Chemical Equilibrium

17. Chemical Equilibrium

- explain what is meant by a reversible reaction
- explain what is meant by dynamic equilibrium
- explain what is meant by chemical equilibrium
- state the equilibrium law ($K_c$ only)
- write expressions for $K_c$
- state Le Chatelier’s principle
- use Le Chatelier’s principle to predict the effect (if any) on equilibrium position of concentration, pressure, temperature and catalyst
- perform a simple experiment to demonstrate the following equilibrium mixture (to demonstrate the effects of both temperature changes and concentration changes on an equilibrium mixture)
  \[ Fe^{3+} + CNS^- \rightarrow Fe(CNS)^{2+} \]
- discuss the Industrial application of Le Chatelier’s principle in the Contact process and in the Haber process

**Definitions:**

- A **reversible reaction** is one in which both the forward and reverse reactions can occur.
- A **dynamic reaction** is one in which both the forward and reverse reactions occur simultaneously.
- **Chemical equilibrium** is when the rate of the forward reaction is equal to the rate of the reverse reaction.

**Le Chatelier’s Principle:**

- **Le Chatelier’s Principle** states that when a stress is applied to system at equilibrium, the system adjusts to oppose the stress.

In other words, if a stress is applied to a reaction at equilibrium (change temperature, concentration or pressure) the system will form more of the reactants/products to “undo” the change we applied.

**Effects of Le Chatelier’s Principle:**

<table>
<thead>
<tr>
<th>Stress</th>
<th>LHS</th>
<th>RHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>Increase</td>
<td>Favours forward reaction</td>
</tr>
<tr>
<td></td>
<td>Decrease</td>
<td>Favours reverse reaction</td>
</tr>
<tr>
<td>Temperature</td>
<td>Increase</td>
<td>Favours endothermic reaction</td>
</tr>
<tr>
<td></td>
<td>Decrease</td>
<td>Favours exothermic reaction</td>
</tr>
<tr>
<td>Pressure</td>
<td>Increase (N.B. Only applied if ALL reactants and products are gaseous)</td>
<td>Favours side of reaction will the least moles of gas</td>
</tr>
<tr>
<td></td>
<td>Decrease</td>
<td>Favours side of the reaction with the largest number of moles of gas</td>
</tr>
<tr>
<td>Catalyst</td>
<td>No change, as both forward and reverse reactions are sped up equally</td>
<td></td>
</tr>
</tbody>
</table>
Industrial Applications of Le Chatelier’s Principle:

1. The Haber Process (Manufacture of Ammonia, NH₃)

\[ 3\text{H}_2 + \text{N}_2 \rightleftharpoons 2\text{NH}_3 \quad \Delta H = -92.4 \text{ kJ mol}^{-1} \text{ (exothermic in fwd direction)} \]

Ammonia is used to make fertilisers and cleaning agents.

By Le Chatelier’s Principle, the best way to maximise the yield of ammonia is to use
1) High Pressure
2) Low Temperature

The actual conditions used are:
1) 200 atm of pressure (too high could be dangerous)
2) 500°C (even though low temperatures increase yield, they also slow down the rate so it would take too long to produce – 500°C is a compromise between yield and production times.)

2. The Contact Process (Manufacture of Sulphuric Acid, H₂SO₄)

We will focus on one step of this reaction, producing sulphur trioxide, SO₃, from sulphur dioxide, SO₂.

\[ 2\text{SO}_2 + \frac{1}{2}\text{O}_2 \rightleftharpoons \text{2SO}_3 \quad \Delta H = -196 \text{ kJ mol}^{-1} \text{ (exothermic in fwd direction)} \]

By Le Chatelier’s Principle, the best way to maximise the yield of SO₃ is to use
1) High Pressure
2) Low Temperature

The actual conditions used are:
1) 1 atm of pressure (cost of high pressure plant is not worth the increase in yield)
2) 450°C (even though low temperatures increase yield, they also slow down the rate so it would take too long to produce – 450°C is a compromise between yield and production times.)

The Equilibrium Constant (K_c):

K_c is called the equilibrium constant and represents the relationship between the concentrations of the reactant and products of a system at equilibrium.

For the reaction: \( a\text{A} + b\text{B} \rightleftharpoons c\text{C} + d\text{D} \)

the equilibrium constant can be written as:

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

Notes:
1. Square brackets represent concentration in mol/L. They are essential, don’t use round brackets!
2. Coefficients are written as powers.
3. Products are always in the numerator, reactants in the denominator.
4. K_c is unaffected by concentration, pressure or catalyst changes. Temperature changes WILL change K_c.

E.g. Write the equilibrium constant expression for the reaction \( \text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI} \)

Solution:

\[ K_c = \frac{[\text{HI}]^2}{[\text{H}_2]^1[\text{I}_2]^1} \]

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