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EB Education Revision Guide

How to work with Dynamic Equilibrium

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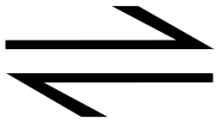
Dynamic Equilibrium

What is a reversible reaction?

Reversible reactions go forwards and backwards, with the reactions happening at the same time. The products can react with each other to produce the original reactants.

"Reactant side" "Product side"



This symbol is used to show that the reaction is going in both directions.

The FORWARD reaction goes to the right.
The BACKWARD reaction goes to the left.

What is equilibrium?

In a closed system (where the reactants and the products cannot escape), reversible reactions will reach equilibrium.

As the reactants (A + B) react, their concentrations will decrease. This means that the forward reaction will slow down.

As more products (C + D) are made, their concentrations increase, and this will cause the backward reaction to speed up.

It will reach a point where the forward reaction is taking place at the same rate as the backward reaction. This is **dynamic equilibrium**.

The concentrations of reactants and products have reached a balance and will not change. Effectively the reaction is over even though it is still happening.

Le Chatelier's Principle

What does it mean?

When a reaction is at equilibrium, it does not mean that the amounts of reactants and products are equal.

The equilibrium could lie to the right. This means the concentration of products is greater than the concentration of reactants.

The equilibrium could lie to the left. This means the concentration of reactants is greater than the concentration of products.

If the equilibrium is in the middle the concentration of reactants and products is equal.

The position of equilibrium depends on the reaction and the conditions. The position of equilibrium of a reversible reaction can be altered by changing the reaction conditions.

The position of equilibrium, and therefore the amounts of reactants and products can be changed by:

- Temperature
- Pressure
- Concentration of reactants or products.

Le Chatelier's principle states that if there is a change in concentration, pressure or temperature in a reversible reaction, the equilibrium position will move to help counteract that change.

This means that if you change the equilibrium position, the reaction will try to compensate for this to bring the equilibrium back to the middle.

Changing temperature

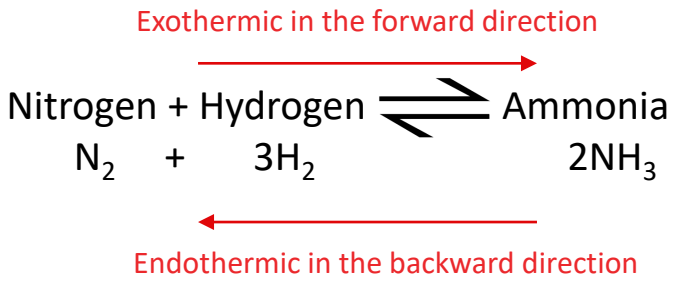
All reversible reactions are exothermic in one direction and endothermic in the other direction.

Exothermic reactions release energy (usually in the form of heat) into the surroundings.

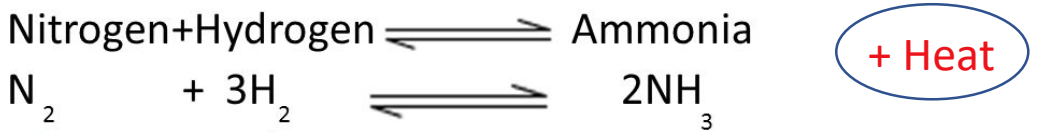
Endothermic reactions take in energy from the surroundings.

When you decrease the temperature in a reaction, the equilibrium will move in the exothermic direction to produce more heat i.e. it will favour the side of the reaction that produces heat.

When you increase the temperature in a reaction, the equilibrium will move in the endothermic direction to absorb the extra heat.

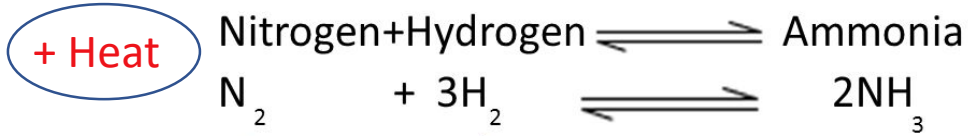


Put in heat



If you increase the temperature the additional heat favours the endothermic reaction, so the equilibrium will shift to the left to remove the extra heat, and you will make less "product", in this case the Ammonia breaks down to make more nitrogen and hydrogen.

Produces heat



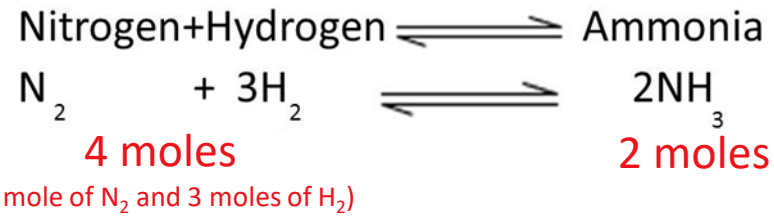
If you decrease the temperature the exothermic side of the reaction will be favoured, so the equilibrium will shift to the right to produce more heat, and you will make more product as this reaction is favoured.

Changing pressure

Changing pressure will only affect equilibria in reactions involving gases.

When you increase the pressure in a reaction, the equilibrium will move towards the side that has fewer moles of gas to reduce the pressure.

When you decrease the pressure in a reaction, the equilibrium will move towards the side that has more moles of gas to increase the pressure.



If you increase the pressure in this reaction, the equilibrium will shift to the right, as there are fewer moles on the right, so you will make more products. The increase in pressure favours the joining of the two reactants to make more product.

If you decrease the pressure, the equilibrium will shift to the left, as there are more moles on the left, so you will make less products. The decrease in pressure favours the breaking down of the product.

Changing concentration

When you increase the concentration of reactants the equilibrium will move to the right to reduce the amount of reactants, and therefore you will make more products.

When you increase the concentration of products the equilibrium will move to the left to reduce the amount of products, and therefore you will make more reactants.

Nitrogen + Hydrogen $\rightleftharpoons$ Ammonia

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

If you increase the concentration of N_2 or H_2 in this reaction, the equilibrium will shift to the right, to use up the extra reactants, so more of these will cause more Ammonia to be made.

If you decrease the concentration of N_2 or H_2, the equilibrium will shift to the left, to increase the concentration of reactants i.e. the Ammonia breaks down as there is more of it to make more reactants.

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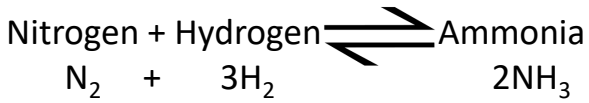
Your turn:

1. Nitrogen and hydrogen react in the Haber Process to form ammonia. This reaction can reach a dynamic equilibrium.



a) What is meant by dynamic equilibrium?

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b) The reaction is exothermic in the forward direction. It is carried out at a temperature of 450°C. How does using a lower temperature affect the equilibrium yield of ammonia?

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c) The reaction is carried out at pressures of 250 atmospheres. How would increasing the pressure in the reaction affect the equilibrium yield of ammonia.

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Your turn:

2. Sulphur dioxide and oxygen can react together to produce sulphur trioxide. This reaction can reach a dynamic equilibrium, and takes place at 1-2 atm pressure.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

a) Explain the effect on the rate of attainment of equilibrium if the process is carried out at a pressure higher than 1-2 atm.

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b) Explain the effect on the equilibrium yield of sulphur trioxide if the process is carried out at a pressure higher than 1 – 2 atm.

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3. The reaction between nitrogen and hydrogen is exothermic. Some ammonia would be formed if nitrogen and hydrogen were reacted together at 150 atm pressure and 300°C, without a catalyst.

$$\text{Nitrogen} + \text{Hydrogen} \rightleftharpoons \text{Ammonia}$$
$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The Haber process takes place at a pressure of 150 atm and a temperature of 450°C, with an iron catalyst.
Explain why the conditions in the Haber process are better for the manufacture of ammonia than the first set of conditions. (6)

Your turn:

4. Chlorine and iodine react together to form iodine monochloride, ICl

a) Write a chemical equation for the reaction.

b) Iodine monochloride reacts reversibly with chlorine to form iodine trichloride.

$$\underset{\text{dark brown}}{ICl} + Cl_2 \rightleftharpoons \underset{\text{yellow}}{ICl_3}$$

In a reaction that is in dynamic equilibrium, the forward and backward reactions occur simultaneously.
Name two other features of a reaction that is in dynamic equilibrium.

1)……
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2)……
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c) The equilibrium mixture becomes darker in colour when it is heated. Use this information to explain whether the backward reaction is exothermic or endothermic.

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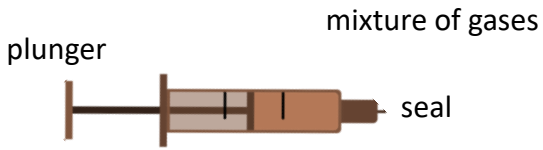
Your turn:

5. Nitrogen dioxide (NO_2) and dinitrogen tetraoxide (N_2O_4) are in equilibrium

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

a) A gas syringe contains a sample of an equilibrium mixture of these two gases. It is brown in colour



The plunger is pulled out to reduce the pressure of the gaseous mixture. When equilibrium is reached the mixture is darker in colour.
Explain why this happens.

b) The sealed tube containing an equilibrium mixture of NO_2 and N_2O_4 which has been kept at room temperature is placed into water at 0°C. The colour changes from brown to pale yellow.

i) Using this information explain whether the forward reaction is exothermic of endothermic.

ii) A bond is formed between the two nitrogen dioxide molecules in the forward reaction.

$$NO_2 + NO_2 \longrightarrow O_2N\text{-}NO_2$$

Explain whether this information supports your answer to bi)

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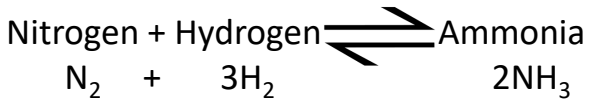
Answers:

1. Nitrogen and hydrogen react in the Haber Process to form ammonia. This reaction can reach a dynamic equilibrium.



a) What is meant by dynamic equilibrium?

Forward and backward reactions take place at the same time

Rate of the forward and backward reactions is the same

No overall change in the amount of reactants and products

b) The reaction is exothermic in the forward direction. It is carried out at a temperature of 450°C. How does using a lower temperature affect the equilibrium yield of ammonia?

Decreasing the temperature will shift the reaction to the left because the forward reaction is exothermic

This will increase the yield of ammonia

c) The reaction is carried out at pressures of 250 atmospheres. How would increasing the pressure in the reaction affect the equilibrium yield of ammonia.

Higher pressure favours the forward reaction/shifts to the right because there are fewer moles on the right

Therefore the yield of ammonia will increase

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TOP TIP:
Be careful with questions like this. If the question is asking about RATE of attainment of equilibrium, the answer should relate to collision theory and rates of reaction, not about Le Chatelier's principle.

Answers:

2. Sulphur dioxide and oxygen can react together to produce sulphur trioxide. This reaction can reach a dynamic equilibrium, and takes place at 1-2 atm pressure.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

a) Explain the effect on the rate of attainment of equilibrium if the process is carried out at a pressure higher than 1-2 atm.

The rate of attainment of equilibrium will increase because when the pressure is increased, the gas molecules are closer together. This means collisions will be more frequent

b) Explain the effect on the equilibrium yield of sulphur trioxide if the process is carried out at a pressure higher than 1 – 2 atm.

The equilibrium yield will increase because an increase in pressure will favour the forwards reaction, because there are fewer moles on the right.

3. The reaction between nitrogen and hydrogen is exothermic. Some ammonia would be formed if nitrogen and hydrogen were reacted together at 150 atm pressure and 300°C, without a catalyst.

$$\text{Nitrogen} + \text{Hydrogen} \rightleftharpoons \text{Ammonia}$$
$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The Haber process takes place at a pressure of 150 atm and a temperature of 450°C, with an iron catalyst.
Explain why the conditions in the Haber process are better for the manufacture of ammonia than the first set of conditions. (6)

At higher temperatures:

- Reaction reaches equilibrium faster because molecules move faster
- There are more frequent collisions because molecules have more energy
- However yield of ammonia will be lower because higher temperatures favour the endothermic reaction so equilibrium shifts to the left
- The catalyst causes the reaction to reach equilibrium faster as it increases the rate of both forward and backward reactions by lowering the activation energy
- The catalyst does not affect yield, and the equilibrium position is not affected

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Answers:

4. Chlorine and iodine react together to form iodine monochloride, ICl

a) Write a chemical equation for the reaction.

$I_2 + Cl_2 \quad 2\ ICl$

b) Iodine monochloride reacts reversibly with chlorine to form iodine trichloride.

$$\underset{\text{dark brown}}{ICl} + Cl_2 \rightleftharpoons \underset{\text{yellow}}{ICl_3}$$

In a reaction that is in dynamic equilibrium, the forward and backward reactions occur simultaneously.
Name two other features of a reaction that is in dynamic equilibrium.

1) Rate of forward reaction = rate of backward reaction

2) Concentration of reactants/products remains constant

c) The equilibrium mixture becomes darker in colour when it is heated. Use this information to explain whether the backward reaction is exothermic or endothermic.

Equilibrium has shifted to the left, more dark brown ICl has been produced

An increase in temperature shifts the reaction in the endothermic direction, therefore the backward reaction is endothermic

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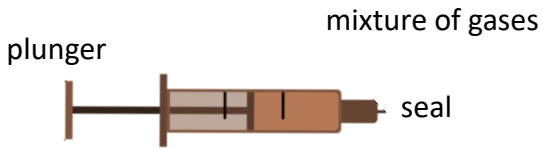
Answers:

5. Nitrogen dioxide (NO_2) and dinitrogen tetraoxide (N_2O_4) are in equilibrium

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

a) A gas syringe contains a sample of an equilibrium mixture of these two gases. It is brown in colour



The plunger is pulled out to reduce the pressure of the gaseous mixture. When equilibrium is reached the mixture is darker in colour.
Explain why this happens.

It goes darker because more NO_2 is formed
Reducing the pressure will shift the equilibrium to the left, as there are more moles of gas on the left

b) The sealed tube containing an equilibrium mixture of NO_2 and N_2O_4 which has been kept at room temperature is placed into water at 0°C. The colour changes from brown to pale yellow.

i) Using this information explain whether the forward reaction is exothermic or endothermic.

The forward reaction is exothermic, as the equilibrium has shifted to the right (more N_2O_4 formed)
A decrease in temperature shifts the equilibrium in the exothermic direction

ii) A bond is formed between the two nitrogen dioxide molecules in the forward reaction.

$$NO_2 + NO_2 \longrightarrow O_2N\text{-}NO_2$$

Explain whether this information supports your answer to bi)

Yes – because forming bonds is exothermic

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