The standard enthalpy of atomization of chlorine	=	+121kJmol ⁻¹
The first electron affinity of chlorine	=	-364kJmol ⁻¹

Calculate the lattice energy of calcium chloride

(2marks)

(d) The lattice and hydration energies of salts AX and BX are given in the table below

	Lattice energy/kJmol ⁻¹	Hydration energy/kJmol ⁻¹
AX	+880	-860
BX	+790	-800

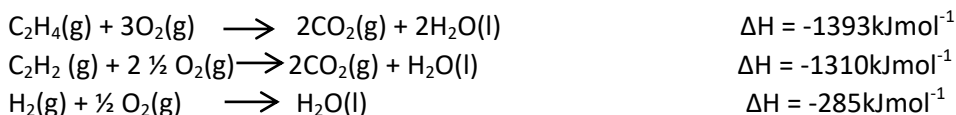
- (i) Calculate the enthalpy of solution of each salt (3marks)
- (ii) Which of the two salts is more soluble in water at a given temperature? Give a reason.
- (e) Explain why hydrated copper sulphate crystals dissolve endothermically whereas anhydrous copper sulphate dissolve exothermically

10.(a)	(i)	Explain what is meant by the term <i>lattice energy</i> .	(2marks)
	(ii)	State two factors that affect the magnitude of lattice energy.	(2marks)
	(iii)	Describe how the factors you have stated in (ii) affect lattice energy.	(6marks)

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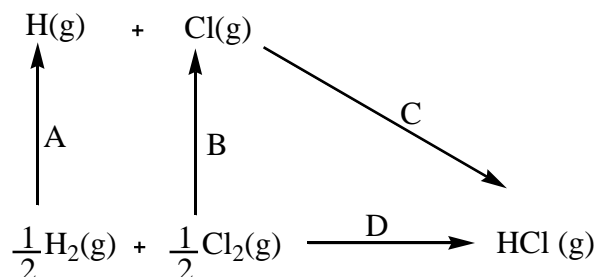
(b)	(i)	Draw a Born-Haber cycle for the formation of solid rubidium chloride from its elements	(6marks)
	(ii)	Calculate the electron affinity of chlorine atom. Use the following data	(3marks)
		Lattice energy of rubidium chloride =	665kJmol ⁻¹
		Dissociation energy of chlorine gas molecule =	226kJmol ⁻¹
		Heat of atomization of rubidium metal =	84kJmol ⁻¹
		Ionization energy of rubidium atom =	397kJmol ⁻¹
		Standard heat of formation of solid rubidium chloride =	-439kJmol ⁻¹

(c) Calculate the heat of hydrogenation of ethane from the following thermodynamic data.



(3marks)

11. The energy diagram for the reaction between hydrogen and chlorine is given below



(a) Identify the energy changes

- A.....
 B.....
 C.....
 D.....

(b) Calculate the enthalpy change for the reaction.

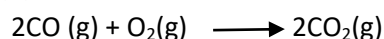
(The H-H, Cl-Cl and H-Cl bond energies are 435.9, 241.8 and 431.0 kJmol⁻¹ respectively) (1½ marks).

12. (a) Some bond energies are given in the table below

Bond	Energy (kJmol ⁻¹)
C-C	-337
C-H	-414
C-O	-360
O-H	-123

Calculate the heat of formation of gaseous ethanol (3marks)

(b) Carbon monoxide burns in oxygen according to the following equation.

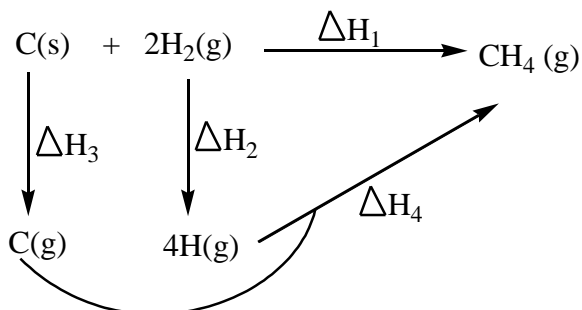


Calculate the enthalpy of combustion of carbon monoxide.

(Heats of formation of carbon monoxide and carbon dioxide are -108 and -393kJmol^{-1} respectively.)

13(a) What is bond energy? (2marks)

(b) The figure below represents the energy diagram for formation of methane



Identify the following energy changes: 3marks

ΔH_1

ΔH_2

ΔH_3

Given that $\Delta H_1 = -75 \text{ kJmol}^{-1}$

$\Delta H_2 = +218 \text{ kJmol}^{-1}$ of hydrogen atom

$\Delta H_3 = +715 \text{ kJmol}^{-1}$

Calculate the value of:

(i) ΔH_4 (2marks)

(ii) The bond energy for C-H bond (2marks)

14 (a) Methane reacts with chlorine in the presence of sun light to form chloromethane. write equation for the reaction and outline mechanism for the reaction.

(b) Some bond energies are given below

Bond	Energy/ kJmol^{-1}
Cl-Cl	242
C-H	435
Cl-H	431
C-Cl	339

Determine the enthalpy change for the reaction.

(3marks)

Suggested answers

1(a) (i) $-1220 = 178 + 590 + 1146 - 328 \times 2 + 242.7 + \Delta H_{\text{Lattice}}$

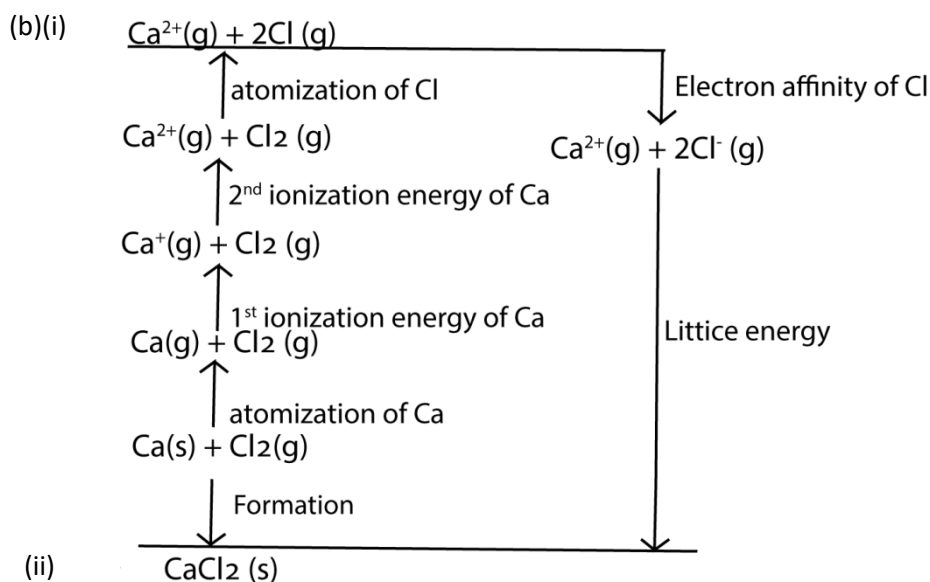
$$\Rightarrow \Delta H_{\text{Lattice}} = -2720 \text{ kJmol}^{-1}$$

$$\begin{aligned} \text{(ii) } \Delta_{\text{solution}} &= \text{lattice} + \text{hydration energies} \\ &= 2720.7 - (1587 + 515 \times 2) \\ &= 103.7 \text{ kJmol}^{-1} \end{aligned}$$

(b) (i) Increasing temperature increases solubility of calcium fluoride.

(ii) enthalpy of solution for CaF_2 is endothermic

2. (a) Standard enthalpy of formation is enthalpy change when 1 mole of a substance is formed from its elements at 298K and 1 atmosphere.



(ii) $\text{CaCl}_2(\text{s})$
Lattice energy = -2237 kJmol^{-1}

(a) It would be less stable because Ca^+ has unstable electron configuration.

$$\begin{aligned} \text{(b) (i) enthalpy of solution} &= \text{lattice energy} + \text{hydration energy} \\ &= 2237 - (1689.6 + 383.7 \times 2) \\ &= -220 \text{ kJmol}^{-1} \end{aligned}$$

(ii) Calcium chloride is soluble because its enthalpy of solution is negative

(e)(i) Charge on the ions

Size of the ions

(ii) – The bigger the charge on the ions, the higher the hydration energy because of strong forces between the ions and water molecules

- The smaller the ions the stronger the force of attraction between the ion and water molecules and the higher the hydration energy.

3.(a)(i) First ionization energy is the enthalpy change when 1 mole of gaseous atoms are converted into 1 mole of gaseous ions with a single positive charge

(ii) Factor affecting first ionization energy

- Nuclear charge on valence electrons: the higher the nuclear charge on the valence electron the higher the first ionization energy due to strong attraction of the nucleus to valence electrons.
- Electronegativity: the higher the electronegativity, the higher the first ionization energy due to strong nuclear attraction on the valence electrons.
- Atomic radius: increase in atomic radius reduce attraction of the nucleus on the valence electrons and reduces first ionization energy.
- Electropositivity: the higher the electronegativity, the lower the first ionization energy due to low nuclear attraction on the valence electrons

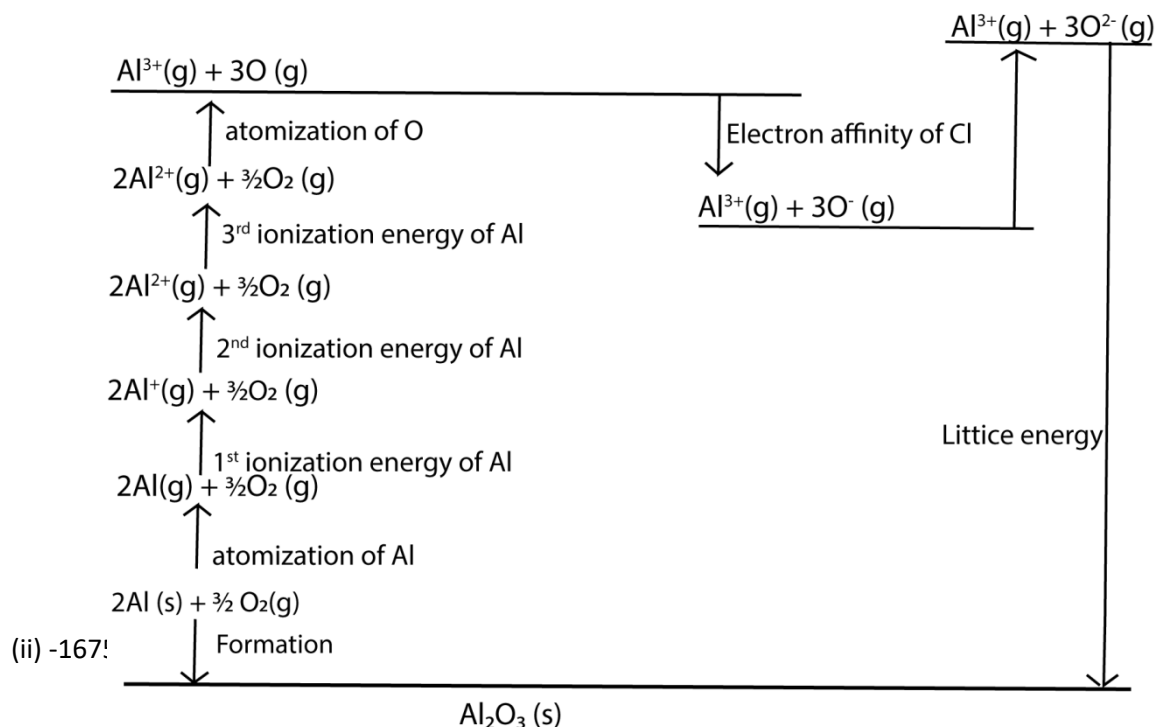
(b) (i) First electron affinity is the enthalpy change when 1 mole of gaseous atoms is converted into 1 mole of gaseous anions with single negative charge

(ii) $O(g) \rightarrow O^-(g)$

(iii) - first electron affinity of oxygen is exothermic because oxygen atoms are highly electronegative with strong attraction to valency electrons.

- The second electron affinity is positive because the added electron added repels the second electrons.

(c)



(iii) Lattice energy is very high showing that aluminium oxide is very stable.

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4. (a) A – atomization energy of barium
 B – ionization energy of of barium
 C – bond energy of chlorine
 D – electron affinity of chlorine
 E – lattice energy

(b) $\Delta H_f = +176 + 1480 + 242 + -364 \times 2 - 2018 = -848 \text{ kJmol}^{-1}$.

5. (a) A given mass m g of sodium chloride is dissolved in x g of excess water and the temperature change $\theta^\circ\text{C}$ is measured.

Assumptions

Heat liberated = heat absorbed by water

$$= xc\theta \text{ (where } c \text{ is specific heat capacity of water)}$$

Formula mass of NaCl = 23 + 35.5 = 58.5g

$\Rightarrow m$ g of NaCl liberate $xc\theta$ J

$\Rightarrow 58.5$ g of NaCl will liberate $\left(\frac{58.5 \times xc\theta}{m}\right) \text{ Jmol}^{-1}$

(b) (i) Heat liberated = $mc\theta$
 $= 50 \times 4.2 \times 8$
 $= 1689$ joules

Formula mass of CuSO_4 = $64 + 32 + 16 \times 4$
 $= 160$ g

4.0g of CuSO_4 liberate 1680J

$\therefore 160$ g of CuSO_4 liberate 67.2 kJmol^{-1}

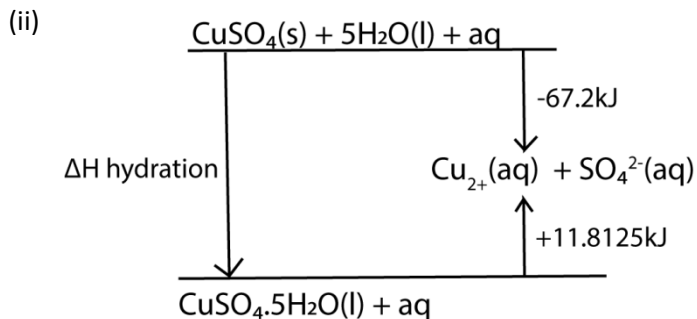
ii) Heat absorbed = $mc\theta$
 $= 50 \times 4.2 \times 0.9$
 $= 189$ joules

Formula mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ = $64 + 32 + 16 \times 4 + 5(2 + 16)$
 $= 250$ g

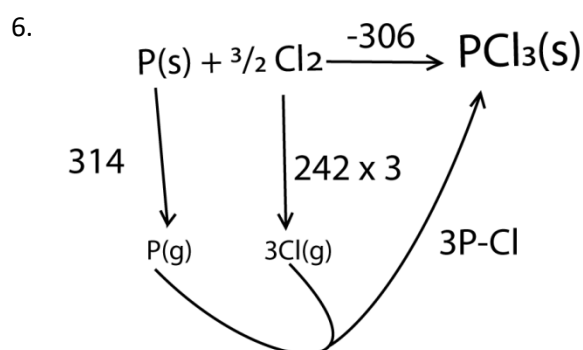
4.0g of CuSO_4 absorb 189J

$\therefore 250$ g of CuSO_4 liberate $11.812 \text{ kJmol}^{-1}$

- (c) (i) anhydrous copper (II) sulphate is more soluble because it liberates heat on dissolving.

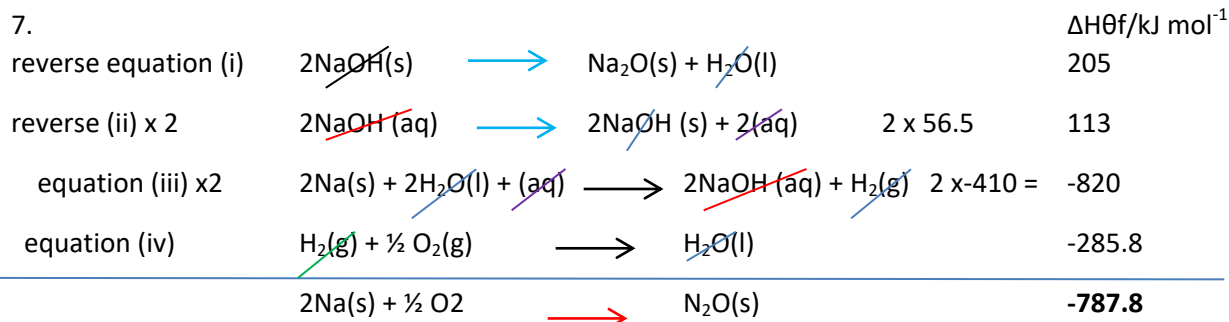


Enthalpy of hydration = $-67.2 - 11.8125 = 79.125\text{kJ}$



$$-306 = 314 + 242 \times 3 + 3\text{P-Cl}$$

$$\text{P-Cl} = 448.7\text{kJmol}^{-1}$$



8 (a)(i) Enthalpy of solution is enthalpy change when 1 mole of ionic salt is dissolved in excess water.

(ii) Lattice energy and hydration energy

(iii) Experiment to determine enthalpy of solution

A given mass m g of ionic salt of molecular mass (M_r) is dissolved in x g of excess water and the temperature change $\theta^\circ\text{C}$ is measured.

Assumptions

Heat liberated = heat absorbed by water

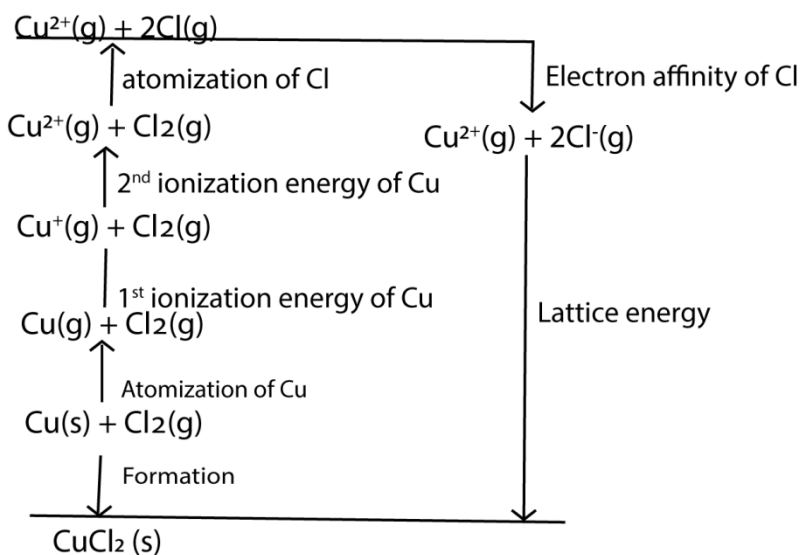
$$= xc\theta \text{ (where } c \text{ is specific heat capacity of water)}$$

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m g of NaCl liberate $x\theta$ J

\Rightarrow Mr g of NaCl will liberate $\left(\frac{Mr \times x\theta}{m}\right) \text{Jmol}^{-1}$

(b)



$$\text{Lattice energy} = -220 - 338.3 - 745 - 1958 - 121.1 + 364 \times 2 = 2654.4 \text{kJmol}^{-1}$$

(ii) Enthalpy of solution = lattice energy + hydration energy
 $= 2654.4 - 2883.9$
 $= 229.5 \text{kJmol}^{-1}$

(iii) Copper II chloride is soluble because enthalpy of solution is negative

9. (a) (i) Hydration energy is enthalpy change that occur when 1mole of gaseous ions is hydrated at 298K and 1 atmosphere.

(ii) Lattice energy is enthalpy change when 1 mole of crystalline ionic compound is dissolved in excess water.

(iii) Enthalpy of solution is enthalpy change when 1 mole of ionic salt is dissolved in excess water

(b) (i) charge on the ions: the bigger the charge on ions the bigger the lattice energy due to strong attraction

(ii) size of the ion: small ions give high lattice energy due to strong attraction.

(c) $-795 = 177 + 590 + 1100 + 121 \times 2 - 364 \times 2 + \Delta H_L$

$$\Delta H_L = -2176 \text{kJmol}^{-1}$$

(d)(i) enthalpy of solution of AX = $880 - 860 = 20 \text{kJmol}^{-1}$

(ii) enthalpy of solution of BX = $790 - 800 = -10 \text{kJmol}^{-1}$

(iii) Bx is more soluble because enthalpy of solution is negative

(e) Enthalpy of solution of hydrated copper (II) sulphate is positive because it involves breakage of bonds of hydration in the crystal lattice during dissolving

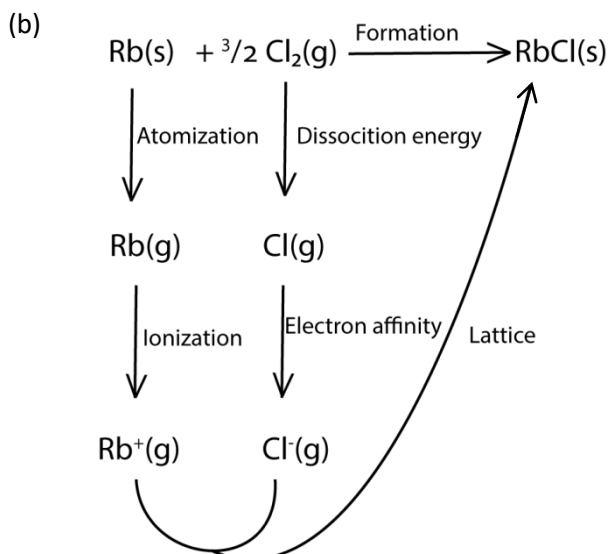
Enthalpy of solution of anhydrous copper (II) sulphate is exothermic due to formation of coordinate bonds between the copper ions or sulphate ions with water molecules to form complex ions

10. (a) (i) Lattice energy is enthalpy change when 1 mole of crystalline ionic compound is dissolved in excess water.

(ii) charge on the ion and size of the ion

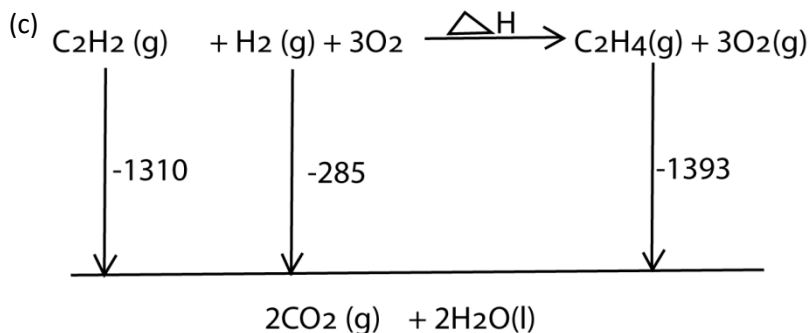
(iii) - charge on the ions: the bigger the charge on ions the bigger the lattice energy due to strong attraction

- size of the ion: small ions give high lattice energy due to strong attraction.



$$-439 = 84 + 397 + \frac{1}{2} \times 226 + \text{electron affinity} - 665$$

$$\text{Electron affinity} = -368 \text{kJmol}^{-1}$$



$$-1310 - 285 = \Delta H - 1393$$

$$\Delta H = -202 \text{ kJ mol}^{-1}$$

11. (a) A – atomization of hydrogen gas

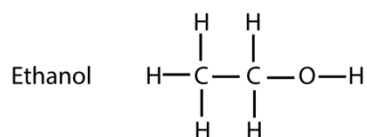
B – atomization of chlorine gas

C – bond energy

D – formation

$$(b) D = \frac{435.9}{2} + \frac{241.8}{2} - 431 = -92.15 \text{ kJ mol}^{-1}$$

12.



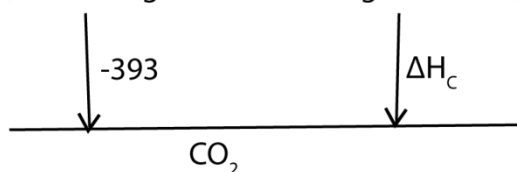
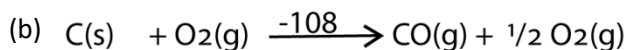
Ethanol has 5C-H bonds = -414×5

1C-C bond = -337×1

1C-O bond = -360×1

1O-H bond = -123×1

Heat of formation = (sum) = $-2890 \text{ kJ mol}^{-1}$



$$-393 = -108 + \Delta H_c$$

$$\Delta H_c = -385 \text{ kJ mol}^{-1}$$

13. (a) Bond energy is energy change required to form 1 mole of a gaseous covalent bond.

(b) ΔH_1 = enthalpy of formation

ΔH_2 = atomization energy of hydrogen

ΔH_3 = atomization of energy carbon

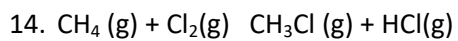
$$\Delta H_1 = \Delta H_3 + \Delta H_2 + \Delta H_4$$

$$-75 = 715 + 218 \times 4 + \Delta H_4$$

$$\Delta H_4 = -1662$$

v

$$\text{C-H bond} = \frac{-1662}{4} = 415.5 \text{ kJmol}^{-1}$$



Enthalpy change = sum of enthalpies of bonds broken – sum of enthalpies of bonds formed

$$= [4\text{C-H} + 1\text{Cl-Cl}] - [3\text{C-H} + 1\text{C-Cl} + 1\text{H-Cl}]$$

$$= [4 \times 435 + 242] - [3 \times 435 + 339 + 431]$$

$$= 93 \text{ kJmol}^{-1}$$

Thank you
Dr. Bbosa Science