11.4 During a research experiment, 1 mol of $O_2(g)$ is initially added to 1 mol of $N_2(g)$ in a 2 dm^3 closed container at 300 K. It is found that the concentration of the NO(g) present in the container at equilibrium, is 0,1 $mol \cdot dm^{-3}$. Calculate the equilibrium constant (K_c) for the reaction at this temperature.

11.5 How will the amount of NO(g) at equilibrium be influenced if:

11.5.1 the pressure is increased by decreasing the volume;

11.5.2 a catalyst is added?

2.8 Dynamic chemical equilibrium system

There are three factors that influence a dynamic chemical equilibrium system:

- The concentration (c) of the reactants and products
- The temperature (T) of the reaction system
- The pressure (p) (with gases) on the reaction system

At equilibrium, the forward and the reverse reactions occur at the same rate. Should the temperature of the reaction mixture, the concentration of one of the reactants or products or the pressure on a gas system change, the system will no longer be isolated or in equilibrium. Either the forward or the reverse rate of reaction will increase because of this change. This reaction is therefore favoured and the equilibrium is disturbed.

In industry, the yield of products can be manipulated by changes in the temperature, concentration and pressure of the reaction system.

2.8.1 Le Chatelier's principle

Le Chatelier's principle:
If the equilibrium in a closed system is disturbed by changing one of the equilibrium conditions (temperature, concentration or pressure), the system will react by counteracting the change to form a new equilibrium.

It is important to keep the following facts in mind:

- According to Boyle's law the pressure of an enclosed gas sample is inversely proportional to the volume of the container, if the temperature remains constant.
  $p \propto {}^{1}/_{V}$ at constant T
  Therefore, an increase in the volume of an enclosed gas sample causes a decrease of pressure in the container. A decrease in the volume of an enclosed gas sample causes an increase of pressure in the container at constant temperature.
- Gases exert pressure due to the collisions between gas particles. The more gas particles there are in an enclosed gas sample, the more collisions occur and the greater the pressure in the container.
- Therefore, the pressure of gas is directly proportional to the quantity (mol) of the gas ($p(g) \propto n(g)$).

Quick facts

The value of the enthalpy (ΔH) determines whether the forward reaction is exothermic or endothermic. To determine which reaction is favoured during a change in temperature, you must use Le Chatelier's principle.

- K_C value only changes if there is a change in temperature.
- If the forward reaction is favoured, K_C value will increase.
- If the reverse reaction is favoured, K_C value will decrease.
- A change in concentration or in pressure will not change K_C value.
- Remember that solids (s) and liquids (ℓ) do not influence states of equilibrium.
- For a given reversible reaction with $\Delta H < 0$, the forward reaction is exothermic and the reverse reaction is endothermic.
- For a given reversible reaction with $\Delta H > 0$, the forward reaction is endothermic and the reverse reaction is exothermic.

In order to use Le Chatelier's principle to predict what effect a change will have on the equilibrium, these questions need to be posed:

1. What is disturbing the equilibrium?
2. How will the system counteract this disturbance?
3. Which reaction will be favoured?
4. What changes will occur in the concentrations of reactants and products?
5. What is the effect on the equilibrium constant, K_C?

The influence of a change in the equilibrium factors on a state of dynamic chemical equilibrium.

Factor	Disturbance/change	Influence on equilibrium
1. Concentration	Increase concentration of reactants.	Forward reaction is favoured.
	Increase concentration of products.	Reverse reaction is favoured.
	Decrease concentration of reactants.	Reverse reaction is favoured.
	Decrease concentration of products.	Forward reaction is favoured.

Factor	Disturbance/change	Influence on equilibrium
2. Temperature	Temperature raised.	Rate of both reactions increases, but the endothermic reaction is favoured.
	Temperature lowered.	Rate of both reactions decreases, but the exothermic reaction is favoured.
3. Pressure	Pressure increased.	Reaction which produces the lowest number of moles of gas, is favoured.
	Pressure decreased.	Reaction which produces the lowest number of moles of gas, is favoured.

Quick facts

Pressure changes will only affect the equilibrium if there are product and/or reactant particles in the gaseous state.

Examples

Study the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H < 0$$

Start by counting the quantity of mol of gas molecules on each side of the equation:

$$3 \text{ mol (g)} \rightleftharpoons 2 \text{ mol (g)}$$

Now determine which reaction is exothermic and which reaction is endothermic.

$\Delta H < 0$, therefore the forward reaction is exothermic and the reverse reaction is endothermic.

- The concentration of the reactants ($[SO_2]$ or $[O_2]$) increases. How does this influence the equilibrium system?

1.	What is disturbing the equilibrium?	Increased [reactants].
2.	How will the system counteract this disturbance?	The system will try to lower the [reactants] by using them up.
3.	Which reaction is favoured?	The forward reaction is favoured.
4.	What will happen to the concentrations of the reactants and products?	[reactants] decreases; [products] increases.
5.	What is the effect on the equilibrium constant, K_C?	K_C value remains constant. Only ΔT changes K_C value.

- The concentration of reactants (therefore $[SO_2]$ or $[O_2]$) decrease. How does this influence the equilibrium system?

1.	What is disturbing the equilibrium?	Decreased [reactants].
2.	How will the system counteract this disturbance?	The system will try to increase the [reactants] by causing the products to react and form reactants.
3.	Which reaction is favoured?	The reverse reaction is favoured.
4.	What will happen to the concentrations of the reactants and products?	[reactants] increases; [products] decreases.
5.	What is the effect on the equilibrium constant, K_C?	K_C value remains constant. Only ΔT changes K_C value.

- The temperature is decreased.
  This is a forward, exothermic reaction, as ΔH is negative.

1.	What is disturbing the equilibrium?	The decreased temperature.
2.	How will the system counteract this disturbance?	The system will try to increase the temperature.
3.	Which reaction is favoured?	The exothermic (forward) reaction is favoured.
4.	What will happen to the concentrations of the reactants and products?	[reactants] decreases; [products] increases.
5.	What is the effect on the equilibrium constant, K_C?	Since the forward reaction is favoured, $[SO_3]$ increases and $[SO_2]$ and $[O_2]$ decrease. Therefore, K_C value will increase.

- The pressure is lowered.

1.	What is disturbing the equilibrium?	The decreased pressure.
2.	How will the system counteract this disturbance?	The system will try to increase the pressure.
3.	Which reaction is favoured?	The system will favour the reaction that produces the most moles of gas, because more molecules can exert more collisions ∴ the reverse reaction is favoured.
4.	What will happen to the concentrations of the reactants and products?	[reactants] increases; [products] decreases.
5.	What is the effect on the equilibrium constant, K_C?	K_C value remains constant. Only ΔT changes K_C value.