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VCE Chemistry ¾
AOS 2 Revision (Rates & Equilibrium) [2.0]
SAC 2 Solutions

51 Marks. 13 Minutes Reading. 76.5 Minutes Writing.

Section A: Multiple Choice Questions (5 Marks)

Question 1 (1 mark) [2.7.5] Apply RICE tables to find K_c.

The reaction shown below is a reversible one:

$$2COF_2(g) \rightleftarrows CO_2(g) + CF_4(g)$$

A change in temperature to an equilibrium mixture causes the amount of CO_2 present to decrease from 1.2 mol to 0.9 mol. When this occurs, the:

A. Amount of CF_4 decreases by 0.3 and the amount of COF_2 increases by 0.6 mol.

B. Amount of CF_4 decreases by 0.3 and the amount of COF_2 increases by 0.3 mol.

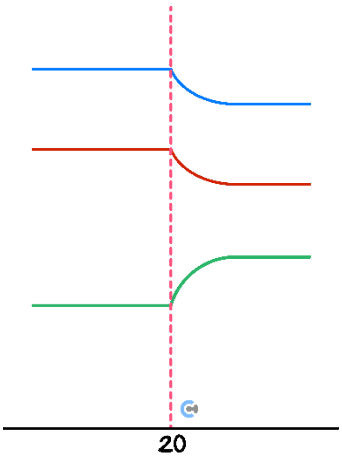
C. Amount of CF_4 decreases by 0.9 and the amount of COF_2 increases by 1.8 mol.

D. Amount of CF_4 decreases by 1.2 and the amount of COF_2 increases by 2.4 mol.

CF_4 will decrease by the same amount as CO_2. The COF_2 will increase by twice this amount.

Question 2 (1 mark) [2.9.3] Find the change made to system from equilibrium graph.

At the 20-minute mark, a change is made to an equilibrium mixture. The effect on the concentrations of this change is shown in the graph below:



The change at the 20-minute mark was:

A. A change in the temperature.

B. The addition of a catalyst.

C. A decrease in volume.

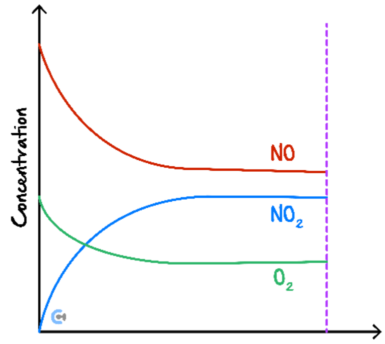
D. A dec

The amounts of each species change slowly after the 20 minute mark – this is consistent with the system adjusting to a change in temperature.

Question 3 (1 mark)

[2.8.2] Graph effects of addition / removal of substances or pressure / volume changes on equilibrium system.

The concentrations of the components of an equilibrium system are shown in the graph below:



The equation for the reaction is:

A. $2NO_2(g) \rightleftarrows 2NO(g) + O_2(g)$

B. $NO(g) + O_2(g) \rightleftarrows NO_2(g)$

C. $2NO(g) + O_2(g) \rightleftarrows 2NO_2(g)$

D. $2NO_2(g) + O_2(g) \rightleftarrows 2NO(g)$

$2NO(g) + O_2(g) \rightleftarrows 2NO_2(g)$

NO and O_2 are both dropping but NO at twice the rate of the O_2. The rate of increase of the NO_2 is the same as the rate of NO dropping so the coefficient for both is the same.

Question 4 (1 mark)

[2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict.

The manufacture of sulphuric acid requires the conversion of SO_2 to SO_3:

$$2SO_2(g) + O_2(g) \rightleftarrows 2SO_3 \qquad \Delta H = -300\ kJ\ mol^{-1}$$

I. Increase in pressure.

II. Addition of a catalyst.

III. Use of extra oxygen.

IV. Increase in temperature.

Which of the above changes will lead to an improved yield of SO_3?

A. I only.

B. I and II only.

C. II and IV only.

D. I, III and IV.

The addition of a catalyst will not affect the yield and an increase in temperature will cause the yield to fall. This leaves I and III as possible alternatives.

Question 5 (1 mark)

[2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system.

Hydrogen iodide can be formed from the reaction between hydrogen and iodine:

$$H_2(g) + I_2(g) \rightleftarrows 2HI(g)$$

A sharp decrease in volume is applied to an equilibrium mixture of these gases. This change will cause:

A. No change to the equilibrium mixture.

B. The concentrations of each species drop, but there is no change in the position of equilibrium.

C. No change in the value of K but it will favour the forward reaction.

D. The pressure of iodine increases.

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Section B: Short Answer Questions (46 Marks)

Question 6 (6 marks)

A red complex, $FeSCN^{2+}(aq)$, is formed from the reaction between iron ions and thiocyanate ions:

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftarrows FeSCN^{2+}(aq)$$

a. Water is added to an equilibrium mixture. Explain the impact this has on the intensity of the red colour. (2 marks)

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

The red intensity will drop significantly due to the dilution and the fact that the system moves in the reverse direction.

[2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system.

b. A few drops of KSCN are added to an equilibrium mixture.

i. Explain the impact of this change on the equilibrium constant value. (1 mark)

No change to K.

ii. State how the fin

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

Higher (While SCN^{-} is added, system partially opposes by decreasing back down, but overall, still increases).

c. An equilibrium mixture is heated, and the intensity of the red increases. Is this reaction exothermic or endothermic? Explain your answer. (2 marks)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system.

Endothermic. As the intensity of red increases, the system shifts forward overall and produces more $FeSCN^{2+}(aq)$. (1M)
As the mixture is heated, the system partially opposes change by decreasing temperature back down, favouring the endothermic reaction. This means the forward reaction is endothermic. (1 M)

Question 7 (6 marks)

The equation for the decomposition of nitrosyl bromide is:

$$2NOBr(g) \rightleftarrows 2NO(g) + Br_2(g)$$

The equilibrium constant at 350°C is 0.032 M

a. Determine the value of K for each of the following reactions:

i. $4NOBr(g) \rightleftarrows 4NO(g) + 2Br_2(g)$. (1 mark)

[2.7.3] Find equilibrium constant when equation is changed.

$(0.032)^2 = 0.00102$

ii. $NO(g) + \frac{1}{2}Br_2(g) \rightleftarrows NOBr(g)$. (1 mark)

[2.7.3] Find equilibrium constant when equation is changed.

$\frac{1}{\sqrt{0.032}} = 5.59$

b. A 2.0 L reactor contains 4 mol of NOBr, 4 mol of NO and 2 mol of Br_2. Which way does the reaction have to favour for equilibrium to be reached, or is the mixture already at equilibrium? (2 marks)

[2.7.4] Apply Q_c to find direction of equilibrium shift.

$Q_c = \frac{4^2 \times 2}{4^2} = 2$ As $Q_c > K_c$, the system needs to move backwards to achieve equilibrium.

c. 5.0 mol of NOBr is introduced to an empty reactor.

i. Will 2.5 mol of Br_2 form? Explain your answer. (1 mark)

[2.7.5] Apply RICE tables to find K_c.

No, in a reversible reaction, all reactant will not be used up.

ii. If the amount of NO to form was found to be 0.20 mol, what amount of Br_2 was formed? (1 mark)

[2.7.5] Apply RICE tables to find K_c.

Amount of Br_2 is 0.10 mol, as the mole ratio is 2: 1.

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Question 8 (6 marks)

The equilibrium reaction of ammonia with oxygen is shown below by the equation:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

Exactly 5.00 *mol* of ammonia and 10.00 *mol* of oxygen are heated in a closed 2.00 *L* sealed container. The reaction reaches equilibrium after 4.0 *min*.

a. If the reaction mixture contained exactly 2.50 *mol* of NO(g) when the system first reaches equilibrium, calculate the value of the equilibrium constant (K_c) at this temperature. (4 marks)

[2.7.5] Apply RICE tables to find K_c.

R	$4NH_3$	$+ 5O_2$	$\rightleftharpoons 4NO$	$+ 6H_2O$
n_i	5mol	10mol	0mol	0mol
n_c	−2.5mol	−3.125mol	+2.5mol	+3.75mol
n_e	2.5mol	6.875mol	2.5mol	3.75mol

$$K_c = \frac{[NO]^4[H_2O]^6}{[NH_3]^4[O_2]^5} = \frac{\left(\frac{2.5}{2}\right)^4 \times \left(\frac{3.75}{2}\right)^6}{\left(\frac{2.5}{2}\right)^4 \times \left(\frac{6.875}{2}\right)^5} = 0.0905\ M^1\ (3sf)$$

b. Temperature is decreased at 8.0 min. State the effect this has on the K_c value. Justify your answer. (2 marks)

[2.9.4] Find equilibrium constant changes due to temperature.

Decreasing the temperature decreased the K_c value - according to Le Chatelier's Principle, the system will partially oppose this decrease in temperature by favouring the backwards, exothermic reaction. As such, the concentration of reactants increases and the concentration of products decreases, decreasing the K_c value.

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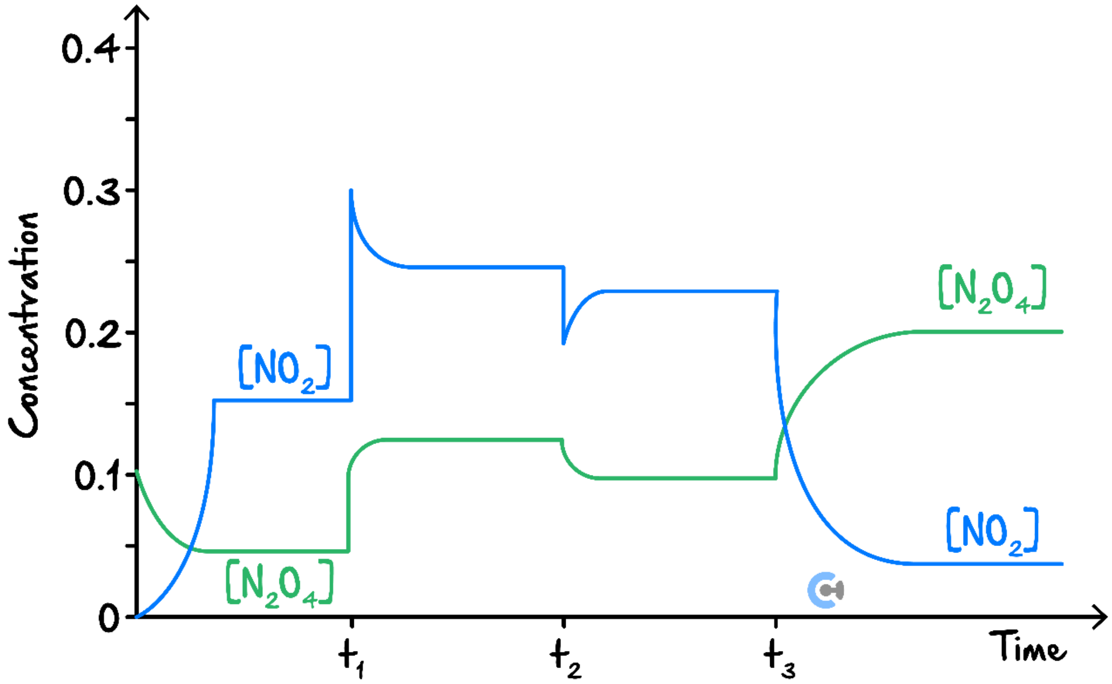
Question 9 (11 marks)

Dinitrogen tetroxide, N_2O_4, decomposes to form nitrogen dioxide, NO_2, as described by the chemical equation:

$$N_2O_4\ (g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = +57\ kJ\ mol^{-1}$$

A sample of pure dinitrogen tetroxide, with a concentration of 0.12 M, was placed in a flask and allowed to reach equilibrium. The graph below shows how the concentrations of the two gases vary when some changes were made to the equilibrium system:



a. How many times did the system reach equilibrium? (

[2.8.2] Graph effects of addition / removal of substances or pressure / volume changes on equilibrium system.

4 times.

b.

[2.9.3] Find the change made to system from equilibrium graph.

i. State the change was made to the system at t_1. (1 mark)

Volume was halved (volume decreased not accepted.

ii. Give an explanation of how this change affected the position of the equilibrium. (1 mark)

[2.8.1] Explain effects of addition/removal of substances or pressure/volume changes on equilibrium system.

There is an upward spike of both species which indicates a change in volume (probably halved)-this is the stress on the system.According to L.C.P.the system will respond by partially opposing the stress- it will go to the side with less mole (back reaction) to partially oppose the change.

c.

[2.9.3] Find the change made to system from equilibrium graph.

i. State the change that was made to the system at t_2. (1 mark)

Some NO_2 was removed from the system as shown by the decrease in concentration of NO_2 only.

ii. Explain how this change affects the rate of production of N_2O_4. (2 marks)

[2.6.1] Explain how factors increase frequency of collisions.

As NO_2 is removed, concentration decreases. This decreases total frequency of collisions, decreasing frequency of successful collisions with correct orientation. (1 M) this decreases rate of reaction. (1 M)
NOTE - The question asks for **rate** and not yield.

d.

[2.9.3] Find the change made to system from equilibrium graph.

i. State the change was made to the system at t_3. (1 mark)

There was a fall in the temperature.

ii. Give an explanation of how this change affected the position of the equilibrium. (1 mark)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system.

The system will oppose the decrease in temperature by going to the exothermic side which in the question is the backward reaction.

e.

[2.7.1] Write equilibrium constant expression & find its value (including units).

i. Write an expression for the equilibrium constant, K_C, for this reaction. (1 mark)

$K_c = [NO_2]^2 / [N_2O_4]$

ii. Calculate the K_C value just before the t_3 change. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units).

$K_c = [NO_2]^2 / [N_2O_4] = 0.23^2 / 0.10 = 0.53$ M

[2.9.4] Find equilibrium constant changes due to temperature.

iii. Which change at t_1, t_2 or t_3 will lead to a different value of K_C? (1 mark)

t_3 will be the only change that alters the K_c value.

Question 10 (2 marks)

[2.7.3] Find equilibrium constant when equation is changed.

Given the following information:

$$Cl_2(g) \rightleftharpoons 2Cl(g) \quad K = 1.13 \times 10^{-6}\ M \text{ at } 1100°C$$

For the following reaction:

$$2Cl(g) \rightleftharpoons Cl_2(g)$$

State the numerical value of the equilibrium constant for the reaction at the same temperature.

Reverse the equation and take reciprocal of K value.

$$2Cl(g) \rightleftharpoons Cl_2(g);\ K = \frac{1}{1.13 \times 10^{-6}}$$
$$= 8.85 \times 10^{-5}\ M^{-1}$$

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Question 11 (7 marks)

Consider the combustion of methane in oxygen in a 1 L container at a total pressure of 100 kPa. The temperature in the container is kept at a constant 400 K.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

a. Could measuring the total pressure inside the container throughout the reaction indicate the reaction rate? Explain your answer. (2 marks)

[2.6.3] Graph differences in rate & yield.

One mark is given for each of the following:

- for answering '**no**'
- explaining that the total pressure of the system would not change throughout the reaction (as three moles of gas would produce 3 moles of gas)

The reaction is repeated using the same amounts of oxygen and methane at 400 K, except a 0.5 L container is used.

b. State the pressure, in kPa, inside this new container. (1 mark)

[2.6.1] Explain how factors increase frequency of collisions.

The mark should be awarded for the answer of **200 kPa**.

c. Using collision theory, explain whether the reaction rate is higher, lower or the same. (2 marks)

[2.6.1] Explain how factors increase frequency of collisions.

One mark is awarded for stating that the reaction rate is **higher**, and one mark for each of the following points:

- the pressure is higher/the concentration of the reactants is higher
- this leads to an increase in collision frequency per se (hence an increase in **successful** collision frequency)

Hydrogen can react with ethane to form ethane using a palladium (Pd) catalyst in the following reaction:

$$C_2H_4(g) + H_2(g) \xrightarrow{Pd(s)} C_2H_6(g)$$

d. Use collision theory to explain fully how adding a catalyst affects the rate of production of ethane. (2 marks)

[2.6.2] Explain how temperature & catalyst affect the proportion of successful collisions.

One mark is awarded for each of the following points:

- a catalyst provides an alternative reaction pathway with a lower activation energy
- this leads to an increase in **successful** collision frequency, as there is a higher proportion of collisions that are successful, leading to a **higher reaction rate**

Question 12 (8 marks)

Sulphur dioxide (SO_2) can react reversibly with oxygen (O_2) to form sulphur trioxide (SO_3), as per the following reaction equation:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The equilibrium constant (K) of this reaction is 10.3 M^{-1}.

a. Write an expression for the equilibrium constant (K) of the above reaction. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units).

The mark is awarded for **either** of the following expressions:

- $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$
- $\frac{[SO_3]^2_{eq}}{[SO_2]^2_{eq}[O_2]_{eq}}$

A 1.00 L vessel containing a mixture of SO_2, O_2 and SO_3 is at equilibrium. It is found that the container has 0.132 mol of O_2 and 0.100 mol of SO_2.

[2.7.1] Write equilibrium constant expression & find its value (including units).

b. Determine the amount, in mol, of SO_3 in the container at equilibrium. (1 mark)

One mark is awarded for **EACH** of:

- writing any of the following:
  - $[SO_3]_2 = K[SO_2][O_2]^2$ or equivalent expression
  - $[SO_3] = 10.3 \times 0.100^2 \times 0.132$
  - $[SO_3] = 0.117$ M
- correct answer for the **amount** of SO_3 in the container at equilibrium
  - $n(SO_3) = 0.117$ mol

$$\begin{aligned}
[SO_2]_{eq} &= \frac{n(SO_2)}{V} \\
&= \frac{0.100}{1.00} \\
&= 0.100\ M \\
[O_2]_{eq} &= \frac{n(O_2)}{V} \\
&= \frac{0.132}{1.00} \\
&= 0.132\ M \\
[SO_3]^2_{eq} &= K[SO_2]^2_{eq}[O_2]_{eq} \\
&= 10.3 \times 0.100^2 \times 0.132 \\
&= 0.0136 \\
[SO_3]_{eq} &= 0.117\ M \\
n(SO_3) &= [SO_3]_{eq} \times 1.00 \\
&= 0.117\ mol
\end{aligned}$$

To this container, 0.100 mol of SO_2 was added.

c.

[2.8.1] Explain effects of addition / removal of substances or pressure / volume changes on equilibrium system.

i. In which direction will the equilibrium shift? Circle your answer. (1 mark)

The mark should be awarded if '**forwards**' is circled.

ii. Explain your answer to part **c. i.** using **reaction rates.** (2 marks)

[2.6.1] Explain how factors increase frequency of collisions.

One mark is awarded for each of the following:

- $[SO_2]$ initially increases (do not accept $n(SO_2)$ initially increases as the important point is that $[SO_2]$ initially increases)
- this increases the rate of the forward reaction (by increasing successful collision frequency between SO_2 and O_2) **making the forward reaction rate faster than the back reaction rate** (which is initially the same as before the addition of SO_2)

d. Calculate the value of the reaction quotient/concentration fraction (Q) as soon as the 0.100 mol of SO_2 was added. Explain briefly how the value of Q subsequently changes over time. (3 marks)

[2.7.4] Apply Q_c to find direction of equilibrium shift.

$$Q = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{0.117^2}{\mathbf{0.200^2} \times 0.132} = 2.59$$

The above is derived from using the rounded value of $[SO_3] = 0.117$ M. Alternatively, you can use the unrounded value of $[SO_3]$ and get an answer of **2.58**.

An alternative method:

$$Q_{new} = \frac{Q_{original}}{4} = \frac{10.3}{4} = 2.58$$

One mark is awarded for each of the following:

- either substituting $[SO_2] = 0.200$ M into the reaction quotient expression **OR** dividing 10.3 (original value for Q) by 4
- obtaining either a value of **2.58** or **2.59**

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