

**SECTION 10 Chemical Equilibrium**

**Multiple-Choice Questions**

ASL05\_01

In which of the following systems will the equilibrium position shift to the left in response to an increase in pressure of the system?

- A.  $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
- B.  $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2\text{HCl}(\text{g})$
- C.  $4\text{Fe}(\text{s}) + 3\text{O}_2(\text{g}) \rightleftharpoons 2\text{Fe}_2\text{O}_3(\text{s})$
- D.  $2\text{SO}_3(\text{g}) \rightleftharpoons 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g})$

DSE11SP\_29

Consider the following system at equilibrium:



What would be the effect on the rates of the forward and backward reactions if the temperature of the system were lowered?

Forward reaction rate	Backward reaction rate
A. Decreases	Increases
B. Decreases	No change
C. Decreases	Decreases
D. Increases	Decreases

DSE11SP\_35

1<sup>st</sup> statement

Catalysts are used in many industrial processes.

2<sup>nd</sup> statement

Catalysts would not affect the percentage of the product in the equilibrium mixture.

DSE12PP\_26

A mixture of  $\text{N}_2\text{O}_4(\text{g})$  and  $\text{NO}_2(\text{g})$  is allowed to attain equilibrium in a gas syringe at room temperature:



The gas mixture in the syringe is compressed rapidly. Which of the following statements correctly describes the expected observation?

- A. The colour of the mixture becomes paler.
- B. The colour of the mixture becomes darker.
- C. The colour of the mixture becomes paler instantaneously and then darker.
- D. The colour of the mixture becomes darker instantaneously and then paler.

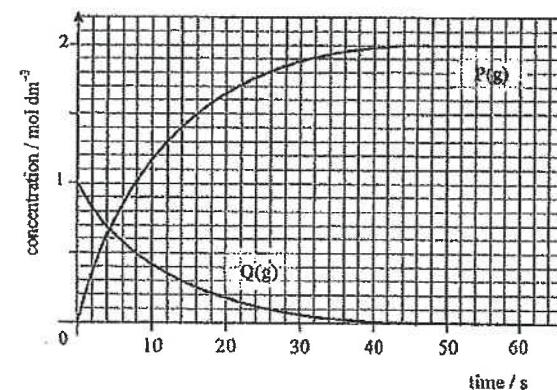
DSE12PP\_31

Which of the following is/are characteristic(s) of chemical equilibrium?

- (1) When a catalyst is added to an equilibrium mixture, the equilibrium position changes.
  - (2) When equilibrium is attained, the rate of forward reaction and that of backward reaction are equal.
  - (3) Equilibrium can be attained from either direction of the reaction.
- |                     |                     |
|---------------------|---------------------|
| A. (1) only         | B. (2) only         |
| C. (1) and (3) only | D. (2) and (3) only |

DSE12\_26

The concentration-time graph for a certain chemical reaction in a closed vessel of fixed volume is shown below:



Which of the following chemical equations correctly represents the reaction?

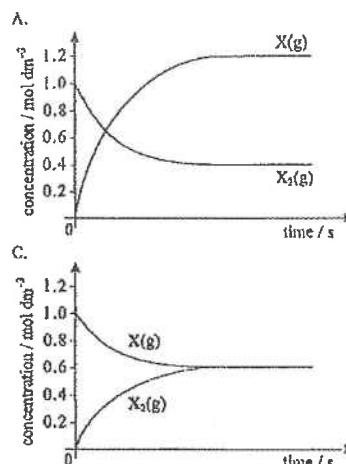
- |  |  |
|--|--|
| A. $\text{P}(\text{g}) \rightleftharpoons \text{Q}(\text{g})$  | B. $\text{Q}(\text{g}) \rightleftharpoons \text{P}(\text{g})$  |
| C. $\text{P}(\text{g}) \rightleftharpoons 2\text{Q}(\text{g})$ | D. $\text{Q}(\text{g}) \rightleftharpoons 2\text{P}(\text{g})$ |

## DSE12\_27

In a 1 dm<sup>3</sup> closed container, 1 mole of X<sub>2</sub>(g) undergoes decomposition to form X(g) until equilibrium is attained. The chemical equation concerned is shown below:



Which of the following graphs correctly shows the variation in concentration of X<sub>2</sub>(g) and X(g) with time?



## DSE13\_35

1<sup>st</sup> statement

Increasing reaction temperature can increase the yield for all reversible chemical reactions.

2<sup>nd</sup> statement

Increasing reaction temperature can shorten the time needed to attain equilibrium for all reversible chemical reactions.

## DSE13\_27

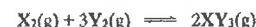


A mixture of X<sub>2</sub>(g) and Y<sub>2</sub>(g) was introduced into a 2.0 dm<sup>3</sup> closed vessel kept at a fixed temperature. When the system attained equilibrium, the vessel contained 0.4 mol of X<sub>2</sub>(g), 0.3 mol of Y<sub>2</sub>(g) and 0.4 mol of XY<sub>3</sub>(g).

Which of the following is the numerical value of K<sub>c</sub> for the above reaction at this temperature?

- |         |         |
|---------|---------|
| A. 3.3  | B. 6.7  |
| C. 14.8 | D. 59.3 |

## DSE13\_28



Which of the following combinations shows the effects of a catalyst on the rate of forward reaction, rate of backward reaction and the yield of XY<sub>3</sub>(g)?

	<u>Rate of forward reaction</u>	<u>Rate of backward reaction</u>	<u>Yield of XY<sub>3</sub>(g)</u>
A.	Increased	Increased	Unchanged
B.	Unchanged	Unchanged	Unchanged
C.	Increased	Decreased	Increased
D.	Decreased	Increased	Decreased

## DSE14\_26

Consider the information below:

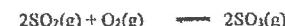
<u>Reaction</u>	<u>Equilibrium constant at 25°C</u>
A(aq) + B(aq) ⇌ C(aq) + D(aq)	K <sub>1</sub>
C(aq) + D(aq) ⇌ E(aq) + F(aq) + G(aq)	K <sub>2</sub>
E(aq) + F(aq) + G(aq) ⇌ A(aq) + B(aq)	K <sub>3</sub>

Which of the following combinations is correct

<u>Relationship of K<sub>1</sub>, K<sub>2</sub> and K<sub>3</sub></u>	<u>Unit of K<sub>3</sub></u>
A. $K_3 = \frac{1}{K_1 \times K_2}$	mol dm <sup>-3</sup>
B. $K_3 = \frac{1}{K_1 \times K_2}$	mol <sup>-1</sup> dm <sup>3</sup>
C. $K_3 = K_1 \times K_2$	mol dm <sup>-3</sup>
D. $K_3 = K_1 \times K_2$	mol <sup>-1</sup> dm <sup>3</sup>

## DSE14\_31

The following system attained equilibrium at a certain temperature:



Which of the following statements is / are correct when the volume of the system is decreased while the temperature remains unchanged?

- (1) The value of K<sub>c</sub> increases.
  - (2) The equilibrium position shifts to the right.
  - (3) The rate of decomposition of SO<sub>3</sub>(g) increases.
- |                     |                     |
|---------------------|---------------------|
| A. (1) only         | B. (2) only         |
| C. (1) and (3) only | D. (2) and (3) only |



Direction: Questions DSE17\_31 and DSE17\_32 refer to the following reaction involving four miscible liquids.



At 25°C, the equilibrium constant  $K_c$  for the reaction is 2.5. In an experiment, 1.0 mol of W(l) and 1.0 mol of X(l) are placed in a closed container keeping at 25°C. When equilibrium is attained, the total volume of the reaction mixture is 0.20 dm<sup>3</sup>.

#### DSE17\_31

How many moles of Y(l) would be present in the container when equilibrium is attained?

- A. 0.44
- B. 0.61
- C. 0.71
- D. 0.83

#### DSE17\_32

When equilibrium is attained, which of the following would increase the number of moles of Y(l)?

- (1) Removing Z(l) from the reaction mixture
- (2) Increasing the volume of the container
- (3) Increasing the temperature of the reaction mixture
- A. (1) only
- B. (2) only
- C. (1) and (3) only
- D. (2) and (3) only

#### DSE17\_34

Consider the following equilibrium system:



Which of the following statements are INCORRECT?

- (1) [CrO<sub>4</sub><sup>2-</sup>(aq)] must be equal to [Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>(aq)].
- (2) Both the forward reaction and the backward reaction have stopped.
- (3) The number of moles of CrO<sub>4</sub><sup>2-</sup>(aq) must be double the number of moles of Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>(aq).
- A. (1) and (2) only
- B. (1) and (3) only
- C. (2) and (3) only
- D. (1), (2) and (3)

#### DSE18\_26

Consider the following equilibrium system in a certain liquid medium at 25 °C:



Which of the following statements is correct (assuming the total volume of the system remains unchanged)?

- A. Adding (CH<sub>3</sub>)<sub>2</sub>C(OH)CN would increase the equilibrium constant  $K_c$ .
- B. Increasing the temperature would increase the concentration of (CH<sub>3</sub>)<sub>2</sub>C(OH)CN.
- C. The concentration of CH<sub>3</sub>COCH<sub>3</sub> must be equal to the concentration of (CH<sub>3</sub>)<sub>2</sub>C(OH)CN.
- D. After adding HCN and when a new equilibrium is attained, the concentration of HCN would be restored to the value before the addition of HCN.

#### DSE18\_29

The equilibrium constant  $K_c$  for the reaction

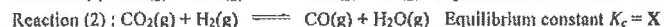


at 70 °C is 0.13 mol dm<sup>-3</sup>. In a 5.0 dm<sup>3</sup> closed container kept at 70 °C, there is a mixture of 0.20 mol of N<sub>2</sub>O<sub>4</sub>(g) and 0.30 mol of NO<sub>2</sub>(g) at a certain amount. Which of the following combinations is correct at that moment?

	Reaction quotient $Q_c / \text{mol dm}^{-3}$	Rate of the reaction
A.	0.09	Backward > forward
B.	0.09	Forward > backward
C.	0.45	Backward > forward
D.	0.45	Forward > backward

#### DSE19\_26

Consider the following two reactions at a certain temperature:



What is X?

- A. 0.8
- B. 1.25
- C. 0.8 mol<sup>-1</sup>dm<sup>3</sup>
- D. 1.25 mol<sup>-1</sup>dm<sup>3</sup>

#### DSE19\_27

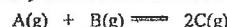
The decomposition of HI(g) into H<sub>2</sub>(g) and I<sub>2</sub>(g) is reversible. In a closed container of 3.0 dm<sup>3</sup> keeping at a fixed temperature, an equilibrium mixture contains 0.10 mol of HI(g), 0.60 mol of H<sub>2</sub>(g) and 0.60 mol of I<sub>2</sub>(g). What is the equilibrium constant  $K_c$  for the decomposition at this temperature?

- A. 0.4
- B. 3.6
- C. 9.0
- D. 36.0

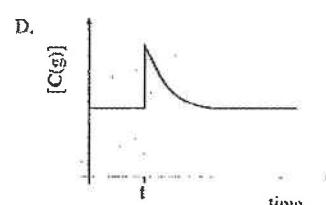
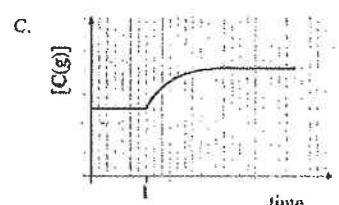
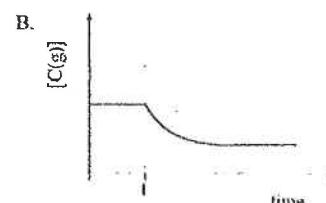
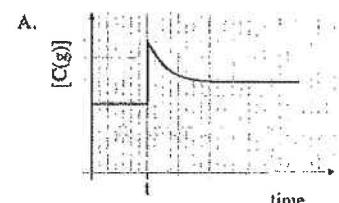
DSE21 31

DSE19 25

Consider the following equilibrium system in a closed container of fixed volume:

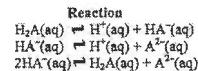


A small amount of B(g) is added at time t and finally a new equilibrium is attained at the same temperature. Which of the following graphs can represent the variation of [C(g)] with time?



DSE20\_26

26. Consider the information below:



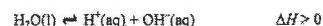
Equilibrium constant at 25 °C  
 $1.3 \times 10^{-3} \text{ mol dm}^{-3}$   
 $3.1 \times 10^{-4} \text{ mol dm}^{-3}$   
 x

What is the numerical value of X?

- A.  $4.2 \times 10^2$   
 B.  $2.4 \times 10^{-3}$   
 C.  $4.0 \times 10^{-8}$   
 D.  $2.5 \times 10^8$

DSE20 33

33. Refer to the following chemical reaction:



The pH of a pure water sample is 7.0 at 25 °C. Which of the following statements is / are correct when the sample has been heated to 50 °C?

- (1) The  $[\text{OH}^- \text{(aq)}]$  of the sample is  $1.0 \times 10^{-7} \text{ mol dm}^{-3}$ .  
 (2) The pH of the sample is smaller than 7.0.  
 (3) The sample remains neutral.

- A. (1) only
  - B. (2) only
  - C. (1) and (3) only
  - D. (2) and (3) only

31. Consider the following reaction under certain conditions :



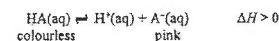
The reaction quotient is  $2.0 \text{ mol dm}^{-3}$  at a certain moment. Which of the following statements is / are correct?

- (1) The reaction quotient is larger than  $2.0 \text{ mol dm}^{-3}$  after a period of time.  
(2) The backward reaction is faster than the forward reaction at that moment.  
(3) The concentration of  $X_1(g)$  must be equal to the concentration of  $X_2(g)$  at that moment.

- A. (1) only
  - B. (2) only
  - C. (1) and (3) only
  - D. (2) and (3) only

DSE21 32

32. Consider the following equilibrium system



Which of the following statements is / are correct?

- (1) Adding  $\text{Na}_2\text{CO}_3(s)$  would make its colour become paler.  
 (2) Increasing the temperature would make its colour become darker.  
 (3) Adding a few drops of concentrated  $\text{HCl(aq)}$  would increase the concentration of  $\text{A}^-(\text{aq})$ .

- A. (1) only
  - B. (2) only
  - C. (1) and (3) only
  - D. (2) and (3) only

### Structural Questions

#### ASL99(I)\_03

The table below lists the equilibrium constants,  $K_c$ , for the reversible reaction.



at three different temperatures.

Temperature / K	500	700	900
$K_c$	$7.76 \times 10^{-3}$	$1.23 \times 10^{-1}$	$6.03 \times 10^{-1}$

- (a) Based on the above information, deduce whether the forward reaction is exothermic or endothermic. (1 mark)
- (b) 2.0 mol of  $H_2(g)$  and 2.0 mol of  $CO_2(g)$  are allowed to react in a  $4.0\text{ dm}^3$  closed container. Calculate the concentration of  $CO(g)$ , in  $\text{mol dm}^{-3}$  in the equilibrium mixture at 700 K. (3 marks)
- (c) State the effect of an increase in pressure on the percentage yield of  $CO(g)$ . Explain your answer. (2 marks)

#### AL99(II)\_04a

In the Haber process, ammonia is synthesized by the exothermic reaction of nitrogen and hydrogen at around 723 K.



In a simulation of the process, a mixture of nitrogen and hydrogen was placed in a closed container. The initial concentrations of nitrogen and hydrogen were  $0.50\text{ mol dm}^{-3}$  and  $1.50\text{ mol dm}^{-3}$  respectively. When the equilibrium was attained at 723 K, 25.0% of the original nitrogen was consumed.

- (i) Calculate the respective concentrations of nitrogen, hydrogen and ammonia in the equilibrium mixture. (3 marks)
- (ii) Calculate  $K_c$  for the reaction at 723 K. (2 marks)
- (iii) (I) State, with explanation, the effect of temperature on  $K_c$  for the reaction. (1 mark)
- (II) Explain why the Haber process is not operated at temperatures much higher or much lower than 723 K. (1 mark)

#### ASL00(I)\_04

An experiment, consisting of four stages, was conducted to determine the equilibrium constant  $K_c$ , of an esterification reaction:

- Stage 1: 0.25 mol of ethanoic acid and 0.25 mol of propan-2-ol were mixed in a pear-shaped flask.  $1.0\text{ cm}^3$  of this mixture was withdrawn and added to a conical flask containing  $25\text{ cm}^3$  of deionized water. The contents of the conical flask were then titrated against 0.30 M sodium hydroxide solution.
- Stage 2: A few drops of concentrated sulphuric (VI) acid were added to the remaining acid-alcohol mixture in the pear-shaped flask with shaking.  $1.0\text{ cm}^3$  of this mixture was withdrawn and immediately titrated against 0.30 M sodium hydroxide solution as in Stage 1.
- Stage 3: Some pumice stones were added to the pear-shaped flask which was then heated under reflux for an hour. After rapid cooling,  $1.0\text{ cm}^3$  of this mixture was withdrawn and immediately titrated against 0.30 M sodium hydroxide solution as in Stage 1.
- Stage 4: The remaining mixture in the pear shaped flask was heated under reflux for another half an hour. After rapid cooling,  $1.0\text{ cm}^3$  of this mixture was withdrawn and immediately titrated against 0.30 M sodium hydroxide as in Stage 1.

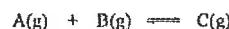
The table below lists the titration results:

	Volume of 0.30 M NaOH(aq) used / $\text{cm}^3$
Stage 1	36.80
Stage 2	36.90
Stage 3	17.55
Stage 4	17.15

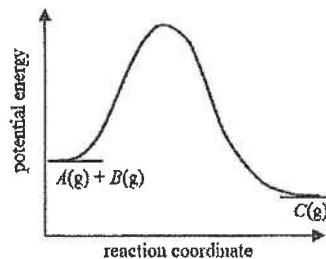
- (a) Write a chemical equation for the esterification reaction. (1 mark)
- (b) What is the purpose of adding concentrated sulphuric(VI) acid in Stage 2? (1 mark)
- (c) (i) Explain why the titration in stage 2 should be carried out immediately. (1 mark)
- (ii) Suggest a suitable indicator for the titration. (1 mark)
- (d) Why are pumice stones used in Stage 3? (1 mark)
- (e) Assuming that equilibrium had been attained in Stage 4, calculate  $K_c$  for the esterification reaction. (4 marks)
- (f) Suggest what further actions should be taken after Stage 4 to confirm that equilibrium has been attained. (1 mark)

ASL01(I)\_02

The energy profile of a reversible reaction



is shown below:



A mixture of A(g), B(g) and C(g) was allowed to reach equilibrium in a closed vessel with a fixed volume.

State the effects as listed in the table below of (i) adding a catalyst to the mixture, and (ii) increasing the temperature of the mixture.

	(i) Adding a catalyst to the mixture	(ii) increasing the temperature of the mixture
Effect on the rate of the forward reaction		
Effect on the rate of the backward reaction		
Effect on the equilibrium position		

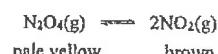
AL02(I)\_01a

The pH of human blood is maintained within a narrow range from 7.35 to 7.45 by a natural buffer system consisting of carbonic acid,  $H_2CO_3(aq)$ , and hydrogencarbonate ions,  $HCO_3^-(aq)$ .

- (i) A buffer solution containing  $H_2CO_3(aq)$  and  $HCO_3^-(aq)$  in equal concentrations has a pH of 6.10. Calculate the dissociation constant,  $K_A$ , for  $H_2CO_3(aq)$ . (2 marks)
- (ii) Calculate the ratio of concentrations of  $HCO_3^-(aq)$  and  $H_2CO_3(aq)$  in blood at pH 7.40. (2 marks)
- (iii) (I) Would the blood pH of a person increase or decrease in the course of physical exertion? Explain your answer. (2 marks)
- (II) Briefly explain why the  $H_2CO_3(aq) / HCO_3^-(aq)$  buffer system can maintain the blood pH. (1 mark)

**AL02(I)\_02a**

A closed system consisting of a mixture of  $\text{N}_2\text{O}_4(\text{g})$  and  $\text{NO}_2(\text{g})$  is allowed to attain equilibrium at 350 K and 700 kPa. The mixture has a light brown color.



describe the color change of the mixture when its temperature is increased under the same pressure. Explain your answer.

(2 marks)

**AL02(II)\_03**

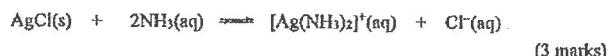
At 298 K, the equilibrium constants,  $K_c$ , for the reaction (1) and (2) below are  $1.8 \times 10^7 \text{ mol}^{-2} \text{ dm}^6$  and  $2.0 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$  respectively.



(a) For each of the reactions (1) and (2), write an expression for its  $K_c$ .

(2 marks)

(b) Calculate the  $K_c$  at 298 K for the following reaction:



(c) Using your result in (b), calculate the solubility, in  $\text{mol dm}^{-3}$ , of  $\text{AgCl}(\text{s})$  in 0.10 M  $\text{NH}_3(\text{aq})$  at 298 K.

(2 marks)

**ASL02(II)\_09 (modified)**

The dissociation of butan-1-amine in water can be represented by the following equation.



(a) Give all acidic species in an aqueous solution of butan-1-amine.

(1 mark)

(b) The dissociation constant,  $K_c$ , of butan-1-amine is  $5.9 \times 10^{-4} \text{ mol dm}^{-3}$  at 298 K. Calculate the pH of a 0.10 M aqueous solution of butan-1-amine at 298 K.

(3 marks)

**ASL03(I)\_01**

$\text{H}_3\text{PO}_4(\text{aq})$  ionizes in three stages to give  $\text{H}_2\text{PO}_4^{2-}(\text{aq})$ ,  $\text{HPO}_4^{2-}(\text{aq})$  and  $\text{PO}_4^{3-}(\text{aq})$ .

(a) At 298 K, the dissociation constants,  $K_a$ , of  $\text{H}_3\text{PO}_4(\text{aq})$ ,  $\text{H}_2\text{PO}_4^{2-}(\text{aq})$  and  $\text{HPO}_4^{2-}(\text{aq})$  are as follows:

	$K_c / \text{mol dm}^{-3}$
$\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{H}_2\text{PO}_4^{2-}(\text{aq})$	$7.9 \times 10^{-3}$
$\text{H}_2\text{PO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{HPO}_4^{2-}(\text{aq})$	$6.2 \times 10^{-8}$
$\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{PO}_4^{3-}(\text{aq})$	$4.4 \times 10^{-13}$

Explain why the dissociation constant decreases with the successive loss of hydrogen ions. (1 mark)

(b) Sketch the expected pH titration curve when  $\text{H}_3\text{PO}_4(\text{aq})$  is titrated with  $\text{NaOH}(\text{aq})$ . (3 marks)

**ASL03(I)\_05**

At 298 K, the pH of a 0.10 M aqueous solution of butanoic acid is 2.9.

(a) (i) Calculate the degree of dissociation of butanoic acid in the solution.

(2 marks)

(ii) Calculate the  $K_c$  of butanoic acid at 298K. (2 marks)

(b) 25.0 cm<sup>3</sup> of 0.10 M butanoic acid is titrated against 0.10 M sodium hydroxide solution. Sketch a graph to show the change in pH during the titration. (3 marks)

**ASL03(II)\_11**

Consider the following reversible reaction:



A gas syringe containing a mixture of  $\text{N}_2\text{O}_4(\text{g})$  and  $\text{NO}_2(\text{g})$  was allowed to attain equilibrium at room temperature and pressure. The syringe was then immersed in ice-water. The color of the mixture gradually became lighter.

(a) State the effect of decreasing the temperature on the rate of the backward reaction. Explain your answer. (3 marks)

(b) (i) Based on the given information, deduce whether the forward reaction is exothermic or endothermic. (2 marks)

(ii) Explain your answer in (i) in terms of chemical bonding. (1 mark)

(c) Suggest a chemical method to dispose of the gaseous mixture in the syringe at the end of the experiment. (1 mark)

## ASL04(II)\_04 (modified)

- (a) Write an equation, with state symbols, for the auto-ionization of water. (1 mark)
- (b) Write an expression for the equilibrium constant,  $K_c$  of auto-ionization of water. (1 mark)
- (c) The table below lists the  $K_w$  of water at three different temperatures.

Temperature / °C	$K_w / \text{mol}^2 \text{dm}^{-6}$
10	$0.3 \times 10^{-14}$
30	$1.5 \times 10^{-14}$
50	$5.5 \times 10^{-14}$

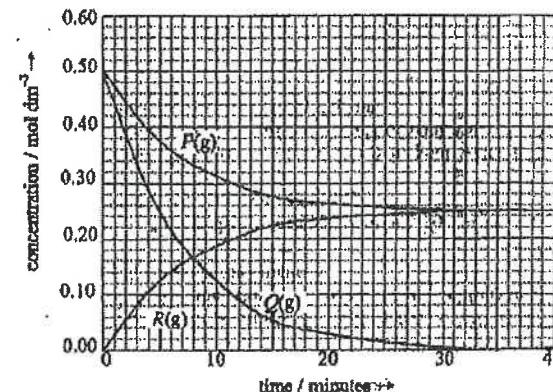
- (i) Calculate the pH of pure water at 50 °C. (2 marks)
- (ii) Is pure water alkaline, neutral or acidic at 50 °C. Explain your answer. (1 mark)
- (iii) With reference to the given information, deduce whether the auto-ionization of water is an exothermic process or an endothermic process. (2 marks)

## ASL04(II)\_08 [Similar to DSE17\_11]

- Chlorate(I) salts, in the form of NaClO or Ca(ClO)<sub>2</sub>, are commonly used as disinfectant.
- (a) In aqueous solution, chlorate(I) ions undergo hydrolysis to give chloric(I) acid, HClO(aq). Write the chemical equation for the hydrolysis of chlorate(I) ions. (1 mark)
- (b) Many swimming pools use chlorate(I) salts to sterilize the pool water. The HClO(aq) formed is very effective for killing microorganism.
- (i) The pH of a sample of pool water is 7.50 at 298 K. Calculate the ratio of concentration of ClO<sup>-</sup>(aq) to that of HClO(aq) in the sample. (At 298 K, the dissociation constant,  $K_c$ , of HClO(aq) is  $2.95 \times 10^{-8} \text{ mol dm}^{-3}$ .) (2 marks)
- (ii) The concentration of HClO(aq) in pool water increases with decrease in pH, yet the pH of pool water should not be kept too low. Briefly explain. (1 mark)
- (c) (i) Write a chemical equation to represent the dissociation of HClO in water. (1 mark)
- (ii) Will the equilibrium position of the system in (i) shift upon the addition of water? Specify the direction of the shift, if any, and explain your answer. (2 marks)

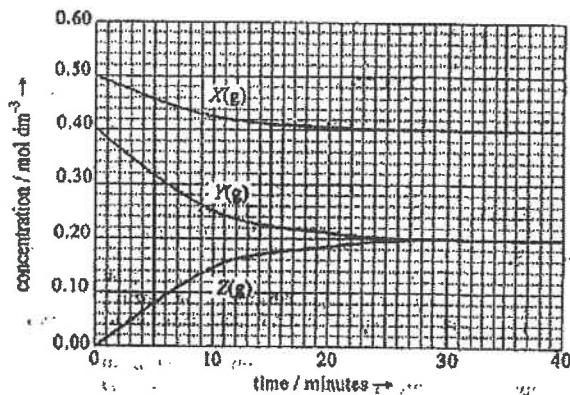
## ASL04(II)\_09 [Similar to DSE18\_13]

- (a)  $P(g)$  reacts with  $Q(g)$  irreversibly to give  $R(g)$ . A mixture of  $P(g)$  and  $Q(g)$  is allowed to react in a closed container of volume 1 dm<sup>3</sup> kept at a constant temperature. The graph below shows the changes in concentration of  $P(g)$ ,  $Q(g)$  and  $R(g)$  in the container with time. ( $P$ ,  $Q$ ,  $R$  do not represent symbols of elements.)



- (i) With reference to the above graph, deduce the chemical equation for the reaction in terms of  $P(g)$ ,  $Q(g)$  and  $R(g)$ . (2 marks)
- (ii) If the mixture of  $P(g)$  and  $Q(g)$  is allowed to react at the same temperature but in a closed container of volume 2 dm<sup>3</sup> instead, will the time required for the reaction to complete remain the same? Explain. (2 marks)
- (iii) Explain why the collision between molecules of  $P(g)$  and  $Q(g)$  will not necessarily lead to a reaction. (1 mark)

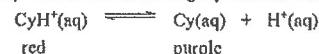
- (b)  $X(g)$  reacts with  $Y(g)$  reversibly to give  $Z(g)$ . A mixture of  $X(g)$  and  $Y(g)$  is allowed to react in a closed container of volume  $1 \text{ dm}^3$  kept at a constant temperature. The graph below shows the changes in concentrations of  $X(g)$ ,  $Y(g)$  and  $Z(g)$  in the container with time. ( $X$ ,  $Y$ ,  $Z$  do not represent symbols of elements.)



- (i) With reference to the above graph, deduce an expression for the equilibrium constant,  $K_c$ , for the reaction.
- (2 marks)
- (ii) Compare the rate of forward reaction and that of the backward reaction
- (1) at the 5th minutes after  $X(g)$  and  $Y(g)$  are mixed.
- (1 mark)
- (2) at the 30th minutes after  $X(g)$  and  $Y(g)$  are mixed.
- (1 mark)
- (You are not required to perform any calculation.)
- (iii) If the mixture  $X(g)$  and  $Y(g)$  is allowed to react at the same temperature but in a closed container of volume  $2 \text{ dm}^3$  instead, will the yield of  $Z(g)$  be the same? Explain.
- (2 marks)

AL05(I)\_03b [Similar to DSE17\_11]

Cyanidin (Cy) is a water-soluble plant pigment which can be found in blackberry, and is responsible for its purple color. The following equilibrium exists in an aqueous solution of cyanidin:



- (i) Write an expression for the acid dissociation constant  $K_a$  of  $\text{CyH}^+(\text{aq})$ .
- (1 mark)

- (ii) In a sample of blackberry juice buffered at pH 3.0 at 298 K, the concentration ratio of  $\text{CyH}^+$  to  $\text{Cy(aq)}$  was found to be 20 to 1. Calculate  $K_a$  of  $\text{CyH}^+(\text{aq})$  at 298 K.
- (2 marks)

- (iii) Blackberry juice is often preserved by adding small amount of  $\text{SO}_2(\text{g})$ , which reacts with  $\text{CyH}^+(\text{aq})$  to give colourless product,  $\text{CySO}_3\text{H}_2(\text{aq})$ . The reaction can be represented by the equation below:



- (i) Write an expression for the equilibrium constant  $K_e$  in reaction (i).
- (1 mark)

- (ii) When sufficient  $\text{SO}_2(\text{g})$  is added to a blackberry juice buffered at pH = 3.00 at 298 K so that concentration of  $\text{SO}_2(\text{aq})$  at equilibrium is  $1.0 \times 10^{-2} \text{ mol dm}^{-3}$ , the concentration of  $\text{CyH}^+(\text{aq})$  drops to one tenth of its original value.

Assuming that  $\text{SO}_2(\text{aq})$  does not react with  $\text{Cy(aq)}$ , calculate  $K_e$  in reaction (i) at 298 K.

(2 marks)

ASL05(II)\_08 [Similar to DSB13\_12]

$\text{Y}_2(\text{g})$  undergoes decomposition according to the following equation:



Two experiments were carried out to study the decomposition of  $\text{Y}_2(\text{g})$ . In these experiments, different amounts of  $\text{Y}_2(\text{g})$  and  $\text{Y(g)}$  were charged into a closed container of volume  $2 \text{ dm}^3$  kept at a constant temperature. The table below lists the initial numbers of moles of  $\text{Y}_2(\text{g})$  and  $\text{Y(g)}$  in the container, as well as the number of moles of  $\text{Y(g)}$  present in the container after one day.

Experiment	Initial number of moles		Number of moles of $\text{Y(g)}$ after one day
	$\text{Y}_2(\text{g})$	$\text{Y(g)}$	
I	4	0	2
II	0	4	$\frac{4}{3}$

- (a) The reaction quotient  $Q$  of the system can be represented by the following expression:

$$Q = \frac{[\text{Y(g)}]^2}{[\text{Y}_2(\text{g})]}$$

For each experiment, calculate  $Q$  of the system after one day. Hence, deduce whether the system had attained equilibrium after one day.

(5 marks)

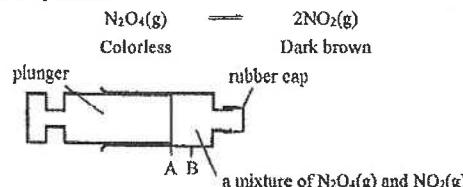
- (b) Consider experiment I

(1) will the yield of Y(g) be affected if the volume of the container is decreased from 2 dm<sup>3</sup> to 1 dm<sup>3</sup>? Explain. (2 marks)

(2) State the effect of an increase in temperature on the yield of Y(g). Explain. (2 marks)

ASL06(I)\_04 [Similar to DSE13\_12c]

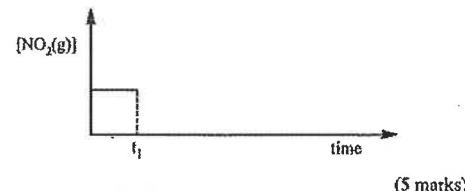
The diagram below shows a gas syringe containing a pale brown mixture of  $\text{N}_2\text{O}_4(\text{g})$  and  $\text{NO}_2(\text{g})$  at equilibrium at room temperature.



In each of the following cases, state the expected observation, with reason(s). Sketch on the given graph to show the expected variation in the concentration of  $\text{NO}_2(\text{g})$  in the mixture until the attainment of a new equilibrium.

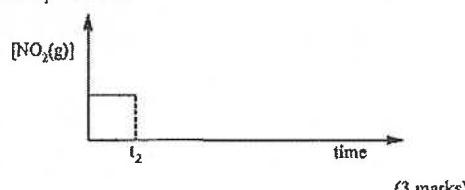
- (a) The plunger is quickly pushed from position A to position B at time  $t_1$ , while the temperature of the mixture is kept constant.

### Expected observation:



(b) Some  $\text{N}_2\text{O}_4(\text{g})$  is introduced into the gas syringe at time  $t_2$ , while the volume and the temperature of the mixture are both kept constant.

#### Expected observation



ASL06(II) 12 (modified)

Propanoic acid is a weak acid

- (a) Explain what is meant by the term 'weak acid'. (1 marks)

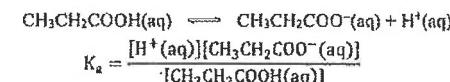
$$K_a \text{ of acid dissociation} = \frac{[\text{H}^+(\text{aq})][\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})]}{[\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})]} = 1.35 \times 10^{-5} \text{ mol dm}^{-3}$$

- (c) Sketch a graph showing the change in pH of the solution mixture when  $25.0 \text{ cm}^3$  of 0.20 M propanoic acid is titrated against 0.20 M aqueous sodium hydroxide. (2 marks)

(d) When sodium propanoate is dissolved in water, the following chemical equilibrium is established:



- (i) If  $K_c$  is the equilibrium constant of the above system, while  $K_s$  and  $K_w$  are the equilibrium constants of the following reactions:



$$\text{H}_2\text{O}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$$

$$K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$$

Show that  $K_c = \frac{K_w}{K_a}$ .

(1 mark)

- (ii) For a 0.20 M aqueous solution of sodium propanoate, calculate  
 (1) The concentration of  $\text{OH}^-(\text{aq})$

- (2) The pH value** (3 marks)

At 298 K, ionic product of water,  $K_w = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$

**ASL07(II)\_04 [Similar to DSEI3\_12]**

The equilibrium constant  $K_c$  for the following reaction is  $0.20 \text{ mol}^{-1} \text{ dm}^3$  at 873 K.



A mixture of 2.0 mol of CO(g), 1.0 mol of Cl<sub>2</sub>(g) and 0.5 mol of COCl<sub>2</sub>(g) is introduced into an evacuated vessel of 4.0 dm<sup>3</sup> kept at 873 K.

- (a) Calculate the reaction quotient of the system at the start of the reaction. Then, decide the direction in which the reaction will proceed to achieve equilibrium.

(3 marks)

- (b) Calculate the concentration of COCl<sub>2</sub>(g) when equilibrium is attained at 873 K.

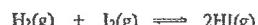
(3 marks)

- (c) Discuss the effect on  $K_c$ , if the volume of the vessel is decreased while keeping the temperature of the system at 873 K.

(1 mark)

**ASL08(I)\_04**

Consider the reaction of H<sub>2</sub>(g) with I<sub>2</sub>(g) at elevated temperature:



4.0 mol of H<sub>2</sub>(g) and 2.0 mol of I<sub>2</sub>(g) were introduced into an evacuated 5.0 dm<sup>3</sup> closed container kept at 713 K.

- (a) Given that the equilibrium constant  $K_c$  for the reaction is 50 at 713 K, calculate the concentration of H<sub>2</sub>(g), I<sub>2</sub>(g) and HI(g), in mol dm<sup>-3</sup>, respectively in the equilibrium mixture.

(4 marks)

- (b) Deduce the effect on the number of moles of HI(g) in the equilibrium mixture

(I) If the volume of the container is reduced to 2.5 dm<sup>3</sup>;

(1.5 marks)

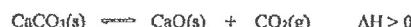
(II) If the initial number of moles of H<sub>2</sub>(g) and I<sub>2</sub>(g) used are both 4.0.

(1.5 marks)

(You may assume all other conditions to be the same in each case, and are not required to carry out calculations.)

**ASL09(II)\_02**

The equilibrium constant  $K_c$  for the thermal decomposition of calcium carbonate is  $2.7 \times 10^{-3}$  mol dm<sup>-3</sup> at 1000 K.



25.0 g of CaCO<sub>3</sub>(s) is introduced into a 5.0 dm<sup>3</sup> evacuated vessel, and the system is allowed to attain equilibrium at 1000 K.

- (a) Write an expression of  $K_c$  for the decomposition.

(1 mark)

- (b) Calculation the percentage of decomposition of CaCO<sub>3</sub>(s) in the above equilibrium system.

(3 marks)

- (c) Will the percentage of decomposition of CaCO<sub>3</sub>(s) increase, decrease or remain unchanged if the temperature of the above equilibrium system is decreased? Explain your answer.

(2 marks)

- (d) If more CaCO<sub>3</sub>(s) is added to the equilibrium system at 1000 K, will the equilibrium concentration of CO<sub>2</sub>(g) change? Explain your answer.

(1 mark)

**AL10(I)\_02 (modified)**

From a saturated aqueous solution of calcium hydroxide, several 20.0 cm<sup>3</sup> aliquots of the solution were withdrawn. Each aliquot was titrated with 0.100 mol dm<sup>-3</sup> hydrochloric acid using a suitable indicator. The mean titre were 9.10 cm<sup>3</sup>. Calculate

- (a) the concentration of hydroxide ions in the saturated solutions, and

(1 mark)

- (b) the solubility of calcium hydroxide at the temperature of the experiment.

(2 marks)

- (c) the equilibrium constant (solubility product) of calcium hydroxide at the temperature of experiment.

(3 marks)

**AL10(I)\_03**

State the expected observation(s) in each of the following experiments, and account for the observation with the aid of chemical equation(s).

Adding excess H<sub>2</sub>SO<sub>4</sub>(aq) to K<sub>2</sub>CrO<sub>4</sub>(aq), and then excess FeSO<sub>4</sub>(aq) to the resulting solution.

(3 marks)

**AL10(II)\_03**

Ammonia is manufactured by Haber process:



- (a) In a simulation of the process, a mixture of 10 mole N<sub>2</sub>(g) and 30 mol H<sub>2</sub>(g) is introduced into a 50 dm<sup>3</sup> closed vessel, which is kept at 673 K and contains the iron catalyst. When the system attains equilibrium, the mole percent of ammonia is 39. Calculate

(I) The equilibrium concentration of each gas, and

(3 marks)

(II) The equilibrium constant,  $K_c$ , of the above reaction at 673 K.

(2 marks)

- (b) Suggest TWO ways to increase the yield of ammonia when the process is put into industrial practice.

(2 marks)

**AL11(II)\_06**

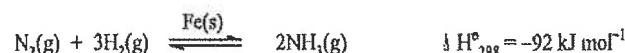
State the expected observation(s) in each of the following experiments, and write the chemical equation(s) of the reaction(s) involved.

- (a) HCl(aq) is added to K<sub>2</sub>CrO<sub>4</sub>(aq)

(2 marks)

**ASL11(II)\_06**

Ammonia is manufactured by the Haber process:



In a simulation study of the process, mixture of N<sub>2</sub>(g) and H<sub>2</sub>(g) were allowed to attain equilibrium under five sets of reaction conditions, and the mole percent of NH<sub>3</sub>(g) in each equilibrium mixture was recorded. The table below lists the results obtained in the five trials:

Trial	Initial mole ratio of N <sub>2</sub> (g) to H <sub>2</sub> (g)	Reaction conditions			mole percent of NH <sub>3</sub> (g) in equilibrium mixture
		Temperature / K	Pressure / atm	catalyst	
1	1 : 3	473	10	Fe(s)	51
2	1 : 3	773	1000	Fe(s)	58
3	1 : 3	473	1000	Fe(s)	<i>a</i>
4	1 : 3	773	10	--	<i>b</i>
5	1 : 3	773	1000	--	<i>c</i>

(No catalyst was used in trials 4 and 5; *a*, *b* and *c* represent the mole percent of NH<sub>3</sub>(g) in the equilibrium mixture in trials 3, 4 and 5 respectively.)

- (a) In which TWO trials would the mole percent of NH<sub>3</sub>(g) in the equilibrium mixture be the same? Explain your answer. (2 marks)
- (b) In which trial would the mole percent of NH<sub>3</sub>(g) in the equilibrium mixture be the highest? Explain your answer. (2 marks)
- (c) The industrial operating conditions for the Haber process are as follows:

Mole ratio of N <sub>2</sub> (g) to H <sub>2</sub> (g)	1 : 3
Temperature	673 K
Pressure	200 atm
Catalyst	Fe(s)

Explain why this set of conditions is used.

(2 marks)

**AL11(II)\_07 (modified) [Similar to DSE16\_10]**

For the reaction below,



The equilibrium constant K<sub>c</sub> is 11.73 mol<sup>-1</sup> dm<sup>3</sup> at 1100 K.

- (a) A mixture of 0.20 mol of SO<sub>2</sub>(g) and 0.20 mol of O<sub>2</sub>(g) is introduced into an evacuated closed container. Calculate the volume of the system in order to achieve an 80% conversion of SO<sub>2</sub> to SO<sub>3</sub>(g) at 1100 K. (4 marks)
- (b) If the above system is subjected to each of the following changes, will the percentage conversion of SO<sub>2</sub>(g) to SO<sub>3</sub>(g) increase, decrease or remain unchanged? Explain your answer in each case.
- (i) Increasing the volume of the container (1 mark)
  - (ii) Decreasing the temperature (1 mark)
  - (iii) Introducing a catalyst (1 mark)

**ASL12(I)\_01**

- (b) Account for the following observations and give the relevant chemical equation(s):

Words written on a paper using KSCN(aq) are invisible. When the paper is sprayed with Fe<sup>3+</sup>(aq), the words appear blood-red. If the words are written with alkaline KSCN(aq) they will turn orange-brown when sprayed with Fe<sup>3+</sup>(aq).

(3 marks)

**ASL12(I)\_07**

The equilibrium constant K<sub>c</sub> for the following reaction can be determined by finding the concentration of I<sup>-</sup>(aq) and that of SO<sub>4</sub><sup>2-</sup>(aq) in the solution phase of the equilibrium mixture:



- (a) Write an expression of K<sub>c</sub> for this reaction. (1 mark)
- (b) You are provided with PbSO<sub>4</sub>(s) and standard KI(aq). Outline how you would prepare, in a school laboratory, an equilibrium mixture for determining K<sub>c</sub> at 313 K. (2 marks)
- (c) The concentration of I<sup>-</sup>(aq) in the solution phase can be found by titration using standard AgNO<sub>3</sub>(aq). What treatment(s) on the equilibrium mixture is/are necessary before carrying out the titrations? (2 marks)
- (d) Given that the concentration of the standard KI(aq) used is 0.100 mol dm<sup>-3</sup> and the concentration of I<sup>-</sup>(aq) in the solution phase of the equilibrium mixture is 0.072 mol dm<sup>-3</sup>, calculate K<sub>c</sub> at 313 K. (2 marks)

**ASL12(II)\_01 (modified)**

At 298 K, the dissociation constant  $K_c$  for  $\text{NH}_3(\text{aq})$  is  $1.8 \times 10^{-5} \text{ mol dm}^{-3}$ .



- (a) Calculate the pH of  $0.10 \text{ mol dm}^{-3}$   $\text{NH}_3(\text{aq})$  at 298 K. (3 marks)
- (b) Calculate the molarity ratio of  $\text{NH}_3(\text{aq})$  to  $\text{NH}_4\text{Cl}(\text{aq})$  required for preparing a pH 10 solution at 298 K. (2 marks)
- (c) Briefly explain how the solution in (b) can resist pH change upon addition of a small amount of acid or alkali. (2 marks)

**ASL13(I)\_04**

Consider the following reversible reaction:



$0.10 \text{ mol}$  of  $\text{CO}(\text{g})$  and  $0.10 \text{ mol}$  of  $\text{H}_2\text{O}(\text{g})$  were introduced into a fixed-volume closed container maintained at  $700 \text{ K}$ . When equilibrium was attained,  $74.0\%$  of  $\text{CO}(\text{g})$  was found to have reacted.

- (a) Calculate the equilibrium constant  $K_c$  for this reaction at  $700 \text{ K}$ . (2 marks)
- (b) State and explain the effect of each of the following changes on the equilibrium concentration of  $\text{H}_2(\text{g})$ .
- (i) Increasing temperature (1 mark)
  - (ii) Introducing extra  $\text{CO}(\text{g})$  into the container. (1 mark)

**AL13(I)\_01**

- (c) Blue cobalt(II) chloride paper is commonly used to test for the presence of water. The addition of water turns the blue paper pink. The pink paper turns back to blue when it is heated in an oven.

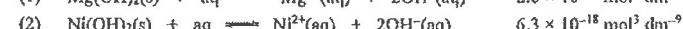
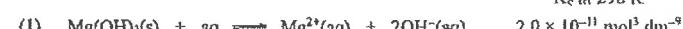
With the aid of a chemical equation, explain the above observations.

(2 marks)

**ASL13(II)\_03**

You are provided with the equilibrium constants,  $K_c$ , at 298 K for reactions (1) and (2) below:

$K_c$  at 298 K



- (a) Write the  $K_c$  expression for reaction (1) and that for reaction (2). (1 mark)
- (b) At 298 K, a mixture of  $\text{Mg(OH)}_2(\text{s})$  and  $0.010 \text{ mol dm}^{-3}$   $\text{NiSO}_4(\text{aq})$  was stirred until the following equilibrium was attained:
- $$\text{Mg(OH)}_2(\text{s}) + \text{Ni}^{2+}(\text{aq}) \rightleftharpoons \text{Ni(OH)}_2(\text{s}) + \text{Mg}^{2+}(\text{aq}) \quad (\alpha)$$
- (i) Write the  $K_c$  expression for reaction (a) and calculate the  $K_c$  at 298 K. (3 marks)
  - (ii) Calculate the concentration of  $\text{Ni}^{2+}(\text{aq})$  ions in this equilibrium mixture. (2 marks)

**DSE11SP\_11 [Similar to DSE14\_I3]**

The table below lists the equilibrium constants,  $K_c$ , for the reversible reaction



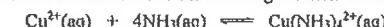
at three different temperatures.

Temperature / K	500	700	900
$K_c$	$7.76 \times 10^{-3}$	$1.23 \times 10^{-1}$	$6.03 \times 10^{-1}$

- (a) Based on the above information, deduce whether the forward reaction is exothermic or endothermic. (2 marks)
- (b)  $2.0 \text{ mol}$  of  $\text{H}_2(\text{g})$  and  $2.0 \text{ mol}$  of  $\text{CO}_2(\text{g})$  are allowed to react in a  $4.0 \text{ dm}^3$  closed container. Calculate the concentration of  $\text{CO}(\text{g})$ , in  $\text{mol dm}^{-3}$ , in the equilibrium mixture at  $700 \text{ K}$ . (2 marks)
- (c) State the effect of an increase in temperature on the rate of the backward reaction. (1 marks)

**DSE12PP\_13**

In an experiment, excess aqueous ammonia is added to an aqueous solution of copper(II) sulphate. The following equilibrium is established and the resulting solution is deep blue in color.

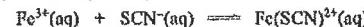


- (a) Write an expression of  $K_c$  for this reaction. (1 mark)
- (b) If the above equilibrium mixture contains  $0.0020 \text{ mol dm}^{-3}$  of  $\text{Cu}^{2+}(\text{aq})$  ions,  $0.0014 \text{ mol dm}^{-3}$  of  $\text{NH}_3(\text{aq})$  and  $0.0800 \text{ mol dm}^{-3}$   $\text{Cu}(\text{NH}_3)_4^{2+}(\text{aq})$  ions, calculate  $K_c$  under the conditions of the experiment. (2 marks)

- (c) When  $\text{H}_2\text{SO}_4(\text{aq})$  is added slowly to the equilibrium mixture until in excess, a blue precipitate is formed and the precipitate subsequently dissolves in the excess acid forming a blue solution. Account for these observations with the help of relevant chemical equation(s).  
(5 marks)

#### DSE12\_13

Consider the reaction represented by the equation below:

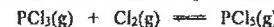


In an experiment,  $25.0 \text{ cm}^3$  of  $0.010 \text{ M}$   $\text{Fe}_2(\text{SO}_4)_3(\text{aq})$  and  $25.0 \text{ cm}^3$  of  $0.010 \text{ M}$   $\text{KSCN}(\text{aq})$  were mixed in a conical flask at room temperature, and equilibrium was attained.

- (a) The concentration of  $\text{Fe}(\text{SCN})^{2+}(\text{aq})$  in the mixture was  $0.0043 \text{ M}$  when equilibrium was attained. Calculate the equilibrium constant  $K_c$  for the above reaction at room temperature.  
(3 marks)
- (b) It is known that  $\text{FePO}_4(\text{s})$  is insoluble in water. Suggest what would be the effect on the equilibrium position if  $\text{Na}_3\text{PO}_4(\text{s})$  is added to the equilibrium mixture.  
(1 mark)

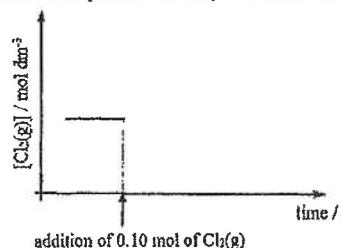
#### DSE13\_12 [Similar to ASL06(I)\_04b, ASL07(II)\_04a, b]

At  $250^\circ\text{C}$ , the equilibrium constant  $K_c$  for the following reaction is  $25 \text{ mol}^{-1} \text{ dm}^3$ .



A  $10 \text{ dm}^3$  sealed container, which is maintained at  $250^\circ\text{C}$ , initially contains  $0.50 \text{ mol}$  of  $\text{PCl}_3(\text{g})$ ,  $0.20 \text{ mol}$  of  $\text{Cl}_2(\text{g})$  and  $0.40 \text{ mol}$  of  $\text{PCl}_5(\text{g})$ .

- (a) For this system under the initial conditions, calculate its reaction quotient. Predict and explain, under the initial conditions, whether the forward reaction rate or the backward reaction rate would be greater.  
(2 marks)
- (b) Calculate the concentration of  $\text{Cl}_2(\text{g})$  when the system attains equilibrium at  $250^\circ\text{C}$ .  
(2 marks)
- (c)  $0.10 \text{ mol}$  of  $\text{Cl}_2(\text{g})$  is added to the equilibrium mixture in (b). Sketch in the graph below, the variation of the concentration of  $\text{Cl}_2(\text{g})$  with time until a new equilibrium is attained. (Assume that the temperature of the system remains at  $250^\circ\text{C}$  throughout the whole process.)



(1 mark)

325

#### DSE14\_13 [Similar to DSE11SP\_11]

Consider the reaction represented by the equation below:



- (a) In an experiment,  $1.02 \text{ mol}$  of  $\text{NO}(\text{g})$  and  $1.29 \text{ mol}$  of  $\text{O}_2(\text{g})$  are mixed in a  $50.0 \text{ dm}^3$  closed container maintained at  $980 \text{ K}$ . When equilibrium is attained,  $61.0\%$  of  $\text{NO}(\text{g})$  is consumed.  
(2 marks)

- (i) Calculate the equilibrium constant  $K_c$  for the above reaction under the experimental conditions.  
(2 marks)

- (ii) Discuss whether  $K_c$  would change if additional  $\text{NO}(\text{g})$  is introduced into the above equilibrium mixture.  
(2 marks)

- (b) The values of  $K_c$  (in appropriate unit) for this reaction at different temperatures are shown below:

Temperature / K	600	700	800	900
$K_c$	$6.88 \times 10^6$	$2.97 \times 10^5$	$2.89 \times 10^3$	$4.68 \times 10^2$

Based on the above data, deduce whether the forward reaction is exothermic or endothermic.  
(1 mark)

#### DSE15\_11

Refer to the following chemical equation:



Under fixed conditions,  $[\text{H}_2\text{O}(\text{l})]$  is considered as a constant. In consideration of the definition of  $K_c$ ,  $[\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$  would also be a constant.

- (a) The pH of an aqueous solution is defined as  $-\log[\text{H}^+(\text{aq})]$ . The pH of water equals  $7.0$  at  $298 \text{ K}$ . Find, at this temperature, the:  
(1 mark)
- (i)  $[\text{H}^+(\text{aq})]$   
(1 mark)
- (ii)  $[\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$   
(2 marks)
- (b)  $[\text{H}_2\text{O}(\text{l})]$  equals  $55.6 \text{ mol dm}^{-3}$  at  $298 \text{ K}$ . Suggest why  $[\text{H}_2\text{O}(\text{l})]$  is considered as a constant with reference to the values of  $[\text{H}^+(\text{aq})]$  and  $[\text{OH}^-(\text{aq})]$ .  
(1 mark)
- (c) Explain whether the pH of water at  $328 \text{ K}$  would be less than  $7.0$ , equal to  $7.0$ , or greater than  $7.0$ .  
(2 marks)

326

## DSE16\_10 [Similar to AL11(II)\_07]

In an experiment, 2.0 mol of  $\text{SO}_2(\text{g})$  and 2.0 mol of  $\text{O}_2(\text{g})$  are allowed to react in a closed container maintained at 950 K. The chemical equation for the reaction is shown below:



When the reaction attains dynamic equilibrium, 1.8 mol of  $\text{SO}_3(\text{g})$  is obtained.

- (a) What is meant by the term 'dynamic equilibrium'? (1 mark)

- (b) At 950 K, the equilibrium constant  $K_c$  for the above reaction is  $878 \text{ dm}^3 \text{ mol}^{-1}$ . Calculate the volume of the container. (3 marks)

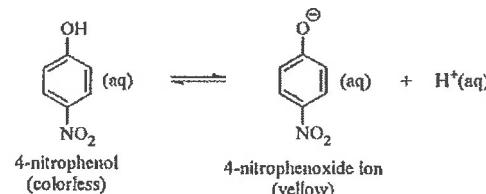
- (c) If the above equilibrium mixture is subjected to each of the following changes, will the number of moles of  $\text{SO}_3(\text{g})$  obtained increase, decrease or remain unchanged? Explain your answer in each case.

- (i) Increasing the temperature (1 mark)

- (ii) Adding a suitable catalyst (1 mark)

## DSE17\_11 [Similar to ASL04(II)\_08, AL05(I)\_03b]

The equation below shows the ionization of 4-nitrophenol in water:



At 25°C, the equilibrium constant  $K_c$  for the ionization is  $8.0 \times 10^{-4} \text{ mol dm}^{-3}$ .

- (a) Write an expression for  $K_c$ . (1 mark)

(You may use  $\text{HA}$  to present 4-nitrophenol and  $\text{A}^-$  to represent 4-nitrophenoxide ion.)

(1 mark)

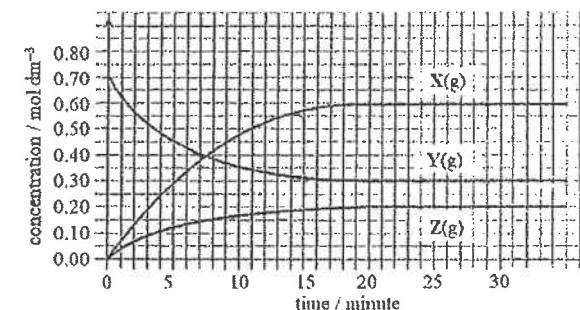
- (b) When the above ionization attains equilibrium at 25°C, the pH of an aqueous of 4-nitrophenol is 2.4. Calculate the ratio of the concentration of 4-nitrophenol to the concentration of 4-nitrophenoxide ions in this solution. (2 marks)

- (c) Suggest if there is any color change when  $\text{NaOH}(\text{aq})$  is added gradually into the solution in (b). Explain your answer. (2 marks)

- (d) Suggest one possible use of 4-nitrophenol is acid-base titration experiment. (1 mark)

## DSE18\_13 [Similar to ASL04(II)\_09]

An experiment was performed for a reversible reaction involving  $\text{X}(\text{g})$ ,  $\text{Y}(\text{g})$  and  $\text{Z}(\text{g})$  in a closed container of  $2.0 \text{ dm}^3$  at a constant temperature. The graph below shows the relevant experimental data.



- (a) According to the graph, how do you know that the reaction is reversible? (1 mark)

- (b) Calculate the equilibrium constant  $K_c$  for the reaction at the temperature of the experiment. (3 marks)

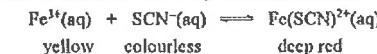
- (c) Comment on the following statement:

'The rate of the forward reaction is zero at the 25<sup>th</sup> minute after the start of the reaction.'

(1 mark)

## DSE19\_12 [Similar as DSE12\_13]

Consider an equilibrium mixture of the following chemical reaction:



- (a) Write an expression for the equilibrium constant  $K_c$  for the reaction. (1 mark)

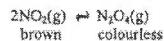
- (b) At a certain temperature, the equilibrium constant  $K_c$  for the reaction is  $1.08 \times 10^3 \text{ dm}^3 \text{ mol}^{-1}$ . The equilibrium mixture is prepared by mixing  $20.0 \text{ cm}^3$  of  $0.030 \text{ M } \text{Fe}(\text{NO}_3)_3(\text{aq})$  with  $10.0 \text{ cm}^3$  of  $0.030 \text{ M } \text{KSCN}(\text{aq})$  in an acidic medium. Calculate the concentration of  $\text{Fe}(\text{SCN})^{2+}(\text{aq})$  in the equilibrium mixture at that temperature. (3 marks)

- (c) It is known that the equilibrium constant  $K_c$  increases when temperature increases. Suggest and explain whether the enthalpy change of the reaction is positive, negative or zero. (1 mark)

- (d) When a little amount of  $\text{Na}_2\text{SO}_3(\text{s})$  is added to the equilibrium mixture, the colour of the mixture becomes paler. Explain this observation. (2 marks)

## DSE20\_09

9. Consider the following reaction mixture at 25°C in a closed container of fixed volume :



- (a) With reference to the table below, calculate a. Hence, determine the equilibrium constant  $K_c$  for the reaction at 25°C.

	NO <sub>2</sub> (g)	N <sub>2</sub> O <sub>4</sub> (g)
Concentration at start / mol dm <sup>-3</sup>	0.0400	0.0010
Concentration at equilibrium / mol dm <sup>-3</sup>	0.0323	a

(3 marks)

- (b) The temperature of the mixture is increased to 55 °C and its colour eventually turns darker. Deduce whether the reaction above is endothermic or exothermic.

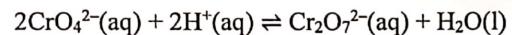
## Marking Scheme

## MCQ

A001001_01	D	D001001_01	C	D001001_03	D	D001001_05	D
D001001_01	D	D001001_01	D	D001001_03	D	D001001_05	D
D0010_07	D (0%)	D0010_07	A (2%)	D0010_09	D	D0010_11	D (0%)
D0010_08	D (0%)	D0010_08	A (2%)	D0010_10	D	D0010_12	D (0%)
D0010_09	D (0%)	D0010_09	A (2%)	D0010_11	D	D0010_13	D (0%)
D0010_10	D (0%)	D0010_10	D	D0010_12	D	D0010_14	D (0%)
D0010_11	D (0%)	D0010_11	D	D0010_13	D	D0010_15	D (0%)
D0010_12	D (0%)	D0010_12	D	D0010_14	D	D0010_16	D (0%)
D0010_13	D (0%)	D0010_13	D	D0010_15	D	D0010_17	D (0%)
D0010_14	D (0%)	D0010_14	D	D0010_16	D	D0010_18	D (0%)
D0010_15	D (0%)	D0010_15	D	D0010_17	D	D0010_19	D (0%)
D0010_16	D (0%)	D0010_16	D	D0010_18	D	D0010_20	D (0%)
D0010_17	D (0%)	D0010_17	D	D0010_19	D	D0010_21	D (0%)
D0010_18	D (0%)	D0010_18	D	D0010_20	D	D0010_22	D (0%)
D0010_19	D (0%)	D0010_19	D	D0010_21	D	D0010_23	D (0%)
D0010_20	D (0%)	D0010_20	D	D0010_22	D	D0010_24	D (0%)
D0010_21	D (0%)	D0010_21	D	D0010_23	D	D0010_25	D (0%)
D0010_22	D (0%)	D0010_22	D	D0010_24	D	D0010_26	D (0%)
D0010_23	D (0%)	D0010_23	D	D0010_25	D	D0010_27	D (0%)
D0010_24	D (0%)	D0010_24	D	D0010_26	D	D0010_28	D (0%)
D0010_25	D (0%)	D0010_25	D	D0010_27	D	D0010_29	D (0%)
D0010_26	D (0%)	D0010_26	D	D0010_28	D	D0010_30	D (0%)
D0010_27	D (0%)	D0010_27	D	D0010_29	D	D0010_31	D (0%)
D0010_28	D (0%)	D0010_28	D	D0010_30	D	D0010_32	D (0%)
D0010_29	D (0%)	D0010_29	D	D0010_31	D	D0010_33	D (0%)
D0010_30	D (0%)	D0010_30	D	D0010_32	D	D0010_34	D (0%)
D0010_31	D (0%)	D0010_31	D	D0010_33	D	D0010_35	D (0%)
D0010_32	D (0%)	D0010_32	D	D0010_34	D	D0010_36	D (0%)
D0010_33	D (0%)	D0010_33	D	D0010_35	D	D0010_37	D (0%)
D0010_34	D (0%)	D0010_34	D	D0010_36	D	D0010_38	D (0%)
D0010_35	D (0%)	D0010_35	D	D0010_37	D	D0010_39	D (0%)
D0010_36	D (0%)	D0010_36	D	D0010_38	D	D0010_40	D (0%)
D0010_37	D (0%)	D0010_37	D	D0010_39	D	D0010_41	D (0%)
D0010_38	D (0%)	D0010_38	D	D0010_40	D	D0010_42	D (0%)
D0010_39	D (0%)	D0010_39	D	D0010_41	D	D0010_43	D (0%)
D0010_40	D (0%)	D0010_40	D	D0010_42	D	D0010_44	D (0%)
D0010_41	D (0%)	D0010_41	D	D0010_43	D	D0010_45	D (0%)
D0010_42	D (0%)	D0010_42	D	D0010_44	D	D0010_46	D (0%)
D0010_43	D (0%)	D0010_43	D	D0010_45	D	D0010_47	D (0%)
D0010_44	D (0%)	D0010_44	D	D0010_46	D	D0010_48	D (0%)
D0010_45	D (0%)	D0010_45	D	D0010_47	D	D0010_49	D (0%)
D0010_46	D (0%)	D0010_46	D	D0010_48	D	D0010_50	D (0%)
D0010_47	D (0%)	D0010_47	D	D0010_49	D	D0010_51	D (0%)
D0010_48	D (0%)	D0010_48	D	D0010_50	D	D0010_52	D (0%)
D0010_49	D (0%)	D0010_49	D	D0010_51	D	D0010_53	D (0%)
D0010_50	D (0%)	D0010_50	D	D0010_52	D	D0010_54	D (0%)
D0010_51	D (0%)	D0010_51	D	D0010_53	D	D0010_55	D (0%)
D0010_52	D (0%)	D0010_52	D	D0010_54	D	D0010_56	D (0%)
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D0010_54	D (0%)	D0010_54	D	D0010_56	D	D0010_58	D (0%)
D0010_55	D (0%)	D0010_55	D	D0010_57	D	D0010_59	D (0%)
D0010_56	D (0%)	D0010_56	D	D0010_58	D	D0010_60	D (0%)
D0010_57	D (0%)	D0010_57	D	D0010_59	D	D0010_61	D (0%)
D0010_58	D (0%)	D0010_58	D	D0010_60	D	D0010_62	D (0%)
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D0010_60	D (0%)	D0010_60	D	D0010_62	D	D0010_64	D (0%)
D0010_61	D (0%)	D0010_61	D	D0010_63	D	D0010_65	D (0%)
D0010_62	D (0%)	D0010_62	D	D0010_64	D	D0010_66	D (0%)
D0010_63	D (0%)	D0010_63	D	D0010_65	D	D0010_67	D (0%)
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D0010_65	D (0%)	D0010_65	D	D0010_67	D	D0010_69	D (0%)
D0010_66	D (0%)	D0010_66	D	D0010_68	D	D0010_70	D (0%)
D0010_67	D (0%)	D0010_67	D	D0010_69	D	D0010_71	D (0%)
D0010_68	D (0%)	D0010_68	D	D0010_70	D	D0010_72	D (0%)
D0010_69	D (0%)	D0010_69	D	D0010_71	D	D0010_73	D (0%)
D0010_70	D (0%)	D0010_70	D	D0010_72	D	D0010_74	D (0%)
D0010_71	D (0%)	D0010_71	D	D0010_73	D	D0010_75	D (0%)
D0010_72	D (0%)	D0010_72	D	D0010_74	D	D0010_76	D (0%)
D0010_73	D (0%)	D0010_73	D	D0010_75	D	D0010_77	D (0%)
D0010_74	D (0%)	D0010_74	D	D0010_76	D	D0010_78	D (0%)
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D0010_76	D (0%)	D0010_76	D	D0010_78	D	D0010_80	D (0%)
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D0010_80	D (0%)	D0010_80	D	D0010_82	D	D0010_84	D (0%)
D0010_81	D (0%)	D0010_81	D	D0010_83	D	D0010_85	D (0%)
D0010_82	D (0%)	D0010_82	D	D0010_84	D	D0010_86	D (0%)
D0010_83	D (0%)	D0010_83	D	D0010_85	D	D0010_87	D (0%)
D0010_84	D (0%)	D0010_84	D	D0010_86	D	D0010_88	D (0%)
D0010_85	D (0%)	D0010_85	D	D0010_87	D	D0010_89	D (0%)
D0010_86	D (0%)	D0010_86	D	D0010_88	D	D0010_90	D (0%)
D0010_87	D (0%)	D0010_87	D	D0010_89	D	D0010_91	D (0%)
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D0010_89	D (0%)	D0010_89	D	D0010_91	D	D0010_93	D (0%)
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D0010_92	D (0%)	D0010_92	D	D0010_94	D	D0010_96	D (0%)
D0010_93	D (0%)	D0010_93	D	D0010_95	D	D0010_97	D (0%)
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D0010_100	D (0%)	D0010_100	D	D0010_102	D	D0010_104	D (0%)
D0010_101	D (0%)	D0010_101	D	D0010_103	D	D0010_105	D (0%)
D0010_102	D (0%)	D0010_102	D	D0010_104	D	D0010_106	D (0%)
D0010_103	D (0%)	D0010_103	D	D0010_105	D	D0010_107	D (0%)
D0010_104	D (0%)	D0010_104	D	D0010_106	D	D0010_108	D (0%)
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D0010_107	D (0%)	D0010_107	D	D0010_109	D	D0010_111	D (0%)
D0010_108	D (0%)	D0010_108	D	D0010_110	D	D0010_112	D (0%)
D0010_109	D (0%)	D0010_109	D	D0010_111	D	D0010_113	D (0%)
D0010_110	D (0%)	D0010_110	D	D0010_112	D	D0010_114	D (0%)
D0010_111	D (0%)	D0010_111	D	D0010_113	D	D0010_115	D (0%)
D0010_112	D (0%)	D0010_112	D	D0010_114	D	D0010_116	D (0%)
D0010_113	D (0%)	D0010_113	D	D0010_115	D	D0010_117	D (0%)
D0010_114	D (0%)	D0010_114	D	D0010_116	D	D0010_118	D (0%)
D0010_115	D (0%)	D0010_115	D	D0010_117	D	D0010_119	D (0%)
D0010_116	D (0%)	D0010_116	D	D0010_118	D	D0010_120	D (0%)
D0010_117	D (0%)	D0010_117	D	D0010_119	D	D0010_121	D (0%)
D0010_118	D (0%)	D0010_118	D	D0010_120	D	D0010_122	D (0%)
D0010_119	D (0%)	D0010_119	D	D0010_121	D	D0010_123	D (0%)
D0010_120	D (0%)	D0010_120	D	D0010_122	D	D0010_124	D (0%)
D0010_121	D (0%)	D0010_121	D	D0010_123	D	D0010_125	D (0%)
D0010_122	D (0%)	D0010_122	D	D0010_124	D	D0010_126	D (0%)
D0010_123	D (0%)	D0010_123	D	D0010_125	D	D0010_127	D (0%)
D0010_124	D (0%)	D0010_124	D	D0010_126	D	D0010_128	D (0%)
D0010_125	D (0%)	D0010_125	D	D0010_127	D	D0010_129	D (0%)
D0010_126	D (0%)	D0010_126	D	D0010_128	D	D0010_130	D (0%)
D0010_127	D (0%)	D0010_127	D	D0010_129	D	D0010_131	D (0%)
D0010_128	D (0%)	D0010_128	D	D0010_130	D	D0010_132	D (0%)
D0010_129	D (0%)	D0010_129	D	D0010_131	D	D0010_133	D (0%)
D0010_130	D (0%)	D0010_130	D	D0010_132	D	D0010_134	D (0%)
D0010_131	D (0%)	D0010_131	D	D0010_133	D	D0010_135	D (0%)
D0010_132	D (0%)	D0010_132	D	D0010_134	D	D0010_136	D

# 2022

32. Consider the following equilibrium system :



Which of the following statements can demonstrate that chromium exhibits the characteristic(s) of transition metals ?

- (1)  $\text{Cr}_2\text{O}_7^{2-}$ (aq) ions are orange in colour.
  - (2) Adding HCl(aq) would shift the equilibrium position to the right.
  - (3) The oxidation states of chromium in  $\text{CrO}_4^{2-}$  and  $\text{Cr}_2\text{O}_7^{2-}$  are the same.
- 
- A. (1) only
  - B. (2) only
  - C. (1) and (3) only
  - D. (2) and (3) only

36. Consider the following statements and choose the best answer :

**1st statement**

At chemical equilibrium, the concentration of reactants must be equal to the concentration of products.

**2nd statement**

At chemical equilibrium, both forward reaction rate and backward reaction rate are equal to zero.

- A. Both statements are true and the 2nd statement is a correct explanation of the 1st statement.
- B. Both statements are true but the 2nd statement is NOT a correct explanation of the 1st statement.
- C. The 1st statement is false but the 2nd statement is true.
- D. Both statements are false.

Consider the following reaction sequence. DSE indicates number of test items.

- (a) The following reaction sequence is observed in the presence of acid catalyst.  
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{H}^+} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl} \xrightarrow{\text{H}^+} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{COCl}$   
 (b) The following is the reaction scheme involving  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$  and its subsequent analysis. DSE indicates number of test items in each question.

### Marking Scheme

#### MCQ

ASL05(I)_01	D	DSE11SP_29	C	DSE11SP_35	B	DSE12PP_26	D
DSE12PP_31	D	DSE12_26	D (88%)	DSE12_27	A (60%)	DSE13_35	C (60%)
DSE13_27	D (61%)	DSE13_28	A (79%)	DSE14_26	B (68%)	DSE14_31	D (28%)
DSE14_35	D (80%)	DSE15_27	A (60%)	DSE15_31	B (61%)	DSE15_33	C
DSE16_26	B (60%)	DSE16_27	D (67%)	DSE17_31	B (56%)	DSE17_32	C (72%)
DSE17_34	D (42%)	DSE18_26	B (71%)	DSE18_29	B (48%)	DSE19_26	B
DSE19_27	D	DSE19_25	C	DSE20_26	B	DSE20_33	D

An experiment was performed using a mixture containing  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$  and water in a closed container of a fixed volume. The final equilibrium composition of the mixture was measured below.

#### Mass Action Equilibrium

- (a) Write an expression for the equilibrium constant,  $K$ , for the reaction  
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl} \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} + \text{HCl}$ . The number of moles of each species at different times in the reaction are given in the table below.

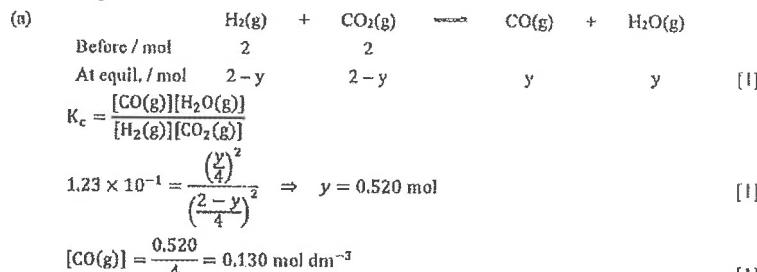
	Initial	10 min	20 min	30 min
Total number of moles	0.00	0.00	0.00	0.00
Number of moles of equilibrium	0.10	0.02	0.02	0.02

- (b) Calculate the number of moles of equilibrium for  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ .
- (c) Calculate the equilibrium constant for the reaction in the following.
- (d) If the volume of the closed container changes to 5.0 and the total concentration of products would increase double, whether the overall reaction becomes more exothermic.

### Structural Questions

#### ASL99(I)\_03

- (a) The reaction is endothermic since the value of  $K_c$  increases with increasing temperature. [1]



- (b) No change.  
Percentage yield only depends on the temperature. [1]

#### AL99(II)\_04a

- (i) When equilibrium is attained
- $$[\text{N}_2(\text{g})] = 0.5 \times 0.75 = 0.375 \text{ mol dm}^{-3} \quad [1]$$
- $$[\text{H}_2(\text{g})] = 1.5 - 3 \times (0.5 \times 0.25) = 1.125 \text{ mol dm}^{-3} \quad [1]$$
- $$[\text{NH}_3(\text{g})] = 2 \times 0.5 \times 0.25 = 0.25 \text{ mol dm}^{-3} \quad [1]$$
- (ii)  $K_c \approx \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3} = \frac{(0.25)^2}{(0.375)(1.125)^3} = 0.117 \text{ mol}^{-2} \text{ dm}^6 \quad [2]$
- (iii) (I)  $K_c$  decreases with increasing temperature.  
The reaction is exothermic. ∴ increase in temperature will cause the equilibrium position to shift to the left. [½]  
(II) The reaction proceeds slowly at low temperature. The yield of  $\text{NH}_3$  is low at high temperature.  
∴ The process is operated at around 723K. [½]

#### ASL00(II)\_04

- (a)  $\text{CH}_3\text{COOH}(\text{l}) + \text{CH}_3\text{CH}(\text{OH})\text{CH}_3(\text{l}) \rightleftharpoons \text{CH}_3\text{COOCH}(\text{CH}_3)_2(\text{l}) + \text{H}_2\text{O}(\text{l}) \quad [1]$
- (b) As catalyst to speed up the reaction. [1]
- (c) (i) To prevent the disturbance of equilibrium position due to the removal of reactant / to prevent the equilibrium state of reaction shifts to the left due to the removal of reactant.  
(ii) Phenolphthalein [1]
- (d) As the anti-bumping granule to ensure the smooth boiling process. [1]
- (e) No. of mole of  $\text{CH}_3\text{COOH}(\text{l})$  in  $1 \text{ cm}^3$  of mixture =  $36.80 \times 10^{-3} \times 0.30 = 0.011$   
 $[\text{CH}_3\text{COOH}(\text{l})] = [\text{CH}_3\text{CH}(\text{OH})\text{CH}_3(\text{l})] = 0.011 + 1 \times 10^{-3} = 11.04 \text{ mol dm}^{-3}$   
 No. of mole of  $\text{CH}_3\text{COOH}(\text{l})$  in  $1 \text{ cm}^3$  of mixture after equilibrium  
 $= [17.15 - (36.90 - 36.8)] \times 10^{-3} \times 0.30 = 5.12 \times 10^{-3}$  [1]

$$[\text{CH}_3\text{COOH}(\text{l})] = [\text{CH}_3\text{CH}(\text{OH})\text{CH}_3(\text{l})] \text{ at equilibrium}$$

$$= 5.12 \times 10^{-3} + 1 \times 10^{-3} = 5.12 \text{ mol dm}^{-3} \quad [1]$$



$$\begin{array}{ll} \text{Initial} & 11.04 & 11.04 \\ \text{At equil.} & 11.04 - y & 11.04 - y & 5.92 & 5.92 \end{array}$$

$$= 5.12 \quad = 5.12$$

$$K_c = \frac{[\text{CH}_3\text{COOCH}(\text{CH}_3)_2(\text{l})][\text{H}_2\text{O}(\text{l})]}{[\text{CH}_3\text{COOH}(\text{l})][\text{CH}_3\text{CH}(\text{OH})\text{CH}_3(\text{l})]} \quad [1]$$

$$= \frac{(5.92)(5.92)}{(5.12)(5.12)} = 1.34 \quad [1]$$

- (f) Allow the mixture heating reflux for another hour and repeat the titration. If the volume of titrant used / amount of  $\text{CH}_3\text{COOH}$  remained is unchanged, the equilibrium has been attained. [1]

#### ASL01(I)\_02

	(i) Adding a catalyst to the mixture	(ii) Increasing the temperature of the mixture
Effect on the rate of the forward reaction	Increase in the same extent	Increase in the smaller extent
Effect on the rate of the backward reaction	Increase in the same extent	Increase in the larger extent
Effect on the equilibrium position	remain unchanged	Shift to left (reactant side)

#### AL02(I)\_01a



$$\text{At equil. / mol dm}^{-3} \quad y \quad y \quad 10^{-6.10}$$

$$K_a = \frac{[\text{HCO}_3^-(\text{aq})][\text{H}^+(\text{aq})]}{[\text{H}_2\text{CO}_3(\text{aq})]} \quad [1]$$

In the solution,  $[\text{HCO}_3^-(\text{aq})] = [\text{H}_2\text{CO}_3(\text{aq})]$

$$\therefore K_a = [\text{H}^+(\text{aq})] = 10^{-6.10} = 7.94 \times 10^{-7} \text{ mol dm}^{-3} \quad [1]$$

$$(ii) \quad K_a = \frac{[\text{HCO}_3^-(\text{aq})][\text{H}^+(\text{aq})]}{[\text{H}_2\text{CO}_3(\text{aq})]} \quad [1]$$

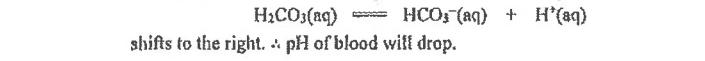
$$7.94 \times 10^{-7} = \frac{[\text{HCO}_3^-(\text{aq})]10^{-7.40}}{[\text{H}_2\text{CO}_3(\text{aq})]} \quad [1]$$

$$[\text{HCO}_3^-(\text{aq})] = \frac{7.94 \times 10^{-7}}{10^{-7.40}} = 20 \quad [1]$$

(Accept answer from 19.8 to 20.0)

(1 mark for method; 1 mark for answer)

- (iii) (I) During physical exertion, the concentration of  $\text{CO}_2$  in blood increases.  
The equilibrium



- (II) Blood contains high concentration of  $\text{HCO}_3^-$ (aq) which reacts with  $\text{H}^+$  produced.  
 $\Delta\text{pH}$  of blood is maintained within the narrow pH range.

AL02(I)\_02a

Color of mixture becomes lighter instantaneously because there is an expansion in volume. [1]  
As the reaction is endothermic, the color of mixture finally becomes darker because [1]  
equilibrium shifts to the right.

AL02(II)\_03

(a) For reaction (1),  $K_{c1} = \frac{[\text{Ag}(\text{NH}_3)_2^+(\text{aq})]}{[\text{Ag}^+(\text{aq})][\text{NH}_3(\text{aq})]^2}$  [1]

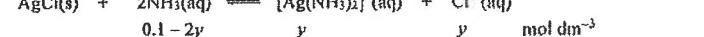
For reaction (2),  $K_{c2} = [\text{Ag}^+(\text{aq})][\text{Cl}^-(\text{aq})]$  [1]

(b) For reaction (3),  $K_{c3} = \frac{[\text{Ag}(\text{NH}_3)_2^+(\text{aq})][\text{Cl}^-(\text{aq})]}{[\text{NH}_3(\text{aq})]^2}$  [1]

$$= \frac{[\text{Ag}(\text{NH}_3)_2^+(\text{aq})]}{[\text{Ag}^+(\text{aq})][\text{NH}_3(\text{aq})]^2} \times [\text{Ag}^+(\text{aq})][\text{Cl}^-(\text{aq})] = K_{c1} K_{c2}$$
 [1]

$$= 1.8 \times 10^7 \times 2.0 \times 10^{-10} = 3.6 \times 10^{-3}$$
 [1]

(c) Assuming that  $[\text{Ag}(\text{NH}_3)_2^+(\text{aq})] = [\text{Cl}^-(\text{aq})]$

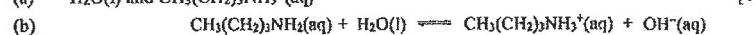
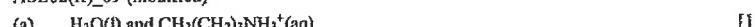


$$3.6 \times 10^{-3} = \frac{[\text{Ag}(\text{NH}_3)_2^+(\text{aq})][\text{Cl}^-(\text{aq})]}{[\text{NH}_3(\text{aq})]^2} = \frac{y^2}{0.1 - 2y}$$
 [1]

$$y = 5.36 \times 10^{-3} \text{ mol dm}^{-3}$$
 [1]

Solubility of  $\text{AgCl(s)}$  =  $5.36 \times 10^{-3} \text{ mol dm}^{-3}$   
(accept  $5.3 \times 10^{-3} \text{ mol dm}^{-3}$  to  $6.3 \times 10^{-3} \text{ mol dm}^{-3}$ )

ASL02(II)\_09 (modified)



$$\text{Initial / M} \quad 0.10$$

$$\text{At equil. / M} \quad 0.10 - y \quad y \quad y$$

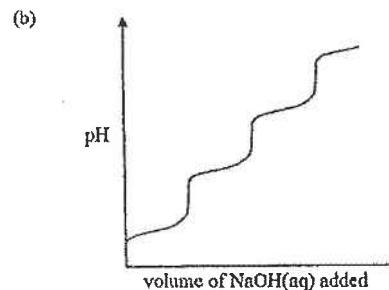
$$K_c = 5.9 \times 10^{-4} = \frac{[\text{CH}_3(\text{CH}_2)_3\text{NH}_3^+(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{CH}_3(\text{CH}_2)_3\text{NH}_2(\text{aq})]} = \frac{y^2}{0.10 - y}$$
 [1]

$$y = [\text{OH}^-(\text{aq})] = 7.68 \times 10^{-3}$$
 [1]

$$\text{pH} = 14 - \text{pOH} = 14 - \log(7.68 \times 10^{-3}) = 11.9$$
 [1]

ASL03(I)\_01

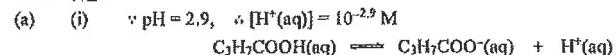
- (a) After the removal of a hydrogen ion, the remaining species has an additional negative charge that attracts the remaining hydrogen atoms more strongly. [1]



[3]

(2 marks for a curve showing the neutralization of  $\text{H}_3\text{PO}_4$ (aq),  $\text{H}_2\text{PO}_4^-$ (aq) and  $\text{HPO}_4^{2-}$ (aq) + 1 mark for labeling the axes)

ASL03(I)\_05



$$\text{At equil} \quad 0.1 \text{ M} - y \quad y \quad y$$

$$y = 10^{-2.9} \text{ M}$$

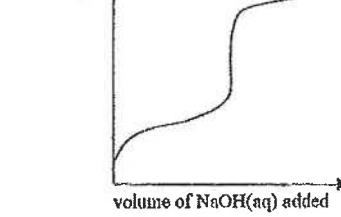
$$\text{degree of dissociation} = 10^{-2.9} / 0.1 = 0.0126$$

$$(ii) K_c = \frac{[\text{H}^+(\text{aq})][\text{C}_2\text{H}_5\text{COO}^-(\text{aq})]}{[\text{C}_2\text{H}_5\text{COOH(aq)}]} = \frac{(10^{-2.9})^2}{0.10 - 10^{-2.9}}$$

$$= 1.6 \times 10^{-5} \text{ mol dm}^{-3}$$



[3]



ASL03(II)\_11

- (a) Backward rate will decrease.

Kinetic energy of the molecules decreases with decrease in temperature.

Hence, the fraction of colliding molecules with K.E. greater than the activation energy becomes smaller.

- (b) (i) When the temperature of the mixture is lowered, the equilibrium position shifts to the left. The reaction is endothermic.

- (ii) The dissociation of  $\text{N}_2\text{O}_4$  requires breaking of covalent bond.  
 $\Delta$  the reaction is endothermic.

[1]

[1]

[1]

[1]

[1]

[1]

(c) Treat the gas in the syringe with NaOH.

[1]

ASL04(I)\_04 (modified)



[1]

$$(b) K_c = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$$

[1]

$$(c) (i) [\text{H}^+(\text{aq})] = \sqrt{K_c} = \sqrt{5.5 \times 10^{-14}} \text{ mol dm}^{-3} = 2.35 \times 10^{-7} \text{ mol dm}^{-3}$$

[1]

$$\text{pH} = -\log(2.35 \times 10^{-7}) = 6.63$$

[1]

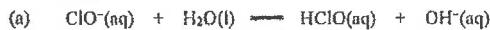
(ii) Neutral because  $[\text{H}^+(\text{aq})] = [\text{OH}^-(\text{aq})]$

[1]

(iii) The value of  $K_w$  increases with temperature. That is, energy is absorbed when water undergoes auto-ionization. The process is endothermic.

[1]

ASL04(II)\_08



[1]



$$K_c = \frac{[\text{H}^+(\text{aq})][\text{ClO}^-(\text{aq})]}{[\text{HClO}(\text{aq})]}$$

$$\frac{K_c}{[\text{H}^+(\text{aq})]} = \frac{[\text{ClO}^-(\text{aq})]}{[\text{HClO}(\text{aq})]}$$

$$\text{pH} = 7.50, \therefore [\text{H}^+(\text{aq})] = 10^{-7.5} \text{ mol dm}^{-3}$$

[1]

$$\frac{[\text{ClO}^-(\text{aq})]}{[\text{HClO}(\text{aq})]} = \frac{2.95 \times 10^{-8}}{10^{-7.5}} = 0.933$$

[1]

(ii) The low pH of pool water would cause eye irritation of swimmers.

[1]



[1]

(ii) The equilibrium position will shift to the right.

[1]

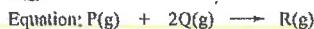
There is a greater number of aqueous species on the right. Dilution leads to a decrease in concentration of the aqueous species and the equilibrium position will shift to the right to counteract the effect of the change.

[1]

ASL04(II)\_09

(a) (i) From the curve, 1 mole of P(g) reacts with 2 moles of Q(g) to give 1 mole of R(g).

[1]



[1]

(ii) The time required will become longer.

[1]

In a larger container, the concentrations of reactants become smaller and hence the collision frequency decreases.

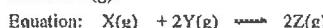
[1]

(iii) Colliding molecules will undergo reaction only if they possess an energy greater than the activation energy and collide in the right orientation.

[1]

(b) (i) From the curve, 1 mole of X(g) reacts with 2 molecules of Y(g) to give 2 moles of Z(g).

[1]



[1]

$$K_c = \frac{[\text{Z(g)}]^2}{[\text{X(g)}][\text{Y(g)}]^2}$$

[1]

- (ii) (i) At the 5<sup>th</sup> minute, forward rate is greater than backward rate.  
(2) At the 35<sup>th</sup> minute, forward rate is equal to backward rate.

[1]

[1]

- (iii) The yield of product decreases.

With an increase in volume, the total pressure decreases. The equilibrium position will shift to the side with a greater number of moles of gases.

[1]

AL05(I)\_03b

$$(i) K_c = \frac{[\text{Cy(aq)}][\text{H}^+(\text{aq})]}{[\text{CyH}^+(\text{aq})]}$$

[1]

$$(ii) \text{pH} = 3.00, [\text{H}^+] = 10^{-3} \text{ M}$$

[2]

$$\frac{[\text{CyH}^+(\text{aq})]}{[\text{Cy(aq)}]} = 20$$

$$\frac{[\text{CyH}^+(\text{aq})]}{[\text{Cy(aq)}]} = \frac{10^{-3}}{K_c} = 20$$

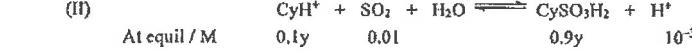
[2]

$$K_c = 5 \times 10^{-5} \text{ M}$$

[1]

$$(iii) (I) K_c = \frac{[\text{CySO}_3\text{H}_2(\text{aq})][\text{H}^+(\text{aq})]}{[\text{CyH}^+(\text{aq})][\text{SO}_3(\text{aq})]}$$

[1]



At equil / M 0.1y 0.01 0.9y 10<sup>-3</sup>

$$K_c = \frac{[\text{CySO}_3\text{H}_2(\text{aq})][\text{H}^+(\text{aq})]}{[\text{CyH}^+(\text{aq})][\text{SO}_3(\text{aq})]} = \frac{(0.9y)(10^{-3})}{(0.1y)(0.01)} = 0.9$$

[1]

ASL05(II)\_08

(a) Experiment 1



Before / mole

4

After 1 day / mol

3

After 1 day / mol dm<sup>-3</sup>

1.5

$$Q = \frac{[\text{Y(g)}]^2}{[\text{Y}_2(\text{g})]} = \frac{(1)^2}{1.5} = \frac{2}{3} \text{ mol dm}^{-3}$$

[1]

Experiment 2



Before / mole

0

After 1 day / mol

4/3

After 1 day / mol dm<sup>-3</sup>

2/3

$$Q = \frac{[\text{Y(g)}]^2}{[\text{Y}_2(\text{g})]} = \frac{(2/3)^2}{2/3} = \frac{2}{3} \text{ mol dm}^{-3}$$

[1]

The system had already attained an equilibrium state because the two reaction quotients are the same.

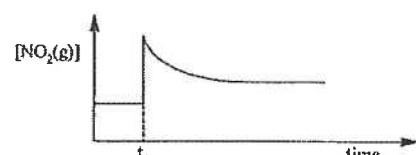
[1]

- (b) (1) Yield of Y(g) will decrease.  
When the volume of the container decreases, the pressure of the system will increase.  
The total number of moles of gaseous products is greater than that of gaseous reactants.  
∴ Increase in pressure will cause the equilibrium position to shift to the left.  
∴ Less Y(g) will be formed.
- (2) The yield of Y(g) will increase.  
For an endothermic reaction, increase in temperature will cause the equilibrium position to shift to the right / will lead to an increase in the value of  $K_c$ . ∴ more Y(g) will be formed.

#### ASL06(I)\_04

- (a) Expected observation:  
The brown color of the mixture turns deeper for a moment and then gets paler gradually.  
Reason:  
When the plunger is moved from A to B, there is a decrease in volume and so an increase in the concentration of brown NO<sub>2</sub>(g).  
A decrease in volume will lead to a shift in the equilibrium position to the left, to produce a smaller number of moles of gaseous molecules, so that [NO<sub>2</sub>(g)] decreases.

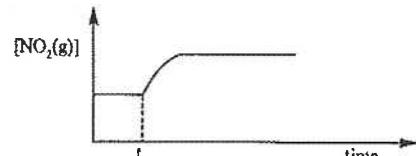
Graph



[1]

- (b) Expected observation:  
The brown color of the mixture gradually gets darker.  
Reason:  
An increase in the concentration of N<sub>2</sub>O<sub>4</sub> will shift the equilibrium position to the right, so that [NO<sub>2</sub>(g)] increases.

Graph



[1]

#### ASL06(II)\_12 (modified)

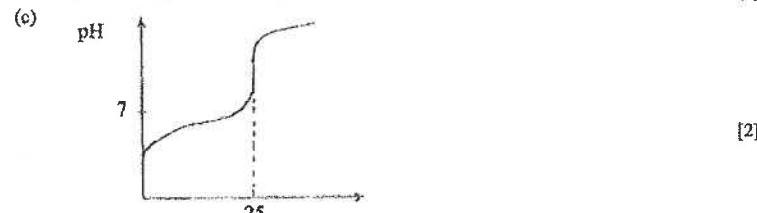
- (a) A weak acid is an acid that only partially ionizes in water. [1]

(b) 
$$K_c = \frac{[\text{H}^+(\text{aq})][\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})]}{[\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})]}$$

$$1.35 \times 10^{-5} = \frac{y^2}{0.2 - y}$$
, where  $y = [\text{H}^+(\text{aq})]$  [1]

$$y = 1.636 \times 10^{-3}$$
 [1]

$$\text{pH} = -\log(1.636 \times 10^{-3}) = 2.79$$
 [1]



[2]

(d) (i) 
$$K_c = \frac{[\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})]}$$

$$= [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] \frac{[\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})]}{[\text{H}^+(\text{aq})][\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})]} = \frac{K_w}{K_a}$$
 [1]

(ii) (i) 
$$K_c = \frac{[\text{CH}_3\text{CH}_2\text{COOH}(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})]}$$
 [1]

$$1.0 \times 10^{-14} = \frac{y^2}{1.35 \times 10^{-5}} = \frac{y^2}{0.2 - y}$$
 [1]

$$[\text{OH}^-(\text{aq})] = y = 1.217 \times 10^{-5} \text{ mol dm}^{-3}$$
 [1]

(2) 
$$\text{pH} = 14 - \text{pOH}$$
  
$$= 14 - \log(1.217 \times 10^{-5})$$
  
$$= 9.09$$
 [1]

#### ASL07(II)\_04

(a) Reaction quotient,  $Q = \frac{[\text{COCl}_2(\text{g})]}{[\text{CO}(\text{g})][\text{O}_2(\text{g})]} = \frac{\frac{0.5}{4}}{\left(\frac{2}{4}\right)\left(\frac{1}{4}\right)} = 1 \text{ mol}^{-1} \text{ dm}^3$  [1]

$Q > K_c$  ∴ Reaction will proceed to the left to achieve equilibrium. [1]

(b)

	CO(g)	+	Cl <sub>2</sub> (g)	↔	COCl <sub>2</sub> (g)
Initial / mol	2		1		0.5
At equil / mol	2 + y		1 + y		0.5 - y

$$K_c = \frac{[\text{COCl}_2(\text{g})]}{[\text{CO}(\text{g})][\text{O}_2(\text{g})]}$$

336

337

$$0.20 = \frac{(0.5 - y)4}{(2+y)(1+y)}, \quad \therefore y = 0.343$$

[1]

$$[\text{COCl}_2(\text{g})] = \frac{0.5 - 0.343}{4} = 0.0339 \text{ mol dm}^{-3}$$

[1]

(c) No change.  $K_e$  is a constant at a constant temperature.

[1]

#### ASL08(I)\_04



Initial / mol	4.0	2.0	0
At equil / mol	4.0 - y	2.0 - y	2y

[1/2]

$$K_e = \frac{[\text{HI}(\text{g})]^2}{[\text{H}_2(\text{g})][\text{I}_2(\text{g})]}$$

[1]

$$50 = \frac{(2y)^2}{(4-y)(2-y)}, \quad \therefore y = 1.87$$

[1/2]

$$[\text{H}_2(\text{g})] = 0.426 \text{ mol dm}^{-3}$$

[1]

$$[\text{I}_2(\text{g})] = 0.026 \text{ mol dm}^{-3}$$

[1/2]

$$[\text{HI}(\text{g})] = 0.747 \text{ mol dm}^{-3}$$

[1/2]

(b) (i) No change.

[1/2]

There is no change in the number of moles of gases in the reaction. No shifting of equilibrium position will result.

[1]

(ii) Increased

[1/2]

The equilibrium position will shift to the right to give a greater number of moles of  $\text{HI}(\text{g})$ .

[1]

#### ASL09(II)\_02

$$(a) K_e = [\text{CO}_2(\text{g})]$$

[1]

$$(b) \text{ Moles of CO}_2(\text{g}) \text{ in the equilibrium mixture} = 2.7 \times 10^{-3} \times 5$$

[1]

$$\text{Moles of CaCO}_3(\text{s}) \text{ originally present} = 25 \div (40.1 + 12 + 16 \times 3) = 0.2498$$

[1]

$$\% \text{ dissociation of CaCO}_3(\text{s}) = \frac{2.7 \times 10^{-3} \times 5}{0.2498} \times 100\% = 5.4\%$$

[1]

(c) Decrease

[1]

The dissociation is an endothermic process. A decrease in temperature will cause the equilibrium position to shift to the left resulting in a smaller percentage of  $\text{CaCO}_3(\text{s})$  to undergo dissociation.

[1]

(d) No. The equilibrium constant depends only on temperature. Adding  $\text{CaCO}_3(\text{s})$  to the system will not affect the concentration of  $\text{CO}_2(\text{g})$ .

[1]

#### AL10(I)\_02 (modified)

(a)  $[\text{OH}^-(\text{aq})]$  in the saturated solution.

$$= \frac{0.1 \times 9.0}{20} = 0.0455 \text{ mol dm}^{-3}$$

[1]



[1]

$$\text{Solubility of Ca(OH)}_2(\text{s}) = \frac{0.0455}{2} = 0.02275 \text{ mol dm}^{-3}$$

[1]



[1]

$$[\text{Ca}^{2+}(\text{aq})] = \frac{0.0455}{2} = 0.02275 \text{ mol dm}^{-3}$$

[1]

$$K_e = [\text{Ca}^{2+}(\text{aq})][\text{OH}^-(\text{aq})]^2 \\ = (0.02275)(0.0455)^2 = 4.71 \times 10^{-5} \text{ mol}^3 \text{ dm}^{-9}$$

[1]

#### AL10(I)\_03

Adding  $\text{H}_2\text{SO}_4(\text{aq})$  to  $\text{K}_2\text{CrO}_4(\text{aq})$ : the yellow solution turn orange ( $\text{Cr}_2\text{O}_7^{2-}$ ).

[1]



[1]

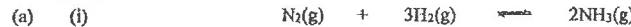
Adding  $\text{FeSO}_4(\text{aq})$  to the orange solution: it turns green ( $\text{Cr}^{3+}$ ).

[1/2]



[1]

#### AL10(II)\_03



Before / mol	10	30	-
At equil / mol	10 - y	30 - 3y	2y

Total no. of mole of gaseous species =  $(10 - y) + (30 - 3y) + 2y = 40 - 2y$

∴ mole percentage of  $\text{NH}_3 = 39\%$

$$\therefore \frac{2y}{40 - 2y} = 0.39, \quad y = 5.61$$

$$\therefore \text{concentration of } \text{NH}_3(\text{g}) = 5.61 \times 2 + 50 = 0.2244 \text{ mol dm}^{-3}$$

[1]

$$\therefore \text{concentration of } \text{N}_2(\text{aq}) = (10 - 5.61) \div 50 = 0.0878 \text{ mol dm}^{-3}$$

[1]

$$\therefore \text{concentration of } \text{H}_2(\text{aq}) = (30 - 3 \times 5.61) \div 50 = 0.2634 \text{ mol dm}^{-3}$$

[1]

$$(ii) \quad K_e = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3} = \frac{(0.2244)^2}{(0.0878)(0.2634)^3} \\ = 31.38 \text{ mol}^{-2} \text{ dm}^6$$

[1]

(b) Increase the pressure of the system

[1]

Remove ammonia by liquefaction and pass the unreacted  $\text{N}_2(\text{g})$  and  $\text{H}_2(\text{g})$  back into the reaction chamber.

[1]

#### AL11(II)\_06

(a) Observation: solution changes from yellow to orange

[1]



[1]

#### ASL11(II)\_06

(a) Trial 2 & 5

[1]

Explanation: The mole ratios of  $\text{N}_2(\text{g})$  to  $\text{H}_2(\text{g})$  are the same in the five trials. ∴ The equilibrium position of the reaction is affected by temperature and pressure only. In trial 2 and 5, both pressure and temperature are the same, thus they have the same yield of  $\text{NH}_3(\text{g})$ .

[1]

(b)	Trial 3													
	Explanation: The reaction is exothermic, low temperature will favour the formation of product.	[1]												
	There is a smaller number of molecules on the product side than on the reactant side. Increase in pressure will favor the formation of product. In trial 3, the pressure is greatest while the temperature is lowest.	[1]												
(c)	Any TWO of the following:	[2]												
	<ul style="list-style-type: none"> <li>Under the operation conditions, the percentage conversion of <math>N_2(g)</math> to <math>NH_3(g)</math> is reasonably high and the use of catalyst can speed up the reaction.</li> <li>Operating the process at 200 atm (much lower than 1000 atm) can help reduce the maintenance cost of the pipelines.</li> <li>Operating the process at 673 K makes the reaction to proceed at a reasonably fast rate without having a great increase on fuel cost.</li> </ul>													
AL11(II)_07 (modified)														
(a)	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ <table style="margin-left: 100px;"> <tr> <td>Initial / mol</td> <td>0.20</td> <td>0.20</td> <td>0</td> </tr> <tr> <td>At equil. / mol</td> <td>0.04</td> <td>0.12</td> <td>0.16</td> </tr> <tr> <td>At equil / mol dm<sup>-3</sup></td> <td>0.04/V</td> <td>0.12/V</td> <td>0.16/V</td> </tr> </table>	Initial / mol	0.20	0.20	0	At equil. / mol	0.04	0.12	0.16	At equil / mol dm <sup>-3</sup>	0.04/V	0.12/V	0.16/V	[1]
Initial / mol	0.20	0.20	0											
At equil. / mol	0.04	0.12	0.16											
At equil / mol dm <sup>-3</sup>	0.04/V	0.12/V	0.16/V											
	$K_c = \frac{[SO_3(g)]^2}{[SO_2(g)]^2 [O_2(g)]} = \frac{\left(\frac{0.16}{V}\right)^2}{\left(\frac{0.04}{V}\right)^2 \left(\frac{0.12}{V}\right)} = \frac{(0.16)^2}{(0.04)^2 (0.12)} = 11.73$	[1]												
	$V = 88 \text{ cm}^3$	[1]												
(b)	<p>(i) Decrease. The no. of gas molecules on the product side is smaller than that on the reactant side. Decrease in pressure will cause the equilibrium position to shift to the left.</p> <p>(ii) Increase. The reaction is exothermic. Decrease in temperature will cause the equilibrium position to shift to the right.</p> <p>(iii) No change. A catalyst will increase the rate of the forward reaction and that of the backward reaction to the same extent and has no effect on the equilibrium constant.</p>	[1]												
ASL12(I)_01														
(b)	The blood-red color is due to the formation of $[Fe(SCN)]^{2+}$ .	[1]												
	$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons [Fe(SCN)]^{2+}(aq)$	[%]												
	OH <sup>-</sup> ion binds more strongly with Fe <sup>3+</sup> ion than SCN <sup>-</sup> ion does.													
	If the solution is made alkaline, brown $Fe(OH)_3(s)$ will be formed instead.	[1]												
	$Fe^{3+}(aq) + 3OH^-(aq) \rightleftharpoons Fe(OH)_3(s)$	[%]												

ASL12(I)_07										
(a)	$K_c = \frac{[SO_4^{2-}(aq)]}{[I^-(aq)]^2}$	[1]								
(b)	Add PbSO <sub>4</sub> (s) to the standard KI(aq). Stir the mixture thoroughly, and allow it to stand in a water bath at 313 K for a long period of time.	[2]								
(c)	Collect the supernatant solution by filtering off solids / decantation.	[1]								
(d)	$PbSO_4(s) + 2I^-(aq) \rightleftharpoons PbI_2(s) + SO_4^{2-}(aq)$ <table style="margin-left: 100px;"> <tr> <td>Initial / mol dm<sup>-3</sup></td> <td>0.100</td> <td></td> </tr> <tr> <td>At equil / mol dm<sup>-3</sup></td> <td>0.072</td> <td>0.014</td> </tr> </table> $[SO_4^{2-}(aq)]_{eq} = \frac{0.1 - 0.072}{2} = 0.014 \text{ mol dm}^{-3}$ $K_c = \frac{[SO_4^{2-}(aq)]}{[I^-(aq)]^2} = \frac{0.014}{(0.072)^2} = 2.7 \text{ (mol dm}^{-3})^{-1}$	Initial / mol dm <sup>-3</sup>	0.100		At equil / mol dm <sup>-3</sup>	0.072	0.014	[1]		
Initial / mol dm <sup>-3</sup>	0.100									
At equil / mol dm <sup>-3</sup>	0.072	0.014								
ASL12(II)_01 (modified)										
(a)	$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ <table style="margin-left: 100px;"> <tr> <td>Initial / mol dm<sup>-3</sup></td> <td>0.10</td> <td></td> <td></td> </tr> <tr> <td>At equil / mol dm<sup>-3</sup></td> <td>0.10 - y</td> <td>y</td> <td>y</td> </tr> </table> $K_c = \frac{[NH_4^+(aq)][OH^-(aq)]}{[NH_3(aq)]} = \frac{y^2}{0.10 - y} = 1.8 \times 10^{-5}$ $y^2 = 1.8 \times 10^{-6} - 1.8 \times 10^{-5}y$ $y = [OH^-(aq)] = 1.33 \times 10^{-3}$ $pH = 14 - pOH = 14 - \log(1.33 \times 10^{-3}) = 11.0$	Initial / mol dm <sup>-3</sup>	0.10			At equil / mol dm <sup>-3</sup>	0.10 - y	y	y	[1]
Initial / mol dm <sup>-3</sup>	0.10									
At equil / mol dm <sup>-3</sup>	0.10 - y	y	y							
(b)	$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ <table style="margin-left: 100px;"> <tr> <td>At equil / mol dm<sup>-3</sup></td> <td>x</td> <td>y</td> <td><math>10^{-4}</math></td> </tr> </table> $K_c = \frac{[NH_4^+(aq)][OH^-(aq)]}{[NH_3(aq)]} = \frac{[NH_4^+(aq)]10^{-4}}{[NH_3(aq)]} = 1.8 \times 10^{-5}$ $\frac{[NH_4^+(aq)]}{[NH_3(aq)]} = 0.18$ <p>Hence, <math>[NH_3(aq)] : [NH_4^+(aq)] = 5.56</math></p>	At equil / mol dm <sup>-3</sup>	x	y	$10^{-4}$	[1]				
At equil / mol dm <sup>-3</sup>	x	y	$10^{-4}$							
(c)	<p>The solution contains both <math>NH_3(aq)</math> and <math>NH_4^+(aq)</math> ions in large amounts.</p> <p>When a small amount of acid (or alkali) is added to the solution, the <math>H^+(aq)</math> ions (or <math>OH^-(aq)</math> ions) added will be consumed by the <math>NH_3(aq)</math> (or <math>NH_4^+(aq)</math>) ions.</p> <p>The equilibrium position will shift to the left (right) to counteract the change and the change in pH is small.</p>	[1]								

## ASL13(I)\_04

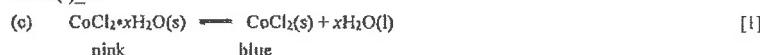
(a)	$\text{CO(g)}$	+	$\text{H}_2\text{O(g)}$	$\rightleftharpoons$	$\text{CO}_2\text{(g)}$	+	$\text{H}_2\text{(g)}$
	Initial / mol	0.10	0.10	--	--	--	--
	At equil / mol	$0.10 \times (1 - 74\%)$ = 0.026	0.026	0.074	0.074		

$$K_c = \frac{[\text{CO}_2\text{(g)}][\text{H}_2\text{(g)}]}{[\text{CO(g)}][\text{H}_2\text{O(g)}]} = \frac{\left(\frac{0.074}{V}\right)^2}{\left(\frac{0.026}{V}\right)^2} = \frac{(0.074)^2}{(0.026)^2}$$

$$= 8.10 \quad [1]$$

- (b) (i) The forward reaction is exothermic. [½]  
 Increase in temperature will shift the equilibrium position to the left thus decreasing the concentration of  $\text{H}_2\text{(g)}$ . [½]
- (ii)  $K_c$  is a constant at a fixed temperature. When extra  $\text{CO(g)}$  is introduced into the container, more  $\text{CO(g)}$  will react with  $\text{H}_2\text{O(g)}$  to maintain a constant value of  $K_c$ .  $\therefore$  Concentration of  $\text{H}_2\text{(g)}$  will increase. [½]

## AL13(I)\_01



With the addition of water, the equilibrium position shifts to the left to give pink  $\text{CoCl}_2 \cdot x\text{H}_2\text{O(s)}$ .

Heating  $\text{CoCl}_2 \cdot x\text{H}_2\text{O(s)}$  removes water. The equilibrium position shifts to the right to give anhydrous  $\text{CoCl}_2\text{(s)}$ .

## ASL13(II)\_03

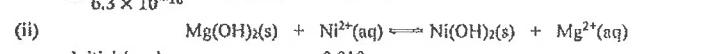
(a) Reaction (1)  
 $K_{c1} = [\text{Mg}^{2+}\text{(aq)}][\text{OH}^-\text{(aq)}]^2$  [½]

Reaction (2)  
 $K_{c2} = [\text{Ni}^{2+}\text{(aq)}][\text{OH}^-\text{(aq)}]^2$  [½]

(b) (i)  $K_a = \frac{[\text{Mg}^{2+}\text{(aq)}]}{[\text{Ni}^{2+}\text{(aq)}]}$  [1]

$$K_a = \frac{[\text{Mg}^{2+}\text{(aq)}]}{[\text{Ni}^{2+}\text{(aq)}]} = \frac{[\text{Mg}^{2+}\text{(aq)}][\text{OH}^{2-}\text{(aq)}]^2}{[\text{Ni}^{2+}\text{(aq)}][\text{OH}^{2-}\text{(aq)}]^2} = \frac{K_{c1}}{K_{c2}}$$

$$= \frac{2.0 \times 10^{-11}}{6.3 \times 10^{-18}} = 3174603 = 3.17 \times 10^6 \quad [1]$$



Initial / mol	0.010		
At equil / mol	0.010 - $y$	$+y$	

$$3.17 \times 10^6 = \frac{[\text{Mg}^{2+}\text{(aq)}]}{[\text{Ni}^{2+}\text{(aq)}]} = \frac{y}{0.010 - y} \quad [1]$$

$$y = 3.15 \times 10^{-9} \text{ mol dm}^{-3} \quad [1]$$

## DSE11SP\_11

- (a)  $K_c$  increase with temperature. The equilibrium position shifts to the right when temperature is increased. [1]

$\therefore$  the forward reaction is endothermic. [1]



Initial conc. / mol dm <sup>-3</sup>	0.5	0.5		
Equil conc. / mol dm <sup>-3</sup>	0.5 - $y$	0.5 - $y$	$y$	$y$

$$K_c = \frac{[\text{CO(g)}][\text{H}_2\text{O(g)}]}{[\text{H}_2\text{(g)}][\text{CO}_2\text{(g)}]} = \frac{y^2}{(0.5 - y)(0.5 - y)} \quad [1]$$

$$1.23 \times 10^{-1} = \frac{y^2}{(0.5 - y)(0.5 - y)} \quad [1]$$

$$y = 0.130 \text{ mol dm}^{-3} \quad [1]$$

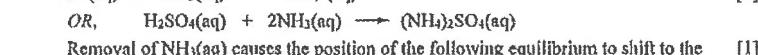
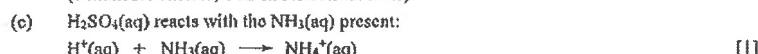
- (c) The rate of the backward reaction increases. [1]

## DSE12PP\_13

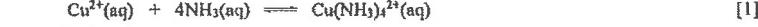
(a)  $K_c = \frac{[\text{Cu}(\text{NH}_3)^{2+}\text{(aq)}]}{[\text{Cu}^{2+}\text{(aq)}][\text{NH}_3\text{(aq)}]^4}$  [1]

(b)  $K_c = \frac{0.0800}{(0.0020)(0.0014)^4} = 1.04 \times 10^{13} (\text{mol dm}^{-3})^{-4}$  [2]

(1 mark for answer; 1 mark for correct units)



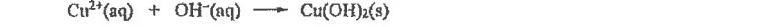
Removal of  $\text{NH}_3\text{(aq)}$  causes the position of the following equilibrium to shift to the left.



$\text{NH}_3\text{(aq)}$  is a weak base:



When  $[\text{Cu}^{2+}\text{(aq)}$ ] builds up it will react with the  $\text{OH}^-\text{(aq)}$  ions to give the blue precipitate.



When excess  $\text{H}_2\text{SO}_4\text{(aq)}$  is added, it will react with the  $\text{Cu}(\text{OH})_2\text{(s)}$  formed to give a blue solution.

(3 marks for chemical equations; 1 mark for explanation of the shift in equilibrium position; 1 mark for the formation of blue precipitate.)

## DSE12\_13

(a)  $[\text{Fe}^{3+}\text{(aq)}]_{\text{initial after mixing}} = 0.010 \times 2 \times 25 + (25 + 25) = 0.01 \text{ M}$  [1]

$$[\text{SCN}^-\text{(aq)}]_{\text{initial after mixing}} = 0.010 \times 25 + (25 + 25) = 0.005 \text{ M}$$



Initial / mol dm <sup>-3</sup>	0.01	0.005	
Reacted / mol dm <sup>-3</sup>	0.01 - 0.0043	0.005 - 0.0043	

At eqm / mol dm <sup>-3</sup>	0.0057	0.0007	0.0043
-------------------------------	--------	--------	--------

$$K_c = \frac{[\text{Fe}(\text{SCN})^{2+}(\text{aq})]}{[\text{Fe}^{3+}(\text{aq})][\text{SCN}^{-}(\text{aq})]} = \frac{0.0043}{(0.0057)(0.0007)} \\ = 1078 \text{ mol}^{-1} \text{ dm}^3 \text{ (accept } 1080 \text{ mol}^{-1} \text{ dm}^3, \text{ no mark for wrong unit)}$$

(b) The equilibrium position will shift to the left hand side / reactant side.

[1]  
[1]  
[1]

- (b) As revealed from the data, when temperature increases,  $K_c$  decreases. Therefore the forward reaction is exothermic.  
OR, As higher temperature favors endothermic side of reaction, so the forward reaction is exothermic.

#### DSE13\_12

(a) Reaction quotient  $= \frac{0.04}{(0.05)(0.02)} \text{ mol}^{-1} \text{ dm}^3$   
 $= 40 \text{ mol}^{-1} \text{ dm}^3$   
 $\because$  Reaction quotient  $> K_c$   
 $\therefore$  Backward reaction rate is greater than the forward reaction rate.

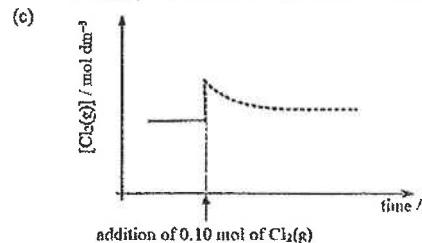
(b) At equilibrium, the concentrations are:  
 $[\text{PCl}_3(\text{g})] = (0.04 - y) \text{ mol dm}^{-3}$   
 $[\text{PCl}_5(\text{g})] = (0.05 + y) \text{ mol dm}^{-3}$   
 $[\text{Cl}_2(\text{g})] = (0.02 + y) \text{ mol dm}^{-3}$

$$\frac{0.04 - y}{(0.05 + y)(0.02 + y)} = 25$$

[1]  
[1]

Solving equation,  $y = 0.0052$   
 $[\text{Cl}_2(\text{g})]_{\text{eqm}} = (0.02 + 0.0052) \text{ mol dm}^{-3} = 0.0252 \text{ mol dm}^{-3}$

[1]



[1]

The final equilibrium level of  $[\text{Cl}_2]$  should lie between the original level and the level when 0.1 mol of  $\text{Cl}_2$  was just added.

#### DSE14\_13

(a) (i)  $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Initial conc.:	1.02±50	1.29±50	
	= 0.0204	= 0.0258	
Equil conc.:	0.0204×0.39	0.0258 – 0.006222	0.0204×0.61
	= 0.007956	= 0.019578	= 0.012444

[1]  
[1]

$$K_c = \frac{[\text{NO}_2(\text{g})]^2}{[\text{NO}(\text{g})]^2[\text{O}_2(\text{g})]} = \frac{(0.012444)^2}{(0.007956)^2(0.019578)} \\ = 125 \text{ dm}^3 \text{ mol}^{-1} \text{ (accept } 118 - 125 \text{ (not accept M}^{-1}\text{)})$$

(ii) No change, because  $K_c$  is independent of concentration / only depends on temperature.

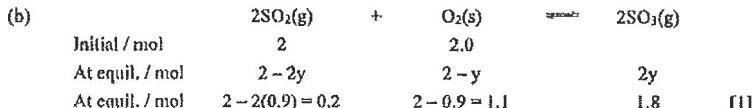
[1]

#### DSE15\_11

- (a) (i)  $-\log[\text{H}^+(\text{aq})] = 7.0$   
 $[\text{H}^+(\text{aq})] = 10^{-7} \text{ mol dm}^{-3}$
- (ii)  $[\text{H}^+(\text{aq})] = [\text{OH}^-(\text{aq})] = 10^{-7} \text{ mol dm}^{-3}$   
 $[\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] = (10^{-7})(10^{-7}) = 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$
- (b) Because  $[\text{H}_2\text{O}(\text{l})] \gg [\text{H}^+(\text{aq})]$  and  $[\text{OH}^-(\text{aq})]$   
OR, Only a very small amount of  $\text{H}_2\text{O}$  is ionized to give  $\text{H}^+(\text{aq})$  and  $\text{OH}^-(\text{aq})$
- (c) The pH of water would be less than 7.  
The ionization of  $\text{H}_2\text{O}(\text{l})$  is endothermic. Increasing the temperature will shift the equilibrium position to the right.

#### DSE16\_10

- (a) At dynamic equilibrium, the rate of forward reaction is equal to the rate of backward reaction, and not equals zero.  
OR, At dynamic equilibrium, reactants are converted to products and products are converted to reactants at equal rate. No net change is observed.



$$878 = \frac{\left(\frac{1.8}{V}\right)^2}{\left(\frac{0.2}{V}\right)^2 \left(\frac{1.1}{V}\right)}$$

$V = 11.92 \text{ dm}^3$  (Accept: 12, 11.9, 11.92, 11.923, Not accept: 12.0, 11.90)

- (c) (i) Decrease. The reaction is exothermic. Increase in temperature will cause the equilibrium position to shift to the left.  
(ii) No change. A catalyst will increase the rate of forward reaction and that of backward reaction to the same extent.  
A catalyst has no effect on the equilibrium position.

#### DSE17\_11

- (a)  $K_c = \frac{[\text{H}^+(\text{aq})][\text{A}^-(\text{aq})]}{[\text{HA}(\text{aq})]}$   
(Accept no state symbols are given in the expression)

(b) In the solution,  $2.4 = -\log [H^+(aq)]$

$$[H^+(aq)] = 4.0 \times 10^{-3} \text{ mol dm}^{-3}$$

Accept  $3.98 \times 10^{-3}$  to  $4.0 \times 10^{-3}$

$$8.0 \times 10^{-6} = \frac{4.0 \times 10^{-3} [A^-(aq)]}{[HA(aq)]}$$

$$\frac{[HA(aq)]}{[A^-(aq)]} = 50000 \quad (\text{Accept } 49750 \text{ to } 50000)$$

(c) The equilibrium position will shift to right, when  $H^+$  ions are consumed by  $\text{NaOH}(aq)$ .

(Also accept: The rate of the backward reaction decreases / HA will decompose to compensate for the loss of  $H^+$ , forming more  $A^-$ )

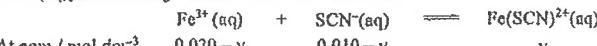
HA is colorless while  $A^-$  is yellow. Increase in  $[A^-]$  cause the solution changes from colorless to yellow / the color/yellow color becomes more intense.

(d) Indicator / use to find out the end-point of acid-base titration.

[1]

(b)  $[\text{Fe}^{3+}(aq)]_{\text{initial after mixing}} = 0.030 \times 20 + 30 = 0.020 \text{ M}$

$$[\text{SCN}^-(aq)]_{\text{initial after mixing}} = 0.030 \times 10 + 30 = 0.010 \text{ M}$$



$$K_c = \frac{[\text{Fe}(\text{SCN})^{2+}(aq)]}{[\text{Fe}^{3+}(aq)][\text{SCN}^-(aq)]} = \frac{y}{(0.020-y)(0.010-y)} = 1.08 \times 10^{-3}$$

$$y = 0.0217 \text{ mol dm}^{-3} \quad (\text{Rejected since larger than both } 0.020 \text{ and } 0.010)$$

$$y = 9.21 \times 10^{-3} \text{ mol dm}^{-3}$$

NOT accept  $9 \times 10^{-3}$  /  $2.097 \times 10^{-3}$  mol dm<sup>-3</sup>

(Accept max. 4 sig.fig.) (Correct unit is required)

(c) Increasing of  $K_c$  means that the equilibrium position is shifted to the right / product side, hence the  $\Delta H$  should be positive.

(d) •  $\text{Na}_2\text{SO}_3(s)$  added reacts with  $\text{Fe}^{3+}(aq)$  so as to decrease the concentration of  $\text{Fe}^{3+}(aq)$ .

• The equilibrium position shifts to the left / reactant side. The concentration of  $\text{Fe}(\text{SCN})^{2+}$  decreases, the colour of the mixture becomes paler.

#### DSE18\_13

(a) None of the final concentration of X(g), Y(g) and Z(g) is equal to zero.

OR X, Y, Z co-exist in the system, and their concentrations remain unchanged after a long period of time.

OR The concentration of the reactant, Y, is still not equal to zero after a long period of time.

(b)  $2Y(g) \rightleftharpoons 3X(g) + Z(g)$

$$K_c = \frac{[X(g)]^3[Z(g)]}{[Y(g)]^2} = \frac{(0.60)^3(0.20)}{(0.30)^2} = 0.48 \text{ mol}^2 \text{dm}^{-6}$$

1 mark for correct equation or  $K_c$  expression

1 mark for correct final concentrations of X, Y and Z, and substituting the numbers into the expression

1 mark for correct numerical answer with correct unit. Not accept  $M^2$ .

(c) The statement is INCORRECT.

At the 25<sup>th</sup> minute after the reaction has started, the reaction attained dynamic equilibrium.

OR The rate of forward reaction is equal to the rate of backward reaction (and both of rates are not equal to zero).

[1]

[2]

#### DSE19\_12

(a)  $K_c = \frac{[\text{Fe}(\text{SCN})^{2+}(aq)]}{[\text{Fe}^{3+}(aq)][\text{SCN}^-(aq)]}$

(State symbols not required)

[1]

#### DSE20\_09

9. (a)  $K_c = [\text{N}_2\text{O}_4(g)] / [\text{NO}_2(g)]^2$

$$[\text{NO}_2(g)]_{\text{eqm}} = 0.0323 \text{ mol dm}^{-3}$$

$$a = [\text{N}_2\text{O}_4(g)]_{\text{eqm}} = 0.001 + (0.04 - 0.0323) / 2 = 0.00485 \text{ mol dm}^{-3}$$

$$K_c = 0.00485 / (0.0323)^2 = 4.649 \text{ mol}^{-1}\text{dm}^3 \quad (\text{Accept } 4.65 \text{ to } 4.66)$$

(Correct unit is required) (Not Accept  $M^{-1}$  or  $(\text{mol dm}^{-3})^{-1}$ )

(Accept answer with maximum 4 decimal places)

1\*

1\*

1

(b) • More  $\text{NO}_2$  is formed and the equilibrium position shifts to left / shifts to reactant side when the temperature increases.

• Increase temperature shifts equilibrium position to endothermic direction. Therefore, the forward reaction is exothermic.

(No 2<sup>nd</sup> mark if no deduction is given, or the deduction is incorrect. e.g. The reaction is exothermic as the equilibrium position shifts to right when the temperature increases.)

1

1