ALL SAINTS' COLLEGE

Science Department

Year 12 Chemistry
2018

Answers

Test 2: Equilibrium

Name: _____

Instructions to Students:

1. 50 minutes permitted
2. Attempt all questions
3. Write in the spaces provided
4. Show all working when required
5. All answers to be in blue or black pen, diagrams in pencil.

Multiple Choice	Short Answer	TOTAL	Final Percentage
/5	/50	/55	

Section One: Multiple Choice

1. A catalyst was added to a reaction mixture. Comparing the new reaction system to the old reaction system, which one of the following will remain unchanged?

a) The activation energy for the forward reaction.
b) The energy of the transition state.
c) The enthalpy change of the reaction.
d) The rate of the reverse reaction.

2. Which of the properties listed below are characteristic of a gaseous system in dynamic equilibrium?

(i) The concentrations of reactants are equal to the concentrations of products.
(ii) The concentrations of reactants and products are constant.
(iii) The rate of the forward reaction is equal to the rate of the reverse reaction.
(iv) The pressure of the system is constant.

a) (i), (ii) and (iii)
b) (i), (ii) and (iv)
c) (ii), (iii) and (iv)
d) (iii) only

3. Consider the following equilibrium system below.

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

If the equilibrium constant (K) for this reaction is 4.1×10^{-31}, which one of the following statements is true for the system where the initial partial pressures of nitrogen and oxygen were equal to each other?

a) Once equilibrium is reached, the reverse rate is much faster than the forward reaction rate.
b) The partial pressure of $NO_{(g)}$ is less than the partial pressure of $N_{2(g)}$.
c) The actual ratio of gaseous N_2 particles to NO gaseous particles is 1:2.
d) When nitrogen gas is injected into a vessel containing mostly oxygen gas, the partial pressure of oxygen decreases dramatically.

4. Consider the reaction below:

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

What would happen to the value of the K constant if the partial pressure of the N_2O_4 is doubled?

a) K would not be affected.
b) K would be halved.
c) K would be doubled.
d) K would increase by a factor of 4.

5. Consider the following equilibrium.

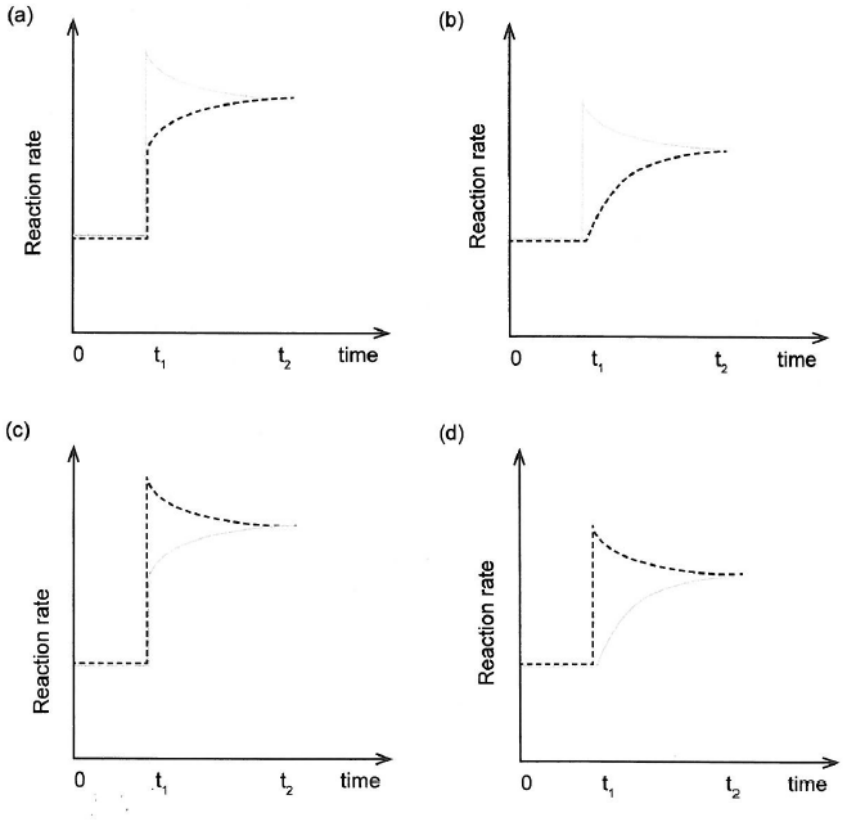
$$2\,ClF_{3\,(g)} \rightleftharpoons 3\,F_{2\,(g)} + Cl_{2\,(g)} \qquad \Delta H = \text{negative}$$

The system is initially at equilibrium. At time t1, the temperature of the system was increased. Which of the following best represents the changes in the forward and reverse reaction rates until equilibrium is re-established at time, t2?

The forward reaction rate is represented by _____

The reverse reaction rate is represented by _ _ _ _ _ _ _

c)

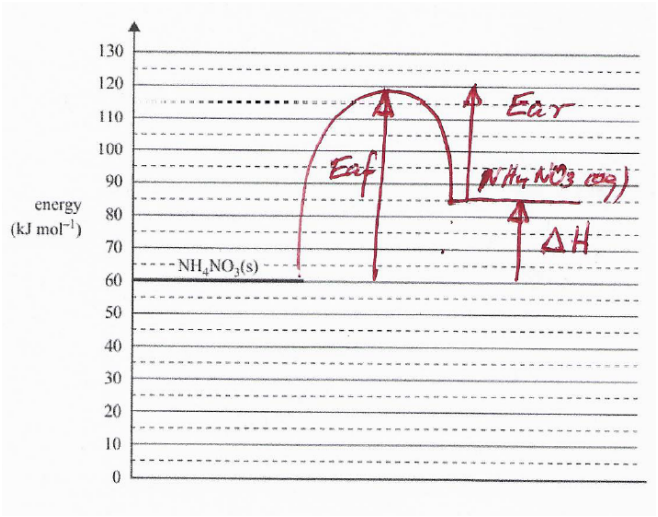


1. An Elastoplast pack, used to treat sporting injuries, contains a bag of water inside a larger bag of finely powdered ammonium nitrate, NH_4NO_3. Squeezing the pack causes the bag of water to break and the NH_4NO_3 to dissolve. The change of energy that occurs can used to treat an injury.

$$NH_4NO_{3\,(s)} \rightarrow NH_4NO_{3\,(aq)} \qquad \Delta H = +25 \text{ kJ mol}^{-1}$$

Assume the activation energy of the **reverse** reaction is 35 kJ mol^{-1}.

a) On the graph below, sketch the energy profile diagram for this reaction. [3]



Correct as endothermic (1)
Forward Ea labelled (1)
ΔH labelled (1)

Deduct 1 mark if scale incorrect

b) What is the value of the activation energy for the forward reaction? **60 kJ/mol** [2]
1 mark for correct value, 1 mark for units

2. Write the equilibrium law expressions for each of the following reactions. [5]

a) $P_{4\,(g)} + 6H_{2\,(g)} \rightleftharpoons 4PH_{3\,(g)}$

$$K = \frac{[PH_3]^4}{[P_4][H_2]^6}$$

b) $Al^{3+}_{(aq)} + 3\,OH^-_{(aq)} \rightleftharpoons Al(OH)_{3\,(s)}$

$$K = \frac{1}{[Al^{3+}][OH^-]^3}$$

c) $2C_2H_{6\,(g)} + 7\,O_{2\,(g)} \rightleftharpoons 4\,CO_{2\,(g)} + 6H_2O_{(l)}$

$$K = \frac{[CO_2]^4}{[C_2H_6]^2\,[O_2]^7}$$

d) $PbCl_{2(s)} \rightleftharpoons Pb^{2+}_{(aq)} + 2Cl^-_{(aq)}$

$$K = [Pb^{2+}][Cl^-]^2$$

e) $H_2SO_{4(l)} + 2H_2O_{(l)} \rightleftharpoons 2H_3O^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

$$K = [H_3O^+]^2\,[SO_4^{2-}]$$

3. In the previous question, you have written equilibrium law expressions or K-constants for various reactions.

a) With reference to the two reactions below, explain what information the equilibrium constant (K) provides. [2]

i. $AgCl_{(s)} \rightleftarrows Ag^+_{(aq)} + Cl^-_{(aq)}$ $K = 1.7 \times 10^{-10}$

ii. $CH_3COOH_{(aq)} \rightleftarrows H^+_{(aq)} + CH_3COO^-_{(aq)}$ $K = 1.8 \times 10^{-5}$

The K constant expresses the relationship between the equilibrium concentrations of reactants to products. (1)
Reaction i) has the smaller K value which means that the reactants are more favoured in this reaction than in reaction ii) (1)

b) What information does the K constant provide in regards to the rate of these reactions? [1]

The K constant only provides information on the relative concentrations of the reactants and products, but not on the rate of the reaction

4. Predict the effects on the yield (position of equilibrium) for each of the following changes made to the systems at equilibrium. State 'increase', 'decrease' or 'no change'. (An explanation is not required.) [5]

Reaction	Change	Effect on the concentration of the species **in bold** once equilibrium is re-established
$H_{2(g)} + Cl_{2(g)} \rightleftarrows 2\ \mathbf{HCl}_{(g)}$	Decrease in volume	**increase**
$[Co(H_2O)_6]^{2+}_{(aq)} + 4Cl^-_{(aq)} \rightleftarrows \mathbf{[CoCl_4]^{2-}}_{(aq)} + 6H_2O_{(l)}$	Addition of silver nitrate solution	**decrease**
$2\ HOCl_{(aq)} + 2\ H_2O_{(l)} \rightleftarrows 2\ H_3O^+_{(aq)} + \mathbf{2\ Cl^-}_{(aq)} + O_{2(g)}$	Addition of sodium hydroxide solution	**Increase**
$Cu(NH_3)_4(H_2O)_2^{2+}_{(aq)} \rightleftarrows \mathbf{Cu(H_2O)_6^{2+}}_{(aq)} + 4\ NH_{3(aq)}$	Addition of of water	**decrease**
$2\ NO_{2(g)} \rightleftarrows \mathbf{N_2O_4}_{(g)}$	Addition of Helium gas	**No change**

5. The reaction between hydrogen and oxygen gas produces water. The equation for this reaction is given below:

$$2H_{2\,(g)} + O_{2\,(g)} \rightleftarrows 2\,H_2O_{(g)} \qquad \Delta H = -484\ kJ\ mol^{-1}$$

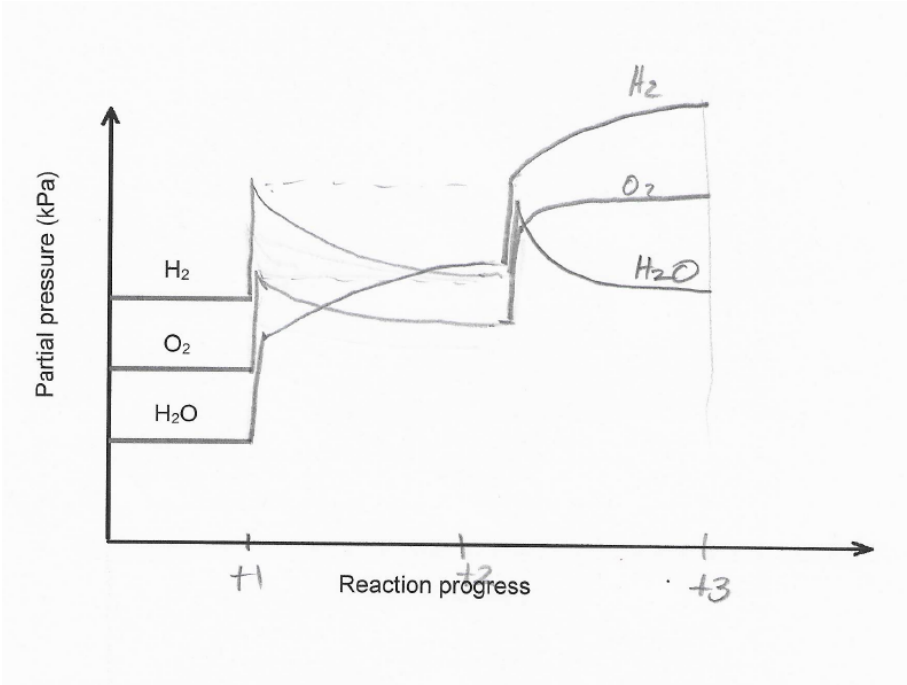
A reaction vessel contains all three gases at equilibrium as shown on the graph below.

a) At time T1, the volume of the reaction vessel is decreased. Show the effect of this on each of the three gases. [3]

Sudden increase of all 3 gases at t1 (1)
Gradual decrease of reactants/increase of product (1)
Molar ratios correct (1)

b) At time T2, the temperature of the reaction mixture is increased. Show the effect of this on each of the three gases. [3]

Sudden increase of all 3 gases at t2 (1)
Gradual increase in reactants/decrease in product (1)
Molar ratios correct/equilibrium reached at t3 (1)



3 Silver ions react with iron (II) ions in the following equilibrium:

$$Ag^{+}_{(aq)} + Fe^{2+}_{(aq)} \rightleftarrows Ag_{(s)} + Fe^{3+}_{(aq)} \qquad \Delta H = -66\ kJ$$

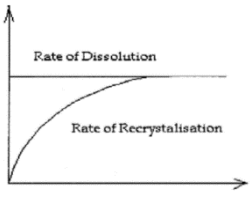
What would be the effect of the following changes once equilibrium has been re-established? Use the terms 'decrease', 'increase' or 'no change'. [12]

Imposed change	Effect on the forward reaction rate when equilibrium is re-established	Effect on $[Fe^{3+}_{(aq)}]$ when equilibrium is re-established	Observation when equilibrium is re-established
Some solid silver nitrate $AgNO_{3\ (s)}$ is added.	**increase**	**increase**	**Pale green**
A catalyst is added at constant temperature and volume.	**increase**	**No change**	**No change**
Some solid sodium chloride $NaCl_{(s)}$ is added	**decrease**	**decrease**	**Pale green, white ppt**
The temperature is increased.	**increase**	**decrease**	**Pale green**

6. A student added small amounts of solid copper sulfate to a beaker containing 100 mL of water. As she kept on adding the solid, the colour of the water became blue. Eventually no more of the salt would dissolve and blue crystals could be observed at the bottom of the beaker.

a) At this point, the student made the following statement: 'No more of the solid is dissolving'. Using a rate graph for forward and reverse reaction, evaluate this comment.

This can be treated as a closed system
as this is a saturated solution. A dynamic equilibrium will establish, evidenced by the fact that the colour does not change any longer. (1)
the rate of dissolving is the same as the rate of crystallisation, both processes are occurring at the same time. (1)
Both rates correct on graph (1)



b) Another student suggested to dissolve
Some copper nitrate into this solution.
Will the presence of the copper sulfate solution affect his attempts and if so how?
Explain your answer briefly. [2]

Yes, the solubility of the copper nitrate will be lowered (1) as the copper ions are competing for dissolution with the copper ions that are already in the solution. (1)

4 Sulfuric acid is the most widely produced synthetic chemical in the world. Australia produces approximately 3.8 million tonnes per year, 70% of which is used in the manufacture of phosphate fertilizers such as superphosphate.
The contact process is the current method of producing sulfuric acid at high concentrations needed for industrial processes and involves the steps as shown below.
The key step in the contact process is the oxidation of sulfur dioxide to sulfur trioxide (step 2) and is a reversible reaction. A mixture of sulfurdioxide and air (with a mole ratio of 1 mole O_2 to 1 mole SO_2) is passed over trays of vanadium(V)oxide catalyst in pellet form at a temperature of around 450 ºC and a pressure of 1-2 atmospheres. The sulfur trioxide is continuously removed from the reaction mixture.

Step 1: $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$

Step 2: $\mathbf{2\,SO_{2(g)} + O_{2(g)} \rightleftarrows 2\,SO_{3(g)}}$ **$\Delta H = -198$ kJ**

Step 3: $SO_{3(g)} + H_2SO_{4(l)} \rightarrow H_2S_2O_{7(l)}$

Step 4: $H_2S_2O_{7(l)} + H_2O_{(l)} \rightarrow 2\,H_2SO_{4(l)}$

Step 5: $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$

a) State the optimal reaction conditions of temperature and pressure that should be adopted in step 2 to increase the yield of this reaction. [2]

Low temperature, high pressure

b) **In regards to step 2 only:** In terms of collision theory, explain how the rate of reactions and therefore the yield of SO_3 are affected by temperature conditions and explain why the selected temperature is chosen. [5]

- Increasing the temperature will increase the kinetic energy of all particles and thus increase the rate of both the forward and reverse reactions as the frequency of collisions is higher. (1)
- Additionally, all particles possess greater energy which more collisions are likely to overcome the energy barrier and be successful. (1)
- As the reverse reaction is endothermic, it will receive a higher kick-start as it has the higher Ea to overcome. (1)
- This means the reverse reaction overtakes the reverse, and the reactants are favoured. (1)
- Rate is favoured by high temperature, and yield by low temperature. So a moderate compromise temperature is chosen. (1)

c) **In regards to step 2 only:** In terms of collision theory, explain how the rate of reactions and therefore the yield of SO_3 are affected by pressure conditions and explain why the selected pressure is chosen. [4]

- A high pressure increases both rates there are more particles per unit area, resulting in an increase in collision frequency. (1)
- A high pressure will increase the forward rate proportionally more as the forward rate has the a greater number of collisions between particles as evidenced by the reaction coefficients. Products are produced faster and yield will increase. (1)
- Both rate and yield are favoured by high pressure (1).
- However, a moderate pressure is adopted for safety and economic reasons. (1)

d) Based on the information provided, **briefly** describe how three other additional measures are adopted in optimising both yield and rate in this process. [3]

- Using the catalyst in pellet form: increases surface area and therefore contact with reactant particles --> increased rate
- Excess of oxygen ensures all sulfur dioxide is used up
- Removing product increases yield as it shifts the equilibrium to the right
- Also accept: presence of catalyst as it lower Ea

END OF TEST