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VCE Chemistry ¾
Rate-Yield Conflict [2.9]
Homework Solutions

Admin Info & Homework Outline:

Student Name	
Questions You Need Help For	
Compulsory Questions	Pg 2-Pg 18
Supplementary Questions	Pg 19-Pg 26

Section A: Compulsory Questions (64 Marks)

Sub-Section [2.9.1]: Explain Effects of Temperature, Inert Gas or Catalyst on Equilibrium System

Question 1 (2 marks)

a. An inert gas is added to a gaseous equilibrium system. The temperature is then increased, and dynamic equilibrium is re-established. Which of the following is incorrect? (1 mark)

A. The concentrations of the reactants and products have changed.

B. The rate of the forward reaction is greater than the rate of the reverse reaction.

C. The inert gas causes no change to the system.

D. The increase in temperature causes the rate of the forward and reverse reaction to increase.

b. In the following equilibrium system, methane can decompose in the following manner:

$$2CH_4(g) \leftrightarrow C_2H_2(g) + 3H_2(g) \quad \Delta H = +300\ kJ\ mol^{-1}$$

State how the system will respond to a temperature decrease. (1 mark)

Reaction shifts reverse.

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Question 2 (6 marks)

The following equilibrium system is investigated.

$$2A(g) + B(g) \rightleftharpoons C(g) \quad \Delta H > 0$$

a. Explain the effect of subsequently adding an inert gas on:

i. The equilibrium constant K_c. (1 mark)

Only temperature can affect the equilibrium constant; K_c does not change. (1)

ii. The concentration of the product. (1 mark)

Adding an inert gas to an equilibrium system does not change the equilibrium position. The concentration of the product does not change. (1)

b. Explain the effect of adding a catalytic powder to this equilibrium system. (2 marks)

Adding a catalyst increases the rate of both the forward and reverse reactions (1)
by providing an alternate reaction pathway with a lower activation energy. The catalyst will not affect the concentrations of the reactants or the products (2).

c. Explain the effect of increasing temperature on the system. (2 marks)

By increasing temperature, the system will partially oppose the change by decreasing temperature back down, favouring the forwards endothermic reaction. (1)
As such, the system will shift to the right. (1)

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Question 3 (5 marks)

A student removes an ampule of a colourless gas X(g) from a cold storage container and notices that it immediately begins to turn orange. The student knows that X(g) takes part in the following equilibrium reaction.

$$Y(g) + W(g) \rightleftharpoons X(g)$$

a. State whether the above reaction is endothermic or exothermic. Justify your answer. (3 marks)

Exothermic. Taking the ampule out of cold storage will increase the temperature of X(g). The system partially opposes an increase in temperature by favouring the endothermic reaction (1). Since X(g) is colourless, the reverse reaction must be taking place (2) to produce Y(g) and W(g), one of which must be orange. Therefore, the reverse reaction is endothermic, and the reaction (as stated) is exothermic (3).

b. Explain the effect of this change on the equilibrium constant K_c. (2 marks)

The increase in temperature is partially opposed by the endothermic reaction, which is the reverse reaction (1).
The concentration of the reactants will increase, and the concentration of the product will decrease. Since the equilibrium constant is the ratio of product concentration to reaction concentration, its value will decrease (2) .
(Can be stated using the expression for K_c.)

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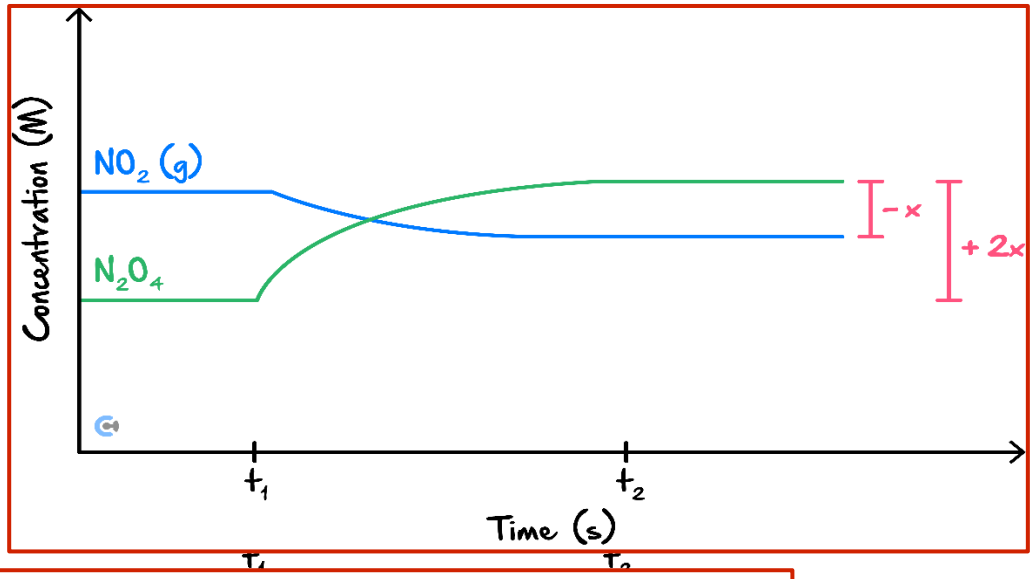
Sub-Section [2.9.2]: Graph Effects of Temperature, Inert Gas Catalyst on Equilibrium Systems

Question 4 (3 marks)

a. The temperature in the following system is increased at t_1. Sketch the shift in the equilibrium position, given that equilibrium is re-established at t_2. (2 marks)

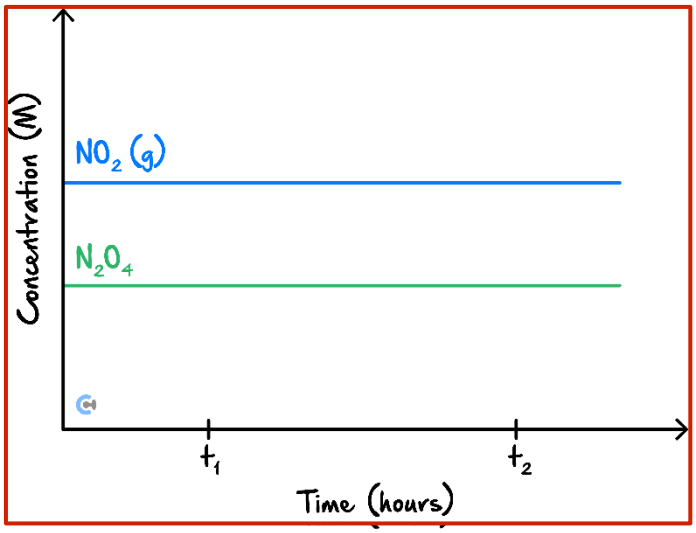
$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \Delta H < 0$$



(1) Correct shapes + Equilibrium established at the same time.
(2) Correct mole ratios.

b. Neon gas is added to the following equilibrium system. Sketch the shift in the equilibrium position. (1 mark)

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \Delta H < 0$$



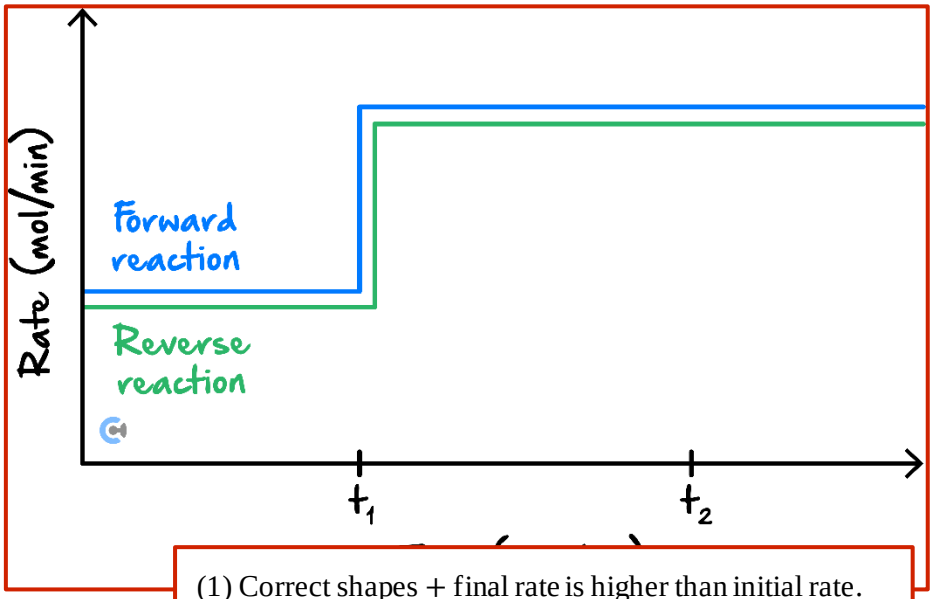
(1) Both lines extended.

Question 5 (3 marks)

Consider the following equilibrium system:

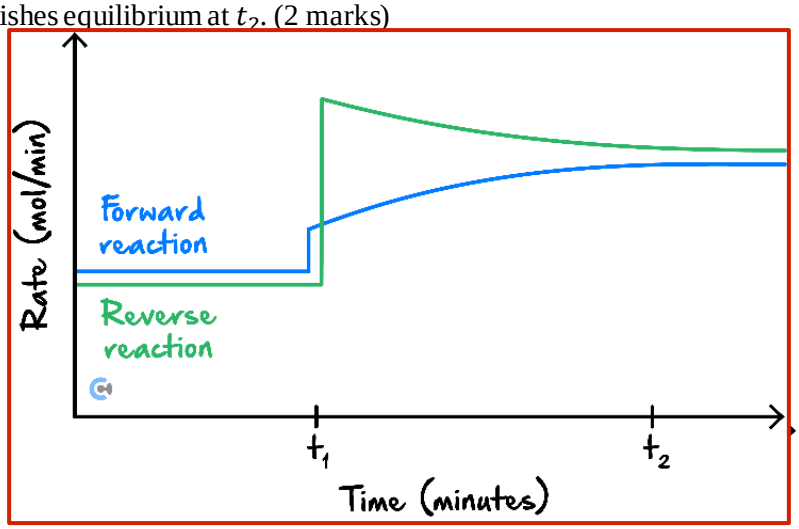
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

a. Catalytic pebbles are added to the system. Sketch the change to the system from t_1 to when the system re-establishes equilibrium at t_2. (1 mark)



(1) Correct shapes + final rate is higher than initial rate.

b. The temperature of an identical system is increased. Sketch the change to this system from t_1 to when the system re-establishes equilibrium at t_2. (2 marks)



(1) Reverse reaction is higher than forward reaction
(2) Rates are equal at equilibrium + final rate is higher than initial.

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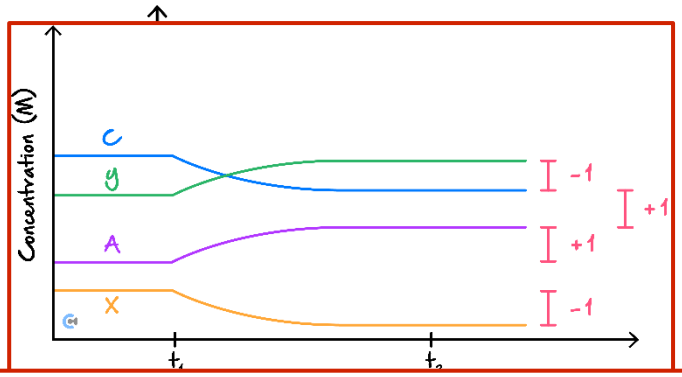
Question 6 (4 marks)

A chemical engineer is designing a process for the synthesis of a chemical X(g) using the equilibrium system below.

$$A(g) + Y(g) \rightleftharpoons C(g) + X(g) \qquad \Delta H < 0$$

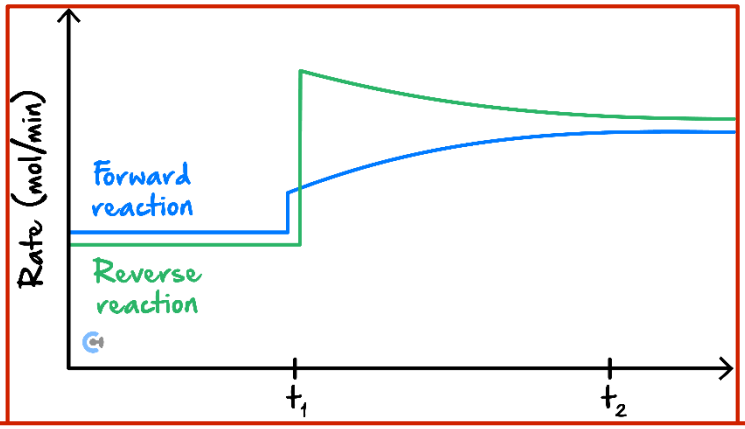
The engineer increases the temperature of the system.

a. Sketch the change in the equilibrium system on the graph below from t_1 to when the system re-establishes equilibrium at t_2. (2 marks)



(1) All four changes have the correct mole ratios + all four reach equilibrium at the same time.
(2) C and X decrease, A and Y increase.

b. Sketch the change in the rate of the system below from t_1 to when the system establishes re-equilibrium at t_2. (2 marks)



(1) Reverse reaction initially increases higher than forward reaction.
(2) Rates are equal at equilibrium, and the final rate is higher than the initial rate.

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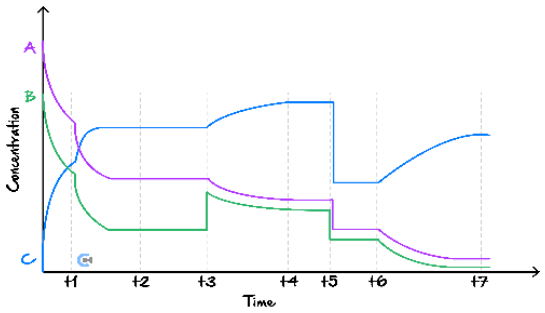
Sub-Section [2.9.3]: Find the Change Made to System from Equilibrium Graph

Question 7 (4 marks)

Several changes have been made to the equilibrium system below.

$$A(g) + B(g) \rightleftharpoons 2C(g) \qquad \Delta H > 0$$

The concentrations are recorded and graphed as shown.



What change was made to the system between:

a. t_1 and t_2? (1 mark)

A. A noble gas has been added to the system.

B. The temperature of the system has been increased.

C. 1.0 mol of C(g) has been added to the system.

D. The temperature of the system has been decreased.

b. t_2 and t_3? (1 mark)

A. A catalyst has been added to the system.

B. 1.0 mol of B(g) has been added to the system.

A. The temperature of the system has been decreased.

B. 1.0 mol of A(g) has been taken out of the system.

c. t_3 and t_4? (1 mark)

A. The temperature of the system has been increased.

B. A noble gas has been added to the system.

C. The volume of the system has been decreased.

D. 1.0 mol of B(g) has been added to the system.

d. t_5 and t_6? (1 mark)

A. The volume of the system has been increased.

B. 1.0 mol of C(g) has been added to the system.

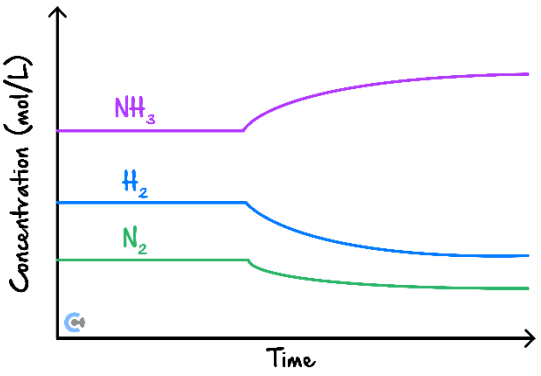
C. A noble gas has been added to the system.

D. The temperature of the system has been decreased.

Question 8 (4 marks)

A chemist attempting to maximise the yield of $NH_3(g)$, makes two changes to an equilibrium system as shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$



a. Describe the changes made to the system. Justify your response. (2 marks)

Temperature has been decreased; the forward exothermic reaction is taking place and the curves match those of a temperature change (1).

A noble gas has been added; noble gases do not cause a change in the equilibrium position or a catalyst has been added; catalysts do not cause a change in the concentration of reacting species (2), only in the rates of reaction.

b. Explain why the **two** of the changes described in **part a.** are made in conjunction with reference to the rate-yield conflict. (2 marks)

Decreasing temperature increases the yield of NH_3 but also decreases the rate of reaction, resulting in a rate-yield conflict (1).
To mitigate this, the chemist adds a catalyst to increase the rate of reaction (2).

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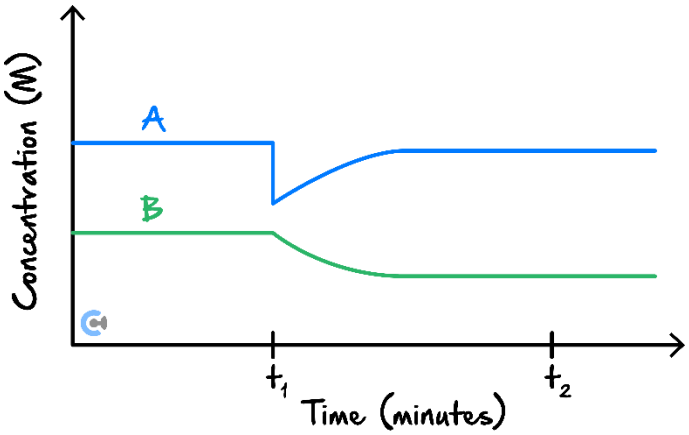
Question 9 (3 marks)

A chemist makes a change to an equilibrium system in solution at t_2 as shown below. The temperature is kept constant.

$$B(aq) \rightleftharpoons A(aq)$$



a. Describe the change the chemist made. Justify your answer. (2 marks)

The concentration of the product has been decreased (1). The forward reaction occurs at a higher rate than the back reaction between t_2 and t_3, which results in more product being produces; this is consistent with Le Chatelier's principle (2).
OR: The back reaction decreases in rate significantly as there are fewer reacting particles (which are products for the back reaction). (2)
Note: Dilution could not cause this change and thus, should not be awarded any marks.

b. Describe change in the equilibrium constant at t_3 compared to t_1 as a result of the change made at t_2. (1 mark)

Temperature does not change; the equilibrium constant does not change. (1)

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Sub-Section [2.9.4]: Find Equilibrium Constant Changes Due to Temperature

Question 10 (1 mark)

The temperature of the equilibrium system below is increased.

$$A(aq) + B(aq) \rightleftharpoons C(aq) \quad \Delta H < 0$$

Which of the following is true?

A. The value of the equilibrium constant stays the same.

B. The concentration of $C(aq)$ increases.

C. The value of the equilibrium constant decreases.

D. The system is colder than before the change.

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Question 11 (4 marks)

A chemist is attempting to determine the thermochemical nature of the following equilibrium system; that is, whether the system is exothermic or endothermic.

$$W(g) \rightleftharpoons X(g) + Y(g)$$

The chemist finds that the value of the equilibrium constant increases when the temperature of the system is decreased.

a. Explain what the increase in the value of the equilibrium constant indicates with reference to the reactants and products. (2 marks)

The equilibrium constant is the ratio of products to reactants (1) OR a measure of reaction progress for some equilibrium position (1). The increase in the equilibrium constant indicates an increase in product concentration and a decrease in reactant concentration (2).

b. Explain whether this system is exothermic or endothermic. (2 marks)

When the temperature is decreased, the concentration of products increases OR the concentration of reactants decreases; the forward reaction takes place (1). A decrease in temperature is partially opposed by the exothermic reaction and therefore, the forward reaction must be exothermic (2).

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Question 12 (7 marks)

The following system has been allowed to reach equilibrium.

$$2A(aq) \rightleftharpoons 3B(aq) + 2C(aq) \quad \Delta < 0$$

At equilibrium, there are 2.00 mol of A and 1.00 mol of B in 1 litre of solution. The value of the equilibrium constant is 4.00 M^3.

a. Calculate the concentration of C in the solution. (2 marks)

$$K_c = \frac{[B]^3[C]^2}{[A]^2} \Rightarrow [C] = \sqrt{\frac{K_c\,[A]^2}{[B]^3}} \quad (1)$$

$$[C] = \sqrt{\frac{4(2.00)^2}{(1.00)^3}} = 4.00\ M \quad (2)$$

A chemist decides to change the temperature of the system.

The chemist measures the concentration of C to be 3.50 M after the change in temperature.

b. Explain whether the chemist increases or decreases the temperature of the system. (2 marks)

The concentration of C decreases and therefore the reverse, endothermic reaction must be taking place (1). The endothermic reaction partially opposes an increase in temperature according to Le Chatelier's principle and thus, the chemist increases the temperature of the system (2).

c.

i. State the expression for the equilibrium constant. (1 mark)

$K_c = \frac{[B]^3[C]^2}{[A]^2}\ M^3$ (units not required)

ii. Calculate the new equilibrium constant. (2 marks)

$4 + \Delta n = 3 \Longrightarrow \Delta n = -0.50$

$[A] = 2 - \frac{2}{2}\Delta n = 2.50\ M$ (1)

$[B] = 1 + \frac{3}{2}\Delta n = 0.25\ M$

$K_c = \frac{[0.25]^3[3.50]^2}{[2.50]^2} = 0.031\ M^3$ (2)

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Sub-Section [2.9.5]: Find Optimum Operating Conditions in All Circumstances Such as the Rate-Yield Conflict

Question 13 (2 marks)

A chemist is trying to increase the yield of NH_3 in the following equilibrium system.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

Suggest **one** change that could achieve this result and does not change the equilibrium constant. Justify your answer.

- More reactants could be added to the system; the system would partially oppose the addition by shifting equilibrium in the forward direction, producing more NH_3.
- NH_3 could be removed from the system; the system would partially oppose the addition by shifting equilibrium in the forward direction, producing more NH_3.
- The pressure of the system could be increased; the system would partially oppose the increase in pressure by shifting equilibrium to the side with the least number of particles, in this case the products, which will produce more NH_3.

(1) Suggestion that is NOT associated with temperature.
(2) Appropriate justification.

Question 14 (4 marks)

A chemist is trying to increase the yield of NH_3 in the following equilibrium system.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

a. Explain the effect of decreasing the temperature of the system on the equilibrium position. (1 mark)

A decrease in temperature is partially opposed by the exothermic reaction which, in this case, is the forward reaction. This increases the concentration of NH_3. (1)

b. Explain the effect of decreasing the temperature of the system on the rate of the forward reaction at equilibrium. (2 marks)

A decrease in temperature reduces the kinetic energy of reacting particles (1) which both decreases the frequency of collisions and the proportion of reacting particles with energy higher than the activation energy. The number of successful collisions decreases, and the rate of the forward reaction also decreases. (2)

c. Explain why decreasing the temperature of this system is not optimal for maximising production of NH_3. (1 mark)

While the concentration of NH_3 is increased, the rate of reaction is decreased. (1)

Question 15 (4 marks)

A chemical engineer is attempting to improve the yield of SO_3 for an industrial process. The following equilibrium system is used to produce SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H < 0$$

a. A civil engineer working on the project suggests decreasing the system's temperature to increase the yield of SO_3. Evaluate this suggestion with reference to both rate and yield. (3 marks)

Decreasing the system's temperature would cause the system to partially oppose using the exothermic forward reaction, which would increase the concentration of SO_3 (1). However, decreasing the temperature of the system would also decrease the rate of reaction (2). This is a conflict and as such, would not significantly improve the yield of SO_3 (3).

b. A "*simple and practical*" change is being proposed to improve the yield of SO_3. Suggest **one** change which can aid with this. (1 mark)

Removing SO_3 as it is produced would cause the system to partially oppose the decrease in SO_3 using the forward reaction, which in turn would produce more SO_3, increasing yield (1).

Note: "Simple and practical" implies this is the only solution; however, any suggestion that increases yield should be accepted **provided there is sufficient justification**; accept no answer without sufficient justification.

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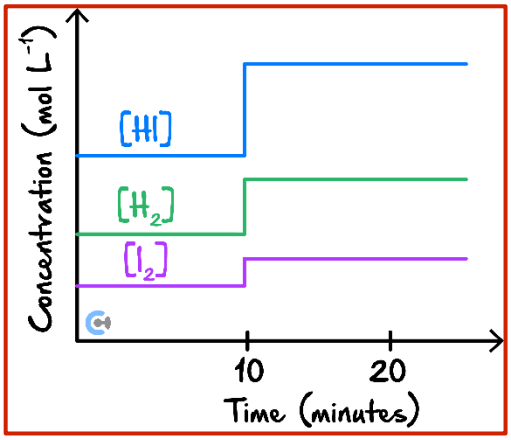
Sub-Section: The 'Final Boss'

Question 16 (8 marks)

A chemist requires concentrated hydrogen iodide. Hydrogen iodide disassociates according to the following equation.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \qquad \Delta H > 0$$

The graph below shows the concentrations of each reacting reagent after the chemist's first attempts at mitigating the effects of disassociation.



a. Suggest a change the chemist could have made to the system at 10 minutes. Justify your response. (2 marks)

The volume of the container has been decreased (1). All three concentrations have been increased simultaneously and the concentrations do not change, which is consistent with a change in volume (2) and what is expected due to the number of particles on each side of the equation respectively.

At 20 minutes, the chemist adds helium gas to the system.

b. Continue the graph on the axes provided above for $[H_2]$ and $[I_2]$ to represent this change. (1 mark)

At 30 minutes, the chemist finds that the concentration of H_2 is 1.00 *M*, the concentration of I_2 is 0.50 *M* and the concentration of HI is 3.00 *M*.

c. Calculate the equilibrium constant value. (1 mark)

$$K_c = \frac{[I_2][H_2]}{[HI]^2}$$

$$K_c = \frac{(0.50)(1.00)}{(3.00)^2} = 0.056$$

The chemist increases the temperature of the system.

d. Describe the change to the value of the equilibrium constant. Explain your answer. (2 marks)

The system partially opposes the increase in temperature using the endothermic forward reaction. This increases the concentration of the products and decreases the concentration of the reactants (1). Since the equilibrium constant is the ratio of product to reactant, the value of the equilibrium constant will increase (2).

e. A colleague of the chemist argues that increasing the temperature of the system creates a rate-yield conflict. Evaluate the colleague's argument and state whether they are correct. (2 marks)

The colleague is correct (1). Increasing the temperature of the reaction increases the rate of reaction. However, the system will also partially oppose the increase in temperature using the endothermic forward reaction, leading to a decrease in HI concentration (2). This is a rate-yield conflict.

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Section B: Supplementary Questions (28 Marks)

Sub-Section [2.9.1]: Explain Effects of Temperature, Inert Gas or Catalyst on Equilibrium System

Question 17 (1 mark)

An inert gas and a catalyst are added to an equilibrium system simultaneously. What is the effect on the equilibrium system?

A. The rates of the forward and reverse reaction remain the same and the concentrations of all reagents increase.

B. The rates of the forward and reverse reactions increase and the concentration of the reagents remains the same.

C. The rate of the forward reaction increases and the concentration of the products increase.

D. Only the rate of the reverse reaction increases and the concentration of the reagents remains the same.

Question 18 (4 marks)

Consider the following equilibrium system.

$$2A(g) + B(g) \rightleftharpoons C(g) \quad \Delta H > 0$$

a. Explain the effect of increasing the temperature of the system. (2 marks)

An increase in temperature will be partially opposed by the endothermic forward reaction (1). This will increase the concentration of the product C. (2)

b. Explain the effect of adding a catalytic powder to the system while increasing the temperature. (2 marks)

Adding a catalyst increases the rate of both the forward and reverse reactions (1) by providing an alternate reaction pathway with a lower activation energy. As a result, the system will establish equilibrium faster after the increase in temperature (2).

Question 19 (4 marks)

The following equilibrium system is used in ColdGlow glow sticks.

$$2X(g) \rightleftharpoons Z(g) + Y(g)$$

ColdGlow glow sticks get brighter based on how cold their surroundings are. Both Z and Y are colourless gases, whereas X has a distinct fluorescent red colour.

a. State whether the above reaction is endothermic or exothermic. Justify your answer. (2 marks)

As the system gets colder (as temperature decreases), the concentration of X increases; the reverse reaction will partially oppose a decrease in temperature and is exothermic (1). The forward reaction is, therefore, endothermic (2).

b. The volume of the glow sticks is decreased and the temperature can be assumed to be constant. Describe and explain any observable effects on the system. (2 marks)

The concentration of all reagents will increase (1) and, as the number of particles on each side of the equation is the same, the concentrations will not decrease. Since the brightness of the ColdGlow glow sticks are directly proportional to the concentration of X, the glow sticks will glow brighter (2).

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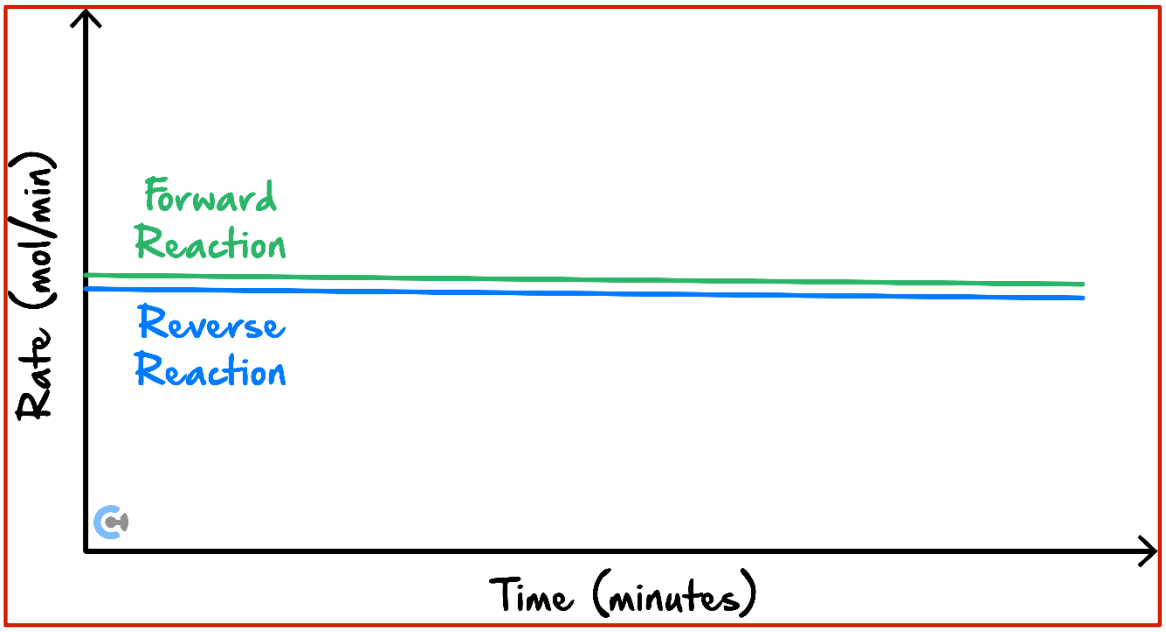
Sub-Section [2.9.2]: Graph Effects of Temperature, Inert Gas Catalyst on Equilibrium Systems

Question 20 (1 mark)

A noble gas is added to an equilibrium system. Sketch the change to the system.



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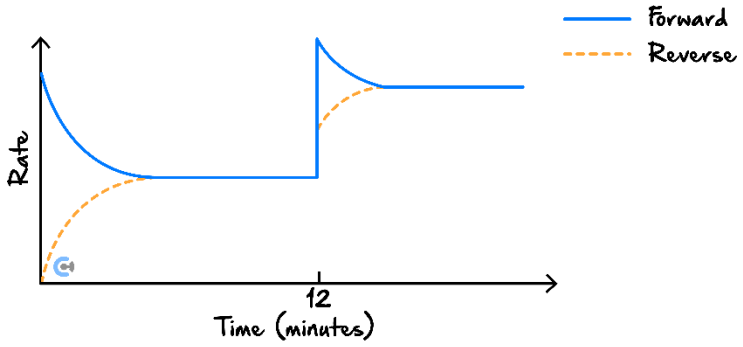
Sub-Section [2.9.3]: Find the Change Made to System from Equilibrium Graph

Question 21 (1 mark)

A change is made to a gaseous equilibrium system at 12 minutes after the system is set up. The effect of the change is shown.



The change made to the system could be:

A. Reactants were added to the system.

B. The temperature was decreased.

C. A catalyst was added to the system.

D. The volume of the system was increased.

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Sub-Section [2.9.4]: Find Equilibrium Constant Changes Due to Temperature

Question 22 (1 mark)

Consider an endothermic equilibrium system for which the equation is unknown. The temperature of the system is increased. Which of the following would be observed once the system re-established equilibrium?

A. The rate of the reverse reaction only, has decreased compared to before the temperature change.

B. The concentration of the reactants has increased.

C. The value of the equilibrium constant has increased.

D. The system feels colder.

Question 23 (7 marks)

The following system has been allowed to reach equilibrium.

$$4X(aq) \rightleftharpoons Y(aq) + Z(aq) \qquad \Delta < 0$$

At equilibrium, there are $4.00\ mol$ of X and $6.00\ mol$ of Y in 2 litre of solution. The value of the equilibrium constant is $0.1875\ M^{-2}$.

a. Calculate the concentration of Z. (2 marks)

$$K_c = \frac{[Y][Z]}{[X]^4} \Rightarrow [Z] = \frac{K_c\,[X]^4}{[Y]} \quad (1)$$

$$[Z] = \frac{0.1875\ \left(\frac{4}{2}\right)^4}{\frac{6}{2}} = 1.00\ M \quad (2)$$

The chemist decides to change the temperature of the system and measures the concentration of Z to be 1.10 *M* after the change in temperature.

b. Explain whether the chemist increases or decreases the temperature of the system. (2 marks)

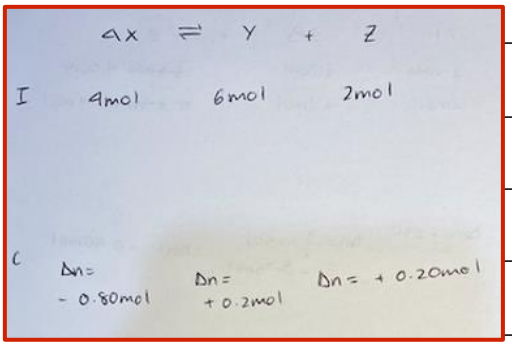
The concentration of Z increases and therefore the forward, exothermic reaction must be taking place (1). The exothermic reaction partially opposes a decrease in temperature according to Le Chatelier's principle and thus, the chemist decreases the temperature of the system (2)

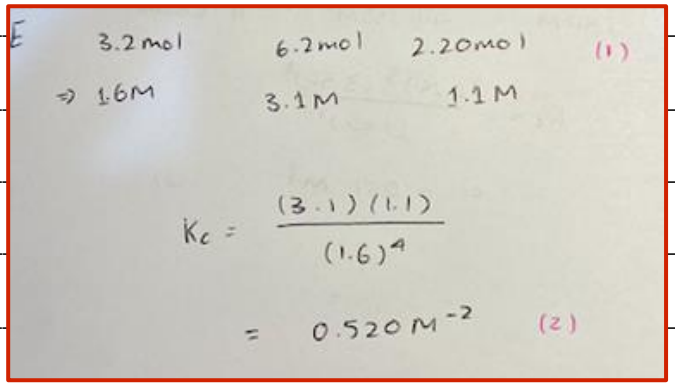
c.

i. State the expression for the equilibrium constant. (1 mark)

$K_c = \frac{[Y][Z]}{[X]^4}$ M^{-2} (units not required)

ii. Calculate the new equilibrium constant. (2 marks)





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Sub-Section [2.9.5]: Find Optimum Operating Conditions in All Circumstances such as the Rate-Yield Conflict

Question 24 (1 mark)

A chemist is trying to maximise the yield of P in an industrial process involving the equilibrium system shown below.

$$2\text{P(aq)} \rightleftharpoons \text{Q(aq)} + 2\text{R(aq)} \qquad \Delta H > 0$$

Which of the following could be applied to the system to maximise the yield of P?

A. Decreasing the volume of the container.

B. Decreasing the temperature of the system.

C. Reacting P with another species in a precipitate reaction.

D. Removing products as they are produced.

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Question 25 (8 marks)

A chemist is trying to increase the yield of Z in the following equilibrium system.

$$X(g) \rightleftharpoons 2Z(g) \qquad \Delta H > 0$$

a. Explain the effect of decreasing the temperature of the system on the value of the equilibrium constant. (2 marks)

A decrease in temperature is partially opposed by the exothermic reverse reaction. This results in an increase in [X] and a decrease in [Z] (1). Since the equilibrium constant is the ratio of products to reactants, the value of the equilibrium constant will decrease (2).

b. Compare the effect of decreasing the temperature of the system on the rate of the forward reaction at equilibrium and the rate of the reverse reaction at equilibrium. (2 marks)

Both the forward and reverse reaction, at dynamic equilibrium, must be occurring at the same rate (1). The effect of decreasing the temperature, therefore, is the same for rates of both the forward and reverse reactions (2).

c. Explain why increasing the volume of this system is not optimal for increasing the rate and yield of Z with explicit reference to collision theory and Le Chatelier's principle. (4 marks)

Increasing the volume will decrease the overall pressure of the system. According to Le Chatelier's principle, this will be opposed by favouring the side with more particles (1), the products. This will increase the concentration of Z (2). However, decreasing the pressure of the system will reduce the number of reacting particles in a given area and therefore decrease the number of collisions (3). This will reduce the number of successful collisions and the rate of reaction (4). This is a rate-yield conflict and thus, is not ideal.

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