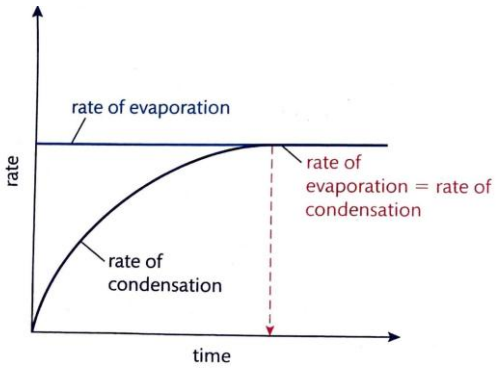
Name: _____ Date: _____ Period: _____

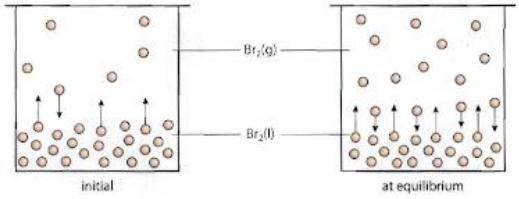
SL Topic 7 Equilibrium - Guided Notes

Slide 3: Equilibrium State

Slide 4: Physical Equilibrium

- This _____ will only occur in a **closed system**
- **Occurs when 2 states of the same substance are in _____**





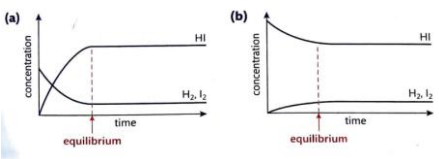
$$Br_2(liquid) \rightleftharpoons Br_2(gas)$$

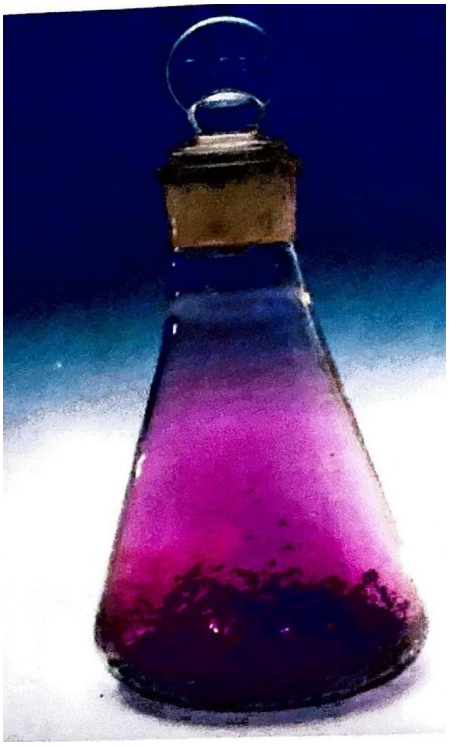
Slide 5: Chemical Equilibrium

- Hydrogen and iodide are both _____, but iodine gas is purple
- **Occurs when a chemical reaction is in the _____ state**
- A **dynamic equilibrium** is reached when the _____ of reactants and products is **constant**.
- *Note: the _____ of reactants and products do not have to be the same at equilibrium

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

colourless gas colourless gas purple gas





Slide 6: Reversible vs. Non-reversible reactions

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

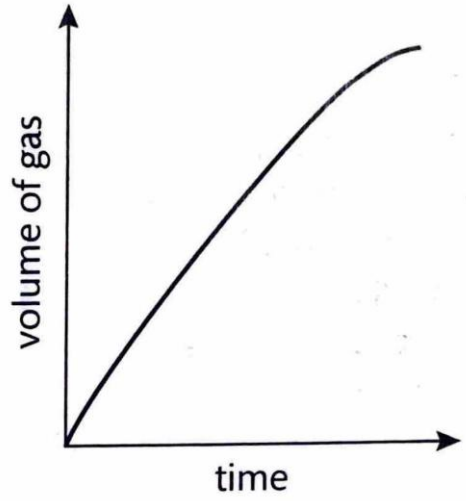
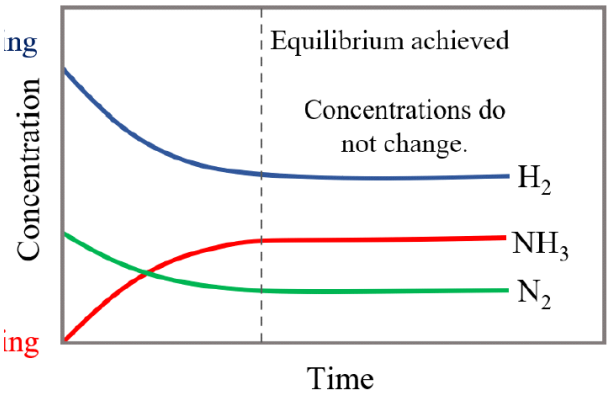


Figure 6.7 Volume of gas against time.

$$N_{2(g)} + 3\,H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$


ng
Concentration
ing
Equilibrium achieved
Concentrations do not change.
H_2
NH_3
N_2
Time

Slide 8: Summary of the Equilibrium State

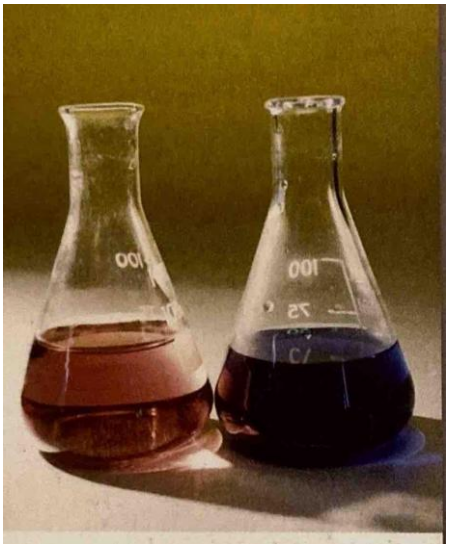
	Feature of equilibrium state	Explanation
1	Equilibrium is dynamic	The reaction has not stopped but both forward and backward reactions are still occurring at the same rate.
2	Equilibrium is achieved in a closed system	A closed system has no exchange of matter with the surroundings, so equilibrium is achieved where both reactants and products can react and recombine with each other.
3	The concentrations of reactants and products remain constant at equilibrium	They are being produced and destroyed at an equal rate.
4	At equilibrium there is no change in macroscopic properties	Macroscopic properties are observable properties such as colour and density. These do not change as they depend on the concentrations of the components of the mixture.
5	Equilibrium can be reached from either direction	The same equilibrium mixture will result under the same conditions, no matter whether the reaction is started with all reactants, all products, or a mixture of both.

Slide 9: Le Chatelier's Principle

- Whatever is done to a system at ____________, the system will respond in the opposite way.
- After a period of time, a new ____________ will be established.
- New equilibrium ____________ will be different from starting equilibrium mixture.
- Allows us to predict ____________ effects of changes that occur at equilibrium.
- **A system at ____________ when subjected to a change will respond in such a way to minimize the effect of the change.**

Slide 10: Changes in Concentration

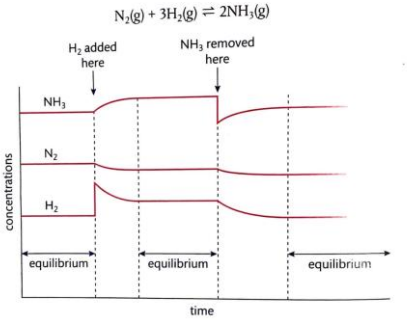
- As $[CoCl_4^{2-}]$ ions increase, color turns blue
- What direction would adding H_2O cause equilibrium to shift?
- What color would the solution turn?
- **Cobalt chloride is often used to test for the presence of water in industrial applications.**
- **Adding concentration causes equilibrium to shift to remove excess substance. Removing concentration causes equilibrium to shift to add more of the substance.**
- **$[Co(H_2O)_6]^{2+}$**
- **$CoCl_4^{2-}$**



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

Slide 11: Changes in Concentration

- **When H_2 is added:**
- the _____ N_2 and H_2 decrease in a 1:3 ratio
- the _____ of NH_3 increases in a 2:1 ratio (relative to N_2).
- _____ shifts to the right
- New equilibrium has a higher _____ of products.
- **When NH_3 is removed:**
- the same _____ occur as when H_2 was added (reaction shifts to the right)
- **In industrial _____, product is removed as it forms to increase the yield of the product.**



Slide 12: Changes in Pressure

- Only apply to gas _____

- There is a direct _____ between the number of gas molecules and pressure exerted by a gas in a fixed volume
- **_____ pressure causes system to attempt to decrease pressure by shifting to the side with the smaller number of molecules.**
- **_____ pressure causes system to shift to side with more molecules.**
- Increasing pressure shifts _____ to the right.
- _____ pressure will increase rate.
- Increasing pressure will not affect _____.
- _____ pressure will increase rate.

Slide 13: Changes in Temperature

- Sign of ΔH indicates if reaction is _____ or exothermic (positive for endothermic, negative for exothermic).
- If _____ is decreased in equilibrium reaction, reaction will shift to produce more heat.
- If _____ is increased in equilibrium reaction, reaction will shift to consume heat.
- **Increasing _____ causes system to attempt to decrease temperature by shifting to endothermic side.**
- **Decreasing _____ causes system to shift to exothermic side.**
- **Heating _____ will cause it to produce more NO_2 (brown)**
- **Cooling reaction will cause it to produce more N_2O_4 (_____)**

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

brown colourless

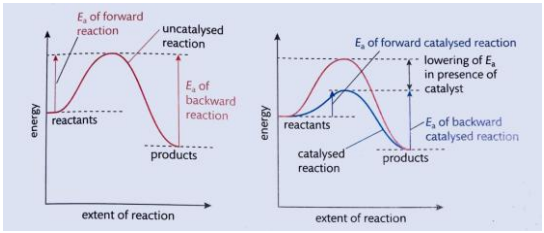
Slide 14: Turn and Talk

- Combustion reactions are generally described as exothermic, but the reaction
- is endothermic. When is it appropriate to refer to an ‘exception to a rule’, and when does the rule need to be reconsidered?

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

Slide 15: Adding a Catalyst

- Catalysts lower the _____ energy of the **forward and reverse reactions**
- Provide alternate reaction pathway with a lower _____ energy
- The rate of forward and reverse _____ increased by the same factor
- Addition of catalyst has **no effect** on position of _____



Slide 16: Summary

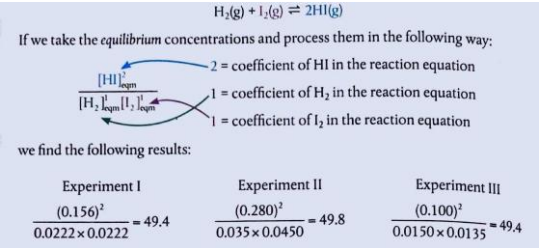
	Effect of ...	Change in position of equilib
1	concentration	changes
2	pressure	changes if reaction involves a ch in the number of gas molecules
3	temperature	changes
4	catalyst	no change

Slide 17: Equilibrium Constant (Kc)

- **A constant that expresses the _____ between reactants and products at equilibrium**
- $K_c =$
- $[C]^c[D]^d$
- $[A]^a[B]^b$
- ***Helpful hints:**
- The _____ of products are in the numerator and the reactants are in the denominator
- Each concentration is raised to the power of its _____ coefficient
- When there is more than one reactant or product the terms are _____
- K_c is a fixed value at **a specified _____**
- **_____ Constant Expression:**
- $aA + bB \quad cC + dD$
- ⇂↿
- These are **equilibrium _____**
- The equilibrium expression is a _____ quality known as 'activity' so has no units

Slide 18: Example of Equilibrium Constant

- *Note: The equilibrium concentrations **do not affect** the equilibrium constant



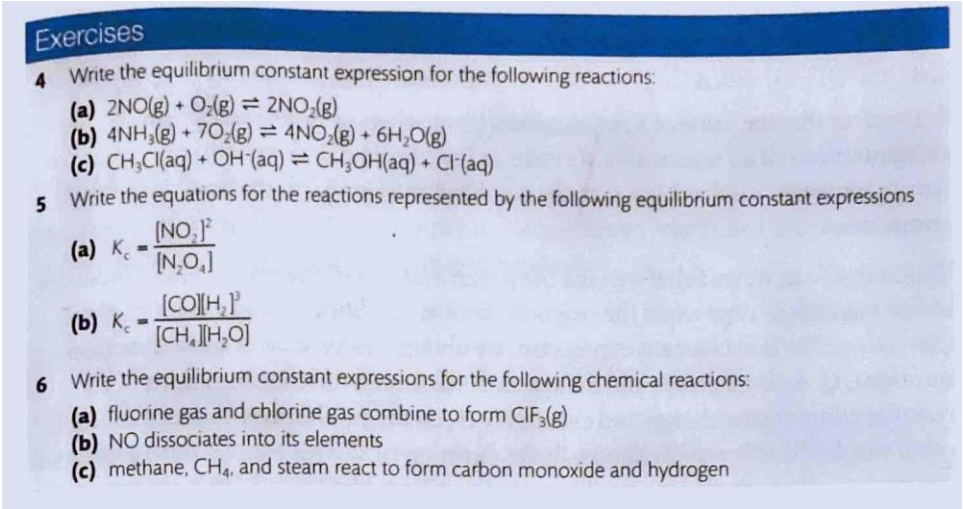
Slide 19: You Try!

Write the equilibrium expression for the following reactions.

(i) $2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$

(ii) $Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}$

Slide 20: Let's Practice!



Exercises

4 Write the equilibrium constant expression for the following reactions:

(a) $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

(b) $4NH_3(g) + 7O_2(g) \rightleftharpoons 4NO_2(g) + 6H_2O(g)$

(c) $CH_3Cl(aq) + OH^-(aq) \rightleftharpoons CH_3OH(aq) + Cl^-(aq)$

5 Write the equations for the reactions represented by the following equilibrium constant expressions

(a) $K_c = \frac{[NO_2]^2}{[N_2O_4]}$

(b) $K_c = \frac{[CO][H_2]^3}{[CH_4][H_2O]}$

6 Write the equilibrium constant expressions for the following chemical reactions:

(a) fluorine gas and chlorine gas combine to form $ClF_3(g)$

(b) NO dissociates into its elements

(c) methane, CH_4, and steam react to form carbon monoxide and hydrogen

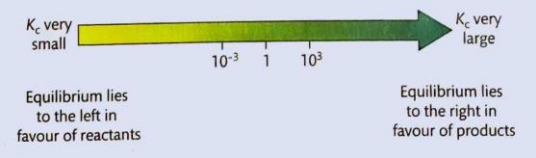
Slide 21: How does Le Chatelier's Principle Affect Kc?

- Increasing the temperature increases the value of K_c for an endothermic reaction and decreases the value of K_c for an exothermic reaction.
- This is because changing temperature differentially changes the **rate** of the forward and reverse reactions (remember they have **different activation energies**).

Effect of ...	Change in position of equilibrium	Change in value of K_c
1 concentration	changes	no change
2 pressure	changes if reaction involves a change in the number of gas molecules	no change
3 temperature	changes	changes
4 catalyst	no change	no change

Slide 22: Kc tells the extent of the reaction

- A high value of Kc indicates _____ more products than reactants.
- _____ lies to the right
- A low value of Kc indicates _____ less products than reactants.
- _____ lies to the left
- _____ the differing **extents** of these reactions
- $K_c >> 1$
- $K_c << 1$



Slide 23: Turn and Talk

- These K_c values were measured at 550K
- What do these K_c values indicate about the extent of these reactions?
- Why do you think these halogens have such different values for their equilibrium constants at the same temperature?

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$	$K_c = 2$
$H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$	$K_c = 10^{10}$
$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$	$K_c = 10^{18}$

Slide 24: The Reaction Quotient (Q)

- If $\mathbf{Q} = \mathbf{K_c}$, reaction is at _____, no net change occurs
- If $\mathbf{Q} < \mathbf{K_c}$, the _____ proceeds to the right, in favor of products
- If $\mathbf{Q} > \mathbf{K_c}$, the reaction proceeds to the left, in favor of _____
- The _____ of all reaction components change to eventually reach equilibrium.
- The value of *Q* changes in the _____ of K_c
- Allows us to predict the _____ that the reaction will proceed.

- This means there are less products compared to _____
- This means there are more products compared to _____
- **A constant that expresses the _____ between reactants and products at a particular moment in time (NOT equilibrium)**

Slide 25: Example

- $H_2(g) + I_2(g)$ $2HI(g)$
- ⇅
- $K_c = 49.5$
- **$Q < K_c$, reaction proceeds to the right**
- **$Q > K_c$, reaction proceeds to the left**

The equilibrium constant expression = $\frac{[HI]^2}{[H_2][I_2]}$

Experiment I, time t $Q = \frac{(0.100)^2}{(0.0500)(0.0500)} = 4.00$

Experiment II, time t $Q = \frac{(0.300)^2}{(0.0250)(0.0350)} = 103$

	Experiment I: concentration at time t / mol dm^{-3}	Experiment II: concentration at time t / mol dm^{-3}
H_2	0.0500	0.0250
I_2	0.0500	0.0350
HI	0.100	0.300

Slide 26: You Try!

The equilibrium constant K_c for the reaction

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

is 1.7×10^2 at 500 K.

Determine whether the reaction mixture is at equilibrium when the concentrations of the components at this temperature are as follows:

$[N_2] = 1.50$

$[H_2] = 1.00$

$[NH_3] = 8.00.$

If it is not at equilibrium, state and explain in which direction the reaction will proceed.

Slide 27: Relationships Between Kc Values

- $K_c =$
- $[C]^c[D]^d$
- $[A]^a[B]^b$
- $aA + bB \quad cC + dD$
- ⇂
- $cC + dD \quad aA + bB$
- ⇂
- $K_c' =$
- $[A]^a[B]^b$
- $[C]^c[D]^d$
- or $K_c' = K_c^{-1}$
- Reverse Reaction
- _____ of a Reaction
- Doubling the _____ coefficients: $K_c^x = K_c^2$
- Tripling the _____ coefficients: $K_c^x = K_c^3$

Slide 28: Relationships Between Kc Values

- **Effect on _____ Expression**
- **Effect on K_c**

inversing the reaction	inverts the expression	$\frac{1}{K_c}$ or K_c^{-1}
doubling the reaction coefficients	squares the expression	K_c^2
tripling the reaction coefficients	cubes the expression	K_c^3
halving the reaction coefficients	square roots the expression	$\sqrt{K_c}$
adding together two reactions	multiplies the two expressions	$K_c^{\text{i}} \times K_c^{\text{ii}}$

Slide 29: You Try!

Worked example

The equilibrium constant for the reaction

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

is 0.04 at a certain temperature. What would be the value of the equilibrium constant, K_c', for the following reaction at the same temperature?

$$\tfrac{1}{2}H_2(g) + \tfrac{1}{2}I_2(g) \rightleftharpoons HI(g)$$

Slide 30: Homogeneous vs. Heterogeneous Equilibrium

- A system has _____ all in the same phase.
- A system has _____ in different phases.

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

$$H_2O(g) + C(s) \rightleftharpoons CO_2(g) + H_2(g)$$

$$2\,HgO(s) \rightleftharpoons 2\,Hg(l) + O_2(g)$$

Slide 31: Equilibrium Theory in Industrial Processes

- Le Chatelier's Principle can be applied to choose _____ that would shift the reaction to the right and increase the yield of the product.
- Rate of the reaction must also be considered since equilibrium _____ would have limited value if a reaction took years to complete.
- Economics of an industrial process depend on _____ and kinetics.
- Haber process (_____ of ammonia)
- Contact process (_____ of sulfuric acid)
- _____ of methanol

Slide 32: N2(g) + 3H2(g) 2NH3(g)

- Haber Process
- **What does this reaction tell us?**
- All reactants and products are gases
- Four gas molecules react to form two gas molecules
- Forward reaction is exothermic, reverse reaction is endothermic
- ΔH = -93 kJ mol^{-1}
- **Application of Le Chatelier's Principle to determine optimal reaction conditions:**
- Concentration of reactants: products in a 1:3 ratio (ammonia is removed as it forms to shift equilibrium to the right)
- Pressure: products have less pressure than reactants, so forward reaction is favored by an increase in pressure (2 x10^7 Pa)
- Temperature: forward reaction is exothermic, so forward reaction favored by low temperature. This will cause the reaction to be too slow, so a **moderate** temperature is used (about 450 °C).
- Catalyst: catalyst of iron, aluminum, and magnesium oxide or ruthenium used to speed up reaction and compensate for the moderate temperature.
- ***Only 10-20% ammonia is made through this reaction, but reactants are recycled to obtain an overall yield of 95%**

Slide 33: The Contact Process

$$2\,SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2\,SO_{3\,(g)}$$

- **Reaction mechanism**
- i. The _____ of sulfur to form sulfur dioxide
- ii. The _____ of sulfur dioxide to sulfur trioxide:
- iii. The _____ of sulfur trioxide with water to produce sulfuric acid.
- Rate-limiting
- ΔH = -196 kJ mol^{-1}

Slide 34: Production of Methanol

- **Methanol Uses:**
- Chemical _____ (used to make other chemicals)
- Use as _____ solvent
- Antifreeze agent
- _____ of biodiesel from fats
- $CO(g) + 2H_2(g)$ $CH_3OH(g)$
- ΔH = -90 kJ mol^{-1}

Slide 35: Turn and Talk

- Scientific research is largely influenced by the social context, which helps to determine funding and set priorities. A good example is Haber's work on ammonia synthesis, which became pressing in Germany in the early years of the 20th century. Scientific discoveries often have significant economic, ethical, and political implications. Some of these may be unintended consequences of the discovery, such as the environmental degradation caused by the excess use of nitrate fertilizers as an outcome of the Haber process.
- Discuss who must take moral responsibility for the application of scientific discoveries, taking into consideration the fact that the full consequences cannot be predicted and often do not become known until much later.