NAME DATE STARTED TARGET END DATE

GCE A LEVEL — CHEMISTRY UNIT 3 QUESTION PACK

1095-01 (Legacy CH5) · New spec Unit 3 Topic 6 · A2 unit, first sat 2017, 80 marks, 1h 45min paper

REVISE.wales

CHEMISTRY — UNIT 3 · Quantitative Equilibria — K_c & K_p

Topic 3.8 — Equilibria: K_c and K_p expressions, calculations, partial pressures and the effect of temperature on K

Writing equilibrium constant expressions, calculating K_c and K_p from initial / equilibrium amounts (ICE tables), distinguishing position-of-equilibrium shifts from changes in K, and predicting how temperature affects K (exothermic vs endothermic).

Legacy 2008 specification

Estimated time for entire question pack: ~2 h 27 min

Derived from the legacy CH5 paper's pace of ~1.3 min/mark, padded for long-prose and calculation answers (92 marks over 5 questions).

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC CH5 papers (2008 modular spec, Jun 2010 – Jun 2016) that maps onto the new-spec A2 Unit 3 Topic 3.8.

Questions are ordered by source paper date.

INSTRUCTIONS

Use black ink or black ball-point pen. Show all working — quality of written communication will affect marks. A calculator is allowed. You will need the WJEC Periodic Table / Data Booklet.

For Examiner's use only

Q	Source	Max	Mark
1	Jun 12 Q4	20	
2	Jun 12 Q5	20	
3	Jun 13 Q1	14	
4	Jun 14 Q5	20	
5	Jun 16 Q3	18	
Total		**92**	

Quantitative Equilibria — K_c & K_p — what the new spec asks

WJEC GCE A Level Chemistry (from 2015) · Unit 3: Physical & Inorganic Chemistry · Topic 3.8.

K_c expression

- aA + bB ⇀ cC + dD ⇒ $K_c = [C]^c[D]^d / [A]^a[B]^b$.
- Use equilibrium concentrations (mol dm^{-3}).
- Units depend on stoichiometry (cancel mol dm^{-3}).
- Exclude pure solids and pure liquids.

K_p expression

- Use partial pressures for gases.
- p_X = mole fraction × total pressure.
- $K_p = (p_C)^c(p_D)^d / (p_A)^a(p_B)^b$.
- Units depend on Δn_{gas}: atm or Pa raised to that power.

ICE tables

- Initial — Change — Equilibrium.
- Use stoichiometry to express changes (x = mol reacting).
- Substitute into expression and solve (often quadratic).
- Convert to concentrations / partial pressures before substituting.

Position vs constant

- Catalyst → no effect on K or position; faster equilibrium.
- Pressure change → no effect on K (gases), position shifts to fewer moles.
- Concentration / pressure change of one species → position shifts, K unchanged.
- Only temperature changes K.

Temperature dependence

- Endothermic forward ($\Delta H > 0$): K ↑ with T.
- Exothermic forward ($\Delta H < 0$): K ↓ with T.
- Le Chatelier: system shifts to oppose change.
- Quantitatively: van't Hoff equation (outside spec).

Quantitative Equilibria — K_c & K_p in one page

Quick-reference notes — revisit before each question.

K_c setup

Equilibrium [products] over [reactants]; exclude pure solids/liquids. Power = stoichiometric coefficient.

ICE table

Tabulate Initial / Change / Equilibrium moles. Convert to concentrations (÷ V) before substituting into K_c.

K_p setup

Use partial pressures $p_X = (n_X/n_{total}) \cdot p_{total}$. Same expression structure as K_c.

Units

Units cancel mol dm^{-3} raised to Δn. If $\Delta n = 0$ (e.g. $H_2 + I_2 \rightharpoonup 2HI$) K is dimensionless.

Effect of T

Endothermic forward: K ↑ with T. Exothermic forward: K ↓ with T. Position shifts in same direction as K change.

Catalyst & pressure

Catalyst: no change to K or position. Total pressure change: K constant; position shifts to fewer gas moles side (if any).

SECTION B

*Answer **both** questions in the separate answer book provided.*

4. *(a)* In the reaction below carbon monoxide is acting as a reducing agent.

$$5CO \; + \; I_2O_5 \longrightarrow 5CO_2 \; + \; I_2$$

Use oxidation states (numbers) to show that carbon monoxide is acting as a reducing agent in this reaction. [2]

(b) State how the stabilities of the +II and +IV oxidation states vary down Group 4. [1]

(c) You are given two solutions. One contains aqueous aluminium ions, Al^{3+}, and the other contains aqueous lead(II) ions, Pb^{2+}.

(i) Describe a reaction to show that both of these ions exhibit amphoteric behaviour. Your answer should state the reagent(s) used, the names of any precipitates and any relevant observations. *Chemical equations are not required.* [4]
QWC [1]

(ii) Describe what is **seen** when iodide ions are added to an aqueous solution of Pb^{2+} ions. Give the **ionic** equation for the reaction that occurs. [2]

(d) Monomeric aluminium chloride is described as containing an electron-deficient species.

(i) Explain, using monomeric covalent aluminium chloride, what is meant by *electron deficient* and why this leads to the ready formation of the Al_2Cl_6 dimer.
You should show the structure of this dimer as part of your answer. [3]

(ii) The electron-deficient nature of the aluminium chloride monomer results in the compound having an affinity for chlorine-containing species. This is important in catalysis and also in the production of specialised solvents.
Give **one** example of the use of the monomer in either of these ways. [1]

(iii) On heating, gaseous dimeric aluminium chloride molecules dissociate into the monomer.

$$Al_2Cl_6(g) \quad \rightleftharpoons \quad 2AlCl_3(g)$$

I State **one** reason why the entropy of this gaseous system is increasing. [1]

II Use the equation

$$\Delta G = \Delta H - T\Delta S$$

to calculate the temperature at which the dissociation of gaseous Al_2Cl_6 molecules into gaseous $AlCl_3$ molecules just occurs spontaneously.
The entropy change for this reaction, ΔS, is 88 $J\,mol^{-1}\,K^{-1}$ and the enthalpy change, ΔH, is 60 $kJ\,mol^{-1}$. [2]

(e) Solutions containing aqueous aluminium ions are weakly acidic because of the dissociation of one of the coordinated water molecules.

$$[Al(H_2O)_6]^{3+}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$$

The acidity of this solution has been used to stop bleeding from minor cuts.

The expression for the equilibrium constant, in terms of concentrations, for the above system is shown below.

$$K_c = \frac{\left[[Al(H_2O)_5(OH)]^{2+}(aq) \right] \left[H^+(aq) \right]}{\left[[Al(H_2O)_6]^{3+}(aq) \right]}$$

Use this expression to calculate the pH of a solution of aluminium ions of concentration 0.10 mol dm^{-3}. The equilibrium constant, K_c, for this system is 1.26×10^{-5} mol dm^{-3}. [3]

Total [20]

5. *(a)* A student obtained some measurements of the partial pressures of reactants and products for the reaction between sulfur(IV) oxide and nitrogen(IV) oxide.

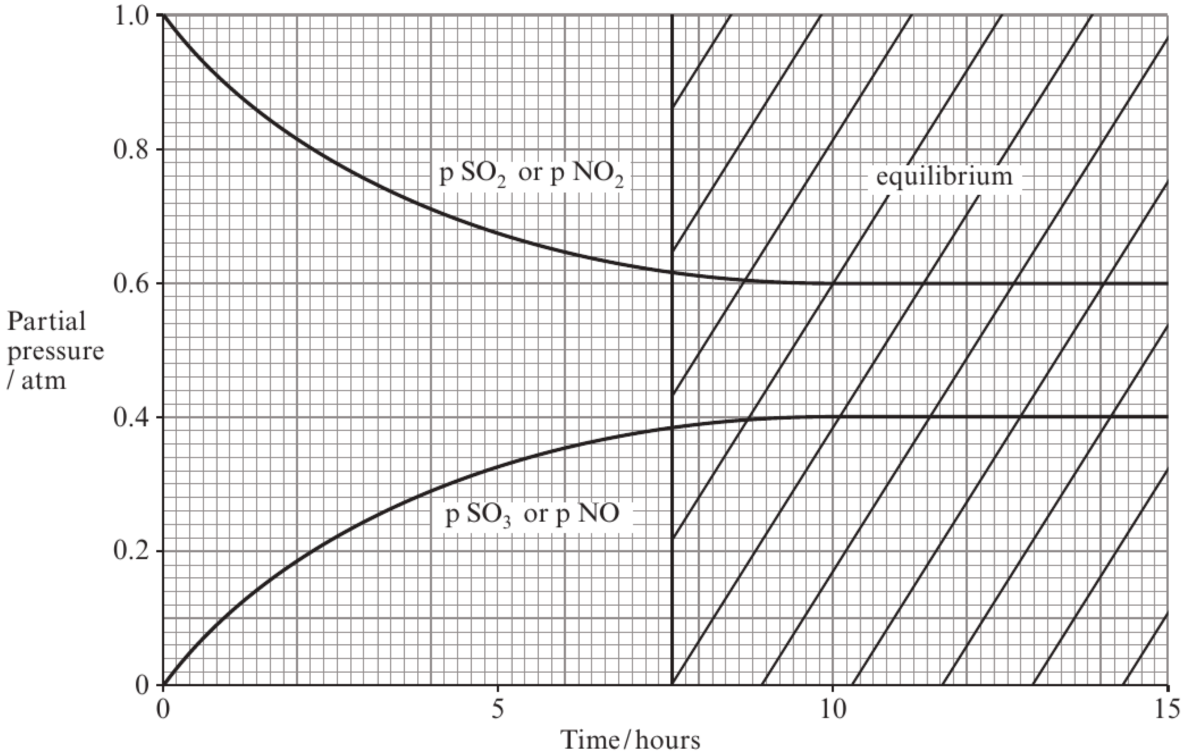
$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$$

The numerical value of K_p for this reaction is 2.5.

(i) Give the expression for the equilibrium constant in terms of partial pressures, K_p, stating its units (if any). [2]

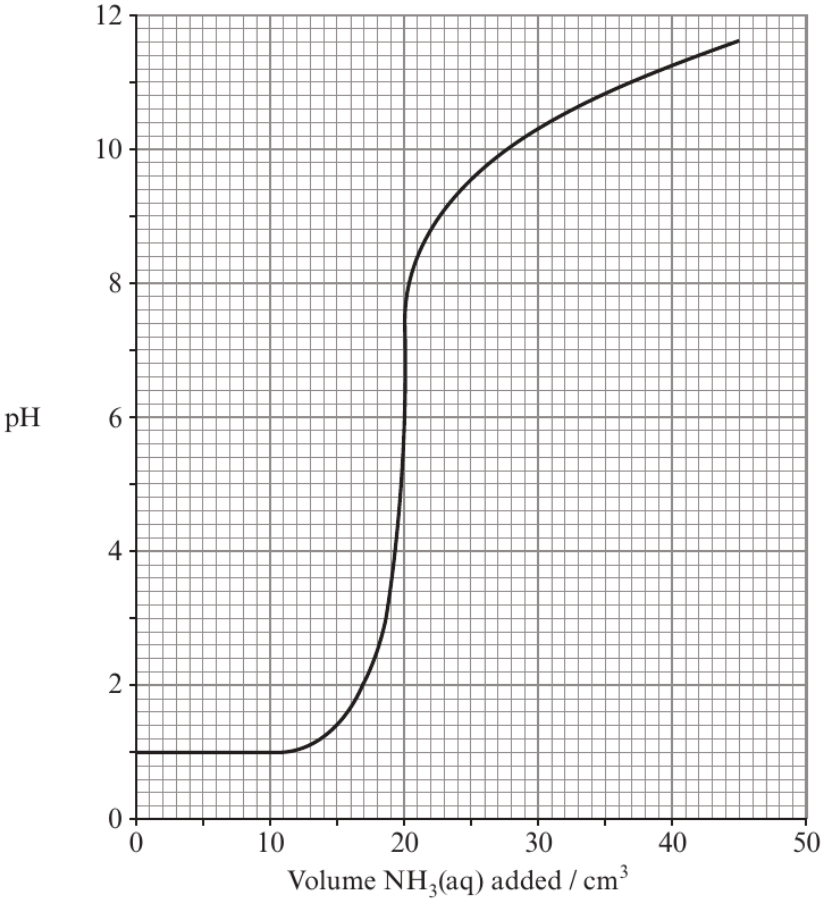
(ii) He decided to present his results in the form of the diagram below.

State the **two** things that are wrong with this diagram, explaining your answer. [4]



(iii) The enthalpy change for this reaction is –41 kJ mol^{-1}. State and explain how the value of the equilibrium constant would change (if at all) when the reaction is run at a higher temperature. [2]

(b) The acid-base titration curve for the reaction between aqueous solutions of nitric acid, HNO_3, and ammonia, both of concentration 0.100 mol dm^{-3}, is shown in the diagram. In this strong acid-weak base system, aqueous ammonia was added to 20.0 cm^3 of aqueous nitric acid.



(i) Describe and explain the shape of the curve obtained when aqueous ammonia is added to the aqueous nitric acid. [3]
QWC [1]

(ii) Deduce, using information obtained from the graph, the mole ratio of the two reactants in this titration. Explain your reasoning. [2]

(iii) I Explain why the pH of a solution of ammonium nitrate is not 7. [1]
II Use the graph to state the pH of the ammonium nitrate solution obtained at the equivalence point. [1]

(iv) Use your answer to (iii) to state the colour obtained if a few drops of the acid-base indicator bromophenol blue are added to the ammonium nitrate solution, giving the reason for your answer. [1]

pH	Colour
$\leqslant 2.8$	yellow
$\geqslant 4.7$	blue

(c) Ammonium nitrate ($M_r = 80$) is used in 'cold packs' to give a cooling effect for sports injuries. The solid crystals are added to water producing an endothermic reaction.

A typical 'cold pack' contains 40 g of ammonium nitrate that is dissolved in water to make 200 g of the solution. Calculate the molar concentration of the ammonium nitrate solution and hence the drop in temperature that occurs when this pack is used.

[1 mole of ammonium nitrate dissolved in water to make 1 kg of solution produces a drop in temperature of 6.2 °C] [3]

Total [20]

Total Section B [40]

Examiner only

SECTION A

*Answer **all** questions in the spaces provided.*

1. 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.

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

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]

....

....

....

....

Examiner only

(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.

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

(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]

....

....

....

....

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(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]

5. *(a)* Chlorine reacts with aqueous sodium hydroxide in one of two ways, depending on the temperature used.

(i) Write the equation for the reaction of chlorine with

I cold aqueous sodium hydroxide, [1]

II hot aqueous sodium hydroxide. [1]

(ii) Classify this type of redox reaction. [1]

(b) Chlorine reacts with many elements to form chlorides. Explain why phosphorus forms two chlorides, PCl_3 and PCl_5, but nitrogen only forms NCl_3. [2]

(c) Most ionic chlorides, e.g. sodium chloride, are soluble in water. However some, e.g. silver chloride, are insoluble.

The enthalpy change of solution of an ionic compound and its solubility depend on the balance between two enthalpy changes. Name these enthalpy changes and state if they are endothermic or exothermic. Explain how the enthalpy change of solution of a compound and its solubility depend on the balance between them. [4]
QWC [1]

(d) Some standard electrode potentials, $E^{\ominus}$, are given below.

System	$E^{\ominus}$/V
$\frac{1}{2}I_2(s) + e^- \rightleftharpoons I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$\frac{1}{2}Br_2(l) + e^- \rightleftharpoons Br^-(aq)$	+1.09
$\frac{1}{2}Cl_2(g) + e^- \rightleftharpoons Cl^-(aq)$	+1.36
$Ce^{4+}(aq) + e^- \rightleftharpoons Ce^{3+}(aq)$	+1.45

(i) Using the information from the table, state which of the **halides** will reduce Fe^{3+} to Fe^{2+}. Give a reason for your answer. [2]

(ii) Write the cell diagram of the cell formed by combining the $Fe^{3+}(aq)$, $Fe^{2+}(aq)$ and $Ce^{4+}(aq)$, $Ce^{3+}(aq)$ half cells and calculate the standard e.m.f. of this cell. [2]

QUESTION 5 CONTINUES ON PAGE 12

(e) A flask containing an initial mixture of 0.100 mol of ethanoic acid and 0.083 mol of methanol was kept at 25 °C until the following equilibrium had been established.

$$CH_3COOH + CH_3OH \rightleftharpoons CH_3COOCH_3 + H_2O \qquad \Delta H = -3\,kJ\,mol^{-1}$$

The ethanoic acid present at equilibrium required 32.0 cm^3 of a 1.25 mol dm^{-3} solution of sodium hydroxide for complete reaction.

(i) Write an expression for the equilibrium constant, K_c, giving the units, if any. [2]

(ii) Calculate the number of moles of ethanoic acid present at equilibrium. [1]

(iii) Calculate the value of the equilibrium constant, K_c, for this reaction. [2]

(iv) State, giving a reason, what happens to the value of the equilibrium constant, K_c, if the temperature is increased. [1]

Total [20]

Total Section B [40]

END OF PAPER

GCE A level

1095/01-A

CHEMISTRY – CH5
Periodic Table

P.M. TUESDAY, 17 June 2014

3. *Read the passage below and then answer the questions in the spaces provided.*

Hydrogen

Hydrogen might be the simplest of all the elements in terms of atomic structure, but a look at the chemistry of hydrogen enables us to gain a better understanding of many important chemical ideas. Several chemical definitions and standards are based on hydrogen chemistry – from standard electrodes to the pH scale.

Hydrogen is the first element in the Periodic Table and is named from the Greek word *hydrogenos* which means water maker. Hydrogen is the only element that has different names for its isotopes. ${}^{1}_{1}H$ is hydrogen, ${}^{2}_{1}H$ is deuterium and ${}^{3}_{1}H$ is tritium.

Acidity is expressed using the pH scale first devised by the Swedish chemist Sorenson.

$$pH = -\log[H^+]$$

The scale usually runs from 0–14 because 1 mol dm^{-3} H^+ (acid) has a pH of 0 and 1 mol dm^{-3} OH^- (alkali) has a pH of 14. An aqueous solution is neutral when the concentrations of H^+ and OH^- are equal. At 25 °C, the ionic product of water, K_w, has a numerical value of 1.0×10^{-14}. Pure water has a pH of 7, and is neutral. This neutral value of pH can be calculated from K_w. Since boiling water has a larger value of K_w than water at 25 °C, it follows that a substance that is dissolved in boiling water to give a solution with a pH of 7 is slightly alkaline!

When measuring electrode potentials, it is potential differences which are measured. This means that the potential of one half-cell is compared with that of another. Again, hydrogen is the basis of the comparison. All electrode potentials are compared with that of the standard hydrogen electrode.

Looking at data for elements, we see that hydrogen often has the greatest or smallest quantity. For example when burned in air, hydrogen evolves more heat per unit mass than any other substance [$\Delta H_c^\theta(H_2) = -286$ kJ mol^{-1}]. Rockets such as the space shuttle, use a mixture of liquid hydrogen and liquid oxygen to propel them into orbit. Cars have been developed that run on hydrogen using fuel cells. The original airships were filled with hydrogen but its flammability led to a catastrophic fire on the Hindenburg in 1937. Modern airships use helium.

Most hydrogen today is used for the processing of fossil fuels and in the production of ammonia.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Other important uses include as a hydrogenating agent in making margarines, in the production of methanol, in the manufacture of hydrochloric acid and also in cryogenics. Hydrogen – the light, flammable gas with its important industrial roles – does far more than just make water!

- End of passage -

Examiner only

(a) Write an expression for the ionic product of water, K_w, *(line 12)* giving its unit, if any. [1]

Unit ....

(b) The value for K_w at 100 °C is 5.13×10^{-13}. Use this to explain why an aqueous solution of a salt with a pH of 7 at this temperature is slightly alkaline *(line 15)*. [3]

....

....

(c) All electrode potentials are compared with the standard hydrogen electrode *(lines 18-19)*. With the aid of a diagram or otherwise explain what is meant by the *standard hydrogen electrode*. [2]

....

....

....

Examiner only

(d) (i) Use the data given to calculate the standard enthalpy change of combustion of methane. [2]

Substance	$CH_4(g)$	$CO_2(g)$	$H_2O(l)$
Standard enthalpy change of formation, ΔH_f^θ / kJ mol^{-1}	−75	−394	−286

ΔH_c^θ = ... kJ mol^{-1}

(ii) Use this result to show that the statement in *line 21* is correct when comparing hydrogen and methane. [2]

....

....

(e) Cars have been developed that run on hydrogen using fuel cells *(lines 23-24)*. Explain the principles underlying the operation of the hydrogen fuel cell. [3]
QWC [1]

....

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....

....

....

....

Examiner only

(f) In the production of ammonia *(lines 26-27)*, nitrogen and hydrogen were mixed in a vessel and allowed to reach equilibrium at a given temperature. The initial partial pressure of nitrogen was 26 atm and that of hydrogen was 82 atm. The equilibrium partial pressure of the remaining nitrogen was 18 atm.

(i) Write an expression for the equilibrium constant, K_p, for this reaction. [1]

(ii) Calculate the equilibrium partial pressures of hydrogen and ammonia and use these to calculate a value for K_p at this temperature, giving the unit if any. [3]

K_p = ...

Unit ....

Total [18]

18

Total Section A [40]

END OF QUESTION PACK

5 questions · 92 marks · ~2 h 27 min
Source: WJEC CH5 (2008 modular spec, Jun 2010 – Jun 2016)
Curated for WJEC Chemistry 2015 spec A2 Unit 3 — Topic 6 (3.8)