SPECIMEN

Advanced GCE

CHEMISTRY A

Unit F325: Equilibria, Energetics and Elements

Specimen Paper

F325 QP

Candidates answer on the question paper.

Time: 1 hour 45 minutes

Additional Materials:
Data Sheet for Chemistry (Inserted)
Scientific calculator

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- ✎ You will be awarded marks for the quality of written communication where this is indicated in the question.
- You may use a scientific calculator.
- A copy of the *Data Sheet for Chemistry* is provided as an insert with this question paper.
- You are advised to show all the steps in any calculations.
- The total number of marks for this paper is **100**.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**13**	
2	**13**	
3	**13**	
4	**19**	
5	**9**	
6	**13**	
7	**20**	
TOTAL	**100**	

This document consists of **17** printed pages, **1** blank page, and a *Data Sheet for Chemistry*.

Answer **all** the questions.

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 as **equation 1.1**.

$$O_3(g) + C_2H_4(g) \longrightarrow 2HCHO(g) + \tfrac{1}{2}O_2(g) \qquad \textbf{equation 1.1}$$

(a) 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 **equation 1.1**, 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]**

(b) 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.

$$NO(g) + \frac{1}{2}O_2(g) \longrightarrow NO_2(g)$$

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

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

Write the overall equation for this reaction sequence.

Identify the catalyst and justify your answer.

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.... **[3]**

[Total: 13]

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

Phenol is a weak Brønsted–Lowry acid.

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

(a) Define the following terms:

(i) A *Brønsted–Lowry* acid,

.... **[1]**

(ii) A *weak* acid.

.... **[1]**

(b) 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**.

[1]

(c) 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]

(d) 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.

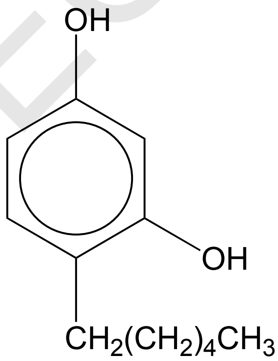
The student decided to use a 0.200 mol dm^{-3} solution of phenol, mixed with an equal volume of sodium phenoxide.

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.

[3]

(e) 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 chemical that could be added to hexylresorcinol to make a buffer solution.

Explain your answer.

....

.... **[1]**

[Total: 13]

[Turn over

3 *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 by **equilibrium 3.1** below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$ **equilibrium 3.1**

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 of **equilibrium 3.1** 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 **equilibrium 3.1** decreased.

(i) Explain what happened to the equilibrium position in **equilibrium 3.1**.

....

.... **[1]**

(ii) Deduce the sign of the enthalpy change for the forward reaction shown in **equilibrium 3.1**. 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]

4 **Table 4.1** shows the enthalpy changes needed to calculate the lattice enthalpy of calcium oxide, CaO.

Table 4.1

process	**enthalpy change/ kJ mol^{-1}**
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
first electron affinity of oxygen	–141
second electron affinity of oxygen	+ 791
enthalpy change of formation of calcium oxide	–635
enthalpy change of atomisation of calcium	+178
enthalpy change of atomisation of oxygen	+248

(a) **(i)** Explain why the second ionisation energy of calcium is **more endothermic** than the first ionisation energy of calcium.

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....

.... **[2]**

(ii) Suggest why the second electron affinity of oxygen is positive.

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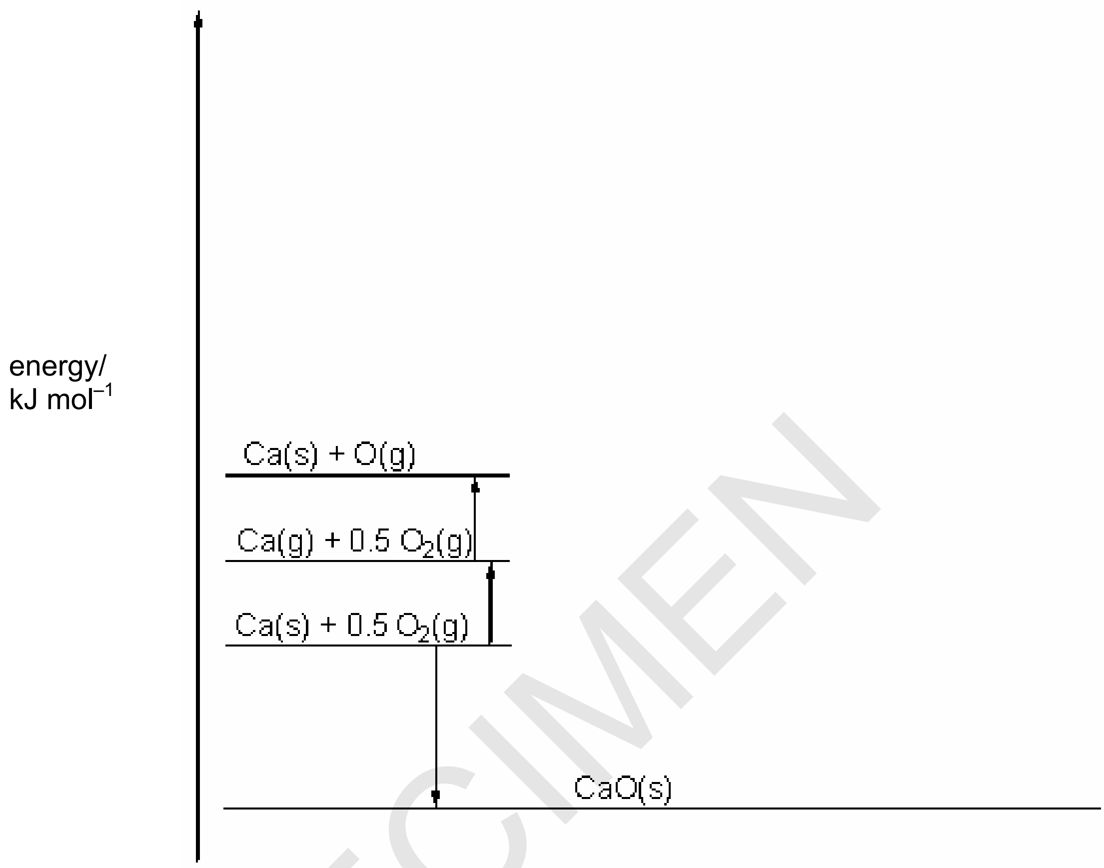
.... **[2]**

(b) Complete the Born–Haber cycle for calcium oxide below.

Use the data in **Table 4.1** to calculate the lattice enthalpy of calcium oxide.



lattice enthalpy = ... kJ mol^{-1} **[5]**

(c) The lattice enthalpies of calcium oxide and magnesium oxide are different.

Comment on this difference.

In your answer you should make clear how the sizes of the lattice enthalpies are related to any supporting evidence.

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.... **[3]**

(d) Most metals can be extracted by reduction from compounds obtained from their naturally-occurring ores.

Metals such as calcium and magnesium are normally extracted by electrolysis but it is feasible that calcium oxide could be reduced by carbon as shown in **equation 4.1**.

$$CaO(s) + C(s) \rightarrow Ca(s) + CO(g) \qquad \textbf{equation 4.1}$$

Use the data in the table below to help you answer parts **(i)–(iii)** below.

	CaO(s)	C(s)	Ca(s)	CO(g)
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–635	0	0	–110
$S^{\ominus}$/J K^{-1} mol^{-1}	39.7	5.7	41.4	197.6

(i) Calculate the standard enthalpy change for the CaO reduction in **equation 4.1**.

$\Delta H^{\ominus}$ = ... kJ mol^{-1} **[1]**

(ii) Calculate the standard entropy change for the CaO reduction in **equation 4.1**.

$\Delta S^{\ominus}$ = ... J K^{-1} mol^{-1} **[1]**

(iii) Calculate the minimum temperature at which the carbon reduction in **equation 4.1** is feasible.

minimum temperature = ... **[5]**

[Total: 19]

5 Use the standard electrode potentials in the table below to answer the questions that follow.

I	$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	$E^\ominus = -0.44$ V
II	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	$E^\ominus = -0.26$ V
III	$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	$E^\ominus = 0.00$ V
IV	$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	$E^\ominus = +0.40$ V

(a) An electrochemical cell was set up based on systems **I** and **II**.

(i) Write half-equations to show what has been oxidised and what has been reduced in this cell.

oxidation:

reduction:

[2]

(ii) Determine the cell potential of this cell.

E_{cell} = ... V **[1]**

(b) An electrochemical fuel cell was set up based on systems **III** and **IV**.

(i) Construct an equation for the spontaneous cell reaction. Show your working.

[2]

(ii) Fuels cells based on systems such as **III** and **IV** are increasingly being used to generate energy.

Discuss **two** advantages and **two** disadvantages of using fuels cells for energy rather than using fossil fuels.

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.... **[4]**

[Total: 9]

6 This question looks at different chemical compounds used in medicine.

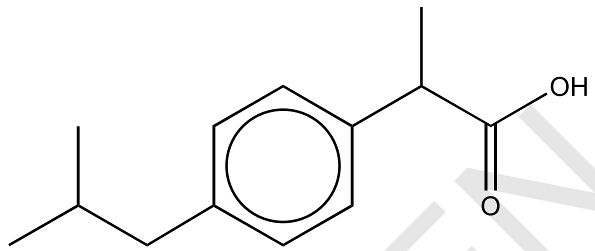
(a) An oxide of nitrogen is used as a general anaesthetic by dentists.

This oxide contains 63.64% N by mass, and has a density of 1.833 g dm^{-3} at room temperature and pressure.

Determine the molecular formula of this gas. Show your working.

[3]

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



Suggest a chemical that would react with a solution of ibuprofen to produce a gas.

Name the gas produced and write an 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 injected 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. Using a mass spectrometer, the molecular ion peak of eugenol was shown to have a *m*/*z* value of 164.

Analyse and interpret this information to determine the molecular formula of eugenol.

Show your working clearly.

[5]

[Total: 13]

7 This question looks at the chemistry of transition elements.

(a) **(i)** Explain what is meant by the terms *transition element*, *complex ion* and *ligand*,

(ii) Discuss, with examples, equations and observations, the typical reactions of transition elements.

In your answer you should make clear how any observations provide evidence for the type of reaction discussed. **[11]**

(b) Describe, using suitable examples and diagrams, the different shapes and stereoisomerism shown by complex ions.

In your answer you should make clear how your diagrams illustrate the type of stereoisomerism involved. **[9]**

[Turn over

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[Total: 20]

Paper Total [100]

END OF QUESTION PAPER

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OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

CHEMISTRY A F325

Unit F325: Equilibria, Energetics and Elements

Specimen Mark Scheme

The maximum mark for this paper is **100**.

Question Number	Answer	Max Mark
1(a)(i)	O_3: Exp 2 has 4 times $[H_2]$ as Exp 1 and rate increases by 4 ✓, so order = 1 with respect to O_3 ✓ C_2H_4: Exp 3 has 2 x $[C_2H_4]$ and 2 x $[O_3]$ as Exp 2; and rate has increased by 4 ✓, so order = 1 with respect to C_2H_4 ✓ rate = k $[O_3]$ $[C_2H_4]$ ✓	[5]
(ii)	use of k = rate / $[O_3]$ $[C_2H_4]$ = 1.0×10^{-12} / (0.5×10^{-7} x 1.0×10^{-8}) to obtain a calculated value ✓ $k = 2 \times 10^3$ ✓ units: $dm^3\ mol^{-1}\ s^{-1}$ ✓	[3]
(iii)	rate = 1.0×10^{-12} /4 = 2.5×10^{-13} ($mol\ dm^{-3}\ s^{-1}$) ✓	[1]
(iv)	rate increases and k increases ✓	[1]
(b)	$1\frac{1}{2}O_2(g) \longrightarrow O_3(g)$/ $O_2(g) + \frac{1}{2}O_2(g) \longrightarrow O_3(g)$ ✓ NO is a catalyst ✓ as it is (used up in step 1 and) regenerated in step 2/ not used up in the overall reaction✓ allow 1 mark for 'O/NO_2 with explanation of regeneration.'	[3]
2(a)(i)	H^+/proton donor ✓	[1]
(ii)	partially dissociates/ionises ✓	[1]
(b)	$C_6H_5OH(aq)$ + $OH^-(aq)$ $\rightleftharpoons$ $C_6H_5O^-(aq)$ + $H_2O(l)$ acid 1 base 2 base 1 acid 2 ✓	[1]

Question Number	Answer	Max Mark
(c)(i)	$K_a = [C_6H_5O^-(aq)] [H^+(aq)] / [C_6H_5OH(aq)]$ ✓	[1]
(ii)	M_r C_6H_5OH = 94 ✓ $[C_6H_5OH(aq)]$ 4.7/94 = 0.050 mol dm^{-3} ✓ $1.3 \times 10^{-10} \approx [H^+(aq)]^2 / 0.050$ mol dm^{-3} ✓ ('=' sign is acceptable) $[H^+] = \sqrt{(1.3 \times 10^{-10}) \times (0.050)} = 2.55 \times 10^{-6}$ mol dm^{-3} ✓ pH = $-\log[H^+] = -\log 2.55 \times 10^{-6} = 5.59$ ✓ 3 marks: $[H^+]$; pH expression ; calc of pH from $[H^+]$	[5]
(d)	$[H^+(aq)] = 1.99 \times 10^{-9}$ mol dm^{-3} ✓ $[C_6H_5O^-(aq)] = K_a [C_6H_5OH(aq)] / [H^+(aq)]$ ✓ $[C_6H_5O^-(aq)]$ = 0.13 mol dm^{-3} ✓ *Calculation should use half the original concentration of phenol to find the concentration of sodium phenoxide in the buffer. This should then be doubled back up again.* *Do **not** penalise an approach that uses the original concentration of phenol in the expression above.*	[3]
(e)	Na/NaOH because some of the hexylresorcinol will react producing a mixture of the acid and the salt/conjugate base ✓ or mono/di salt of hexylresorcinol because the acid and its salt/conjugate base makes a buffer ✓	[1]
3(a)	rate of forward reaction = rate of reverse reaction ✓ concentrations of reactants and products are constant but they are constantly interchanging ✓	[2]
(b)(i)	$K_c = [CH_3OH] / [CO] [H_2]^2$ ✓	[1]
(ii)	use of $K_c = [CH_3OH] / [CO] [H_2]^2$ and moles to obtain a calculated value ✓ convert moles to concentration by ÷ 2: $[CO] = 3.10 \times 10^{-3}$ mol dm^{-3}; $[H_2] = 2.60 \times 10^{-5}$ mol dm^{-3}; $[CH_3OH] = 2.40 \times 10^{-2}$ mol dm^{-3} ✓ $K_c = [2.60 \times 10^{-5}] / [3.10 \times 10^{-3}] [2.40 \times 10^{-2}]^2$ = 14.6 / 14.56 ✓ If moles not converted to concentration, calculated K_c value = 3.64 *(scores 1st and 3rd marks)* units: dm^6 mol^{-2} ✓	[4]

Question Number	Answer	Max Mark
(c)(i)	fewer moles of gas on right hand side ✓	[1]
(ii)	None ✓	[1]
(d)(i)	moved to left hand side/reactants increase/less products ✓	[1]
(ii)	Δ*H* negative because high temperature favours the endothermic direction ✓	[1]
(e)(i)	$CH_3OH + 1½ O_2 \longrightarrow CO_2 + 2H_2O$✓	[1]
(ii)	adds oxygen/oxygenated ✓	[1]
4(a)(i)	Ca^+ is smaller than Ca/ proton : electron ratio in Ca^+ > Ca ✓ greater attraction from nucleus ✓	[2]
(ii)	"oxide" ion, O^- and electron are both negative ✓ hence energy is required to overcome repulsion ✓	[2]
(b)	completes Born-Haber cycle showing 1st IE↑ 2nd IE↑ 1st EA ↓ 2nd EA↑ and LE↓✓✓✓ (lose 1 mark for each error/omission) LE = –✓3451 kJ mol^{-1} ✓	[5]
(c)	differences in size of lattice enthalpies linked to ionic sizes/attraction using **more/less exothermic** rather than bigger or smaller. ✓ Mg^{2+} is smaller/Mg^{2+} has greater charge density✓ hence has stronger attraction for O^{2-}✓	[3]
(d)(i)	525 kJ mol^{-1} ✓	[1]
(ii)	193.6 J K^{-1} mol^{-1} ✓	[1]
(iii)	uses $\Delta G = \Delta H - T\Delta S$ ✓ To be feasible, $\Delta G = 0$ or $\Delta G < 0$ ✓ minimum $T = \Delta H / \Delta S$ ✓ Converts Δ*S* from J to kJ/÷1000 or converts Δ*H* from kJ to J ✓ 2712 K/ 2438 °C / 2439 °C ✓ *(units essential)*	[5]

Question Number	Answer	Max Mark
5(a)(i)	oxidation: Fe $\rightarrow$ Fe^{2+} + $2e^-$ ✓ reduction: V^{3+} + e^- $\rightarrow$ V^{2+} ✓	**[2]**
(ii)	E_{cell} = 0.18 V ✓	**[1]**
(b)(i)	system **III** x 2 and reversed + system **IV** ✓ $2 H_2 + O_2 \rightarrow 2H_2O$/ $H_2 + ½O_2 \rightarrow H_2O$ ✓	**[2]**
(ii)	advantages: only H_2O formed/ non-polluting greater efficiency ✓ disadvantages: H_2 difficult to store ✓ H_2 difficult to manufactured initially / limited life cycle of H_2 adsorber/absorber ✓	**[4]**
6(a)	empirical formula N : O = 63.64/14 : 36.36/16 ✓ = 4.56 : 2.27 = 2 : 1. Empirical formula = N_2O ✓ molecular formula M_r of gas = 1.833 x 24 = 44 ✓ (calc 43.992) with these two pieces of evidence, assume that molecular formula = N_2O	**[3]**
(b)	any chemical that reacts to produce gas: e.g. carbonate and CO_2 ✓ accept: metal more reactive than Pb and H_2 balanced equation to match chemical added ✓	**[2]**
(c)	M_r(Lidocaine) = 236 ✓ moles Novocaine = 100 x 10^{-3}/236 = 4.24 x 10^{-4} ✓ concentration of Novocaine = 4.24 x 10^{-4} x (1000/5) = 0.0847/0.0848 mol dm^{-3} ✓	**[3]**

Question Number	Answer	Max Mark
(d)	mass C = 12 x 3.74/44.0 = 12 x 0.085 = 1.02 g ✓ mass H = 2/18 x 0.918 = 0.102 g ✓ mass O = 1.394 – (1.020 + 0.102) = 0.272 g ratio C : H : O = 1.02/12 : 0.102/1 : 0.272/16 ✓ = 0.0850 : 0.102 : 0.0170 / 5 : 6 : 1 / C_5H_6O ✓ $C_5H_{10}O$ has relative mass of 82 M_r is 164 = 2 x 82 ∴ molecular formula = $C_{10}H_{12}O_2$ ✓	[5]
7(a)(i)	transition element: has at least one ion with a partly filled d-orbital ✓ example showing electronic configuration with d orbital as between d^1 – d^9 ✓	[2]
	complex ion: a central metal ion surrounded by ligands with an example. ✓ ligand: molecule/ion with lone pair of electrons capable of forming co-ordinate/dative bonds to a metal ion ✓	[2]
(ii)	precipitation: equation ✓ colour of precipitate ✓	[2]
	ligand substitution: equation ✓ colour of substituted complex ✓	[2]
	redox: equation ✓ colour change ✓	[2]
	✎ The candidate clearly links observations to provide evidence for two reactions discussed. ✓	[1] [11]

Question Number	Answer	Max Mark
(b)	complex ions: octahedral example ✓ with 3-D diagram ✓	[2]
	tetrahedral example ✓ with 3-D diagram ✓	[2]
	square planar example (see also below) ✓ with 3-D diagram ✓	[2]
	stereoisomerism: *cis-trans* example, e.g. $Ni(NH_3)_2Cl_2$; platin with 3-D diagram ✓ optical example, e.g. $Ni(en)_3^{2+}$ ✓ with 3D diagrams ✓	[3]
	The candidate clearly links features on the diagrams with a characteristic of the stereoisomerism involved ✓	[1] [Max: 9]
	Paper Total	**[100]**

Assessment Objectives Grid (includes QWC)

Question	AO1	AO2	AO3	Total
1(a)(i)			5	5
1(a)(ii)		3		3
1(a)(iii)		1		1
1(a)(iv)		1		1
1(b)		3		3
2(a)(i)	1			1
2(a)(ii)	1			1
2(b)		1		1
2(c)(i)		1		1
2(c)(ii)		5		5
2(d)		3		3
2(e)		1		1
3(a)	2			2
3(b)		5		5
3(c)		2		2
3(d)(i)		1		1
3(d)(ii)		1		1
3(e)(i)		1		1
3(e)(ii)		1		1
4(a)(i)		2		2
4(a)(ii)		2		2
4(b)	2	3		5
4(c)	3			3
4(d)(i)		1		1
4(d)(ii)		1		1
4(d)(iii)	2	3		5
5(a)(i)		2		2
5(a)(ii)	1			1
5(b)(i)		2		2
5(b)(ii)	4			4
6(a)		3		3
6(b)		2		2
6(c)		3		3
6(d)			5	5
7(a)	11			11
7(b)	9			9
Totals	**36**	**54**	**10**	**100**