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A' Level Chemistry

Year 1

Unit 9: Equilibria

Summer Examination Revision Pack

The questions in this pack should be attempted **AFTER** completing all other revision.

Grade Accelerator

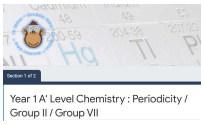
Recall Definitions
Drawing Diagrams
Using Equations
Drawing Graphs

Quizlet Classes

Flashcard Based
Games
Tests & Quizzes
Keyword Spell Checker

Condensed Notes

Keywords & Definitions
Key Concepts
Application
Key Skills



Online Forms

Take Time to Answer
Use Paper & Calculator
Work It Out
Review Missed Marks

Use the 3 Wave Process when completing these revision packs.

1. Complete the questions without assistance
(Can't answer a question? Leave it and move on)
2. Use your notes to fill any gaps after step 1
3. Use the mark scheme to fill in any remaining gaps.

1. Having gaps after step 1 is normal, that's why we are doing revision!
2. If your notes don't help during step 2, they are not good enough!
(Change your note taking method and try to understand the problem)
3. If you don't understand why the mark scheme answer is correct, **see Andy.**

If you struggle with the questions in the pack, **STOP!** and complete some more revision.

If you come to a complete dead-end, **STOP!** and speak to **Andy** asap.

0 4 When substances **P** and **Q** react together to form substance **R** an equilibrium is established according to the equation

$$P(g) + Q(g) \rightleftharpoons 2R(g)$$

The equilibrium constant expression is $K_c = \dfrac{[R]^2}{[P][Q]}$

1.0 mol of **P** and 1.0 mol of **Q** were mixed in a container with volume 1.0 dm^3

At equilibrium, x mol of **P** had reacted.

0 4 . 1 The amount, in moles, of each of P and Q at equilibrium is $(1 - x)$.

Deduce in terms of x the amount, in moles, of **R** in the equilibrium mixture.

[1 mark]

0 4 . 2 At 298 K the value of the equilibrium constant $K_c = 3.6$

Calculate a value for the equilibrium concentration, in mol dm^{-3}, of **R.**

[3 marks]

Equilibrium concentration of **R** _____ mol dm^{-3}

4

	Level 0 **0 marks**	**Insufficient correct chemistry**		

Question	Marking Guidance	Mark	Additional Comments/Guidance
04.1	mol R=2x	1	
04.2	$3.6 = \frac{(2x)^2}{(1-x)^2}$ $\sqrt{3.6} = \frac{2x}{1-x}$ (only positive root to be used) $\sqrt{3.6} - \sqrt{3.6}\,x = 2x$ $1.9 = 3.9x$ $X=0.49$ $[R] = 0.97 mol dm^{-3}$ (allow range 0.97-.098)	1 1 1	M1 can be awarded for the insertion of their answer from 04.1 correctly M2 can be awarded if their expression is expanded M3 solve for x from their expression in M1 and use it to calculate [R]

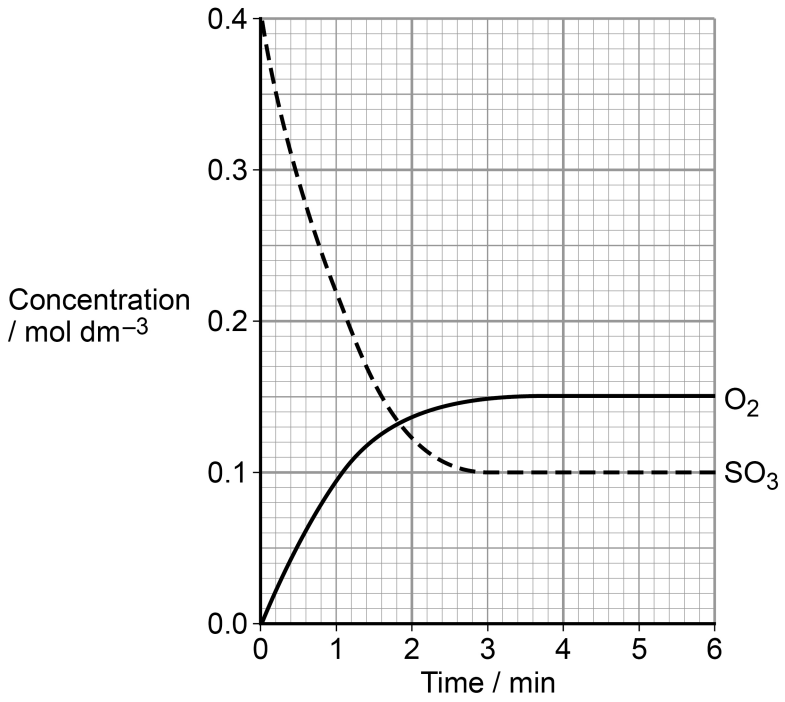
0 5 This question is about equilibrium.

Sulfur trioxide decomposes to form sulfur dioxide and oxygen at temperature T_1 according to the equilibrium shown.

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

The graph in **Figure 4** shows the concentrations of sulfur trioxide and of oxygen over a period of 6 minutes at temperature T_1

Figure 4



0 5 . 1 State the time, to the nearest minute, when equilibrium is first established.
Explain your answer.

[2 marks]

Time _____ minutes

Explanation _____

_____

_____

_____

_____

0 5 . 2 Sketch on the graph in **Figure 4** how the concentration of sulfur dioxide changes over these 6 minutes at temperature T_1

[2 marks]

0 5 . 3 The temperature of the mixture was changed to T_2 and the mixture left to establish a new equilibrium.
In the new equilibrium mixture the concentration of sulfur trioxide was found to be 0.07 mol dm^{-3}

Deduce which of T_1 and T_2 is the higher temperature.
Explain your deduction.

[2 marks]

Higher temperature _____

Explanation _____

_____

_____

_____

_____

6

Turn over for the next question

Qu	Marking Guidance	Additional Comments	Mark
5.1	3 minutes	M2 dependent on M1 or near miss	1
	(At equilibrium, $rate_{fwd} = rate_{back}$ so) concentrations (of O_2 and SO_3) remain constant	Not concentrations are the same/equal Allow (after this point) gradient is zero / curve flattens out	1
5.2	Sketch begins at origin <u>and</u> goes up until 3 mins		1
	Levels off at 0.3 mol dm^{-3}	Mark Independently	1
5.3	T_2 (Not worth a mark alone)	T_1, CE=0	
	Equilibrium has <u>moved / shifted</u> to <u>RHS/forward</u> in <u>endothermic</u> direction	Both RHS / forward and endothermic needed	1
	Equilibrium has opposed the increase in T / Equilibrium moves to decrease the T	Not just to oppose the change	1

Do not write outside the box

0 5 Nitrogen monoxide reacts with chlorine to form nitrosyl chloride (NOCl).

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$$

0 5 . 1 1.50 mol of NO are mixed with 1.00 mol of Cl_2 and the mixture is left to reach equilibrium at a given temperature.
The equilibrium mixture contains 0.350 mol of NOCl

Calculate the amount, in moles, of NO and of Cl_2 in the equilibrium mixture.

[2 marks]

Amount of NO _____ mol

Amount of Cl_2 _____ mol

0 5 . 2 Give the expression for the equilibrium constant, K_c, for the reaction between nitrogen monoxide and chlorine to form nitrosyl chloride.

[1 mark]

K_c =

Do not write outside the box

0 5 . 3 A different equilibrium mixture is prepared in a flask of volume 800 cm^3 at a different temperature.
At equilibrium this mixture contains 0.850 mol of NO and 0.458 mol of Cl_2
For the reaction at this temperature $K_c = 1.32 \times 10^{-2}\ mol^{-1}\ dm^3$

Determine the amount, in moles, of NOCl in this equilibrium mixture.

[4 marks]

Amount of NOCl _____ mol

7

Turn over for the next question

Question	Marking guidance	Additional Comments/Guidelines	Mark
05.1	Amount of Nitrogen monoxide = 1.15 mol Amount of Chlorine = 0.825 mol	Answers to min 2sf	1 1
05.2	$K_c = \frac{[NOCl]^2}{[NO]^2[Cl_2]}$		1
05.3	$1.32 \times 10^{-2} = \frac{[NOCl]^2}{\left[0.85/0.800\right]^2 \left[0.458/0.800\right]}$ $[NOCl]^2 = 8.53 \times 10^{-3}$ mol^{2}dm^{-6} $[NOCl] = 0.0924$ mol dm^{-3} n(NOCl) = 0.0924 x 0.800 = 0.0739 mol (answer to 2sf or more)	M1 = divides mole quantities by 0.800 M2 = evaluates $[NOCl]^2$ M3 = $\sqrt{}$M2 M4 = M3 x 0.800 (allow ecf on an incorrect volume used in M1) If no division in M1 then max 3 M2 = 4.37×10^{-3} M3 = 0.0661 mol dm^{-3} M4 = 0.0529 mol If Kc upside down then can still score 4 M1 = divides mole quantities by 0.800 M2 = 48.96 M3 = 7.00 mol dm^{-3} M4 = 0.600 mol Incorrect rearrangement loses M2	1 1 1 1

Section A

Answer **all** questions in this section.

1 Ethene reacts with steam in the presence of an acid catalyst to form ethanol.

$$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$$

0 1 . 1 Write an expression for the equilibrium constant K_c for this equilibrium. Deduce the units of K_c.

[2 marks]

Expression _____

_____

_____

Units _____

0 1 . 2 An equilibrium mixture was found to contain 0.700 mol of ethene, 1.20 mol of steam and 4.40 mol of ethanol at a temperature ***T***. The volume of the container was 2.00 dm^3.

Calculate a value of K_c for this equilibrium at this temperature.

Give your answer to an appropriate number of significant figures.

[2 marks]

_____

_____

_____

_____

_____

_____

Question	Marking Guidance	Mark	Comments
01.1	M1 $(K_c =) \frac{[CH_3CH_2OH]}{[CH_2{=}CH_2][H_2O]}$ M2 $mol^{-1}\ dm^3$	1 1	M1 penalise missing brackets or use of (); allow correct molecular formulae in correct expression (and allow CH_2CH_2); ignore powers shown as 1 M2 units must be in simplest form on one line (or $dm^3\ mol^{-1}$) M2 units are consequential on expression in M1 ($mol^{-1}\ dm^3$ only scores if it is the units for the expression in M1)
01.2	M1 $\frac{[\frac{4.40}{2.00}]}{[\frac{0.70}{2.00}]\times[\frac{1.20}{2.00}]}$ or $\frac{2.20}{0.35 \times 0.60}$ or $\frac{4.40}{0.70 \times 1.20} \times 2.00$ M2 10.5 (must be 3sf)	1 1	10.5 (3sf) scores both marks; correct value to 2sf (10) or 4sf or more (10.476…) scores 1 mark Volume not used is CE=0 If use incorrect expression for K_c in 1.2 then no marks in 1.2 If a value from the question is copied incorrectly into the expression, could still score M2 if then used correctly in calculation (AE -1) Ignore units

0 8 Methanol can be manufactured in a reversible reaction as shown by the equation.

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

0 8 . 1 State and explain the effect of using a catalyst on the yield of methanol in this equilibrium.

[2 marks]

0 8 . 2 Give an expression for the equilibrium constant (K_c) for this reaction.

[1 mark]

0 8 . 3 A mixture of carbon monoxide and hydrogen was allowed to reach equilibrium in a container of volume 250 cm^3 at temperature *T*.
At equilibrium, the mixture contained 0.340 mol of carbon monoxide, 0.190 mol of hydrogen and 0.0610 mol of methanol.

Calculate the value of the equilibrium constant (K_c) for this reaction at temperature *T*.

[3 marks]

K_c _____ $mol^{-2}\ dm^6$

0 8 . 4 Methanol decomposes on heating in a reaction that is the reverse of that used in its manufacture.

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

Use your answer from Question **08.3** to determine the value of K_c for this equilibrium at temperature *T*.
State the units for this value of K_c

(If you were unable to complete the calculation in Question **08.3**, assume a value of $K_c = 0.825\ mol^{-2}\ dm^6$. This is **not** the correct value.)

[2 marks]

Value of K_c _____

Units of K_c _____

8

Question	Marking Guidance	Mark	Comments
8.1	**M1** no effect (on yield) **M2** increases rate / speed of both / forward and reverse reactions <u>equally / by the same amount</u>	1 1	CE = 0 if yield changes If no reference to effect on yield, could still score **M2** Ignore reference to no change in position of equilibrium, and reference to lowering activation energies **M2** allow changes rate of both / forward and reverse reactions <u>equally / by the same amount</u>
8.2	$(K_c =) \frac{[CH_3OH]}{[CO][H_2]^2}$	1	Must be square brackets Ignore state symbols Ignore units
8.3	**M1** divides moles by volume (0.250 or $\frac{250}{1000}$) **M2** $K_c = \frac{\frac{0.0610}{0.250}}{\left[\frac{0.340}{0.250}\right]\left[\frac{0.190}{0.250}\right]^2} \left(= \frac{0.244}{1.36 \times 0.76^2}\right)$ **M3** 0.311	1 1 1	Correct answer scores 3; **M3** to at least 2sf (0.3106159 …); ignore units Allow ECF from **M1** to **M2** if an attempt to calculate concentration has been made by dividing by some factor of 250 cm^3 Allow ECF from **M2** to **M3** for use of an expression containing each reagent in a correctly substituted K_c expression If volume not used, then allow **M3** only for 4.97 (4.96985 … to at least 2sf)

8.4	**M1** $\frac{1}{Answer\ to\ 8.3}$ = 3.22 **M2** $mol^2\ dm^{-6}$	1 1	**M1** to at least 2sf (0.31 gives 3.2(258)) **M1** = 1.21 if alternative answer to 8.3 used If an error was made in 8.3, but the candidate produced an answer in 8.4 that did fit the inverted calculation from 8.3, then candidate could score **M1** (if volumes are not used, then candidate would get 0.20(12.)

Do not write outside the box

0 5 . 3 Methanol is made by the reaction of carbon monoxide with hydrogen.

$$CO + 2H_2 \rightleftharpoons CH_3OH \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

The reaction uses a copper-based catalyst, a pressure of 10 MPa and a temperature of 550 K

These conditions are used to provide a balance between equilibrium yield, reaction rate and cost.

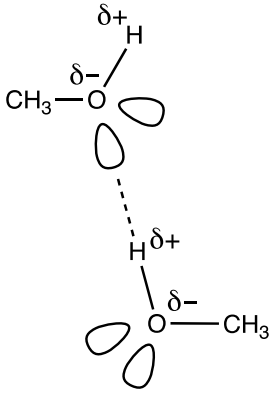
Describe how the use of a catalyst, and changes in pressure and temperature, each affect equilibrium yield, reaction rate and cost.

[6 marks]

Do not write outside the box

10

Turn over ►

Question	Marking guidance	Additional Comments/Guidelines	Mark
05.1	 **M1** on at least one O atom two lone pairs and on at least one OH δ+ on H and δ– on O **M2** dotted line shown between lone pair on one molecule and the correct H on another **M3** O····H–O in straight line	Accept pair of dots or crosses for lone pair in place of orbital shape (orbital shape may or may not include two electrons) Ignore any partial charges on C–H or C–O bonds For straight line in **M3**, allow a deviation of up to 15° If a different molecule containing hydrogen bonding due to O–H bond drawn (e.g. ethanol, water) or an incorrect attempt at the structure of methanol, then maximum of 2 marks (i.e. only penalise if would score all three marks otherwise)	1 1 1
05.2	Idea that lone pairs have greater repulsion than bonding pairs	There must be a comparison between the repulsion of a lone pair and bonding pair Allow covalent bond = bonding pair	1

<table>
<tr><td rowspan="5">05.3</td><td colspan="2">This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.</td><td>6</td><td rowspan="5">Stage 1
Describes the effect of catalyst use
1a use of a catalyst has no impact on equilibrium yield
1b use of a catalyst gives faster rate
1c use of catalyst lowers costs

Stage 2
Describes the effect of pressure
2a higher pressure gives a higher equilibrium yield
2b higher pressure gives a faster rate
2c the higher the pressure, the greater the cost

Stage 3
Describes the effect of temperature
3a lower temperature gives a higher equilibrium yield
3b higher temperature gives a faster rate
3c the higher the temperature, the greater the cost

Note that converse statements are fine (e.g. 1a higher temperature gives a lower equilibrium yield)</td></tr>
<tr><td>Level 3
(5-6 marks)</td><td>All stages are covered and each stage is generally correct and virtually complete.
(6 v 5) Answer is well structured, with no repetition or irrelevant points, and covers all aspects of the question. Accurate and clear expression of ideas with no errors in use of technical terms.</td></tr>
<tr><td>Level 2
(3-4 marks)</td><td>All stages are covered but stage(s) may be incomplete or may contain inaccuracies OR
two stages are covered and are generally correct and virtually complete
(4 v 3) Answer has some structure and covers most aspects of the question. Ideas are expressed with reasonable clarity with, perhaps, some repetition or some irrelevant points. If any, only minor errors in use of technical terms.</td></tr>
<tr><td>Level 1
(1-2 marks)</td><td>Two stages are covered but stage(s) may be incomplete or may contain inaccuracies OR
only one stage is covered but is generally correct and virtually complete
(2 v 1) Answer includes statements which are presented in a logical order and/or linked.</td></tr>
<tr><td>0 marks</td><td>Insufficient correct chemistry to gain a mark.</td></tr>
</table>

Do not write outside the box

0 8 Hydrogen gas can be made by reacting ethanol with steam in the presence of a catalyst.

$$C_2H_5OH(g) + H_2O(g) \rightleftharpoons 2\,CO(g) + 4\,H_2(g)$$

0 8 . 1 Give an expression for K_c for this equilibrium.

State its units.

[2 marks]

K_c

Units of K_c _____

0 8 . 2 **Table 4** shows the amount of each substance in an equilibrium mixture in a container of volume 750 cm^3

Table 4

Substance	$C_2H_5OH(g)$	$H_2O(g)$	$CO(g)$	$H_2(g)$
Amount of substance / mol	0.0750	0.156	0.110	0.220

Calculate K_c

[3 marks]

K_c _____

Question 8 continues on the next page

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0 8 . 3 The pressure of the equilibrium mixture was increased by reducing the volume of the container at constant temperature.

Predict the effect of increasing the pressure on the equilibrium yield of hydrogen. Explain your answer.

Predict the effect of increasing the pressure on the value of K_c

[4 marks]

Effect on equilibrium yield of hydrogen _____

Explanation _____

Effect on value of K_c _____

9

Question	Marking guidance	Additional Comments/Guidelines	Mark
08.1	**M1** $\frac{[CO]^2\,[H_2]^4}{[C_2H_5OH]\,[H_2O]}$ **M2** $mol^4\ dm^{-12}$	**M2** allow for units that are consequential on **M1**	1 1

08.2	**M1** clear attempt made to divide moles by volume to find concentrations **M2** $\frac{[\frac{0.110}{0.750}]^2\ [\frac{0.220}{0.750}]^4}{[\frac{0.075}{0.750}]\ [\frac{0.156}{0.750}]}$ **M3** 7.66 x 10^{-3}	7.66 x 10^{-3} scores **M1,2,3** 7.66 x 10^{-15} scores **M1,3** **M1** can use 0.750 or 750 (or 75, 7.5, 0.075, 0.0075, etc) **M2** $\frac{(0.147)^2\ (0.293)^4}{(0.100)\ (0.208)}$ or $\frac{(0.0215)\ (0.00740)}{(0.100)\ (0.208)}$ for **M2** volume used must be 0.750 or 750 (if use V at this stage, then must be one of these values of V used later on) **M3** ignore units **If moles are used in place of concentration** penalise **M1**, but **M2** and **M3** could score for ECF **M2** $\frac{(0.110)^2\ (0.220)^4}{(0.075)\ (0.156)}$ **M3** = 2.42 x 10^{-3} **Allow ECF if incorrect expression for K_c is used**	1 1 1

08.3	**M1** yield would decrease **M2** equilibrium (position) moves left / shifts left / in direction of reverse reaction to oppose increase in pressure / to reduce pressure **M3** fewer moles/molecules of gas on left hand side / fewer moles/molecules of gaseous reactants **M4** no effect on K_c	mark each point independently **M2** need both parts; ignore favours reverse reaction for the first part **M3** 2 moles/molecules (of gas) on left hand side v 6 moles/molecules (of gas) on right hand side	1 1 1 1

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0 9 Hydrogen can be prepared on an industrial scale using the reversible reaction between methane and steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\,H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

The reaction is done at a temperature of 800 °C and a low pressure of 300 kPa in the presence of a nickel catalyst.

Explain, in terms of equilibrium yield and cost, why these conditions are used.

[6 marks]

Do not write outside the box

6

Turn over ►

<table>
<tr><th>Question</th><th>Marking guidance</th><th>Additional Comments/Guidelines</th><th>Mark</th></tr>
<tr>
<td>09</td>
<td>This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.
<table>
<tr><td>Level 3:
All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer is well structured with no repetition or irrelevant points.
Accurate and clear expression of ideas with no errors in use of technical terms.</td><td>5-6</td></tr>
<tr><td>Level 2:
All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer shows some attempt at structure.
Ideas are expressed with reasonable clarity with, perhaps, some repetition or some irrelevant points.
Some minor errors in use of technical terms.</td><td>3-4</td></tr>
<tr><td>Level 1:
Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.

Answer includes isolated statements but these are not presented in a logical order or show some confusion.
Answer may contain valid points which are not clearly linked to an argument structure. Errors in the use of technical terms.</td><td>1-2</td></tr>
</table>
</td>
<td>Indicative chemistry content

Stage 1: Temperature
1a. The reaction is endothermic (so equilibrium shifts to RHS to reduce the temperature)
1b. So, higher temperature increases the yield
1c. High temperatures are costly (so compromise temperature used)

Stage 2: Pressure
2a. More moles of gas on the right hand side, (so equilibrium shifts to RHS to increase the yield)
2b. So, lower pressure increases the yield
2c. A low pressure means a low cost

Stage 3: Catalyst
3a. Catalyst has no effect on yield
3b. Adding a catalyst allows a lower temperature to be used
3c. So, this lowers the cost

Level 0
Insufficient correct chemistry to gain a mark.</td>
<td>6

0</td>
</tr>
</table>

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0 6 . 2 In the second experiment, another flask is used for a combustion reaction.

Method

- Remove all the air from the flask.
- Add 0.0010 mol of 2,2,4-trimethylpentane (C_8H_{18}) to the flask.
- Add 0.0200 mol of oxygen to the flask.
- Spark the mixture to ensure complete combustion.
- Cool the mixture to the original temperature.

The equation is

$$C_8H_{18}(g) + 12\,\frac{1}{2}O_2(g) \longrightarrow 8\,CO_2(g) + 9\,H_2O(l)$$

Calculate the amount, in moles, of gas in the flask after the reaction.

[2 marks]

Amount of gas _____ mol

7

Turn over for the next question

Question	Marking guidance	Additional Comments/Guidelines	Mark
06.2	**M1** amount of CO_2 formed in flask = 0.008 mol **M2** amount of gas in flask = 0.0075 (O_2) + 0.0080 (**M1**) = 0.0155 mol	Allow ECF from **M1** to **M2**	1 1