1. One cause of low-level smog is the reaction of ozone, O_3, with ethene, C_2H_4. The smog contains methanal, HCHO(g).

The equation for methanal production is shown below.

$$O_3(g) + C_2H_4(g) \rightarrow 2HCHO(g) + ½\ O_2(g)$$

The rate of the reaction was investigated, using a series of different concentrations of either $C_2H_4(g)$ or $O_3(g)$, by measuring the initial rate of formation of HCHO(g).

The results are shown below.

experiment	**$[O_3(g)]$ / 10^{-7} mol dm^{-3}**	**$[C_2H_4(g)]$ / 10^{-8} mol dm^{-3}**	**initial rate / 10^{-12} mol dm^{-3} s^{-1}**
1	0.5	1.0	1.0
2	2.0	1.0	4.0
3	4.0	2.0	16.0

(i) Analyse and interpret the results to deduce the order of reaction of each reactant and the rate equation.

Explain your reasoning.

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.....

[5]

(ii) Calculate the value of the rate constant and state the units.

rate constant =..... units……

[3]

(iii) Using the equation above, deduce the initial rate of **formation** of $O_2(g)$ in experiment 1.

Explain your reasoning.

answer = ... mol dm^{-3} s^{-1}

[1]

(iv) The experiment was repeated at a higher temperature.

How would the new conditions affect the rate of the reaction and the value of the rate constant?

.....

.....

[1]

[Total 10 marks]

2. Nitrogen monoxide, NO, is involved in formation of ozone at low levels.

Nitrogen monoxide is produced by combustion in car engines. Ozone is then formed following the series of reactions shown below.

$$NO(g) + ½O_2(g) \rightarrow NO_2(g)$$

$$NO_2(g) \rightarrow NO(g) + O(g)$$

$$O_2(g) + O(g) \rightarrow O_3(g)$$

Write the overall equation for this reaction sequence.

Identify the catalyst and justify your answer.

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.....

[Total 3 marks]

3. Phenol, C_6H_5OH, is a powerful disinfectant and antiseptic.

Phenol is a weak Brønsted–Lowry acid.

$$C_6H_5OH(aq) \rightleftharpoons H^+(aq) + C_6H_5O^-(aq) \qquad K_a = 1.3 \times 10^{-10} \text{ mol dm}^{-3}$$

Define the following terms:

(i) A Brønsted–Lowry acid,

.....

[1]

(ii) A *weak* acid.

.....

[1]

[Total 2 marks]

4. When phenol is mixed with aqueous sodium hydroxide, an acid–base reaction takes place.

$C_6H_5OH(aq)$ + $OH^-(aq)$ $\rightleftharpoons$ $C_6H_5O^-(aq)$ + $H_2O(l)$

....

In the available spaces,

- label one conjugate acid–base pair as **acid 1** and **base 1**,
- label the other conjugate acid–base pair as **acid 2** and **base 2**.

[Total 1 mark]

5. A solution of phenol in water has a concentration of 4.7 g dm^{-3}.

(i) Write an expression for the acid dissociation constant, K_a, of phenol.

[1]

(ii) Calculate the pH of this solution of phenol.

[5]

[Total 6 marks]

6. As part of an investigation, a student needed to prepare a buffer solution with a pH value of 8.71. From the K_a value of phenol, the student thought that a mixture of phenol and sodium phenoxide could be used to prepare this buffer solution.

The student decided to use a 0.200 mol dm^{-3} solution of phenol, mixed with an equal volume of sodium phenoxide.

Use your knowledge of buffer solutions to determine the concentration of sodium phenoxide solution that the student would need to mix with the 0.200 mol dm^{-3} phenol solution.

[Total 3 marks]

7. *Syngas* is a mixture of carbon monoxide and hydrogen gases, used as a feedstock for the manufacture of methanol.

A dynamic equilibrium was set up between carbon monoxide, CO, hydrogen, H_2, and methanol, CH_3OH, in a 2.0 dm^3 sealed vessel.

The equilibrium is shown below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

The number of moles of each component at equilibrium is shown below

component	CO(g)	$H_2(g)$	$CH_3OH(g)$
number of moles at equilibrium	6.20×10^{-3}	4.80×10^{-2}	5.20×10^{-5}

(a) State **two** features of a system that is in *dynamic equilibrium*.

.....

.....

.....

[2]

(b) (i) Write an expression for K_c for this equilibrium system.

[1]

(ii) Calculate K_c for this equilibrium. State the units.

K_c = …….. units:……..

[4]

(c) The pressure was increased whilst keeping the temperature constant. The mixture was left to reach equilibrium.

The equilibrium position above shifted to the right.

(i) Explain why the equilibrium position shifted to the right.

.....

.....

[1]

(ii) What is the effect, if any, on the value of K_c?

.....

[1]

(d) The temperature was increased whilst keeping the pressure constant. The mixture was left to reach equilibrium.

The value of K_c for the equilibrium above decreased.

(i) Explain what happened to the equilibrium position in the equilibrium.

.....

.....

[1]

(ii) Deduce the sign of the enthalpy change for the forward reaction shown in the equilibrium above.

Explain your reasoning.

.....

.....

[1]

(e) Methanol can be used as an additive to petrol.

(i) Write an equation for the complete combustion of methanol, CH_3OH.

.....

[1]

(ii) Suggest why methanol is added to petrol.

.....

.....

[1]

[Total 13 marks]

8. Nitrogen monoxide reacts with hydrogen at 500 °C as in the equation below.

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

A series of experiments was carried out to investigate the kinetics of this reaction. The results are shown in the table below.

experiment	[NO] / mol dm^{-3}	[H_2] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.10	0.20	2.6
2	0.10	0.50	6.5
3	0.30	0.50	58.5

In this question, one mark is available for the quality of spelling, punctuation and grammar.

(i) For each reactant, deduce the order of reaction. Show your reasoning.

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[4]

Quality of Written Communication [1]

(ii) Deduce the rate equation for this reaction.

.....

[1]

(iii) Calculate the rate constant, *k*, for this reaction. State the units for *k*.

k = ... units .....

[3]

[Total 9 marks]

9. Nitrogen monoxide, NO, is involved in formation of ozone at low levels and the breakdown of ozone at high levels.

(i) In the lower atmosphere, NO is produced by combustion in car engines. Ozone is then formed following the series of reactions shown below.

$$NO(g) + 1/2O_2(g) \rightarrow NO_2(g)$$

$$NO_2(g) \rightarrow NO(g) + O(g)$$

$$O_2(g) + O(g) \rightarrow O_3(g)$$

Write the overall equation for this reaction sequence.

Identify the catalyst and justify your answer.

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.....

.....

.....

[3]

(ii) In the upper atmosphere, NO removes O_3 by the following reaction mechanism.

$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$ slow

$O(g) + NO_2(g) \rightarrow NO(g) + O_2(g)$ fast

Suggest the rate equation for this process. Explain your reasoning.

.....

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.....

[2]

[Total 5 marks]

10. When heated, phosphorus pentachloride, PCl_5, dissociates.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

A chemist placed a mixture of the three gases into a container. The initial concentration of each gas was the same: 0.30 mol dm^{-3}. The container was left until equilibrium had been reached.

Under these conditions, K_c = 0.245 mol dm^{-3}.

(a) Write an expression for K_c for this equilibrium.

[1]

(b) Use the value of K_c for this equilibrium to deduce whether the concentration of each gas increases, decreases or stays the same as the mixture approaches equilibrium.

(i) Show your answer by placing a tick in the appropriate cells in the table below.

	initial concentration / mol dm^{-3}	greater than 0.30 mol dm^{-3}	less than 0.30 mol dm^{-3}	equal to 0.30 mol dm^{-3}
PCl_5	0.30			
PCl_3	0.30			
Cl_2	0.30			

[1]

(ii) Explain your deduction.

.....

.....

.....

.....

[1]

(c) The chemist compressed the equilibrium mixture at constant temperature and allowed it to reach equilibrium under these new conditions.

(i) Explain what happens to the value of K_c.

.....

.....

[1]

(ii) Explain what happened to the composition of the equilibrium mixture.

.....

.....

.....

.....

[2]

(d) The chemist heated the equilibrium mixture and the equilibrium moved to the left.

(i) Explain what happens to the value of K_c.

.....

.....

[1]

(ii) Explain what additional information this observation reveals about the reaction.

.....

.....

.....

.....

[2]

[Total 9 marks]

11. In sewage plants, biological activity can be reduced by increasing the pH of the water. This is achieved by adding small amounts of solid calcium hydroxide, $Ca(OH)_2$, to the sewage water.

In all parts of this question, assume that measurements have been made at 25 °C.

(a) The pH of aqueous solutions is determined by K_w.

K_w has a value of 1.0×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) What name is given to K_w?

.....

[1]

(ii) Write the expression for K_w.

.....

[1]

(b) A chemist checked the concentration of aqueous calcium hydroxide, $Ca(OH)_2$, in the sewage water by titration with 5.00×10^{-3} mol dm^{-3} hydrochloric acid.

$$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$$

The chemist titrated 25.0 cm^3 of the sewage water with 21.35 cm^3 of HCl to reach the endpoint of the titration.

Calculate the concentration, in mol dm^{-3}, of the calcium hydroxide in the sewage water.

concentration = ... mol dm^{-3}

[3]

(c) The chemist analysed a sample of water from another part of the sewage works and he found that the calcium hydroxide concentration was 2.7×10^{-3} mol dm^{-3}.

When solid calcium hydroxide dissolves in water, its ions completely dissociate.

$$Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

Calculate the pH of this sample.

[3]

(d) After further treatment, the water could be used for drinking. In the drinking water produced, the OH^- concentration was 100 times greater than the H^+ concentration.

What was the pH of this drinking water?

[1]

[Total 9 marks]

12. 'Superphosphate' fertilisers contain calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$. This compound is one of the world's most important fertilisers. When dissolved in water, $Ca(H_2PO_4)_2$ dissociates forming $H_2PO_4^-$ ions which are easily taken up by plants.

(a) Calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, is produced by treating rock phosphate, containing $Ca_3(PO_4)_2$, with sulphuric acid, H_2SO_4.

Write a balanced equation for this reaction.

.....

[1]

(b) Aqueous $H_2PO_4^-$ ions can act as a weak acid.

Write an equation to represent the dissociation of the $H_2PO_4^-$ ion.

.....

[1]

(c) The $H_2PO_4^-$ ion can act as either an acid or a base.

(i) State the formula of the conjugate **base** of $H_2PO_4^-$.

.....

[1]

(ii) State the formula of the conjugate **acid** of $H_2PO_4^-$.

.....

[1]

(iii) A solution of calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, in water acts as a buffer solution.

Suggest, with the aid of equations, how this buffering action takes place.

.....

.....

.....

.....

.....

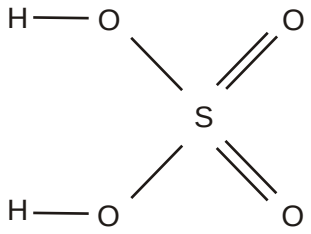
[3]

[Total 7 marks]

13. In order to obtain full marks in this question, you must show **all** your working clearly.

In its reactions, sulphuric acid, H_2SO_4, can behave as an acid, an oxidising agent and as a dehydrating agent.

The displayed formula of pure sulphuric acid is shown below.



Dilute sulphuric acid takes part in the typical acid reactions, reacting with metals, carbonates and bases.

Write balanced equations for the reaction of sulphuric acid with

a metal, ...

a carbonate, ...

a base. .....

[Total 3 marks]

14. Methanoic acid, HCOOH, is a weak organic acid which occurs naturally in ants and stinging nettles.

(a) Use an equation for the dissociation of methanoic acid to show what is meant by a *weak acid*.

.....

.....

[1]

(b) A 1.50×10^{-2} mol dm^{-3} solution of HCOOH has $[H^+] = 1.55 \times 10^{-3}$ mol dm^{-3}.

(i) Calculate the pH of this solution and give one reason why the pH scale is a more convenient measurement for measuring acid concentrations than $[H^+]$.

.....

.....

.....

[2]

(ii) Write the expression for K_a for methanoic acid.

[1]

(iii) Calculate the values of K_a and pK_a for methanoic acid.

[3]

(iv) Estimate the percentage of HCOOH molecules that have dissociated in this aqueous solution of methanoic acid.

[1]

[Total 8 marks]

15. A student titrated the 1.50×10^{-2} mol dm^{-3} methanoic acid with aqueous sodium hydroxide.

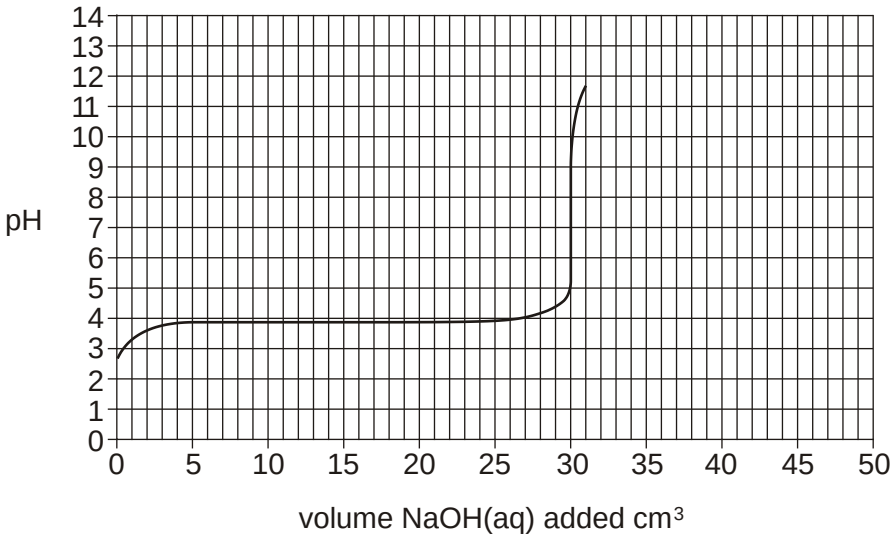
A 25.00 cm^3 sample of the HCOOH(aq) was placed in a conical flask and the NaOH(aq) was added from a burette until the pH no longer changed.

(i) Write a balanced equation for the reaction between HCOOH(aq) and NaOH(aq).

.....

[1]

(ii) Part of the pH curve for this titration is shown below.



Calculate the concentration, in mol dm^{-3}, of the aqueous sodium hydroxide.

concentration = ...mol dm^{-3}

[3]

(iii) Calculate the pH of the aqueous sodium hydroxide.
$K_w = 1.00 \times 10^{-14}$ mol dm^{-3}

pH = ...

[2]

(iv) The pH ranges in which colour changes for three acid-base indicators are shown below.

indicator	pH range
metacresol purple	7.4 – 9.0
2,4,6-trinitrotoluene	11.5 – 13.0
ethyl orange	3.4 – 4.8

Explain which of the three indicators is suitable for this titration.

.....

.....

.....

[2]

[Total 8 marks]

16. The preparation of hydrogen iodide, HI(g), from hydrogen and iodine gases is a reversible reaction which reaches equilibrium at constant temperature.

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

(a) Write the expression for K_c for this equilibrium.

[1]

(b) A student mixed together 0.30 mol $H_2(g)$ with 0.20 mol $I_2(g)$ and the mixture was allowed to reach equilibrium. At equilibrium, 0.14 mol $H_2(g)$ was present.

(i) Complete the table below to show the amount of each component in the equilibrium mixture.

component	$H_2(g)$	$I_2(g)$	HI(g)
initial amount / mol	0.30	0.20	0
equilibrium amount / mol			

[2]

(ii) Calculate K_c to an appropriate number of significant figures. State the units, if any.

K_c = ...

units, if any .....

[3]

(c) The student compressed the equilibrium mixture so that its volume was reduced. The temperature was kept constant.

Comment on the value of K_c **and** the composition of the equilibrium mixture under these new conditions.

.....

.....

.....

.....

[2]

[Total 8 marks]

17. Hydroiodic acid, HI(aq), is a strong acid that is an aqueous solution of hydrogen iodide. In the laboratory, hydroiodic acid can be prepared by the method below.

> A mixture of 480 g of iodine and 600 cm^3 of water was put into a flask. The mixture was stirred and hydrogen sulphide gas, $H_2S(g)$, was bubbled through for several hours.
>
> The mixture became yellow as sulphur separated out. The sulphur was filtered off and the solution was purified by fractional distillation. A fraction of HI(aq) was collected containing 440 g of HI in a total volume of 750 cm^3.

(i) Construct a balanced equation, with state symbols, for the preparation of hydroiodic acid.

.....

[2]

(ii) Determine the percentage yield of hydroiodic acid.

[3]

(iii) Calculate the pH of the hydroiodic acid fraction.

[2]

[Total 7 marks]

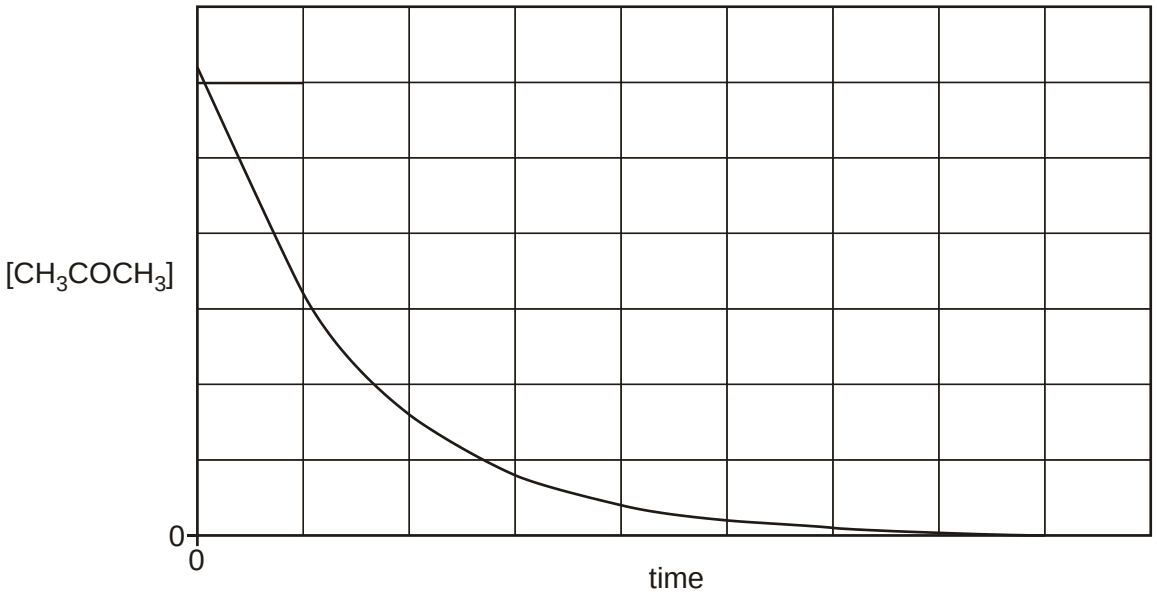
18. In this question, one mark is available for the quality of use and organisation of scientific terms.

Propanone reacts with iodine in the presence of dilute hydrochloric acid.

A student carried out an investigation into the kinetics of this reaction.

He measured how the concentration of propanone changes with time. He also investigated how different concentrations of iodine and hydrochloric acid affect the initial rate of the reaction.

The graph and results are shown below.



$[CH_3COCH_3]$ / mol dm^{-3}	$[I_2]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1.5×10^{-3}	0.0300	0.0200	2.1×10^{-9}
1.5×10^{-3}	0.0300	0.0400	4.2×10^{-9}
1.5×10^{-3}	0.0600	0.0400	4.2×10^{-9}

The overall equation for the reaction is given below.

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$$

This is a multi-step reaction.

- What conclusions can be drawn about the kinetics of this reaction from the student's investigation? Justify your reasoning.
- Calculate the rate constant for this reaction, including units.
- Suggest the equations for a possible two-step mechanism for this reaction. Label the rate-determining step and explain your reasoning.

(Allow one lined page)

Quality of Written Communication [1]

[Total 14 marks]

19. This question looks at different compounds used in medicine.

(a) Nitrous oxide, N_2O, is the gas used as a general anaesthetic.

(i) What is the oxidation number of nitrogen in nitrous oxide?

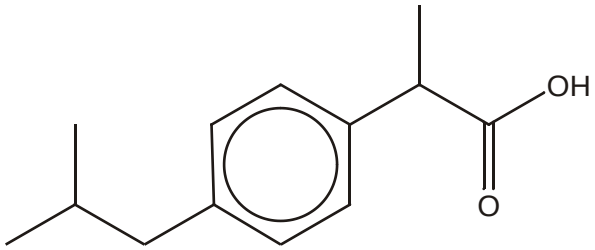
.....

[1]

(ii) Suggest a '*dot-and-cross*' diagram for nitrous oxide. Show outer electrons only.
The sequence of atoms in a nitrous oxide molecule is N N O.

[1]

(b) The structure of the painkiller ibuprofen is shown below.



(i) Determine the molecular formula of ibuprofen.

[1]

(ii) Suggest a chemical that would react with a solution of ibuprofen to produce a gas.
Name the gas produced and write a balanced equation for the reaction.

chemical .....

gas .....

equation

[2]

(c) Lidocaine, $C_{13}H_{20}N_2O_2$, is used as a local anaesthetic in dentistry. Lidocaine is administered by syringe as a solution containing 100 mg in 5.00 cm^3.

Calculate the concentration, in mol dm^{-3}, of lidocaine in the syringe.

concentration = ...mol dm^{-3}

[3]

(d) Eugenol is used as a painkiller in dentistry. It is an organic compound of C, H and O.

A sample of 1.394 g of eugenol was analysed by burning in oxygen to form 3.74 g of CO_2 and 0.918 g of H_2O. The relative molecular mass of eugenol was shown to be 164 using a mass spectrometer.

Calculate the molecular formula of eugenol.

[5]

[Total 13 marks]

20. Nitrogen dioxide is one of the major pollutants in air, formed by reaction of nitrogen monoxide with oxygen.

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

(a) What is meant by the *rate of reaction*?

.....

.....

[1]

(b) A series of experiments was carried out to investigate the kinetics of this reaction. The results are shown in the table below.

Experiment	$[O_2]$ / mol dm^{-3}	[NO] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.00100	0.00100	7.10
2	0.00400	0.00100	28.4
3	0.00400	0.00300	256

(i) For each reactant, deduce the order of reaction. Show your reasoning.

$O_2(g)$ .....

.....

.....

.....

NO(g) .....

.....

.....

.....

[4]

(ii) Deduce the rate equation for this reaction.

.....

[1]

(iii) Calculate the rate constant, *k*, for this reaction. State the units for *k*.

k = ... units .....

[2]

[Total 8 marks]

21. Nitrogen dioxide reacts with carbon monoxide emitted from car exhausts in the following reaction.

$$NO_2 + CO \rightarrow NO + CO_2$$

The rate equation for this reaction is $rate = k[NO_2]^2$.

This is a multi-step reaction. The first step is the rate-determining step.

(i) What is meant by the *rate-determining step*?

.....

.....

[1]

(ii) Suggest a two-step reaction mechanism for this reaction that is consistent with the kinetic data and the overall reaction.

[2]

[Total 3 marks]

22. The K_a values for three acids are shown in the table below.

acid		K_a / mol dm^{-3}
ethanoic acid	CH_3COOH	1.70×10^{-5}
phenol	C_6H_5OH	1.28×10^{-10}
sulphurous acid	H_2SO_3	1.50×10^{-2}

(a) What information is provided by K_a values?

.....

.....

[1]

(b) When sulphurous acid and ethanoic acid are mixed together, an acid-base reaction takes place.

$$H_2SO_3(aq) + CH_3COOH(aq) \rightleftharpoons HSO_3^-(aq) + CH_3COOH_2^+(aq)$$

....

(i) In the spaces above

- label one **conjugate acid-base pair** as acid 1 and base 1,
- label the other **conjugate acid-base pair** as acid 2 and base 2.

[2]

(ii) Predict and explain the acid-base reaction that would take place if ethanoic acid were mixed with phenol. Include an equation in your answer.

.....

.....

.....

.....

[2]

(c) The pH value of 0.0450 mol dm^{-3} hydrochloric acid is different from that of 0.0450 mol dm^{-3} ethanoic acid.

Calculate the pH values of these two acids. Show all your working.

[5]

[Total 10 marks]

23. An excess of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} hydrochloric acid. The same mass of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} ethanoic acid.

Both reactions produced 54 cm^3 of hydrogen gas, measured at room temperature and pressure, but the reaction with ethanoic acid took much longer to produce this gas volume.

Explain why the reactions produced the same volume of a gas but at different rates.

Use equations in your answer.

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[Total 4 marks]

24. Chocolate mousse contains gelatine and a compound to promote fast setting of the mousse.

Compound **A** is such a setting agent. It has two acidic hydrogen atoms per molecule and is one of the six acids listed below.

oxalic acid	HOOCCOOH
malonic acid	$HOOCCH_2COOH$
succinic acid	$HOOC(CH_2)_2COOH$
glutaric acid	$HOOC(CH_2)_3COOH$
adipic acid	$HOOC(CH_2)_4COOH$
pimelic acid	$HOOC(CH_2)_5COOH$

The student analysed a sample of compound **A** by titration.

The student dissolved 2.82 g of compound **A** in water and made the solution up to 250 cm3 in a volumetric flask. He titrated 25.0 cm^3 of this solution with 0.175 mol dm^{-3} NaOH.

22.05 cm^3 of NaOH were required for complete neutralisation.

Use the results of the student's analysis to identify compound **A** from the list above.

Show all of your working.

[Total 5 marks]

25. In the UK, almost all the sulphuric acid, H_2SO_4, is manufactured by the Contact process.
One stage in the Contact process involves the reaction between sulphur dioxide and oxygen.

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

The table below shows values of the equilibrium constant, K_p, for this equilibrium at different temperatures.

temperature / °C	*Kp* / kPa^{-1}
25	4.0×10^{22}
200	2.5×10^{8}
800	1.3×10^{-3}

(a) Write an expression for the equilibrium constant, K_p, of this reaction.

[2]

(b) In this question, one mark is available for the quality and use of scientific terms.

- The conversion of sulphur dioxide and oxygen into sulphur trioxide is carried out at slightly above atmospheric pressure. Comment on this statement.
- Explain what happens to the equilibrium amounts of SO_2, O_2 and SO_3 as temperature increases at constant pressure.
- Deduce the sign of ΔH for the forward reaction in the equilibrium. Explain your reasoning carefully.

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[6]

Quality of Written Communication [1]

(c) An equilibrium is set up for the SO_2, O_2, SO_3 equilibrium at 400 °C.

At this temperature

- the equilibrium partial pressure of SO_2 is 10 kPa
- the equilibrium partial pressure of O_2 is 50 kPa
- $K_p = 3.0 \times 10^2$ kPa^{-1}.

Calculate the equilibrium partial pressure of SO_3 at 400 °C. Hence determine the percentage of SO_3 in the equilibrium mixture at this temperature.

answer .....%

[3]

(d) In the UK, almost all the sulphuric acid manufactured uses sulphur as a starting material for SO_2 production. In some countries, metal ores such as zinc sulphide, ZnS, are used instead to form SO_2 by heating with air.

(i) Construct a balanced equation to show the reaction that takes place when zinc sulphide is heated in air.

.....

[2]

(ii) Suggest why countries may find it more economic to manufacture sulphuric acid from zinc sulphide.

.....

.....

[1]

[Total 15 marks]

26. One cause of low-level smog is the reaction of ozone, O_3, with ethene. The smog contains methanal, $CH_2O(g)$, and the equation for its production is shown below.

$$O_3(g) + C_2H_4(g) \rightarrow 2CH_2O(g) + \frac{1}{2}O_2(g) \qquad \textbf{equation 1}$$

(a) The rate of the reaction doubles when the initial concentration of either $O_3(g)$ or $C_2H_4(g)$ is doubled.

(i) What is the order of reaction with respect to

O_3 .....

C_2H_4? .....

[1]

(ii) What is the overall order of the reaction?

.....

[1]

(iii) Write the rate equation for this reaction.

.....

[1]

(b) For an initial concentration of ozone of 0.50×10^{-7} mol dm^{-3} and one of ethene of 1.0×10^{-8} mol dm^{-3}, the initial rate of methanal formation was 1.0×10^{-12} mol dm^{-3} s^{-1}.

(i) How could the **initial** rate of methanal formation be measured from a concentration/time graph?

.....

.....

[2]

(ii) Calculate the value of the rate constant and state the units.

rate constant =..... units.....

[3]

(iii) The initial rate of methanal formation is different from that of oxygen formation in **equation 1**.

Explain why.

.....

.....

[1]

(iv) The experiment was repeated but at a higher temperature. What would be the effect of this change on the rate and the rate constant of the reaction?

.....

.....

.....

[2]

[Total 11 marks]

27. In the stratosphere, ozone forms when oxygen free radicals react with oxygen molecules.

$$O_2 + O \rightarrow O_3$$

The oxygen free radicals are initially formed as diradicals when oxygen gas, O_2, is dissociated by strong ultraviolet radiation,

$$O_2(g) \rightarrow 2O(g)$$

(i) Suggest why oxygen free radicals, O, are often called **di**radicals.

.....

.....

[1]

(ii) Draw a '*dot-and-cross*' diagram of an ozone molecule. Show outer electrons only.

[2]

(iii) Chlorine free radicals formed from CFCs deplete the ozone layer in a chain reaction.

Typically, 1 g of chlorine free radicals destroys 150 kg of ozone during the atmospheric lifetime of the chlorine free radical (one to two years).

Calculate how many ozone molecules are destroyed in this chain reaction by a single chlorine free radical before the free radical is destroyed.

answer.....

[3]

[Total 6 marks]

28. Phenol, C_6H_5OH, is a powerful disinfectant and antiseptic. Phenol is a weak Brønsted-Lowry acid.

What is meant by the following terms;

(i) a *Brønsted-Lowry* acid;

.....

[1]

(ii) a *weak* acid?

.....

.....

[1]

[Total 2 marks]

29. When phenol is mixed with aqueous sodium hydroxide, an acid-base reaction takes place.

$C_6H_5OH(aq)$ + $OH^-(aq)$ $\rightleftharpoons$ $C_6H_5O^-(aq)$ + $H_2O(l)$

....

In the spaces above,

- label one **conjugate acid-base pair** as acid 1 and base 1,
- label the other **conjugate acid-base pair** as acid 2 and base 2.

[Total 2 marks]

30. A solution of phenol in water has a concentration of 38 g dm^{-3}.
The acid dissociation constant, K_a, of phenol is 1.3×10^{-10} mol dm^{-3}.

(i) Write an expression for the acid dissociation constant, K_a, of phenol.

[1]

(ii) Calculate the pH of this solution.

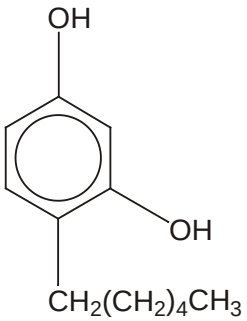
answer.....

[5]

[Total 6 marks]

31. Hexylresorcinol is an antiseptic used in solutions for cleansing wounds and in mouthwashes and throat lozenges.

The structure of hexylresorcinol is shown below.



Identify a compound that could be added to hexylresorcinol to make a buffer solution. Explain your answer.

[Total 2 marks]

32. Compound **B** is an organic base. A student analysed this base by the procedure below.

He first prepared a solution of **B** by dissolving 4.32 g of **B** in water and making the solution up to 250 cm^3. The student then carried out a titration in which 25.00 cm^3 of this solution of **B** were neutralised by exactly 23.20 cm^3 of 0.200 mol dm^{-3} HC*l*.

1 mole of **B** reacts with 1 mole of HC*l*.

Use this information to calculate the molar mass of base **B** and suggest its identity.

[Total 6 marks]

33. The decomposition of dinitrogen pentoxide, N_2O_5, at 45 °C was investigated. The reaction that takes place is shown below.

$$2N_2O_5 \rightarrow 4NO_2 + O_2$$

In an experiment, N_2O_5 with a concentration of 0.60 mol dm^{-3} was decomposed at 45 °C.

At this temperature, the reaction has a constant half-life of 1200 s.

(i) How can you tell that this reaction is first order with respect to N_2O_5?

.....

.....

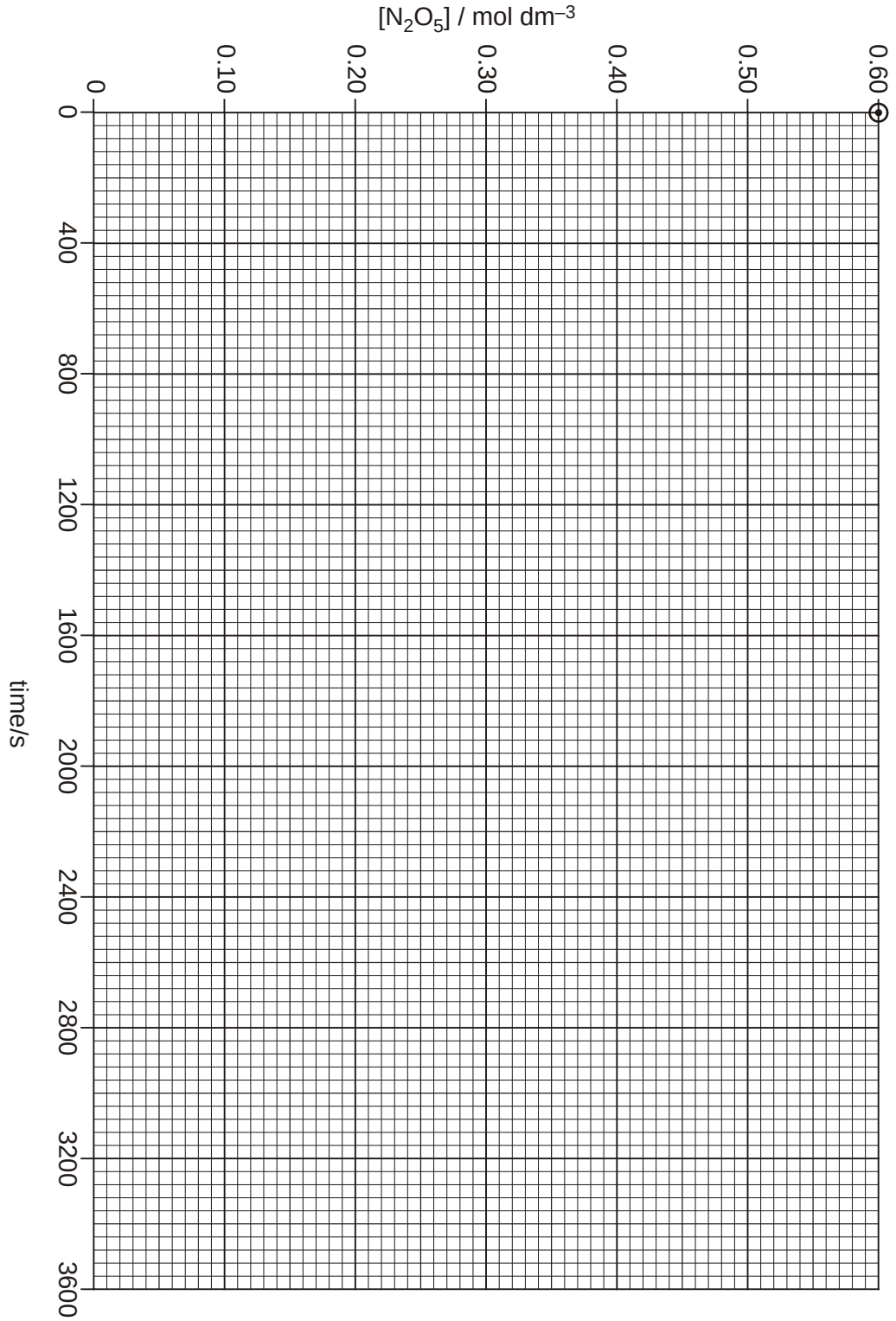
[1]

(ii) Write down an expression for the rate equation of this decomposition.

.....

[1]

(iii) Complete the graph below to show how the $[N_2O_5]$ changes over the first 3600 s of the reaction.



[2]

(iv) The rate of this reaction can be determined from this graph.

Show on the graph how the rate can be measured after 1200 s.

[1]

(v) The rate can also be calculated from the rate equation. The rate constant for this reaction is 6.2×10^{-4} s^{-1}.

Calculate the initial rate of this reaction. State the units.

rate =…… units……..

[2]

[Total 7 marks]

34. A student investigated the hydration of 2-methylpropene, $(CH_3)_2C=CH_2$, with dilute aqueous acid to form 2-methylpropan-2-ol, $(CH_3)_3COH$.

The following mechanism has been proposed for this hydration.

step 1 $(CH_3)_2C=CH_2 + H^+(aq) \rightarrow (CH_3)_3C^+$ rate determining step

step 2 $(CH_3)_3C+ + H_2O \rightarrow (CH_3)_3COH + H^+(aq)$

(i) Step 1 is the rate-determining step for this hydration.

What is meant by the term *rate-determining step*?

.....

.....

[1]

(ii) Write a balanced equation for the overall hydration reaction.

.....

[1]

(iii) Suggest the role of $H^+(aq)$ in this mechanism. Explain your reason.

.....

.....

.....

[2]

(iv) Use the mechanism above to suggest the rate equation for this hydration.

.....

[1]

[Total 5 marks]

35. Methanol, $CH_3OH(g)$, is manufactured from carbon monoxide and hydrogen in an equilibrium reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

(a) In this question, one mark is available for the quality of use and organisation of scientific terms.

Explain the advantages and disadvantages of running this reaction

- at a high pressure,
- at a high temperature.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[5]

Quality of Written Communication [1]

(b) This equilibrium reaction is normally carried out at 10MPa pressure and 550 K, and starting with a 1 : 2 CO : H_2 mixture. At equilibrium, only 10% of the CO has reacted.

(i) Deduce the equilibrium amounts, mole fractions and partial pressures of CO, H_2 and CH_3OH present at equilibrium. Write your answers in the table below.

Assume that you have started with a mixture of 1.0 mol CO and 2.0 mol H_2.

	CO	H_2	CH_3OH
initial amount /mol	1.0	2.0	0.0
equilibrium amount /mol	0.9		
mole fraction at equilibrium			
partial pressure at equilibrium /MPa			

[4]

(ii) Write the expression for K_p for this equilibrium.

[2]

(iii) The CO : H_2 ratio in the starting mixture was changed from 1 : 2 to 1 : 3 and the mixture was allowed to reach equilibrium at the same temperature and pressure.

Explain, in terms of K_p, the effect of this change on the equilibrium yield of CH_3OH.

.....

.....

.....

.....

.....

[3]

(iv) In another experiment, the equilibrium partial pressures were:

CO, 3.70 MPa; H_2, 5.10 MPa; CH_3OH, 0.261 MPa.

Calculate the value of K_p for this equilibrium. Express your answer to an appropriate number of significant figures. State the units of K_p.

K_p = ... units.....

[2]

(c) In the UK, the annual production of methanol is 500 000 tonnes. Methanol has many uses in fuels as a reliable and low pollution form of energy.

Suggest an equation for the combustion of methanol.

.....

[1]

[Total 18 marks]

36. A student carried out an investigation with aqueous solutions of nitric acid, sodium hydroxide, ethanoic acid and water.

Nitric acid, HNO_3, is a strong Brønsted-Lowry acid.

(i) Explain what is meant by a *strong acid* and a *Brønsted-Lowry acid*.

.....

.....

.....

[2]

(ii) What is the conjugate base formed from HNO_3?

.....

[1]

[Total 3 marks]

37. A student carried out an investigation with aqueous solutions of nitric acid, sodium hydroxide, ethanoic acid and water.

The student diluted 0.015 mol dm^{-3} nitric acid with an equal volume of water and measured the pH of the diluted acid at 25 °C.

(i) Calculate the pH of 0.015 mol dm^{-3} nitric acid.

[2]

(ii) Calculate the pH of the diluted acid.

[1]

[Total 3 marks]

38. A student measured the pH of a solution of sodium hydroxide as 13.54 at 25 °C.

Kw = 1.0×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) Write down an expression for the ionic product, K_w, for water.

.....

[1]

(ii) Calculate the concentration, in mol dm^{-3}, of this solution of sodium hydroxide.

[2]

[Total 3 marks]

39. A student prepared two solutions.

- Solution **A** was made by mixing together 25 cm^3 0.010 mol dm^{-3} aqueous sodium hydroxide with 50 cm^3 0.010 mol dm^{-3} ethanoic acid, CH_3COOH. Solution **A** is a buffer solution.
- Solution **B** was made by mixing together 25 cm^3 0.020 mol dm^{-3} aqueous sodium hydroxide with 50 cm^3 0.010 mol dm^{-3} ethanoic acid, CH_3COOH. Solution **B** is **not** a buffer solution.

(i) What is meant by a *buffer solution*?

.....

.....

[1]

(ii) Explain why Solution **A** is a buffer solution whereas Solution **B** is **not**.

.....

.....

.....

.....

.....

.....

.....

[4]

[Total 5 marks]

40. A student measured the pH of water as 7.0 at 25 °C. The student then warmed the water to 40 °C and measured the pH as 6.7.

What do these results tell you about the tendency of water to ionise as it gets warmer? Explain your reasoning in terms of equilibrium.

.....

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.....

[Total 2 marks]