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VCE Chemistry ¾
Equilibrium [0.18]
Workshop Solutions

Error Logbook:

New Ideas/Concepts	Didn't Read Question
Pg / Q #: ____________________ Notes:	Pg / Q #: ____________________ Notes:
Algebraic/Arithmetic/ Calculator Input Mistake	**Working Out Not Detailed Enough**
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Section A: Recap

Sub-Section: Regular Recap

Learning Objective: [2.7.1] - Write Equilibrium Constant Expression & Find Its Value (Including Units)

- K_c Expression:

$$aA + bB + \ldots \rightleftharpoons cC + dD + \ldots$$

$$K_c = \frac{[C]^c \times [D]^d \times \ldots}{[A]^a \times [B]^b \times \ldots}$$

- **K_c value key property:** Always has the ____ same value ____ at a certain temperature, irrespective of the amounts of the reactants/products which we start off with!

- K_c units need to be calculated separately each time.

Homogenous Equilibrium	Heterogenous Equilibrium
[only one] / [multiple] state(s) of matter present in equation	[only one] / [multiple] state(s) of matter present in equation

Aqueous (aq) or Gaseous (g) Substances	Solid (s) or Liquid (l) Substances
[have] / [don't have] concentration	[have] / [don't have] concentration
Concentration is as stated.	Concentration one ____.

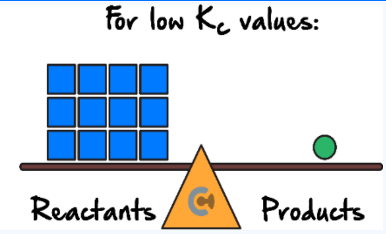
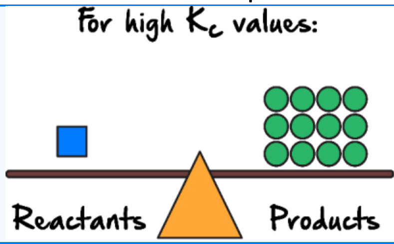
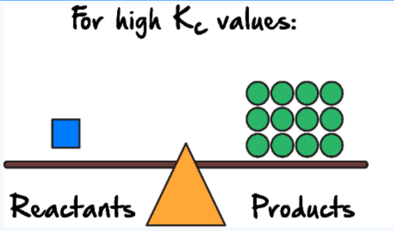
- When plugging values into K_c expression, [amount (mol)] / [concentration (M)] should be plugged in.

- Calculate units by.

Space for Personal Notes

Definition

Learning Objective: [2.7.2] - Identify the Extent of Reaction

$K_c < 10^{-4}$	$10^{-4} < K_c < 10^{4}$	$K_c > 10^{4}$
[small] / [medium] / [large] extent of reaction	[small] / [medium] / [large] extent of reaction	[small] / [medium] / [large] extent of reaction
[reactants] / [both] / [products] favoured at equilibrium	[reactants] / [both] / [products] favoured at equilibrium	[reactants] / [both] / [products] favoured at equilibrium
		

Definition

Learning Objective: [2.7.3] - Find Equilibrium Constant When Equation is Changed

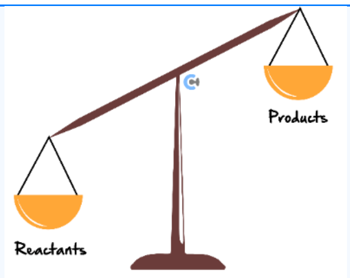
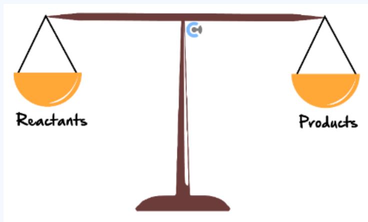
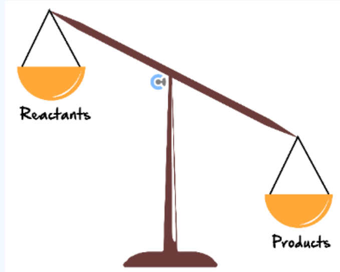
- When **reversing equations**, take the ____reciprocal____.
- When **multiplying by a coefficient**, take the __power__ of that coefficient.
- **Units:** __Follow__ how equation has been changed!

Definition

Learning Objective: [2.7.4] - Apply Q_c to Find the Direction of the Equilibrium Shift

Equilibrium Constant (K_c)	Reaction Quotient (Q_c)
$K_c = \frac{[C]^c \times [D]^d \times \ldots}{[A]^a \times [B]^b \times \ldots}$	$Q_c = \frac{[C]^c \times [D]^d \times \ldots}{[A]^a \times [B]^b \times \ldots}$
Is found by using concentrations **at equilibrium**!	Is found at **any point in time** (could be at equilibrium, could not be at equilibrium!).

- If $Q_c = K_c$, the system [is] / [is not] at equilibrium.
- If $Q_c \neq K_c$, the system [is] / [is not] at equilibrium.

$Q_c < K_c$	$Q_c = K_c$	$Q_c > K_c$
[undershot] / [perfect shot] / [overshot]	[undershot] / [perfect shot] / [overshot]	[undershot] / [perfect shot] / [overshot]
[forwards] / [neither] / [reverse] reaction favoured	[forwards] / [neither] / [reverse] reaction favoured	[forwards] / [neither] / [reverse] reaction favoured
		

Learning Objective: [2.7.5] - Apply RICE Tables to Find K_c

- **Stands for:**
  - Reaction
  - Initial
  - Change
  - Equilibrium
- **Good idea to add a fifth row:** Concentration.
- **Key Terms:** "Empty" or "evacuated" means there are no other substances present at the beginning.
- **Steps:**
  1. Fill out knowns.
  2. Find n_c (use stoichiometric ratios & $+/-$ signs)
  3. Find n_e

Space for Personal Notes

Sub-Section: RICE Tables with Unknown Change in Concentration

Context

- This is outside the study design and will not be tested in the final exam!
- However, **sometimes in school SACs**, the change in moles of any substance cannot be derived.
- However, we know that there will be a change in moles as the system tries to reach equilibrium.
- As such, we can use a variable (such as x) to denote the change in moles and solve the question from there.

Question 1 Walkthrough.

In the following acid dissociation reaction:

$$HA(aq) + H_2O(l) \rightleftharpoons A^-(aq) + H_3O^+(aq)$$

0.150 M concentration of HA(aq) is added to 1.00 L water. Given that the equilibrium constant (K_c value) for the system is 1.6×10^{-2} M, find the concentration of A^- at equilibrium.

R	$HA_{(aq)}$ +	$H_2O_{(l)}$ ⇌	$A^-_{(aq)}$ +	$H_3O^+_{(aq)}$
n_i	0.150 mol	N/A	0	0
n_c	$-x$	N/A	$+x$	$+x$
n_e	$0.150-x$	N/A	x	x
C_e	$0.150-x$		x	x

$K_c = \frac{[A^-][H_3O^+]}{[HA]} = 1.6\times10^{-2} M$ ($H_2O_{(l)}$ has no conc)

$\frac{(x)(x)}{0.150-x} = 1.6\times10^{-2}$

$x^2 = 0.0024 - 0.016x$

$x^2 + 0.016x - 0.0024 = 0$

Using quadratic formula:

$x = \frac{-b\pm\sqrt{b^2-4ac}}{2a} = \frac{-0.016\pm\sqrt{0.016^2-4(0.0024)}}{2}$

$x = 0.0416$ mol or $x = -0.0576$ mol

$x = 0.0416$ (conc can't be negative)

As $x = [A^-]$,

$[A^-] = 0.0416M$

NOTE: We see that in this particular instance, the quadratic formula was used! It is for this exact reason that the VCAA final exam will not cover questions like this. However, for school SACs, it might pop up, and thus we've briefly covered it here.

ALSO NOTE: Just to repeat, these types of questions **are not on the study design** but may pop up in SACs!

Question 2

The reaction of bromine gas with chlorine gas, shown here, has a K_c value of 7.20 at 200°C. If a closed and initially empty vessel was charged with the two reactants, each at an initial concentration of $0.200\ M$, what would be the equilibrium amount (in moles) of BrCl(g) assuming that the vessel has a volume of $4.00\ L$?

$$Br_2(g) + Cl_2(g) \rightleftharpoons 2BrCl(g) \qquad K_c = 7.20$$

that the vessel has a volume of 4.00 L? $n_i = 0.8\ mol$

R	$Br_2(g)$	$Cl_2(g)$	$2BrCl(g)$
n_i	0.8	0.8	0
n_c	$-x$	$-x$	$+2x$
n_e	$0.8-x$	$0.8-x$	$+2x$
c	$\frac{0.8-x}{4}$	$\frac{0.8-x}{4}$	$\frac{2x}{4} = \frac{1}{2}x$

$K_c = 7.20$

$$K_c = \frac{[BrCl]^2}{[Br_2][Cl_2]} = 7.2$$

$$\frac{\left(\frac{1}{2}x\right)^2}{\left(\frac{0.8-x}{4}\right)^2} = 7.2$$

$$\frac{\frac{1}{2}x}{\frac{0.8-x}{4}} = 2.68$$

$$\frac{2x}{0.8-x} = 2.68$$

$$2x = 2.68(0.8-x)$$

$$2x = 2.1466 - 2.68x$$

$$4.68x = 2.1466$$

$$x = 0.458$$

Section B: Warm Up (12.5 Marks)

INSTRUCTION: 12.5 Marks. 1 Minute Reading. 8 Minutes Writing.

Question 3 (2 marks)

Write the expression for the equilibrium constant and then determine its units.

a. $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons [Fe(SCN)]^{2+}(aq)$. (1 mark)

K_c expression	Units
$K_c = \frac{[[Fe(SCN)]^{2+}]}{[Fe^{3+}][SCN^-]}$	M^{-1}

b. $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$. (1 mark)

K_c expression	Units
$K_c = \frac{[HCl]^2}{[Cl_2][H_2]}$	$\frac{M^2}{MM}$ ∴ no units

Space for Personal Notes

Question 4 (2 marks)

A 5.212 L vessel contains a mixture of 0.1 mol of CO, 2.1 mol of O_2 and 1.8 mol of CO_2 in equilibrium at 420°C according to the equation:

$$CO(g) + \frac{1}{2}O_2(g) \rightleftharpoons CO_2(g)$$

Calculate the value of the equilibrium constant K_c, at 420°C.

$c = \frac{n}{V}$

$[CO] = \frac{0.1}{5.212} = 1.9...\times10^{-2}\ M$

$[O_2] = \frac{2.1}{5.212} = 4.029...\times10^{-1}\ M$

$[CO_2] = \frac{1.8}{5.212} = 3.45...\times10^{-1}\ M$

$K_c = \frac{[CO_2]}{[O_2]^{\frac{1}{2}}[CO]}$

units: $\frac{M}{M^{\frac{1}{2}}M} = M^{-\frac{1}{2}}$

sub concentrations in

$K_c = \frac{(3.45\times10^{-1})}{(4.029..\times10^{-1})^{\frac{1}{2}}(1.9..\times10^{-2})}$

$= 2.736\times10^{1}\ M^{-\frac{1}{2}}$

$\therefore 3\times10^{1}\ M^{-\frac{1}{2}}$ 1sf

Question 5 (7 marks)

The Haber process is well known for synthesising ammonia (NH_3). The reaction is depicted below:

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

a. Write the K_c expression for this process. (1 mark)

$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$

b. At a particular temperature, an equilibrium mixture of 0.69 mol of NH_3, 0.218 mol of H_2 and 0.42 mol of N_2 are present in a 125.1 L reaction vessel. Calculate the value of the equilibrium constant at this temperature. (2 marks)

$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$

units: $\frac{M^2}{M^3M} = M^{-2}$

$c = \frac{n}{V}$

$[NH_3] = \frac{0.69}{125.1} = 5.5\times10^{-3}\ M$

$[H_2] = \frac{0.218}{125.1} = 1.74\times10^{-3}\ M$

$[N_2] = \frac{0.42}{125.1} = 3.36\times10^{-3}\ M$

sub in K_c expression

$K_c = \frac{(5.5\times10^{-3})^2}{(1.74\times10^{-3})^3(3.36\times10^{-3})}$

$= 1.71\times10^{6}\ M^{-2} \therefore 1.7\times10^{6}\ M^{-2}$ 2sf

c. At the same temperature, it is known that the reaction is not at equilibrium, with the mixture of 0.3 mol of NH_3, 0.11 mol of N_2 and 0.888 mol of H_2.

i. Find the reaction quotient. (2 marks)

$[NH_3] = \frac{0.3}{125.1} = 2.40 \times 10^{-3}$ M
$[N_2] = \frac{0.11}{125.1} = 8.79 \times 10^{-4}$ M
$[H_2] = \frac{0.888}{125.1} = 7.1 \times 10^{-3}$ M

$Q_c = \frac{(2.4 \times 10^{-3})^2}{(7.1 \times 10^{-3})^3 (8.79 \times 10^{-4})}$

$= 1.83 \times 10^4\ M^{-2}$
$= 2 \times 10^4\ M^{-2}$ 1sf

ii. Does the reaction need to shift forward or backward to establish equilibrium? Justify your answer with correct reasoning. (2 marks)

As $2 \times 10^4 < 1.7 \times 10^6$ ($Q_c < K_c$), reaction would shift forward to establish equilibrium.

Question 6 (1.5 marks)

For the chemical reaction: $2HI(g) \leftrightharpoons H_2(g) + I_2(g)$, the equilibrium constant quantity is 2.011 at 690°C. For each equation, calculate the value of K_c at the same temperature. Ensure to include units (if applicable).

a. $16HI(g) \leftrightharpoons 8H_2(g) + 8I_2(g)$. (0.5 marks)

2.675×10^2 (no units), 4sf

b. $2I_2(g) + 2H_2(g) \leftrightharpoons 4HI(g)$. (0.5 marks)

2.473×10^{-1} (no units), 4sf

c. $\frac{3}{2}I_2(g) + \frac{3}{2}H_2(g) \leftrightharpoons 3HI(g)$. (0.5 marks)

3.507×10^{-1} (no units), 4sf

Space for Personal Notes

Section C: Ramping it Up (9 Marks)

INSTRUCTION: 9 Marks. 1 Minute Reading. 7 Minutes Writing.

Question 7 (1 mark)

For the equation:

$$2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)$$

The expression of the equilibrium constant for the **reverse** reaction is:

A. $K_c = \frac{[CO_2]^2}{[CO]^2[O_2]}$

B. $K_c = \frac{[CO]^2}{[CO_2]^2[O_2]}$

C. $K_c = \frac{2[CO][O_2]}{2[CO_2]}$

D. $K_c = \frac{[CO]^2[O_2]}{[CO_2]^2}$

Question 8 (1 mark)

If the equilibrium constant for an unknown reaction was 8.88×10^5, the extent of reaction would be:

A. Small extent of reaction, the reaction hardly proceeds forwards.

B. Large extent of reaction, the reaction hardly proceeds backwards.

C. Medium extent of reaction, the reaction has both products and reactants at sufficient quantities at equilibrium.

D. Sufficient extent of reaction, the products are favoured at equilibrium.

Space for Personal Notes

Question 9 (4 marks)

The reaction for the oxidation of sulphur dioxide, SO_2, is shown below.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -197\ kJ\ mol^{-1}$$

1.00 mol of SO_2 and 1.00 mol of oxygen, O_2, are placed into an evacuated, sealed 3.00 L container at 100°C. After the reaction reaches equilibrium, the container contains 20.0 g of sulphur trioxide, SO_3. Calculate the equilibrium constant, K_c, for this reaction at 100°C.

Multiple approaches were evident in students' responses to this question. The following is representative of one common approach:

$n(SO_3)$ at equilibrium = 20.0 / 80.1 = 0.25 mol*

	n(SO_2) (mol)	n(O_2) (mol)	n(SO_3) (mol)
Initial	1.00	1.00	0.00
Change	-2x	-x	+2x
Final*	1.00-0.25 = 0.75	1.00-0.125 = 0.875	0.25

Therefore

$[SO_2]_{eqm} = {}^{0.75}/_{3.00} = 0.25$ M, $[O_2]_{eqm} = {}^{0.875}/_{3.00} = 0.292$ M, $[SO_3]_{eqm} = {}^{0.25}/_{3.00} = 0.083$ M*

$K = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{0.083^2}{0.25^2 \times 0.292} = 0.38\ M^{-1}$*

In order to gain full marks, students were required to submit the final calculated value with the correct units. Consequential marks were awarded when students were able to show clear calculations.

Space for Personal Notes

Question 10 (3 marks)

Methanol is a primary alcohol used to manufacture many other chemicals. One method used in methanol production is shown by the following equation:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H \text{ is positive}$$

In one experiment at a particular temperature, the equilibrium constant for the reaction above is 0.417 M^{-2}. An equilibrium mixture in a 5.0 L vessel contained 1.25×10^{-2} mol of CH_3OH and 0.51 mol of CO, as well as hydrogen gas.

a. What does the magnitude of the equilibrium constant indicate about the extent of reaction in this equilibrium mixture? (1 mark)

K_c value is between 10^{-4} and 10^4, meaning that there is a medium extent of reaction.

b. Calculate the amount, in *mol*, of hydrogen gas in the equilibrium mixture. (2 marks)

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2} = 0.417$$

$$[H_2]^2 = \frac{[CH_3OH]}{[CO] \times 0.417} = \frac{\left(\frac{1.25 \times 10^{-2}}{5.0}\right)}{\left(\frac{0.51}{5.0}\right) \times 0.417} = 0.0587 \text{ M}$$

$$[H_2] = \sqrt{0.0587} = 0.242 \text{ M}$$

Therefore $n(H_2) = 0.242 \times 5.0 = 1.2$ mol

Space for Personal Notes

Section D: Getting Trickier I (9 Marks)

INSTRUCTION: 9 Marks. 1 Minute Reading. 7 Minutes Writing.

Question 11 (1 mark)

$$Br_2(g) + I_2(g) \rightleftharpoons 2IBr(g) \qquad K_c = 1.2 \times 10^2 \text{ at } 150°C$$

Given the information above, what is K_c for the reaction $4IBr(g) \rightleftharpoons 2Br_2(g) + 2I_2(g)$ at 150°C ?

A. 1.6×10^{-2}

B. 4.1×10^{-3}

C. 6.9×10^{-5}

D. 8.03×10^{-5}

Question	% A	% B	% C	% D	% No answer	Comments
27	15	20	59	6	0	$Br_2(g) + I_2(g) \rightleftharpoons 2IBr(g)$ $K_c = 1.2 \times 10^2$ Reverse equation – take reciprocal of the value of the equilibrium constant $2IBr(g) \rightleftharpoons Br_2(g) + I_2(g)$ $K_c = 1 / 1.2 \times 10^2$ Double coefficients – square the value of the equilibrium constant $4IBr(g) \rightleftharpoons 2Br_2(g) + 2I_2(g)$ $K_c = (1 / 1.2 \times 10^2)^2$ $= 6.9 \times 10^{-5}$ Option B was incorrect because it was consistent with dividing by 2 rather that raising to the power of 2.

Question 12 (4 marks)

Hydrogen gas is produced industrially using the chemical reaction shown in the equation below.

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

a. Methane gas is extracted from natural gas.

Why is this method for the industrial production of hydrogen gas not sustainable? (1 mark)

Obtaining methane via fracking and natural gas is unsustainable as it is non-renewable, taking millions of years to form.

b. The numerical value of the equilibrium constant for the reaction at a particular temperature is 0.26. A mixture of the following gases is held in a sealed 3.0 L container at this temperature.

CH_4	H_2O	CO	H_2
1.5 mol	0.75 mol	0.90 mol	0.60 mol

i. Show that this mixture of gases is not at equilibrium. (2 marks)

$$\text{concentration fraction} = \frac{[CO][H_2]^3}{[CH_4][H_2O]}$$

$$= \frac{\left(\frac{0.90}{3}\right)\left(\frac{0.60}{3}\right)^3}{\left(\frac{1.5}{3}\right)\left(\frac{0.75}{3}\right)}$$ 1 mark

$= 0.019\ M^2$ 1 mark

The value of K at this temperature is 0.26 and so the reaction cannot be at equilibrium because the concentration fraction ≠ K. 1 mark

ii. Which way would the reaction shift (to the product side or to the reactant side) in order to reach equilibrium? (1 mark)

The concentration fraction is lower than the value of K, and so the reaction shifts to the product side to raise the value of the concentration fraction to K. 1 mark

Space for Personal Notes

Question 13 (4 marks)

Carbon monoxide (CO) and hydrogen (H_2) can be formed from methane (CH_4) reacting with water vapour (H_2O). The equation for the reaction is shown below.

$$CH_4(g) + H_2O(g) \leftrightharpoons CO(g) + 3H_2(g)$$

A sample of 0.18 mol of CO and 0.20 mol of H_2 is added to an initially evacuated 6.01 L reaction vessel.

At equilibrium, there is 0.020 mol of CH_4 present. Calculate the K_c value for this reaction.

$$K_c = \frac{[H_2]^3[CO]}{[H_2O][CH_4]} = \frac{(2.33\times10^{-2})^3(2.66\times10^{-2})}{(3.33\times10^{-3})(3.33\times10^{-3})} = 3.04\times10^{-2}\ M^2$$

$$\therefore 3\times10^{-2}\ M^2 \text{ 1sf}$$

Space for Personal Notes

Section E: Getting Trickier II (4 Marks)

INSTRUCTION: 4 Marks. 1 Minute Reading. 4 Minutes Writing.

Question 14 (4 marks)

Ammonia gas reacts with oxygen gas according to the following chemical equation:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -900\ kJ\ mol^{-1}$$

In one experiment at a particular temperature (T_1), 0.300 mol of ammonia gas was mixed with 0.400 mol of oxygen gas in a sealed evacuated 2.00 L container and was allowed to reach equilibrium. 0.200 mol of nitrogen oxide gas was present in the equilibrium mixture.

a. Determine the amount (in mol) of each component in the equilibrium mixture. (2 marks)

	$4NH_3$	$5O_2$	$4NO$	$6H_2O$
n initially	**0.300**	**0.400**	**0**	**0**
change	−0.200	$-\frac{5}{4} \times 0.200$	+0.200	$+\frac{6}{4} \times 0.200$
n equilibrium	0.100	0.150	**0.200**	0.300
equil. conc. = $\frac{n}{V}$	0.0500	0.075	0.100	0.150

3 marks

1 mark each for correct mol of NH_3, O_2 and H_2O.

b. Calculate the value of the equilibrium constant (K_c) at T_1. (2 marks)

$$K_c = \frac{[NO]^4[H_2O]^6}{[NH_3]^4[O_2]^5}$$ 1 mark

$$= \frac{(0.100)^4 \times (0.150)^6}{(0.050)^4 \times (0.075)^5}$$

$$= 76.8\ M$$ 1 mark

Let's take a BREAK!

Space for Personal Notes

Section F: VCAA-Level Questions I (7 Marks)

INSTRUCTION: 7 Marks. 30 Seconds Reading. 6 Minutes Writing.

Question 15 (7 marks)

Inspired from VCAA Chemistry Exam 2009
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2009chem2-w.pdf#page=13

Dimethyl ether, CH_3OCH_3, is used as an environmentally friendly propellant in spray cans. It can be synthesised from methanol according to the following equation.

$$2CH_3OH(g) \rightleftharpoons CH_3OH(g) + H_2O(g); \qquad \Delta H = -24\ kJ\ mol^{-1}$$

The equilibrium constant, K, for this reaction at 350°C, is 5.74.

a. Write an expression for K for this reaction. (1 mark)

Marks	0	1	Average
%	21	79	0.8

Any one of:

- $K = [CH_3OCH_3][H_2O] / [CH_3OH]^2$
- $5.74 = [CH_3OCH_3][H_2O] / [CH_3OH]^2$
- $[CH_3OCH_3][H_2O] / [CH_3OH]^2$.

The most common error was leaving $[H_2O]$ out of the equilibrium expression.

b. Calculate the value of K at 350°C for the following reaction. (1 mark)

$$CH_3OCH_3(g) + H_2O(g) \rightleftharpoons 2CH_3OH(g)$$

Marks	0	1	Average
%	31	69	0.7

$2CH_3OH(g) \rightleftharpoons CH_3OCH_3(g) + H_2O(g);\ K = 5.74$
$CH_3OCH_3(g) + H_2O(g) \rightleftharpoons 2CH_3OH(g);$
$K = 1 / 5.74$
$= \mathbf{0.174}$ *

A surprising number of students left the answer as 1/5.74 and did not calculate it out.

c. Methanol is pumped into an empty 20.0 L reactor vessel. At equilibrium, the vessel contains 0.340 mol of methanol at 350°C.

i. Calculate the concentration, in $mol\ L^{-1}$, of methanol at equilibrium. (1 mark)

$[CH_3OH] = 0.340 / 20.0$
$= \mathbf{0.0170}$ * (M)

ii. Calculate the amount, in mol, of dimethyl ether present at equilibrium. (2 marks)

$[CH_3OCH_3] = [H_2O]$
$5.74 = [CH_3OCH_3]^2 / (0.0170)^2$
$[CH_3OCH_3]^2 = 5.74 \times (0.0170)^2$
$[CH_3OCH_3] = \sqrt{[5.74 \times (0.0170)^2]}$*
$= 0.0407$ M
$n(CH_3OCH_3) = 0.0407 \times 20.0$
$= \mathbf{0.815}$* (mol)

Many students struggled with the mathematics in this question, mainly through not squaring the $[CH_3OH]$ or not realising that since the equilibrium $[CH_3OCH_3]$ is the same as the equilibrium $[H_2O]$ it was necessary to take the square root.

iii. Calculate the amount, in mol, of methanol initially pumped into the reaction vessel. (2 marks)

$n(CH_3OH)$ reacted $= 2 \times n(CH_3OCH_3)$
$= 2 \times 0.815$*
$= 1.630$ (mol)
$n(CH_3OH)$ at eqm $= 0.340$ mol
$n(CH_3OH)$ initially $= 1.630 + 0.340$*
$= \mathbf{1.970}$ (mol)

This question was well done, with a good proportion of students recognising that they simply needed to double their answer to Question 3cii. and add the $n(CH_3OH)$ at equilibrium – this was given in the stem of the question.

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Section G: Multiple Choice Questions (6 Marks)

INSTRUCTION: 6 Marks. 1 Minute Reading. 6 Minutes Writing.

Question 16 (1 mark)

Consider the following equilibrium expression.

$$K = \frac{[L]\,[M]^4}{[J]^6\,[K]}$$

The equation of the **backward** reaction for this equilibrium expression is:

A. $6J + K \rightleftharpoons L + 4M$

B. $L + M_4 \rightleftharpoons J_6 + K$

C. $J_6 + K \rightleftharpoons L + M_4$

D. $L + 4M \rightleftharpoons 6J + K$

Question 17 (1 mark)

Given the following information

$$Cl_2(g) \rightleftharpoons 2Cl(g); \qquad K = 1.13 \times 10^{-6}\ M \text{ at } 1100°C$$

What would be the numerical value of the equilibrium constant for the reaction $2Cl(g) \rightleftharpoons Cl_2(g)$ at the same temperature?

A. 8.85×10^5

B. 4.42×10^5

C. 2.26×10^{-6}

D. 2.26×10^{-6}

11	71	5	10	14	Reverse the equation and take reciprocal of K value. $2Cl(g) \rightleftharpoons Cl_2(g)$; $K = \frac{1}{1.13\times10^{-6}} = 8.85 \times 10^{-5}\ M^{-1}$

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Question 18 (1 mark)

At 700°C, the equilibrium constant, K_c, for the reaction is 1.075×10^8.

$$2H_2(g) + S_2(g) \rightleftharpoons 2H_2S(g)$$

Which relationship is always correct for the equilibrium at this temperature?

A. $[H_2S]^2 < [H_2]^2[S_2]$

B. $[S_2] = 2[H_2S]$

C. $[H_2S] < [S_2]$

D. $[H_2S]^2 > [H_2]^2[S_2]$

Question 19 (1 mark)

Hydrogen and fluorine react according to the following equation.

$$\frac{1}{2}H_2\,(g) + \frac{1}{2}F_2(g) \rightleftharpoons HF(g) \qquad \Delta H = -271\ KJ\ mol^{-1}$$

In an experiment, 0.250 mol of hydrogen and 0.340 mol of fluorine were placed in a reaction vessel that had a volume of V litres. Once equilibrium was established, there was 0.220 mol of HF present in the reaction vessel.

Which one of the following expressions can be used to calculate the value of the equilibrium constant for this reaction?

A. $\dfrac{[HF]}{\frac{1}{2}[H_2] + \frac{1}{2}[F_2]}$

B. $\dfrac{[HF]}{[H_2]\,[F_2]}$

C. $\dfrac{n(HF)}{n(H_2) \times n(F_2)}$

D. $\dfrac{n(HF)}{n(H_2)^{\frac{1}{2}} \times n(F_2)^{\frac{1}{2}}}$

Since there is the same number of mole of particles on both sides, the volume of the container is not a factor in the determination of the equilibrium constant or the concentration fraction (reaction quotient).

$K = [HF]/\{[H_2]^{½}[F_2]^{½}$

$= (n(HF)/V)/\{(n(H_2)/V)^{½} \text{ x } \{(n(F_2)/V)^{½}\}$

$= (n(HF)/V)/\{(n(H_2)^{½}/V^{½}) \text{ x } \{(n(F_2)^{½}/V^{½})\}$

$= (n(HF)/V)/\{(n(H_2)^{½} \text{ x } (n(F_2)^{½}/V\} = n(HF)/\{n(H_2)^{½} \text{ x } (n(F_2)^{½}\}$

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Question 20 (1 mark)

Nitrosyl chloride (NOCl) is a highly toxic gas that decomposes according to the equation,

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

To investigate the reaction, 1.2 mol of NOCl(g) is placed in an empty 1.0 L flask and allowed to reach equilibrium. The flask and its contents are kept at a constant temperature.

If $[Cl_2] = 0.20\ M$ at equilibrium, what is the equilibrium concentration of NOCl(g)?

A. 0.80 M

B. 1.00 M

C. 1.10 M

D. 1.40 M

Question	% A	% B	% C	% D	Comments
2	2	1	91	6	
6	67	15	11	7	$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$ Initially 1.2 M - - Reacting 0.40 M → 0.40 M 0.20 M Equilibrium 0.80 M 0.40 M 0.20 M The 0.20 mol Cl_2 present in the 1.0 L flask at equilibrium was produced by the reaction of 0.40 mol NOCl, leaving 0.80 mol NOCl at equilibrium.

Question 21 (1 mark)

What does it mean if the reaction quotient at a particular temperature is equal to the equilibrium constant for a chemical equation at another temperature?

A. The reaction is at equilibrium.

B. The forward reaction is favoured.

C. The reverse reaction is favoured.

D. Insufficient information provided.

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Section H: VCAA-Level Questions II (6 Marks)

INSTRUCTION: 6 Marks. 30 Seconds Reading. 5 Minutes Writing.

Question 22 (6 marks)

Inspired from VCAA Chemistry Exam 2012
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2012/2012chem2-w.pdf#page=18

In an experiment, 1.0 mol of pure phosgene, $COCl_2$, is placed in a 3.0 L flask where the following reaction takes place.

$$COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g) \qquad K = 2.1 \times 10^{-8}\ M$$

a. It can be assumed that, at equilibrium, the amount of unreacted $COCl_2$ is approximately equal to 1.0 mol.

On the basis of the data provided, explain why this assumption is justified. (2 marks)

Marks	0	1	2	Average
%	43	11	46	1.0

Both of

- the equilibrium constant is extremely small
- the amount of CO and Cl_2 produced/$COCl_2$ reacted in getting to equilibrium is so small that (to two significant figures) the $n(COCl_2)$ at equilibrium will still be 1.0 mol.

One mark was awarded for recognising the very small K value/ratio of products to reactants, and the second mark for explaining what the low K value means in terms of extent of reaction.

Overall performance on this question showed that a large proportion of students did not see the significance of the size of the K value and the implication for extent of reaction. Many students referred to the somewhat arbitrary value of 10^{-4} as the deciding factor in what makes a K value 'small'. Also, a number of students confused the K value with acidity constants and answered, inappropriately, in the context of weak acids. The ability to interpret what a K value implies about the extent of a reaction is an expected skill at this level.

b.

i. Calculate the equilibrium concentration, in $mol\ L^{-1}$, of carbon monoxide, CO. Assume that the amount of unreacted $COCl_2$ is approximately equal to 1.0 mol. (3 marks)

Marks	0	1	2	3	Average
%	31	9	15	45	1.8

At equilibrium, [CO] = 'y' M = [Cl_2]

[$COCl_2$] = 1.0 ÷ 3.0

= 0.33 M

K = [CO][Cl_2] ÷ [$COCl_2$]

'y' × 'y' ÷ 0.33 = 2.1×10^{-8}

'y'^{2} = $2.1 \times 10^{-8} \times 0.33$

'y' = $\sqrt{(2.1 \times 10^{-8} \times 0.33)}$

'y' = 8.3×10^{-5}

[CO] = 8.3×10^{-5} M ($8.3 \times 10^{-5} - 8.4 \times 10^{-5}$)

One mark was awarded for recognising that [CO] = [Cl_2]. The second mark was awarded for using [$COCl_2$] – that is, one third or 0.33 in the correct equilibrium law. The third mark was awarded for accurately calculating [CO].

Common errors on this question included not calculating the [$COCl_2$], not recognising that [CO] = [Cl_2], dividing rather than multiplying by 0.33, not taking the square root and accuracy errors associated with rounding off one third to 0.3.

ii. What is the equilibrium concentration of chlorine gas? (1 mark)

Marks	0	1	Average
%	37	63	0.7

8.3×10^{-5} mol L^{-1} (M)

The required answer was effectively the answer to part bi. with appropriate units. If no units are specified in the question, as in bii., they must be included as part of the answer.

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Section I: Extension Questions (14 Marks)

Question 23 (4 marks)

Ammonia is produced according to the following equilibrium equation.

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

There are 4.50 moles of nitrogen, 1.00 mole of hydrogen gas and 5.80 moles of ammonia in a 10.0 L vessel. The system is at equilibrium at 298 K. The value of K_{eq} at this temperature is 748.

How many moles of nitrogen gas need to be added to the vessel to increase the amount of ammonia by 0.050 moles?

	$N_2(g)$	$+ 3H_2(g)$	$\rightleftharpoons 2NH_3(g)$
n_i	$4.50 + x$	1.00	5.80
n_c	-0.025	-0.075	$+0.050$
n_e	$4.475 + x$	0.925	5.85
c_e	$\frac{4.475 + x}{10}$	0.0925	0.585

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$[N_2] = \frac{[NH_3]^2}{K_c[H_2]^3}$$

$$[N_2] = \frac{[0.585]^2}{748 \times [0.0925]^3}$$

$$[N_2] = 0.578076$$

$$[N_2] = \frac{4.475 + x}{10} = 0.57807$$

$$4.475 + x = 5.7807$$

$$x = 1.30575\ mol$$

$$x = 1.31\ mol$$

$\therefore$ 1.31 mol of N_2 needs to be added.

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Question 24 (10 marks)

The reaction quotient for the following **unbalanced** chemical equation at a particular point in time is 2.30 M^2, where x represents the coefficient of species B:

$$2A(g) \rightleftharpoons xB(g) \qquad Q_c = 2.30\ M^2$$

a. Using the information provided, write the expression for Q_c for this reaction, and determine what x, the coefficient of B, must be. (2 marks)

$Q_c = \frac{[B]^x}{[A]^2}$ (1)

Since units of Q_c is M^2: $\frac{M^x}{M^2} = M^2$

$\Rightarrow x - 2 = 2 \Rightarrow x = 4$ (2)

$\therefore Q_c = \frac{[B]^4}{[A]^2}$ & $2A(g) \rightleftharpoons 4B(g)$

b. Hence, if the concentration of species A at this point in time is found to be 0.179 M, calculate the concentration of species B at this point in time for the reaction, in M. (2 marks)

$Q_c = \frac{[B]^4}{[A]^2} = 2.30$

$2.30 = \frac{[B]^4}{(0.179)^2}$

$\Rightarrow [B] = (2.30 \times (0.179)^2)^{\frac{1}{4}}$

$= 0.521\ M$ (3 s.f.)

Given that the equilibrium constant, K_c, for this reaction at the same temperature is 5.81 M^2:

c.

i. State whether the system is at equilibrium or not. If not, outline how the position of equilibrium will shift. (1 mark)

Not at equilibrium as Q_c does not equal K_c. Since $K_c > Q_c$, the position of equilibrium will shift to the right/towards the products.

ii. Hence or otherwise, explain whether the forward or backward reaction's rate will be greater than the others from this point in time until equilibrium is established. (1 mark)

Since position must shift to the right, the forward reaction will be favoured. That is, the forwards reaction's rate will be greater than the backwards' rate to establish equilibrium.

d. Your Chemistry teacher at school tells the class that "once equilibrium is established, the reactions stop occurring and therefore the concentrations of all species in the reaction remain constant". As a Contour student, critically evaluate your teacher's statement. (2 marks)

They are incorrect that the reactions stop occurring. Equilibrium is dynamic – the forwards and reverse reactions continue to occur but at the same rate. (1)
They are correct in stating that the concentrations of all species in the reaction remain constant, but this is due to the fact that the forwards and reverse reactions occur at the same rate, not because the reactions have ceased. (2)

e. At equilibrium, if the amount of B present is known to be 60.0% of the amount of A present, calculate what the concentration of species A must be, in $mol\ L^{-1}$. (2 marks)

$K_c = 5.81 = \frac{[B]^4}{[A]^2}$

Since both A & B must be in the same vessel, V is fixed. ∴ mole ratios = conc ratios

$\therefore 5.81 = \frac{(0.6[A])^4}{[A]^2}$

$\Rightarrow 5.81 = \frac{0.1296[A]^4}{[A]^2}$

$\Rightarrow [A]^2 = \frac{5.81}{0.1296} = 44.83$

$\Rightarrow [A] = \sqrt{44.83} = 6.70\ M$ (3 s.f.)

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