CHEMISTRY 12 – EQUILIBRIUM PROPERTIES & ENTROPY AND ENTHALPY WORKSHEET
CHEMISTRY 12 – EQUILIBRIUM PROPERTIES WORKSHEET

1) Write **six** statements that apply to all chemical equilibrium systems. **(2 marks)**

   System must be closed
   Temperature is constant
   Forward and reverse reaction rates are equal
   Macroscopic properties are constant
   Can be achieved from either direction
   Concentration of reactants and products are constant

2) Why are chemical equilibria referred to as dynamic? **(1 mark)**

   Since the forward and reverse reactions continue to occur; microscopic changes occur

3) How is a chemical system at equilibrium recognized? **(1 mark)**

   Constant macroscopic properties such as colour and temperature

4) Consider the following system:

$$2\ CO_{(g)} + O_{2\,(g)} \rightleftarrows 2\ CO_{2\,(g)}$$

   A container is initially filled with CO_2. How will the [CO] and [CO_2] change as the system reaches equilibrium? **(1 mark)**

   [CO] ↑ & [CO_2] ↓

5) Consider the following:

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

   Initially, NH_3 is added to an empty flask. How do the rates of the forward and reverse reactions change as the system proceeds to equilibrium? **(1 mark)**

   Forward reaction rate ↓ & reverse reaction rate ↑

6) Consider the following equilibrium system:

$$3\ Fe_{(s)} + 4\ H_2O_{(g)} \rightleftarrows Fe_3O_{4\,(s)} + 4\ H_{2\,(g)}$$

   What could be added to Fe_3O_4 to allow the system to reach equilibrium? **(1 mark)**

   In order to reach equilibrium, the system needs to have "one complete side". In order for the products to be complete, **H_2** must be added to Fe_3O_4.

7) Consider the equilibrium:

$$NiO_{(s)} + CO_{(g)} \rightleftarrows Ni_{(s)} + CO_{2\,(g)}$$

The following chemicals are placed in separate 1.0 L containers.

Container I	NiO, Ni
Container II	CO_2, Ni
Container III	NiO, CO, Ni
Container IV	CO, CO_2

In which closed container(s) can equilibrium be established? **(1 mark)**

In order to establish equilibrium, the system must have "one complete side". Container II has both of the products (Ni & CO_2) while container III has both of the reactants (NiO & CO) therefore they are the only containers that will reach equilibrium. Containers I and IV are both missing either a reactant or a product and therefore do not have a "complete side" and will not establish an equilibrium.

8) Consider the following reaction:

$$2\,ICl_{(g)} \rightleftarrows I_{2\,(g)} + Cl_{2\,(g)}$$

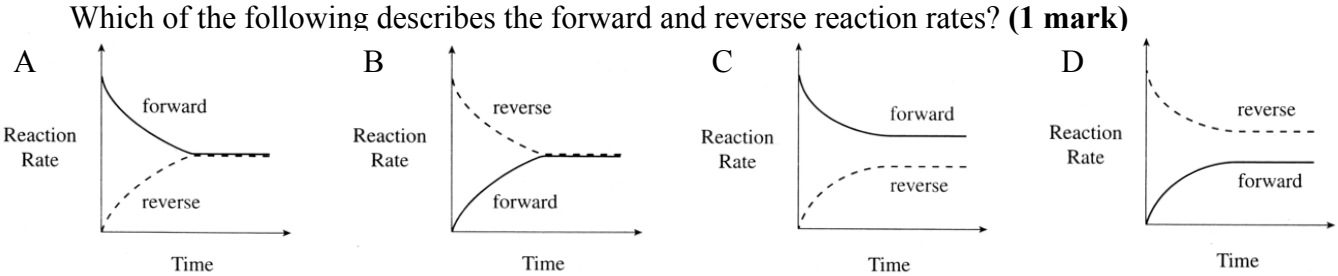
A closed container is initially filled with ICl. What are the changes in the rate of the forward reaction and $[I_2]$, as the system approaches equilibrium? **(1 mark)**

Forward reaction rate ↓ & $[I_2]$ ↑

9) A student places some $N_2O_{4\,(g)}$ into a closed reaction container and the following equilibrium is established:

$$2\,NO_{2\,(g)} \rightleftarrows N_2O_{4\,(g)}$$

Which of the following describes the forward and reverse reaction rates? **(1 mark)**



Since the reaction is starting with N_2O_4 the reverse reaction rate is extremely fast while the forward reaction rate is not occurring. In order for this reaction to reach equilibrium (forward reaction rate = reverse reaction rate), the reverse reaction rate must ↓ and the forward reaction rate must ↑. This is shown by graph B.

10) Consider the following reaction:

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

Initially, SO_3 is added to an empty flask. How do the rate of the forward reaction and $[SO_3]$ change as the system proceeds to equilibrium? **(1 mark)**

Forward reaction rate ↑; $[SO_3]$ ↓

11) Consider the following system:

$$N_{2\ (g)} + 2\ O_{2\ (g)} \rightleftarrows 2\ NO_{2\ (g)}$$

Equal moles of N_2 and O_2 are added, under certain conditions, to a closed container. How do the rate of the reverse reaction and $[NO_2]$ change as the system proceeds to equilibrium? **(1 mark)**

Reverse reaction rate ↑; $[NO_2]$ ↑

12) NO_2 is being consumed at a rate of 0.031 mol/s in the equilibrium below. How many moles of N_2O_4 are being produced each second? **(1 mark)**

$$2\ NO_{2\ (g)} \rightleftarrows N_2O_{4\ (g)}$$

$$\frac{\text{mol } N_2O_4}{s} = \frac{0.031 \text{ mol } NO_2}{1 s} \times \frac{1 \text{ mol } N_2O_4}{2 \text{ mol } NO_2}$$

$$= 0.016 \text{ mol } N_2O_4/s$$

13) SO_2 and O_2 are placed in a sealed flask where they react to produce SO_3. When equilibrium is achieved, SO_3 is being produced at a rate of 0.0082 mol/s.

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

(a) How many moles of SO_3 are being consumed each second? **(1 mark)**

In a chemical equilibrium, each reactant is being "put back" by the reverse reaction at the same rate that it is being "used up" by the forward reaction and vice versa for each product. Therefore, the rate of any chemical's consumption equals the rate of its production. Since SO_3 is being produced at a rate of 0.0082 mol/s, it is also being consumed at the same rate (**0.0082 mol/s**).

(b) How many grams of O_2 are being consumed each second? **(1 mark)**

$$\frac{g\ O_2}{s} = \frac{0.0082 \text{ mol } SO_3}{s} \times \frac{1 \text{ mol } O_2}{2 \text{ mol } SO_3} \times \frac{32.0 g}{1 \text{ mol } O_2}$$

$$= 0.13 g\ O_2/s$$

14) Chemical reactions tend toward a position of minimum enthalpy and maximum entropy.

a) What is meant by the term *enthalpy*? **(1 mark)**

A measure of the heat content contained in the system

b) What is meant by the term *entropy*? **(1 mark)**

A measure of the randomness/disorder of the system

15) For the forward reaction, how do enthalpy and entropy change for the following equilibrium reactions: **(7 marks)**

Equilibrium	ΔH	ΔS
$4\ HCl_{(g)} + O_{2\ (g)} \rightleftarrows 2\ H_2O_{(g)} + 2\ Cl_{2\ (g)} + 111.4\ kJ$	↓	↓
$CaCO_{3\ (s)} \rightleftarrows CaO_{(s)} + CO_{2\ (g)}$ $\Delta H = +175\ kJ$	↑	↑
$2\ NO_{(g)} + O_{2\ (g)} \rightleftarrows 2\ NO_{2\ (g)} + 113\ kJ$	↓	↓
$2\ N_{2\ (g)} + O_{2\ (g)} + energy \rightleftarrows 2\ N_2O_{(g)}$	↑	↓
$2\ Li_{(s)} + 2\ H_2O_{(l)} \rightleftarrows 2\ LiOH_{(aq)} + H_{2\ (g)}$ $\Delta H = -433\ kJ$	↓	↑
$2\ NO_{2\ (g)} \rightleftarrows N_2O_{4\ (g)}$ $\Delta H = +59\ kJ$	↑	↓
$2\ H_2O_{(l)} + energy \rightleftarrows 2\ H_{2\ (g)} + O_{2\ (g)}$	↑	↑

16) For each of the following reactions, decide on the basis of entropy and enthalpy considerations whether a reaction in the direction shown will go to completion, reach a state of equilibrium or not occur at all. (Assume a closed system) **(8 marks)**

Reaction	$\overset{?}{\rightleftarrows}$
$Cl_{2\ (g)} \rightarrow Cl_{2\ (aq)} + 25\ kJ$	Equilibrium since min enthalpy favours → & max entropy favours ←
$Na_{(s)} + H_2O_{(l)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)} + ½\ H_{2\ (g)}$ $\Delta H = -184\ kJ$	Completion since min enthalpy favours → & max entropy favours →
$N_{2\ (g)} + O_{2\ (g)} \rightarrow NO_{2\ (g)}$ $\Delta H = +33.8\ kJ$	Not occur since min enthalpy favours ← & max entropy favours ←

$P_{4\,(s)} + 6\,H_{2\,(g)} \rightarrow 4\,PH_{3\,(g)}$ $\Delta H = +\,37$ kJ	Not occur since min enthalpy favours ← & max entropy favours ←
$Na_2CO_{3\,(s)} + 2\,HCl_{(aq)} \rightarrow 2\,NaCl_{(aq)} + CO_{2\,(g)} + H_2O_{(l)} + 27.7$ kJ	Completion since min enthalpy favours → & max entropy favours →
$C_2H_{2\,(g)} + H_{2\,(g)} \overset{?}{\rightleftarrows} C_2H_{4\,(g)}$ $\Delta H = -175$ kJ	Equilibrium since min enthalpy favours → & max entropy favours ←
$2\,Na_2CO_{3\,(s)} + 2\,HCl_{(aq)} \overset{?}{\rightleftarrows} 2NaCl_{(aq)} + CO_{2\,(g)} + H_2O_{(l)} + 27.7$ kJ	Completion since min enthalpy favours → & max entropy favours →
$N_2O_{(g)} + NO_{2\,(g)} \overset{?}{\rightleftarrows} 3\,NO_{(g)}$ $\Delta H = +156$ kJ	Equilibrium since min enthalpy favours ← & max entropy favours →

17) Two substances are mixed and no reaction occurs. With respect to enthalpy and entropy, explain why no reaction occurs? **(1 mark)**

If no reaction occurs, then both minimum enthalpy and maximum entropy would favour the reactants, therefore in the forward direction the ΔH ↑ & ΔS ↓

18) Two substances are mixed and a spontaneous reaction occurs. With respect to enthalpy and entropy, explain why the reaction goes to completion? **(1 mark)**

If a reaction goes to completion, then both minimum enthalpy and maximum entropy would favour the products, therefore in the forward direction the ΔH ↓ & ΔS ↑

19) Describe how enthalpy and entropy change, in the forward direction, as an exothermic reaction reaches equilibrium. Explain your reasoning. **(2 marks)**

Since this reaction reaches equilibrium, the directions of minimum enthalpy and maximum entropy **must oppose each other**. Since the reaction is exothermic, minimum enthalpy favours the products therefore maximum entropy must favour the reactants. In the forward direction, ΔH ↓ & ΔS ↓.

Students will often think that since the reaction is exothermic and ΔH ↓ (which is correct) therefore the ΔS must ↑ (which is wrong) to be opposite. The important thing to remember is that ↓ & ↑ is not opposing each other since those arrows are showing the changes. The arrows that must oppose each other are the directions that minimum enthalpy and maximum entropy favour, that is ← & →.