WJEC EDUQAS A-LEVEL CHEMISTRY · COMPONENT 1

CHEMISTRY



EXAM QUESTION PACK

PI5.1 EQUILIBRIUM CONSTANTS

SCORE	PERCENTAGE
/110	%

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1. Carbon oxide sulfide, COS, is obtained by heating together carbon monoxide and gaseous sulfur.

$$2CO(g) + S_2(g) \rightleftharpoons 2COS(g)$$

State and explain any change that occurs when more carbon monoxide is added to the equilibrium mixture.

[2]

(Total 2)

2. Weak *acids* establish a *dynamic equilibrium* when dissolved in water.

Give brief explanations of what is meant by the following terms.

[2]

Acid

Dynamic equilibrium

(Total 2)

3.

Halogens and their compounds take part in a wide variety of reactions.

(a) Give the chemical name of a chlorine-containing compound of commercial or industrial importance. State the use made of this compound. [1]

.....

.....

(b) Hydrogen reacts with iodine in a reversible reaction.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

An equilibrium was established at 300 K, in a vessel of volume 1 dm^3, and it was found that 0.311 mol of hydrogen, 0.311 mol of iodine and 0.011 mol of hydrogen iodide were present.

(i) Write the expression for the equilibrium constant in terms of concentration, K_c. [1]

(ii) Calculate the value of K_c at 300 K. [1]

K_c = ...

(iii) What are the units of K_c, if any? [1]

.....

(iv) Equilibria of H_2, I_2 and HI were set up at 500 K and 1000 K and it was found that the numerical values of K_c were 6.25×10^{-3} and 18.5×10^{-3} respectively.

Use these data to deduce the sign of ΔH for the forward reaction. Explain your reasoning. [3]

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.....

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.....

(c) When concentrated hydrochloric acid is added to a pink aqueous solution of cobalt(II) chloride, the colour changes to blue.

Cobalt takes part in an equilibrium reaction.

$$[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6H_2O(l)$$

(i) What is the oxidation state of cobalt in $[CoCl_4]^{2-}$? [1]

.....

(ii) What type of bonding is present in $[CoCl_4]^{2-}$? [1]

.....

(iii) Use the equation to identify the ions responsible for the pink and blue colours described above. Explain why the colour change occurs when concentrated hydrochloric acid is added to the pink solution. [3]

.....

.....

.....

.....

(iv) Draw diagrams to clearly show the shape of the $[Co(H_2O)_6]^{2+}$ ion and the $[CoCl_4]^{2-}$ ion. [2]

$[Co(H_2O)_6]^{2+}$ $[CoCl_4]^{2-}$

Total [14]

4. (a) Planners have to ensure a secure supply of energy in the future. It has been suggested that the use of fossil fuels should be reduced, the use of renewable energy increased and that energy efficiency should be greatly improved.

By considering both the benefits and the difficulties involved, discuss whether you think that these suggestions are realistic.

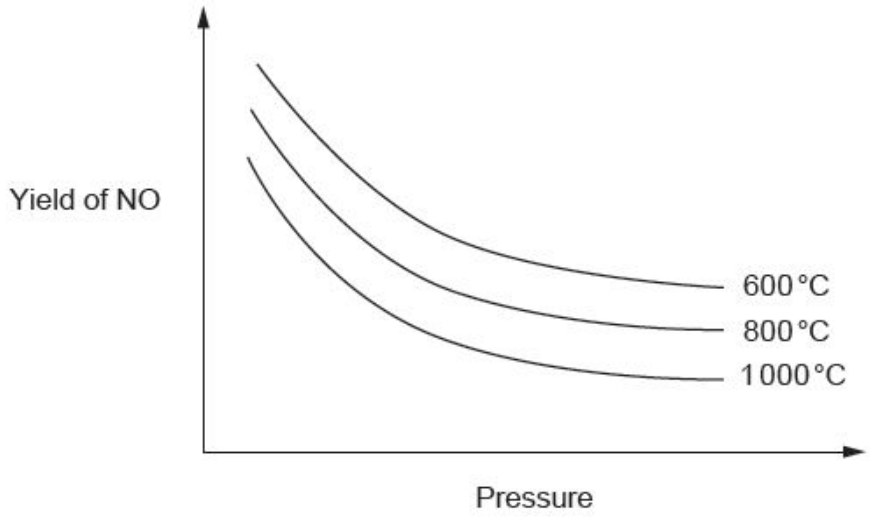
[4] QWC [1]

(b) Nitric acid is produced by the Ostwald process.

The first stage involves the oxidation of ammonia over a platinum/rhodium catalyst.

ammonia + oxygen $\rightleftharpoons$ nitric oxide + water

The graph below shows how the yield of nitric oxide, NO, depends on the temperature and pressure used in its production.



(i) I. State the general variations in this yield with temperature and pressure

[1]

II. Use the graphs to explain whether the reaction is endothermic or exothermic and whether there are more moles of gaseous products than reactants.

[4] QWC [1]

(ii) Normally the process is carried out at a temperature of around 900 °C.

Suggest why this temperature is used.

[2]

(iii) State the **type** of catalyst used.

[1]

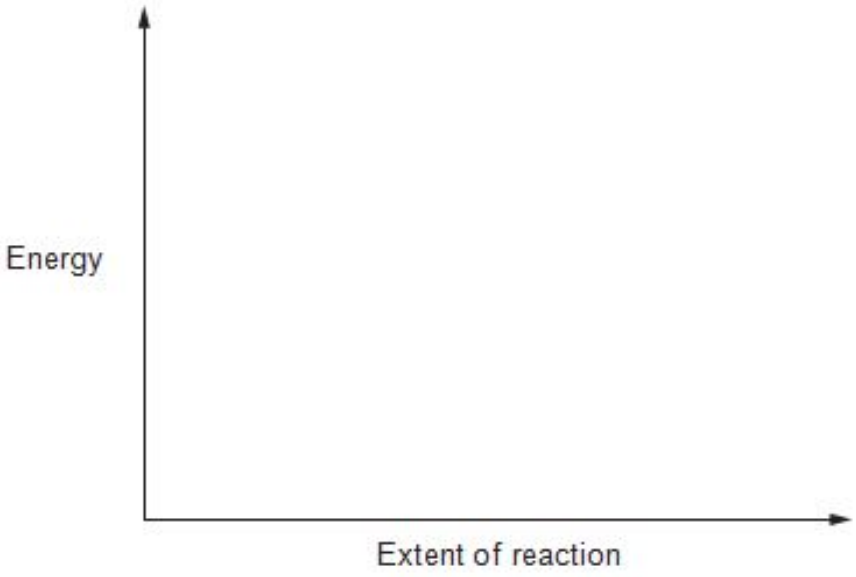
(iv) Explain why there has been much research to find a better catalyst.

[2]

(v) The next stage in the Ostwald process is to convert the nitric oxide to nitrogen dioxide.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g) \qquad \Delta H = -114 \text{ kJ mol}^{-1}$$

Sketch on the axes below the energy profile for this reaction, clearly labelling the enthalpy change of reaction, ΔH. [2]



(vi) Write an expression that connects the enthalpy change of a reaction, ΔH, with the activation energies of the forward (E_f) and reverse (E_b) reactions. [1]

Total [19]

5. Ethanol is an important industrial chemical and can be made by the direct hydration of ethene using a phosphoric acid catalyst.

$$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \quad \Delta H = -46 \text{ kJ mol}^{-1}$$

(a) State, giving your reasons, the general conditions of temperature and pressure required to give a high equilibrium yield of ethanol in this process. [4]

QWC [1]

(b) Using the standard enthalpy change for the reaction above and the standard enthalpy changes of formation ($\Delta H_f^{\ominus}$) given in the table below, calculate the standard enthalpy change of formation of gaseous ethanol. [3]

Compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$CH_2{=}CH_2(g)$	52.3
$H_2O(g)$	–242

(c) Another way of calculating the enthalpy change of a reaction is by using average bond enthalpies. Use the values in the table below to calculate the enthalpy change for the direct hydration of ethene. [3]



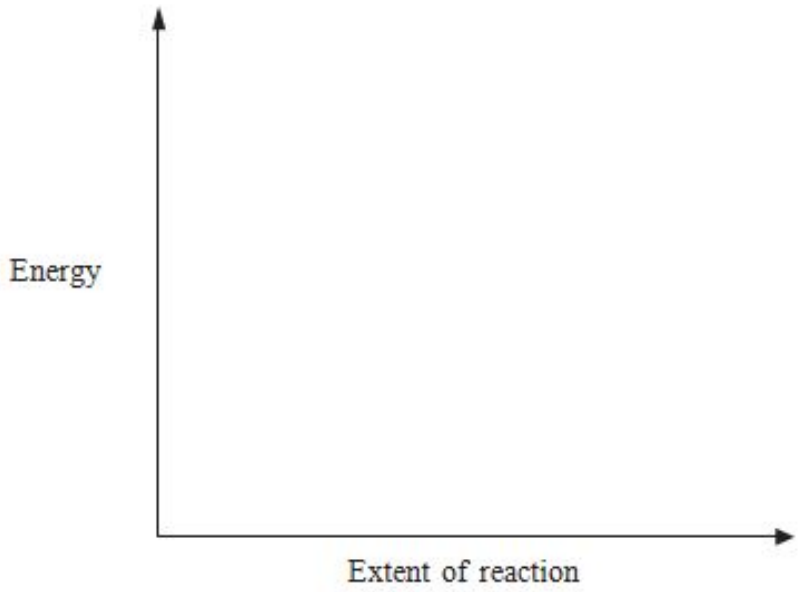
Bond	Average bond enthalpy / kJ mol^{-1}
C —C	348
C =C	612
C —H	412
C —O	360
O—H	463

(d) (i) Give a reason why the calculated value in *(c)* is different to the actual value, –46 kJ mol^{-1}. [1]

(ii) Explain whether your answer to part (i) supports the use of average bond enthalpies to calculate the energy change for a reaction. [1]

(e) Phosphoric acid is an example of a heterogeneous catalyst.
Explain the term *heterogeneous* in this context. [1]

(f) (i) Sketch on the axes below the energy profile for an exothermic reaction. [1]



(ii) On the same axes, sketch and label the energy profile if the same reaction is carried out using a catalyst. [1]

Total [16]

6. Hydrocarbons play an important role in our life today, both as fuels and as raw materials for the synthesis of a wide range of materials. Most hydrocarbons are isolated from crude oil, however there is increasing interest in alternative methods of obtaining these molecules.

(a) One route to the production of hydrocarbons is the Fischer-Tropsch process, which uses hydrogen and carbon monoxide as starting materials to produce a range of molecules. The equation below shows the production of pentane, C_5H_{12}, by this route.

$$11H_2(g) + 5CO(g) \longrightarrow C_5H_{12}(l) + 5H_2O(l) \qquad \Delta H^{\ominus} = -1049\,kJ\,mol^{-1}$$

The enthalpies of formation of some of these substances are given in the table below.

Substance	Standard enthalpy of formation, $\Delta H_f^{\ominus}$ / kJ mol^{-1}
Hydrogen, $H_2(g)$	0
Carbon monoxide, CO(g)	–111
Water, $H_2O(l)$	–286

(i) State the temperature and pressure used as standard conditions. Give units for each. [2]

Temperature ..... *Pressure* .....

(ii) State why the standard enthalpy of formation for hydrogen gas is 0 kJ mol^{-1}. [1]

.....

.....

.....

(iii) Use the values given to calculate the standard enthalpy of formation for pentane, $C_5H_{12}(l)$, in kJ mol^{-1}. [3]

.....

.....

.....

.....

(b) The Fischer-Tropsch process uses a heterogeneous catalyst containing iron.

(i) State what is meant by the term *heterogeneous* in this context. [1]

.....

.....

(ii) Explain how a catalyst increases the rate of a chemical reaction. [2]

.....

.....

(iii) Chemical manufacturers consider catalysts to be a key part of production methods that have the minimum possible effect on the environment ('Green Chemistry'). Give **one** reason why the use of catalysts reduces the effect on the environment.[1]

.....

.....

.....

(iv) An alternative method of increasing the rate of a chemical reaction is to increase the temperature. Explain why temperature affects the rate of a chemical reaction. [3]
QWC [1]

.....

.....

.....

.....

(c) One method of producing the hydrogen gas required for the Fischer-Tropsch process is to use the reversible reaction below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -42\,kJ\,mol^{-1}$$

(i) State and explain the effect, if any, of increasing pressure on the yield of hydrogen gas produced at equilibrium. [2]

.....

.....

.....

(ii) State and explain the effect, if any, of increasing temperature on the yield of hydrogen gas produced at equilibrium. [2]

.....

.....

(iii) This reaction uses a catalyst based on iron oxide. State the effect of using a catalyst on the position of equilibrium. [1]

.....

Total [19]

7. (a) The combustion of fossil fuels containing sulfur impurities is known to cause acid rain. This acid rain can cause the erosion of marble statues as the calcium carbonate in them reacts with the acid in the rain.

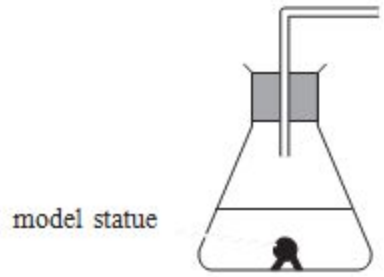
Give **one** other problem caused by acid rain.

[1]

(b) A chemist is developing coatings for marble that will slow down the rate of their erosion by acid rain. To compare different coatings he uses small model statues, all of which are the same size and shape as each other. He proposes to measure the rate of reaction by adding acid and measuring the volume of gas given off at set time intervals.

(i) Complete the diagram to show the apparatus that could be used to perform this experiment.

[1]



(ii) Explain why it is important that the model statues are the same size and shape as each other

[1]

(ii) State **two** other factors he will need to keep constant if he is to collect valid data.

[2]

(c) One gas that causes acid rain is sulfur dioxide. This gas is used to produce sulfur trioxide in the Contact Process. The reaction occurring is shown in the following equation.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(i) State and explain the effect of increasing pressure on the equilibrium yield of sulfur trioxide.

[2]

(ii) When the temperature is increased the rate at which equilibrium is reached is increased and the yield of sulfur trioxide is decreased.

I State whether this reaction is endothermic, exothermic or neither, giving a reason for your answer.

[2]

II Explain why increasing the temperature leads to an increase in the rate of reaction.

[3]

III To increase the rate of a reaction, a catalyst can be used. Give a **different** catalysed reaction and name the catalyst for this reaction.

[1]

(d) Ethanoic acid, CH_3COOH, is one of the most familiar compounds used as a flavouring and preservative for food. Originally ethanoic acid was produced by oxidation of ethanol by bacteria in the presence of air (route **A** below). Today there are many other possible routes and three of these are shown as routes **B**, **C** and **D** below.

Route	Carbon-containing starting materials	Conditions	Overall equation	Atom economy
A	ethanol		$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$	76.9%
B	methanol, carbon monoxide	150 °C, 30 atm	$CH_3OH + CO \rightleftharpoons CH_3COOH$	100.0%
C	butane	150 °C, 55 atm	$2C_4H_{10} + 5O_2 \rightarrow 4CH_3COOH + 2H_2O$	87.0%
D	sugars		$C_6H_{12}O_6 \rightarrow 3CH_3COOH$	

(i) State the atom economy of route **D** for production of ethanoic acid.

[1]

(ii) Route **B** is the route most commonly used for producing ethanoic acid today for both financial and *Green Chemistry* reasons. Apply the principles of *Green Chemistry* to the information above to give **two** reasons why route **B** is favoured over route **C**.

[2]

1.

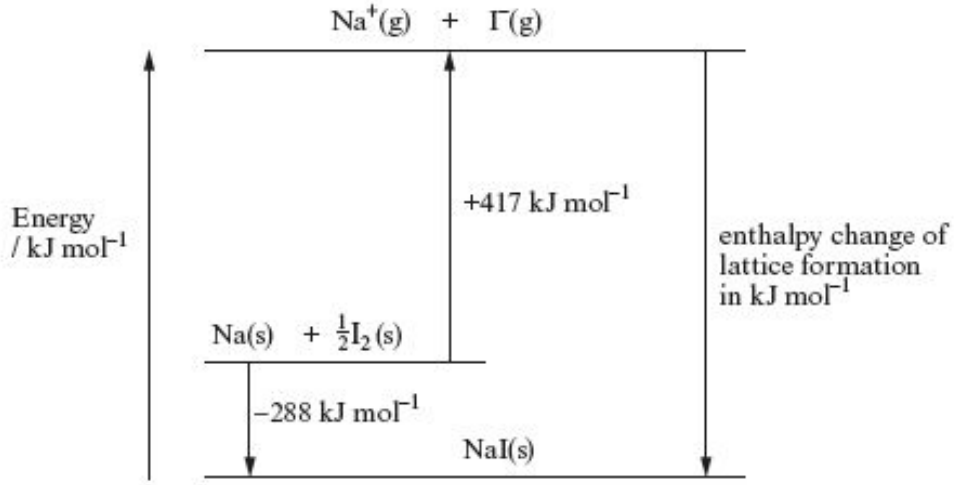
2.

(iii) Route **B** uses a homogeneous catalyst. State what effect the catalyst will have on the position of this equilibrium.

[1]

(Total 17)

8. *(a)* The diagram shows an outline of the Born-Haber cycle for the formation of sodium iodide (NaI) from its elements.



Use the information given to calculate the enthalpy change of lattice formation (in kJ mol^{-1}) of sodium iodide. [2]

.....

.....

(b) Sodium iodide is very soluble in water at room temperature.

(i) Complete the sentence below using the relevant enthalpy terms.

For a compound to be very soluble in water the value of the enthalpy of

..... will be greater than the enthalpy of .....

[1]

(ii) Aqueous solutions of sodium iodide become yellow in the presence of oxygen due to the slow production of iodine.
One suggested reason for this is that a low concentration of hydrogen ions in the solution produces iodine according to the equation below.

$$4H^+(aq) + 4I^-(aq) + O_2(aq) \rightleftharpoons 2I_2(aq) + 2H_2O(l)$$

Use Le Chatelier's principle to suggest a reagent that you could add, apart from water, to decrease the amount of yellow iodine present. Explain your choice. [2]

.....

.....

.....

.....

(c) Sodium chloride and sodium iodide both react with concentrated sulfuric acid to give the corresponding hydrogen halide e.g.

$$NaI + H_2SO_4 \longrightarrow NaHSO_4 + HI$$

However, the reaction with sodium iodide continues, giving hydrogen sulfide and iodine as two of the products. This further type of reaction does not occur when sodium chloride is used in place of sodium iodide.

(i) Describe what is **seen** when solid sodium iodide is added to concentrated sulfuric acid. [2]

.....

.....

.....

(ii) The following equations show the standard electrode potentials for the Cl_2/Cl^- and I_2/I^- systems.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \qquad E^\ominus = +1.36\,V$$

$$I_2 + 2e^- \rightleftharpoons 2I^- \qquad E^\ominus = +0.54\,V$$

Use these values to explain why only hydrogen iodide (represented as I^- in the equation) is able to further react with concentrated sulfuric acid in this way. [2]

.....

.....

.....

.....

(d) The reaction of chlorine with sodium hydroxide solution gives aqueous sodium chlorate(I) as one of the chlorine-containing products.

(i) Give the equation for this reaction. [1]

.....

(ii) State **one** use for a solution of sodium chlorate(I). [1]

.....

Total [11]

9. The decomposition of dinitrogen(IV) oxide into nitrogen(IV) oxide is a reversible reaction that establishes a dynamic equilibrium.

$$\underset{\text{pale yellow}}{N_2O_4(g)} \rightleftharpoons \underset{\text{dark brown}}{2NO_2(g)} \qquad \Delta H = +57 \text{ kJ mol}^{-1}$$

(a) State the meaning of the term ***dynamic equilibrium***.

[1]

(b) The conditions applied to an equilibrium mixture of dinitrogen(IV) oxide and nitrogen(IV) oxide were changed. For each of the following, state what was **seen** and explain any change that occurred.

[5]

Temperature increased

Pressure increased

A catalyst was added

(c) Hydrazine, N2H4, is an unstable liquid that decomposes according to the following equation.

$$N_2H_4(l) \longrightarrow N_2(g) + 2H_2(g)$$

(i) Calculate the volume of gas that could be obtained from 14 kg of hydrazine.
Assume that the volume of 1 mol of gas is 24.0 dm^3

[3]

(ii) Use of hydrazine is as a fuel in rockets. Apart from any energy changes, state **one** feature of this reaction that suggests it would be useful in rocket propulsion.

[1]

(d) Nitrogen (IV) oxide reacts with water.

$$H_2O + 2NO_2 \longrightarrow HNO_2 + HNO_3$$

Both nitric(III) acid, HNO_2, and nitric(V) acid, HNO_3, are described as being acids.

(i) Define an *acid*. [1]

(ii) Complete the equation to show nitric(III) acid behaving as an acid. [1]

$$HNO_2 + H_2O \longrightarrow$$

(iii) When concentrated nitric(V) acid is mixed with concentrated sulfuric acid the reaction shown below occurs.

$$HNO_3 + H_2SO_4 \longrightarrow H_2NO_3^+ + HSO_4^-$$

Explain this reaction in terms of acid-base behaviour. [2]

Total [14]

4 (a) Benefits:
Stops fossil fuels from running out
Reduces CO_2 emissions / greenhouse emissions / global warming / effect of global warming
Reduces SO_2 emissions / acid rain
There will be an investment in new technology

Difficulties:
Dependence on fossil fuel/Unlikely to meet current demand
Renewable energy currently more expensive
Reliability of supply from renewables
Major development in energy efficiency technologies required
Opposition by vested interests
(Maximum 3 marks from list, but need examples of both) (3)

Consideration and discussion of benefits/difficulties (1) [4]

QWC Legibility of text; accuracy of spelling, punctuation and grammar, clarity of meaning [1]

(b) (i) I As temperature increases yield decreases
As pressure increases yield decreases [1]

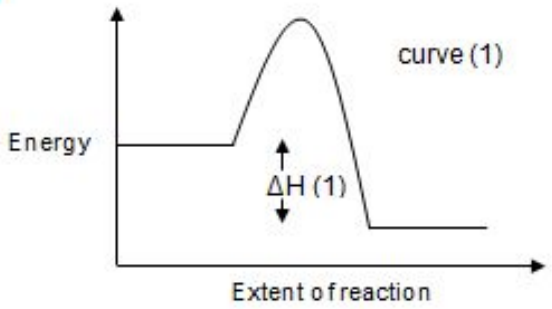
II As temperature is increased, equilibrium moves to the left (1)
Therefore forward reaction is exothermic (1)
As pressure is increased, equilibrium moves to the left (1)
Therefore more gas moles in products (1) [4]
QWC The information is organised clearly and coherently, using specialist vocabulary where appropriate [1]

(ii) If temperature is too low, then reaction is too slow (1)
If temperature is too high, yield is too low (1)
Compromise temperature – acceptable rate and yield (1)
(Accept any two points) [2]

(iii) Heterogenous catalyst [1]

(iv) Lower temperatures could be used (1)
Less energy consumption / increased yield (1)
Equilibrium could be reached more quickly (1)
(Accept any two points) [2]

(v)



[2]

(vi) $\Delta H = E_r - E_b$ [1]

Total [19]

5 (a) Low temperature (1)
As temperature is decreased equilibrium moves in exothermic direction. (1)

High pressure (1)

As pressure is increased equilibrium moves towards side with smaller number of gas moles (1) [4]

QWC The information is organised clearly and coherently, using specialist vocabulary where appropriate [1]

(b) ΔHreaction = ΔH_f products – ΔH_f reactants (1)

$-46 = \Delta H_f$ ethanol – (52.3 – 242)

ΔH_f ethanol = -46 – 189.7 (1)

ΔH_f ethanol = -235.7 kJ mol^{-1} (1) [3]

(c) Bonds broken = 1648 + 612 + 926 = 3186 kJ mol^{-1} (1)

Bonds formed = 2060 + 348 + 360 + 463 = 3231 kJ mol^{-1} (1)

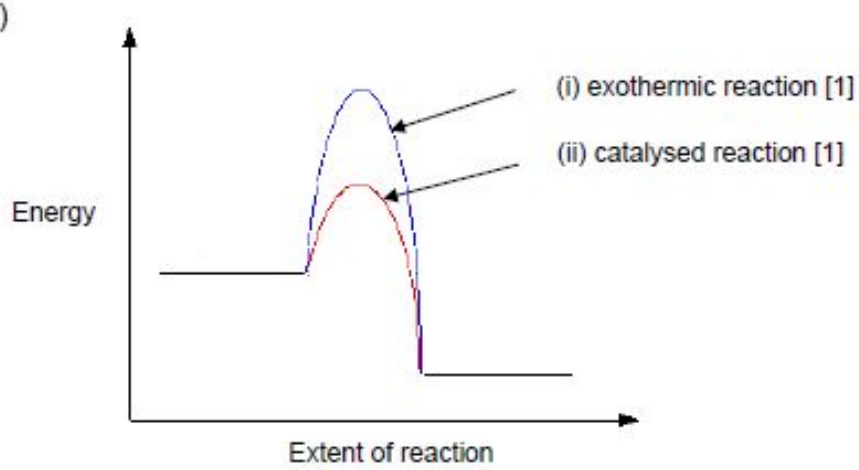
ΔH reaction = 3186 – 3231 = -45 kJ mol^{-1} (1)
[3]

(d) (i) Average bond enthalpies used (not actual ones) [1]

(ii) Yes, since answers are close to each other [1]

(e) Catalyst is in different (physical) state to reactants [1]

(f)



Total [16]

6 (a) (i) Temperature: 298K / 25°C (1) Pressure: 1 atm / 101.325 kPa or 100 kPa (1) [2]

(ii) Hydrogen gas is an element in its standard state [1]

(iii) $\Delta H = \Delta H_f (C_5H_{12}) + 5\ \Delta H_f (H_2O) - 5\ \Delta H_f (CO) - 11\Delta H_f (H_2)$ (1)

$\Delta H_f (C_5H_{12}) = -1049 - 5\ (-286)\ + 5\ (-111)$ (1)

$\Delta H_f (C_5H_{12}) = -174\ kJ\ mol^{-1}$ (1) [3]

(b) (i) Catalyst in different state to reactants [1]

(ii) Catalysts provide an alternative route (1) with a lower activation energy (1) [2]

(iii) Lower temperature or less time so less energy needed / Can make alternative production method possible with sustainable starting materials or less waste products [1]

(iv) At higher temperatures particles have more energy (1)

More collisions have energy above activation energy (1)

(Can obtain these two marks from correctly labelled Boltzmann energy distribution plot with two temperature lines (1) and Activation energy (1))

Successful collisions occur more frequently (1) – 3 max [3]

QWC: selection of a form and style of writing appropriate to purpose and to complexity of subject matter [1]

(c) (i) No effect (1)

Same number of (gas) molecules on both sides of reaction (1) [2]

(ii) Lower yield of hydrogen (1)

Reaction shifts in endothermic direction to (try to counteract increase in temperature) (1) [2]

(iii) No effect [1]

Total [19]

7

(a) killing marine life / killing trees [1]

(b) (i) either gas syringe or inverted burette attached to sealed vessel [1]

(ii) different surface area would affect rate of reaction [1]

(iii) concentration / volume / nature of acid (1)

temperature (1) [2]

(c) (i) increasing pressure will shift the reaction to side with fewer gas molecules (1)

increasing yield of SO_3 (1) – reason must be given [2]

(ii) I increasing temperature shifts equilibrium in endothermic direction (1)

as SO_3 yield is decreased forward reaction must be exothermic (1) [2]

II increasing temperature increases energy of particles (1)

more collisions have energy above activation energy (1)

successful collisions occur more frequently (1)

can gain first two points from labelled Boltzmann distribution curve [3]

III e.g. iron in production of ammonia or any valid example [1]

(d) (i) atom economy = 100% [1]

(ii) any two points from:

lower pressure used in B (1)

methanol is a renewable starting material (1)

higher atom economy in B or less waste in B (1)

[ignore reference to cost]
2 max [2]

(iii) no effect on position of equilibrium [1]

Total [17]

8 (a) - 705 ($kJ\ mol^{-1}$) (1) for correct sign (1) for correct number [2]

(b) (i) ..... hydration .....

..... lattice **breaking** [1]

(ii) e.g. add a small 'amount' of an alkali / sodium hydroxide / NaOH / OH^- ions (1)
this would remove / react with hydrogen ions giving water, shifting the position of equilibrium to the left (removing iodine) (1)
add $P6^{2+}$ / Ag^+ ect. [2]

(c) (i) Any TWO from
white / misty fumes (of HI)
yellow solid / solution (of sulfur)
brown / black solid / purple vapour (of iodine)
bubbles / effervescence / fizzing

One mark for each correct response [2]

(ii) The values show that chlorine is the best oxidising agent, as it has the most positive E^θ value and therefore iodide is the better reducing agent (1)
and is 'strong' enough to reduce the sulfuric acid. / OWTTE (1) [2]

(d) (i) $2\ NaOH + Cl_2 \rightarrow NaOCl + NaCl + H_2O$ [1]

(ii) e.g. bleach, kills bacteria [1]

Total [11]

9 (a) (a reaction in which) the rate of the forward reaction is equal to the rate of the backward reaction [1]

(b) goes darker / more brown (1)

because the (forward) reaction has a +ve ΔH / is endothermic (1)

goes paler / less brown (1)

because there are more moles / molecules on RHS (1)

no change (because catalysts do not affect the position of an equilibrium) (1) [5]

(c) (i) moles N_2H_4 = 14000/32.04 = 437.0 (1)

this produces 437.0 × 3 = 1311 moles of gas (1)

volume = 1311 × 24 = 3.15×10^4 dm^3 (1) [minimum 2 sf] [3]

(ii) (large volume of) gas produced [1]

(d) (i) an acid is a proton / H^+ donor [1]

(ii) $\rightarrow NO_2^- + H_3O^+$ [1]

(iii) sulfuric acid is behaving as the acid / nitric acid is behaving as a base (1)

as it donates a proton / as it accepts a proton (1) [2]

Total [14]