CHEMISTRY

ATAR course examination 2018

Marking Key

Marking keys are an explicit statement about what the examining panel expect of candidates when they respond to particular examination items. They help ensure a consistent interpretation of the criteria that guide the awarding of marks.

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

Question No.	Answer
1	c
2	d
3	b
4	a
5	a
6	d
7	d
8	b
9	c
10	All *
11	b
12	c
13	d
14	c
15	a
16	c
17	c
18	d
19	b
20	c
21	b
22	d
23	a
24	a
25	a

* Question 10 – all distractors were deemed correct; all candidates were awarded 1 mark.

Section Two: Short answer 35% (79 Marks)

General Notes:
- Answers provided in brackets are desired but not essential for the relevant mark to be allocated.
- Clear and unambiguous demonstration of the candidate's understanding in their response is required rather than the exact wording in the marking key.
- Notes provided within the marking key will indicate which elements of the model answers are required for the allocated mark.

Question 26 **(10 marks)**

Solid copper(II) hydroxide is added to excess 0.100 mol L^{-1} carbonic acid solution.

(a) Write the balanced equation, with appropriate state symbols, for the reaction that takes place between the copper(II) hydroxide and carbonic acid. (3 marks)

Description	Marks
$Cu(OH)_2(s)$ + $H_2CO_3(aq)$ → $CuCO_3(s)$ + $2\,H_2O(\ell)$ **or** $Cu(OH)_2(s) + 2\,H_2CO_3(aq) → CuCO_3(s) + CO_2(g) + 3\,H_2O(\ell)$	
correct species	1
balancing	1
state symbols	1
Total	3

(b) Predict **all** visible changes that would be observed, if any, while the reactants are mixed together and afterwards. (3 marks)

Description	Marks
Any **three** of the following: • the blue solid disappears (dissolves/reacts) • a green precipitate/solid is produced • once the reaction is complete the solution is colourless • effervescence or bubbles formed	1–3
Total	3
Note: Accept colourless, odourless gas instead of effervescence Note: candidate must provide a minimum of three correct observations for full marks Note: do not accept 'clear' without reference to colour	

(c) Predict **two** observations that would be different if excess 0.100 mol L^{-1} hydrochloric acid was used instead of the 0.100 mol L^{-1} carbonic acid. (2 marks)

Description	Marks
$(Cu(OH)_2(s)$ + $2\,HC\ell(aq)$ → $CuC\ell_2(aq)$ + $2\,H_2O(\ell))$ Any **two** of the following: • no solid at all is produced • the solution would be blue once the reaction was complete • the reaction would occur faster • no gas produced	1–2
Total	2
Note: equation not required	

Question 26 (continued)

(d)   State **two** personal safety measures the experimenter should take when conducting
        these experiments.   (2 marks)

Description	Marks
Any **two** of the following: • wear safety glasses • wear closed in shoes • wear a laboratory coat • tie back long hair • wear a hair net • avoid coming in contact with the chemicals (e.g. wearing gloves) • avoid breathing any vapour • read materials data sheet	1–2
Total	**2**
Accept other relevant answers Note: Do not accept PPE Note: Do not accept actions taken in response to an accident	

Question 27 **(12 marks)**

(a) Write the ionisation equation for phosphoric acid in water which shows the **second** proton of the acid being released into solution. (2 marks)

Description	Marks
$H_2PO_4^-(aq)$ + $H_2O(\ell)$ $\rightleftharpoons$ $HPO_4^{2-}(aq)$ + $H_3O^+(aq)$	2
(one minor error)	(1)
Total	2
Note: State symbols not required Note: Minor errors could include no double arrow, one charge missing	

(b) Other than water, list **three** species (elements, compounds, ions) that would be found in the reacting vessel open to the atmosphere at the completion of the reaction between excess solid magnesium carbonate and an aqueous solution of phosphoric acid.

(3 marks)

Description	Marks
Only the first **three** species listed are marked. 1. magnesium carbonate, $MgCO_3(s)$ 2. magnesium phosphate, $Mg_3(PO_4)_2(s)$ 3. $H_2CO_3(aq)$ (from the reaction of CO_2 with H_2O) 4. $HCO_3^-(aq)$ (from the reaction of CO_2 with H_2O) 5. $CO_3^{2-}(aq)$ (from the reaction of CO_2 with H_2O) 6. $H_3O^+(aq)$ ions (from the self-ionisation of water) 7. OH^- (from the self-ionisation of water) 8. CO_2 9. $Mg^{2+}/PO_4^{3-}/HPO_4^{2-}/H_2PO_4^-/O_2$	1–3
Total	3
Note: the equation for the reaction is: $3\ MgCO_3(s)$ + $2\ H_3PO_4(aq)$ $\rightarrow$ $Mg_3(PO_4)_2(s)$ + $3\ H_2O(\ell)$ + $3\ CO_2\ (g)$ $MgCO_3$ is in excess so there is no H_3PO_4 left A small amount of carbon dioxide gas, $CO_2(g)$, will dissolve and react with water, H_2O, to form H_2CO_3 (which will form $HCO_3^-(aq)$ and $CO_3^{2-}(aq)$ ions). Note: Only mark the first three listed	

Question 27 (continued)

(c) Other than it having too low a molar mass, state **two** reasons why the concentration of the sodium hydroxide solution cannot be reliably determined by weighing out an amount of solid sodium hydroxide and dissolving it in a known volume of distilled water?

(2 marks)

Description	Marks
Any **two** of the following: • hygroscopic – it absorbs atmospheric moisture which changes the mass of the NaOH sample. • deliquescent – it dissolves in the water it absorbs, so no mass of solid can be weighed • absorbs atmospheric carbon dioxide gas, $CO_2(g)$ to form sodium carbonate, $Na_2CO_3(s)$, and water, $H_2O(\ell)$. • Not known purity (% purity not known)	1–2
Total	2
Note: Do not accept 'not available in pure form'	

(d) Select the acid-base indicator from the table above that would be most suitable for the titration between phosphoric acid, $H_3PO_4(aq)$, and sodium hydroxide solution, NaOH(aq). Justify your choice of indicator, including **one** relevant equation.

(5 marks)

Description	Marks
Phenolphthalein	
Recognition that PO_4^{3-} present in solution at equivalence point. ($3\,OH^-(aq)\ +\ H_3PO_4(aq)\ \rightarrow\ PO_4^{3-}(aq)\ +\ 3\,H_2O(\ell)$)	
The solution at the equivalence point will be (slightly) basic (with a pH of approximately 9) due to the excess of hydroxide ions	
The phosphate ion undergoes hydrolysis to form hydroxide ions. $PO_4^{3-}(aq)\ +\ H_2O(\ell)\ \rightleftharpoons\ HPO_4^{2-}(aq)\ +\ OH^-(aq)$	1–5
The pH at which the indicator changes colour approximates the pH of the equivalence point	
The Na^+ ion does not hydrolyse/has no effect on the pH of the solution/is a neutral ion	
Total	5
Note: candidate must give five valid points for full marks, and must include an equation. Note: no hydrolysis equation, maximum of four marks Note: If phenol red with explanation above, four maximum Alternative responses that candidate may provide: Methyl Orange The pH of the first equivalence point is around 4.7. If candidate identify this and supplied appropriate logic with equation, up to full marks may be awarded. If a candidate recognises that the third equivalence point is beyond the end point of phenolphthalein and explains why none of the indicators would be appropriate with sufficient reasoning, up to full marks may be awarded.	

Question 28 **(8 marks)**

(a) Write the half equation to show the reaction at the electrode at which oxidation occurs.

(3 marks)

Description	Marks
H_2 + CO_3^{2-} → CO_2 + H_2O + 2 e^-	
correct equation	3
correct species but not balanced	2
Balanced for incorrect species (equation must have merit)	1
Total	**3**

(b) Write the overall equation for the current-producing reaction. (3 marks)

Description	Marks
O_2 + 2 H^+ + 2 H_2 + CO_3^{2-} → 3 H_2O + CO_2 **or** 2 H_2 + O_2 → 2 H_2O	
correct equation	3
correct species but not balanced	2
Balanced for incorrect species (equation must have merit)	1
Total	**3**

(c) State **two** reasons why this fuel cell is a more environmentally-friendly alternative to the internal combustion engine. (2 marks)

Description	Marks

Any **two** statements giving an environmental advantage of the fuel cell:
• The carbon dioxide gas is recycled so that it doesn't enter the atmosphere (like the waste gases produced by an internal combustion engine)
• It uses (O_2 and CO_2) as its fuel sources these are all renewable can be obtained from the atmosphere (whereas the internal combustion engine uses non-renewable fossil fuels.)
• In addition to the production of carbon dioxide gas, the by-products of the:
    combustion engine include pollutant gases including the oxide gases of nitrogen and sulfur. These are significant contributors to acid rain.
    fuel cell is water.
• The process of obtaining (drilling for oil) the fuel for the combustion engine damages the surrounding environments and the refining process (fractional distillation) for this fuel produces its own atmospheric pollutants.
	1–2

Total	**2**

Question 29 **(15 marks)**

(a) Write an equation for the buffer system ($H_3C_6H_5O_7$ / $H_2C_6H_5O_7^-$) containing citric acid, $H_3C_6H_5O_7$ and monosodium citrate, $NaH_2C_6H_5O_7$. (2 marks)

Description	Marks
$H_3C_6H_5O_7(aq)$ + $H_2O(\ell)$ ⇌ $H_2C_6H_5O_7^-(aq)$ + $H_3O^+(aq)$ **or** $H_2C_6H_5O_7^-(aq)$ + $H_2O(\ell)$ ⇌ $H_3C_6H_5O_7(aq)$ + $OH^-(aq)$ (one minor error, include lack of double arrow)	2 (1)
Total	2
Note: State symbols are not required.	

(b) Calculate the mass of monosodium citrate, $NaH_2C_6H_5O_7$, that would need to be dissolved in 100.0 mL of distilled water to make the most effective buffer solution. (3 marks)

Description	Marks
To form most effective buffer c ($H_3C_6H_5O_7$) = c($H_2C_6H_5O_7^-$) = 0.200 mol L^{-1}	1
V ($H_2C_6H_5O_7^-$) = 100.0 mL c ($H_2C_6H_5O_7^-$) = 0.200 mol L^{1-} n ($H_2C_6H_5O_7^-$) = c.V = 0.200 x 0.100 = 0.0200 mol	1
m ($NaH_2C_6H_5O_7$) = n.M = 0.0200 x 214.106 = 4.28 g	1
Total	3

(c) If a citric acid buffer was prepared to a pH of 3.5, what would be the concentration of the hydroxide ion at 25.0 °C? (3 marks)

Description	Marks
pH = -log [H$^+$] -3.5 = log [H$^+$] [H$^+$] = 3.1622777 x 10^{-4} (or 10$^{-3.5}$)	1
So [OH$^-$] = 1 x10^{-14}/3.16 x 10^{-4}	1
= 3.16 x 10^{-11} mol L^{-1}	1
Total	3
Note: alternative answer pOH = 14 – 3.5 (1 mark) = 10.5 [OH$^-$] = 10$^{-10.5}$ (1 mark) = 3.16 x 10^{-11} mol L^{-1} (1 mark) (must express in this form for three marks)	

(d)   Explain why only a small change in pH is observed in this buffer solution when a small amount of sodium hydroxide solution is added, compared to adding a similar amount of sodium hydroxide solution to a system that is not a buffer solution. Your answer should refer to the buffer equilibrium in part (a).

(4 marks)

Description	Marks
The added OH^- ions are removed by reaction with citric acid ($H_3C_6H_5O_7(aq)$ + $OH^-(aq)$ → $H_2C_6H_5O_7^-(aq)$ + $H_2O(\ell)$)	1
This increases the concentration of citrate ion ($H_2C_6H_5O_7^-$) and decreases concentration of citric acid ($H_3C_6H_5O_7$) so the buffer equilibrium favours production of citric acid	1
This in turn reduces the concentration of H_3O^+ ions (This in turn increases concentration of OH^-)	1
Recognition that when OH^- is added to a non-buffer solution, there is no weak acid/species for it to react with and so contributes fully to pH change	1
Total	**4**

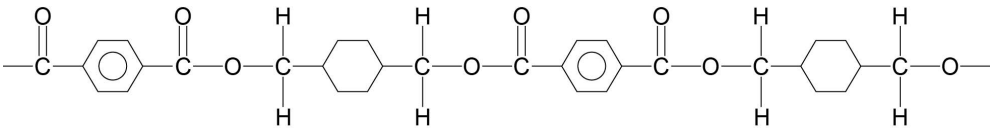| Alternative marking key for Question 29 (d)	
Description	**Marks**
$H_3C_6H_5O_7(aq)$ + $H_2O(\ell)$ ⇌ $H_2C_6H_5O_7^-(aq)$ + $H_3O^+(aq)$ The OH- reacts with the H_3O^+ and reduces its concentration	1
The reduction in H_3O^+ causes the equilibrium to shift to the right **or** The reduction of the H_3O^+ reduces the rate of the reverse reaction more than the forward reaction resulting in increase in the amount of H_3O^+ present when equilibrium is re-established. **or** Therefore, the forward reaction rate is greater relative to the reverse until equilibrium is re-established and the $[H_3O^+]$ increases again as the system adjusts.	1
As the concentration of H_3O^+ increases to close to before the addition of OH^-, there is minimal change in pH	1
Recognition that when OH^- is added to a non-buffer solution, there is no weak acid/species for it to react with and so contributes fully to pH change	1
Total	**4**

(e)   Increasing the concentration of this buffer solution will increase its buffering capacity. Explain this statement.   (3 marks)

Description	Marks
Recognition that increasing the concentration involves increasing the concentrations of both the citric acid and citrate ions.	1
The increased concentrations of **citric acid** and **citrate ions** will be able to react with more hydrogen ions, $H^+(aq)$, or hydroxide ions, $OH^-(aq)$, that are added to the system.	1
Therefore more acid or base could be added before there is significant change in the pH of the system	1
Total	**3**

Question 30 **(7 marks)**

(a) In the space below, draw the structural formula of PCTG, showing **two** repeating units. (2 marks)

Description	Marks
	2
(one minor error)	(1)
Total	**2**
Note: One complete unit maximum of one mark Minor errors include missing hydrogens, terminating, not including ring in benzene Incorrect or missing ester links is a major error, 0 marks	

(b) State the name or give the formula of the by-product of this polymerisation process. (1 mark)

Description	Marks
water **or** H_2O	1
Total	**1**

(c) Name **two** reagents that could be used to synthesise (C) from (B) in Step 3. (2 marks)

Description	Marks
• acidified (potassium/sodium) dichromate (solution) **and** acidified (potassium) permanganate (solution) **or** • sulfuric acid with either (potassium) permanganate solution **or** (potassium/sodium) dichromate solution	2
• (potassium/sodium) dichromate solution **and/or** • (potassium/sodium) permanganate solution	1
Total	**2**
Note: No acid mentioned, maximum of one mark	

(d) Write a balanced half equation to show (B) reacting to form (C). (2 marks)

Description	Marks
H_3C—⬡—CHO + H_2O → H_3C—⬡—$COOH$ + 2 H^+ + 2 e^-	2
(one minor error)	(1)
Total	**2**
Note: Accept molecular or condensed structures	

Question 31 **(6 marks)**

(a) Write the equilibrium constant expression for this reaction. (2 marks)

Description	Marks
$$K = \frac{[H_3AsO_4]^2 [O_2]^5}{[O_3]^5}$$	2
(one minor error)	(1)
Total	2
Note: Minor errors – not including K=, single transcription error	

(b) The arsenate ion, $HAsO_4^{2-}$(aq), is amphoteric, meaning it can act as an acid and as a base.

(i) With the aid of equations, describe the amphoteric nature of $HAsO_4^{2-}$ in this aqueous solution. (3 marks)

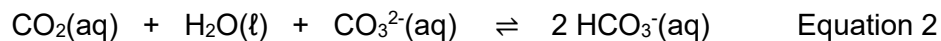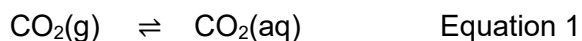| Description	Marks
Recognition that $HAsO_4^{2-}$ has the capacity to both gain and lose a proton **or** indicates which equation represents $HAsO_4^{2-}$ acting as an acid or acting as a base	1
Equation 1 $HAsO_4^{2-}$ + H_2O ⇌ $H_2AsO_4^-$ + OH^-	1
Equation 2 $HAsO_4^{2-}$ + H_2O ⇌ AsO_4^{3-} + H_3O^+	1
Total	3

(ii) State why an aqueous solution containing $HAsO_4^{2-}$ is found to have a pH>7 at 25 °C. (1 mark)

Description	Marks
Given the solution is basic, reaction 1 must occur to a greater extent than reaction 2. **or** The K value of reaction 1 in (i) is larger than the K value of reaction 2 in (ii).	1
Total	1

Question 32 **(4 marks)**

Use the following equations to explain why an increasing concentration of atmospheric carbon dioxide will decrease the formation of calcium carbonate.

$$CO_2(g) \rightleftharpoons CO_2(aq) \qquad \text{Equation 1}$$

$$CO_2(aq) + H_2O(\ell) + CO_3^{2-}(aq) \rightleftharpoons 2\,HCO_3^-(aq) \qquad \text{Equation 2}$$

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightleftharpoons CaCO_3(s) \qquad \text{Equation 3}$$

Description	Marks
• increased concentration of $CO_2(aq)$ shifts equilibrium forward (equation 2) • thus reducing $[CO_3^{2-}(aq)]$ • decreased CO_3^{2-} shifts equilibrium left in equation 3 • therefore the formation of $CaCO_3$ is decreased (equation 3)	1–4
Total	4

Question 33 **(11 marks)**

(a)   Given that the molecular formulas indicate that the compounds contain the same number of carbon atoms and differ only in the number of one or two hydrogen or oxygen atoms, propose an hypothesis for why there is a variation in the boiling points of these compounds.   (2 marks)

Description	Marks
A detailed statement based on the information available and other relevant knowledge that can be tested experimentally	2
A brief statement based on available information that can be tested experimentally	1
Total	**2**
Possible answers for two marks include: • Variation in boiling points can be accounted for by the different arrangements of the oxygen and hydrogen atoms (functional groups) attached to the carbon chain. • Increasing boiling points can be accounted for by increasing intermolecular forces which occur because of different arrangements of atoms/functional groups. • The boiling point is affected to a greater extent by the presence of one oxygen atom rather than the absence of two hydrogen atoms.	
Possible answers for one mark include: • Boiling points increase with increasing strength of intermolecular forces • Boiling points increase with increasing solubility	

(b)   Explain why these organic compounds have very different solubilities in water. (6 marks)

Description	Marks
The strength of the dispersion forces between butane and water is weak compared to the forces of attraction between butane molecules dispersion and water molecules dispersion, (dipole-dipole) and hydrogen bonding and so there is insufficient energy available to disrupt the butane-butane and water-water forces of attraction and so solubility is low.	1
The strength of the dispersion, dipole-dipole and hydrogen bonding between butanone and water is greater than the forces of attractions between the molecules in each substance, dispersion/dipole in butanone, and so sufficient energy is released during bond formation to disrupt more forces of attraction in the solute and solvent and so has higher solubility.	1–2
The strength of the forces of attractions between butan-1-ol and water, dispersion, dipole-dipole and hydrogen bonding, is greater than the forces of attractions between the molecules in each substance, dispersion, dipole-dipole and hydrogen bonding in butan-1-ol, and so sufficient energy is released, and dissolving occurs.	1–2
As there are more sites for hydrogen bonding between water and butan-1-ol, solubility will be greater than for butanone and water.	1
Total	**6**

Question 33 (continued)

Alternative marking key for Question 33 (b)	
Description	**Marks**
Recognition that dissolving occurs when the energy released during the forming of solute-solvent forces of attraction is sufficient to disrupt the solute-solute and solvent-solvent forces of attraction.	1
Recognition that force of attraction between water and butane are weak due to only dispersion forces and reference stronger dispersion and hydrogen bonding in water and so solubility is poor.	1
Recognition that there is hydrogen bonding, dispersion and dipole-dipole forces of attraction between butanone and water and are stronger than the forces of attraction between molecules in butanone and between molecules in water, and so dissolving occurs.	1–2
Recognition that there is hydrogen, dispersion and dipole-dipole forces of attraction between butan-1-ol and water and are stronger than the forces of attraction between the molecules in butan-1-ol and between the molecules in water and so dissolving occurs.	1
Recognition that there is more hydrogen bonding between butan-1-ol and water compared to butanone and water and so the solubility is higher	1
Total	**6**

(c) Complete the table below to describe a chemical test that could be used to distinguish between butan-1-ol and butanoic acid by stating the reagent/s used and the distinguishing observations. (3 marks)

Reagent used	acidified (potassium) permanganate (solution)	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	purple solution decolourises	no observable change
Note: accept H^+/MnO_4^-		

or

Reagent used	acidified (potassium) dichromate (solution)	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	orange solution turns green	no observable change
Note: accept $H^+/Cr_2O_7^{2-}$		

or

Reagent used	carbonate/hydrogencarbonate (salt) solution	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	no observable change	effervescence/bubbling
Note: accept $CO_3^{2-}(aq)$		

or

Reagent used	add an acidified alcohol – specify alcohol	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	no observable change	fruity odour detected

or

Reagent used	add an acidified carboxylic acid – specify acid	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	fruity odour detected	no observable change

or

Reagent used	magnesium	
Substance being tested	**Butan-1-ol**	**Butanoic acid**
Observation	No observable change	effervescence/bubbling

Description	Marks
reagent used	1
observation with butan-1-ol	1
observation with butanoic acid	1
Total	**3**
Accept other relevant answers	

Question 34 **(6 marks)**

For the molecular formula $C_6H_{12}O$ draw **two** different structural isomers, one which can be readily oxidised by acidified dichromate solution and one which cannot be readily oxidised by acidified dichromate solution. Show all atoms.

Isomer that **can** be readily oxidised by acidified dichromate solution.

Isomer that **cannot** be readily oxidised by acidified dichromate solution.

Description	Marks
Isomer which **can** be readily oxidised by acidified dichromate solution	
Readily oxidized isomer (aldehyde)	
correct functional group	1
correct structural formula given	1
all atoms shown correctly connected	1
Subtotal	3
Isomer which **cannot** be readily oxidised by acidified dichromate solution	
Isomer not oxidized (ketone) (2-hexanone)	
correct functional group	1
correct structural formula given	1
all atoms shown correctly connected	1
Subtotal	3
Total	6
Accept other relevant answers	

Section Three: Extended answer **40% (94 Marks)**

Question 35 **(16 marks)**

A chemical, commonly called iopromide (IOP), is used to enhance the images produced by a medical procedure called a CT scan. It contains carbon, hydrogen, iodine, nitrogen and oxygen, $C_vH_wI_xN_yO_z$.

Use the following information to determine the molecular formula of IOP.

- The molar mass of IOP is 791.102 gmol^{-1}.
- A 5.62 g sample of IOP contained 0.2986 g of nitrogen, N.
- A 3.54 g sample of IOP is fully combusted to produce;
    1.72 L of carbon dioxide gas, CO_2(g), at 125 °C and 155.3 kPa.
    0.967 g of water vapour, H_2O(g).
- All of the iodine contained in a 2.523 g sample of IOP is converted to iodide, I$^-$. This sample is then dissolved in water and excess lead(II) nitrate solution, $Pb(NO_3)_2$(aq), is added to precipitate the iodine as lead(II) iodide, PbI_2(s). This produced 2.21 g of lead(II) iodide.

Description	Marks
Carbon	
$V(CO_2)$ = 1.72 L T = 125 + 273.15 = 398.15 K P = 155.3 kPa	
PV = nRT 155.3 x 1.72 = n x 8.314 x 398.15	1
n(C) = $n(CO_2)$ = 0.08069 mol m(C) = 0.08069 x 12.01 = 0.9691 g	1
Percentage of C by mass in IOP = 0.9691/3.54 x 100 = 27.37 %	1
Hydrogen	
$m(H_2O)$ = 0.967 g $n(H_2O)$ = 0.967/18.016 = 0.05367 mol	1
n(H) = 2 x 0.053674511 = 0.1073 mol m(H) = 0.107349023 x 1.008 = 0.1082 g	1
Percentage of H by mass in IOP = 0.1082/3.54 x 100 = 3.05 %	1
Nitrogen	
Percentage of N by mass in IOP = 0.2986/5.62 x 100 = 5.313 %	1
Iodine	
$m(PbI_2)$ = 2.21 g $M(PbI_2)$ = 461 g mol^{-1}	1
$n(PbI_2)$ = 2.21 /461 = 4.793926247 x 10^{-3} mol n(I) = 2 x 4.793 x 10^{-3} = 0.009587 mol m(I) = 0.009587 x 126.9 = 1.216 g	1
Percentage of I by mass in IOP = 1.216 / 2.523 x 100 = 48.22 %	1
Oxygen (add all % to work out % oxygen)	
% oxygen = 100 – (27.37 % C + 3.056 % H + 5.313 % N + 48.22 % I)	1
= 100 - 83.97 = 16.03 %	1

Question 35 (continued)

	C	H	N	I	O	
%	27.37	3.056	5.313	48.22	16.03	
Moles	2.279	3.032	0.3792	0.3800	1.002	1
Mole ratio	6.0107	7.996	1	1	2.64	1
	x 3	x 3	x 3	x 3	x 3 = 7.92	
	18	24	3	3	8	1
this gives the formula as $C_{18}H_{24}I_3N_3O_8$						
the empirical formula mass (791.102 g mol^{-1}) is identical to the molar mass given so this is also the molecular formula mass (791.102 g mol^{-1}) molecular formula is $C_{18}H_{24}I_3N_3O_8$						1
					Total	**16**

Alternative marking key for Question 35 (for proportion method)	
Description	**Marks**
Carbon in 3.54g	
PV = nRT 155.3 x 1.72 = n x 8.314 x 398.15	1
n(C) = n(CO$_2$) = 0.08069 mol m(C) = 0.080694356 x 12.01 = 0.9691 g	1 1
Hydrogen in 3.54g	
m(H$_2$O) = 0.967 g n(H$_2$O) = 0.967/18.016 = 0.05367 mol	1
n(H) = 2 x 0.053674511 = 0.10735 mol m(H) = 0.107349023 x 1.008 = 0.1082 g	1 1
Nitrogen in 3.54g	
Mass N in 3.54g = 0.2986/5.62 x 3.54 = 0.1881 g	1
Iodine in 3.54g	
m(PbI$_2$) = 2.21 g M(PbI$_2$) = 461 g mol^{-1}	1
n(PbI$_2$) = 2.21 /461 = 4.793926247 x 10^{-3} mol n(I) = 2 x 4.793926247 x 10^{-3} = 9.588 x 10^{-3} mol m(I) = 9.588 x 10^{-3} x 126.9 = 1.217 g	1
Mass I in 3.54g = 1.217 / 2.523 x 3.54 = 1.707 g	1
Oxygen (add all mass to work out mass of oxygen)	
m oxygen = 3.54 – (m C + m H + m N + m I)	1
= 3.54 – 2.972 = 0.5675 g	1

	C	H	N	I	O	
mass	0.9691 g	0.1082 g	0.1881 g	1.7071 g	0.5675 g	
Moles	0.0807	0.1073	0.0134	0.01345	0.0355	1
Mole ratio	6	8.01	1	1	2.65	1
	x 3	x 3	x 3	x 3	x 3 = 7.92	
	18	24	3	3	8	1
this gives the formula as $C_{18}H_{24}I_3N_3O_8$						
the empirical formula mass (791.102 g mol^{-1}) is identical to the molar mass given so this is also the molecular formula mass (791.102 g mol^{-1}) molecular formula is $C_{18}H_{24}I_3N_3O_8$						1
					Total	**16**

Question 36 **(17 marks)**

(a) Outline the difference between random and systematic errors. Give an example of each that might be encountered in this investigation. (4 marks)

Description	Marks
Random errors are fluctuations in measured data due to limitations of the measurement device/technique, they occur unpredictably and to varying extents throughout the experiment. Non-directional effect on results.	1
Examples • concentration of heavy metals may vary at depth • judgement made by the sample collector about depth • different collectors at different sites	1
Systematic errors are repeatable errors that occur due to faulty equipment or poor experiment design, they occur consistently to the same extent throughout the experiment. Results are skewed in one direction.	1
Examples • faulty timer • concentration of the nitric acid may not be exactly the same as labelled • water bottles and whether or not 100 mL is marked accurately on them (glassware uncertainty).	1
Total	**4**

Water samples were collected from 59 of the 180 possible locations.

(b) (i) Calculate the sample size as a percentage of the testable locations. (1 mark)

Description	Marks
sample size = (59/180) x 100 = 32.8 %	1
Total	**1**

(ii) Propose **two** reasons why samples were not collected from all locations. (2 marks)

Description	Marks
• too expensive • too time consuming • accessibility • sample size deemed to be sufficient (statistical)	1–2
Total	**2**

Note: reason to be related to the context of the investigation

(iii) Predict the effect of using a smaller sample size on the reliability of the overall results. Justify your answer. (2 marks)

Description	Marks
Prediction: less reliable	1
Justification: • smaller sample size means less locations sampled which means less chance of collecting samples with the full range of heavy metal concentrations **or** • Increases the effect of random errors	1
Total	**2**

Question 36 (continued)

(c) Calculate the minimum mass of sodium phosphate needed to remove all the cadmium(II) ions from the water. Give your final answer to the appropriate number of significant figures. Assume that there are no species other than cadmium(II) ions present in the dam that will react with the phosphate ions. (8 marks)

Description	Marks
to ensure all $Cd^{2+}(aq)$ accounted for, use upper limit of error margin $c(Cd^{2+}(aq))$ = 0.5310 + 0.09100 = 0.6220 mg L^{-1}	1
Total amount of water: 1 123 000 000	
Total mass(Cd^{2+}) = 1 123 000 000 x 0.6220 = 698 506 000 mg = 698 506 g	1
Total n(Cd^{2+}) = m/M = 698 506/112.4 g mol^{-1} = 6214.46 mol	1
$3Cd^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Cd_3(PO_4)_2(s)$ $3Cd^{2+} : 2PO_4^{3-}$	1
$n(Na_3PO_4)$ = (2/3) x 6214.46 = 4142.97 moles of phosphate	1
add Na_3PO_4 hence: $n(Na_3PO_4)$ = 4142.97 $M(Na_3PO_4)$ = 163.94 $m(Na_3PO_4)$ = 4142.97 x 163.94	1
= 679 198.501 g = 6.792 x 10^5 g	1
answer to four significant figures	1
Total	8

Question 37 **(12 marks)**

(a) Explain the effect of temperature on reaction rate by applying collision theory. Support your explanation with an appropriate and clearly-labelled diagram. (7 marks)

Description	Marks
• increased temperature increases the average kinetic energy of the particles	1
• thus more particles have energy higher than the E_A (or clearly annotated on diagram)	1
• therefore, a greater **proportion** of the collisions are successful	1
• the particles are also moving faster so collide **more** frequently	1
• therefore the overall rate of reaction is higher	1
Clearly labelled diagram as below: (Boltzmann diagram) For copyright reasons this image cannot be reproduced in the online version of this document, but may be viewed at https://blogs.glowscotland.org.uk/gc/hchemunit/files/2015/06/Picture27.png	1–2
Total	**7**

Question 37 (continued)

This graph shows how the amount of gallium extracted from red mud varies over time at a hydrochloric acid concentration of 1.00 mol L^{-1}.
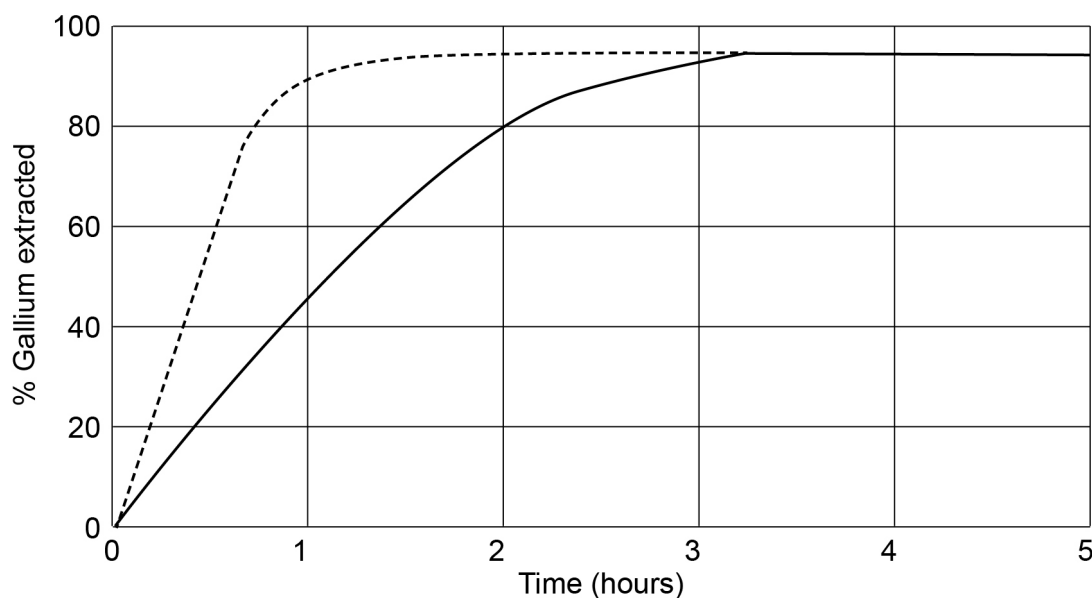
(b)   Sketch on the graph above the result that would be obtained if the hydrochloric acid concentration was changed to 2.00 mol L^{-1}.   (2 marks)

Description	Marks
Line drawn clearly with steeper slope	1
Line drawn clearly reaching same plateau/horizontal earlier	1
Total	2

(c)   Use collision theory to justify the position and shape of the graph you sketched in part (b). Assume that all other reaction conditions were kept constant.   (2 marks)

Description	Marks
• higher concentration means (more particles present in the same volume hence) greater **frequency** of collisions therefore the rate of reaction increases (hence the steeper slope for 2.00 mol L^{-1} HCℓ)	1
• the faster reaction rate explains why the reaction is finished faster (reaches a plateau)	1
Total	2

(d)   State **one** reason why the hydrochloric acid used in this analysis needed to be in excess.   (1 mark)

Description	Marks
Any **one** of the following: • to ensure that all of the gallium was extracted from the red mud • so it doesn't limit the reaction • so all of the gallium(III) oxide reacts • to ensure maximum gallium yield	1
Total	1

Question 38 **(18 marks)**

(a) With reference to rates of reaction, equilibrium and economic considerations, explain why the above conditions are considered optimal for the Sabatier reaction. In your response, address any compromises in conditions. (7 marks)

Description	Marks
Temperature • high temperature gives a fast rate of reaction • reaction is exothermic so a low temperature increases the product yield • so temperature conditions to maximise rate and yield are opposite therefore a compromise is needed. • hence the moderate temperature of (300 – 400 °C) that is used	1–3
Pressure • high pressure increases the rate of the reaction • in this reaction high pressure increases the product yield	1–2
Economics • using high temperatures and pressures increases the operating costs (high energy requirements, cost of specialised equipment)	1
• use of catalyst which increases the reaction rate, means lower pressures and temperatures can be used to achieve reasonable reaction rates, improving the economics of the process	1
Total	**7**

(b) Predict the effect of each of the following changes on the methane yield in the Sabatier reaction. (5 marks)

Description		Marks
• a suitable catalyst is added	no effect	1
• the volume of the reaction vessel is increased	decrease	1
• the temperature is increased	decrease	1
• methane is removed through a special valve as soon as it forms	increase	1
• the partial pressure of carbon dioxide is decreased	decrease	1
	Total	**5**

Imposed change	Effect on methane yield (circle your answer)		
a suitable catalyst is added	increase	decrease	(no effect)
the volume of the reaction vessel is increased	increase	(decrease)	no effect
the temperature is increased	increase	(decrease)	no effect
methane is removed through a special valve as soon as it forms	(increase)	decrease	no effect
the partial pressure of carbon dioxide is decreased	increase	(decrease)	no effect

Question 38 (continued)

Graphs can be drawn to show the effects of imposed changes on equilibrium systems. The graph below shows the effects of some changes that might be made to the reacting system in a flexible vessel.
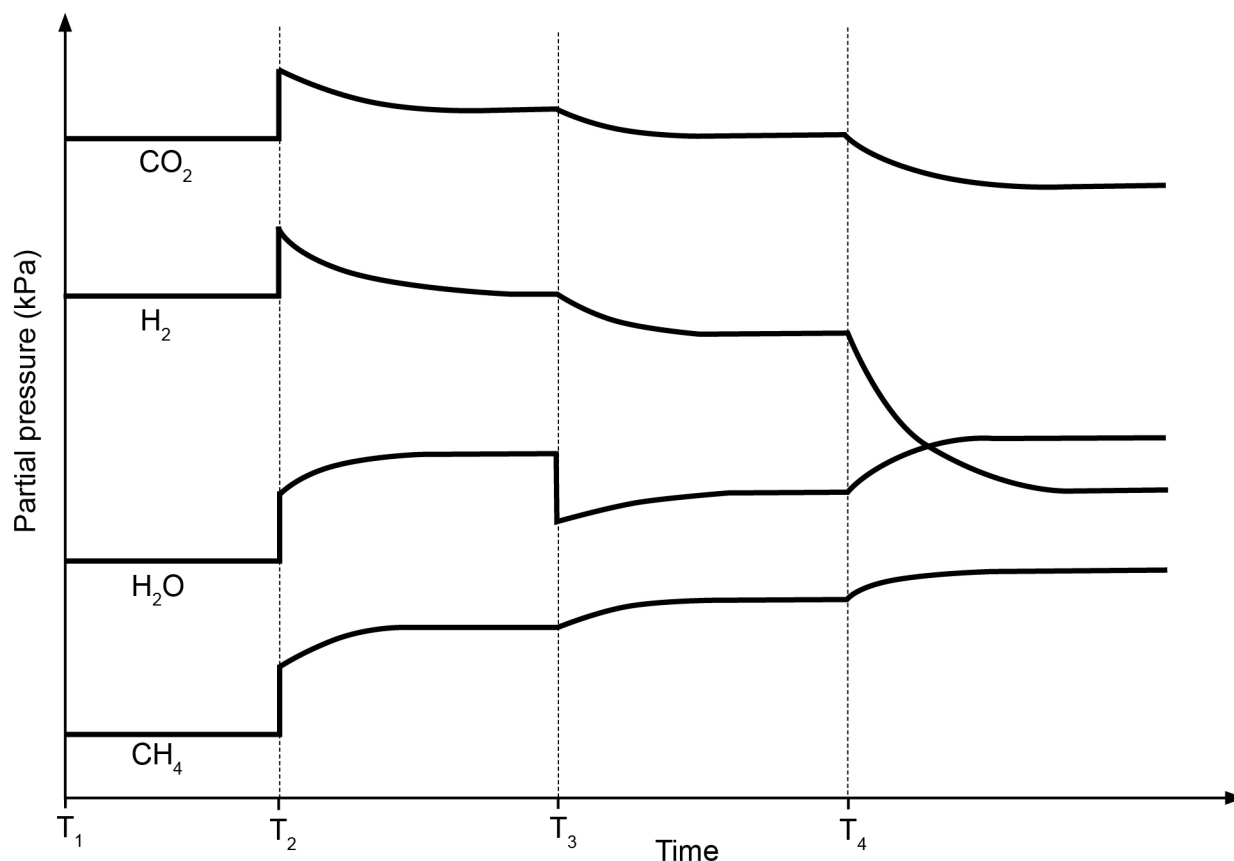
(c)   With reference to the above graph, answer the following questions.

(i)   What happened at T_1?   (1 mark)

Description	Marks
Any **one** of the following: • the system has reached equilibrium • addition of a catalyst • no change	1
Total	**1**

(ii)   Identify the change imposed at each time in the table below.   (2 marks)

Description	Marks
T_2: the volume of the reaction vessel is decreased (Accept: Pump in same number of moles of each reactant at the same time)	1
T_3: some H_2O was **removed** from the reaction vessel	1
Total	**2**
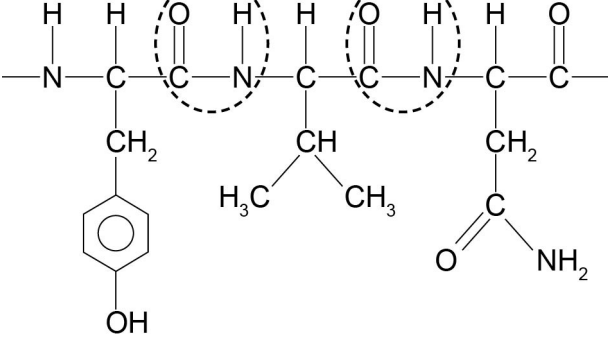
(iii) The temperature of the reaction vessel was decreased at T_4. Sketch on the graph above to show how this affected the partial pressures of all species present. Include any changes to scale and continue until a new equilibrium is established. (3 marks)

Description	Marks
CO_2 and H_2 curve down	1
CH_4 and H_2O curve up	1
H_2 changes 4x as much as CO_2 and H_2O changes 2x as much as CH_4	1
Total	**3**
Note: focus on whether lines represent increase or decrease (and by what factor)	
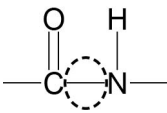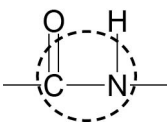
Question 39 **(14 marks)**

(a) Draw the full structural formula of this section of the reflectin. Show all hydrogen atoms.

(3 marks)

Description	Marks
Note: ⬭ circles relate to part (b)	
correct structure (peptide bonds and order correct)	3
terminated structure drawn **or** amino acids structures are correct but drawn in an incorrect order	2
peptide links correct but rest of structure incorrect	1
Total	3

(b) Circle **one** peptide bond in the structure that you drew in part (a). (1 mark)

Description	Marks
correctly circled on diagram as below	1
Total	1
Note other acceptable alternatives as shown in diagram above in (a) or as follows:	

(c)   Draw the full structural formula of leucine, Leu, in each of the conditions specified below. Show all hydrogen atoms. (4 marks)

Description	Marks

Low pH (acidic)
 	
$H_3N^+ - CH - C \begin{smallmatrix} O \\ OH \end{smallmatrix}$
          CH_2
          $CH - CH_3$
          CH_3
	2

(one minor error)	(1)
Subtotal	**2**

High pH (basic)
 	
$H_2N - CH - C \begin{smallmatrix} O \\ O^- \end{smallmatrix}$
          CH_2
          $CH - CH_3$
          CH_3
	2

(one minor error)	(1)
Subtotal	**2**
Total	**4**

(d)   Explain why the structure of Leu is pH dependent. (3 marks)

Description	Marks
at neutral pH (it exists as zwitterion) and has NH_3^+ and COO^-	1
amine group (is basic and so) is protonated at low (acidic) pH	1
carboxylic acid group (is acidic and so) is deprotonated at high (basic) pH	1
Total	**3**

Alternative marking key for Question 39 (d) if considered as zwitterion (name not required)	
Description	**Marks**
Neutral pH contains NH_3^+ and COO^- groups	1
NH_3^+ (is acidic and) is deprotonated at high pH	1
COO^- (is basic and) is protonated at low pH	1
Total	**3**

Question 39 (continued)

(e)   Identify the pair **most** strongly attracted to each other. Justify your choice.   (3 marks)

Description	Marks
Cys and Cys (this can be demonstrated by circling the diagram)	1
Cys and Cys have disulfide bridges/bonds which are **covalent**. The disulfide bridges/bonds are much stronger than the other forces of attraction (intermolecular forces) present between the other pairs.	1–2
Total	**3**

Question 40 **(17 marks)**

The molar mass of salicylic acid is 138.121 g mol^{-1}.
The molar mass of aspirin is 180.158 g mol^{-1}.
This reaction is an equilibrium reaction with a K value of approximately 5.

(a)   In the synthesis of aspirin, 45.0 g of salicylic acid was reacted with excess acetic anhydride. This produced 50.2 g of aspirin. What was the percentage yield of this reaction?   (4 marks)

Description		Marks
n(aspirin) = n(salicylic acid) = 45/138.121 = 0.3258 mol		1
m(aspirin) = 0.3258 × 180.158 = 58.695 g		1
% yield = 50.2/58.695 × 100		1
= 85.5%		1
	Total	4

(b)   Complete the equation for the reaction between salicylic acid and sodium hydroxide solution.   (2 marks)

Description	Marks
+ OH$^-$(aq) → + H$_2$O(ℓ)	2
(one minor error)	(1)
Total	2

(c)   Calculate the mass of salicylic acid in the sample and therefore the percentage purity of the sample.   (5 marks)

Description		Marks
n (OH$^-$) in 20.00 mL = 0.0966 x 0.01845 = 1.78 x 10^{-3} mol		1
= n(acid in 20.00 mL)		1
n (acid in 250 mL) = 250/20 x 1.78 x 10^{-3} = 2.23 x 10^{-2} mol		1
m (acid) = 138.121 x (2.23 x 10^{-2}) = 3.08 g		1
% purity = (3.08/3.55) x 100 = 86.7%		1
	Total	5

Question 40 (continued)

(d) Identify **two** incorrect procedures from the list above, select the effect on the calculated concentration of salicylic acid and give the reason for the effect. (6 marks)

Description		Marks
Number	3	1
Effect	decrease	1
Explanation	there will be a lower titre of NaOH	1
	Subtotal	3
Number	4	1
Effect	decrease	1
Explanation	the acid will be diluted in the pipette due to residual water from rinsing	1
	Subtotal	3
	Total	6
Note: If Number 6 identified as an error, the explanation must be appropriated for the effect identified.		

ACKNOWLEDGEMENTS