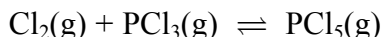


## SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question select one answer from A to D and put a cross in the box ☐. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☐.

1 Consider the equilibrium



Which of the following is true when the total pressure of the system is increased at constant temperature?

		Value of $K_p$	Mole fraction of $\text{PCl}_5(\text{g})$
<input type="checkbox"/>	A	decreases	decreases
<input type="checkbox"/>	B	unaltered	increases
<input type="checkbox"/>	C	decreases	increases
<input type="checkbox"/>	D	unaltered	unaltered

(Total for Question 1 = 1 mark)

2 In which of the following reactions is nitric acid acting as a base?

- ☐ A  $\text{HNO}_3 + \text{NaOH} \rightarrow \text{NaNO}_3 + \text{H}_2\text{O}$
- ☐ B  $\text{HNO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{NO}_3^-$
- ☐ C  $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$
- ☐ D  $\text{HNO}_3 + \text{NaHCO}_3 \rightarrow \text{NaNO}_3 + \text{H}_2\text{O} + \text{CO}_2$

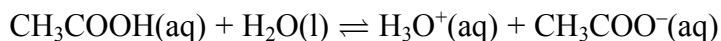
(Total for Question 2 = 1 mark)

3 Why does phenolphthalein, which is colourless in acidic solutions, turn pink in alkaline solutions?

- ☐ A It is oxidized to a pink compound by hydroxide ions.
- ☐ B It forms a pink anion by loss of  $\text{H}^+$  ions.
- ☐ C It forms a pink anion by gain of  $\text{H}^+$  ions.
- ☐ D It forms a pink cation by gain of  $\text{H}^+$  ions.

(Total for Question 3 = 1 mark)

- 4 The dissociation of ethanoic acid in aqueous solution is represented by



Which of the following statements is true for this equilibrium?

- ☐ A  $\text{CH}_3\text{COOH}$  is an acid and its conjugate base is  $\text{CH}_3\text{COO}^-$ .
- ☐ B  $\text{H}_2\text{O}$  is an acid and its conjugate base is  $\text{OH}^-$ .
- ☐ C At equilibrium, the concentrations of each substance are the same.
- ☐ D At equilibrium, the reaction from left to right and the reaction from right to left have stopped.

(Total for Question 4 = 1 mark)

- 5 Why are aqueous solutions of sodium ethanoate slightly alkaline?

- ☐ A The sodium ions react with water to give an alkali.
- ☐ B The ethanoate ions react with water to give hydroxide ions.
- ☐ C All sodium salts give alkaline solutions.
- ☐ D The sodium ethanoate is fully ionized in solution.

(Total for Question 5 = 1 mark)

- 6 When ammonium nitrate crystals dissolve in water, the entropy of the system

- ☐ A remains the same.
- ☐ B falls, because the hydrated ions are more ordered than the solid.
- ☐ C rises, because the ions in the crystal become hydrated in the solution.
- ☐ D rises, because the ions are arranged more randomly in the solution than in the crystal.

(Total for Question 6 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

**Question 7: N/A**

- 8 During the preparation of a liquid compound, samples were taken of the product at various stages in the purification procedure. Which of the following techniques would be most suitable for showing the change in composition of these samples during the purification procedure?

- ☐ A Gas-liquid chromatography
- ☐ B Fractional distillation
- ☐ C Filtration
- ☐ D Distillation

(Total for Question 8 = 1 mark)

- 9 Which of the following compounds would react with lithium tetrahydridoaluminate (lithium aluminium hydride) **and** also with phosphorus(V) chloride (phosphorus pentachloride)?

- ☐ A  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$
- ☐ B  $\text{CH}_3\text{CH}_2\text{COCH}_3$
- ☐ C  $\text{CH}_3\text{CH}=\text{CHCH}_3$
- ☐ D  $\text{CH}_2=\text{CHCH}_2\text{CH}_2\text{OH}$

(Total for Question 9 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

**Question 10: N/A**

**Question 11: N/A**

**Question 12: N/A**

**13** A solution of a weak acid cannot be titrated with a weak base using an indicator to find the end-point because

- ☐ **A** the pH change is too gradual close to the equivalence point.
- ☐ **B** there are too few  $\text{H}^+$  ions to affect the indicator.
- ☐ **C** there are too few  $\text{OH}^-$  ions to affect the indicator.
- ☐ **D** the pH change occurs outside the range of any indicator.

**(Total for Question 13 = 1 mark)**

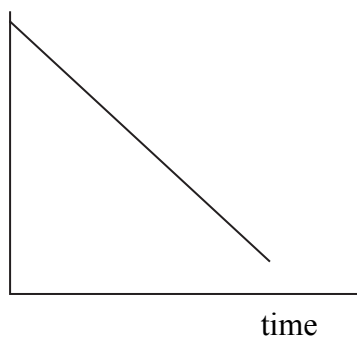
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**Question 14: N/A**

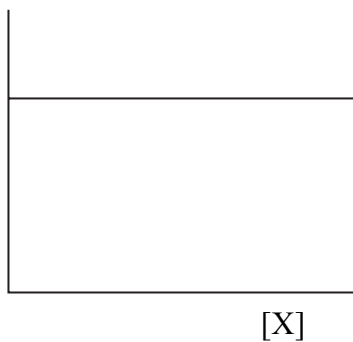
**Question 15: N/A**

16 Which of the following graphs shows that a reaction is first order with respect to reactant **X**?

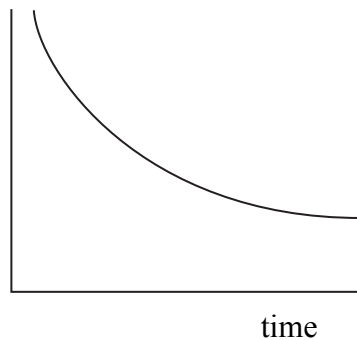
☐ **A** [X]



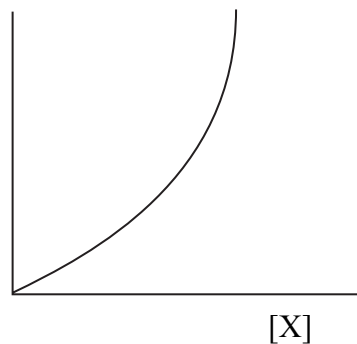
☐ **B** rate



☐ **C** [X]

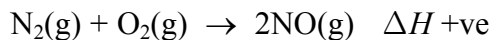


☐ **D** rate



(Total for Question 16 = 1 mark)

17 Which of the following changes will lead to the greatest increase in the **rate** of the following endothermic reaction?

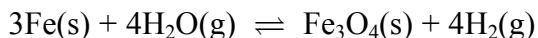


		Temperature	Initial concentration of N <sub>2</sub> and O <sub>2</sub>
<input type="checkbox"/>	<b>A</b>	decrease by 15%	decrease by 15%
<input type="checkbox"/>	<b>B</b>	increase by 15%	stay the same
<input type="checkbox"/>	<b>C</b>	decrease by 15%	increase by 15%
<input type="checkbox"/>	<b>D</b>	increase by 15%	increase by 15%

(Total for Question 17 = 1 mark)

Question 18: N/A

- 19 Iron and steam at high temperature react in a closed vessel to give an equilibrium mixture



Which of the following is the correct expression for  $K_p$ ?

☐ A  $K_p = \frac{P_{\text{H}_2}}{P_{\text{H}_2\text{O}}}$

☐ B  $K_p = \frac{P_{\text{Fe}_3\text{O}_4} P_{\text{H}_2}^4}{P_{\text{Fe}}^3 P_{\text{H}_2\text{O}}^4}$

☐ C  $K_p = \frac{P_{\text{H}_2}^4}{P_{\text{H}_2\text{O}}^4}$

☐ D  $K_p = P_{\text{H}_2}^4$

(Total for Question 19 = 1 mark)

- 20 At 100 °C, pure water has a pH of 6, whereas at 25 °C it has a pH of 7. This is because

- ☐ A the dissociation of water is endothermic, so the concentration of hydrogen ions is lower at 100 °C than it is at 25 °C.
- ☐ B the dissociation of water is exothermic, so the concentration of hydrogen ions is lower at 100 °C than it is at 25 °C.
- ☐ C the dissociation of water is endothermic, so the concentration of hydrogen ions is higher at 100 °C than it is at 25 °C.
- ☐ D at 100 °C, water has a higher concentration of hydrogen ions than of hydroxide ions.

(Total for Question 20 = 1 mark)

**TOTAL FOR SECTION A = 20 MARKS**



## SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

21 (a) (i) Define pH.

(1)

(ii) Calculate the pH of  $0.0100 \text{ mol dm}^{-3}$  hydrochloric acid, which is a strong acid.

(1)

(b) Ethanoic acid is a weak acid with an acid dissociation constant,  $K_a$ , of value  $1.75 \times 10^{-5} \text{ mol dm}^{-3}$  at  $25^\circ\text{C}$ .

(i) Calculate the pH of  $0.0100 \text{ mol dm}^{-3}$  ethanoic acid at  $25^\circ\text{C}$ , stating any ONE assumption that you have made.

(4)

Assumption .....

- (ii) The pH of hydrochloric and of ethanoic acid at two different concentrations is given in the table.

	pH of 0.00100 mol dm <sup>-3</sup> solution	pH of 0.000100 mol dm <sup>-3</sup> solution
Hydrochloric acid	3.0	4.0
Ethanoic acid	3.9	4.4

In the case of hydrochloric acid, dilution by a factor of 10 increases the pH by one unit. Suggest why ethanoic acid behaves differently.

(2)

- (c) Orange marmalade usually contains sodium citrate as a preservative. Together with the fruit in the marmalade, it forms a buffer solution which, at a suitable pH, inhibits mould growth.

- (i) Define the term **buffer solution**.

(2)

- (ii) What is the substance in the fruit that produces a buffer with sodium citrate?

(1)

- (iii) Explain how a buffer solution works using this system or any other of your choice. Support your explanation with equations.

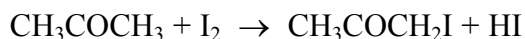
(4)

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(Total for Question 21 = 15 marks)

**Question 22: N/A**

**23** Iodine and propanone react in the presence of an aqueous acid catalyst as follows



To determine the rate equation for the reaction, propanone is reacted with iodine in the presence of aqueous hydrochloric acid at constant temperature. Samples are withdrawn at known times, quenched with sodium hydrogencarbonate solution, and the iodine remaining titrated with a standard solution of sodium thiosulfate.

The rate equation for the reaction is

$$\text{rate} = k[\text{CH}_3\text{COCH}_3]^1 [\text{H}^+]^1 [\text{I}_2]^0$$

(a) The graph of  $[\text{I}_2]$  against time is a straight line, showing that the order of reaction with respect to iodine is zero.

(i) Explain why the propanone and the hydrogen ions must be in large excess in this experiment in order to give this straight line.

(2)

(ii) What further experiment could be done to show that the order of reaction with respect to propanone is one? State the effect of this change on the graph.

(2)

- (iii) Explain why the minimum number of steps in the mechanism for this reaction is two.

(2)

(b) Sodium hydrogencarbonate stops the reaction by neutralizing the acid catalyst.

- (i) Give the ionic equation for the reaction between sodium hydrogencarbonate and acid.

(1)

- (ii) Sodium hydroxide cannot be used for neutralization because under very alkaline conditions a reaction occurs between propanone and iodine.

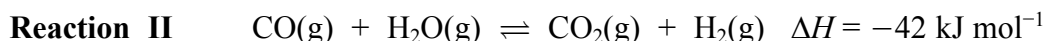
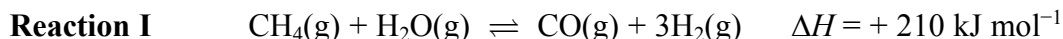
Write the equation for this reaction. State symbols are **not** required.

(3)

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(Total for Question 23 = 10 marks)

- 24 Hydrogen is used in very large quantities as a fuel, as a reducing agent, and in the production of ammonia. Hydrogen is manufactured by steam reforming of methane from natural gas. Two reactions are involved, both being in equilibrium in closed systems.



- (a) Write the expression for the equilibrium constant,  $K_p$ , for reaction I.

(1)

- (b) Reaction I occurs at a temperature of 1000 K and a pressure of 30 atm over a nickel catalyst.

- (i) State and explain the effect, if any, **on the value of  $K_p$**  of increasing the pressure on the reaction.

(1)

- (ii) Explain, in terms of your answers to (a) and (b)(i), why an increase in the pressure leads to a decrease in yield in reaction I.

(2)

- (iii) Increasing the pressure on this heterogeneously-catalysed reaction **I** has very little effect on the rate of the reaction. Suggest why this is so.

(2)

- (c) The expression for  $K_p$  for reaction **II** is

$$K_p = \frac{P_{\text{CO}_2} P_{\text{H}_2}}{P_{\text{CO}} P_{\text{H}_2\text{O}}}$$

At a particular temperature and 30 atm pressure, a mixture of equal amounts of carbon monoxide and steam react to give an equilibrium mixture where 75 % of the CO has reacted.

Calculate the value of  $K_p$  showing your working.

(3)



(d) Carbon dioxide and hydrogen are separated by washing the gas with potassium carbonate solution to give potassium hydrogencarbonate solution, leaving hydrogen in the gas stream. Potassium carbonate is expensive and is regenerated by heating the potassium hydrogencarbonate and liberating the carbon dioxide.

- (i) Hydrogen is often claimed to be a non-polluting fuel as it only produces water on burning.

Explain why its manufacture using reactions **I** and **II** does **not** support this claim.

(1)

- (ii) Write the equation for the thermal decomposition of potassium hydrogencarbonate.

State symbols are **not** required.

(1)

- (e) Although industrial processes are often discussed in terms of equilibria, they are rarely allowed to reach equilibrium.

Suggest why, apart from insufficient reaction time, this is so.

(1)

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(Total for Question 24 = 12 marks)

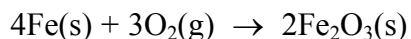
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**TOTAL FOR SECTION B = 50 MARKS**

## SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

25 The oxidation of iron metal in the presence of oxygen is spontaneous.



(a) Explain the meaning of **spontaneous** in a thermodynamic context.

(1)

(b) (i) Find the values of the standard molar entropies of iron and of iron(III) oxide from your data booklet.

(1)

(ii) The standard molar entropy at 298 K for oxygen molecules  $\text{O}_2$  is  $+205 \text{ J mol}^{-1} \text{ K}^{-1}$ .

Calculate the standard entropy change of the system for the reaction between iron and oxygen. Include a sign and units in your answer.

(2)

(iii) The standard enthalpy change for the reaction at  $25^\circ\text{C}$  is  $-1648 \text{ kJ mol}^{-1}$ .

Calculate  $\Delta S_{\text{surroundings}}$ .

(1)

- (iv) Use your answers to (b)(ii) and (iii) to calculate the total standard entropy change for the reaction. Include a sign and units in your answer.

(2)

- \*(v) The reaction is thermodynamically spontaneous.

Use your answers to (b)(ii), (iii) and (iv) to explain, in terms of the physical states of the substances in the reaction and the movement of the molecules in the surroundings, why this is so.

(3)

(Total for Question 25 = 10 marks)