Stage 2 Chemistry

**Monitoring the Environment:** Equilibrium and Yield

**Science Understanding**

* Chemical systems may be open or closed.
* Over time, reversible chemical reactions carried out in a closed system at fixed temperature eventually reach a state of chemical equilibrium.
* The changes in concentrations of reactants and products, as a system reaches equilibrium, can be represented graphically.
  + Draw and interpret graphs representing changes in concentrations of reactants and products.
* The position of equilibrium in a chemical system at a given temperature can be indicated by a constant, Kc, related to the concentrations of reactants and products.
  + Write Kc expressions that correspond to given reaction equations for homogeneous equilibrium systems.
  + Undertake calculations involving Kc and initial and/or equilibrium quantities of reactants and products for homogeneous equilibrium systems.
* The final equilibrium concentrations, and hence position of equilibrium, for a given reaction depend on various factors.
  + Predict and explain, using Le Châtelier’s principle, the effect on the equilibrium position of a system of a change in the:
    - concentration of a reactant or product
    - overall pressure of a gaseous mixture
    - temperature of an equilibrium mixture for which the ΔH value for the forward or back reaction is specified.
* Predict the change that occurred in a system, or whether a reaction is exothermic or endothermic, given the effect of the change on the equilibrium position of the system.

**Chemical Equilibrium**

Most chemical reactions are reversible. Reversible reactions occur when both the forward and back reaction are possible.

Reactants ⇌ Products

If a reversible chemical reaction is carried out

* In a closed system (no loss or gain of products or reactants to the surroundings)
* At a constant temperature

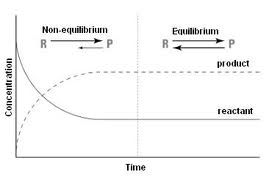
*(note that a closed system is not necessarily a constant temperature, heat may enter or leave)*

The concentration of reactants and products will eventually reach constant values. The system has then said to have reached \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

All observable properties are then constant, such as concentration, colour, pressure and pH.

**Note that concentrations are not necessarily *equal*, just constant.**

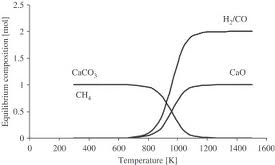
Equilibriums can be represented using a concentration vs time graph

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* The equilibrium is reached once \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* The mole ratio of this reaction is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Concentrations of products and reactants do not have to cross over

Rate vs Time

* ****Prior to equilibrium the rate of forward reaction exceeds the rate of backwards reaction
* Reaction does not stop, forward and backward reactions are occurring at the same rate

****The following figure represents a real equation where mole ratio for part of the reaction is 2:1. The change in the curves is proportional to the mole ratio

Write a balanced equation for this reaction:

**The equilibrium constant, Kc**

The equilibrium constant can be used to give an indication of the yield of products relative to the quantities of reactants.

Eg the reaction of reactants A and B forming products C and D. Lower case numbers represent the mole ratio.

aA + bB ⇌ cC + dD

When at equilibrium

* [A] represents the molar concentration (mol L-1) of A
* Kc is the equilibrium constant and has no units

Eg H2 + I2 ⇌ 2HI

Kc =

Kc >1 represents

* A higher yield of products
* Reaction has proceeded towards the products

Kc <1 represents

* A lower yield of products
* Reaction has proceeded towards the products to a small extent at equilibrium

**Example Questions**

1. calculate the Kc for the following equation

2SO2 + O2 ⇌ 2SO3

[O2] = 0.0180 mol L-1 [SO2] = 0.0250 mol L-1 [SO3] = 0.0320 mol L-1

Kc = \_\_\_\_\_\_\_\_\_\_\_\_

1. Calculate the initial concentration of the reactants given that there was no SO3 initially

|  |  |  |  |
| --- | --- | --- | --- |
|  | O2 | SO2 | SO3 |
| Mole Ratio |  |  |  |
| Initial concentration (mol L-1) |  |  |  |
| Change in concentration (mol L-1) |  |  |  |
| Equilibrium concentration (mol L-1) |  |  |  |

1. In another experiment carried out in the same conditions, the Kc was found to be 5.
   1. Has this reaction reached equilibrium? How can you tell?
   2. Were there a greater proportion of reactants or products in this second reaction mixture?

**SUPPORTING QUESTIONS**

1. 3 characteristics of a system at equilibrium are:
2. Balance and write Kc expressions for the following equilibria
   1. NH3 ⇌ N2 + H2
   2. NO2 ⇌ NO + O2
   3. Ca(OH)2 ⇌ Ca2+ + OH-
3. Hydrogen gas reacts with bromine gas to form hydrogen bromide
4. Calculate Kc values for the reaction

H2 + Br2 ⇌ 2HBr

Where [H2] = 0.02 mol L-1, [Br2] = 0.03 mol L-1, [HBr] = 0.02 mol L-1

1. Calculate the initial concentration of the reactants given that there was no HBr initially
2. In another experiment carried out the same temperature, the equilibrium concentrations of the reactants were 0.03 and 0.01 respectively. Calculate the equilibrium concentration of HBr
3. Sketch a graph of concentration against time for the reaction in question 3
4. Using your answers to question 3a, determine if the following reactions have reached equilibrium
   1. [H2] = 0.1 mol L-1, [Br2] = 0.6 mol L-1, [HBr] = 0.2 mol L-1
   2. [H2] = 0.4 mol L-1, [Br2] = 0.5 mol L-1, [HBr] = 0.7 mol L-1
   3. [H2] = 3.50 mol L-1, [Br2] = 4.20 mol L-1, [HBr] = 3.00 mol L-1
5. The value of the equilibrium constant (Kc) is 0.026. The equilibrium concentration of the two products is 0.15 mol L-1. Use the Kc expression to determine the equilibrium concentration of the reactant.

PCl5(g) ⇌ Cl2(g) + PCl3(g)

**Changing the position of equilibrium**

The extent to which a reaction favours reactants or products can be altered, which is an important consideration in industry.

The equilibrium position can be shifted by:

* Concentration of reactants or products
* Pressure (if reactants or products are gases)
* Temperature

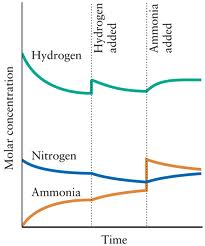
**Le Châtelier’s Principle**

*If a factor affecting the position of the equilibrium is altered, the position of the equilibrium shifts to oppose (counteract) the effect of the change.*

**Effect of Concentration**

Increasing the concentration of a reactant by adding more to the reaction mixture will force the equilibrium towards the products as the reactant is consumed.

Decreasing the concentration of a product by removing it will force the equilibrium towards making more of the product. A common way is with a gaseous product being allowed to bubble off.

****The following is an example of changing the position of the equilibrium reaction H2 + N2 ⇌ NH3

Hydrogen added: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ammonia added \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Note the mole ratio!**

**Effect of Pressure**

When pressure is increased the concentration of all reactants and products is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

When pressure is decreased the concentration of all reactants and products is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

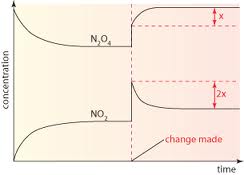
* Pressure changes will only affect a system if at least one reactant or product is a gas.
* If pressure is increased the equilibrium will re-establish itself to reduce the number of molecules.
* Conversely if pressure is decreased the equilibrium will re-establish itself to increase the number of molecules.

If neither side of the equilibrium has a difference of molecules then pressure will have no effect on the equilibrium position. The concentration of both reactants and products will still be changed by the change in volume of the reaction vessel.

The following is an example of changing the pressure for the equilibrium reaction

N2O4(g) ⇌ 2NO2(g)

Note that the left hand side has \_\_\_\_\_ molecule, whereas the right hand side has \_\_\_\_\_\_ molecules.



When pressure is increased:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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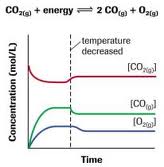
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Effect of temperature**

Reactions will always have a temperature change. If a forwards reaction is exothermic then the reverse reaction will be endothermic by the same amount.

Increasing the temperature will cause the equilibrium to re-establish itself in favour of the endothermic reaction.

Decreasing the temperature will cause the equilibrium to re-establish itself in favour of the exothermic reaction.

\_\_\_\_\_\_\_\_thermic reaction

Temperature is decreased

Equilibrium is re-established to favour the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ reaction

**Effect of catalysts**

A catalyst speeds up both the forwards and backwards reactions; therefore the reaction will **reach equilibrium sooner**, but have **no effect on the** **position** of the equilibrium.

**Question 1**

Gaseous ammonia (NH3) is manufactured commercially via the Haber process, which reacts hydrogen gas together with nitrogen gas, releasing 92.4 kJ of heat per mole.

1. Write a balanced thermochemical equation for the Haber process
2. What effect would increasing the heat have on the rate of reaction?
3. What effect would an increase in heat have on the yield of the reaction?
4. To increase the yield a high pressure is generally used, explain why high pressure will increase the yield of ammonia

The bottom of the reaction vessel is often cooled, this allows a liquid to form and be removed from the reaction.

1. Predict and explain which of the reactants or products would form a liquid
2. Explain the effect on the equilibrium of removing this chemical, and hence on the yield of ammonia

**Question 2**

Predict the changes that were made to the following reaction conditions

1. An exothermic reaction had an increased proportion of products
2. An increased volume of CO was detected in the following reaction (no reactants or products were added or removed). CH4(g) + H2O(g) ⇌ CO(g) + 3H2(g)

**Question 3**

A decrease in the concentration of products was found when the temperature was changed from 30° to 150°. Was the reaction exothermic or endothermic?

**Question 4**

Barium carbonate decomposes to barium oxide and carbon dioxide via an equilibrium reaction.

1. Write an equation for this process
2. Suggest the states of matter for the 3 chemicals
3. This decomposition happens more quickly in an open container, using Le Chateliers principle to explain why this is.