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VCE Chemistry ¾
Equilibrium [0.18]
Workshop

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**
Pg / Q #: _____ Notes:	Pg / Q #: _____ Notes:

Section A: Recap

Sub-Section: Regular Recap

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

- K_c Expression:

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

$$K_c =$$

- **K_c value key property:** Always has the _____ 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.

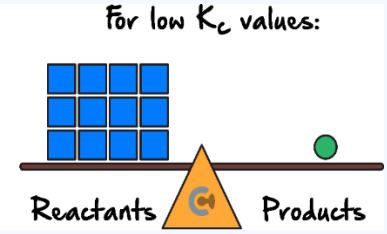
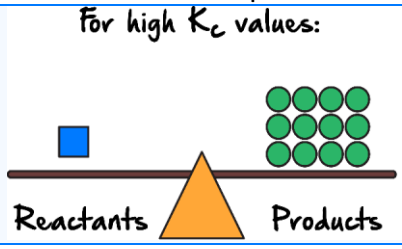
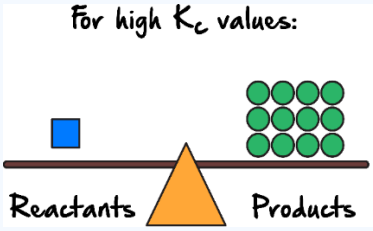
Homogenous Equilibrium	Heterogenous Equilibrium
[only one] / [multiple] state(s) of matter present in equation	[only one] / [multiple] state(s) of matter present in equation

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 is _____.

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

Space for Personal Notes

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
		

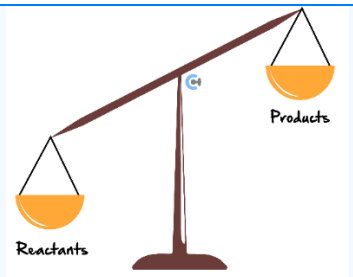
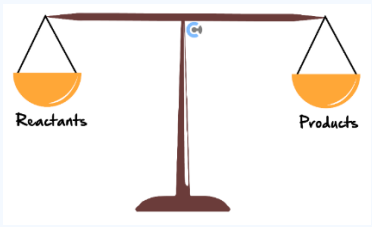
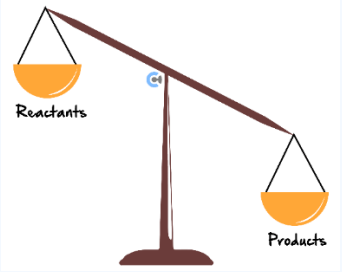
Learning Objective: [2.7.3] - Find Equilibrium Constant When Equation is Changed

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

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:
  - _____
  - _____
  - _____
  - _____
- Good idea to add a fifth row: _____.
- Key Terms: "Empty" or "evacuated" means there are _____ other substances present at the beginning.
- Steps:
  1. Fill out _____.
  2. Find _____
  3. Find _____

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.

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 $4.00\ L$?

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

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

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

K_c expression	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.

_____

_____

_____

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)

_____

_____

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)

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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)

_____

_____

_____

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

_____

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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)

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

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

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.

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 $1.25 \times 10^{-2}\ mol$ 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)

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_____

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

_____

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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 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)

_____

_____

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)

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_____

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

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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.

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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)

_____

_____

_____

_____

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

_____

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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)

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_____

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

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

_____

_____

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)

_____

_____

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

_____

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

_____

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Space for Personal Notes

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}

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

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

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

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

Space for Personal Notes

Question 20 (1 mark)

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

$$2\text{NOCl(g)} \rightleftharpoons 2\text{NO(g)} + \text{Cl}_2\text{(g)}$$

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 $[\text{Cl}_2] = 0.20\ M$ 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 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)

_____

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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)

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

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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?

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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:

$$2\text{A(g)} \rightleftharpoons x\text{B(g)} \qquad Q_c = 2.30\ M^2$$

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)

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)

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)

_____

_____

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)

_____

_____

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)

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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)

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