CONTOUR EDUCATION

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VCE Chemistry ¾
Equilibrium [2.7]
Workbook

Outline:

Learning Objectives:

- ☐ **CH34 [2.7.1]** - Write equilibrium constant expression & find its value (including units)
- ☐ **CH34 [2.7.2]** - Identify the extent of reaction
- ☐ **CH34 [2.7.3]** - Find equilibrium constant when equation is changed
- ☐ **CH34 [2.7.4]** - Apply Q_c to find the direction of equilibrium shift
- ☐ **CH34 [2.7.5]** - Apply RICE tables to find K_c

Section A: Introduction to Dynamic Equilibrium

Sub-Section: Reversible Reactions

Context

- Some reactions **do not go to** ____________________.

REMINDER: Don't forget to find the limiting reagent and divide the moles by the ____________________ in the equation!

Exploration: Reaction 1 – Hydrogen gas and Oxygen gas

- Consider the following reaction:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

- Consider $3\ mol$ of hydrogen gas and $2\ mol$ of oxygen gas.
- **After some time:**

Mole	$H_2(g)$	$O_2(g)$	$H_2O(g)$
Initial	$3.00\ mol$	$2.00\ mol$	$0.00\ mol$
Final	$0.00\ mol$	$0.50\ mol$	$3.00\ mol$

- What do you notice about some of the reactants? ______________________________

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Exploration: Reaction 2 – Sulphur dioxide and Oxygen gas

- Consider the following reaction:

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

- Consider $2\ mol$ of Sulphur dioxide gas and $0.9\ mol$ of oxygen gas.
- **Expected Occurrence After some time:**

Mole	$SO_2(g)$	$O_2(g)$	$SO_3(g)$
Initial	$2.00\ mol$	$0.90\ mol$	$0.00\ mol$
Final (Expected)	$0.20\ mol$	$0.00\ mol$	$1.80\ mol$

What happens in reality?

Mole	$SO_2(g)$	$O_2(g)$	$SO_3(g)$
Final (Actual)	$0.9\ mol$	$0.35\ mol$	$1.10\ mol$

Why does this happen?

Reversible Reaction

- A **reversible reaction** is one that can go ________________________. It does this:
  - ____________________________ - (at the same time.)
  - ____________________________ - (by itself.)
- Reversible Reactions are only invested in **closed systems** in VCAA.
- **Example:**

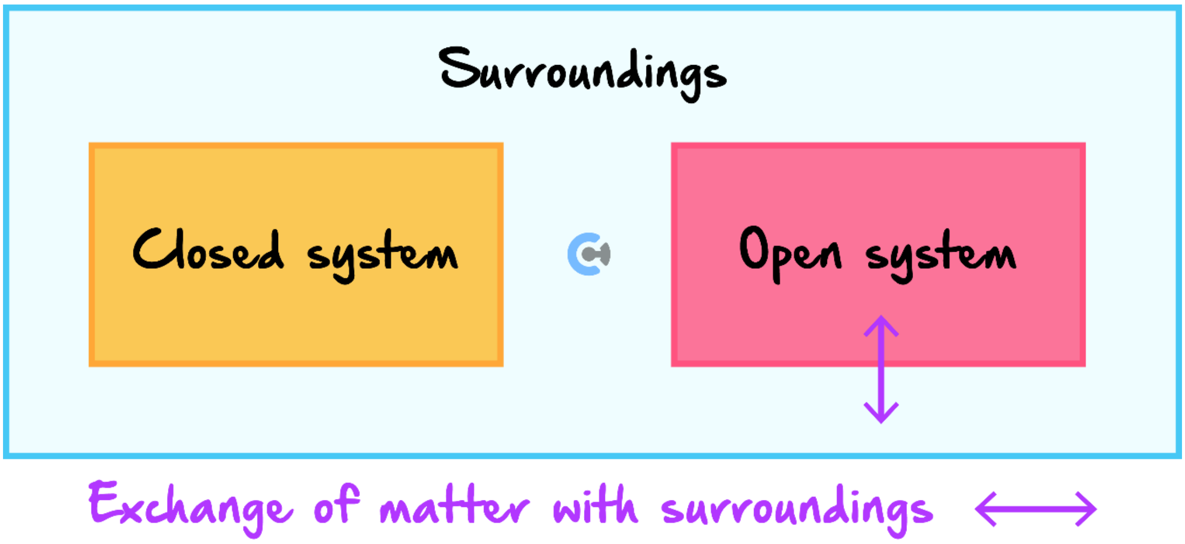
$$2SO_2(g) + O_2(g) \qquad 2SO_3(g)$$

Definition

Closed System vs Open System

Open System	Closed System
Matter can be added/removed from the system.	**Matter cannot** be added/removed from the system.

- In either system, energy can be added/removed from the system.



Discussion: For each of the following systems, state if they're an open or closed system.

- A stoppered glass bottle. [Open] / [Closed]
- A boiling saucepan (no lid) [Open] / [Closed]
- The Sun. [Open] / [Closed]
- Sealed reaction vessel. [Open] / [Closed]

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Sub-Section: Dynamic Equilibrium

Now that we've looked at reversible reactions, let's have a look at dynamic equilibrium!

Exploration: Orange & Blue Simulation to Equilibrium

- Consider the following:

$$\text{Orange Form} \rightleftharpoons \text{Blue Form}$$

- **Assume the rate is different, where:**
  - 50% of orange → blue.
  - 10% of blue → orange.
- Started with 60 orange substances and 0 blue.
- **Let's see what will happen with time:**

Time	Orange	Blue
0	60	0
1		
2		
3	13.2	46.8
4	11.28	48.72
5	10.512	49.488
After a long time		

- **Reaches point where:**

Rate of forwards reaction **Rate of backwards reaction**

- **Amount of orange and blue substances at this point:** [Changes] / [Stays the same]
- Is there a reaction still occurring at this point? [Yes] / [No]
- Point is known as ______________________________.

Let's look at a real-time simulation that shows this:

Exploration: Simulation

- **Link:** https://phet.colorado.edu/sims/cheerpj/ideal-gas/latest/ideal-gas.html?simulation=reversible-reactions
- **Video Link:** https://drive.google.com/file/d/1t0v9aENfLhyu0a_MddDF8asDS2yxIVML/view?usp=drive_link
- **Observations**:
  - At the beginning, amount of substance A: [Increases] / [Decreases] / [Stays constant]
  - After some time, amount of substance A: [Increases] / [Decreases] / [Stays constant]
  - After some time, the rough amounts of each substance:

Substance A	Substance B

- At this point, the **system has reached equilibrium**!
  - Is substance A turning into substance B? [Yes] / [No]
  - Is substance B turning into substance A? [Yes] / [No]

- Reasoning why substances stay roughly constant:

  Rate of forwards reaction Rate of backwards reaction

Definition

Equilibrium Mixtures

- For reversible reactions, after some time, the system reaches equilibrium.
- **At equilibrium:**
  - Amount of each substance ____________________.
  - Rate of forwards reaction Rate of backwards reaction.

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Section B: Equilibrium Constant

Sub-Section: Concentration

REMINDER: Don't forget!

- Concentration indicates how much of a substance is present in a certain volume of water.
- Denoted by: c

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

How do we depict concentration in working out?

Concentration Notation

- Moles Notation: $n(\text{HCl})$
- Concentration Notation:

Method 1	Method 2

Question 1

If there are 0.380 mol of an unknown substance dissolved in 450 mL of water, find its concentration.

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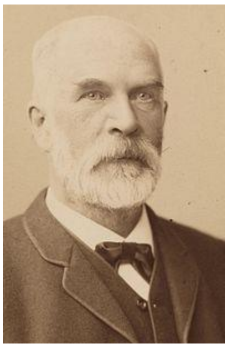
Sub-Section: Equilibrium Constant Expression

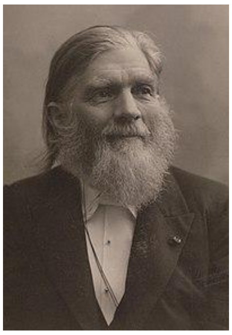
How do we know and predict the amount of substances present at equilibrium?

History: Guldberg and Waage

- Between 1864 and 1879, Cato M. Gulberg and Peter Waage derived equilibrium constant using kinetic data and rate equation.



Cato M. Guldberg, 1836 - 1902



Peter Waage, 1833 - 1900

- The **derivation of the equilibrium constant** is **too complicated** and is **not covered in VCE Chemistry**!
- Gulberg and Waage proposed the following equilibrium constant (K_c) equation!

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Definition

Equilibrium Constant (K)

- **Definition:** The equilibrium constant expression shows ______________________________ of each particle at ____________________.
- **Symbol:**

$$K$$

  - K stands for 'constant'.
- In VCE Chemistry, only __________________ equilibrium constants are considered.

$$K_c$$

  - c - stands for concentration.

Extension: Different Equilibrium Constants (K) (University Chemistry)

- **Pressure Equilibrium Constant (K_p):** Uses partial pressures of gases in equilibrium expressions.
- **Dissociation Constants (K_a, K_b):** Represent equilibrium constants for weak acid and weak base dissociation.
- **Solubility Product Constant (K_{sp}):** Describes solubility equilibrium for sparingly soluble salts.
- **VCE Chemistry Focus:** Only K_c (concentration equilibrium constant) is assessed; K_p, K_a, K_b, and K_{sp} are not included in the study design.

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How do we find the Equilibrium Constant (K)?

Exploration: The Equilibrium Constant (K_c)

- The equilibrium constant:

$$K_c = \frac{c(\text{products})}{c(\text{reactants})} = \frac{[\text{products}]}{[\text{reactants}]}$$

  - 'Products' mean substances on the right-hand side of the equation.
  - 'Reactants' mean substances on the left-hand side of the equation

- Consider the following:

$$\text{A} + 3\text{B} \rightleftharpoons 2\text{C} + \frac{1}{2}\text{D}$$

- The equilibrium constant for the above is:

$$K_c = \frac{[\text{C}]^2 \times [\text{D}]^{\frac{1}{2}}}{[\text{A}] \times [\text{B}]^3}$$

  - **Instead of adding** the reactants or products together, they are ________________ instead!
  - **Coefficients** in the equation turn into ______________.

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Equilibrium Constant (K_c) Expression

- **For an equation:**

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

- **The equilibrium constant expression:**

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

- **Data Book:** Page 3

- **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!

NOTE: To save time, the **multiplication signs** are usually **omitted.**

$$K_c = \frac{[C]^2 \times [D]^{\frac{1}{2}}}{[A] \times [B]^3} \rightarrow \frac{[C]^2[D]^{\frac{1}{2}}}{[A][B]^3}$$

Let's look at a question together!

Question 2 Walkthrough.

Write the expression for the equilibrium constant.

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

____

____

How about the Units?

Exploration: Determining the Units

- Consider the following equilibrium expression:

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

- Units for Concentration: ________________.

Amount of Reactants	Amount of Products

- Equilibrium expression for just units:

- Simplified Expression: *(Label Above)*

- Final units for this expression: ______________.

NOTE: The units for the equilibrium constant are dependent on the equilibrium expression!

ALSO NOTE: Do not write the units like this: $\frac{1}{M^2}$ – we leave it in this form instead: M^{-2}.

Units for Equilibrium Expression

- Need to be calculated separately and are different for each equilibrium expression.

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<u>Misconception</u>

"We should include units in the equilibrium constant expression."

- Example:

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

TRUTH: Do not do this, as it means the units are doubling up!

Equilibrium Constant Expression:

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

NOTE: This is something that is commonly taught wrong by teachers, but if your teacher forces you to do write it in, do it for the SAC, but not the final exam because it is actually wrong!

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Your Turn!

Question 3

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

a. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

K_c expression	Units

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

K_c expression	Units

c. $\frac{1}{2}Cu^{2+}(aq) + 2NH_3(aq) \rightleftharpoons \frac{1}{2}Cu(NH_3)_4(aq)$

K_c expression	Units

d. $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

K_c expression	Units

NOTE: Sometimes, the equilibrium constant will have no units! In this scenario, simply just leave it blank, or write in brackets '(no units)'!

Question 4

Inspired by VCAA Chemistry Exam 2014
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2014/2014chem-amd-w.pdf#page=2

Hydrogen is produced on an industrial scale from methane. The equation for the reaction is:

$$2H_2O(g) + CH_4(g) \leftrightharpoons CO_2(g) + 4H_2(g)$$

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

A. $K = \frac{[H_2O]^2[CH_4]}{[H_2]^4[CO_2]}$

B. $K = \frac{[H_2]^4[CO_2]}{[H_2O]^2[CH_4]}$

C. $K = \frac{[H_2O][CH_4]}{[H_2][CO_2]}$

D. $K = \frac{4[H_2][CO_2]}{2[H_2O][CH_4]}$

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Question 5 Additional Question.

Inspired by VCAA Chemistry Exam 2019
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2019/2019chem-w.pdf#page=13

There are four equilibrium reactions shown below.

Reaction 1	$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$
Reaction 2	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
Reaction 3	$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$
Reaction 4	$2NO_2(g) \rightleftharpoons N_2O_4(g)$

In which reaction is the units for K_c value M^{-2}?

A. Reaction 1

B. Reaction 2

C. Reaction 3

D. Reaction 4

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Sub-Section: Heterogeneous Equilibrium

Let's have a look at a particular scenario together!

Exploration: Thermal Decomposition of Calcium Carbonate

- Consider the following:

$$BaCO_3(s) \rightleftharpoons Ba^{2+}(aq) + CO_3{}^{2-}(aq)$$

- Equilibrium Constant Expression:

$$K_c = \frac{[CO_3{}^{2-}][Ba^{2+}]}{[BaCO_3]}$$

Is there anything wrong with this?

- Consider $Ba^{2+}(aq)$ and $CO_3{}^{2-}(aq)$,

State of matter	Can they have concentration?
	[Yes] / [No]

- Consider $Ba_2CO_3(s)$,

State of matter	Can it have concentration?
	[Yes] / [No]

- Concentration of solids assigned value: ____________.

- Actual equilibrium constant expression:

Homogenous vs Heterogenous Equilibrium

Homogenous Equilibrium	Heterogenous Equilibrium
Only one state of matter present in equation	**Multiple states** 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 ______.

Let's look at a question together!

Question 6 Walkthrough.

Write the K_c expression for the following equation:

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

____

____

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Your Turn!

Question 7

Write the K_c expression for the following equations:

a. $PbCl_2(s) \rightleftharpoons Pb^{2+}(aq) + 2Cl^-(aq)$

---

b. $H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq)$

Question 8 Additional Question.

Write the K_c expression for the following equation:

$$C_2H_5OH(l) \rightleftharpoons C_2H_5OH(aq)$$

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Sub-Section: Finding the Equilibrium Constant

Now let's use this to find the equilibrium constant value!

Finding equilibrium constant value

- Steps
  1. Write the equilibrium expression.
  2. Plug in the **concentration** (not the moles) of each substance.
  3. Include the units in the final answer!

TIPS: Plugging into calculator

- Use the fraction tool to insert large fractions first.
- Use brackets when necessary!

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Let's look at a question together!

Question 9 Walkthrough.

A 2.00 L vessel contains a mixture of 0.0860 mol of H_2, 0.124 mol of I_2 and 0.716 mol of HI in equilibrium at 460°C according to the equation:

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

Calculate the value of the equilibrium constant, K_c, at 460°.

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Your Turn!

Question 10

Acetone C_3H_6O is used to remove nail polish and can be prepared from the following reaction:

$$C_3H_7OH(g) \rightleftharpoons C_3H_6O(g) + H_2(g)$$

a. Write the expression for the K_c value.

____

b. At a particular temperature, an equilibrium mixture of $0.034\ mol$ of C_3H_7OH, $0.174\ mol$ of Acetone and $0.161\ mol$ of Hydrogen gas are present in a $10\ L$ reaction vessel. Calculate the value of the equilibrium constant, K_c, at this temperature.

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____

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Question 11

The following equation is used to show what occurs when nitrogen and hydrogen gas are mixed together.

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

a. In a 3.00 L container, there is 2.00 mol of nitrogen gas, 1.29 mol of hydrogen gas and 0.426 mol of Ammonia gas. Find the equilibrium constant at this temperature.

b. If the volume of the container was doubled at the same temperature, what would happen to the equilibrium constant?

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Question 12 Additional Question.

The second half of the steam reforming process to produce hydrogen is a reversible reaction, as shown below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

A reaction vessel with a volume of 3.0 L contains the following amounts of each substance.

- 0.90 mol of CO
- 1.50 mol of H_2O
- 0.60 mol of CO_2
- 0.40 mol of H_2

Find the equilibrium constant value.

____

____

____

<u>REMINDER</u>: Don't forget!

- Include units in the final answer!
- The equilibrium constant remains ________________________ at the same temperature! Changes in volume or other species do not change the equilibrium constant!

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Sub-Section: Using Equilibrium Constant to Find [Substance]

Now, let's have a look at scenarios where the K_c value is given, and the amount of another species is asked for instead!

Definition

Finding equilibrium constant value

- Steps

1. Write the equilibrium expression.
2. **Rearrange the expression first.**
3. Plug in the **concentration** (not the moles) of each substance & K_c value.

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Let's look at a question together!

Question 13 Walkthrough.

For the following equation, whereby Nitrous oxide is in equilibrium with nitrogen and oxygen gases.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$

Given that the K_c value is 3.90 and there are 2.00 mol of nitrogen gas and 3.50 mol of oxygen gas in a 2.50 L reaction vessel at equilibrium, find the amount of nitrogen monoxide present (in mol).

NOTE: The equilibrium expression uses concentration, so the amount (mol) needs to be found separately afterwards!

ALSO NOTE: Keeping track of the units can help double-check if you've done the right thing!

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Your Turn!

Question 14

For the following equation:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

a. Write an expression for the equilibrium constant.

---

b. Given the K_c value is 0.134 M at 25°C and at equilibrium, the concentration of PCl_3 is 0.320 M and the concentration of Cl_2 is also 0.320 M, find the concentration of PCl_5 at equilibrium.

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c. Given that the volume of the reaction vessel is 3.00 L, find the amount of PCl_5 present at equilibrium.

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Question 15

For the following equation:

$$2A(g) + 3B(g) \rightleftharpoons X(g) + Y(g)$$

a. Write the expression for the K_c value.

---

b. Given the K_c value is $200\ M^{-3}$ at a certain temperature and equilibrium, the concentration of B is $0.492\ M$, the concentration of X is $1.614\ M$ and the concentration of Y is $2.340\ M$, find the number of moles of A at equilibrium, given that the reaction vessel has a volume of $4.00\ L$.

Question 16 Additional Question.

The oxidations of Sulphur dioxide, SO_2, to Sulphur trioxide, SO_3, can be represented by the following equation:

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

$$K_c = 1.75\ M^{-1} \text{ at } 1000°C$$

An equilibrium mixture has a concentration of $0.12\ M$ SO_2 and $0.16\ M$ oxygen gas O_2. The temperature of the container is 1000°C.

The equilibrium concentration of SO_3 at 1000°C is:

A. $1.5 \times 10^{-4}\ M$

B. $4.0 \times 10^{-3}\ M$

C. $1.2 \times 10^{-2}\ M$

D. $6.3 \times 10^{-2}\ M$

Section C: Changing K_c Values

Let's have a look at how some of the changes to the equation will affect the K_c value

Exploration: Effect of Reversing Equation

- Consider the following equation:

Original: $2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3(g) \quad K_c = 2.8 \times 10^2\ M^{-1}$ at 100 K

- Original K_c value expression:

- Consider the Reversed Equation:

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

- New K_c value expression:

- Relationship between $K_c(\text{new})$ and $K_c(\text{old})$:

- $K_c(\text{new})$ value:

- Conclusion:
  - When reversing equations, take the ________________.
  - Units are also reciprocated!

Exploration: Multiplying Coefficient

- Consider the following equation:

$$\text{Original: } 2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad K_c = 2.8 \times 10^2 \ M^{-1} \text{ at } 100 \text{ K}$$

- Original K_c value expression:

$$K_c(\text{original}) = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

- **Consider the Doubled Equation:**

$$\text{New: } 4SO_2(g) + 2O_2(g) \rightleftharpoons 4SO_3(g)$$

- New K_c value expression:

$$K_{c-new} = \frac{[SO_3]^4}{[SO_2]^4[O_2]^2}$$

- Relationship between $K_c(\text{new})$ and $K_c(\text{old})$:

- $K_c(\text{new})$ value:

- **Conclusion**: When multiplying an equation by some common coefficient, take that K_c value to the __________________ that coefficient.

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Exploration: Dividing by Coefficients

- For the following reaction:

$$\text{Original: } 2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad K_c = 2.8 \text{ x } 10^2\ M^{-1} \text{ at } 100 \text{ K}$$

- Consider the Halved Equation:

$$\text{New: } SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$$

- **Conclusion**: The equilibrium constant is raised to the power of ________________.

Equilibrium Equation Effect on K_c

- **Rule #1:** When **reversing equations**, take the **reciprocal**.
- **Rule #2:** When **multiplying by a coefficient**, take the **power** of that coefficient.
- **Units:** Follow how the equation has been changed!

Let's look at a question together!

Question 17 Walkthrough.

For the chemical reaction, the equilibrium constant is 5.20 M^{-1} at 250°C:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

Find the equilibrium constant for the following equation:

$$\frac{1}{2}N_2O_4(g) \rightleftharpoons NO_2(g)$$

____

____

TIPS:

- First, **figure out what happened to the equation** before finding the new equilibrium constant!
- When an equation is reciprocated, just put the K_c value to the power of ________ !

Your Turn!

Question 18

For the chemical reaction:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

The equilibrium constant is 1.70 M at 250°C. For each equation, calculate the value of K_c at the same temperature.

a. $4PCl_5(g) \rightleftharpoons 4PCl_3(g) + 4Cl_2(g)$

b. $\frac{1}{2}PCl_5(g) \rightleftharpoons \frac{1}{2}PCl_3(g) + \frac{1}{2}Cl_2(g)$

c. $\frac{1}{2}PCl_3(g) + \frac{1}{2}Cl_2(g) \rightleftharpoons \frac{1}{2}PCl_5(g)$

d. $2PCl_3(g) + 2Cl_2(g) \rightleftharpoons 2PCl_5(g)$

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Question 19 Additional Question.

For the following reaction, the original equilibrium constant has a magnitude of 0.400.

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

a. Find the units of the K_c with a value of 0.400.

---

b. The equation is now changed and is represented like so

$$6NH_3(g) \rightleftharpoons 3N_2(g) + 9H_2(g)$$

Find the new K_c constant.

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Section D: Extent of Reaction

Sub-Section: Extent of Chemical Reaction

Extent of Chemical Reaction

- The extent of the reaction indicates how much the reaction has proceeded from **reactants** → **products**.

$$\textbf{Reactants} \rightleftharpoons \textbf{Products}$$

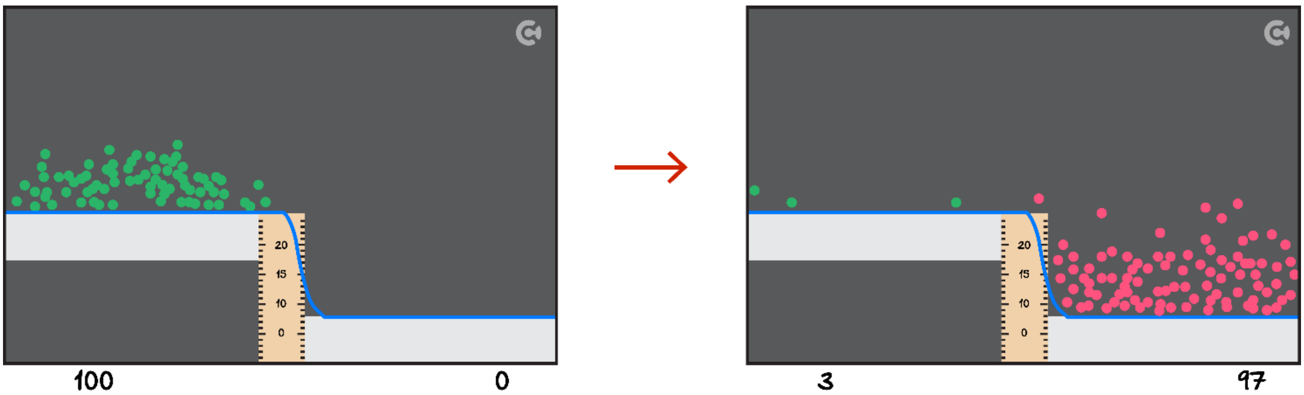
Exploration: Extent of Reaction

- Assume reaction occurs in a $1.00\ L$ reaction vessel.

Equation	K_c expression
$A(g) \rightleftharpoons B(g)$	$K_c = \frac{[B]}{[A]}$

Scenario #1

- **Start with 100 of the reactants (substance A):**



- **Extent of Reaction:** Reaction occurred to a [small] / [medium] / [large] extent.

- **Equilibrium Constant Value** (given 3 substance A and 97 substance B at equilibrium):

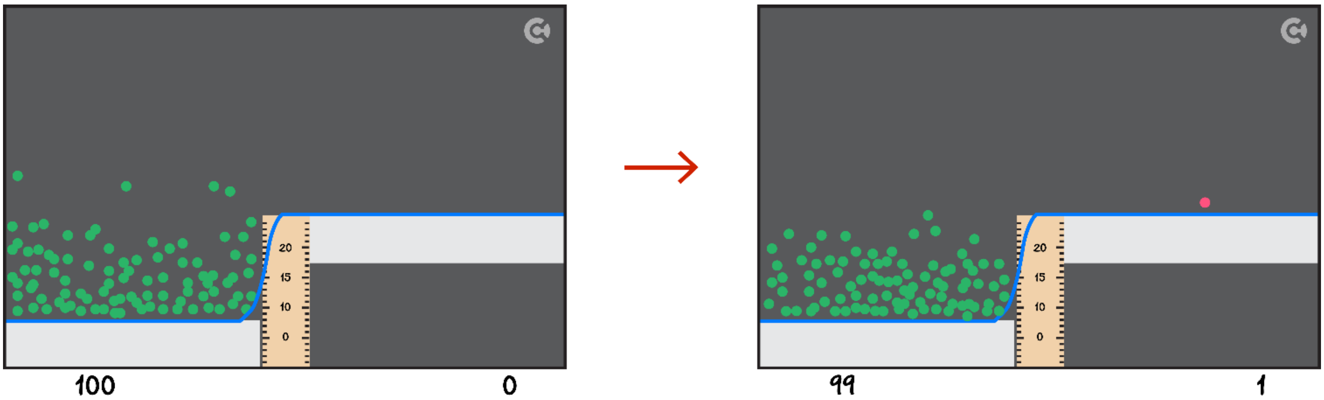
$$K_c = \frac{[\mathrm{B}]}{[\mathrm{A}]} =$$

- **The equilibrium constant is:** $[K_c \ll 1]$ / $[K_c \approx 1]$ / $[K_c \gg 1]$

- **Large Extent of reaction** → [small] / [medium] / [large] equilibrium constant!

Scenario #2

- **Start with 100 of the reactants (substance A):**



- **Extent of Reaction:** Reaction occurred to a [small] / [medium] / [large] extent.

- **Equilibrium Constant Value** (given 99 substance A and 1 substance B at equilibrium):

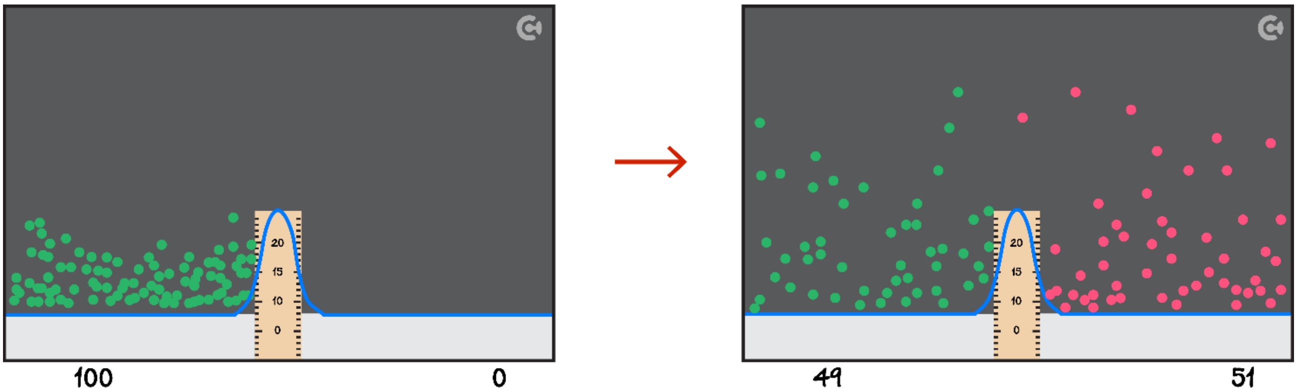
$$K_c = \frac{[\mathrm{B}]}{[\mathrm{A}]} =$$

- **The equilibrium constant is:** $[K_c \ll 1]$ / $[K_c \approx 1]$ / $[K_c \gg 1]$

- **Small Extent of reaction** → [small] / [medium] / [large] equilibrium constant!

Scenario #3

- Start with 100 of the reactants (substance A):



- **Extent of Reaction:** Reaction occurred to a [small] / [medium] / [large] extent.
- **Equilibrium Constant Value** (given 49 substance A and 51 substance B at equilibrium):

$$K_c = \frac{[B]}{[A]} =$$

- The equilibrium constant is: $[K_c \ll 1]$ / $[K_c \approx 1]$ / $[K_c \gg 1]$
- Small Extent of reaction → [small] / [medium] / [large] equilibrium constant!

NOTE: The K_c value will always be greater than 0 – it will **never be negative.**

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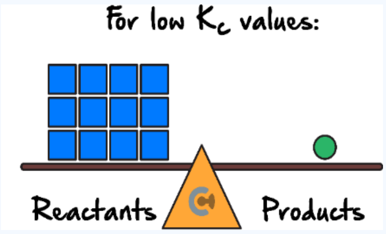
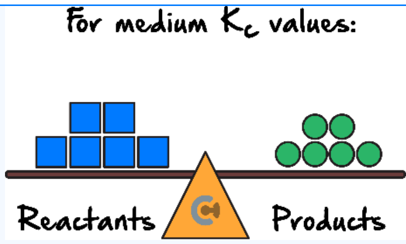
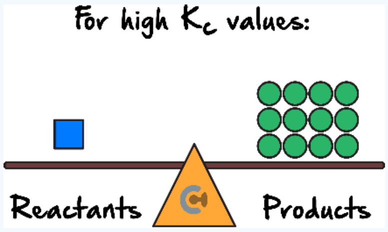
Definition

Extent of Reaction

Small Extent of Reaction	Medium Extent of Reaction	Large Extent of Reaction
$K_c < 10^{-4}$	$10^{-4} < K_c < 10^{4}$	$K_c > 10^{4}$
[reactants] / [both] / [products] favoured at equilibrium	[reactants] / [both] / [products] favoured at equilibrium	[reactants] / [both] / [products] favoured at equilibrium
		

Try some questions!

Question 20

If a chemical reaction has a very large equilibrium constant (K_c), what does this indicate about the extent of the reaction?

A. The reactants are favoured and the extent of reaction is small.

B. The products are favoured and there is a large extent of reaction.

C. Neither reactants nor products are favoured.

D. The reaction does not occur.

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Question 21

The value of the equilibrium constant, K_c, for a reaction is 1.0×10^{-10}. Which statement about the extent of the reaction is correct?

A. The reaction hardly proceeds.

B. The reaction goes almost to completion.

C. The products have a higher concentration than the reactants.

D. The concentrations of reactants and products are the same.

Question 22

For the equilibrium

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

With a K_c value of 0.500 M^{-2}, what does this tell you about the extent of reaction?

A. Ammonia (NH_3) is produced in large quantities.

B. The reaction heavily favours the formation of nitrogen and hydrogen.

C. The reaction moderately favours the formation of ammonia.

D. The reaction has a small extent towards the formation of ammonia.

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Section E: Reaction Quotient (Q_c)

Sub-Section: Finding the Reaction Quotient

We've covered the equilibrium constant, but what is the reaction quotient?

Reaction Quotient (Q_c)

- **Expression**: Same expression as the equilibrium constant expression!
- **Expression Value Obtained:** By substituting the ________________ concentration of all the reactants and products!
- **Symbol:**

$$Q_c$$

Exploration: The use of the reaction quotient

- Consider the following:

$$\text{A} \rightleftharpoons \text{B}$$

Equilibrium Constant Expression	Reaction Quotient Expression

If they have the same expression, what is the difference?

- **Difference**: ________________ we substitute in!
- **Scenario Context**: At a certain temperature, the K_c value is 1.00.

Scenario #1: $10.00\ M$ of A and $0.00\ M$ of B

- Is the system at equilibrium? [Yes] / [No]

K_c Value	Q_c Value
$K_c = 1.0$	

Relationship between K_c and Q_c value	At Equilibrium?
K_c Q_c	System [is] / [is not] at equilibrium!

Scenario #2: $6.00\ M$ of A and $4.00\ M$ of B

K_c Value	Q_c Value
$K_c = 1.0$	

Relationship between K_c and Q_c value	At Equilibrium?
K_c Q_c	System [is] / [is not] at equilibrium!

Scenario #3: $5.00\ M$ of A and $5.00\ M$ of B

K_c Value	Q_c Value
$K_c = 1.0$	

Relationship between K_c and Q_c value	At Equilibrium?
K_c Q_c	System [is] / [is not] at equilibrium!

Definition

Using Q_c and K_c values

Equilibrium Constant (K_c)	Reaction Quotient (Q_c)
$K_c = \dfrac{[\mathrm{C}]^{\mathrm{c}} \times [\mathrm{D}]^{\mathrm{d}} \times \ldots}{[\mathrm{A}]^{\mathrm{a}} \times [\mathrm{B}]^{\mathrm{b}} \times \ldots}$	$Q_c = \dfrac{[\mathrm{C}]^{\mathrm{c}} \times [\mathrm{D}]^{\mathrm{d}} \times \ldots}{[\mathrm{A}]^{\mathrm{a}} \times [\mathrm{B}]^{\mathrm{b}} \times \ldots}$
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.

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Let's try a question together!

Question 23 Walkthrough.

A equilibrium mixture currently contains 0.050 mol of A and 0.270 mol of B at 3.00 L. The reaction which takes place is the following:

$$2A \rightleftharpoons B$$

Given that $K_c = 150\ M^{-1}$ at this temperature, is the system at equilibrium?

____

____

____

NOTE: When plugging the values in, make sure to **write Q_c** and **not K_c** in your working out if you're finding, the Q_c value!

ALSO NOTE: To justify if the system is at equilibrium or not, be sure to write the line:

$$Q_c = K_c \text{ or } Q_c \neq K_c$$

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Your Turn!

Question 24

What does it mean if the reaction quotient (Q_c) is equal to the equilibrium constant (K_c) for a chemical reaction?

A. No reaction is occurring.

B. The forward reaction is favoured.

C. The reverse reaction is favoured.

D. The reaction is at equilibrium.

Question 25

Steam reforming is the process whereby hydrogen gas can be obtained from Methane gas. The equation that takes place is shown below:

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

a. Write the expression for the equilibrium constant.

b. The equilibrium constant is known to be $4.32\ M^2$ at a given temperature.

i. Given the following concentrations of each substance, is the system at equilibrium?

$$[CH_4] = 6.50\ M, [H_2O] = 1.92\ M, [CO] = 3.45\ M, [H_2] = 2.50\ M$$

ii. Given the following concentrations of each substance, is the system at equilibrium?

$$[CH_4] = 2.50\ M, [H_2O] = 2.92\ M, [CO] = 1.50\ M, [H_2] = 1.15\ M$$

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Sub-Section: Using the Reaction Quotient

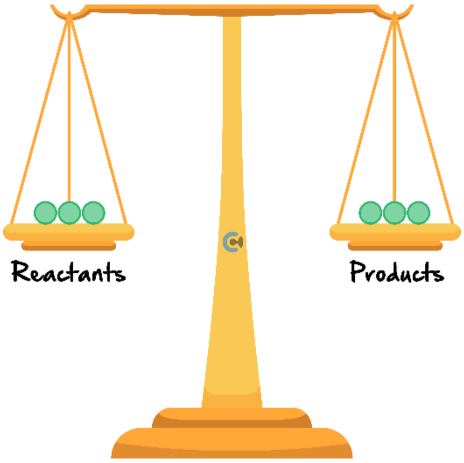
We can actually do more with the reaction quotient!

Context

- Reaction quotient can be used to determine **which way the reaction goes**!

Exploration: Differing Q_c Values

- Think equilibrium like a traditional weighing scale:



- Consider a system with reaction:

$$\textbf{reactants} \rightleftharpoons \textbf{products}$$

- K_c and Q_c value are represented by:

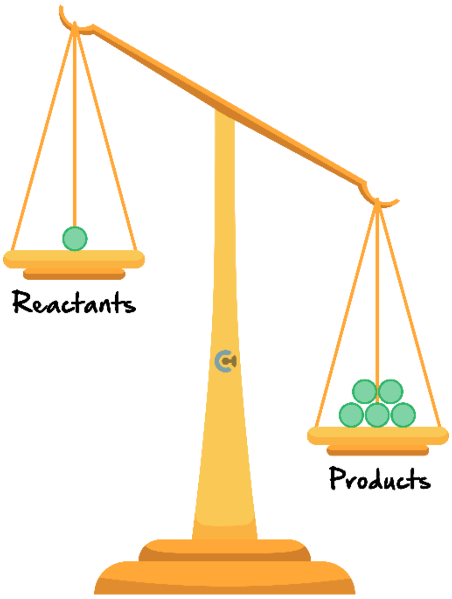
$$K_c = \frac{[\text{products}]}{[\text{reactants}]} \text{ and } Q_c = \frac{[\text{products}]}{[\text{reactants}]}$$

What will happen if $Q_c > K_c$?

$$Q_c > K_c \qquad Q_c = \frac{[\text{products}]}{[\text{reactants}]}$$

Amount of Reactants	Amount of Products
[too little] / [too many]	[too little] / [too many]

- It looks like so:



- Imagine reactant was going from reactants → products.
- **Equilibrium was:** [Undershot] / [Overshot]
- **To Re-establish Equilibrium:** [Reactants → Products] / [Products → Reactants]
- **Type of Reaction Favoured:** [Forwards] / [Reverse] reaction

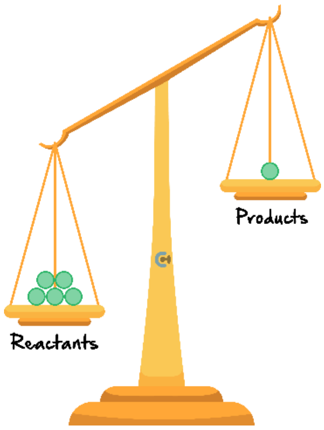
What will happen if $Q_c < K_c$?

- If we have a **smaller Q_c value**, what does that mean about the **amount** of **reactants** and **products** we have compared to how much we should have at equilibrium?

$$Q_c < K_c \qquad Q_c = \frac{[\text{products}]}{[\text{reactants}]}$$

Amount of Reactants	Amount of Products
[too little] / [too many]	[too little] / [too many]

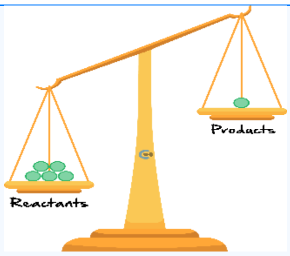
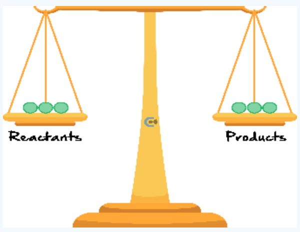
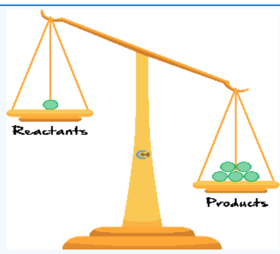
- It looks like so:



- Imagine reactant was going from reactants → products.
- **Equilibrium was:** [Undershot] / [Overshot]
- **To Re-establish Equilibrium:** [Reactants → Products] / [Products → Reactants]
- **Type of Reaction Favoured:** [Forwards] / [Reverse] reaction

Definition

<u>Comparing Q_c and K_c Values</u>

$Q_c < K_c$	$Q_c = K_c$	$Q_c > K_c$
[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
		

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Let's look at a question together!

Question 26 Walkthrough.

An equilibrium system has the following equation at 30°C in a 5.00 L reaction vessel.

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

There is 3.00 mol of hydrogen gas, 2.20 mol of iodine gas and 1.85 mol of hydrogen iodide present at a certain point in time. The equilibrium constant is known to be 0.80 at this temperature.

Determine which direction the equilibrium system will shift to re-establish equilibrium.

TIP: Whenever the question asks to figure out which direction the system will shift to re-establish equilibrium, you should always try to find the reaction quotient (Q_c) value!

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Your Turn!

Question 27

A reaction has a Q_c value lower than its K_c value. What can be inferred about the system?

A. The system has not yet reached equilibrium and the forward reaction is favoured.

B. The system is at equilibrium.

C. The reverse reaction is favoured to reach equilibrium.

D. The system is beyond equilibrium, favouring the reverse reaction.

Question 28

The following equation is provided for a particular equilibrium system:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

The following concentrations are given at a particular temperature.

$$[CO(g)] = [H_2O(g)] = 1.0\ M$$

$$[CO_2(g)] = [H_2(g)] = 15\ M$$

The equilibrium constant value is known to be K = 10.0, which side of the reaction will be favoured as the system tries to reach equilibrium?

____

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Question 29

For the below, equilibrium reaction the concentrations at a certain point are $[CO] = 0.12\ M, [H_2] = 0.4\ M$, and $[CH_3OH] = 1.5\ M$.

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

If K_c is $78.1\ M^{-2}$, determine which of the following is true.

A. The forwards reaction is favoured.

B. The backwards reaction is favoured.

C. No reaction takes place, as the system is already at equilibrium.

D. None of the above.

Question 30 Additional Question.

Given the reaction with $K_c = 50$:

$$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$$

At a certain moment, the concentrations are $[H_2] = 0.2\ M, [Cl_2] = 0.3\ M$, and $[HCl] = 0.4\ M$. In which direction will the reaction proceed?

____

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REMINDER: Don't forget Even if the system is at equilibrium, a reaction is always occurring, it's just that both the forwards and backwards reaction are occurring at the same rate!

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Section F: RICE Tables

Sub-Section: RICE Tables

Context

- Sometimes, amounts of substances are provided **before equilibrium is reached**, and when it **reaches equilibrium**!

Let's look at an example together!

Exploration: RICE Table Scenario

- Consider the following reaction:

$$A + 2B \rightleftharpoons C$$

- There is $1.0\ mol$ of each of A and B added, to an empty reaction vessel. At equilibrium, there is $0.40\ mol$ of C.
- Direction of system shift: [forwards] / [backwards] / [no direction]
- Is there $1.0\ mol$ of A present at equilibrium? [Yes] / [No]
- Can we plug in all the current values into the K_c expression like usual? [Yes] / [No]

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To find the equilibrium constant, we must use a RICE table!

RICE Table

- **Use**: Where the concentration of all species is not known at equilibrium.
- **Stands for:**
  - ____________________
  - ____________________
  - ____________________
  - ____________________
- **Good idea to add a fifth row**: ____________________.
  - **Reasoning**: K_c value uses concentration and not the moles.
- **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.

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Let's try some questions together!

Question 31 Walkthrough.

0.050 mol of nitrogen gas and 0.590 mol of hydrogen gas are added to an evacuated 4.00 L reaction vessel.

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

At equilibrium, there is 0.030 mol of ammonia gas present. Calculate the K_c value for this reaction.

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Question 32 Walkthrough.

For the following equilibrium, 3.70 mol of methane, and 6.00 mol of hydrogen sulphide are added to an evacuated 3.00 L.

$$CH_4(g) + 2H_2S\,(g) \rightleftharpoons CS_2(g) + 4H_2(g)$$

At equilibrium, there are 2.10 mol of CS_2 present. Find the value of the equilibrium constant.

TIPS:

- When drawing a RICE table, use each line as a row! The RICE table is majority of your working out, so use majority of the space!
- **Include the coefficients** of the equation in the reaction row!

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Recall!

Active Recall: What are the steps of using a RICE Table?

1. Fill out ____________________.

2. Find __________ (use stoichiometric ratios & +/– signs.).

3. Find __________.

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Your Turn!

Question 33

An equilibrium is established between dinitrogen tetraoxide, $N_2O_4(g)$, and nitrogen dioxide, $NO_2(g)$, at a specified temperature according to the following equation:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

a. Write the expression for the equilibrium constant.

____

____

b. 0.540 *mol* of $N_2O_4(g)$ was placed in an initially empty 2.00 *L* vessel. When equilibrium was achieved, 0.280 *mol* of $NO_2(g)$ was present. Calculate the value of the equilibrium constant.

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Question 34

At a particular temperature, 12.0 moles of SO_3 is placed into a 3.0 L evacuated rigid container and the SO_3 dissociates by the reaction:

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

At equilibrium, 9.0 moles of SO_2 is present. Calculate the K_c value for this reaction.

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Question 35 Additional Question.

When 0.40 moles of PCl_5 is initially heated in an evacuated 10.0 L container, an equilibrium is established in which 0.25 moles of Cl_2 is present.

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$$

What is the K_c value of the expression?

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Contour Check

☐ **Learning Objective**: [2.7.1] Write equilibrium constant expression & find its value (including units)

Study Design

"Calculations involving equilibrium expressions (including units) for a closed homogeneous equilibrium system and the dependence of the equilibrium constant (K) value on the system temperature and the equation used to represent the reaction"

Key Takeaways

☐ K_c Expression:

$$\mathbf{aA + bB + \ldots \rightleftharpoons cC + dD + \ldots}$$

$$K_c =$$

☐ **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.

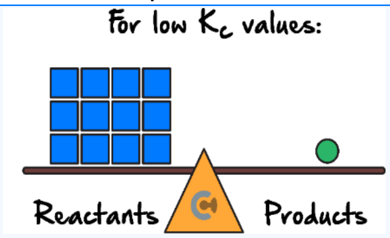
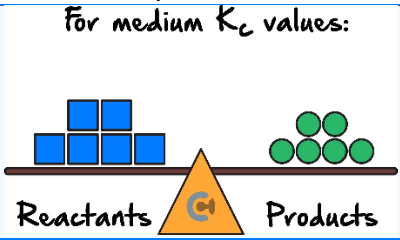
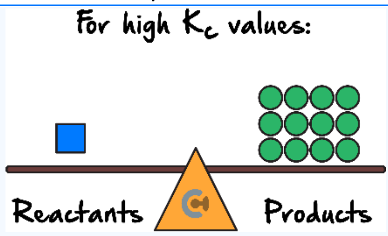
☐ Calculate units by substituting in ____________.

☐ Learning Objective: [2.7.2] Identify the extent of reaction

Study Design

"The distinction between reversible and irreversible reactions, and between rate and extent of a reaction"

Key Takeaways

$K_c < 10^{-4}$	$10^{-4} < K_c < 10^4$	$K_c > 10^4$
[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

Key Takeaways

- ☐ 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 direction of equilibrium shift

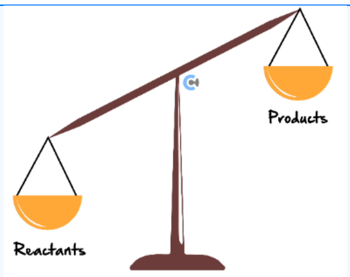
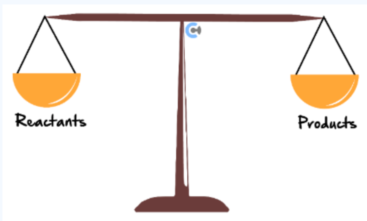
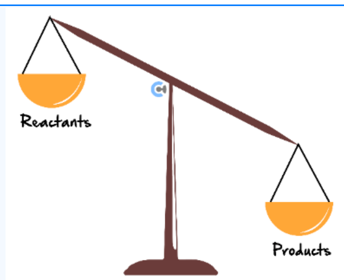
Study Design

"The reaction quotient (Q) as a quantitative measure of the extent of a chemical reaction: that is, the relative amounts of products and reactants present during a reaction at a given point in time"

Key Takeaways

Equilibrium Constant (K_c)	Reaction Quotient (Q_c)
$K_c = \frac{[\text{C}]^c \times [\text{D}]^d \times \ldots}{[\text{A}]^a \times [\text{B}]^b \times \ldots}$	$Q_c = \frac{[\text{C}]^c \times [\text{D}]^d \times \ldots}{[\text{A}]^a \times [\text{B}]^b \times \ldots}$
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

Study Design

"Calculations involving equilibrium expressions (including units) for a closed homogeneous equilibrium system and the dependence of the equilibrium constant (K) value on the system temperature and the equation used to represent the reaction"

Key Takeaways

- **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 __________.

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