Cambridge AS & A Level

CHEMISTRY

Paper 2

Topical Past Paper Questions

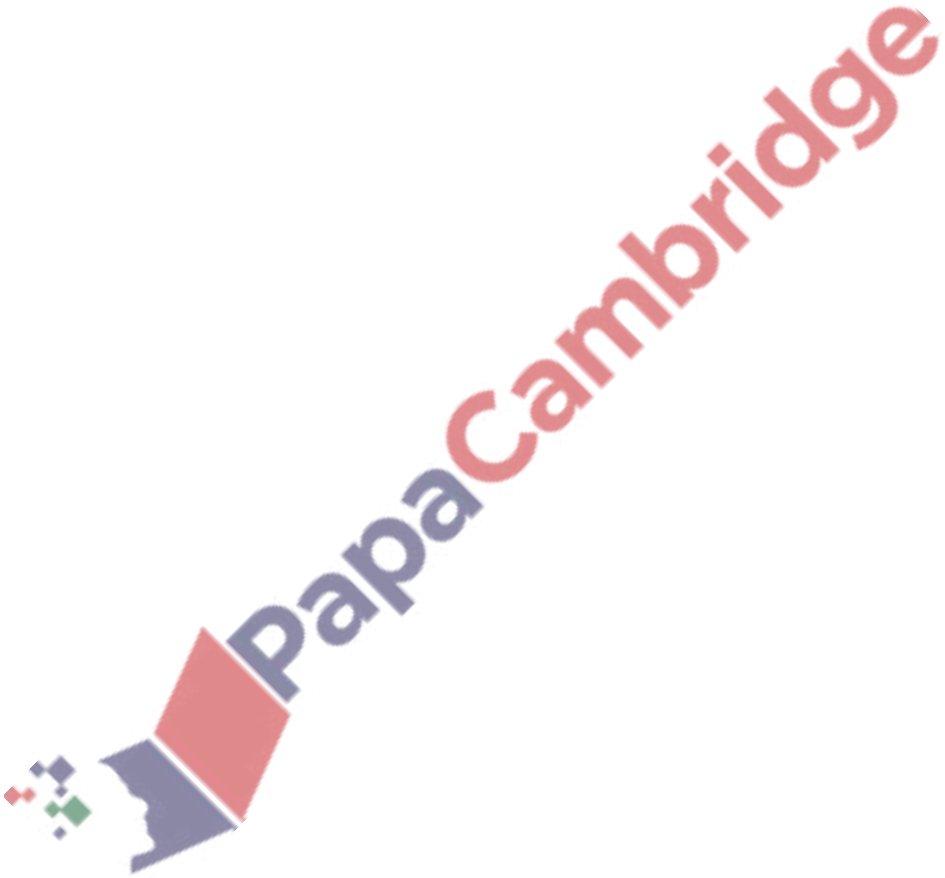
+ Answer Scheme

2015 - 2021

PapaCambridge

Chapter 7

Equilibria



7.1 Chemical equilibria: reversible reactions, dynamic equilibrium

26. 9701_s21_qp_23 Q: 2

Methanol, CH_3OH, is soluble in water because it forms hydrogen bonds with water molecules.

(a) Draw a fully labelled diagram to show how a hydrogen bond forms between a water molecule and a methanol molecule.

[3]

(b) Methanol has a melting point of –97.6 °C and a boiling point of 64.7 °C.

A sample of pure liquid methanol is added to a flask and then sealed. The sealed flask is left for several days at constant temperature. The vapour pressure is then measured as 17 kPa.

(i) Describe what is meant by the term *vapour pressure of methanol*.

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.....

..... [2]

(ii) Explain why some of the liquid becomes a vapour.

.....

.....

..... [1]

(iii) Suggest and explain why the vapour pressure of water at room temperature is lower than the vapour pressure of methanol at room temperature. Refer to the correct intermolecular forces in your answer.

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.....

..... [2]

(c) Methanol is made by reacting carbon monoxide with hydrogen.

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

Carbon monoxide and hydrogen react at 1.0×10^7 Pa and 200 °C. Eventually the reaction mixture reaches dynamic equilibrium.

The table shows the amounts of each species present in the mixture.

	CO(g)	H_2(g)	CH_3OH(g)
initial amount / mol	1.0	2.0	0
equilibrium amount / mol	0.030	0.060	0.97

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

.....

.....

..... [2]

(ii) Calculate the partial pressure of methanol vapour at equilibrium under these conditions. Show your working.

..... Pa [2]

(iii) Write an expression for the equilibrium constant, K_p, for this reaction. State the units in your answer.

K_p =

units = ... [2]

[Total: 14]

27. 9701_s18_qp_23 Q: 1

The elements sodium to chlorine, in the third period, all form oxides.

(a) Draw a diagram to show the shape of the molecule of each of the oxides, SO_3 and Cl_2O.
Name each shape.
In SO_3 each oxygen atom forms a double bond with the sulfur atom.

SO_3	Cl_2O
.....	.....

[4]

(b) (i) Explain why the melting point of MgO is higher than that of Na_2O.

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.....

..... [2]

(ii) Explain why the melting point of SiO_2 is much higher than that of SO_3.

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.....

.....

..... [2]

(c) SO_3 is produced by the reaction between SO_2 and O_2 in the Contact process. A dynamic equilibrium is established.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(i) Explain why increasing the total pressure, at constant temperature, increases the rate of production of SO_3 and increases the yield of SO_3.

rate .....

.....

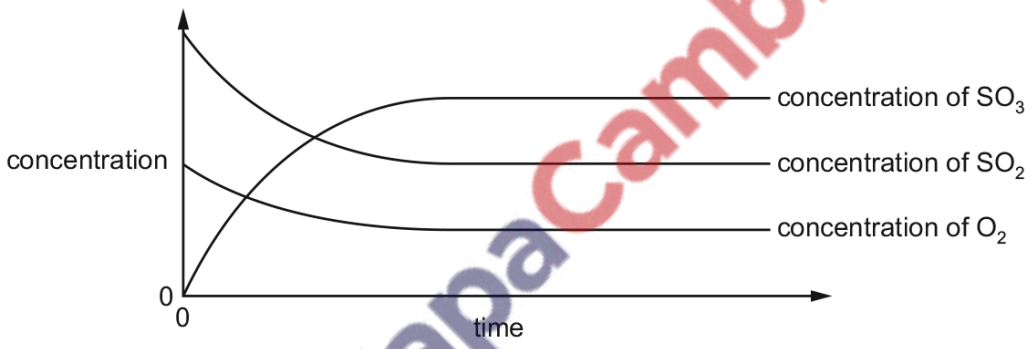
.....

yield .....

.....

..... [4]

The graph shows how the concentrations of all three species in the system change with time for a typical reaction mixture. The gradients of all three lines decrease with time and then level off in this dynamic equilibrium.



(ii) Explain why the gradients of the SO_2 and O_2 lines decrease with time.

.....

..... [2]

(iii) Explain why all three lines become horizontal.

.....

..... [1]

(iv) Suggest a reason why the initial gradient of the SO_2 line is steeper than that of the O_2 line.

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..... [1]

(d) 2.00 moles of $SO_2(g)$ and 2.00 moles of $O_2(g)$ are sealed in a container with a suitable catalyst, at constant temperature and pressure. The resulting equilibrium mixture contains 1.98 moles of $SO_3(g)$.
The total volume of the equilibrium mixture is 40.0 dm^3.

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

(i) Write the expression for the equilibrium constant, K_c, for the reaction between $SO_2(g)$ and $O_2(g)$ to produce $SO_3(g)$.

K_c =

[1]

(ii) Calculate the amount, in moles, of $SO_2(g)$ and $O_2(g)$ in the equilibrium mixture.

$SO_2(g)$ = ... mol

$O_2(g)$ = ... mol
[2]

(iii) Use your answers to **(d)(i)** and **(d)(ii)** to calculate the value of K_c for this equilibrium mixture. Give the units of K_c.

K_c = ...

units = ...
[3]

[Total: 22]

28. 9701_w17_qp_22 Q: 2

At 450 K phosphorus(V) chloride, $PCl_5(g)$, decomposes to form phosphorus(III) chloride, $PCl_3(g)$, and chlorine, $Cl_2(g)$. A dynamic equilibrium is established as shown.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g) \qquad \Delta H = +124\,kJ\,mol^{-1}$$

(a) The enthalpy change of formation of $PCl_3(g)$ under these conditions is given.

$$\Delta H_f\, PCl_3(g) = -320\,kJ\,mol^{-1}$$

Calculate the enthalpy change of formation of $PCl_5(g)$ 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 $PCl_5(g)$.

.....

.....

..... [2]

(ii) State and explain the effect of increasing temperature on the percentage of $PCl_5(g)$ that decomposes.

.....

.....

..... [2]

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

.....

.....

.....

..... [2]

(d) When 2.00 mol of $PCl_5(g)$ are decomposed at 450 K and 1.00×10^5 Pa the resulting equilibrium mixture contains 0.800 mol of $Cl_2(g)$.

(i) Calculate the partial pressure of phosphorus(V) chloride, $p PCl_5$, in this equilibrium mixture.

$p PCl_5$ = ... Pa [2]

(ii) Write the expression for the equilibrium constant, K_p, for the decomposition of $PCl_5(g)$.

K_p =

[1]

(iii) The partial pressures of $PCl_3(g)$ and of $Cl_2(g)$ in this equilibrium mixture are both 2.86×10^4 Pa.

Calculate the value of K_p and state its units.

K_p = ...

units = ...

[2]

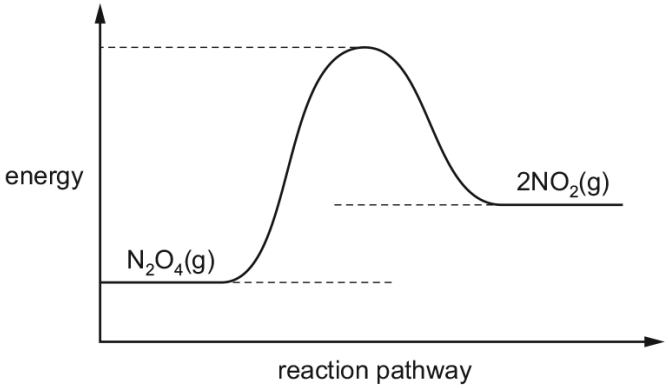
[Total: 12]

29. 9701_w16_qp_22 Q: 2

Dinitrogen tetraoxide, N_2O_4, and nitrogen dioxide, NO_2, exist in dynamic equilibrium with each other.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = +54\,kJ\,mol^{-1}$$

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 1.68×10^5 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 = ... [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 NO_2 = ... [1]

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, 1.68×10^5 Pa, to calculate the value of the equilibrium constant, K_p, and give its units.

K_p = ...

units = ...
[3]

[Total: 13]

7.2 Ionic equilibria

30. 9701_s18_qp_21 Q: 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.

$$2\,O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2\,O{=}\overset{\overset{O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(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.

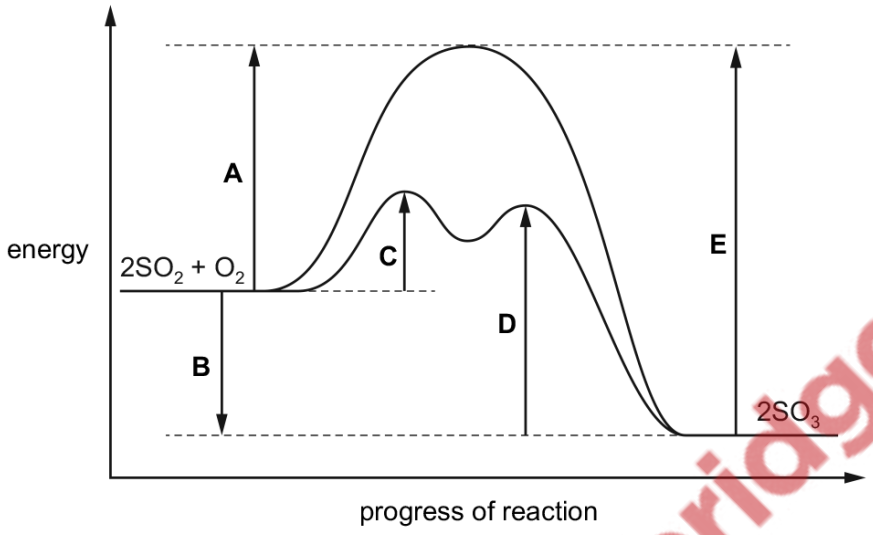
bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

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.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(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]

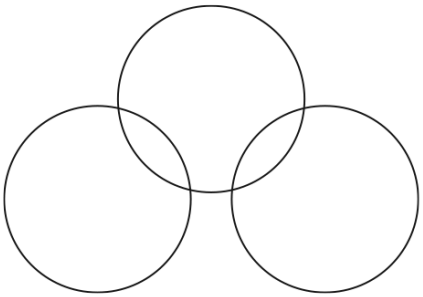
(e) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $H_2S_2O_7$.
The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum, $H_2S_2O_7$, 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]

31. 9701_s18_qp_22 Q: 2

Ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2$, has a relative formula mass, M_r, of 284.

(a) Define the term *relative formula mass*.

.....

.....

.....

..... [2]

(b) One of the cations in ammonium iron(II) sulfate is the ammonium ion, NH_4^+.

(i) Draw a 'dot-and-cross' diagram of an ammonium ion. Show outer shell electrons only.

Use × to show electrons from nitrogen.
Use ● to show electrons from hydrogen.

[2]

(ii) Suggest the shape of an ammonium ion and predict the bond angle.

shape .....

bond angle .....
[2]

(c) In aqueous solution the ammonium ion acts as a weak Brønsted-Lowry acid.

(i) Explain the meaning of the term *weak Brønsted-Lowry acid*.

.....

.....

.....

..... [2]

(ii) Write an equation to show this behaviour of the ammonium ion in water. Include state symbols.

..... [2]

(d) Mohr's salt, $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$, is the hydrated form of ammonium iron(II) sulfate.

x represents the number of moles of water in 1 mole of the salt.

A student wanted to determine the value of x. 0.784 g of the hydrated salt was dissolved in water and this solution was acidified.

All of the solution was titrated with 0.0200 mol dm^{-3} potassium manganate(VII). 20.0 cm^3 of this potassium manganate(VII) solution was required for complete reaction with the Fe^{2+} ions.

(i) Use changes in oxidation numbers to balance the equation for the reaction taking place.

$MnO_4^-(aq)$ + ...$Fe^{2+}(aq)$ + ...$H^+(aq)$ → .....$Mn^{2+}(aq)$ + ...$Fe^{3+}(aq)$ + ...$H_2O(l)$

[1]

(ii) State the role of the Fe^{2+} ions in this reaction.

Explain your answer.

.....

..... [2]

(iii) Calculate the amount, in moles, of manganate(VII) ions that reacted.

amount = ... mol [1]

(iv) Calculate the amount, in moles, of Fe^{2+} ions in the sample of the salt.

amount = ... mol [1]

(v) Calculate the relative formula mass of $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

relative formula mass = ... [1]

(vi) Calculate the value of x.

x = ... [1]

[Total: 17]
