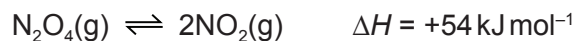
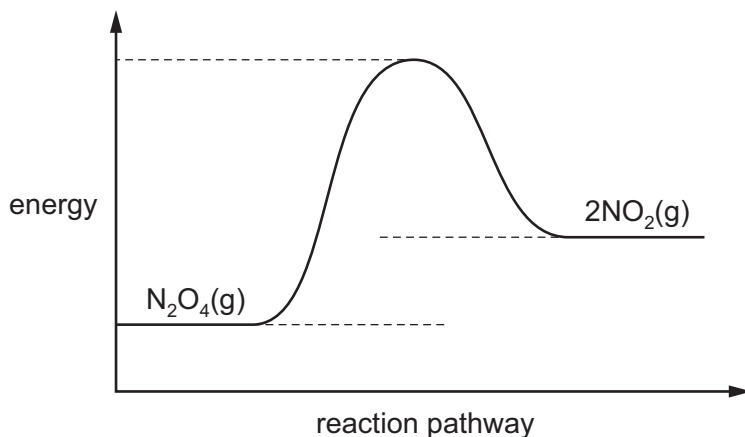


1. Question part 1/2 | 9701 Oct-Nov 2016 P2 V2 Q2

- 2 Dinitrogen tetroxide, N_2O_4 , and nitrogen dioxide, NO_2 , exist in dynamic equilibrium with each other.



The energy profile for this reaction is shown.



- (a) Add labelled arrows to the energy profile to indicate

- the enthalpy change of the reaction, ΔH ,
- the activation energy of the forward reaction, E_a .

[2]

- (b) 0.0500 mol of N_2O_4 was placed in a sealed vessel of volume 1.00 dm^3 , at a temperature of 50°C and a pressure of $1.68 \times 10^5 \text{ Pa}$. The mass of the resulting equilibrium mixture was 4.606 g.

- (i) Calculate the average molecular mass, M_r , of the resulting equilibrium mixture. Give your answer to **three** significant figures.

$M_r = \dots\dots\dots$ [2]

- (ii) The number of moles of N_2O_4 that dissociated can be represented by n .

State, in terms of n , the amount, in moles, of NO_2 in the equilibrium mixture.

moles of $\text{NO}_2 = \dots\dots\dots$ [1]

9701 Chemistry Paper 2 - Equilibria

Topical questions | 18 questions

1. Question part 2/2 | 9701 Oct-Nov 2016 P2 V2 Q2

The number of moles of N_2O_4 remaining at equilibrium is $(0.05 - n)$.

(iii) State, in terms of n , the total amount, in moles, of gas in the equilibrium mixture.

[1]

(iv) State, in terms of n , the mole fraction of NO_2 in the equilibrium mixture.

[1]

In this equilibrium mixture, the mole fraction of NO_2 is 0.400.

(v) Use your answers to (ii) and (iv) to calculate the amount in moles of each gas in the equilibrium mixture. Give your answers to **three** significant figures.

amount of N_2O_4 = ... mol

amount of NO_2 = ... mol
[2]

(vi) Write the expression for the equilibrium constant, K_p , for this equilibrium.

$K_p =$

[1]

(vii) Use the total pressure of the mixture, $1.68 \times 10^5 \text{ Pa}$, to calculate the value of the equilibrium constant, K_p , and give its units.

$K_p =$

units = ...
[3]

[Total: 13]

2. Question part 1/4 | 9701 May-June 2017 P2 V2 Q3

- 3 The hydrogen halides, HCl , HBr and HI , can undergo thermal decomposition. In a sealed container an equilibrium is established according to the equation shown.



- (a) Some bond energies are shown in the table.

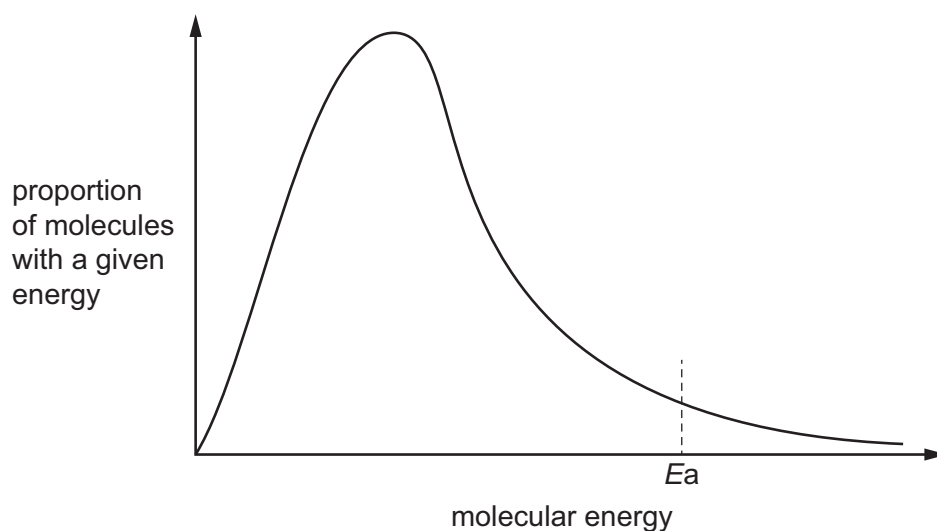
	bond energy / kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

Use these data to calculate a value for the enthalpy change, ΔH , for the thermal decomposition of hydrogen bromide, HBr , according to the equation shown.

$$\Delta H = \dots\dots\dots \text{kJ mol}^{-1} \quad [1]$$

- (b) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) With reference to the curves, state and explain the effect of increasing temperature on the **rate** of decomposition of HBr.

.....

.....

.....

..... [3]

- (iii) The decomposition of HBr is endothermic.

State the effect of increasing temperature on the **percentage** of HBr that decomposes.
Use Le Chatelier's principle to explain your answer.

.....

.....

.....

..... [3]

- (iv) At 700 K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.

Explain this difference with reference to bond strengths and the factors that affect them.

.....

.....

.....

..... [3]

- (c) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2 .

- (i) Calculate the amounts, in mol, of H_2 and HCl present in the equilibrium mixture.

$\text{H}_2 = \dots\dots\dots$ mol

$\text{HCl} = \dots\dots\dots$ mol
[2]

- (ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of $\text{HCl} = \dots\dots\dots$

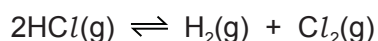
mole fraction of $\text{H}_2 = \dots\dots\dots$

mole fraction of $\text{Cl}_2 = \dots\dots\dots$
[1]

- (d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HCl	0.88
H_2	0.06
Cl_2	0.06

- (i) Write the expression for the equilibrium constant, K_p , for the decomposition of HCl .



$K_p =$

[1]

9701 Chemistry Paper 2 - Equilibria

Topical questions | 18 questions

2. Question part 4/4 | 9701 May-June 2017 P2 V2 Q3

- (ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

.....

..... [1]

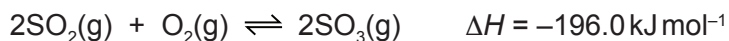
- (iii) Calculate the value of K_p for this experiment.

$K_p =$ [1]

[Total: 18]

3. Question part 1/4 | 9701 May-June 2017 P2 V3 Q3

- 3 Sulfur trioxide, SO_3 , is manufactured from sulfur dioxide and oxygen by the Contact process.



- (a) The enthalpy change of formation of SO_2 , $\Delta H_f^\circ \text{SO}_2(\text{g})$, is $-296.8 \text{ kJ mol}^{-1}$.

- (i) Define the term *enthalpy change of formation*.

.....

 [2]

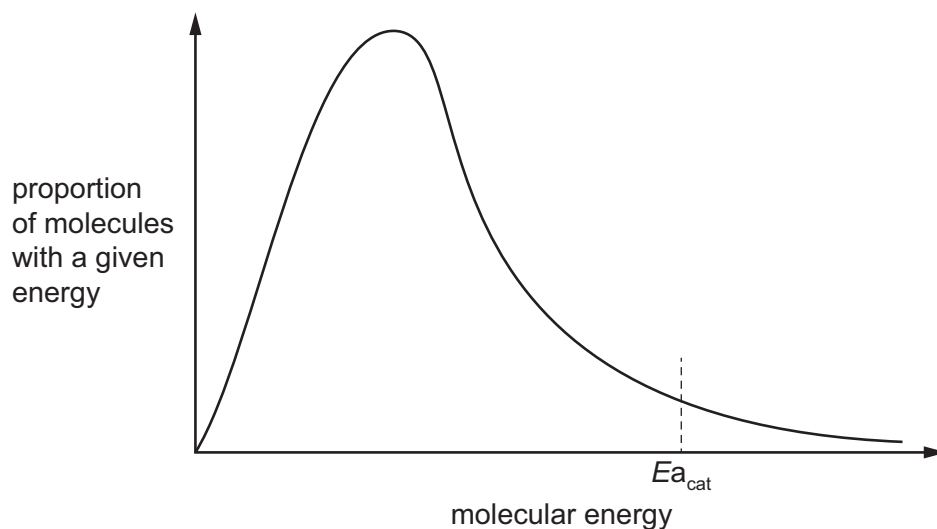
- (ii) Use the data to calculate the enthalpy change of formation of $\text{SO}_3(\text{g})$.

$$\Delta H_f^\circ \text{SO}_3(\text{g}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (b) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5 .

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.

$E_{a,\text{cat}}$ represents the activation energy for the reaction in the presence of the catalyst.



- (i) Add a labelled mark, $E_{a,\text{uncat}}$, to the diagram to indicate the activation energy in the absence of the catalyst. [1]

3. Question part 2/4 | 9701 May-June 2017 P2 V3 Q3

(ii) State the benefit of using a catalyst in this reaction. Explain how it achieves this effect.

.....

.....

.....

..... [2]

(iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate

.....

.....

.....

yield

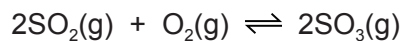
.....

.....

..... [4]

3. Question part 3/4 | 9701 May-June 2017 P2 V3 Q3

- (c) At a pressure of $1.50 \times 10^5 \text{ Pa}$, 1.00 mol of sulfur dioxide gas, SO_2 , was mixed with 1.00 mol of oxygen gas, O_2 . The final equilibrium mixture formed was found to contain 0.505 mol of O_2 .



- (i) Calculate the amount, in mol, of SO_2 and SO_3 in the equilibrium mixture.

$\text{SO}_2 = \dots\dots\dots \text{ mol}$

$\text{SO}_3 = \dots\dots\dots \text{ mol}$
[1]

- (ii) Calculate the partial pressure of oxygen gas, $p\text{O}_2$, in the equilibrium mixture.

$p\text{O}_2 = \dots\dots\dots \text{ Pa}$ [2]

3. Question part 4/4 | 9701 May-June 2017 P2 V3 Q3

- (d) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2 , the partial pressures of SO_2 , O_2 and SO_3 were as shown.

$$p\text{SO}_2 = 8.42 \times 10^2 \text{ Pa}$$

$$p\text{O}_2 = 6.00 \times 10^4 \text{ Pa}$$

$$p\text{SO}_3 = 9.10 \times 10^4 \text{ Pa}$$

- (i) Write the expression for the equilibrium constant, K_p , for the production of SO_3 from SO_2 and O_2 .

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction and state the units.

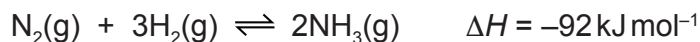
$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 17]

- 1 Ammonia, NH_3 , is manufactured from nitrogen and hydrogen by the Haber process.



- (a) Some bond energies are given.

$$\text{N} \equiv \text{N} = 944 \text{ kJ mol}^{-1}$$

$$\text{H}-\text{H} = 436 \text{ kJ mol}^{-1}$$

- (i) Explain the meaning of the term *bond energy*.

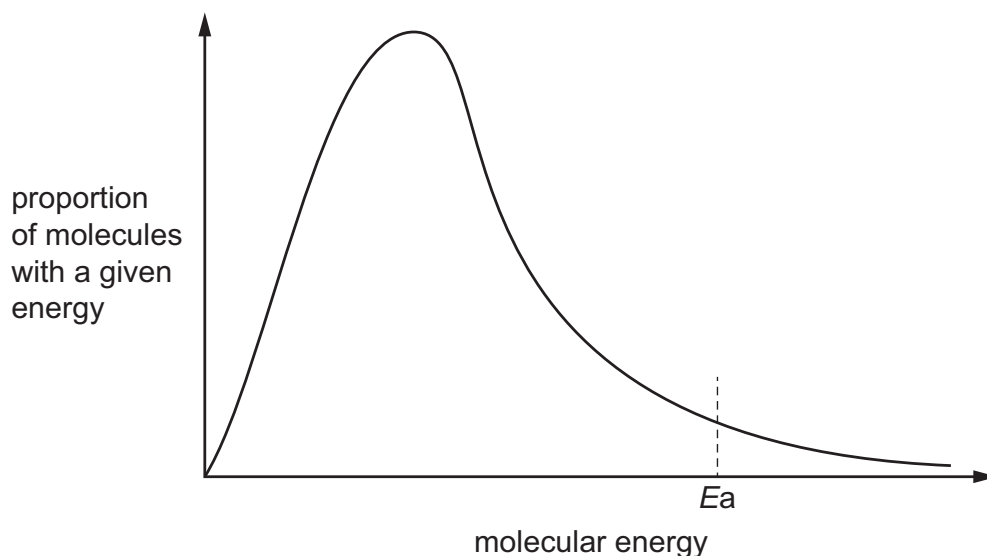
.....
..... [2]

- (ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... kJ mol^{-1} [2]

- (b) The Haber process is usually carried out at a temperature of approximately 400°C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400°C is shown.
 E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

.....
.....
.....
..... [3]

- (iii) State and explain the effect of increasing temperature on the yield of ammonia. Use Le Chatelier's principle to explain your answer.

.....
.....
.....
..... [3]

- (c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $\text{N}_2(\text{g})$, was mixed with 3.00 mol of hydrogen, $\text{H}_2(\text{g})$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $\text{NH}_3(\text{g})$.

- (i) Calculate the amounts, in mol, of $\text{N}_2(\text{g})$ and $\text{H}_2(\text{g})$ in the equilibrium mixture.

$\text{N}_2(\text{g}) = \dots\dots\dots$ mol

$\text{H}_2(\text{g}) = \dots\dots\dots$ mol
[2]

- (ii) Calculate the partial pressure of ammonia, p_{NH_3} , in the equilibrium mixture.

Give your answer to **three** significant figures.

$p_{\text{NH}_3} = \dots\dots\dots$ Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure/Pa
$\text{N}_2(\text{g})$	2.20×10^6
$\text{H}_2(\text{g})$	9.62×10^5
$\text{NH}_3(\text{g})$	1.40×10^4

- (i) Write the expression for the equilibrium constant, K_p , for the production of ammonia from nitrogen and hydrogen.

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction.

State the units.

$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

- (iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p .

effect on yield of ammonia

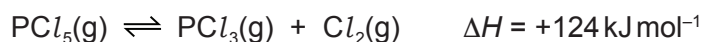
effect on value of K_p

[2]

[Total: 22]

5. Question part 1/2 | 9701 Oct-Nov 2017 P2 V2 Q2

- 2 At 450 K phosphorus(V) chloride, $\text{PCl}_5(\text{g})$, decomposes to form phosphorus(III) chloride, $\text{PCl}_3(\text{g})$, and chlorine, $\text{Cl}_2(\text{g})$. A dynamic equilibrium is established as shown.



- (a) The enthalpy change of formation of $\text{PCl}_3(\text{g})$ under these conditions is given.

$$\Delta H_f^\circ \text{PCl}_3(\text{g}) = -320 \text{ kJ mol}^{-1}$$

Calculate the enthalpy change of formation of $\text{PCl}_5(\text{g})$ under these conditions.

Include a sign with your answer.

enthalpy change = ... kJ mol^{-1} [1]

- (b) (i) State and explain the effect of increasing temperature on the rate of decomposition of $\text{PCl}_5(\text{g})$.

.....

 [2]

- (ii) State and explain the effect of increasing temperature on the percentage of $\text{PCl}_5(\text{g})$ that decomposes.

.....

 [2]

- (c) Explain the meaning of the term *dynamic equilibrium* and the conditions necessary for it to become established.

.....

 [2]

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Topical questions | 18 questions

5. Question part 2/2 | 9701 Oct-Nov 2017 P2 V2 Q2

(d) When 2.00 mol of $\text{PCl}_5(\text{g})$ are decomposed at 450 K and $1.00 \times 10^5 \text{ Pa}$ the resulting equilibrium mixture contains 0.800 mol of $\text{Cl}_2(\text{g})$.

(i) Calculate the partial pressure of phosphorus(V) chloride, $p\text{PCl}_5$, in this equilibrium mixture.

$$p\text{PCl}_5 = \dots\dots\dots \text{ Pa} \quad [2]$$

(ii) Write the expression for the equilibrium constant, K_p , for the decomposition of $\text{PCl}_5(\text{g})$.

$$K_p =$$

[1]

(iii) The partial pressures of $\text{PCl}_3(\text{g})$ and of $\text{Cl}_2(\text{g})$ in this equilibrium mixture are both $2.86 \times 10^4 \text{ Pa}$.

Calculate the value of K_p and state its units.

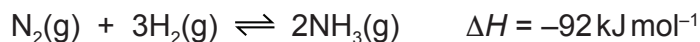
$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 12]

- 1 Ammonia, NH_3 , is manufactured from nitrogen and hydrogen by the Haber process.



- (a) Some bond energies are given.

$$\text{N} \equiv \text{N} = 944 \text{ kJ mol}^{-1}$$

$$\text{H}-\text{H} = 436 \text{ kJ mol}^{-1}$$

- (i) Explain the meaning of the term *bond energy*.

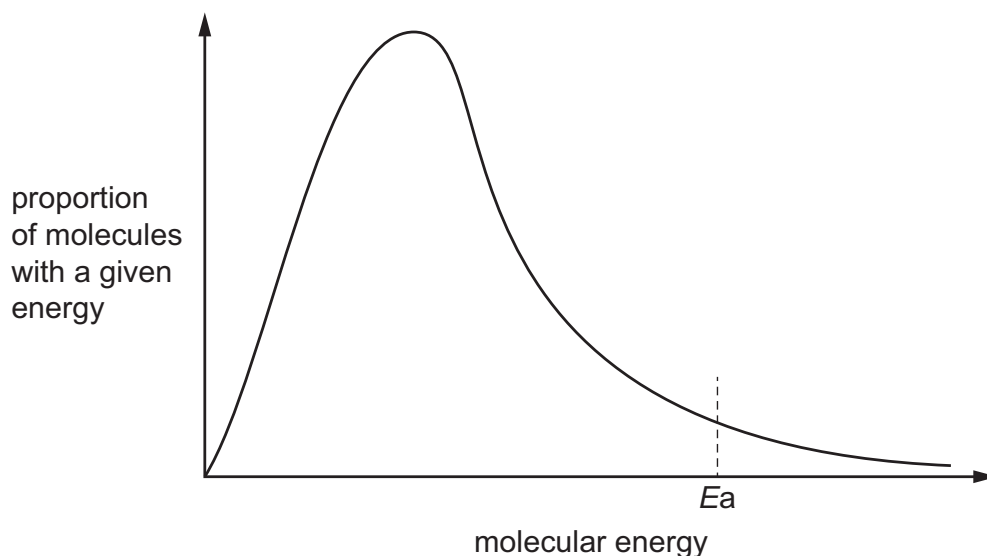
.....
..... [2]

- (ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... kJ mol^{-1} [2]

- (b) The Haber process is usually carried out at a temperature of approximately 400°C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400°C is shown.
 E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

.....
.....
.....
..... [3]

- (iii) State and explain the effect of increasing temperature on the yield of ammonia. Use Le Chatelier's principle to explain your answer.

.....
.....
.....
..... [3]

- (c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $\text{N}_2(\text{g})$, was mixed with 3.00 mol of hydrogen, $\text{H}_2(\text{g})$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $\text{NH}_3(\text{g})$.

- (i) Calculate the amounts, in mol, of $\text{N}_2(\text{g})$ and $\text{H}_2(\text{g})$ in the equilibrium mixture.

$\text{N}_2(\text{g}) = \dots\dots\dots$ mol

$\text{H}_2(\text{g}) = \dots\dots\dots$ mol
[2]

- (ii) Calculate the partial pressure of ammonia, p_{NH_3} , in the equilibrium mixture.

Give your answer to **three** significant figures.

$p_{\text{NH}_3} = \dots\dots\dots$ Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure/Pa
$\text{N}_2(\text{g})$	2.20×10^6
$\text{H}_2(\text{g})$	9.62×10^5
$\text{NH}_3(\text{g})$	1.40×10^4

- (i) Write the expression for the equilibrium constant, K_p , for the production of ammonia from nitrogen and hydrogen.

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction.

State the units.

$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

- (iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p .

effect on yield of ammonia

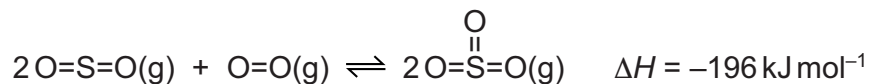
effect on value of K_p

[2]

[Total: 22]

1 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5 .



- (a) (i)** State the effect of a catalyst on a reaction.
Explain how a catalyst causes this effect.

.....

 [2]

- (ii)** State the meaning of the term *heterogeneous* as applied to catalysts.

.....

 [1]

- (b)** Some bond energies are given.

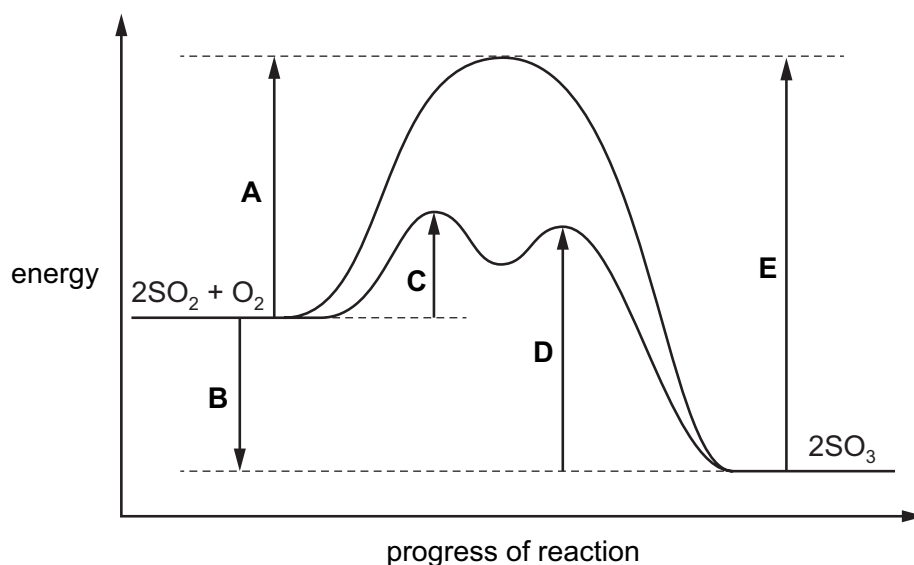
bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3 .

S=O bond energy in SO_3 = ... kJ mol^{-1} [2]

The Contact process is usually carried out at a temperature of about 400°C and a pressure just above atmospheric pressure. Using a higher or lower temperature and pressure would affect both the rate of production of sulfur trioxide and the yield of sulfur trioxide.

- (c) A reaction pathway diagram for both the catalysed and uncatalysed reactions between SO_2 and O_2 is shown.



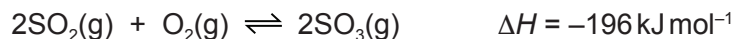
The letters **A–E** represent energy changes.

Complete the table by stating which letter, **A–E**, represents the energy change described.

energy change	letter
the energy change for the production of SO_3	
the activation energy for the production of SO_3 in the absence of a catalyst	
the activation energy for the first step in the decomposition of SO_3 in the presence of a catalyst	

[3]

The equation for this stage of the Contact Process is shown.



- (d) (i) State and explain the effect of increasing temperature on the rate of production of SO_3 .

.....
.....
.....
..... [3]

- (ii) State and explain the effect of increasing temperature on the yield of SO_3 .

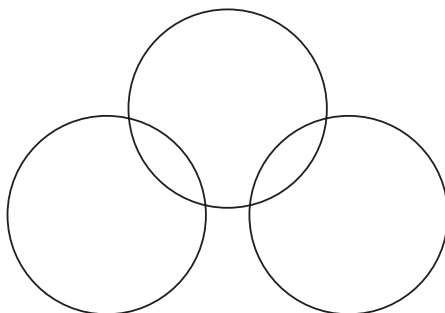
.....
.....
.....
..... [3]

- (e) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $\text{H}_2\text{S}_2\text{O}_7$.
The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum, $\text{H}_2\text{S}_2\text{O}_7$, with water to form sulfuric acid.

..... [1]

- (f) SO_2 reacts with water to form sulfurous acid.
Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.
- (i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SO_2 . Show outer electrons only.



[1]

- (ii) State the meaning of the term *strong Brønsted-Lowry acid*.

.....
.....
..... [2]

- (iii) Write an equation to show the acid-base behaviour of sulfuric acid with water. Include state symbols.

..... [2]

[Total: 20]

- 2** The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2 , HCl and CaF_2 .

	F_2	HCl	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

- (a) (i)** State what is meant by the term *relative formula mass*.

.....
.....
..... [2]

- (ii)** F_2 and HCl are both covalent molecules.

Suggest why the boiling point of HCl is higher than that of F_2 .

.....
.....
..... [2]

- (iii)** Explain why CaF_2 has a very high boiling point.

.....
..... [1]

- (iv)** $CaF_2(aq)$ can be made by the reaction of calcium carbonate with hydrofluoric acid, $HF(aq)$.

Write an equation for this reaction. Include state symbols.

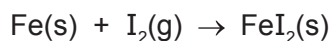
..... [2]

- (b) (i) Complete the electronic configuration of a chloride ion.

1s² [1]

- (ii) When Cl₂ is passed over hot iron, FeCl₃ is formed.

However, when I₂(g) is passed over hot iron, the following reaction occurs.



State what you would observe during the reaction between Fe and I₂. Explain why FeI₂(s) is formed rather than FeI₃(s).

observation

.....

explanation

.....

..... [2]

- (iii) FeI₂ is soluble in water.

A student carries out a chemical test to confirm that a solution of FeI₂ contains aqueous iodide ions, I⁻(aq). The student adds a single reagent and a precipitate forms.

Identify the reagent the student uses. State the colour of the precipitate that forms.

reagent

colour of precipitate

[2]

- (iv) Compounds containing I⁻ are often contaminated by bromide ions, Br⁻.

Identify a further reagent that the student could use to show that the precipitate formed in (iii) contained iodide ions.

..... [1]

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(i) Draw a 'dot-and-cross' diagram to represent the bonding in a molecule of HOF.

Show the outer shell electrons only.

[2]

(ii) HOF can be made by the reaction of F_2 with ice at -40°C . The reaction is similar to the reaction of Cl_2 with cold water.

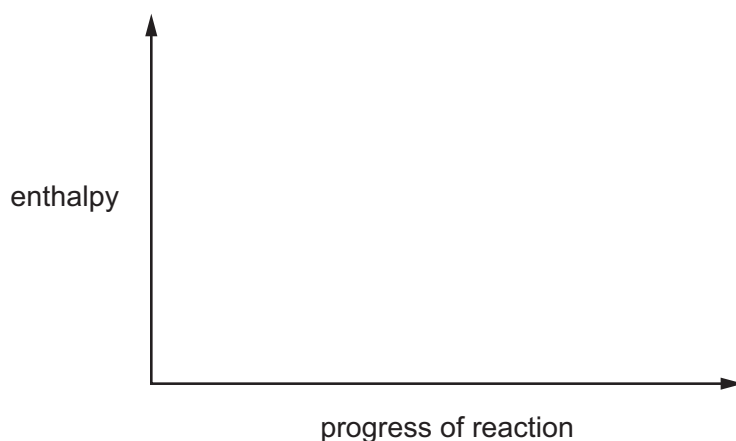
Suggest an equation for the reaction of F_2 with ice.

..... [1]

(iii) HOF is an unstable compound and decomposes to form HF and O_2 .



Draw a fully labelled reaction pathway diagram on the axes provided to show the decomposition of HOF into HF and O_2 .



[2]

- (iv) Pure HF is a colourless liquid at 273 K. The liquid contains HF molecules that have strong hydrogen bonds between them.

Draw a fully labelled diagram to suggest how a hydrogen bond can form between two HF molecules.

[3]

- (d) Interhalogen compounds, such as BrCl or IF_5 , contain two or more different halogen atoms that are covalently bonded.

D is an interhalogen compound that contains only chlorine and fluorine.

At 0°C and $101\,325\text{ Pa}$, 1 dm^3 of **D** has a mass of 4.13 g .

- (i) Use the general gas equation to calculate the relative molecular mass, M_r , of **D**.

$M_r = \dots\dots\dots$
[3]

- (ii) Use your answer to (i) to determine the molecular formula of **D**.

If you were unable to calculate the M_r in (i), assume that the M_r is 130.5 . This is **not** the correct value.

molecular formula of **D** = $\dots\dots\dots$
[1]

[Total: 25]

9701 Chemistry Paper 2 - Equilibria

Topical questions | 18 questions

8. Question part 5/5 | 9701 Feb-March 2019 P2 V2 Q2

Question 3 starts on the next page.

9. Question part 1/2 | 9701 May-June 2019 P2 V2 Q1

1 Methylpropane, $(\text{CH}_3)_2\text{CHCH}_3$, is an isomer of butane, $\text{CH}_3(\text{CH}_2)_2\text{CH}_3$.

(a) (i) Explain why methylpropane and butane are a pair of isomers.

.....
..... [2]

(ii) Identify the type of isomerism shown by methylpropane and butane.

..... [1]

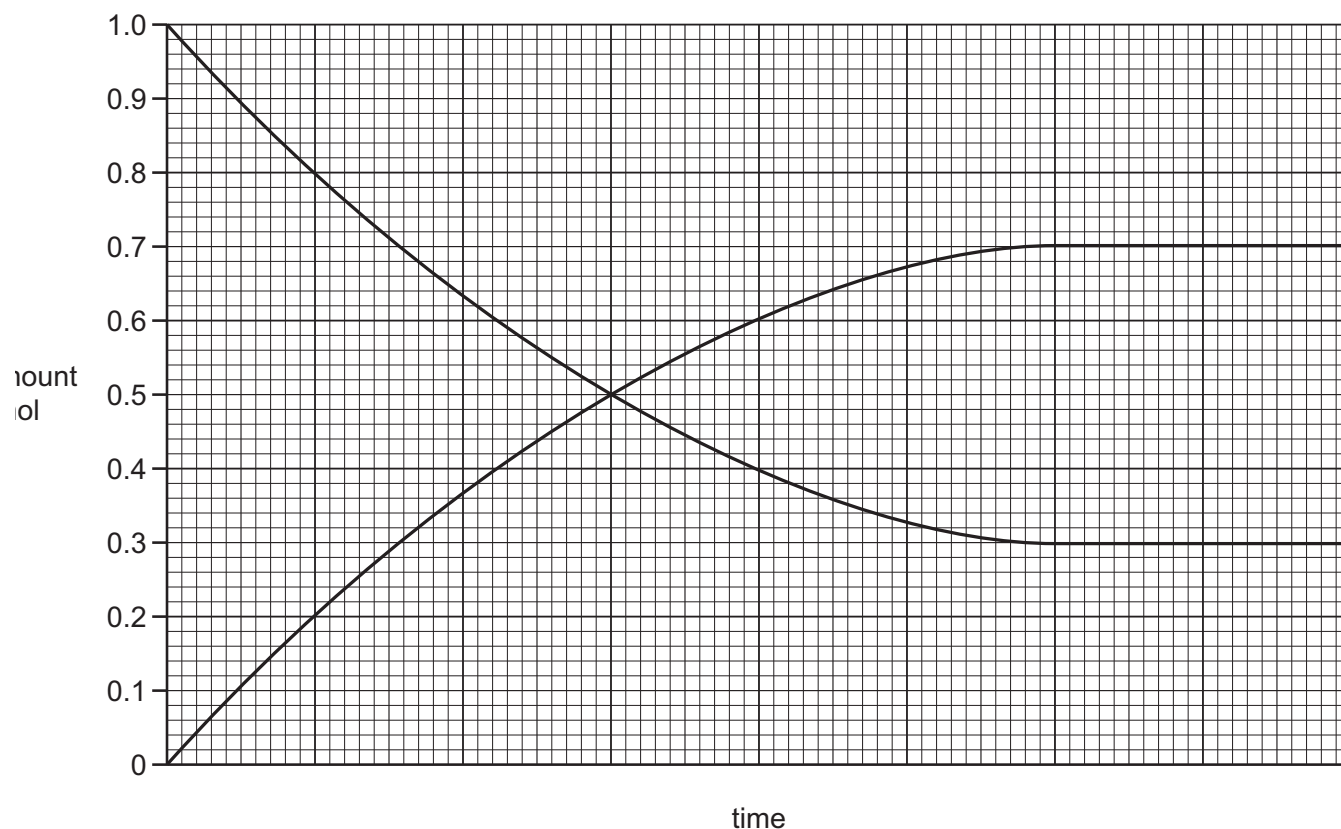
(b) When a sample of butane is heated to 373 K, in the presence of a catalyst, and allowed to reach equilibrium the following reaction occurs.



State and explain the effect on the composition of this equilibrium mixture when the temperature is increased to 473 K.

.....
.....
..... [2]

- (c) 1 mole of butane gas was added to a 1 dm^3 closed system, at a constant temperature and pressure. The amount of butane and methylpropane was measured at regular time intervals.



- (i) Label the graph with a t to show the time taken to reach dynamic equilibrium. [1]

- (ii) Use the graph to find the concentration of butane and methylpropane in the mixture at equilibrium.

concentration of butane = ... mol dm^{-3}

concentration of methylpropane = ... mol dm^{-3}

[1]

- (iii) Write an expression for K_c for this reaction.

[1]

- (iv) Calculate a value for K_c and state its units.

$K_c = \dots\dots\dots$ units = ... [2]

[Total: 10]

10. Question part 1/5 | 9701 Oct-Nov 2021 P2 V2 Q1

1 Hydrogen iodide, HI, is a colourless gas at room temperature.

(a) (i) Explain why HI has a higher boiling point than HCl and HBr.

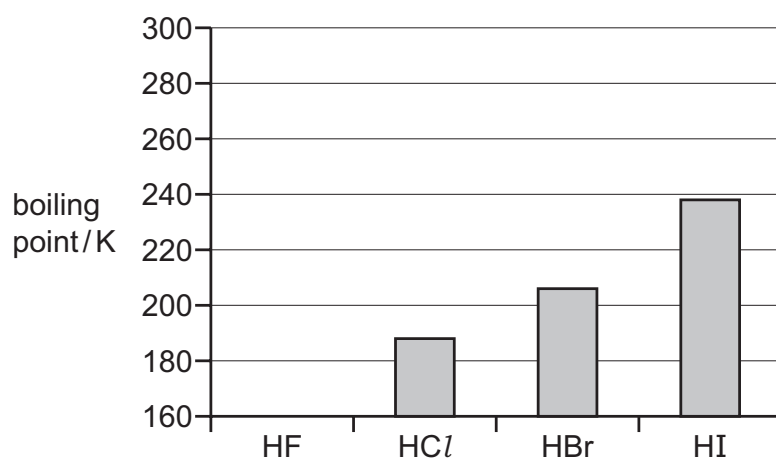
.....

.....

.....

..... [2]

(ii) The bar chart shows the boiling points of HCl, HBr and HI. The boiling point of HF is not shown.



Hydrogen bonds form between HF molecules.

Draw a bar on the bar chart to predict the boiling point of HF.

Explain your answer.

.....

..... [2]

(b) The standard enthalpy change of formation, $\Delta H_f^\ominus$, of HI(g) is $+26.5 \text{ kJ mol}^{-1}$.

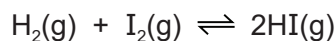
Define the term *standard enthalpy change of formation*.

.....

.....

..... [2]

- (c) HI(g) can be formed by reacting H₂(g) with I₂(g). The reaction is reversible, and an equilibrium forms quickly at high temperatures.



- (i) Construct an expression for the equilibrium constant, K_p , for the reaction of H₂(g) and I₂(g) to form HI(g).

$$K_p =$$

[1]

- (ii) The equilibrium partial pressures of the gases at 200 °C are as follows.

$$p_{\text{H}_2(\text{g})} = 895 \text{ Pa}$$

$$p_{\text{I}_2(\text{g})} = 895 \text{ Pa}$$

$$p_{\text{HI}(\text{g})} = 4800 \text{ Pa}$$

Calculate K_p for this reaction.

$$K_p = \dots\dots\dots [1]$$

- (iii) State how the value of K_p would change, if at all, if the reaction were carried out at 100 °C rather than 200 °C.

Explain your answer.

.....
.....
.....
..... [2]

(d) HI reacts with oxygen to form iodine and water.

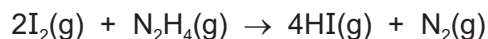
(i) Construct an equation for the reaction of HI with oxygen.

..... [1]

(ii) Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....
.....
.....
..... [2]

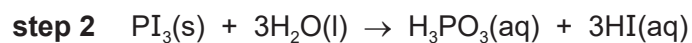
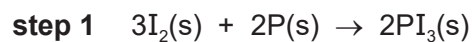
(e) HI(g) can also be formed by the reaction of I₂(g) with hydrazine, N₂H₄(g).



State the change in pressure that would occur when 2 mol I₂(g) fully reacts with 1 mol N₂H₄(g) in a sealed container at constant temperature. Explain your answer.

.....
.....
.....
..... [2]

(f) In the laboratory, HI(aq) can be formed in a two-step process.



(i) Draw a 'dot-and-cross' diagram of a PI_3 molecule.

[2]

(ii) Name the type of reaction in **step 2**.

..... [1]

(iii) $\text{H}_3\text{PO}_3(\text{aq})$ and $\text{HI}(\text{aq})$ are both strong Brønsted–Lowry acids.

Give the meaning of the term *strong Brønsted–Lowry acid*.

.....
.....
..... [2]

(iv) Give the formula of the conjugate base of H_3PO_3 .

..... [1]

(g) HI(g) reacts with propene, $\text{CH}_3\text{CH}=\text{CH}_2(\text{g})$ to form a mixture of 1-iodopropane and 2-iodopropane.

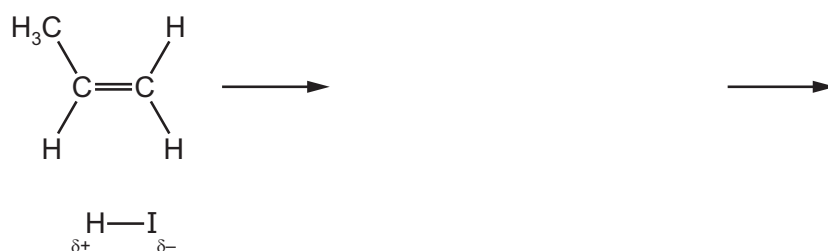
(i) Identify which of 1-iodopropane and 2-iodopropane is the major product of this reaction.

Explain your answer.

.....
.....
.....
..... [2]

(ii) Complete the diagram to show the mechanism of the reaction between HI and $\text{CH}_3\text{CH}=\text{CH}_2$ that forms the major product identified in (g)(i).

Include curly arrows, lone pairs of electrons and charges as necessary.



[3]

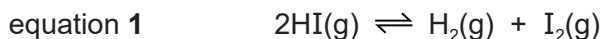
[Total: 26]

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11. Question part 1/2 | 9701 May-June 2022 P2 V2 Q3

- 3 (a)** 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.



- (i)** Explain what is meant by dynamic equilibrium.

.....
.....
..... [2]

- (ii)** Describe **one** difference in the initial appearance of the reaction mixture compared to the mixture at equilibrium.

..... [1]

- (iii)** Write an expression for K_p for the reaction described in equation 1.

$K_p =$

[1]

- (iv)** At equilibrium the partial pressure of HI(g) is 86.4 kPa.

Calculate the amount of HI(g) present in the mixture at equilibrium. Show your working.

amount of HI(g) = ... mol [2]

11. Question part 2/2 | 9701 May-June 2022 P2 V2 Q3

- (b) Use equation 1 and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH , for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
H–H	436
I–I	151
H–I	299

$$\Delta H = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

- (c) Describe the effect of increasing pressure on the value of K_p for the decomposition of HI(g).

..... [1]

- (d) HCl(g) is prepared by adding NaCl(s) to concentrated H_2SO_4 .

HI(g) is **not** prepared by adding NaI(s) to concentrated H_2SO_4 because the HI(g) produced also reacts with concentrated H_2SO_4 .

- (i) Identify the type of reaction that occurs when NaI(s) reacts with concentrated H_2SO_4 to form HI(g).

..... [1]

- (ii) Write an equation for the reaction of HI(g) and concentrated H_2SO_4 .

..... [1]

- (iii) Explain why HI(g) reacts with concentrated H_2SO_4 whereas HCl does not.

..... [1]

[Total: 12]

12. Question part 1/2 | 9701 May-June 2023 P2 V3 Q4

- 4 (a) Hydrogen chloride gas is made in the laboratory by adding concentrated sulfuric acid to potassium chloride.

(i) Construct an equation for this reaction.

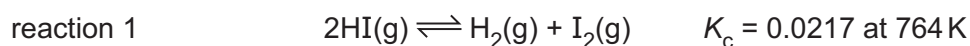
..... [1]

- (ii) Explain why hydrogen iodide is **not** prepared by adding concentrated sulfuric acid to sodium iodide.

.....

..... [2]

- (b) A sample of HI(g) is added to a 2.00 dm³ sealed vessel at 764 K and allowed to reach equilibrium.



At equilibrium the mixture contains 1.70 mol of HI(g).

- (i) State **one** difference in the appearance of the initial reaction mixture compared to the mixture at equilibrium.

.....

..... [1]

- (ii) Deduce the expression for equilibrium constant K_c for reaction 1.

$$K_c =$$

[1]

- (iii) Calculate the concentration of I₂ present in the reaction mixture at equilibrium.
Show your working.

concentration of I₂ = ... mol dm⁻³ [3]

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12. Question part 2/2 | 9701 May-June 2023 P2 V3 Q4

(c) The experiment is repeated at 500 K. The value of K_c under these conditions is 0.00625.

(i) Describe the difference in the composition of the equilibrium mixture at 500 K compared to 764 K.

.....
..... [1]

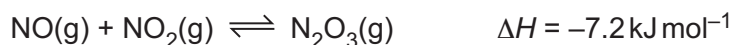
(ii) Use Le Chatelier's principle to deduce whether the decomposition of HI(g) is endothermic or exothermic. Explain your answer.

.....
.....
..... [1]

[Total: 10]

13. Question part 1/4 | 9701 Oct-Nov 2023 P2 V2 Q2

- 2 NO and NO₂ react at 25 °C to give N₂O₃ as shown in the equation.



The reaction is reversible and reaches equilibrium in a closed system.

- (a) Fig. 2.1 shows how the rate of the forward reaction changes with time.

Initially, the rate of the reverse reaction is zero.

Complete Fig. 2.1 to sketch how the rate of the **reverse** reaction changes with time.

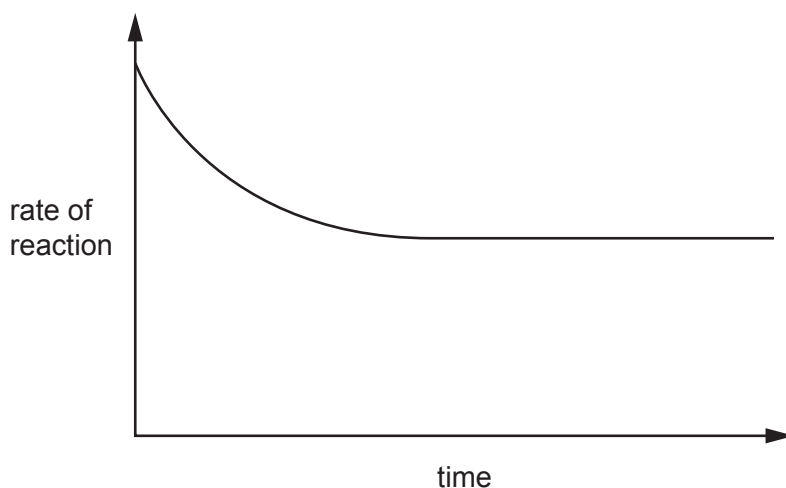


Fig. 2.1

[1]

- (b) State how the position of equilibrium changes, if at all, when the reaction takes place at 100 °C.

Explain your answer.

Assume the pressure remains constant.

.....

.....

.....

..... [2]

- (c) Table 2.1 shows the composition of an equilibrium mixture of $\text{NO}(\text{g})$, $\text{NO}_2(\text{g})$ and $\text{N}_2\text{O}_3(\text{g})$ at 101 kPa.

Table 2.1

gas	number of moles at equilibrium/mol
NO	0.605
NO_2	0.605
N_2O_3	0.390

Calculate K_p , the equilibrium constant with respect to partial pressures.

Deduce the units of K_p .

$K_p =$ units [3]

- (d) Identify one natural process and one man-made process that cause the formation of atmospheric NO and NO_2 .

natural process

man-made process.....

[2]

(e) NO_2 is a brown gas that can be used to form nitric acid.

(i) NO_2 is a free radical.

Define free radical.

..... [1]

(ii) NO_2 has a catalytic role in the oxidation of atmospheric sulfur dioxide.

Write equations to show the catalytic role of NO_2 in this oxidation.

.....
..... [2]

(iii) State **one** environmental consequence of the oxidation of atmospheric sulfur dioxide.

..... [1]

(f) A student titrates nitric acid with a base to form a solution containing aqueous magnesium nitrate.

(i) Identify a base that the student could use.

..... [1]

(ii) The student evaporates the water to obtain magnesium nitrate solid. When this solid is heated it decomposes.

Write an equation for the decomposition of magnesium nitrate.

..... [1]

(iii) State how the thermal stability of Group 2 nitrates changes down the group.

..... [1]

[Total: 15]

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13. Question part 4/4 | 9701 Oct-Nov 2023 P2 V2 Q2

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14. Question part 1/2 | 9701 May-June 2024 P2 V1 Q3

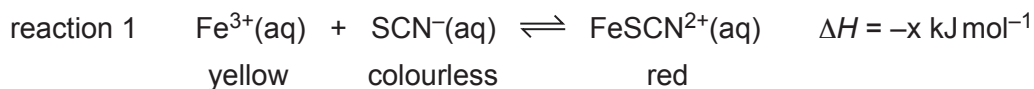
3 (a) Define Le Chatelier's principle.

.....

.....

..... [2]

(b) Reaction 1 describes the reversible reaction between yellow $\text{Fe}^{3+}(\text{aq})$ and colourless $\text{SCN}^{-}(\text{aq})$ to produce red $\text{FeSCN}^{2+}(\text{aq})$.



A mixture of $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{FeSCN}^{2+}(\text{aq})$ is at equilibrium at 20°C .

The temperature of this mixture is then increased to 50°C and allowed to reach equilibrium.

Deduce the changes that occur, if any, in the equilibrium mixture at 50°C compared to the equilibrium mixture at 20°C .

- change in appearance

.....

- change in relative concentration of $\text{FeSCN}^{2+}(\text{aq})$

.....

- change in value of the equilibrium constant, K_c

.....

[3]

- (c) In another experiment, equimolar amounts of $\text{Fe}^{3+}(\text{aq})$ and $\text{SCN}^{-}(\text{aq})$ are mixed together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3 .



At equilibrium the mixture contains:

- $[\text{SCN}^{-}] = 1.30 \times 10^{-3} \text{ mol dm}^{-3}$
- $[\text{FeSCN}^{2+}] = 0.300 \times 10^{-3} \text{ mol dm}^{-3}$.

- (i) Calculate the initial amount, in mol, of $\text{Fe}^{3+}(\text{aq})$ added to $\text{SCN}^{-}(\text{aq})$ to produce this mixture.

initial amount of $\text{Fe}^{3+}(\text{aq}) = \dots\dots\dots \text{ mol}$ [2]

- (ii) Calculate K_c for reaction 1 and state its units.

Show your working.

$K_c = \dots\dots\dots$

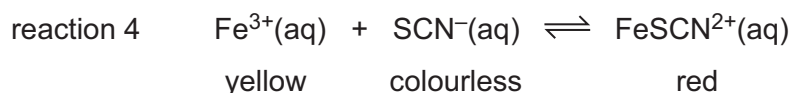
units $\dots\dots\dots$
[2]

[Total: 9]

- 3 (a) Describe what is meant by dynamic equilibrium.

.....
.....
..... [2]

- (b) Reaction 4 describes the reversible reaction between yellow $\text{Fe}^{3+}(\text{aq})$ and colourless $\text{SCN}^{-}(\text{aq})$ to produce red $\text{FeSCN}^{2+}(\text{aq})$.



An equilibrium mixture contains $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{FeSCN}^{2+}(\text{aq})$. A few colourless crystals of soluble $\text{KSCN}(\text{s})$ are added. The mixture is then left until it reaches equilibrium again. The temperature of both equilibrium mixtures is the same.

- (i) Deduce the changes that occur, if any, in the equilibrium mixture after $\text{KSCN}(\text{s})$ is added compared to the original equilibrium mixture.

- change in appearance

.....

- change in relative concentration of $\text{Fe}^{3+}(\text{aq})$

.....

- change in value of the equilibrium constant, K_c

.....

[3]

15. Question part 2/4 | 9701 May-June 2024 P2 V2 Q3



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(ii) The expression for the equilibrium constant, K_c , for reaction 4 is shown.

$$K_c = \frac{[\text{FeSCN}^{2+}(\text{aq})]}{[\text{Fe}^{3+}(\text{aq})] \times [\text{SCN}^{-}(\text{aq})]}$$

$5.00 \times 10^{-5} \text{ mol}$ of $\text{Fe}^{3+}(\text{aq})$ and $5.00 \times 10^{-5} \text{ mol}$ of $\text{SCN}^{-}(\text{aq})$ are added together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3 .

At equilibrium the concentration of $\text{FeSCN}^{2+}(\text{aq})$ is $4.23 \times 10^{-4} \text{ mol dm}^{-3}$.

Calculate the equilibrium constant, K_c , for reaction 4.

Include the units in your answer.

$K_c =$

units

[4]



(c) Determine the full electronic configuration of Fe^{3+} .

..... [1]

(d) $\text{SCN}^{-}(\text{aq})$ is colourless.

Complete the dot-and-cross diagram in Fig. 3.1 to show the arrangement of outer electrons in an SCN^{-} ion.

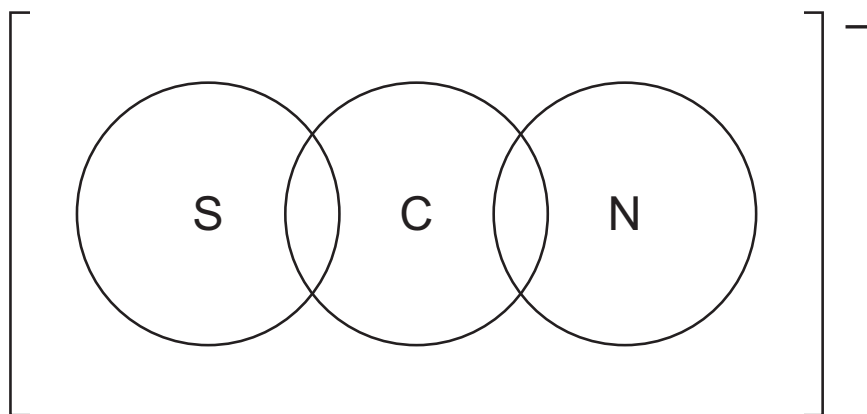


Fig. 3.1

[2]

[Total: 12]

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15. Question part 4/4 | 9701 May-June 2024 P2 V2 Q3



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- 2 $\text{N}_2(\text{g})$ reacts with $\text{H}_2(\text{g})$ in the Haber process, as shown in reaction 1.

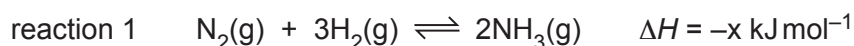


Table 2.1 shows the different conditions used to produce three equilibrium mixtures, **A**, **B** and **C**.

Table 2.1

	A	B	C
initial molar ratio of $\text{N}_2 : \text{H}_2$ added	1 : 3	1 : 3	1 : 3
temperature / °C	500	500	1000
pressure / atm	1000	1000	1000
iron present in mixture	no	yes	no
percentage yield of $\text{NH}_3(\text{g})$ at equilibrium	58	x	y

- (a) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **B** compared to **A**.

.....

 [1]

- (b) (i) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **C** compared to **A**.

.....

 [1]

- (ii) Describe and explain the change to the rate of the forward reaction that occurs to establish the equilibrium in **C** compared to **A**.

You do **not** need to refer to the Boltzmann distribution in your answer.

.....

 [2]

- (c) (i) Write an expression for the equilibrium constant, K_p , for reaction 1. State the units.

$$K_p =$$

units

[2]

- (ii) Equilibrium mixture **D** is made when 1.0 mol of $N_2(g)$ and 3.0 mol of $H_2(g)$ are added to a sealed container at $750^\circ C$ and 1000 atm and left to reach equilibrium. This mixture contains 1.16 mol of $NH_3(g)$.

Calculate the mole fraction of $NH_3(g)$ in **D**.

mole fraction of $NH_3(g)$ = ... [2]

- (iii) The mole fraction of $N_2(g)$ is 0.625 in a new equilibrium mixture, **E**.

Calculate the partial pressure of $N_2(g)$ in **E** when the total pressure is 1000 atm.

partial pressure of $N_2(g)$ = ... atm [1]

(d) When oxides of nitrogen escape into the atmosphere they may be involved in:

- formation of acid rain from sulfur dioxide
- formation of photochemical smog.

(i) Identify the role of NO and NO₂ in the formation of H₂SO₄ from SO₂ in the atmosphere to produce acid rain.

Use relevant equations to support your answer.

.....

.....

.....

.....

.....

..... [3]

(ii) Outline how NO and NO₂ may contribute to the formation of photochemical smog.

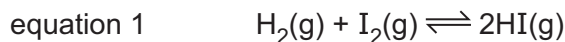
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.....

..... [2]

[Total: 14]

- 3 $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ react to form $\text{HI}(\text{g})$ in a reversible reaction, as shown in equation 1.



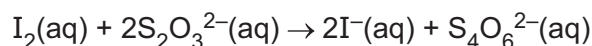
In three separate experiments, a student combines different amounts of two or more of the gases from equation 1. In each experiment, the gases are left to reach equilibrium at a given temperature.

- (a) In experiment 1, $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ are combined.

Water is then added to the equilibrium mixture to produce 1.00 dm^3 of solution **A**.

The amount of $\text{I}_2(\text{aq})$ present in 1.00 dm^3 of solution **A** is found by titration with $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.

Exactly 32.90 cm^3 of $0.200 \text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3$ reacts with all of the I_2 in a 25.0 cm^3 sample of solution **A**.



- (i) Calculate the amount, in mol, of $\text{S}_2\text{O}_3^{2-}$ that reacts in the titration.

amount of $\text{S}_2\text{O}_3^{2-} = \dots\dots\dots \text{ mol}$ [1]

- (ii) Use your answer to (a)(i) to calculate the amount, in mol, of I_2 present in 1.00 dm^3 of solution **A**.

(If you were unable to obtain an answer in (a)(i), then use $9.42 \times 10^{-3} \text{ mol}$. This is **not** the correct answer.)

amount of I_2 in 1.00 dm^3 of solution **A** = $\dots\dots\dots \text{ mol}$ [2]

- (b) In experiment 2, 0.100 mol of $\text{H}_2(\text{g})$, 0.200 mol of $\text{I}_2(\text{g})$ and 0.300 mol of $\text{HI}(\text{g})$ are combined.

At equilibrium 0.154 mol of I_2 is present.

Calculate the amounts, in mol, of H_2 and HI in the equilibrium mixture produced in experiment 2.

amount of H_2 in equilibrium mixture = $\dots\dots\dots \text{ mol}$

amount of HI in equilibrium mixture = $\dots\dots\dots \text{ mol}$
[3]

17. Question part 2/2 | 9701 May-June 2025 P2 V4 Q3



- (c) In experiment 3, 0.0772 mol of H_2 and 0.0986 mol of I_2 are present in an equilibrium mixture at 298 K.



Use the equilibrium constant, K_c , to calculate the amount, in mol, of HI present in the equilibrium mixture in experiment 3.

amount of HI in equilibrium mixture = ... mol [1]

- (d) The value of K_c for the dissociation of HCl at 298 K is 5.50×10^{-34} .



- (i) Define covalent bond.

.....
 [1]

- (ii) Describe and explain the relative thermal stabilities of the hydrogen halides HCl and HI .

.....

 [2]

- (iii) Use the data given in (c) and (d) to suggest a value for the equilibrium constant for the **dissociation** of $\text{HBr}(\text{g})$ at 298 K.

..... [1]

[Total: 11]

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18. Question part 1/2 | 9701 Oct-Nov 2025 P2 V4 Q2

- 2 Aluminium oxide, Al_2O_3 , and phosphorus(V) oxide, P_4O_{10} , are both used as reagents and catalysts.

- (a) The melting point of Al_2O_3 is $2072^\circ C$. The melting point of P_4O_{10} is $340^\circ C$.

Explain the difference in the melting points of these two compounds.

.....
.....
.....
..... [3]

- (b) A 5.00 dm^3 sealed flask contains 0.400 mol of $CO(g)$ and 0.800 mol of $H_2(g)$ and an Al_2O_3 catalyst. The flask is heated to a temperature of $290^\circ C$ and allowed to reach equilibrium. Equation 1 shows the reaction.



The equilibrium constant, K_c , of equation 1 is given.

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$$

- (i) State the units of K_c .

..... [1]

- (ii) The equilibrium mixture contains 0.280 mol of $CH_3OH(g)$.

Calculate the value of K_c .

Give your answer to **three** significant figures.

value of K_c = ... [3]

- (iii) State and explain the effect, if any, on the value of K_c when the overall pressure in the sealed flask is increased.

.....
..... [1]

18. Question part 2/2 | 9701 Oct-Nov 2025 P2 V4 Q2



- (c) P_4O_{10} catalyses the reversible reaction of CO with H_2 to form CH_3OH .



P_4O_{10} then acts as a dehydrating agent, causing CH_3OH to form CH_3OCH_3 .

- (i) Explain how the presence of a catalyst affects a chemical reaction.

.....
.....
..... [1]

- (ii) Construct an equation for the dehydration reaction of CH_3OH to form CH_3OCH_3 .

..... [1]

- (iii) Write an equation to show the reaction of P_4O_{10} with an excess of water.

..... [1]

[Total: 11]