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| Description: Vertical full colour positive | Safety Bay Senior High School | | | | | |
| **CHEMISTRY UNIT 3 & 4** | | | | | | |
| **Test #1:** | | | | | | |
| **Reaction Rates & Chemical Equilibrium** | | | | | | |
|  | | | | | | |
| **NAME:** | | |  | | | |
|  | | |  | | | |
| **Time allowed for this paper** | | | | | | |
| Reading time: | | 5 minutes | | | | |
| Working time: | | 50 minutes | | | | |
|  | | | | | | |
| **Structure of this paper:** | | | | | | |
| Section | | | Number of questions | Marks available | | Marks achieved |
| Section One: Multiple Choice | | | 8 | 8 | |  |
| Section Two: Short Answer | | | 7 | 42 | |  |
|  | | |  | | **Total** | \_\_\_\_\_\_ / 50 |

**Section One: Multiple Choice**

This section has 10 questions. Answer **all** questions by circling the correct option. If you make a mistake, put a cross through your answer and then circle your new answer. No marks will be given if more than one answer is completed for any question.

Suggested working time: 10 minutes

1. Some carbon dioxide is to be generated by reacting 50 g of calcium carbonate with a solution of hydrochloric acid.  
     
   Which of the following is **least** likely to lead to an increase in the rate of formation of carbon dioxide?
   1. grinding the calcium carbonate to a fine powder
   2. increasing the temperature
   3. **increasing the pressure within the container**
   4. increasing the concentration of hydrochloric acid
2. Physical and chemical reactions can reach a state of dynamic equilibrium if they are reversible and are in a closed system.

Which of the following can describes the characteristics of a **closed system**?

|  |  |  |
| --- | --- | --- |
|  | **Matter** | **Energy** |
| (a) | Can leave and enter | Can leave and enter |
| (b) | Can enter, but not leave | Can leave and enter |
| **(c)** | **Cannot leave or enter** | **Can leave and enter** |
| (d) | Cannot leave or enter | Cannot leave or enter |

1. Iodine is a solid that forms a brown solution in water.

I2(aq)

I2(s)

I2(s) ⇌ I2(aq)

The system is at equilibrium.

Adding more solid iodine will:

* 1. make the solution darker brown
  2. make the solution lighter brown
  3. **have no effect on the equilibrium**
  4. increase the value of the equilibrium constant

**Questions 4-5 refer to the following information:**

Oxygen in the blood is carried around by haemoglobin. Oxygen carried by haemoglobin can be represented by the symbol HbO2(aq), where Hb represents a molecule of haemoglobin.

Carbon monoxide is a gas which can also bind to haemoglobin molecules. Haemoglobin cannot carry both oxygen and carbon monoxide at the same time, leading to the following equilibrium.

HbO2(aq) + CO(g) ⇌ HbCO(aq) + O2(g)

1. What is the equilibrium expression for the above reaction?

|  |  |
| --- | --- |
| (a) |  |
| (b) |  |
| **(c)** |  |
| (d) |  |

1. A traffic warden working at a busy city intersection becomes sleepy after a few hours work, a sign of oxygen deprivation. The atmosphere at the intersection is found to contain several parts per million of carbon monoxide (CO).

On the basis of this information, the equilibrium constant for the forward reaction of this equation is:

* 1. less than one
  2. **greater than one**
  3. one
  4. unable to be estimated from the information provided

1. One of the pollutants from car exhausts is carbon monoxide. One of the reactions that occurs inside catalytic converters attached to car exhausts changes the carbon monoxide to carbon dioxide.

2 CO(g) + O2(g) ⇌ 2 CO2(g)

Which of the following changes could be applied to this system to increase the activation energy of particles, resulting in a greater proportion of collisions being successful.

* 1. Adding a platinum catalyst to a system.
  2. Increasing the temperature of a system while maintaining constant volume.
  3. Decreasing the volume of a system while maintaining constant temperature.
  4. **None of the above.**

**The next two questions refer to the following information:**

Ethanol (CH3CH2OH) can be produced from the reaction between ethene and water in the presence of a sulfuric acid catalyst.

C2H4(g) + H2O(g) ⇌ CH3CH2OH(g) ΔH = -46 kJ mol-1

1. When ethene and water react together to form an equilibrium mixture with ethanol, which one of the following best represents how the rates of forward and back reactions change over time?

|  |  |  |  |
| --- | --- | --- | --- |
| (a) | C2H4(g) + H2O(g) 🡪 CH3CH2OH(g)  CH3CH2OH(g) 🡪 C2H4(g) + H2O(g)  Rate  Time | (b) | C2H4(g) + H2O(g) 🡪 CH3CH2OH(g)  CH3CH2OH(g) 🡪 C2H4(g) + H2O(g)  Rate  Time |
| (c) | C2H4(g) + H2O(g) 🡪 CH3CH2OH(g)  CH3CH2OH(g) 🡪 C2H4(g) + H2O(g)  Rate  Time | (d) | C2H4(g) + H2O(g) 🡪 CH3CH2OH(g)  CH3CH2OH(g) 🡪 C2H4(g) + H2O(g)  Rate  Time |

1. At equilibrium at a particular temperature, 10% of the ethene is converted to ethanol. In order to increase the percentage yield of ethanol at equilibrium you should:
   1. lower the temperature and lower the pressure
   2. **lower the temperature and raise the pressure**
   3. raise the temperature and lower the pressure
   4. raise the temperature and raise the pressure

**Section Two: Short Answer**

Write your answers in the spaces provided. When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to the appropriate number of significant figures and include appropriate units where available.

Suggested working time: 40 minutes

1. **(3 marks)**

The graph below represents the energy changes over the course of a chemical reaction.

CO(g) + NO2(g) ⇌ CO2(g) + NO(g)

X

400

300

200

100

0

CO(g) + NO2(g)

(reactants)

extent of reaction

CO2(g) + NO(g)

(products)

energy  
(kJ mol-1)

* 1. Give the magnitude and sign of the ΔH for the forward reaction in kJ mol-1. (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| -200 kJ mol-1 | 1 mark |
| TOTAL: | 1 mark |

* 1. Give the activation energy for the reverse reaction in kJ mol-1. (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| 310 kJ mol-1 (Accept 305-315) | 1 mark |
| TOTAL: | 1 mark |

* 1. What term is used to describe the intermediate formed at point X? (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Activated complex or Transition state | 1 mark |
| TOTAL: | 1 mark |

1. **(5 marks)**

Carbon monoxide and hydrogen can be produced from the reaction of methane with steam according to the equation:

CH4(g) + H2O(g) ⇌ CO(g) + 3 H2(g) ΔH = +206 kJ mol-1

**H2(g)**

**CO(g) with catalyst**

**Equilibrium**

time

CH4(g)

CO(g)

concentration

* 1. Indicate on the appropriate axis the point at which equilibrium is achieved. (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| See graph above | 1 mark |
| TOTAL: | 1 mark |

* 1. List **two** characteristics of a system which is in dynamic chemical equilibrium. (2 marks)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Equal rates of forwards and reverse reaction | 1 mark |
| Substances have constant/unchanging concentrations | 1 mark |
| Unchanging macroscopic properties | 1 mark |
| System is closed – Matter cannot escape | 1 mark |
| TOTAL: | 2 marks |

* 1. On the graph above, draw a line to show the change in concentration of hydrogen gas as the reaction proceeds. **Label this line**. (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| See graph above. Increases at 3x rate of CO(g). | 1 mark |
| TOTAL: | 1 mark |

* 1. On the graph above, draw a line to show how the formation of carbon monoxide would have been different if a catalyst had been used. **Label this line**. (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| See graph above. Same yield, but reaches equilibrium faster. | 1 mark |
| TOTAL: | 1 mark |

1. **(2 marks)**

Write equilibrium constant expressions for the following systems:

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
|  | 1 mark |
|  | 1 mark |
| TOTAL: | 2 marks |

**Partial marks:**

* **Award 1 mark (/2) if equilibrium expressions including (ℓ) and (s) phases, but were otherwise correct.**
* **Award 1 mark (/2) if top and bottom lines of equilibrium expressions were inverted, but were otherwise correct.**

1. **(9 marks)**

One step in the synthesis of nitric acid involves the following reversible reaction:

2 NO(g) + O2(g) ⇌ 2 NO2(g) ΔH = -114 kJ

Four separate containers of NO(g) and O2(g) were prepared and allowed to reach equilibrium. A change was imposed on each of the four containers, and the system given time to reach equilibrium again.

Complete the table below to show the effect of each change. In each case the comparison should be the system at the **new equilibrium** compared to the system at the **old equilibrium**. Give answers as ‘increased’, ‘decreased’ or ‘no change’.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Container** | **Change imposed** | **Rate of forward reaction at  new equilibrium** | **Yield of  NO2 at  new equilibrium** | **Effect on equilibrium constant (K)** |
| 1 | The volume of the container is increased at a constant temperature | Decreased | Decreased | No change |
| 2 | More oxygen is added to the container at constant volume and temperature | Increased | Increased | No change |
| 3 | The container is rapidly cooled | Decreased | Increased | Increased |

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| See table above. | 9 x 1 mark |
| TOTAL: | 9 marks |

1. **(14 marks)**

Carbon monoxide reacts with fluorine to produce carbon oxyfluoride as shown in the equation:

CO(g) + F2(g) ⇌ COF2(g); ΔH = -ve

A scientist studying this reaction measured the concentration of the three gases in a sealed 2.0 L reaction vessel over a period of time. The results are shown below.

time (minutes)

CO

Concentration (mol L-1)

0

0.0

0.1

0.2

0.3

0.4

0.5

5

10

20

25

30

35

40

15

CO

F2

F2

COF2

COF2

* 1. At t=15 minutes, a change was imposed on the system.  
     1. What occurred at t=15 to cause the changes shown in the graph? (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| additional F2(g) added to the system | 1 mark |
| TOTAL: | 1 mark |

* + 1. Explain the variation in the concentration of the substances from t=15 to t=20. (4 marks)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Increase in [F2] increases the rate of forwards reaction | 1 mark |
| …due to more collisions between F2 and CO molecules | 1 mark |
| As rate of forwards reaction > rate of reverse reaction, over time there is an increasing concentration of products (COF2) and decreasing concentration of reactants (F2, CO) | 1 mark |
| At ~t=17.5 the system reaches equilibrium again / the forwards and reverse reaction rates become equal again, leading to constant concentrations | 1 mark |
| TOTAL: | 4 marks |

* 1. At t = 30 minutes, the temperature of the reaction vessel was changed.   
       
     Sketch a graph of the forward and reverse reaction rates from t=28 minutes to t=36 minutes.   
      (4 marks)

Reverse

Forward

time (minutes)

Reaction rate

28

29

30

32

33

34

35

36

31

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| **Both** rates decrease at t=30 | 1 mark |
| After initial temperature change, forward rate > reverse rate | 1 mark |
| Rates equalise again, correct curve shape | 1 mark |
| Rates are equal before change and after equilibrium is reached (~t=33-34) | 1 mark |
| TOTAL: | 4 marks |

* 1. Two further changes were imposed on the system.
* A catalyst was added at t = 40 minutes
* The volume of the container was doubled at t = 60 minutes

Sketch the concentrations of the three substances from t = 40 to t = 80 as these changes are imposed and equilibrium is restored. (5 marks)

CO(g) + F2(g) ⇌ COF2(g); ΔH = -ve

time (minutes)

CO

Concentration (mol L-1)

35

0.0

0.1

0.2

0.3

0.4

0.5

40

45

55

60

65

70

75

50

F2

COF2

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Addition of catalyst has no effect on concentrations | 1 mark |
| Doubling volume at t=60 minutes causes all concentrations to **halve** | 1 mark |
| Reducing pressure favours reverse reaction (less COF2, more F2 and CO) | 1 mark |
| Correct curve shape while re-establishing equilibrium, correct ratio (1:1:1) | 1 mark |
| Reaction eventually re-establishes equilibrium – constant concentrations | 1 mark |
| TOTAL: | 5 marks |

1. **(4 marks)**

One of the steps involved in the industrial preparation of sulfuric acid is the oxidation of sulfur dioxide to sulfur trioxide according to the equation:

2 SO2(g) + O2(g) ⇌ 2 SO3(g)

* 1. The graph below shows the percentage conversion of sulfur dioxide to sulfur trioxide at equilibrium at 1 atmosphere pressure and various temperatures.

100

50

temperature °C

% conversion to SO2

400 600 800 1000

There is almost complete conversion of sulfur dioxide to sulfur trioxide at 300 °C. However, this reaction is performed at a higher temperature of approximately 450 °C in industry. Why? (1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Reaction is too slow at 300 °C, but reasonable speed at 450 °C. | 1 mark |
| TOTAL: | 1 mark |

* 1. Provide justifications for the following statements:  
     1. ‘High pressures increase the equilibrium yield of sulfur trioxide in this reaction.’

(1 mark)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Increasing the overall pressure would favour the side of the reaction with the least moles of gas (i.e. favour the forwards reaction) | 1 mark |
| TOTAL: | 1 mark |

* + 1. ‘Atmospheric pressure is **usually** used in industry, even though high pressures increase the equilibrium yield of sulfur trioxide in this reaction.’ (2 marks)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Any two of following:   * High pressures pose safety risk * High pressures are more expensive to maintain * Reaction has high enough yield at atmospheric pressure | 2 x 1 mark |
| TOTAL: | 2 marks |

1. **(5 marks)**

Rising atmospheric carbon dioxide, primarily from human fossil fuel combustion, is causing changes in seawater carbonate chemistry. This is due to carbon dioxide dissolving into the ocean in accordance with the following equation:

Equation 1: CO2(g) ⇌ CO2(aq)

The aqueous carbon dioxide then undergoes further reactions with lead to increased ocean acidity.

Equation 2: CO2(aq) ⇌ H2CO3(aq)

Equation 3: H2CO3(aq) ⇌ HCO3–(aq) + H+(aq)

Waters near the Arctic and Antarctica are particularly susceptible to ocean acidification because, like all gases, the solubility of carbon dioxide increases as the temperature of water decreases. Additionally, the cooling of water near the surface causes it to increase in density and sink towards the bottom of the ocean, sequestering (storing) carbon dioxide.

* 1. Is Equation 1 an endothermic or exothermic process? Justify your answer. (2 marks)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Forward reaction is exothermic | 1 mark |
| CO2 is more soluble at low temperatures, indicating forward reaction is favoured by low temperatures. Low temperatures favour exothermic reactions. | 1 mark |
| TOTAL: | 2 marks |

* 1. Calcification is the process by which marine organisms such as coral develop calcium carbonate shells and skeletons. This process forms solid calcium carbonate from aqueous calcium ions and carbonate ions:

Ca2+(aq) + CO32-(aq) ⇌ CaCO3(s)

Ocean acidification has resulted in a decrease in the rate of calcification in marine organisms. Account for this decrease in rate, supporting your answer with an appropriate equation. (3 marks)

|  |  |
| --- | --- |
| **Answer** | **Cumulative Marks** |
| Increase in H+(aq) causes a decrease in [CO32-] | 1 mark |
| H+(aq) + CO32-(aq) ⇌ HCO3-(aq) | 1 mark |
| The lower concentration of CO32- results in slower reaction rate for calcification reaction | 1 mark |
| TOTAL: | 3 marks |