Chemist:_____

December 2, 2022, Period 5

# SCH 4U1 UNIT 3 Test 1
## Chemical Systems and Equilibrium

| | |
|---|---|
| Knowledge & Understanding: | /10 |
| Thinking and Investigation | /9 |
| Communication: | /8 |
| Application: | /11 |

## KNOWLEDGE & UNDERSTANDING [10 marks]

**Part A - Multiple Choice.** Select the letter of the choice that ***best*** completes the statement or answers the question.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *1.* | (A) | B | C | D | *4.* | A | (B) | C | D |
| *2.* | A | B | C | (D) | *5.* | (A) | B | C | D |
| *3.* | A | B | (C) | D | | | | | |

1. Which statement is **always true** for a chemical reaction that has **reached equilibrium**?

(A.) The rate of the forward reaction is equal to the rate of the reverse reaction.
B. Both forward and reverse reactions have stopped.
C. The amount of products is greater than the amount of reactants on.
D. The amounts of reactants and products are constantly changing.

2. Which of the following is an example of a **heterogeneous** equilibrium?

A. $Na_2SO_{4(s)} \rightleftharpoons Na_2SO_{4(aq)}$
B. $Fe^{3+}_{(aq)} + SCN^-_{(aq)} \rightleftharpoons FeSCN^{2+}_{(aq)}$
C. ✓ $Cu^{2+}_{(aq)} + 2OH^-_{(aq)} \rightleftharpoons Cu(OH)_{2(s)}$
(D.) Two of the above are heterogeneous

3. If the equilibrium constant for a given reaction is 6.0, what is the equilibrium constant for the **reverse reaction**?

A. -6.0
B. - 0.167
(C.) 0.167
D. 6.0

4. Part of the Contact Process, used to manufacture sulfuric acid is:

$$2SO_2\,(g) + O_2(g) \rightleftharpoons 2SO_3\,(g) \quad \Delta H° = -196\ kJ$$

Which conditions **maximize** the production of $SO_3$?

| | Temperature (°C) | Pressure (kPa) |
|---|---|---|
| A. | Low | Low |
| (B.) | Low | High |
| C. | High | High |
| D. | High | Low |

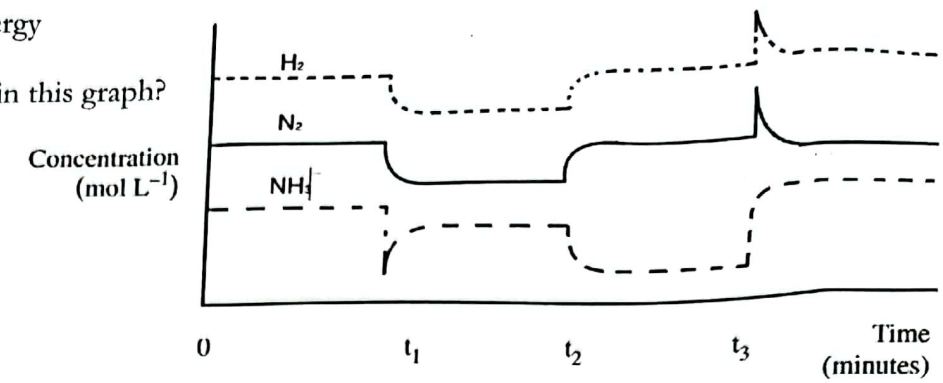
5. A **sealed jar of sodium chloride solution** has some crystals of solid sodium chloride sitting on the base of the jar. **What type of equilibrium** is being displayed in the jar?

(A.) Solubility equilibrium
B. Phase equilibrium
C. Chemical equilibrium
D. Static equilibrium

6. The following graph shows three different stresses on the reaction

$N_{2(g)} + 3H_{2(g)} \leftrightarrows 2NH_{3(g)}$ + energy

Which stresses occur, in order, in this graph?




A. Container volume decreases, temperature increases, temperature decreases
B. $[NH_3]$ decreases, temperature decreases, container volume decreases
C. $[NH_3]$ increases, temperature increases, container volume decreases
D. $[NH_3]$ decreases, temperature decreases, container volume increases

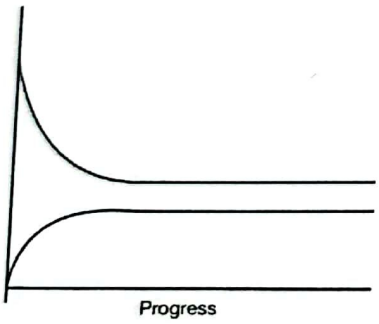
7. Identify the following statements as **True (T) or False (F)** (0.5 each, 2 marks total)

a) A system must be closed in order for equilibrium to be achieved — T

b) A glass of water with ice is an example of a thermal equilibrium — F

c) A decrease in temperature will shift the equilibrium position in favour of the endothermic reaction. — F

d) An increase in container volume will result in a shift in equilibrium position to the side with more total moles present. → must be moles of GAS — F

8. 


The graph to the left shows a chemical system as a reaction reaches equilibrium. State what the **units of the vertical axis** of the graph are, and **explain your reasoning.**

[2 marks]

concentration (mol/L)

at equilibrium concentrations are constant but not necessarily equal
↳ rates would be both constant and equal

**THINKING & INVESTIGATION** **[9 marks]**

9. Consider the following equilibrium:

$$2\,NO(g) + O_2(g) \leftrightarrows 2\,NO_2(g)$$

When 2.00 moles of $NO_{(g)}$ and 1.00 moles of $O_{2(g)}$ are placed in a 2.000 L flask at 445 K, the equilibrium concentration of $NO_2$ is ~~[illegible]~~ 0.78 mol/L.

Determine the **equilibrium concentrations** of $NO_2$ and $O_2$

[3 marks]

| | 2NO | + O2 | ⇌ 2NO2 |
|---|---|---|---|
| I | 2.00 mol / 2.00 L = 1.00 mol/L ✓ | 1.00 mol / 2.00 L = 0.500 mol/L | 0 ✓ must shift right |
| C | −2☺ | −☺ | +2☺ |
| E | 1.00 −2☺ | 0.500 −☺ | +2☺ |

+2☺ = 0.78

☺ = 0.39

[NO] = 1.00 − 0.78 ✓ = 0.22 mol/L

[O2] = (0.500 − 0.39) = 0.11 mol/L

2 sf, units −0.5 com

10. The following reaction occurs in a closed container at 35°C ($K_{eq} = 1.60 \times 10^4$):

$$2NOCl_{(g)} \leftrightarrows 2NO_{(g)} + Cl_{2(g)}$$

The initial concentrations in the container are:
$[NOCl_{(g)}] = 0.35$ mol/L $[NO_{(g)}] = 5.50$ mol/L $[Cl_{2(g)}] = 2.50$ mol/L

Determine **which way the system must shift** to reach equilibrium. Show all your work.
*Do NOT calculate equilibrium concentrations!*

[2 marks]

$K_{eq} = \frac{[Cl_2][NO]^2}{[NOCl]^2}$ ✓ $Q = 6.17 \times 10^2$

$Q = \frac{(2.50)(5.50)^2}{(0.35)^2}$ $Q < K_{eq}$ ∴ must shift right ✓

**Space for continuation, correction or rough work (make sure to indicate "mark" if you want work here marked)**

11. 1.50 mol/L of $SO_{3(g)}$ and 1.50 mol/L of $NO_{(g)}$ are placed in a container and allowed to reach equilibrium. **Using an ICE table**, determine the **concentration of $SO_{2(g)}$** at equilibrium.

$$SO_{2(g)} + NO_{2(g)} \rightleftharpoons NO_{(g)} + SO_{3(g)} \quad K_{eq} = 2.95$$

| | $SO_{2(g)}$ | $NO_{2(g)}$ | $NO_{(g)}$ | $SO_{3(g)}$ |
|---|---|---|---|---|
| I | 0 | 0 | 0.150 mol/L | 0.150 mol/L |
| C | +y | +y | −y | −y |
| E | +y | +y | 1.50−y | 1.50−y |

$K_{eq} = \frac{[NO][SO_3]}{[NO_2][SO_2]}$

$2.95 = \frac{(0.150-y)^2}{y^2}$

perfect square

$1.7176 = \frac{1.50-y}{y}$

$y = 0.55196$

$[SO_2] = 0.552$ mol/L

3 sf

[4 marks]

**COMMUNICATION** **[8 marks]**

**Overall form** (units, significant figures, showing work etc.) throughout test [2 marks]

12. The following equilibrium has a $K_{eq}$ of $1.4 \times 10^{-4}$ at 200°C

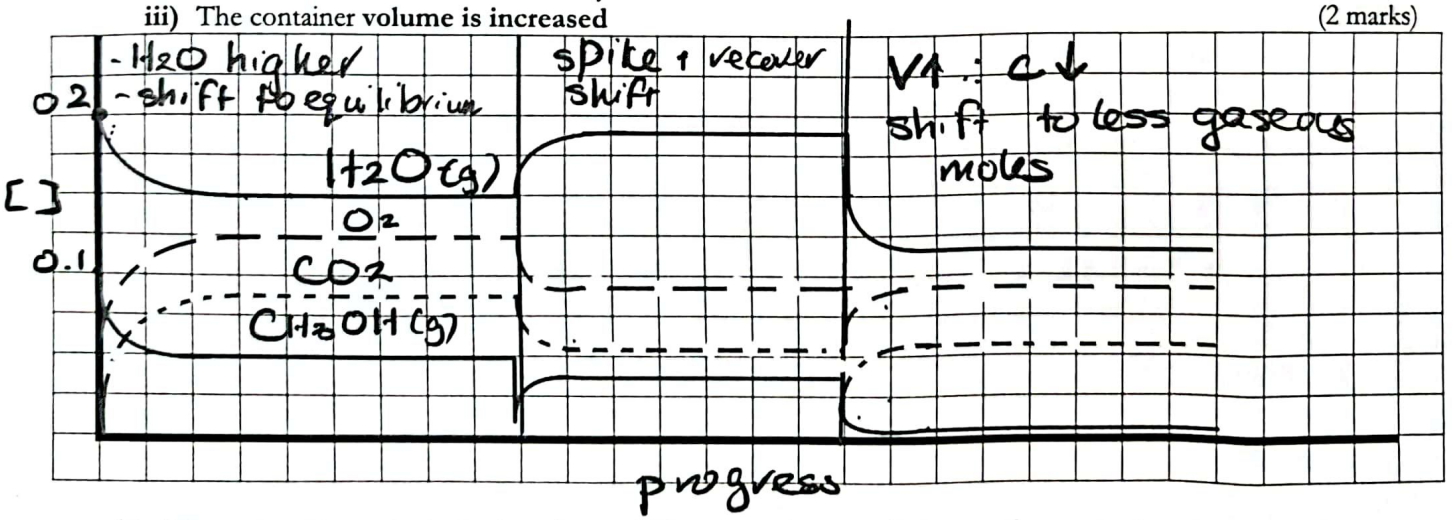
$$CO_{2\,(g)} + 3O_{2(g)} \leftrightarrows CH_3OH_{\,(g)} + H_2O_{\,(g)}$$

(a) **Draw a graph** that shows what would happen if [total 5 marks]

i) **0.1 mol/L $CH_3OH_{(g)}$ and 0.2 mol/L $H_2O_{\,(g}$** are put in a container and allowed to reach equilibrium. (1 mark)

ii) **$CH_3OH_{(g)}$ is removed** from the system (2 marks)

iii) The container **volume is increased** (2 marks)




b) When placed in an ice bath, the mixture shifts to contain **more $CO_{2\,(g)}$** . **State whether the forward reaction is endothermic or exothermic.** [1 mark]

forward endothermic - decrease temp shifts exothermic (reverse)

**APPLICATION** **[11 marks]**

13. A saturated solution of sodium chloride (salt), with some excess salt crystals remaining on the bottom of the solution. Over time if measured, it would be observed that the **mass of crystals** remains the same, but the **shape of the crystals** might change.

**Explain** these two observations using **equilibrium principles.** [3 marks]

- at equilibrium the rates of dissolving and crystallizing would be constant and equal
- since crystallizing ions might attach in a different location from dissolving, the shape may change
- since dissolving + crystallizing occur at same rate mass of solid will not change

14. The Haber Process has been an extremely important industrial reaction since it's development by F. Haber prior to World War 1. The thermochemical equation for the reaction is shown below:

$$N_{2(g)} + 3H_{2(g)} \leftrightarrows 2NH_{3(g)} \quad \Delta H = -92kJ$$

(a) When F. Haber first tried to get his process to work he used the principles of equilibrium to choose conditions that would favour ammonia production. Explain **what the problem was** and **why** this problem was not evident <u>from equilibrium principles alone</u>.

- the production was too slow
- equilibrium principles give position of equilibrium but not how fast the position will be reached

[2 marks]

(b) State and explain **two of the main things** that Haber did to **allow the reaction to be commercially useful** (be SPECIFIC about conditions and why they worked)

any 2 1) identify 2) explain

- catalyst (Fe + KOH) - speeds up rate (can use lower temperature)
- high pressure (200atm) - shift to side with less gaseous moles (higher = too expensive)
- high temperature (~400°C) - faster production rate (compromise since lower favours equilibrium shift)
- removal of $NH_3$ - keeps position shifting left

[4 marks]

15. In a series of experiments, hydrogen and carbon dioxide react as shown in the equation below.

$$H_2(g) + CO_2(g) \leftrightarrows H_2O(g) + CO(g)$$

For this reaction the **values of $K_{eq}$ with different temperatures** are

| Temperature (°C) | $K_{eq}$ |
|---|---|
| 650 | $1.01\times10^{-1}$ |
| 450 | $4.23\times10^{-2}$ |
| 250 | $7.76\times10^{-3}$ |

On the basis of these results, the scientist determines that the reaction is endothermic. **State, with a reason, whether or not you agree.**

as temperature ↓ $K_{eq}$ ↓
∴ reaction is endothermic disagree

[2 marks]

**EXTRA SPACE for continuations or corrections**
***(make sure you indicate which question you are continuing or correcting)***