WACE EXAM CHEMISTRY 2014 STAGE 3

Term 4; Week 4

Reading time before commencing work: ten minutes
Working time for paper: three hours

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Multiple-choice	25	25	50	25	25
Section Two: Short answer	11	11	60	72	35
Section Three: Extended answer	6	6	70	82	40
				Total	100

Skip the following questions:

1
2
3
4
5
6
8
9
28
38

Section One: Multiple-choice **25% (25 Marks)**

This section has **25** questions. Answer **all** questions on the separate Multiple-choice Answer Sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 50 minutes.

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1. Which one of the following is a representation of a lead(IV) ion with 125 neutrons?

   (a) $^{125}_{4}Pb$

   (b) $^{207}_{82}Pb^{4+}$

   (c) $^{82}_{125}Pb^{4+}$

   (d) $^{125}_{82}Pb^{4+}$

2. Which one of the following species does **not** have an electron configuration of 2,8,8?

   (a) $C\ell^-$
   (b) S^{2-}
   (c) Ar
   (d) Na^+

3. The successive ionisation energies for an element, X, are shown below.

Equation for process	Ionisation energy (kJ mol^{-1})
$X(g) \rightarrow X^+(g) + e^-$	1012
$X^+(g) \rightarrow X^{2+}(g) + e^-$	1903
$X^{2+}(g) \rightarrow X^{3+}(g) + e^-$	2914
$X^{3+}(g) \rightarrow X^{4+}(g) + e^-$	4958
$X^{4+}(g) \rightarrow X^{5+}(g) + e^-$	6276
$X^{5+}(g) \rightarrow X^{6+}(g) + e^-$	21270
$X^{6+}(g) \rightarrow X^{7+}(g) + e^-$	25400
$X^{7+}(g) \rightarrow X^{8+}(g) + e^-$	29860

   The element **most** likely to be X is

   (a) aluminium.
   (b) nitrogen.
   (c) chlorine.
   (d) phosphorus.

See next page

4. The ability of an atom in a chemical bond to draw electrons toward itself is responsible for the phenomenon of polar covalent bonding and is known as

(a) electron density.
(b) electronegativity.
(c) ionisation energy.
(d) dipole moment.

5. Which of the following is the **most** polar bond?

(a) C-N
(b) N-O
(c) O-F
(d) P-Cℓ

6. Which of the following pairs of elements will be **most** similar in their chemical properties?

(a) Si and Sn
(b) K and Ca
(c) P and S
(d) Na and Cs

7. The following table lists the phases of some group 16 hydrides at room temperature.

Group 16 hydride	Phase at room temperature
H_2O	liquid
H_2S	gas
H_2Se	gas
H_2Te	gas

Which of the following statements **best** explains why H_2O is liquid at room temperature and the other group 16 hydrides are gases?

(a) The polarity of the group 16 hydrides increases going down the group.
(b) There are greater dispersion forces between the molecules with higher molar masses.
(c) Dipole-dipole forces vary in their strength for these molecules due to the different electronegativities of the group 16 elements.
(d) The size and shape of the molecules can influence phase.

8. Which one of the following covalent compounds has polar molecules?

(a) CH_2F_2
(b) CF_4
(c) SO_3
(d) CO_2

See next page

9. Absolute zero may be regarded as the temperature at which

(a) water changes to a solid.
(b) all substances become solid.
(c) all particle motion ceases.
(d) particles have vibrational energy only.

10. Consider the following endothermic reaction

$$N_2O(g) + NO_2(g) \rightleftharpoons 3NO(g) \quad \Delta H = +156 \text{ kJ mol}^{-1}$$

Which one of the following changes to the system at equilibrium will increase the value of its equilibrium constant, K?

(a) increased pressure
(b) addition of a catalyst
(c) increased temperature
(d) decreased temperature

11. Which one of the following is the equilibrium law expression for the equilibrium represented below?

$$2\,CrO_4^{2-}(aq) + 2\,H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(\ell)$$

(a) $\dfrac{[Cr_2O_7^{2-}]}{[CrO_4^{2-}]^2[H^+]^2}$

(b) $\dfrac{[CrO_4^{2-}]^2[H^+]^2}{[Cr_2O_7^{2-}]}$

(c) $\dfrac{[CrO_4^{2-}]^2[H^+]^2}{[Cr_2O_7^{2-}][H_2O]}$

(d) $\dfrac{[Cr_2O_7^{2-}][H_2O]}{[CrO_4^{2-}]^2[H^+]^2}$

See next page

12. Aqueous solutions of iron(III) ions and thiocyanate ions form the equilibrium represented below.

$$\underset{\text{pale brown}}{Fe^{3+}(aq)} + \underset{\text{colourless}}{SCN^{-}(aq)} \rightleftharpoons \underset{\text{deep red}}{[Fe(SCN)]^{2+}(aq)}$$

The reaction is exothermic.

Which one of the following statements about changes to the system and the effect on the colour of the solution is true?

(a) Adding water will make it turn darker red.
(b) Cooling the solution will make it turn darker red.
(c) Adding a small volume of aqueous Na_2CO_3 solution will turn it darker red.
(d) Adding solid iron(III) chloride to the solution will make it lighter red.

13. Which of the following is the strongest acid?

	Acid	Acid dissociation (equilibrium) constant
(a)	CH_3COOH	1.8×10^{-5}
(b)	HCO_3^-	5.6×10^{-11}
(c)	HF	6.8×10^{-4}
(d)	$H_2C_2O_4$	5.4×10^{-2}

14. Which of the following 0.1 mol L^{-1} aqueous solutions has the highest pH?

(a) ammonium sulfate
(b) hydrochloric acid
(c) potassium phosphate
(d) sodium nitrate

15. Consider the following reaction.

$$OBr^{-}(aq) + H_2O(\ell) \rightleftharpoons HOBr(aq) + OH^{-}(aq)$$

Which one of the following represents an acid-base conjugate pair for this reaction?

(a) OBr^-/H_2O
(b) $HOBr/OH^-$
(c) OBr^-/OH^-
(d) H_2O/OH^-

See next page

16. Consider the self-ionisation of water:

$$2\ H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq) \qquad \Delta H > 0.$$

Which of the following statements about aqueous solutions is true?

I All aqueous solutions contain H_3O^+ and OH^- ions.
II In any neutral aqueous solution at any temperature, $[H_3O^+] = [OH^-]$
III In aqueous solutions with pH greater than 7, $[H_3O^+] > [OH^-]$
IV A neutral aqueous solution at 100 °C has a pH < 7

(a) I only
(b) I and II only
(c) I, II and III only
(d) I, II and IV only

17. The equation below shows the reaction when sulfur dioxide gas (SO_2) is bubbled through a solution containing hypochlorite ions ($C\ell O^-$).

$$C\ell O^-(aq) + SO_2(g) + H_2O(\ell) \rightarrow C\ell^-(aq) + SO_4^{2-}(aq) + 2\ H^+(aq)$$

Which of the following statements about this reaction is correct?

I The sulfur in sulfur dioxide is oxidised.
II The hydrogen in water is reduced.
III The hypochlorite ion is the reducing agent.
IV The water is the oxidising agent.

(a) I only
(b) II and III only
(c) III and IV only
(d) I and IV only

18. Consider the following mixtures:

I solid I_2 is added to a solution of H_2S
II liquid Br_2 is added to a solution of Fe^{2+}
III freshly exposed $A\ell$ metal is added to a solution of $HC\ell$
IV a piece of cobalt metal is placed in an aqueous solution of Cr^{3+}.

Based on E° values, in which of the above mixtures will a chemical reaction occur?

(a) II only
(b) I and III only
(c) I, II and III only
(d) III and IV only

See next page

19. A buffer solution is made by dissolving ammonium chloride in a dilute solution of ammonia. The following equilibrium exists in the prepared solution:

$$NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq).$$

A small amount of a strong acid is added to the buffer solution. Once the equilibrium has been re-established, the effect would be

(a) an overall decrease in the H^+ ion concentration.
(b) that the equilibrium has shifted to the left.
(c) an overall increase in the NH_4^+ ion concentration.
(d) an overall increase in the OH^- ion concentration.

20. Which of the following compounds has the highest boiling point?

(a) 1-chloropropane
(b) propan-1-ol
(c) propanal
(d) methylpropane

21. How many isomers are there with the molecular formula $C_2H_2Br_2$?

(a) 2
(b) 3
(c) 4
(d) 5

22. Which one of the following is **not** a primary amine?

(a) CH_3NH_2

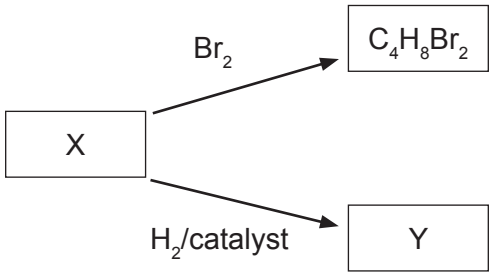
(b) $CH_3CH(NH_2)CH_3$

(c) CH_3NHCH_3

(d) $CH_3CH_2CH_2NH_2$

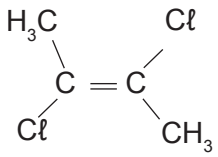
See next page

23. In the following diagram what are the molecular formulae of substances X and Y likely to be?



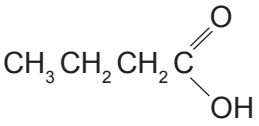
	X	**Y**
(a)	C_4H_8	C_4H_6
(b)	C_4H_8	C_4H_{10}
(c)	C_4H_{10}	C_4H_8
(d)	C_4H_6	C_4H_8

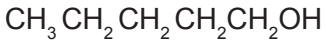
24. Which one of the following is the IUPAC name for the compound below?

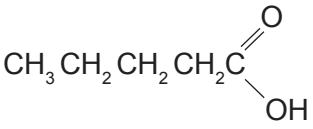


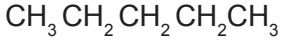
(a) 2,3-dichloro-*trans*-but-2-ene
(b) 2,3-dichloro-*cis*-but-2-ene
(c) 1,2-dichloro-*trans*-but-2-ene
(d) 1,2-dichloro-*cis*-but-2-ene

Question 25 refers to the structures shown below.

I 

II 

III 

IV 

25. Which one of the following gives their increasing order of solubility in water?

(a)	IV	<	II	<	III	<	I
(b)	IV	<	II	<	I	<	III
(c)	III	<	I	<	IV	<	II
(d)	I	<	III	<	II	<	IV

End of Section One

See next page

Section Two: Short answer **35% (72 Marks)**

This section has **11** questions. Answer **all** questions. Write your answers in the spaces provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: 60 minutes.

Question 26 **(4 marks)**

For the following reactions, describe fully the observed changes, including any:

- colour changes
- odours
- precipitates (give the colour)
- gases evolved (give the colour or describe as colourless).

(a) Lead(II) nitrate solution is added to potassium iodide solution. (1 mark)

$Pb^{2+}(aq) + 2\,I^{-}(aq) \rightarrow PbI_2(s)$

Observation:

(b) Solid copper(II) carbonate is added to dilute nitric acid solution. (3 marks)

$CuCO_3(s) + 2\,H^{+}(aq) \rightarrow Cu^{2+}(aq) + CO_2(g) + H_2O(\ell)$

Observation:

Question 27 **(4 marks)**

Write balanced ionic equations to represent the reactions described below.

(a) Chlorine gas is bubbled through an aqueous solution of sodium bromide. (2 marks)

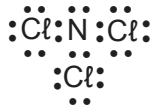
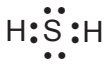
See next page

(b) Solid nickel oxide is added to dilute hydrochloric acid solution. (2 marks)

Question 28 **(8 marks)**

Complete the table below by **either** drawing the Lewis structures **or** naming the shape of the molecules. For Lewis structures, any lone pairs must be shown.

All electron shell pairs should be represented as either : or as —.

Molecule/Ion	Lewis structure	Name of shape
NCl_3		
H_2S		
SiH_4		Tetrahedral
O_3		Bent (V-shaped)
NO_3^-		Trigonal planar

See next page

Question 29 **(9 marks)**

Ethanol, C_2H_5OH, and hexane, C_6H_{14}, are two common industrial solvents.

(a) (i) Identify the polarity of molecules that are soluble in each of these solvents. (2 marks)

	Polarity of molecules/substances that are soluble in solvent
Ethanol	(circle one only) Polar Non-polar
Hexane	(circle one only) Polar Non-polar

(ii) Explain the interactions between solute and solvent particles in solutions of these two solvents. (3 marks)

(b) Ethanol and water are often mixed together in the manufacture of a range of substances. The following data were recorded during one production process.

Substance	Volume (mL)
water	50
ethanol	50
mixture of water and ethanol	96

The 'loss' of 4 mL on mixing water with ethanol implies strong interactions between the water and ethanol molecules. Describe these interactions and explain the origin of their strength. (4 marks)

See next page

Question 30 **(9 marks)**

Hydrogen can be made by reacting methane (natural gas) with water (steam). The reaction can form the chemical equilibrium represented below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g) \quad \Delta H = +206 \text{ kJ mol}^{-1}$$

State the conditions of temperature and pressure that would optimise the yield of hydrogen at a reasonable rate of reaction. Using collision theory and principles of chemical equilibrium, explain your choice of conditions.

	Optimum conditions	**Explanation**
Temperature	(circle one only) high moderate low (1 mark)	(3 marks)
Pressure	(circle one only) high moderate low (1 mark)	(4 marks)

See next page

Question 31 **(5 marks)**

(a) State the role of the standard hydrogen half-cell in determining the table of Standard Reduction Potentials. (2 marks)

(b) State **three** limitations of Standard Reduction Potential tables. (3 marks)

One:

Two:

Three:

Question 32 **(6 marks)**

Nitrogen gas from the atmosphere undergoes a series of redox reactions to transform it into nitrate ions that are absorbed by plants. The process can be simplified into the following three steps.

Step 1 – Nitrogen-fixing soil bacteria reduce nitrogen gas to ammonium ions.
Step 2 – Nitrifying bacteria then oxidise ammonium ions to nitrite ions.
Step 3 – Nitrifying bacteria then oxidise nitrite ions to nitrate ions.

Write the half-equations for each of these steps. Assume acidic conditions.

Step 1

Step 2

Step 3

See next page

Question 33 **(9 marks)**

(a) Methanoic acid, HCOOH, may be produced by oxidation of an alcohol with acidified potassium permanganate, MnO_4^-, solution.

Write the oxidation and reduction half-equations and the final redox equation for this reaction. (5 marks)

Oxidation half-equation	
Reduction half-equation	
Final redox equation	

(b) Methanoic acid reacts with ethanol in the presence of sulfuric acid to produce a sweet smelling compound.

Write the balanced equation for the reaction of methanoic acid with ethanol. (2 marks)

(c) Draw the structural formula for the sweet smelling compound and give its IUPAC name. Show **all** H atoms in the structure. (2 marks)

Name: _____

See next page

Question 34 **(5 marks)**

Alcohols can be classified as primary, secondary or tertiary.

Complete the table below by drawing the structure for a primary alcohol, a secondary alcohol and a tertiary alcohol, each with the molecular formula $C_5H_{12}O$. Show **all** H atoms in your structures.

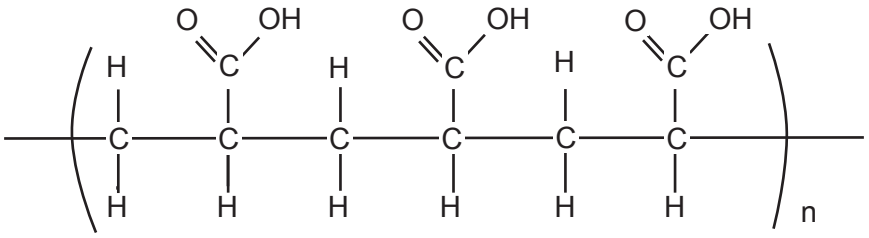
Give the IUPAC names for the primary and secondary alcohols you have drawn.

	Structure	**Name**
Primary alcohol		
Secondary alcohol		
Tertiary alcohol		Name not required.

See next page

Question 35 **(4 marks)**

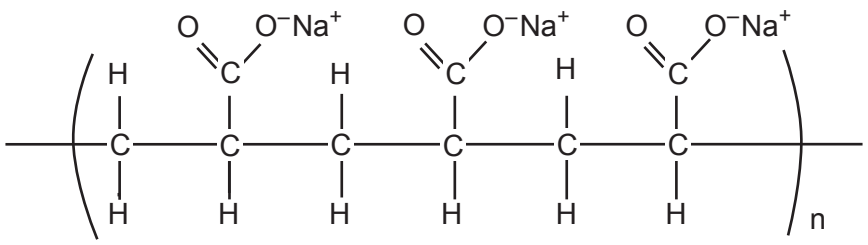
(a) The structure below represents a segment of polyacrylic acid.



Draw the structure for the monomer of this addition polymer. (1 mark)

See next page

(b) The structure below represents sodium polyacrylate made by reacting polyacrylic acid with sodium hydroxide.



Sodium polyacrylate is a superabsorbent polymer that can absorb approximately 800 times its own weight in water. It is a white powder that swells when water is added. The sodium ions are removed from the polymer structure by interactions with water molecules and then other water molecules move into the swollen structure, where they are held.

(i) What is the name of the interactions occurring between water molecules and sodium ions to enable the removal of the latter from the polymer? (1 mark)

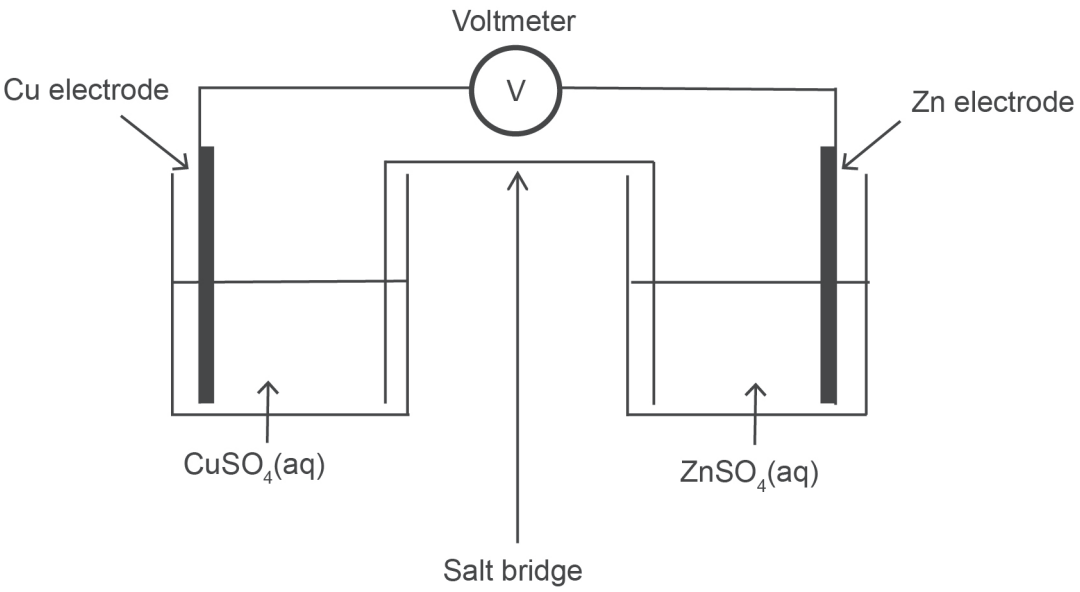
(ii) Explain how the polymer sodium polyacrylate can absorb large quantities of water. (2 marks)

Question 36 **(9 marks)**

A student investigated the effect of concentration of the electrolyte on the electrical potential of electrochemical cells. The student measured the electrical potential for the cell shown in the diagram below. In all trials the volumes of solutions and their temperatures were the same and the surface areas of the copper and zinc electrodes were the same.

The overall cell reaction is as follows:

$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$



(a) What is the independent variable in this investigation? (1 mark)

(b) What is the dependent variable in this investigation? (1 mark)

(c) Why did the volumes and temperatures of solutions and surface areas of the electrodes need to be the same in each trial? (1 mark)

See next page

The student found that as the concentration of Cu^{2+} ions increased, electrical potential increased, but as concentration of Zn^{2+} ions increased, electrical potential decreased, as shown in the table below.

Trial	Cu^{2+} concentration (mol L^{-1})	Zn^{2+} concentration (mol L^{-1})	Electrical potential, E (V)
1	0.00001	1.00	1.01
2	0.010	1.00	1.04
3	1.00	1.00	1.09
4	1.00	0.010	1.16
5	1.00	0.00001	1.26

(d) Explain the increase in electrical potential as the concentration of Cu^{2+} ions increased and the decrease in electrical potential as the concentration of Zn^{2+} ions increased. (2 marks)

(e) The student also observed that as the cells were allowed to run for a while their electrical potential slowly decreased from its maximum value. Why did this happen? (2 marks)

The student concluded:

'As the concentration of the oxidant increases, so does the cell voltage (electrical potential).'

(f) List **two** ways to improve the investigation. (2 marks)

One: _____

Two: _____

End of Section Two

See next page

Section Three: Extended answer **40% (82 Marks)**

This section contains **six (6)** questions. You must answer **all** questions. Write your answers in the spaces provided.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to **three** significant figures.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: 70 minutes.

Question 37 **(9 marks)**

Aqua regia is a mixture of concentrated hydrochloric acid and nitric acid that is able to dissolve gold. One of its uses is in the analysis of gold content in gold ore.

As part of quality control processes, a chemist in a gold analysis laboratory analysed aqua regia to ensure the required 3:1 mole ratio of hydrochloric acid to nitric acid. The chemist found that 20.0 mL of aqua regia needed 28.6 mL of 8.00 mol L^{-1} sodium hydroxide for complete neutralisation. The reaction for the neutralisation reaction between the sodium hydroxide and acid is represented by the equation below:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell).$$

(a) Calculate the moles of hydrogen ions present in the 20.0 mL sample of aqua regia. (2 marks)

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The chemist analysed the chloride content of the aqua regia by adding excess silver nitrate solution to a separate 20.0 mL sample of aqua regia. This resulted in the precipitation of 24.6 g of solid.

(b) Write the balanced ionic equation for precipitation of silver chloride from aqua regia. (1 mark)

(c) Calculate the moles of hydrochloric acid in the 20.0 mL of aqua regia. (3 marks)

(d) Determine whether the aqua regia had the required ratio of hydrochloric acid to nitric acid. State clearly whether the ratio was as required and support your answer with clear workings. (3 marks)

See next page

Question 38 **(12 marks)**

Below is a table showing the atomic radius, first ionisation energy and melting point for the Second Period elements.

Element	Atomic number	Atomic radius (nm)	First ionisation energy(kJ mol^{-1})	Melting point (°C)
Lithium	3	0.152	520	180
Beryllium	4	0.112	900	1 278
Boron	5	0.085	801	2 300
Carbon	6	0.077	1 086	3 727
Nitrogen	7	0.075	1 402	–210
Oxygen	8	0.073	1 314	–219
Fluorine	9	0.072	1 681	–220
Neon	10	0.071	2 081	–249

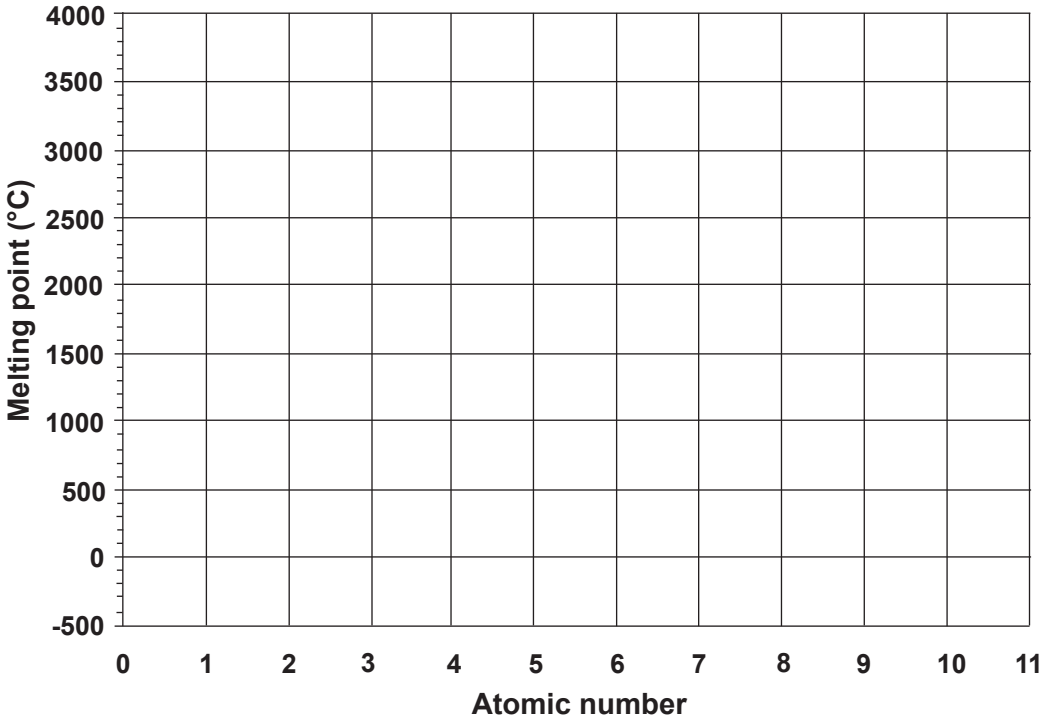
(a) State and explain the trend in atomic radius across the Second Period. (3 marks)

(b) State and explain the trend in first ionisation energy across the Second Period. (4 marks)

See next page

(c) Plot a graph of atomic number against melting point for the Second Period elements. (2 marks)

(If you need to make a second attempt at this grid item, the grid is repeated at the end of this Question/Answer Booklet. Cancel the graph on this page.)



(d) Based on their bonding when solid, explain the difference in melting points of lithium, carbon and neon. (3 marks)

See next page

Question 39 **(14 marks)**

An organic compound that contains only carbon, hydrogen, oxygen and bromine was analysed to determine its empirical formula. A combustion analysis of 1.50 g of the compound produced 1.58 g of carbon dioxide and 0.563 g water.

On treatment of 1.75 g of the compound to convert the bromine in the compound to bromide ions and further reaction with silver nitrate, 1.97 g of silver bromide was precipitated.

(a) Determine the empirical formula of the compound. (10 marks)

See next page

(b) 1.95 g of the compound was vaporised and was found to occupy 0.387 L at 95.0 kPa and 105 °C. Determine the molecular formula of the compound. (2 marks)

(c) Further analysis of the organic compound revealed that it had a carboxylic acid functional group. Draw a possible structural formula of the organic compound. (2 marks)

See next page

Question 40 **(15 marks)**

Citric acid is the active ingredient in some bathroom and kitchen cleaning solutions. A student determined the content of citric acid in a cleaner by titration with sodium hydroxide solution.

The sodium hydroxide solution first needed to be standardised. To do this, the student dissolved approximately 4 g of sodium hydroxide pellets in water, to give an approximately 0.1 mol L^{-1} solution. This solution was standardised by titrating 20.00 mL of the NaOH solution with a 0.105 mol L^{-1} standard hydrochloric acid solution. The average titration volume was 17.45 mL.

(a) Explain why sodium hydroxide is not suitable as a primary standard. (2 marks)

(b) Show that the concentration of the sodium hydroxide solution is 0.0916 mol L^{-1}. Show sufficient workings to justify your answer. (3 marks)

The student then weighed a 10.00 mL aliquot of the cleaner and found it weighed 10.4 g. This 10.00 mL aliquot was next diluted to 100.0 mL in a volumetric flask. Against the standardised sodium hydroxide solution, 20.00 mL aliquots of the diluted cleaner were titrated. The table below shows the results of the titrations.

Titre	1	2	3	4
Final reading (mL)	25.30	23.55	22.40	22.25
Initial reading (mL)	3.50	2.70	1.50	1.30
Titre volume (mL)				

(c) Calculate the average titre volume to be used in the calculation of the citric acid content. (2 marks)

See next page

(d) Given that citric acid ($C_6H_8O_7$) is a weak triprotic acid, determine the percentage composition by mass of citric acid in the cleaner. The molar mass of citric acid is 192.124 g mol^{-1}. (6 marks)

(e) Select a suitable indicator for this titration from the table below. Explain your choice. (2 marks)

Indicator	Colour change (low pH – high pH)	pH range
Methyl yellow	red-yellow	2.4 – 4.0
Litmus	red-blue	5.0 – 8.0
Bromothymol blue	yellow-blue	6.0 – 7.6
Thymol blue	yellow-blue	8.0 – 9.6

See next page

Question 41 **(24 marks)**

Rock phosphate is a non-renewable source of phosphate fertiliser. Because of concerns about its eventual depletion, urine is being investigated as an alternative renewable source for phosphate.

The phosphate in urine will precipitate as calcium hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, and struvite, $MgNH_4PO_4.6H_2O$, as the pH of the urine increases. The pH increases due to the hydrolysis of urea, $CO(NH_2)_2$, in urine to ammonia and carbon dioxide.

(a) Write the balanced equation for the hydrolysis of urea. (2 marks)

(b) Explain briefly why hydrolysis of urea causes an **increase** in pH. Include an appropriate balanced equation in your answer. (2 marks)

To determine phosphorus concentration in urine, a researcher collected 5.00 L of urine. After allowing the pH to increase to about 9 and adding excess magnesium ions to complete precipitation, 25.3 g of calcium hydroxyapatite and struvite precipitate were collected.

Analysis showed that 82.3% by mass of the precipitate was struvite and the rest calcium hydroxyapatite.

(c) Determine the concentration, in grams per litre, of the phosphorus in the urine. Express your answer to **three** significant figures. (Assume all phosphorus has been precipitated.) (9 marks)

Molar masses (in g mol^{-1}): struvite 245.418; calcium hydroxyapatite 1004.636.

See next page

Once all the phosphorus has been removed, the nitrogen present can be recovered from the urine in the form of ammonium ions and converted to a nitrogen fertiliser. Recovery of the nitrogen can be achieved as follows:

Step 1
Sodium hydroxide is added to the phosphorus-depleted urine to increase its pH.

Step 2
The solution is heated to 40 °C to convert the aqueous ammonia to the gas phase and a stream of air is passed through the solution.

Step 3
The ammonia-enriched air is allowed to come into contact with a room-temperature solution of sulfuric acid. The ammonia is absorbed by the solution to react with the acid to give ammonium sulfate.

(d) Explain, using collision theory, why increasing the pH of the phosphorus-depleted urine converts the ammonium ions to ammonia. Support your answer with a balanced equation. (3 marks)

See next page

Question 41 (continued)

(e) State the purpose of heating the solution to 40 °C. (1 mark)

(f) Write a balanced equation for the reaction in Step 3. (2 marks)

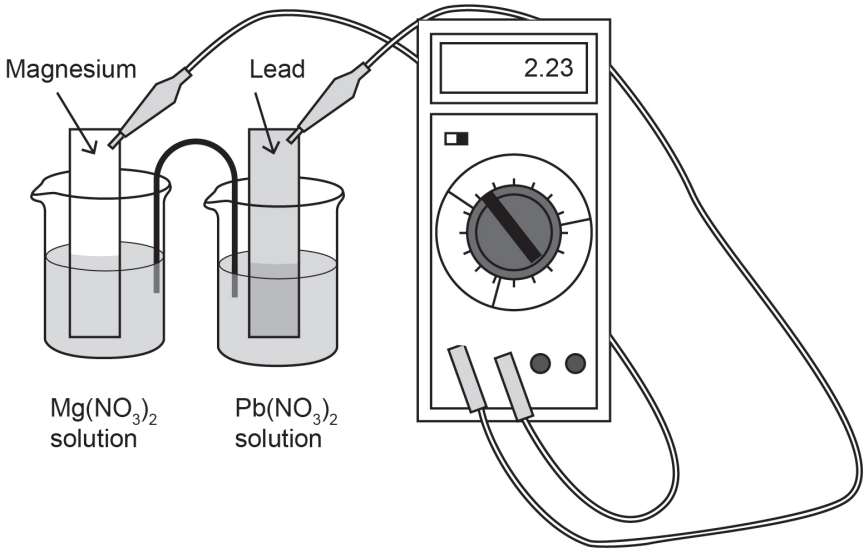
(g) The amount of ammonium sulfate recovered from the 5.00 L of urine in this experiment is 72.65 g. If the process is 78% efficient, what is the concentration of nitrogen, in grams per litre, in the phosphorus-depleted urine? (5 marks)

See next page

Question 42 **(8 marks)**

Using the diagram below, explain the role of the following in the operation of an electrochemical (galvanic) cell:

- anode process
- cathode process
- lead(II) nitrate electrolyte
- salt bridge
- electron flow in external circuit.



End of questions

Section One: Multiple-choice **25% (25 Marks)**

Question No.	Answer
1	B
2	D
3	D
4	B
5	D
6	D
7	C
8	A
9	C
10	C
11	A
12	B
13	D
14	C
15	D
16	D
17	A
18	C
19	C
20	B
21	B
22	C
23	B
24	A
25	A

End of Section One

Section Two: Short answer **35% (72 Marks)**

Question 26 **(4 marks)**

For the following reactions, describe fully the observed changes, including any

- colour changes
- odours
- precipitates (give the colour)
- gases evolved (give the colour or describe as colourless).

(a) Lead(II) nitrate solution is added to potassium iodide solution. (1 mark)

$Pb^{2+}(aq) + 2\,I^{-}(aq) \rightarrow PbI_2(s)$

(b) Solid copper(II) carbonate is added to dilute nitric acid solution. (3 marks)

$CuCO_3(s) + 2\,H^{+}(aq) \rightarrow Cu^{2+}(aq) + CO_2(g) + H_2O(\ell)$

	Description	Marks
(a)	Yellow precipitate formed	1
(b)	Green solid dissolves to give blue solution and a colourless and (odourless) gas is evolved (1 for solid dissolving; 1 for colour change green to blue and 1 for colourless,(odourless) gas)	1–3
Incorrect		0
	Total	**4**

Question 27 **(4 marks)**

Write balanced ionic equations to represent the reactions described below.

(a) Chlorine gas is bubbled through an aqueous solution of sodium bromide. (2 marks)

$$C\ell_2(g) + 2\,Br^{-}(aq) \rightarrow 2\,C\ell^{-}(aq) + Br_2(aq)$$

(b) Solid nickel oxide is added to dilute hydrochloric acid solution. (2 marks)

$$NiO(s) + 2\,H^{+}(aq) \rightarrow Ni^{2+}(aq) + H_2O(\ell)$$

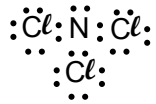
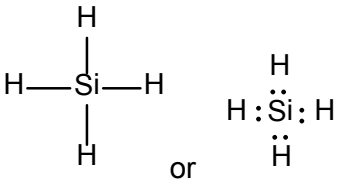
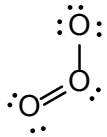
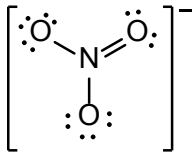
Description	Marks
Correct formulae for reactants and products	1–2
Balanced equations	1–2
Incorrect	0
Total	**4**

NB: State symbols not required.
Award 1 mark for correctly balanced molecular equation.

Question 28 **(8 marks)**

Complete the table below by **either** drawing the Lewis structures **or** naming the shape of the molecules. For Lewis structures, any lone pairs must be shown.

All electron shell pairs should be represented as either : or as —.

Molecule/Ion	Lewis structure	Name of shape
$NC\ell_3$		**(Trigonal) pyramidal**
H_2S		**Bent (V-shaped)**
SiH_4		tetrahedral
O_3		Bent (V-shaped)
NO_3^-		Trigonal planar

Description	Marks
Shapes correctly named	1–2
All Lewis structures correct including lone pairs	6
• Octet around central atom is correctly shown (i.e. bonds are correct) for all structures but lone pairs are missing; **or** • Lewis structures correct but square brackets and charge missing around NO_3^-	5
• Octet around central atom is correctly shown (i.e. bonds are correct) for all structures but lone pairs are missing; **and** • Lewis structures correct but square brackets and charge missing around NO_3^-	4
Award 3 marks if each structure has the correct number of valence electrons shown but not correctly distributed	3
Incorrect	0
Total	**8**

NB: Lewis structure does not need to represent the shape.

Question 29 **(9 marks)**

Ethanol C_2H_5OH, and hexane, C_6H_{14}, are two common industrial solvents.

(a) (i) Identify the polarity of molecules that are soluble in each of these solvents. (2 marks)

	Polarity of molecules/substances that are soluble in the solvent
Ethanol	(circle one only) **Polar** Non-polar
Hexane	(circle one only) Polar **Non-polar**

Description	**Marks**
Recognition that ethanol will dissolve polar molecules	1
Recognition that hexane will dissolve non-polar molecules	1
Incorrect	0
Total	**2**

(ii) Explain the interactions between solute and solvent particles in solutions of these two solvents. (3 marks)

Description	**Marks**
Recognition that:	
solutions using ethanol is a result of dipole/dipole or hydrogen bond interactions between solute and solvent	1
solutions using hexane is a result of dispersion forces between solute and solvent	1
interactions between solute/solvent must be of similar strength to the solute/solute and solvent/solvent interactions	1
Incorrect	0
Total	**3**

Question 29 (continued)

(b) The 'loss' of 4 mL on mixing water with ethanol implies strong interactions between the water and ethanol molecules. Describe these interactions and explain the origin of their strength. (4 marks)

Description	Marks
Recognition that the interactions between water and ethanol are of similar strength to those in the individual liquids	1
Recognition that water and ethanol have hydrogen bonding	1
Explains hydrogen bonding in terms of: • oxygen being extremely electronegative leading to the high polarity of the O-H bond or • a big difference in electronegativity of O and H	1
Explains the strength of the H-bond (any one of the following) • highly polar • high charge density of H • low electron density • appropriate annotated diagram	1
Incorrect	0
Total	**4**

Question 30 **(9 marks)**

Hydrogen can be made by reacting methane (natural gas) with water (steam). The reaction can form the chemical equilibrium represented below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

State the conditions of temperature and pressure that would optimise the yield of hydrogen at a reasonable rate of reaction. Using collision theory and principles of chemical equilibrium, explain your choice of conditions.

	Optimum conditions	**Explanation**
Temperature	high temperature (1 mark)	High temperature increases the proportion of molecules colliding with energy above the E_a and so increasing the reaction rates for both the forward and reverse reactions but the (forward) endothermic direction will increase more so increasing yield of H_2. (3 marks)
Pressure	moderate pressure (1 mark)	High pressure increases frequency of collisions between molecules and increases rates for both the forward and reverse reactions but increases reverse reaction rate more (because there are fewer gas molecules on reactant side). Low pressure will increase yield of H_2 but the rate of the reaction will be too slow so a compromise moderate pressure is needed. (4 marks)

Description	**Marks**
Recognition of high temperature and moderate pressure	1–2
Recognition that high temperature increases the proportion of molecules colliding with energy above the E_a	1
Recognition that high temperature increases rates of forward (and reverse) reaction(s)	1
Recognition that high temperature increases the rate of forward reaction more than rate of reverse reaction **or** accept Le Chatelier's Principle explanation	1
Recognition that high pressure increases frequency of collisions between molecules	1
Recognition that high pressure increases rates of **both** forward and reverse reactions	1
Recognition that high pressure increases rate of reverse reaction more than forward	1
Recognition that low pressure will increase yield of H_2 but the rate of the reaction will be too slow. Compromise between yield and reaction rate	1
Incorrect	0
Total	**9**

NB: Where the student chooses the incorrect optimum conditions but their explanation matches the marking key, they may be awarded marks for the explanation.

Question 31 **(5 marks)**

(a) State the role of the standard hydrogen half-cell in determining the table of Standard Reduction Potentials. (2 marks)

Description	Marks
Recognition that the hydrogen half-cell:	
is the reference half-cell	1
against which the reduction potential of all other half-cells are measured	1
Incorrect	0
Total	**2**

(b) State **three** limitations of Standard Reduction Potential tables. (3 marks)

Description	Marks
Any three of: • The values of E^0 depend upon concentration. (1 mol L^{-1}) • Applies only to aqueous solutions • The emf of a cell can depend on temperatures • The values of E^0 give no indication of reaction rate/high activation energy • Predictive tool – reaction may not occur • All gases at 100kPa (standard pressure)	1–3
Incorrect	0
Total	**3**

Question 32 **(6 marks)**

Nitrogen gas from the atmosphere undergoes a series of redox reactions to transform it into nitrate ions that are absorbed by plants. The process can be simplified into the following three steps.

Step 1 – Nitrogen-fixing soil bacteria reduce nitrogen gas to ammonium ions.

Step 2 – Nitrifying bacteria then oxidise ammonium ions to nitrite ions.

Step 3 – Nitrifying bacteria then oxidise nitrite ions to nitrate ions.

Write the half-equations for each of these steps. Assume acidic conditions.

$N_2 + 8\ H^+ + 6\ e^- \rightarrow 2\ NH_4^+$

$NH_4^+ + 2\ H_2O \rightarrow NO_2^- + 8\ H^+ + 6\ e^-$

$NO_2^- + H_2O \rightarrow NO_3^- + 2\ H^+ + 2\ e^-$

Description	Marks
2 marks for a correct half-equation	0–6
Incorrect	0
Total	**6**

NB: For an incorrect half-equation, award 1 mark if reactants and products are correct but electrons or balancing incorrect; if atoms are consistently balanced for all the half-equations but electrons incorrect award 4 marks.

Question 33 **(9 marks)**

(a) Methanoic acid, HCOOH, may be produced by oxidation of an alcohol with acidified potassium permanganate, MnO_4^-, solution.

Write the oxidation and reduction half-equations and the final redox equation for this reaction. (5 marks)

Oxidation half-equation	$CH_3OH(\ell) + H_2O(\ell) \rightarrow HCOOH(\ell) + 4\ H^+(aq) + 4\ e^-$ (×5)
Reduction half-equation	$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$ (×4)
Final redox equation	$5\ CH_3OH(\ell) + 4\ MnO_4^-(aq) + 12\ H^+(aq) \rightarrow 5\ HCOOH(\ell) + 4\ Mn^{2+}(aq) + 11\ H_2O(\ell)$

Description	Marks
Correct oxidation half-equation; for an incorrect oxidation half-equation, award 1 mark if reactants and products are correct but electrons or balancing incorrect	1–2
Correct reduction half-equation	1
Correct final redox equation; for an incorrect redox equation, award 1 mark if reactants and products are correct but balancing incorrect	1–2
Incorrect	0
Total	**5**

NB: State symbols not required.

If oxidation/reduction reversed award a maximum of 4 marks.

Balancing includes cancelling of H^+ and H_2O

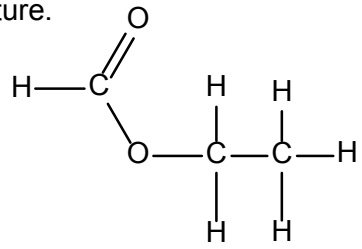
(b) Methanoic acid reacts with ethanol in the presence of sulfuric acid to produce a sweet smelling compound.

Write the balanced equation for the reaction of methanoic acid with ethanol. (2 marks)

$$HCOOH + CH_3CH_2OH \rightarrow HCOOCH_2CH_3 + H_2O$$

Description	Marks
Correct equation	2
Only 3 formulae correct or water missing	1
Incorrect	0
Total	**2**

(c) Draw the structural formula for the sweet smelling compound and give its IUPAC name. Show **all** H atoms in the structure. (2 marks)



Name: ethyl methanoate

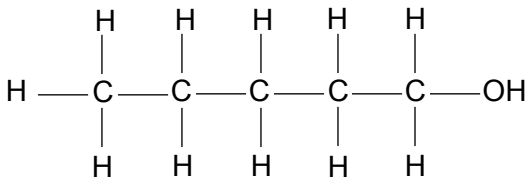
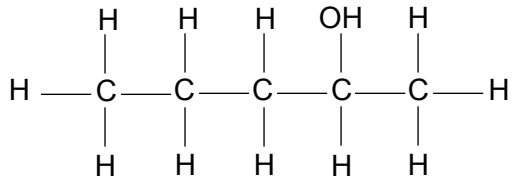
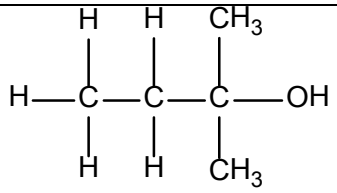
Description	Marks
Correct structure (condensed structure acceptable)	1
Correct name – ethyl methanoate	1
Incorrect	0
Total	**2**

Question 34 **(5 marks)**

Alcohols can be classified as primary, secondary or tertiary.

Complete the table below by drawing the structure for a primary alcohol, a secondary alcohol and a tertiary alcohol, each with the molecular formula $C_5H_{12}O$. Show **all** H atoms in your structures.

Give the IUPAC names for the primary and secondary alcohols you have drawn.

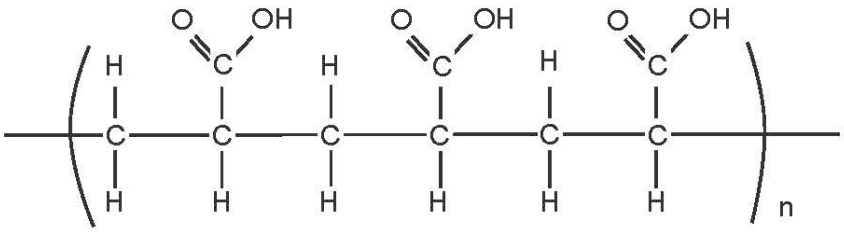
	Structure	Name
Primary alcohol		Pentan-1-ol 2-methylbutan-1-ol 2,2-dimethylpropan-1-ol
Secondary alcohol		Pentan-2-ol Pentan-3-ol 3-methylbutan-2-ol
Tertiary alcohol		Name not required.

Description	Marks
A correct primary alcohol structure with MF $C_5H_{12}O$ drawn	1
Name matches alcohol structure drawn	1
A correct secondary alcohol structure with MF $C_5H_{12}O$ drawn	1
Name matches alcohol structure drawn	1
Correct tertiary alcohol structure with MF $C_5H_{12}O$ drawn	1
Incorrect	0
Total	**5**

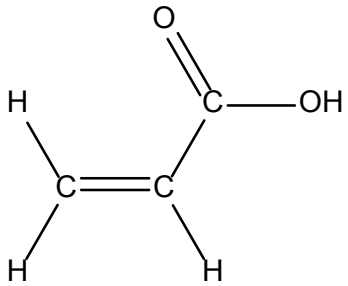
NB: Award 2 of the possible 3 marks for structures if all H atoms not shown; condensed structures acceptable.

Question 35 **(4 marks)**

(a) The structure below represents a segment of polyacrylic acid.



Draw the structure for the monomer of this addition polymer. (1 mark)



Description	Marks
Correct structure	1
Incorrect	0
Total	**1**

(b) (i) What is the name of the interactions occurring between water molecules and sodium ions to enable the removal of the latter from the polymer? (1 mark)

Description	Marks
The water molecules and sodium ions interact through ion-dipole attractions	1
Incorrect	0
Total	**1**

(ii) Explain how the polymer sodium polyacrylate can absorb large quantities of water. (2 marks)

Description	Marks
Recognition that water molecules form hydrogen bonds with the carboxylate groups (accept ion-dipole)	1
Recognition that there are a large number of carboxylate groups in the polymer so a large number of water molecules can hydrogen bond to the polymer	1
Incorrect	0
Total	**2**

Question 36 **(9 marks)**

(a) What is the independent variable in this investigation? (1 mark)

Description	Marks
Concentrations of solution (accept concentration of one of Cu^{2+} or Zn^{2+})	1
Incorrect	0
Total	**1**

(b) What is the dependent variable in this investigation? (1 mark)

Description	Marks
Electrical potential/voltage/volts	1
Incorrect	0
Total	**1**

(c) Why did the volumes and temperatures of solutions and surface areas of the electrodes need to be the same in each trial? (1 mark)

Description	Marks
To be confident that any changes in electrical potential are due to concentration changes only	1
Incorrect	0
Total	**1**

(d) Explain the increase in electrical potential as the concentration of Cu^{2+} ions increased and the decrease in electrical potential as the concentration of Zn^{2+} ions increased. (2 marks)

Description	Marks
The rate of forward reaction increases as concentration of Cu^{2+} ions increased (Accept forward reaction favoured)	1
The rate of reverse reaction increases as concentration of Zn^{2+} ions increased (Accept reverse reaction favoured)	1
Incorrect	0
Total	**2**

(e) The student also observed that as the cells were allowed to run for a while their electrical potential slowly decreased from its maximum value. Why did this happen? (2 marks)

Description	Marks
Recognition that as the cell operates the concentration of reactants decreases	1
Recognition that forward reaction rate decreases **or** system approaches equilibrium	1
Incorrect	0
Total	**2**

The student concluded:

'As the concentration of the oxidant increases, so does the cell voltage (electrical potential).'

(f) List **two** ways to improve the investigation. (2 marks)

Description	Marks
Test other cells	1
Repeat trials	1
Incorrect	0
Total	**2**

Section Three: Extended answer **40% (82 Marks)**

Question 37 **(9 marks)**

Aqua regia is a mixture of concentrated hydrochloric acid and nitric acid that is able to dissolve gold. One of its uses is in the analysis of gold content in gold ore.

As part of quality control processes, a chemist in a gold analysis laboratory analysed aqua regia to ensure the required 3:1 mole ratio of hydrochloric acid to nitric acid. The chemist found that 20.0 mL of aqua regia needed 28.6 mL of 8.00 mol L^{-1} sodium hydroxide for complete neutralisation. The reaction for the neutralisation reaction between the sodium hydroxide and acid is represented by the equation below:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell).$$

(a) Calculate the moles of hydrogen ions present in the 20.0 mL sample of aqua regia.
(2 marks)

Description	Marks
n(NaOH) = 0.0286 × 8.00 = 0.2288 mol	1
$n(H^+) = n(OH^-) = 0.229$ mol	1
Incorrect	0
Total	**2**

The chemist analysed the chloride content of the aqua regia by adding excess silver nitrate solution to a separate 20.0 mL sample of aqua regia. This resulted in the precipitation of 24.6 g of solid.

(b) Write the balanced ionic equation for precipitation of silver chloride from aqua regia.
(1 mark)

$$Ag^+(aq) + C\ell^-(aq) \rightarrow AgC\ell(s)$$

Description	Marks
Correctly balanced equation	1
Incorrect	0
Total	**1**

NB: State symbols not required.

Question 37 (continued)

(c) Calculate the moles of hydrochloric acid in the 20.0 mL of aqua regia. (3 marks)

Description	Marks
$M(AgC\ell) = 143.35 \text{ g mol}^{-1}$	1
$n(AgC\ell) = \frac{24.6}{143.35} = 0.1716 \text{ mol}$	1
$n(HC\ell) = n(C\ell^-) = n(AgC\ell) = 0.172 \text{ mol}$	1
Incorrect	0
Total	**3**

(d) Determine whether the aqua regia had the required ratio of hydrochloric acid to nitric acid. State clearly whether the ratio was as required and support your answer with clear workings. (3 marks)

Description	Marks
$n(HNO_3) = n(H^+)\text{total} - n(HC\ell) = 0.2288 - 0.1716 = 0.0572 \text{ mol}$	1
$\text{Ratio} = \frac{n(HC\ell)}{n(HNO_3)} = \frac{0.1716}{0.0572} = 3.00$	1
Yes the ratio of $HC\ell$ to HNO_3 is 3:1	1
Incorrect	0
Total	**3**

Question 38 **(12 marks)**

(a) State and explain the trend in atomic radius across the Second Period. (3 marks)

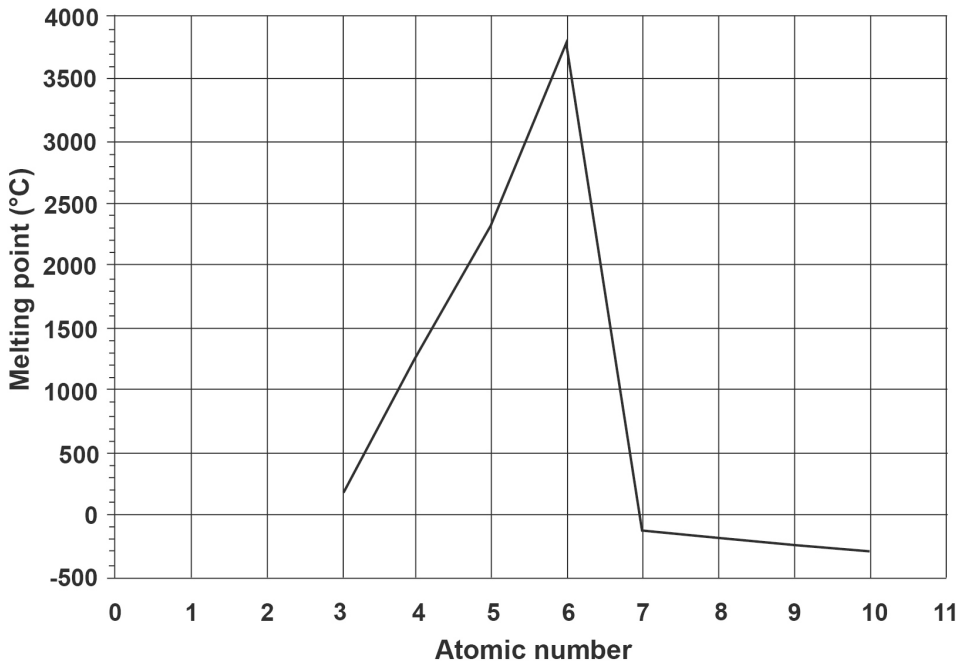
Description	Marks
Recognition that the atomic radius decreases across the period	1
Recognition that each successive electron is in the same valence shell	1
Recognition that increasing positive charge of the nucleus pulls the electrons closer to the nucleus	1
Incorrect	0
Total	**3**

(b) State and explain the trend in first ionisation energy across the Second Period. (4 marks)

Description	Marks
Recognition that the first ionisation energy increases across the period	1
Recognition that the valence shell is closer to nucleus (radius reduced) across the period	1
Recognition that the positive charge increases in nucleus.	1
Recognition that with increasing positive charge of the nucleus there is an increase in the force of attraction and more energy is needed to remove an electron	1
Incorrect	0
Total	**4**

(c) Plot a graph of atomic number against melting point for the Second Period elements. (2 marks)

Description	Marks
Accurate plotting of points	1
Straight line connecting points	1
Incorrect	0
Total	**2**



Question 38 (continued)

(d) Based on their bonding when solid, explain the difference in melting points of lithium, carbon and neon. (3 marks)

Description	Marks
Recognition that as a metal lithium has a moderately high melting point due to moderate forces of attraction between cations and delocalised electrons	1
Recognition that carbon's very high melting point can be explained by its strong covalent bonding between all carbon atoms in the network structure	1
Recognition that neon's low melting point can be explained by the weak dispersion forces between neighbouring neon atoms (so only small amounts of energy are needed to overcome these attractive forces)	1
Incorrect	0
Total	**3**

Question 39 **(14 marks)**

An organic compound that contains only carbon, hydrogen, oxygen and bromine, was analysed to determine its empirical formula. A combustion analysis of 1.50 g of the compound produced 1.58 g of carbon dioxide and 0.563 g water.

On treatment of 1.75 g of the compound to convert the bromine in the compound to bromide ions and further reaction with silver nitrate, 1.97 g of silver bromide was precipitated.

(a) Determine the empirical formula of the compound. (10 marks)

Description	Marks
$m(C) = 1.58 \times \frac{12.01}{44.01} = 0.431\,g$ $\%(C) = \frac{0.431}{1.50} \times 100 = 28.7\%$	1–2
$m(H) = 0.563 \times \frac{2.016}{18.016} = 0.0630\,g$ $\%(H) = \frac{0.0630}{1.50} \times 100 = 4.20\%$	1–2
$m(Br) = 1.97 \times \frac{79.9}{79.9+107.9} = 0.838\,g$ $\%(Br) = \frac{0.838}{1.75} \times 100\% = 47.9\%$	1–2
% O = 100 – 28.7 – 4.2 – 47.9 = 19.2	1
C H Br O Ratio by mass: 28.7 4.20 47.9 19.2 Ratio by mol: $\frac{28.7}{12.01}$ $\frac{4.20}{1.008}$ $\frac{47.9}{79.9}$ $\frac{19.2}{16}$ 2.39 4.17 0.599 1.20 Divide by smallest: $\frac{2.39}{0.599}$ $\frac{4.17}{0.599}$ $\frac{0.599}{0.599}$ $\frac{1.20}{0.599}$ 3.98 6.96 1 2.00 Therefore empirical formula is $C_4H_7BrO_2$	1–3
Total	**10**

Question 39 (continued)

(b) 1.95 g of the compound was vaporised and was found to occupy 0.387 L at 95.0 kPa and 105 °C. Determine the molecular formula of the compound. (2 marks)

Description	Marks
$n = \frac{95 \times 0.387}{8.314 \times 378.15} = 0.0117 \text{ mol}$ $M = \frac{1.95}{0.0117} = 167$	1
$EFM(C_4H_7BrO_2) = (4 \times 12.01) + (7 \times 1.008) + 79.9 + (2 \times 16) = 166.996$ Since empirical mass = molecular mass, the molecular formula is $C_4H_7BrO_2$	1
Total	**2**

(c) Further analysis of the organic compound revealed that it had a carboxylic acid functional group. Draw a possible structural formula of the organic compound. (2 marks)

Description	Marks
$CH_2BrCH_2CH_2COOH$ or $CH_3CHBrCH_2COOH$ or $CH_3CH_2CHBrCOOH$	1–2
Total	**2**

NB: If molecule drawn with carboxylic acid shown with one minor error, 1 mark.

A correct structure is drawn for an incorrect molecular formula, if it represents a carboxylic acid, 2 marks.

Accept a correct bond-line structure, 2 marks

Question 40 **(15 marks)**

(a) Explain why sodium hydroxide is not suitable as a primary standard (2 marks)

Description	Marks
Any two of the following: • does not have high molar mass • absorbs moisture/is deliquescent/hygroscopic • reacts with CO_2 from the atmosphere • mass varies over time • cannot be obtained pure	1-2
Incorrect	0
Total	**2**

(b) Show that the concentration of the sodium hydroxide solution is 0.0916 mol L^{-1}. Show sufficient workings to justify your answer. (3 marks)

Description	Marks
$n(HC\ell) = 0.01745 \times 0.105 = 1.832 \times 10^{-3}$ mol	1
$n(NaOH) = n(HC\ell) = 1.832 \times 10^{-3}$ mol	1
$c(NaOH) = \frac{n}{v} = \frac{1.832 \times 10^{-3}}{0.02} = 9.16 \times 10^{-2}\ mol L^{-1}$	1
Incorrect	0
Total	**3**

(c) Calculate the average titre volume to be used in the calculation of the citric acid content. (2 marks)

Description	Marks
Differences in initial and final readings = 21.80, 20.85, 20.90, 20.95	1
Titre volume = $\frac{20.85 + 20.90 + 20.95}{3} = 20.90$ mL	1
Incorrect	0
Total	**2**

Question 40 (continued)

(d) Given that citric acid ($C_6H_8O_7$) is a weak triprotic acid, determine the percentage composition by mass of citric acid in the cleaner. The molar mass of citric acid is 192.124 g mol^{-1}. (6 marks)

Description	Marks
n(NaOH) = 0.02090 × 0.0916 = 1.914 × 10^{-3} mol	1
In 20 mL of dilute citric acid, n(citric) = $\frac{1.914 \times 10^{-3}}{3} = 6.381 \times 10^{-4}$ mol	1
n(citric) in 100 mL = 6.381 ×10^{-4} × 5 = 0.003191 mol	1
hence in 10 mL original = 0.003191 mol	1
m(citric) = n × M = 0.003191 × 192.124 = 0.613 g	1
Therefore % composition = $\frac{0.613}{10.4} \times 100 = 5.89\%$	1
Incorrect	0
Total	**6**

(e) Select a suitable indicator for this titration from the table below. Explain your choice. (2 marks)

Indicator	Colour change (low pH – high pH)	pH range
Methyl yellow	red-yellow	2.4 – 4.0
Litmus	red-blue	5.0 – 8.0
Bromothymol blue	yellow-blue	6.0 – 7.6
Thymol blue	Yellow-blue	8.0 – 9.6

Description	Marks
Thymol blue	1
The citrate ion hydrolyses to give hydroxide ions and so an equivalence point in the basic region or appropriate equation	1
Incorrect	0
Total	**2**

Question 41 **(24 marks)**

(a) Write the balanced equation for the hydrolysis of urea. (2 marks)

$CO(NH_2)_2(aq) + H_2O(\ell) \rightarrow CO_2(aq) + 2\ NH_3(aq)$

Description	Marks
Correct formulae for reactants and products	1
Balanced equation	1
Incorrect	0
Total	**2**

NB: States for reactants and products not required.

(b) Explain briefly why hydrolysis of urea causes an **increase** in pH. Include an appropriate balanced equation in your answer. (2 marks)

Description	Marks
Statement showing recognition that NH_3 hydrolyses to give OH^-	1
Balanced hydrolysis equation	1
Incorrect	0
Total	**2**

NB: States for reactants and products not required.

The pH increases because the ammonia produced by hydrolysis of urea in turn hydrolyses to produce hydroxide ions.

$$NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

(c) Determine the concentration, in grams per litre, of the phosphorus in the urine. Express your answer to **three** significant figures. (Assume all phosphorus has been precipitated.) (9 marks)

Molar masses (in g mol^{-1}): struvite 245.418; calcium hydroxyapatite 1004.636.

Description	Marks
$m(MgNH_4PO_4.6H_2O)$ in the precipitate = 0.823 × 25.3 = 20.823 g	1
$m(Ca_{10}(PO_4)_6(OH)_2)$ in the precipitate = 25.3 - 20.823 = 4.478 g	1
n(P) in struvite = $n(MgNH_4PO_4.6H_2O) = \frac{20.823}{245.418} = 8.484\times10^{-2}$ mol	1
$n(Ca_{10}(PO_4)_6(OH)_2) = \frac{4.478}{1004.636} = 4.457\times10^{-3}$ mol	1
n(P) in calcium hydroxyapatite = $4.457 \times 10^{-3} \times 6 = 2.674 \times 10^{-2}$ mol	1
Total $n(P) = 8.484 \times 10^{-2} + 2.674 \times 10^{-2} = 1.116 \times 10^{-1}$ mol	1
$m(P) = 1.116 \times 10^{-1} \times 30.97 = 3.456$ g	1
Concentration = $\frac{3.456}{5.00} = 0.691\ g\ L^{-1}$	1
Answer expressed in **three** significant figures	1
Incorrect	0
Total	**9**

(d) Explain, using collision theory, why increasing the pH of the phosphorus-depleted urine converts the ammonium ions to ammonia. Support your answer with a balanced equation. (3 marks)

Description	Marks
Recognition that concentration of OH^- ions increases so the frequency of collisions between NH_4^+ and OH^- ions increases	1
Recognition that rate of the forward reaction in the equilibrium increases relative to the reverse reaction	1
Balanced equation	1
Incorrect	0
Total	**3**

NB: Increased pH increases concentration of OH^- so the frequency of collisions between NH_4^+ and OH^- ions increases and thus the rate of the forward reaction in the equilibrium below increases relative to the reverse reaction and so increases production of ammonia. (The increase in hydroxide ion concentration shifts the equilibrium below to the production of ammonia.)

$$NH_4^+(aq) + OH^-(aq) \rightleftharpoons NH_3(aq) + H_2O(\ell)$$

(e) State the purpose of heating the solution to 40 °C. (1 mark)

The solubility of NH_3 in water is reduced at high temperature.

Description	Marks
Statement showing recognition that solubility of NH_3 in water is reduced at high temperature; Accept $NH_3(aq) \rightarrow NH_3(g)$ is endothermic so increasing temperature favours the endothermic process and equilibrium shifts right producing more $NH_3(g)$	1
Incorrect	0
Total	**1**

(f) Write a balanced equation for the reaction in Step 3. (2 marks)

Accept any of the following:

$$NH_3(aq) + H^+(aq) \rightarrow NH_4^+(aq)$$

$$2\ NH_3(aq) + H_2SO_4(aq) \rightarrow 2\ NH_4^+(aq) + SO_4^{2-}(aq)$$

$$2\ NH_3(aq) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq)$$

$$NH_3(aq) + HSO_4^-(aq) \rightarrow NH_4^+(aq) + SO_4^{2-}(aq)$$

Description	Marks
Correct formulae for reactants and products	1
Balanced equation	1
Incorrect	0
Total	**2**

Question 41 (continued)

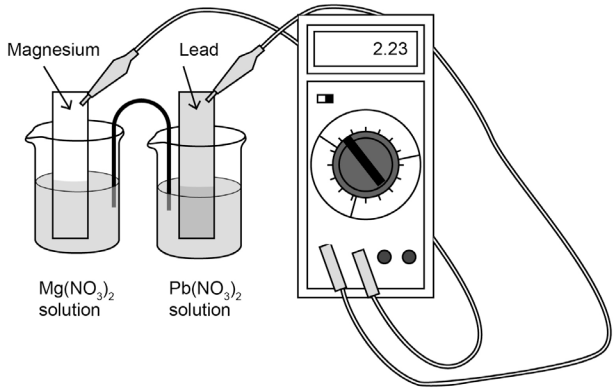
(g) The amount of ammonium sulfate recovered from the 5.00 L of urine in this experiment is 72.65 g. If the process is 78% efficient, what is the concentration of nitrogen, in grams per litre, in the phosphorus-depleted urine? (5 marks)

Description	Marks
$n((NH_4)_2SO_4) = \frac{72.65}{132.144} = 0.5498$ mol	1
$n(N) = 2 \times n((NH_4)_2SO_4) = 2 \times 0.5498 = 1.0996$ mol	1
For 78% efficient, $m(N) = 1.0996 \times 14.01 = 15.405$ g	1
For 100%, $m(N) = \frac{15.405}{0.78} = 19.75$ g	1
Concentration $= \frac{19.75}{5.00} = 3.95$ g L^{-1}	1
Incorrect	0
Total	**5**

Question 42 **(8 marks)**

Using the diagram below, explain the role of the following in the operation of an electrochemical (galvanic) cell:

- anode process
- cathode process
- lead(II) nitrate electrolyte
- salt bridge and ion migration
- electron flow in external circuit.



Description	Marks
Anode oxidation occurs	1
Mg loses electrons to form Mg ions or equation for reaction at the anode $Mg \rightarrow Mg^{2+} + 2e^-$	1
Cathode reduction occurs	1
Pb gains electrons to form Pb or equation for reaction at the cathode $Pb^{2+} + 2e^- \rightarrow Pb$	1
Lead(II) nitrate electrolyte is the source of Pb^{2+} ions	1
Salt bridge allows for the movement of ions between the two half-cells	1
Salt bridge allows electrical neutrality to be maintained or to complete the circuit	1
Electron follow provides energy to do work e.g. produces a reading on the meter	1
Total	**8**