

IB ALL HL P2 REVISION BOOK

HIGHER LEVEL

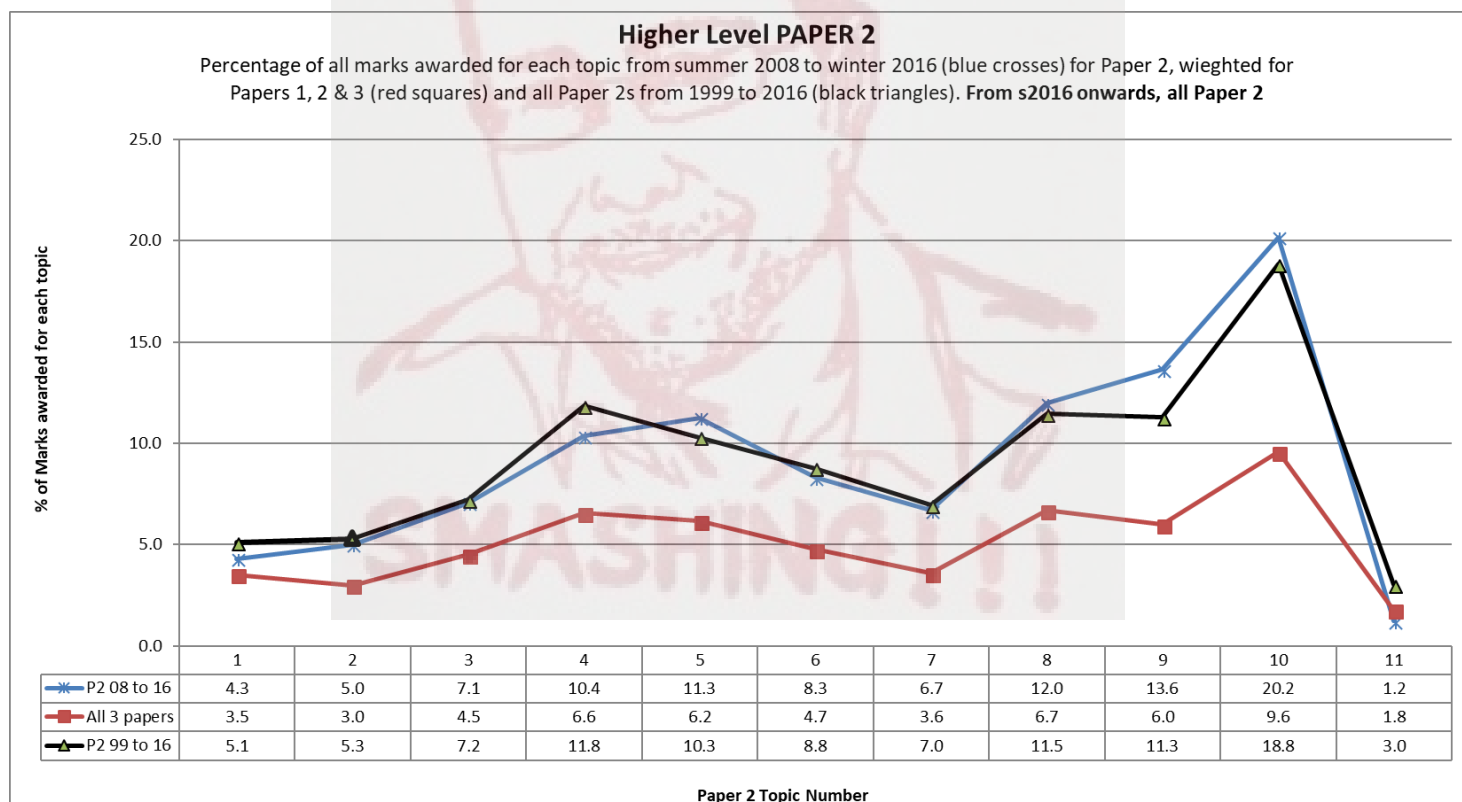
1165marks

Paper 2

2019 to 2015 inclusive (DRAFT)

Missing 17w, 2019sTZ1, 2019sTZ2

All Higher Level topics have been combined with their respective Standard Level equivalent, so in HL topic 2 revision resources there will be topics 2 and 12.



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Missing 17w, 2019sTZ1, 2019sTZ21

All topics ranked according to their impact on your final grade using exam papers from 1999 to 20163

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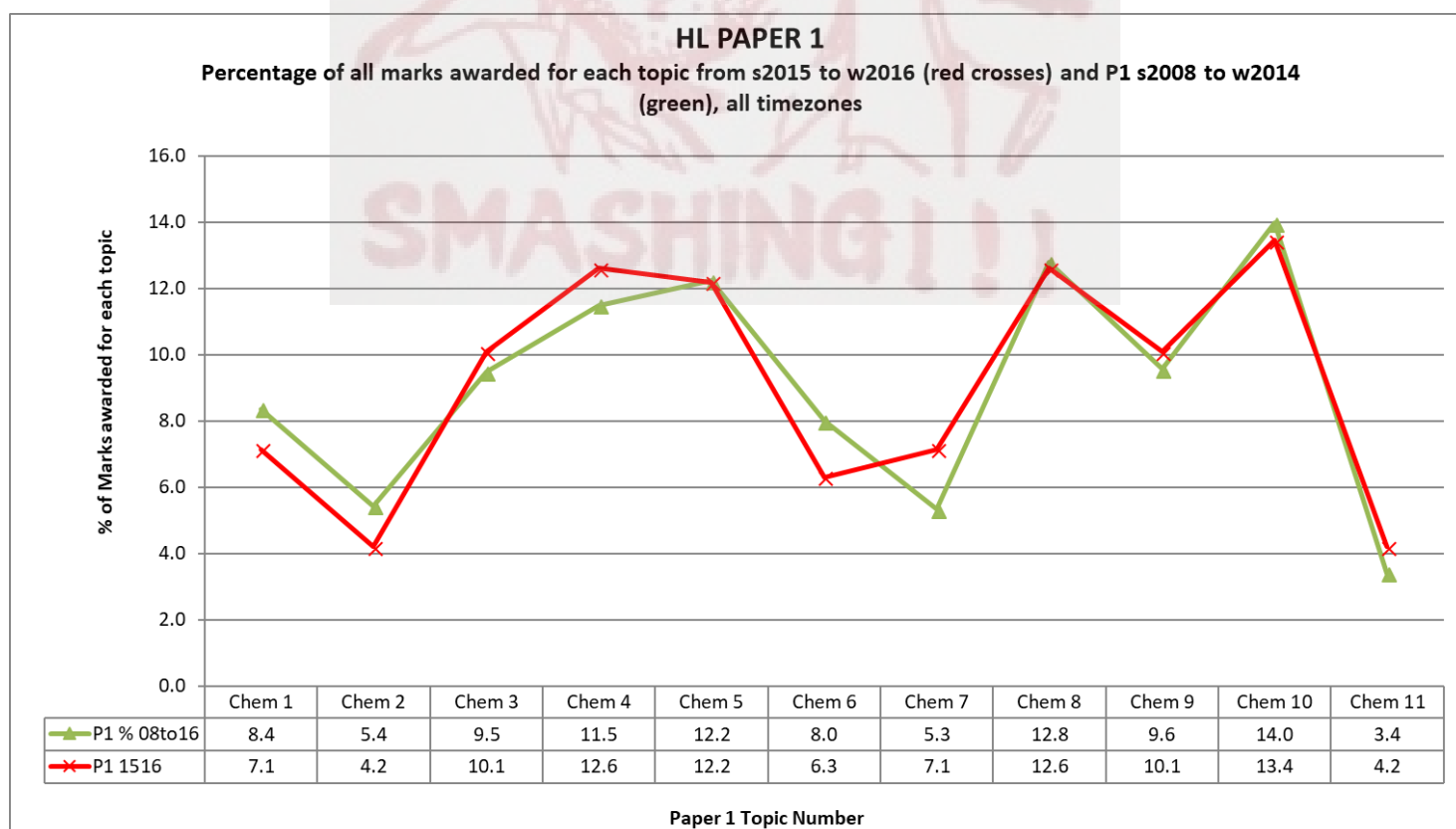
Topic Chem 223

Patrick Brannac

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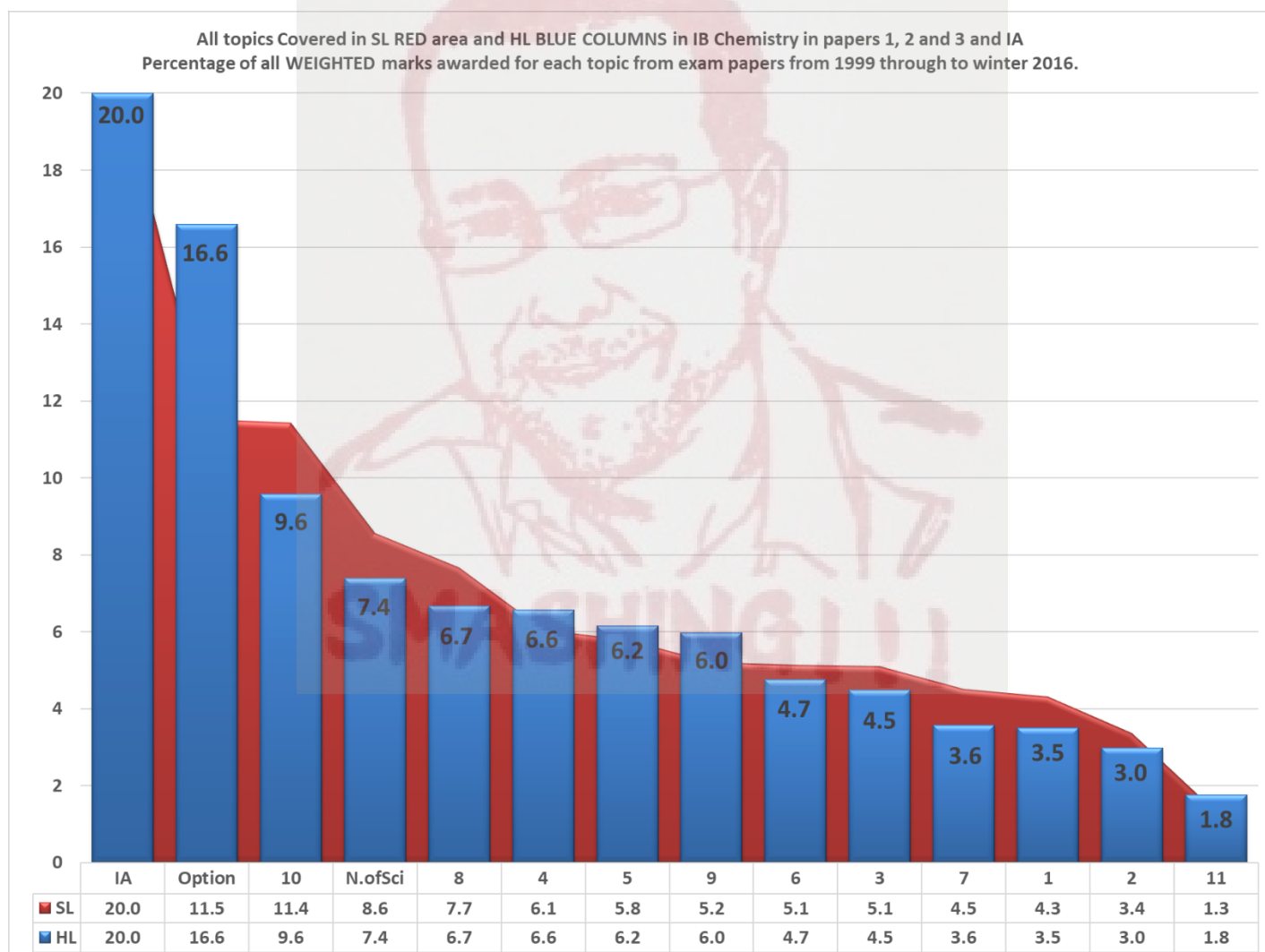
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All topics ranked according to their impact on your final grade using exam papers from 1999 to 2016

Topic	Option	10	N.ofSci	8	4	5	9	6	1	3	7	2	11
Rank	1	2	3	4	5	6	7	8	9	10	11	12	14
% of IB Grade	16.6	8.4	7.4	6.5	6.3	6.3	5.8	5.0	4.1	4.0	3.1	2.5	1.8
Paper 1		14.0		12.8	11.5	12.2	9.6	8.0	8.4	9.3	3.7	4.7	3.4
Paper 2 A		11.1		9.2	9.3	12.3	9.5	11.9	11.8	6.3	6.1	6.0	3.2
Paper 2 B		20.0		12.6	13.2	9.1	12.2	6.9	1.6	5.8	6.9	2.9	2.9
Paper 2 ALL		15.6		10.9	11.2	10.7	10.8	9.4	6.7	6.1	6.5	4.5	3.1
Paper 3	69.2		30.8										

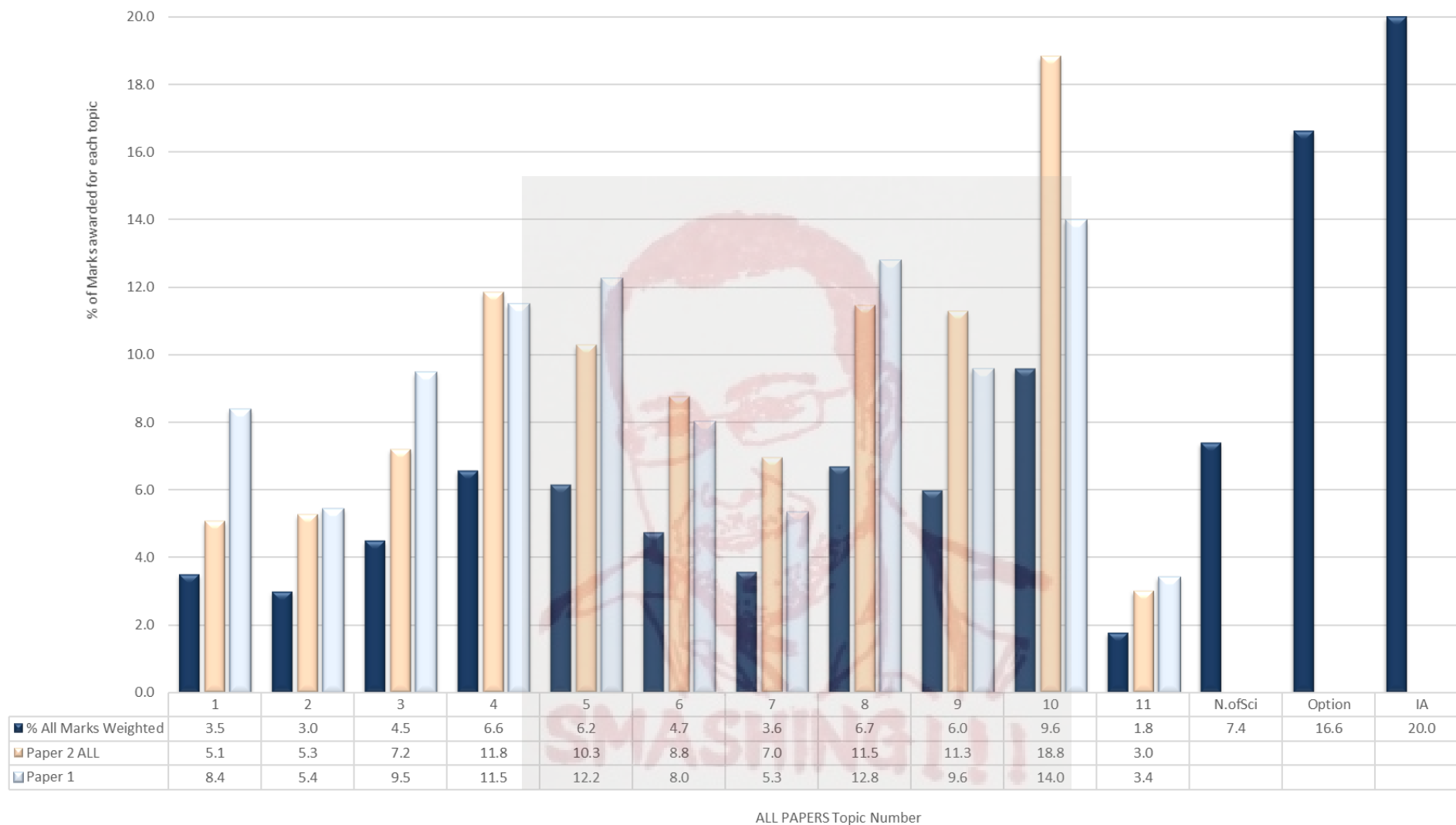
Standard and Higher Level components compared



Essentially, IA has the exact same weight, the Option in HL is almost 50% more important than in SL but Topic 10 is more important in SL than HL. All other topics contribute almost equally to a SL and HL grade.



All topics Covered in HIGHER Level Chemistry in papers 1, 2 and 3
Percentage of all WEIGHTED marks awarded for each topic from exam papers from 1999 through to winter 2016.



The dark blue bars are where your final IB grade will be from:

1. Your IA is the single most important part of your IB HL, more important than even the Option. Imagine how much time in class, at home and in revision you have or will give to topics 9, 10 and 11. **Your IA, on average, will be worth more to your final grade than all those combined.**
2. The Option is the most important topic for your IB grade compared to the everything else
3. Topic 10, Organic Chemistry, is by far the most important topic for papers 1 and 2.



7. Automobile air bags inflate by a rapid decomposition reaction. One typical compound used is guanidinium nitrate, $\text{C}(\text{NH}_2)_3\text{NO}_3$, which decomposes very rapidly to form nitrogen, water vapour and carbon.

(a) (i) Deduce the equation for the decomposition of guanidinium nitrate.

[1]

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(ii) Calculate the total number of moles of gas produced from the decomposition of 10.0g of guanidinium nitrate.

[1]

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(iii) Calculate the pressure, in kPa, of this gas in a 10.0 dm^3 air bag at 127°C , assuming no gas escapes.

[1]

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(iv) Suggest why water vapour deviates significantly from ideal behaviour when the gases are cooled, while nitrogen does not.

[2]

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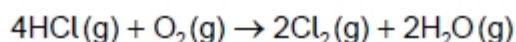
(b) Another airbag reactant produces nitrogen gas and sodium.

Suggest, including an equation, why the products of this reactant present a safety hazard. [2]

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6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

- (ii) Copper(II) chloride is used as a catalyst in the production of chlorine from hydrogen chloride.



- (b) Solid copper(II) chloride absorbs moisture from the atmosphere to form a hydrate of formula $\text{CuCl}_2 \cdot x\text{H}_2\text{O}$.

A student heated a sample of hydrated copper(II) chloride, in order to determine the value of x . The following results were obtained:

Mass of crucible = 16.221 g

Initial mass of crucible and hydrated copper(II) chloride = 18.360 g

Final mass of crucible and anhydrous copper(II) chloride = 17.917 g

Determine the value of x .

[3]

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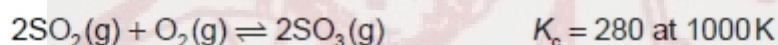
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5. This reaction is used in the manufacture of sulfuric acid.



- (a) State why this equilibrium reaction is considered homogeneous.

[1]

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2. An organic compound containing carbon, hydrogen and oxygen has 62.02 % carbon and 10.43 % hydrogen by mass.

(a) Determine the empirical formula of the compound, showing your working. [3]

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1. 3.26 g of iron powder are added to 80.0 cm³ of 0.200 mol dm⁻³ copper(II) sulfate solution. The following reaction occurs:



(a) (i) Determine the limiting reactant showing your working. [2]

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(ii) The mass of copper obtained experimentally was 0.872 g. Calculate the percentage yield of copper. [2]

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1. A student determined the percentage of the active ingredient magnesium hydroxide, $\text{Mg}(\text{OH})_2$, in a 1.24 g antacid tablet.

The antacid tablet was added to 50.00 cm^3 of $0.100 \text{ mol dm}^{-3}$ sulfuric acid, which was in excess.

- (a) Calculate the amount, in mol, of H_2SO_4 . [1]

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- (b) Formulate the equation for the reaction of H_2SO_4 with $\text{Mg}(\text{OH})_2$. [1]

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- (c) The excess sulfuric acid required 20.80 cm^3 of $0.1133 \text{ mol dm}^{-3}$ NaOH for neutralization.

Calculate the amount of excess acid present. [1]

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- (d) Calculate the amount of H_2SO_4 that reacted with $\text{Mg}(\text{OH})_2$. [1]

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(e) Determine the mass of $\text{Mg}(\text{OH})_2$ in the antacid tablet.

[2]

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(f) Calculate the percentage by mass of magnesium hydroxide in the 1.24 g antacid tablet to three significant figures.

[1]

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Topic **Chem 1 Q# 7** / IB Chem/2018/s/TZ 1/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

1. Urea, $(\text{H}_2\text{N})_2\text{CO}$, is excreted by mammals and can be used as a fertilizer.

(a) (i) Calculate the percentage by mass of nitrogen in urea to two decimal places using section 6 of the data booklet.

[2]

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(ii) Suggest how the percentage of nitrogen affects the cost of transport of fertilizers giving a reason.

[1]

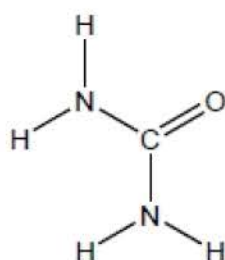
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- (b) The structural formula of urea is shown.



- (c) Urea can be made by reacting potassium cyanate, KNCO , with ammonium chloride, NH_4Cl .



Determine the maximum mass of urea that could be formed from 50.0 cm^3 of 0.100 mol dm^{-3} potassium cyanate solution.

[2]

- (f) The combustion of urea produces water, carbon dioxide and nitrogen.

Formulate a balanced equation for the reaction.

[2]

- (g) Calculate the maximum volume of CO_2 , in cm^3 , produced at STP by the combustion of 0.600 g of urea, using sections 2 and 6 of the data booklet.

[1]

2. (a) An acidic sample of a waste solution containing $\text{Sn}^{2+}(\text{aq})$ reacted completely with $\text{K}_2\text{Cr}_2\text{O}_7$ solution to form $\text{Sn}^{4+}(\text{aq})$.

(iii) 13.239 g of $\text{K}_2\text{Cr}_2\text{O}_7(\text{s})$ were dissolved in distilled water to form a 0.100 dm^3 solution. Calculate its molar concentration. [1]

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(iv) 10.0 cm^3 of the waste sample required 13.24 cm^3 of the $\text{K}_2\text{Cr}_2\text{O}_7$ solution. Calculate the molar concentration of $\text{Sn}^{2+}(\text{aq})$ in the waste sample. [2]

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1. There are many oxides of silver with the formula Ag_xO_y . All of them decompose into their elements when heated strongly.

(a) (i) After heating 3.760 g of a silver oxide 3.275 g of silver remained. Determine the empirical formula of Ag_xO_y . [2]

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(ii) Suggest why the final mass of solid obtained by heating 3.760 g of Ag_xO_y may be greater than 3.275 g giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

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- (b) Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag .

The relative atomic mass of silver is 107.87. Show that isotope ^{107}Ag is more abundant.

[1]

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- (d) Outline the model of electron configuration deduced from the hydrogen line emission spectrum (Bohr's model).

[2]

- (c) (i) One possible product, X, of the reaction of ethane with chlorine has the following composition by mass:

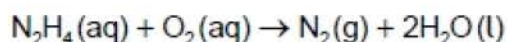
carbon: 24.27%, hydrogen: 4.08%, chlorine: 71.65%

Determine the empirical formula of the product.

[2]

[illegible]

- (h) Hydrazine is used to remove oxygen from water used to generate steam or hot water.



The concentration of dissolved oxygen in a sample of water is $8.0 \times 10^{-3} \text{ g dm}^{-3}$.

- (i) Calculate, showing your working, the mass of hydrazine needed to remove all the dissolved oxygen from 1000 dm^3 of the sample. [3]

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- (ii) Calculate the volume, in dm^3 , of nitrogen formed under SATP conditions.
(The volume of 1 mol of gas = 24.8 dm^3 at SATP.) [1]

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Topic Chem 1 Q# 13/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q2d

2. Titanium and vanadium are consecutive elements in the first transition metal series.

- (h) TiCl_4 reacts with water and the resulting titanium(IV) oxide can be used as a smoke screen.

- (i) Formulate an equation for this reaction. [2]

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- (ii) Suggest **one** disadvantage of using this smoke in an enclosed space. [1]

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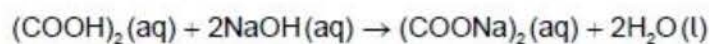
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Topic Chem 1 Q# 14/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/zzzz

2. The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined by titration with a standard solution of sodium hydroxide, $\text{NaOH}(\text{aq})$.



- (c) 5.00 g of an impure sample of hydrated ethanedioic acid, $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a $0.100 \text{ mol dm}^{-3}$ solution of sodium hydroxide using a suitable indicator.



The mean value of the titre was 14.0 cm^3 .

- (ii) Calculate the amount, in mol, of NaOH in 14.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ solution. [1]

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- (iii) Calculate the amount, in mol, of ethanedioic acid in each 25.0 cm^3 sample. [1]

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- (iv) Determine the percentage purity of the hydrated ethanedioic acid sample. [3]

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(b) Bute, a painkiller used on horses, has caused widespread concern recently because analytical tests showed that it entered the food chain through horse meat labelled as beef. The drug is suspected of causing cancer.

- (i) Analysis of a sample of bute carried out in a food safety laboratory gave the following elemental percentage compositions by mass:

Element	Percentage
C	73.99
H	6.55
N	9.09
O	Remainder

Calculate the empirical formula of bute, showing your working.

[3]

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- (ii) The molar mass, M , of bute, is $308.37 \text{ g mol}^{-1}$. Calculate the molecular formula.

[1]

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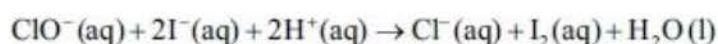


1. Two IB students carried out a project on the chemistry of bleach.

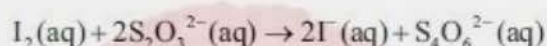
- (a) The bleach contained a solution of sodium hypochlorite, NaClO(aq) . The students determined experimentally the concentration of hypochlorite ions, ClO^- , in the bleach:

Experimental procedure:

- The bleach solution was first diluted by adding 25.00 cm^3 of the bleach to a 250 cm^3 volumetric flask. The solution was filled to the graduation mark with deionized water.
- 25.00 cm^3 of this solution was then reacted with excess iodide in acid.



- The iodine formed was titrated with $0.100 \text{ mol dm}^{-3}$ sodium thiosulfate solution, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$, using starch indicator.



The following data were recorded for the titration:

	First titre	Second titre	Third titre
Final burette reading of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ (in $\text{cm}^3 \pm 0.05$)	23.95	46.00	22.15
Initial burette reading of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ (in $\text{cm}^3 \pm 0.05$)	0.00	23.95	0.00

- (i) Calculate the volume, in cm^3 , of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ required to react with the iodine to reach the end point. [1]

SMASHING!!!



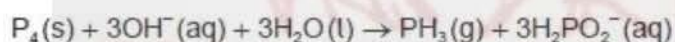
- (ii) Calculate the amount, in mol, of $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ that reacts with the iodine. [1]

- (iii) Calculate the concentration, in mol dm^{-3} , of hypochlorite ions in the **diluted** bleach solution. [1]

- (iv) Calculate the concentration, in mol dm^{-3} , of hypochlorite ions in the **undiluted** bleach solution. [1]

Topic **Chem 1 Q# 17**/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

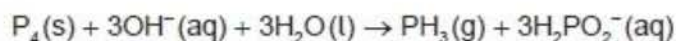
1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 .
- (b) Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium hydroxide. The equation for the reaction is:



- (i) The first reagent is written as P_4 , not 4P . Describe the difference between P_4 and 4P . [1]



(c) 2.478 g of white phosphorus was used to make phosphine according to the equation:



- (i) Calculate the amount, in mol, of white phosphorus used. [1]

- (ii) This phosphorus was reacted with 100.0 cm³ of 5.00 mol dm⁻³ aqueous sodium hydroxide. Deduce, showing your working, which was the limiting reagent. [1]

- (iii) Determine the excess amount, in mol, of the other reagent. [1]

- (iv) Determine the volume of phosphine, measured in cm³ at standard temperature and pressure, that was produced. [1]

- (d) Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.



1 Mole of Phosphine was completely combusted in air./ www.SmashingScience.org :o)

- (ii) The oxide formed in the reaction with air contains 43.6% phosphorus by mass. Determine the empirical formula of the oxide, showing your method. [3]

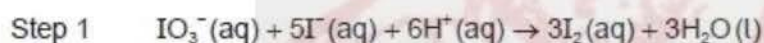
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- (iii) The molar mass of the oxide is approximately 285 g mol^{-1} . Determine the molecular formula of the oxide. [1]

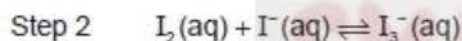
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Topic Chem 1 Q# 18/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

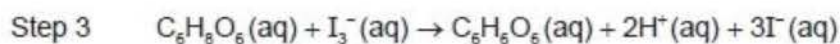
1. A student used the technique of titration to determine the concentration of ascorbic acid ($\text{C}_6\text{H}_8\text{O}_6$) in a sample of orange juice. Excess potassium iodide, $\text{KI}(\text{aq})$, was added to acidified orange juice. The resulting solution was titrated with potassium iodate, $\text{KIO}_3(\text{aq})$, in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.



Iodine is only slightly soluble in water, but in the presence of excess iodide ions, $\text{I}^-(\text{aq})$, it forms the soluble tri-iodide ion, $\text{I}_3^-(\text{aq})$.



Ascorbic acid reacts with tri-iodide ions as follows.



- (b) Calculate the mass, in g, of potassium iodate, $\text{KIO}_3(\text{s})$, which was required to prepare 0.250 dm^3 of a $2.00 \times 10^{-3} \text{ mol dm}^{-3}$ solution. [2]

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- (c) The concentration of KIO_3 used in the titration was $2.00 \times 10^{-3} \text{ mol dm}^{-3}$. The titration produced the following results.

	Titration 1	Titration 2	Titration 3
Final volume of $\text{KIO}_3 (\pm 0.05 \text{ cm}^3)$	7.10	14.40	21.60
Initial volume of $\text{KIO}_3 (\pm 0.05 \text{ cm}^3)$	0.00	7.10	14.40
Volume added of $\text{KIO}_3 (\pm 0.10 \text{ cm}^3)$	7.10	7.30	7.20
Mean volume added of $\text{KIO}_3 (\pm 0.10 \text{ cm}^3)$	7.20		

- (iii) Determine the amount, in mol, of $\text{KIO}_3(\text{aq})$, in the mean volume. [1]

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- (d) Determine the amount, in mol, of ascorbic acid, $\text{C}_6\text{H}_8\text{O}_6(\text{aq})$, in the sample of acidified orange juice. [2]

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- (e) Calculate the mass, in g, of ascorbic acid, $\text{C}_6\text{H}_8\text{O}_6(\text{aq})$, present in the sample of acidified orange juice. [1]

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1. Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, $\text{HOOC}-\text{COOH} \cdot x\text{H}_2\text{O}$, by titrating a known mass of the acid with a $0.100 \text{ mol dm}^{-3}$ solution of $\text{NaOH}(\text{aq})$.

0.795 g of ethanedioic acid was dissolved in distilled water and made up to a total volume of 250 cm^3 in a volumetric flask.

25 cm^3 of this ethanedioic acid solution was pipetted into a flask and titrated against aqueous sodium hydroxide using phenolphthalein as an indicator.

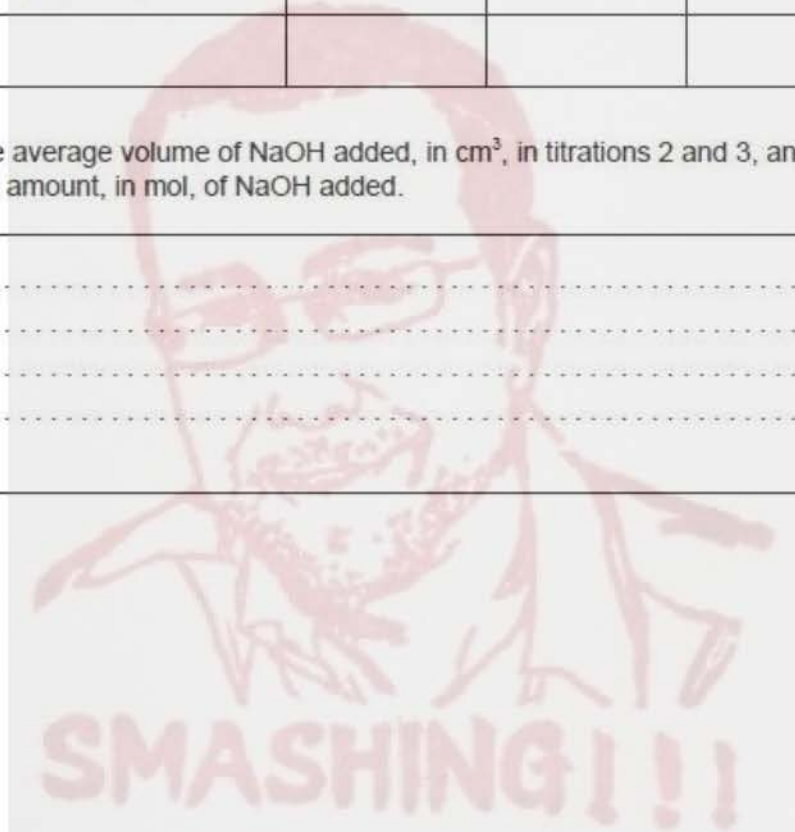
The titration was then repeated twice to obtain the results below.

Volume of $0.100 \text{ mol dm}^{-3} \text{ NaOH} / \text{cm}^3$	Titration 1	Titration 2	Titration 3
Final burette reading (± 0.05)	13.00	25.70	38.20
Initial burette reading (± 0.05)	0.00	13.00	25.70
Volume added			

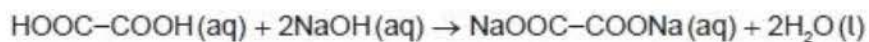
- (a) Calculate the average volume of NaOH added, in cm^3 , in titrations 2 and 3, and then calculate the amount, in mol, of NaOH added.

[2]

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- (b) (i) The equation for the reaction taking place in the titration is:



Determine the amount, in mol, of ethanedioic acid that reacts with the average volume of NaOH (aq).

[1]

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- (ii) Determine the amount, in mol, of ethanedioic acid present in 250 cm³ of the original solution.

[1]

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- (iii) Determine the molar mass of hydrated ethanedioic acid.

[1]

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- (iv) Determine the value of x in the formula HOOC-COOH•xH₂O.

[2]

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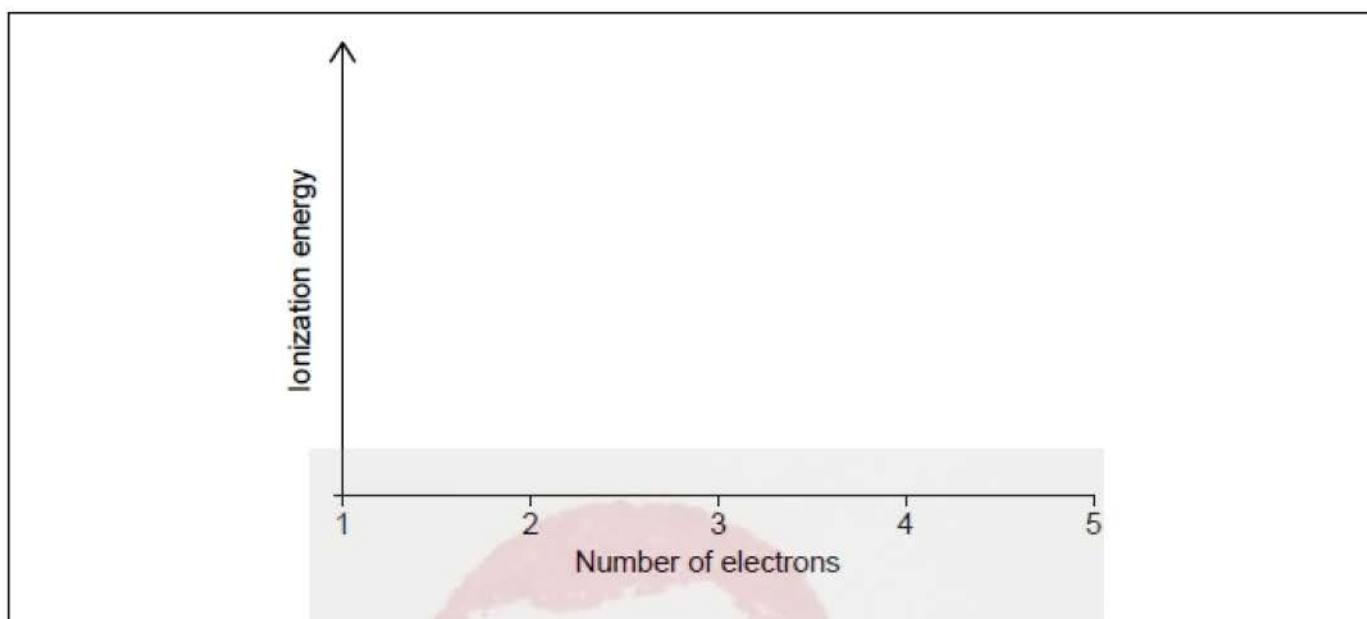
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- (c) Sketch a graph to show the relative values of the successive ionization energies of boron.

[2]



- (c) The first six ionization energies, in kJ mol^{-1} , of an element are given below.

IE_1	IE_2	IE_3	IE_4	IE_5	IE_6
578	1816	2744	11576	14829	18375

Explain the large increase in ionization energy from IE_3 to IE_4 .

[2]

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4. Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

(a) State the nuclear symbol notation, ${}_Z^AX$, for magnesium-26.

[1]

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(b) Mass spectroscopic analysis of a sample of magnesium gave the following results:

	% abundance
Mg-24	78.60
Mg-25	10.11
Mg-26	11.29

Calculate the relative atomic mass, A_r , of this sample of magnesium to two decimal places.

[2]

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(c) Magnesium ions produce no emission or absorption lines in the visible region of the electromagnetic spectrum. Suggest why most magnesium compounds tested in a school laboratory show traces of yellow in the flame.

[1]

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- (d) (i) Explain the convergence of lines in a hydrogen emission spectrum. [1]

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- (ii) State what can be determined from the frequency of the convergence limit. [1]

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Topic Chem 2 Q# 23/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

- (d) (i) State the condensed electron configuration of sulfur. [1]

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- (ii) Deduce the orbital diagram of sulfur, showing all the orbitals present in the diagram. [1]

Topic Chem 2 Q# 24/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4 . This acid is formed from the sulfur dioxide pollutant, SO_2 .

- (e) With reference to section 9 of the data booklet, explain the difference between the atomic radius and the ionic radius of nitrogen. [1]

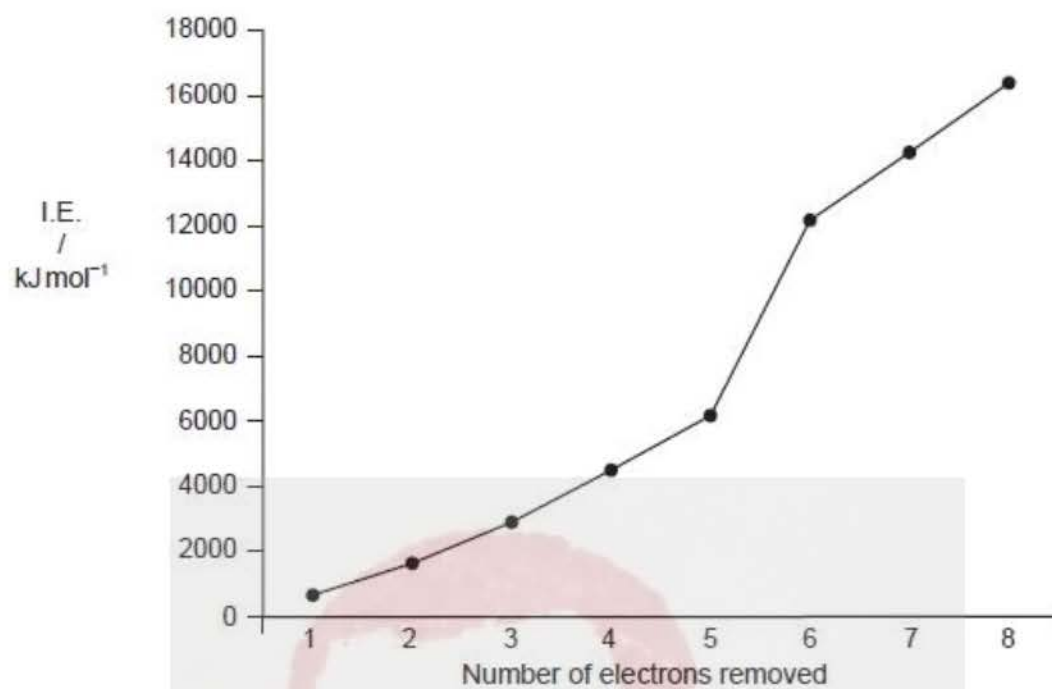
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(e) Eight successive ionisation energies of vanadium are shown in the graph below:



- (i) State the sub-levels from which each of the first four electrons are lost. [1]

First: Second: Third: Fourth:

- (ii) Outline why there is an increase in ionization energy from electron 3 to electron 5. [1]

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- (iii) Explain why there is a large increase in the ionization energy between electrons 5 and 6. [3]

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- (iv) Vanadium is comprised almost entirely of ^{51}V . State the number of neutrons an atom of ^{51}V has in its nucleus. [1]

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Topic **Chem 2 Q# 26/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7/ www.SmashingScience.org :o)
Table 5 refers to the periodic table

- (g) The two most abundant isotopes of bromine have the mass numbers 79 and 81. Calculate the relative abundance of ^{79}Br using table 5 of the data booklet, assuming the abundance of the other isotopes is negligible. [2]

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6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

(a) (i) State the electron configuration of the Cu^+ ion.

[1]

(f) Dilute copper(II) chloride solution is light blue, while copper(I) chloride solution is colourless.

(i) Describe how the blue colour is produced in the Cu(II) solution. Refer to section 17 of the data booklet.

[3]

(ii) Deduce why the Cu(I) solution is colourless.

[1]

4. Properties of elements and their compounds can be related to the position of the elements in the periodic table.

(a) Explain the decrease in atomic radius from Na to Cl.

[2]



- (b) Explain why the radius of the sodium ion, Na^+ , is smaller than the radius of the oxide ion, O^{2-} .

[2]

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Topic Chem 3 Q# 29/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. Bromine can form the bromate(V) ion, BrO_3^- .

- (a) (i) State the electron configuration of a bromine atom.

[1]

.....

- (ii) Sketch the orbital diagram of the **valence shell** of a bromine atom (ground state) on the energy axis provided. Use boxes to represent orbitals and arrows to represent electrons.

[1]

Energy
↑

- (e) State and explain the magnetic property of iron(II) and iron(III) ions.

[2]

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- (c) When calcium compounds are introduced into a gas flame a red colour is seen; sodium compounds give a yellow flame. Outline the source of the colours and why they are different.

[2]

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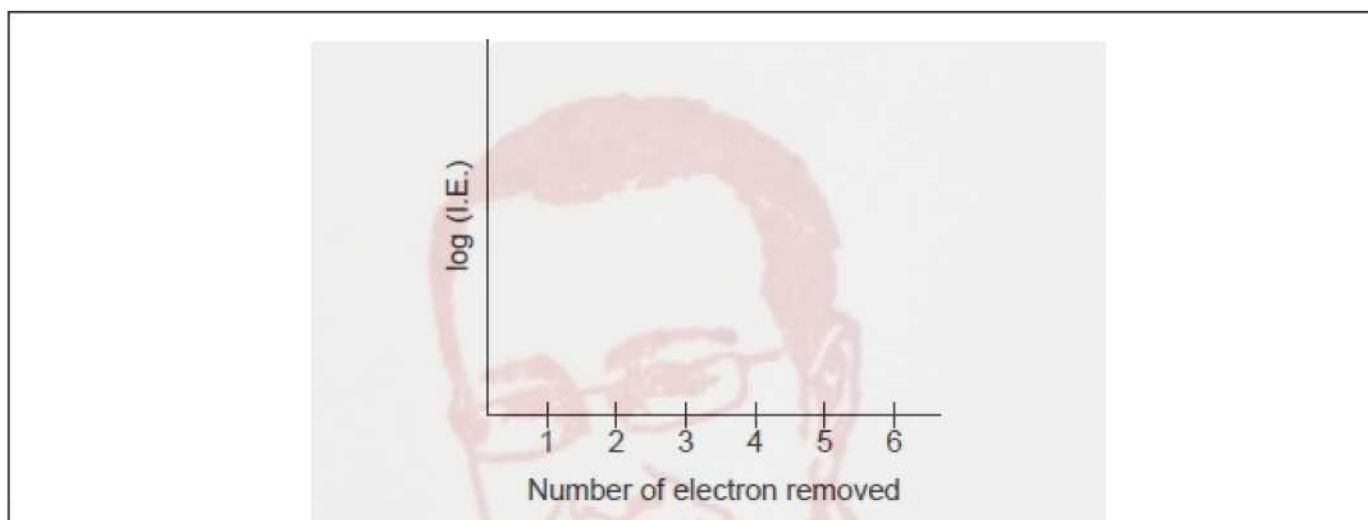
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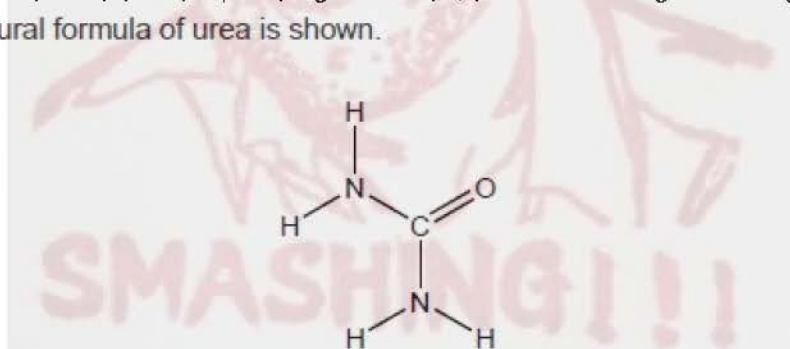
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- (e) Sketch a graph of the first six ionization energies of calcium.

[2]



- (b) The structural formula of urea is shown.



- (h) Describe the bond formation when urea acts as a ligand in a transition metal complex ion.

[2]

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1. There are many oxides of silver with the formula Ag_xO_y . All of them decompose into their elements when heated strongly.
- (c) (i) Some oxides of period 3, such as Na_2O and P_4O_{10} , react with water. A spatula measure of each oxide was added to a separate 100cm^3 flask containing distilled water and a few drops of bromothymol blue indicator. The indicator is listed in section 22 of the data booklet.

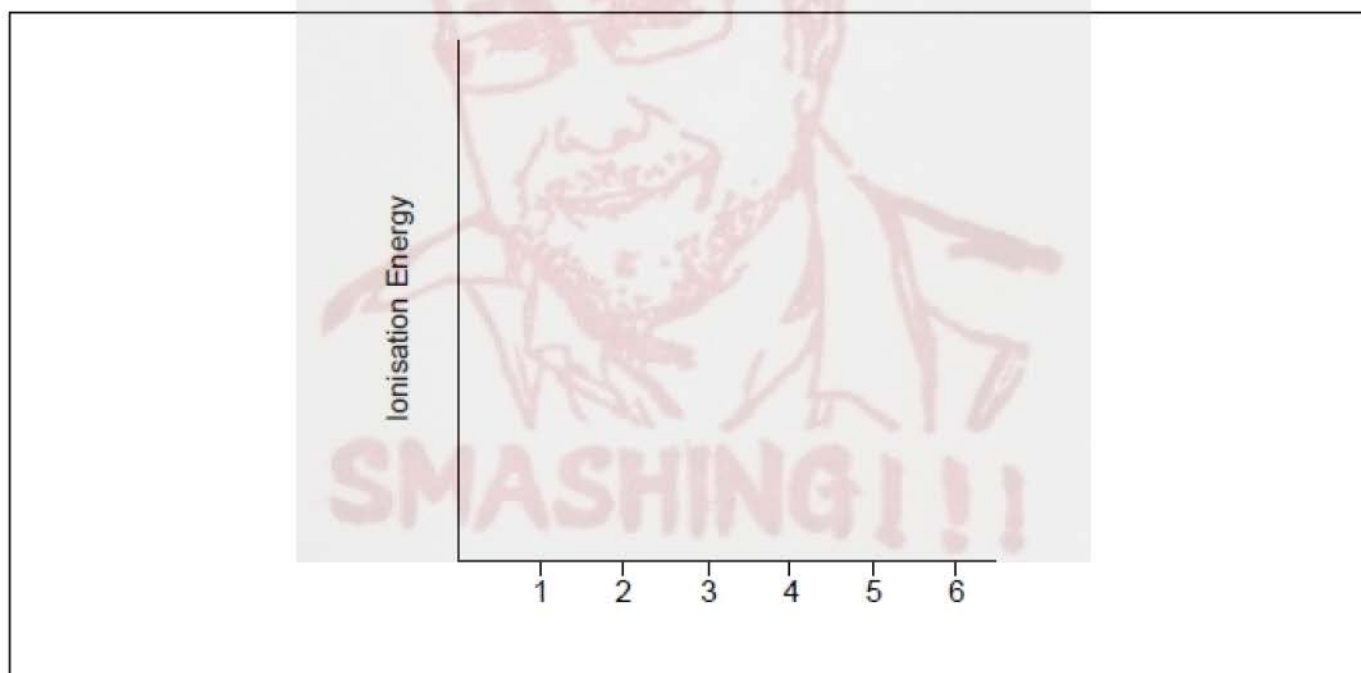
Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide.

[3]

Flask containing	Colour of solution	Product formula
Na_2O		
P_4O_{10}		

2. Titanium and vanadium are consecutive elements in the first transition metal series.
- (iii) Sketch a graph of the first six successive ionization energies of vanadium on the axes provided.

[1]



- (e) Describe, in terms of the electrons involved, how the bond between a ligand and a central metal ion is formed.

[1]

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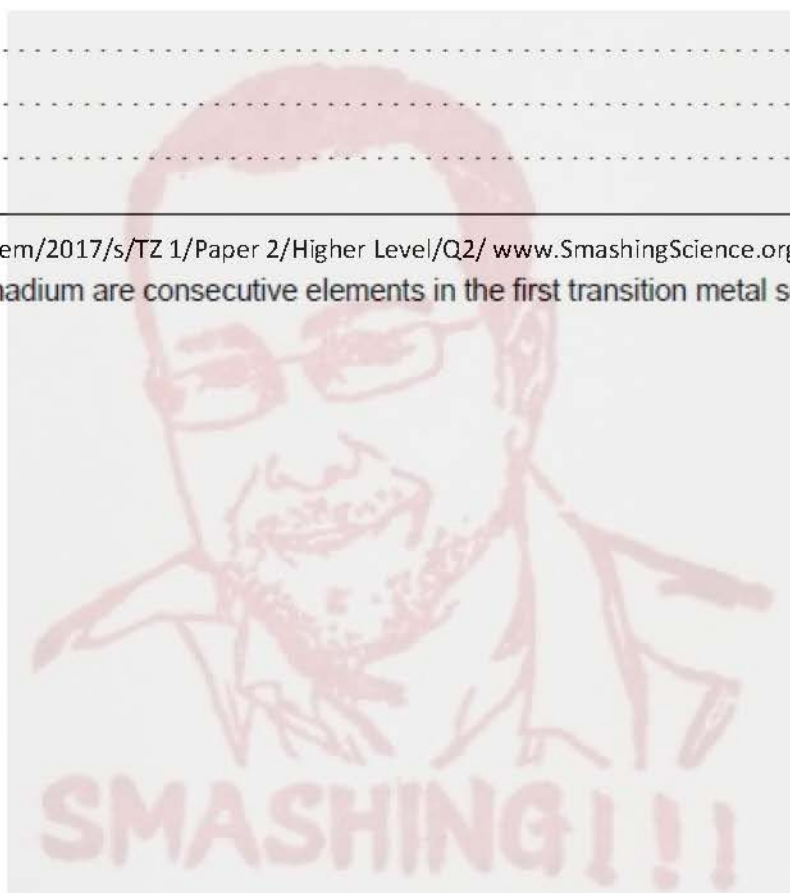
- (f) Outline why transition metals form coloured compounds.

[4]

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Topic Chem 3 Q# 34/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q2/ www.SmashingScience.org :o)

2. Titanium and vanadium are consecutive elements in the first transition metal series.



- (b) Titanium exists as several isotopes. The mass spectrum of a sample of titanium gave the following data:

Mass number	% abundance
46	7.98
47	7.32
48	73.99
49	5.46
50	5.25

Calculate the relative atomic mass of titanium to two decimal places.

[2]

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- (c) State the number of protons, neutrons and electrons in the ${}^{48}_{22}\text{Ti}$ atom.

[1]

Protons:	
.....	
Neutrons:	
.....	
Electrons:	
.....	

- (d) (i) State the full electron configuration of the ${}^{48}_{22}\text{Ti}^{2+}$ ion.

[1]

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- (e) Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water. [1]

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- (f) Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine. [2]

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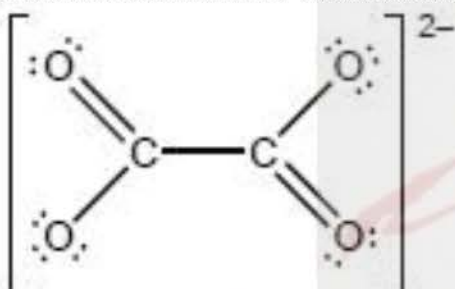
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- (g) In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound. [1]

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This is the Lewis structure for the ethandioate ion:



- (f) Explain how ethanedioate ions act as ligands. [2]

SMASHING!!!

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4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.



- (c) Outline, giving the **full** electron configuration of the vanadium atom, what is meant by the term transition metal. [2]

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- (d) In an aqueous solution of vanadium(III) chloride, the vanadium exists as $[\text{V}(\text{H}_2\text{O})_6]^{3+}$, $[\text{VCl}(\text{H}_2\text{O})_5]^{2+}$ or $[\text{VCl}_2(\text{H}_2\text{O})_4]^+$ depending on the concentration of chloride ions in the solution.

- (i) Describe how Cl^- and H_2O bond to the vanadium ion. [1]

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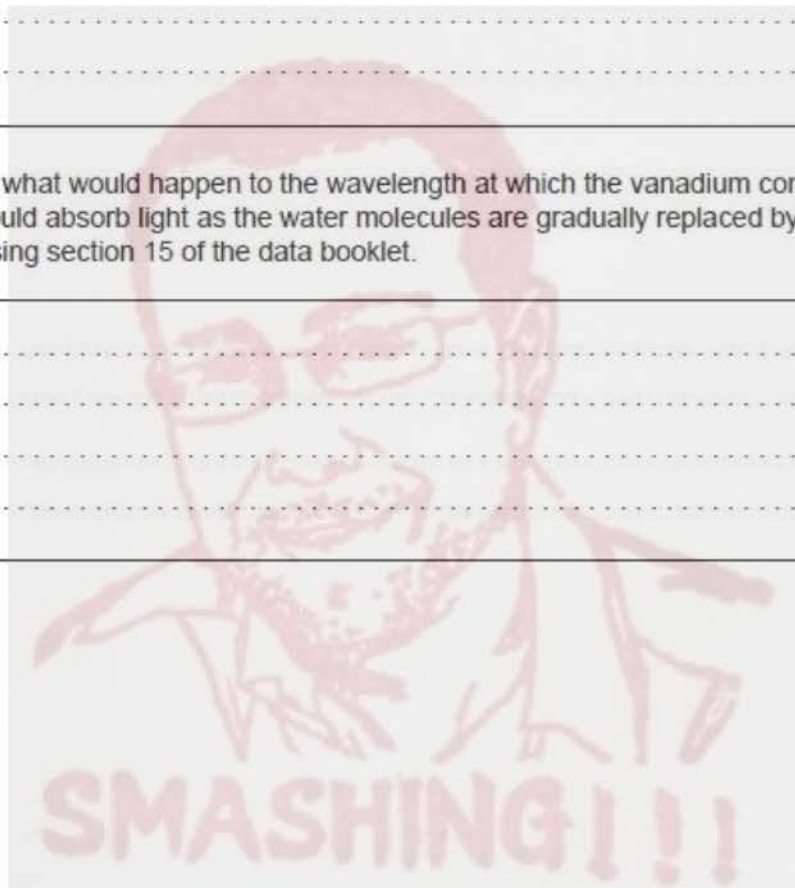
- (ii) Outline what would happen to the wavelength at which the vanadium complex ions would absorb light as the water molecules are gradually replaced by chloride ions, using section 15 of the data booklet. [2]

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- (e) (i) State the acid-base character of the oxides of the period 3 elements Na to Ar. [2]

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- (ii) State balanced equations to illustrate the acid-base character of sodium oxide and sulfur trioxide. [2]

Sodium oxide:

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Sulfur trioxide:

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5. (a) (i) Define the term electronegativity. [1]

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- (ii) Suggest why the noble gases are generally not assigned electronegativity values. [1]

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- (c) Outline **one** reason why the sodium ion, Na^+ , has a smaller radius than the sodium atom. [1]

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[4]

[2]

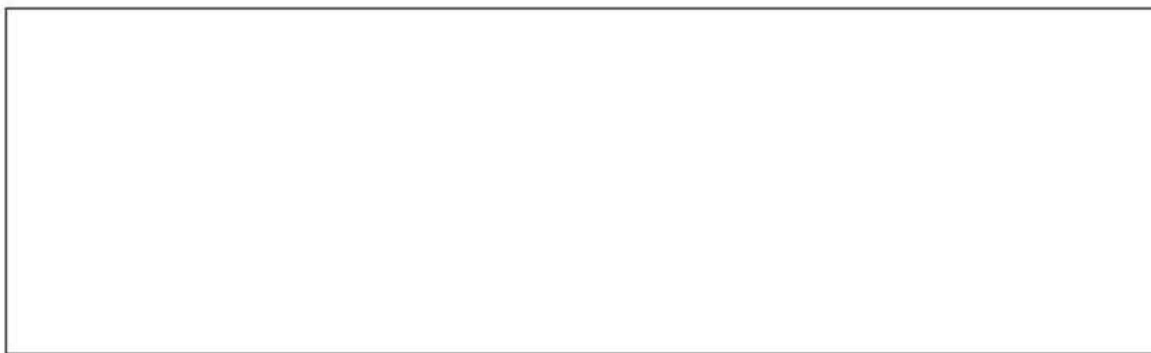
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[2]

(c) Chromium forms the complex ion $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$

(iv) Draw the structures of **two** possible isomers of this complex ion.

[2]



Topic **Chem 3 Q# 43/** IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/

8. Chromium is a transition metal with many uses.

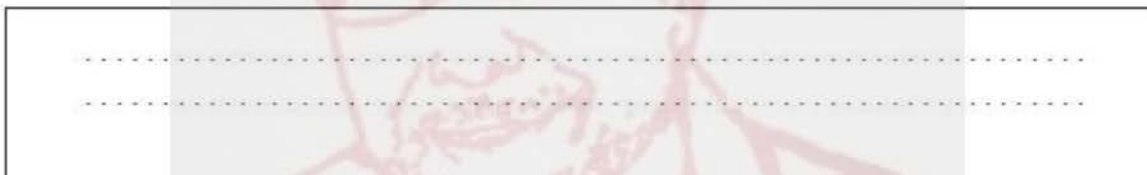
- (a) (i) Draw an orbital diagram (using the arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal.

[1]



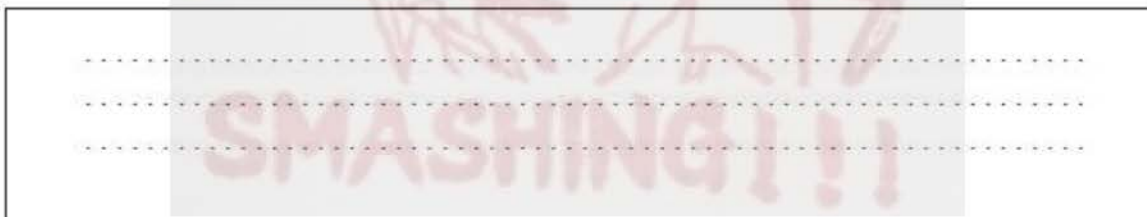
- (ii) Outline the nature of the metallic bonding present in chromium.

[1]



- (iii) Explain why chromium metal is malleable.

[1]



(c) Chromium forms the complex ion $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$.

(i) Deduce the oxidation number of chromium in this complex. [1]

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(ii) Describe the nature of the ligand-chromium ion bonds in terms of acid-base theory. [2]

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(iii) Explain why $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$ is coloured. [4]

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Topic Chem 3 Q# 44/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

(e) Describe how chlorine's position in the periodic table is related to its electron arrangement. [2]

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2. This question is about the compounds of some period 3 elements.

- (a) State the equations for the reactions of sodium oxide with water and phosphorus(V) oxide with water.

[2]

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4. Copper is a metal that has been used by humans for thousands of years.

- (a) State the full electron configuration of ^{65}Cu .

[1]

.....

- (b) State one difference in the physical properties of the isotopes ^{63}Cu and ^{65}Cu and explain why their chemical properties are the same.

[2]

Physical:	.....
Chemical:	.....
	

6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

- (iii) When excess ammonia is added to copper(II) chloride solution, the dark blue complex ion, $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$, forms.

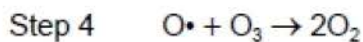
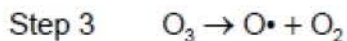
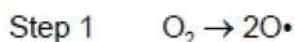
State the molecular geometry of this complex ion, and the bond angles within it.

[1]

Molecular geometry:	.....
Bond angles:	.....



1. The equations show steps in the formation and decomposition of ozone in the stratosphere, some of which absorb ultraviolet light.



- (a) Draw the Lewis structures of oxygen, O_2 , and ozone, O_3 .

[2]

- (b) Outline why both bonds in the ozone molecule are the same length and predict the bond length in the ozone molecule. Refer to section 10 of the data booklet.

[2]

Reason:	
.....	
.....	
.....	
Length:	
.....	

- (c) Predict the bond angle in the ozone molecule.

[1]



- (d) Discuss how the different bond strengths between the oxygen atoms in O_2 and O_3 in the ozone layer affect radiation reaching the Earth's surface.

[2]

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- (e) (i) Identify the steps which absorb ultraviolet light.

[1]

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- (ii) Determine, showing your working, the wavelength, in m, of ultraviolet light absorbed by a single molecule in one of these steps. Use sections 1, 2 and 11 of the data booklet.

[2]

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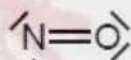
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- (f) Ozone depletion is catalysed by nitrogen monoxide, NO, which is produced in aircraft and motor vehicle engines, and has the following Lewis structure.



Show how nitrogen monoxide catalyses the decomposition of ozone, including equations in your answer.

[2]

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Topic **Chem 4 Q# 49/** IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. Bromine can form the bromate(V) ion, BrO_3^- .



(b) (i) Draw two Lewis (electron dot) structures for BrO_3^- .

[2]

Structure I – follows octet rule:

Structure II – does not follow octet rule:

(ii) Determine the preferred Lewis structure based on the formal charge on the bromine atom, giving your reasons.

[2]

(c) Predict, using the VSEPR theory, the geometry of the BrO_3^- ion and the O–Br–O bond angles.

[3]

Geometry:

Reason:

O–Br–O angle:

7. Some physical properties of molecular substances result from the different types of forces between their molecules.

- (a) (i) Explain why the hydrides of group 16 elements (H_2O , H_2S , H_2Se and H_2Te) are polar molecules.

[2]

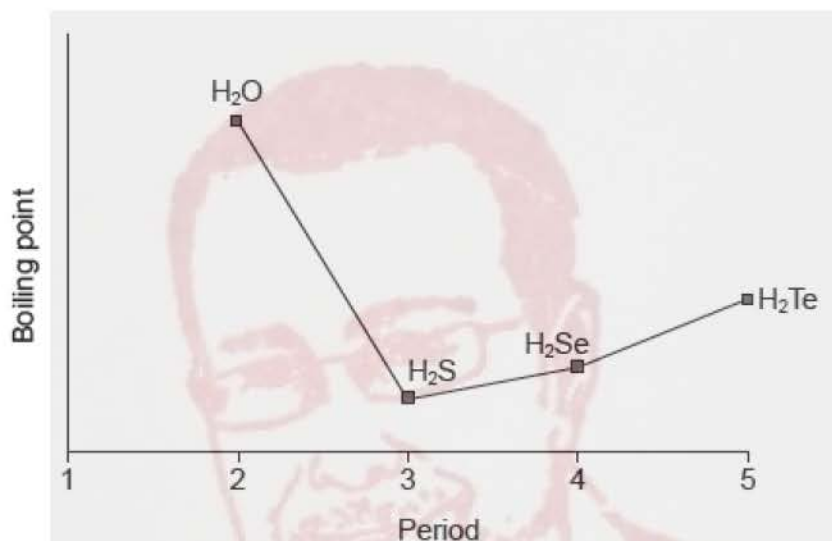
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- (ii) The graph shows the boiling points of the hydrides of group 16 elements.



Explain the increase in the boiling point from H_2S to H_2Te .

[2]

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- (b) Lewis structures show electron domains and are used to predict molecular geometry.

Deduce the electron domain geometry and the molecular geometry for the NH_2^- ion.

[2]

Electron domain geometry:

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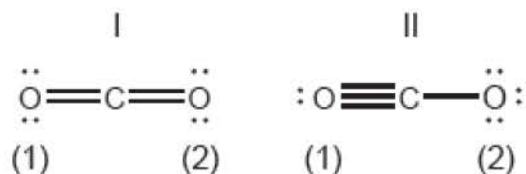
Molecular geometry:

.....



(c) Resonance structures exist when a molecule can be represented by more than one Lewis structure.

(i) Carbon dioxide can be represented by at least two resonance structures, I and II.



Calculate the formal charge on each oxygen atom in the two structures. [2]

Structure	I	II
O atom labelled (1)		
O atom labelled (2)		

(ii) Deduce, giving a reason, the more likely structure. [1]

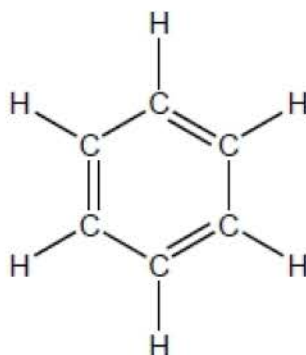
(d) Absorption of UV light in the ozone layer causes the dissociation of oxygen and ozone.

Identify, in terms of bonding, the molecule that requires a longer wavelength to dissociate. [2]

(e) Carbon and silicon are elements in group 14.

Explain why CO₂ is a gas but SiO₂ is a solid at room temperature. [2]

(d) One possible Lewis structure for benzene is shown.



State one piece of physical evidence that this structure is **incorrect**.

[1]

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2. Calcium carbide, CaC_2 , is an ionic solid.

(a) Describe the nature of ionic bonding.

[1]

SMASHING!!!

(d) (i) Suggest **two** reasons why solid calcium has a greater density than solid potassium.

[2]

SMASHING!!!

(ii) Outline why solid calcium is a good conductor of electricity.

[1]

SMASHING!!!

(g) (i) Describe how sigma (σ) and pi (π) bonds are formed.

[2]

sigma (σ):

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.....

pi (π):

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(ii) Deduce the number of σ and π bonds in a molecule of ethyne.

[1]

sigma (σ):

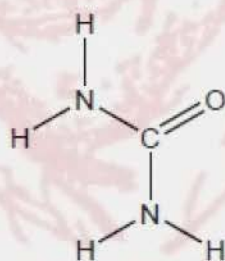
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pi (π):

.....

Topic Chem 4 Q# 53/ IB Chem/2018/s/TZ 1/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

(b) The structural formula of urea is shown.



Predict the electron domain and molecular geometries at the nitrogen and carbon atoms, applying the VSEPR theory.

	Electron domain geometry	Molecular geometry
Nitrogen		
Carbon		trigonal planar

[3]



- (e) (i) Suggest one reason why urea is a solid and ammonia a gas at room temperature. [1]

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- (ii) Sketch two different hydrogen bonding interactions between ammonia and water. [2]



- (i) The C–N bonds in urea are shorter than might be expected for a single C–N bond. Suggest, in terms of electrons, how this could occur. [1]

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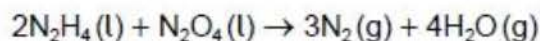
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4. Bonds can be formed in many ways.

- (a) The landing module for the Apollo mission used rocket fuel made from a mixture of hydrazine, N_2H_4 , and dinitrogen tetroxide, N_2O_4 .



- (i) State and explain the difference in bond strength between the nitrogen atoms in a hydrazine and nitrogen molecule. [2]

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- (ii) State why hydrazine has a higher boiling point than dinitrogen tetroxide. [1]

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- (b) (i) Discuss the bonding in the resonance structures of ozone. [3]

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- (ii) Deduce one resonance structure of ozone and the corresponding formal charges on each oxygen atom. [2]



- (b) Deduce the Lewis (electron dot) structure, molecular geometry and the bond angles of PCl_3 .

[3]

Lewis structure:

Molecular geometry:

.....

Bond angles:

.....

- (ii) Explain the electrical conductivity of molten Na_2O and P_4O_{10} .

[2]

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SMASHING!!!



8. There is concern about damage done to the ozone layer in the stratosphere by jet-propelled aircraft.

- (a) Formulate two equations to show how nitrogen(II) oxide, NO, catalyses the destruction of ozone. [2]

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- (b) Suggest why the loss of ozone is an international environmental concern. [2]

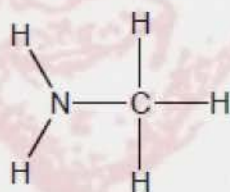
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5. Two hydrides of nitrogen are ammonia and hydrazine, N_2H_4 . One derivative of ammonia is methanamine whose molecular structure is shown below.



- (a) Estimate the H–N–H bond angle in methanamine using VSEPR theory. [1]

.....

- (b) State the electron domain geometry around the nitrogen atom and its hybridization in methanamine. [2]

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2. Titanium and vanadium are consecutive elements in the first transition metal series.

(a) Describe the bonding in metals.

[2]

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.....
.....

d

(ii) Suggest why the melting point of vanadium is higher than that of titanium.

[1]

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.....

(iv) Explain why an aluminium-titanium alloy is harder than pure aluminium.

[2]

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(g) (i) State the type of bonding in potassium chloride which melts at 1043K.

[1]

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(ii) A chloride of titanium, TiCl_4 , melts at 248K. Suggest why the melting point is so much lower than that of KCl.

[1]

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- (h) Describe the structure and bonding in solid magnesium oxide. [2]

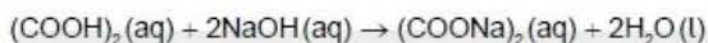
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- (c) 5.00 g of an impure sample of hydrated ethanedioic acid, $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a $0.100 \text{ mol dm}^{-3}$ solution of sodium hydroxide using a suitable indicator.



- (d) Draw the Lewis (electron dot) structure of the ethanedioate ion, $^-\text{OOC}\text{COO}^-$. [1]

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- (e) Outline why all the C–O bond lengths in the ethanedioate ion are the same length and suggest a value for them. Use section 10 of the data booklet. [2]

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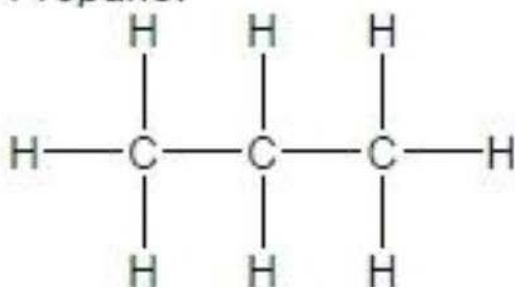
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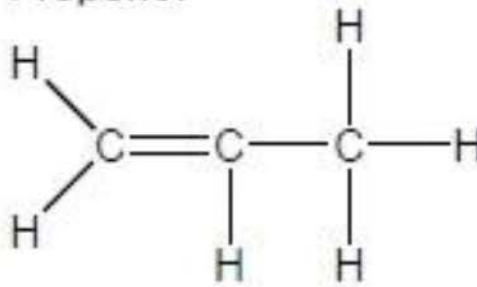
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5. Propane and propene are members of different homologous series.

Propane:



Propene:



- (b) (i) Draw diagrams to show how sigma (σ) and pi (π) bonds are formed between atoms.

[2]

Sigma (σ):

Pi (π):

- (ii) State the number of sigma (σ) and pi (π) bonds in propane and propene.

[2]

	Number of sigma (σ) bonds	Number of pi (π) bonds
Propane		
Propene		

Topic Chem 4 Q# 63/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

Ethene has the formula CH_2CH_2

- (d) Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene.

[2]

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6. Ozone, dinitrogen monoxide, CFCs, sulfur hexafluoride and methane are all examples of greenhouse gases.

- (a) (i) Draw one valid Lewis (electron dot) structure for each molecule of the greenhouse gases listed below. [2]

	Lewis (electron dot) structure
Ozone	
Sulfur hexafluoride	

- (ii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule listed below. [2]

	Electron domain geometry	Molecular geometry
Ozone		
Sulfur hexafluoride		



- (iii) Identify which molecule(s) given in part (a) (i) has/have an extended octet of [1]
electrons.

.....

- (iv) State the bond angles for each species in part (a) (ii). [1]

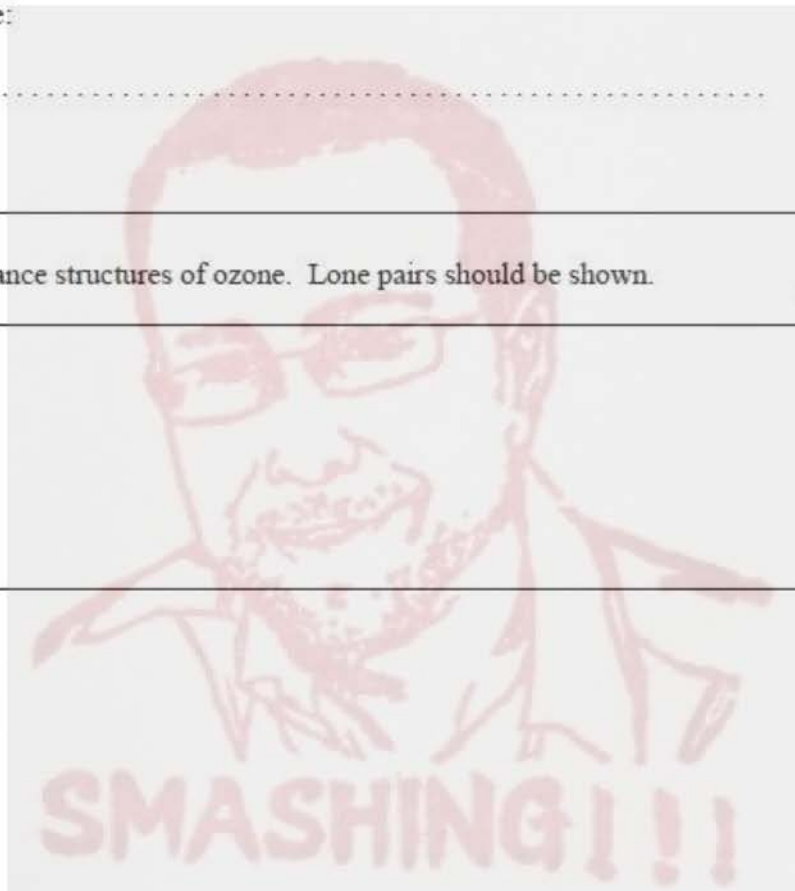
Ozone:

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Sulfur hexafluoride:

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- (v) Draw all the resonance structures of ozone. Lone pairs should be shown. [1]



(b) Nitrous oxide can be represented by different Lewis (electron dot) structures.

- (i) Deduce the formal charge (FC) of the nitrogen and oxygen atoms in three of these Lewis (electron dot) structures, A, B and C, represented below. [2]

LHS: atom on left-hand side; RHS: atom on right-hand side.

	Lewis (electron dot) structure	FC of O on LHS	FC of central N	FC of N on RHS
A	$:\ddot{\text{O}}=\text{N}=\ddot{\text{N}}:$			
B	$:\ddot{\text{O}}-\text{N}\equiv\text{N}:$			
C	$:\text{O}\equiv\text{N}-\ddot{\text{N}}:$			

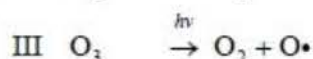
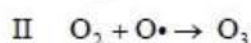
- (ii) FC can be useful in electron book-keeping, but electronegativity values are ignored when FCS are assigned.

Based on the assignment of FCS of the atoms in part (i), deduce which Lewis (electron dot) structure of N_2O (A, B or C) is expected to be the preferred structure. Explore why another factor needs to be considered. [2]

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- (d) (i) The concentration of ozone in the upper atmosphere is maintained by the following three reactions, I, II and III.



Explain by reference to the bonding in O_2 and O_3 , which of the reactions, I or III, needs more energy.

[3]

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- (ii) Using dichlorodifluoromethane, CCl_2F_2 , as an example, outline the reactions in which ozone depletion occurs in the upper atmosphere. Formulate an equation for each step in this process and explain the initial step by reference to the bonds in CCl_2F_2 .

[5]

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- (c) One of the intermediates in the reaction between nitrogen monoxide and hydrogen is dinitrogen monoxide, N_2O . This can be represented by the resonance structures below:



- (i) Analyse the bonding in dinitrogen monoxide in terms of σ -bonds and π -bonds. [3]

- (ii) State what is meant by resonance. [1]

Topic Chem 4 Q# 66/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 .

- (a) (i) Draw a Lewis (electron dot) structure of phosphine. [1]

- (ii) State the hybridization of the phosphorus atom in phosphine. [1]



- (iv) Outline whether you expect the bonds in phosphine to be polar or non-polar, giving a brief reason.

[1]

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- (v) Phosphine has a much greater molar mass than ammonia. Explain why phosphine has a significantly lower boiling point than ammonia.

[2]

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Topic Chem 4 Q# 67/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q6/ www.SmashingScience.org :o)

- (c) (i) Deduce the type of hybridization shown by the nitrogen atoms in NF_4^+ , N_2H_2 and N_2H_4 .

[3]

	NF_4^+	N_2H_2	N_2H_4
Hybridization			

- (ii) Describe how sigma (σ) and pi (π) bonds form.

[2]

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- (iii) Draw the Lewis (electron dot) structures of SF_4 and SF_6 . Use the valence shell electron pair repulsion (VSEPR) theory to predict the name of the shape of each molecule. [4]

- (d) (i) List the following compounds in order of **increasing** boiling point: CH_3CHO , $\text{CH}_3\text{CH}_2\text{CH}_3$, CH_3COOH , $\text{CH}_3\text{CH}_2\text{OH}$. [2]

- (ii) Explain the order of boiling points in the compounds listed in part (d) (i), in terms of intermolecular forces. [4]



- (b) Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group whereas the melting points of the group 7 elements (F → I) increase down the group. [3]

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- (c) Consider the molecules PBr_3 and SF_4 .

- (i) Deduce the Lewis (electron dot) structure of both molecules. [2]

- (ii) Predict the shapes of the two molecules, giving the Br–P–Br bond angle in PBr_3 and the F–S–F bond angles in SF_4 . [4]

	PBr_3	SF_4
Shape:		Shape:
Bond angle:		Bond angles:



(iii) Explain why both PBr_3 and SF_4 are polar.

[2]

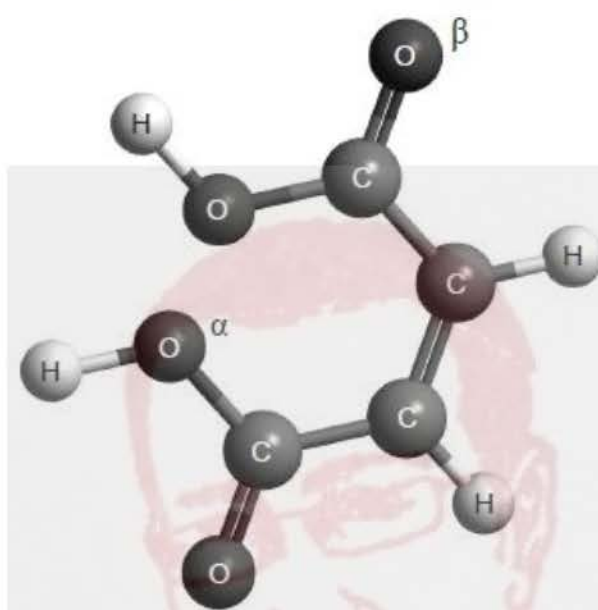
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(d) The structure of *cis*-but-2-ene-1,4-dioic acid is shown below.



(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed.

[2]

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- (ii) Deduce the hybridization of the oxygen atoms labelled α and β . [1]

α :

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β :

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- (iii) Describe sigma (σ) and pi (π) bonds between atoms. [2]

σ bond:

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π bond:

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- (iv) Identify the number of sigma (σ) and pi (π) bonds present in a molecule of *cis*-but-2-ene-1,4-dioic acid. [1]

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Topic Chem 4 Q# 70/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q8/ www.SmashingScience.org :o)

- (b) (i) State the name of Cr_2O_3 . [1]

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- (ii) Describe the ionic bonding present in Cr_2O_3 and how the ions are formed. [2]

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(iii) Suggest why solid Cr_2O_3 does **not** conduct electricity.

[1]

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Topic **Chem 4 Q# 71/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7/ www.SmashingScience.org :o)

(f) Describe the formation of σ and π bonds in an alkene.

[2]

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Topic **Chem 4 Q# 72/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5/ www.SmashingScience.org :o)

(g) Identify **three** allotropes of carbon and describe their structures.

[4]

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Topic **Chem 4 Q# 73/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

(f) SCl_2 and SClF_5 are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules.

[3]

Molecule	Shape	Bond angle	Polarity
SCl_2			
SClF_5			



- (b) (i) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure. [2]

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- (ii) Predict whether phosphorus(V) oxide and sodium oxide conduct electricity in their solid and molten states. Complete the boxes with "yes" or "no". [2]

	Phosphorus(V) oxide	Sodium oxide
Solid state		
Molten state		

- (c) Describe the bonding in solid copper. [2]

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1. Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, $\text{HOOC}-\text{COOH} \cdot x\text{H}_2\text{O}$, by titrating a known mass of the acid with a $0.100 \text{ mol dm}^{-3}$ solution of $\text{NaOH}(\text{aq})$.

- (c) Identify the strongest intermolecular force in solid ethanedioic acid. [1]

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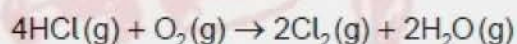
- (d) Deduce the Lewis (electron dot) structure of ethanedioic acid, $\text{HOOC}-\text{COOH}$. [1]

- (e) Predict and explain the difference in carbon-oxygen bond lengths in ethanedioic acid and its conjugate base, $^-\text{OOC}-\text{COO}^-$. [3]

Topic Chem 5 Q# 77/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q7./ www.SmashingScience.org :o)

6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

- (ii) Copper(II) chloride is used as a catalyst in the production of chlorine from hydrogen chloride.



Calculate the standard enthalpy change, $\Delta H^\ominus$, in kJ, for this reaction, using section 12 of the data booklet.

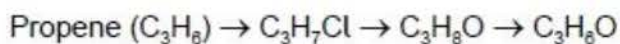
[2]

- (d) Determine the enthalpy of solution of copper(II) chloride, using data from sections 18 and 20 of the data booklet.

The enthalpy of hydration of the copper(II) ion is $-2161 \text{ kJ mol}^{-1}$.

[2]

3. Propene is an important starting material for many products. The following shows some compounds which can be made from propene, C_3H_6 .



- (b) An experiment was carried out to determine the order of reaction between one of the isomers of C_3H_7Cl and aqueous sodium hydroxide. The following results were obtained.

Experiment	$[C_3H_7Cl] / \text{mol dm}^{-3}$	$[OH^-] / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.05	0.10	3.1×10^{-4}
2	0.10	0.20	1.3×10^{-3}
3	0.15	0.10	9.2×10^{-4}

- (c) (i) Write an equation for the complete combustion of the compound C_3H_8O formed in (a)(iv). [1]

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- (ii) Determine the enthalpy of combustion of this compound, in kJ mol^{-1} , using data from section 11 of the data booklet. [3]

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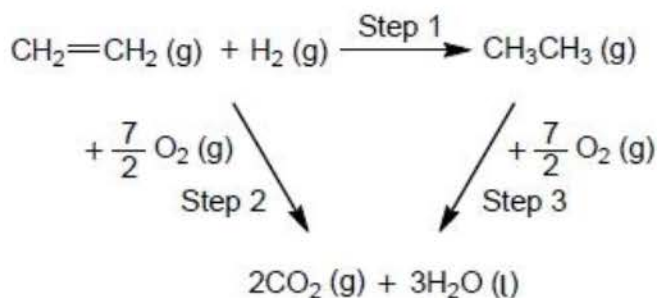
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7. Consider the following Hess's law cycle:



- (b) Calculate the standard enthalpy change, $\Delta H^\ominus$, of step 2 using section 13 of the data booklet.

[1]

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- (c) Determine the standard enthalpy change, $\Delta H^\ominus$, of step 1.

[1]

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- (d) Suggest one reason why the calculated value of $\Delta H^\ominus$ using Hess's Law in part (c) can be considered accurate and one reason why it can be considered approximate.

[2]

Accurate:

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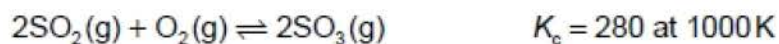
Approximate:

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5. This reaction is used in the manufacture of sulfuric acid.



- (b) Predict, giving your reason, the sign of the standard entropy change of the forward reaction.

[1]

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- (c) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in kJ, for this reaction at 1000 K. Use sections 1 and 2 of the data booklet.

[2]

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- (d) Predict, giving your reasons, whether the forward reaction is endothermic or exothermic. Use your answers to (b) and (c).

[2]

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Topic Chem 5 Q# 81/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q4/ www.SmashingScience.org :o)

4. Properties of elements and their compounds can be related to the position of the elements in the periodic table.

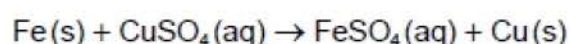
- (d) Predict, giving your reasons, whether Mn^{2+} or Fe^{2+} is likely to have a more exothermic enthalpy of hydration.

[2]

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Topic Chem 5 Q# 82/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

1. 3.26 g of iron powder are added to 80.0 cm³ of 0.200 mol dm⁻³ copper(II) sulfate solution. The following reaction occurs:



- (b) (i) The reaction was carried out in a calorimeter. The maximum temperature rise of the solution was 7.5°C .

Calculate the enthalpy change, ΔH , of the reaction, in kJ, assuming that all the heat released was absorbed by the solution. Use sections 1 and 2 of the data booklet.

[2]

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- (ii) State another assumption you made in (b)(i).

[1]

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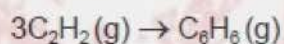
Topic Chem 5 Q# 83/ IB Chem/2018/s/TZ 1/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. This question is about ethene, C_2H_4 , and ethyne, C_2H_2 .

- (c) (i) Under certain conditions, ethyne can be converted to benzene.

Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 11 of the data booklet.

[2]



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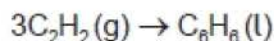
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- (ii) Determine the standard enthalpy change, $\Delta H^\ominus$, for the following similar reaction, using $\Delta H_f^\ominus$ values in section 12 of the data booklet. [2]



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- (iii) Explain, giving two reasons, the difference in the values for (c)(i) and (ii). If you did not obtain answers, use -475 kJ for (i) and -600 kJ for (ii). [2]

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- (iv) Calculate the standard entropy change, $\Delta S^\ominus$, in J K^{-1} , for the reaction in (ii) using section 12 of the data booklet. [1]

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- (v) Determine, showing your working, the spontaneity of the reaction in (ii) at 25°C . [3]

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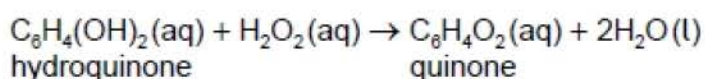
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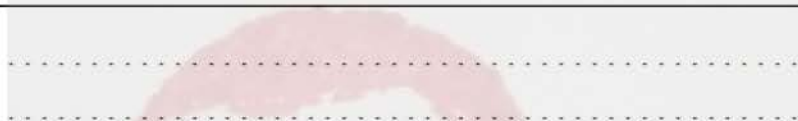
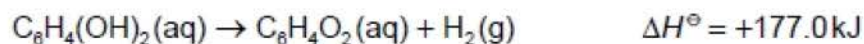
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9. The Bombardier beetle sprays a mixture of hydroquinone and hydrogen peroxide to fight off predators. The reaction equation to produce the spray can be written as:



- (a) (i) Calculate the enthalpy change, in kJ, for the spray reaction, using the data below. [2]



- (ii) The energy released by the reaction of one mole of hydrogen peroxide with hydroquinone is used to heat 850 cm^3 of water initially at 21.8°C . Determine the highest temperature reached by the water.

Specific heat capacity of water = $4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$.

(If you did not obtain an answer to part (i), use a value of 200.0 kJ for the energy released, although this is not the correct answer.)

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- (b) (i) Hydrogenation of propene produces propane. Calculate the standard entropy change, $\Delta S^\ominus$, for the hydrogenation of propene. [2]

Formula	$S^\ominus / \text{JK}^{-1}\text{mol}^{-1}$
$\text{H}_2(\text{g})$	+131
$\text{C}_3\text{H}_6(\text{g})$	+267
$\text{C}_3\text{H}_8(\text{g})$	+270

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- (ii) The standard enthalpy change, $\Delta H^\ominus$, for the hydrogenation of propene is $-124.4 \text{ kJ mol}^{-1}$. Predict the temperature above which the hydrogenation reaction is not spontaneous. [2]

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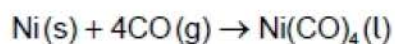
Topic Chem 5 Q# 85/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q4/ www.SmashingScience.org :o)

4. Millerite, a nickel sulfide mineral, is an important source of nickel. The first step in extracting nickel is to roast the ore in air.

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(c) The reaction for the formation of liquid tetracarbonylnickel is shown below:



- (i) Calculate the standard entropy change, $\Delta S^\ominus$, of the reaction, in JK^{-1} , using the values given.

[2]

	$S^\ominus / \text{JK}^{-1}\text{mol}^{-1}$
Ni(s)	29.9
CO(g)	197.6
Ni(CO) ₄ (l)	313.4

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- (ii) Calculate a value for $\Delta H^\ominus$ in kJ.

[1]

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
CO(g)	-110.5
Ni(CO) ₄ (l)	-633.0

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SMASHING!!!



- (iii) Use your answers to (c)(i) and (c)(ii), to determine the temperature, in °C, at which the decomposition of liquid tetracarbonylnickel to nickel and carbon monoxide becomes favourable.

(If you did not get answers to (c)(i) and (c)(ii), use -500 J K^{-1} and -200 kJ respectively but these are not the correct answers.)

[3]

- (d) Suggest why experiments involving tetracarbonylnickel are very hazardous.

[1]

Topic Chem 5 Q# 86/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

- (a) Ethane-1,2-diol can be formed according to the following reaction.

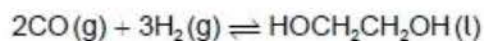


- (iii) Calculate the enthalpy change, $\Delta H^\ominus$, in kJ, for this reaction using section 11 of the data booklet. The bond enthalpy of the carbon–oxygen bond in $\text{CO}(\text{g})$ is 1077 kJ mol^{-1} .

[3]



- (b) (i) Calculate $\Delta H^\ominus$, in kJ, for this similar reaction below using $\Delta H_f^\ominus$ data from section 12 of the data booklet. $\Delta H_f^\ominus$ of $\text{HOCH}_2\text{CH}_2\text{OH}(\text{l})$ is $-454.8 \text{ kJ mol}^{-1}$. [1]



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- (ii) Deduce why the answers to (a)(iii) and (b)(i) differ. [1]

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- (iii) $\Delta S^\ominus$ for the reaction in (b)(i) is -620.1 J K^{-1} . Comment on the decrease in entropy. [1]

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- (iv) Calculate the value of $\Delta G^\ominus$, in kJ, for this reaction at 298 K using your answer to (b)(i). (If you did not obtain an answer to (b)(i), use -244.0 kJ , but this is not the correct value.) [2]

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- (v) Comment on the statement that the reaction becomes less spontaneous as temperature is increased. [1]

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(c) Ozone in the atmosphere can be formed from the combustion of methane.

- (i) State the equation for this combustion reaction. [1]

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- (ii) Calculate the standard enthalpy change for the reaction, $\Delta H^\ominus$, in kJ mol^{-1} , using the thermodynamic data in section 12 of the data booklet and the information given below. [1]

$\text{O}_3(\text{g})$
$\Delta H_f^\ominus = +142.3 \text{ kJ mol}^{-1}$

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- (iii) State why the standard enthalpy change of formation, $\Delta H_f^\ominus$, for oxygen is not given. [1]

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- (iv) Calculate the standard entropy change for the reaction, $\Delta S^\ominus$, in $\text{JK}^{-1}\text{mol}^{-1}$, using the thermodynamic data in section 12 of the data booklet and the information given below. [1]

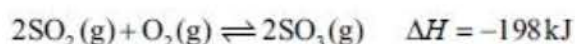
$\text{O}_2(\text{g})$	$\text{O}_3(\text{g})$
$S^\ominus = +205.0 \text{ JK}^{-1}\text{mol}^{-1}$	$S^\ominus = +237.6 \text{ JK}^{-1}\text{mol}^{-1}$

- (v) Deduce the standard change in Gibbs Free Energy, $\Delta G^\ominus$, in kJ mol^{-1} , for this reaction at 298 K. [1]

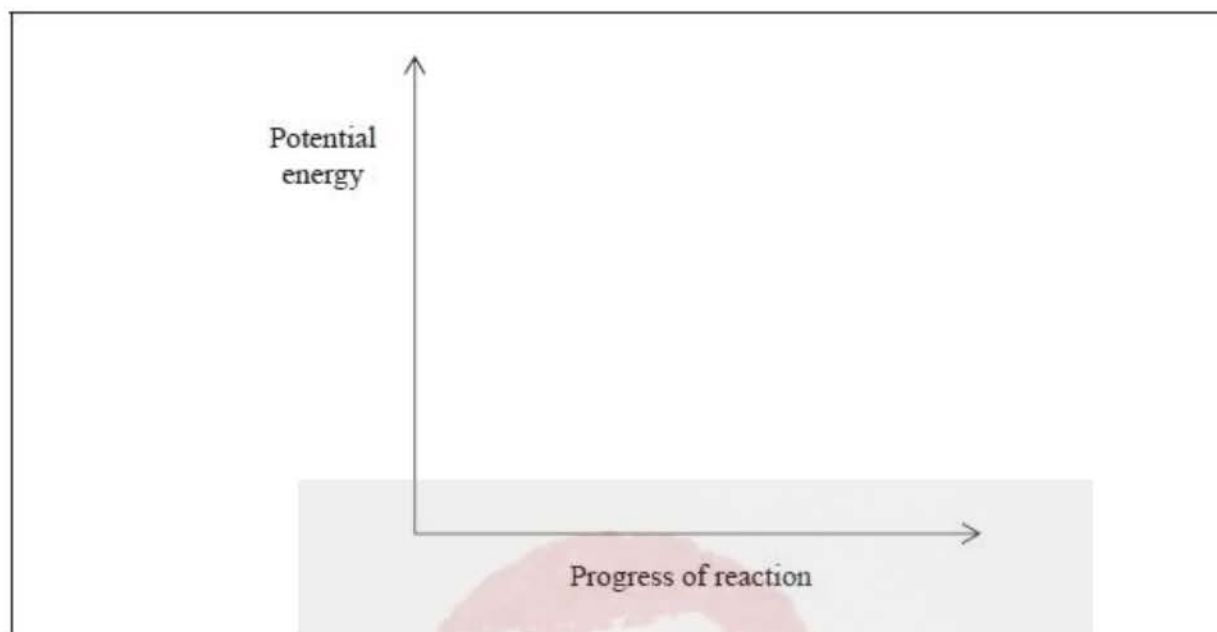
- (vi) Deduce, giving a reason, whether the reaction is spontaneous or non-spontaneous at this temperature. [1]

Topic Chem 5 Q# 88/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4 . This acid is formed from the sulfur dioxide pollutant, SO_2 .
- (b) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:



- (c) Sketch the potential energy profile for the forward reaction in part (b) to show the effect of a catalyst on the activation energy, E_{act} . [2]



Topic Chem 5 Q# 89/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

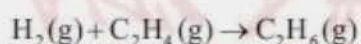
5. Many automobile manufacturers are developing vehicles that use hydrogen as a fuel.

- (a) Suggest why such vehicles are considered to cause less harm to the environment than those with internal combustion engines. [1]

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- (b) Hydrogen can react with ethene to form ethane.



Using average bond enthalpies at 298 K from section 11 of the data booklet, calculate the change in enthalpy, ΔH , in kJ mol^{-1} , for this reaction. [3]

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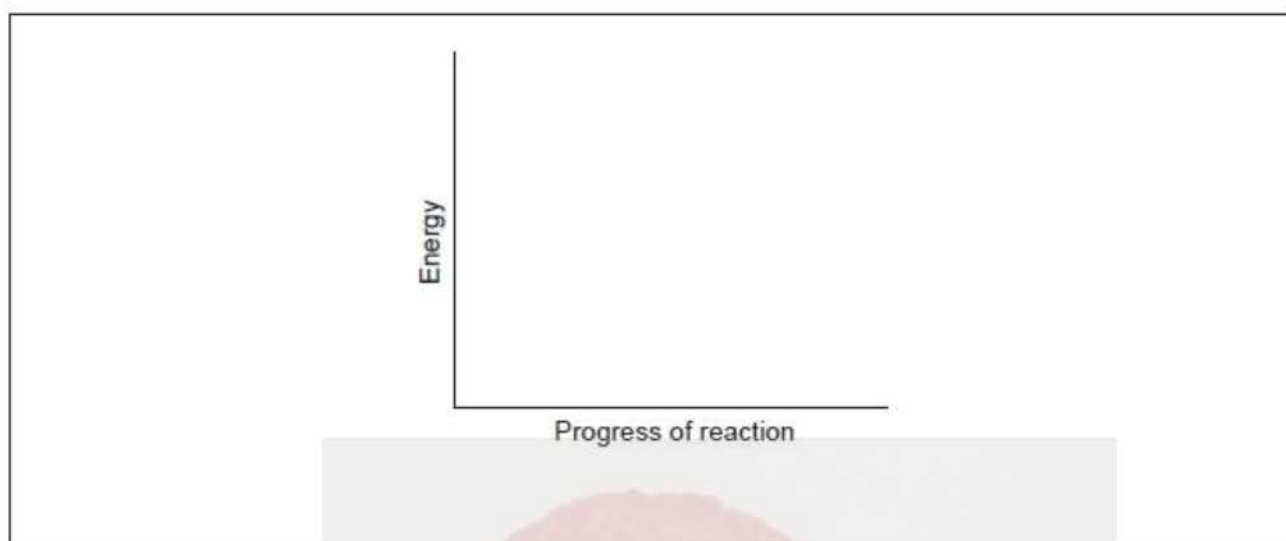
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- (b) The enthalpy change for the reaction between nitrogen monoxide and hydrogen is -664 kJ and its activation energy is 63 kJ .



- (i) Sketch the potential energy profile for the overall reaction, using the axes given, indicating both the enthalpy of reaction and activation energy. [2]
- (ii) This reaction is normally carried out using a catalyst. Draw a dotted line labelled "Catalysed" on the diagram above to indicate the effect of the catalyst. [1]

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 .

- (d) Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.
- (i) 200.0 g of air was heated by the energy from the complete combustion of 1.00 mol phosphine. Calculate the temperature rise using section 1 of the data booklet and the data below. [1]

Standard enthalpy of combustion of phosphine, $\Delta H_c^\ominus = -750 \text{ kJ mol}^{-1}$

Specific heat capacity of air = $1.00 \text{ J g}^{-1} \text{ K}^{-1} = 1.00 \text{ kJ kg}^{-1} \text{ K}^{-1}$

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4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.

- (a) (i) State why you would expect tin(II) chloride to have a similar lattice enthalpy to strontium chloride, using section 9 of the data booklet.

[1]

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- (ii) Calculate the molar enthalpy change when strontium chloride is dissolved in water, using sections 18 and 20 of the data booklet.

[2]

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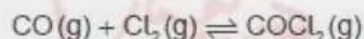
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2. Phosgene, COCl_2 , is usually produced by the reaction between carbon monoxide and chlorine according to the equation:



(a)

- (iii) The standard enthalpy change of formation of phosgene, $\Delta H_f^\ominus$, is $-220.1 \text{ kJ mol}^{-1}$. Determine the standard enthalpy change, $\Delta H^\ominus$, for the forward reaction of the equilibrium, in kJ, using section 12 of the data booklet.

[2]

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- (iv) Calculate the standard entropy change, $\Delta S^\ominus$, in JK^{-1} , for the forward reaction at 25°C , using your answers to (a) (ii) and (a) (iii).
(If you did not obtain an answer to (a) (ii) and/or (a) (iii) use values of $+20.0\text{ kJ}$ and -120.0 kJ respectively, although these are not the correct answers.)

[2]

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Topic Chem 5 Q# 94/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

6. Iron (III) oxide is the main source of iron but the decomposition of $\text{Fe}_2\text{O}_3(\text{s})$ into its elements is extremely difficult due to a large positive value of $\Delta G^\ominus$.

- (a) Consider the following reactions:



Suggest, with a reason, whether it is possible to produce iron by reacting Fe_2O_3 with CO . [2]

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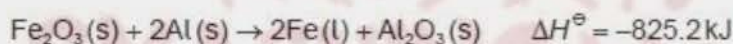
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- (b) The thermite reaction is one of the most exothermic reactions.



Species	$S^\ominus / \text{JK}^{-1}\text{mol}^{-1}$	$\Delta G_f^\ominus / \text{kJ mol}^{-1}$
$\text{Al}(\text{s})$	+28.3	0
$\text{Al}_2\text{O}_3(\text{s})$	+50.9	-1582
$\text{Fe}(\text{l})$	+34.8	+10.0
$\text{Fe}_2\text{O}_3(\text{s})$	+87.5	-742



- (i) Calculate the standard free energy change, $\Delta G^\ominus$, in kJ mol^{-1} , by using values of the standard free energy change of formation, $\Delta G_f^\ominus$, from the table above. [2]

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- (ii) Calculate the standard entropy change, $\Delta S^\ominus$, in $\text{JK}^{-1}\text{mol}^{-1}$, by using values of standard entropy, $S^\ominus$, from the table. [1]

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- (iii) Calculate the standard free energy change, $\Delta G^\ominus$, for the reaction using $\Delta H^\ominus$ and $\Delta S^\ominus$ values at 25°C . [2]

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Topic Chem 5 Q# 95/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Table 11/ www.SmashingScience.org

3. Propane, $\text{C}_3\text{H}_8(\text{g})$, undergoes complete combustion to form carbon dioxide, $\text{CO}_2(\text{g})$, and water, $\text{H}_2\text{O}(\text{g})$.

- (a) State an equation for the complete combustion of propane, $\text{C}_3\text{H}_8(\text{g})$. [1]

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- (b) Calculate the standard enthalpy change for the reaction in part (a) using bond enthalpy values given in table 10 of the data booklet. [3]

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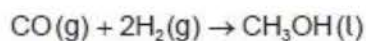
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3. Carbon monoxide reacts with hydrogen to produce methanol.



Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$\Delta G_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J mol}^{-1} \text{K}^{-1}$
CO (g)	-110.5	-137.2	+197.6
CH ₃ OH (l)	-239.0	-166.0	+126.8

(a) Calculate the standard enthalpy change, $\Delta H^\ominus$, in kJ mol^{-1} , for the reaction. [1]

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(b) Calculate the standard free energy change, $\Delta G^\ominus$, in kJ mol^{-1} , for the reaction ($\Delta G_f^\ominus(\text{H}_2) = 0 \text{ kJ mol}^{-1}$). [1]

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(c) Using the values obtained in parts (a) and (b), calculate the standard entropy change, $\Delta S^\ominus$, in $\text{J mol}^{-1} \text{K}^{-1}$, for the reaction at 298 K. [1]

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(d) Determine the absolute entropy, $S^\ominus$, in $\text{J mol}^{-1} \text{K}^{-1}$, for $\text{H}_2(\text{g})$ at 298 K. [2]

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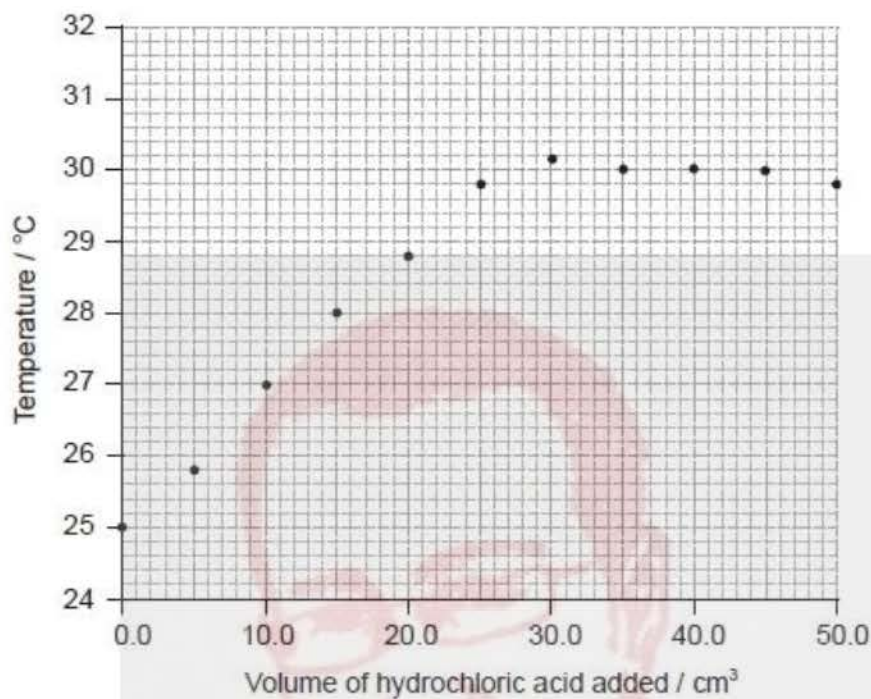
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1. A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added 5.0 cm^3 portions of hydrochloric acid to 25.0 cm^3 of 1.00 mol dm^{-3} sodium hydroxide solution in a glass beaker until the total volume of acid added was 50.0 cm^3 , measuring the temperature of the mixture each time. Her results are plotted in the graph below.



The initial temperature of both solutions was the same.

- (a) (i) By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the 25.0 cm^3 of sodium hydroxide solution. [2]

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- (ii) Determine the concentration of the hydrochloric acid, including units. [2]

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- (b) (i) Determine the change in temperature, ΔT . [1]

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- (ii) Calculate the enthalpy change, in kJ mol^{-1} , for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

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- (iii) The accepted theoretical value from the literature of this enthalpy change is -58 kJ mol^{-1} . Calculate the percentage error correct to **two** significant figures. [1]

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- (iv) Suggest the major source of error in the experimental procedure **and** an improvement that could be made to reduce it. [2]

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- (g) Determine the standard enthalpy change of formation, $\Delta H_f^\ominus$, of NaCl(s), in kJ mol^{-1} , using a Born-Haber cycle and tables 7, 10 and 13 of the data booklet. The standard enthalpy change of atomization (standard enthalpy change of sublimation), $\Delta H_{\text{at}}^\ominus$, of Na(s) is $+108 \text{ kJ mol}^{-1}$.

[4]

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- (b) (i) Define the term *average bond enthalpy*.

[2]

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- (ii) Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in kJ mol^{-1} , using the values in table 10 of the data booklet, assuming all reactants and products are gaseous.

[4]

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- (c) Students can also measure the enthalpy of combustion of ethanol in the laboratory using calorimetry. Suggest the major source of systematic error in these procedures.

[1]

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- (f) (i) The standard enthalpy change of combustion, $\Delta H_c^\ominus$, of propanoic acid is $-1527 \text{ kJ mol}^{-1}$. Determine the standard enthalpy change of formation of propanoic acid, in kJ mol^{-1} , using this information and data from table 12 of the data booklet.

[4]

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- (ii) Deduce, giving a reason, the sign of the standard entropy change of the system for the formation of propanoic acid from its elements.

[2]

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Topic Chem 6 Q# 100/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q7./ www.SmashingScience.org :o)

6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

- (ii) Copper(II) chloride is used as a catalyst in the production of chlorine from hydrogen chloride.



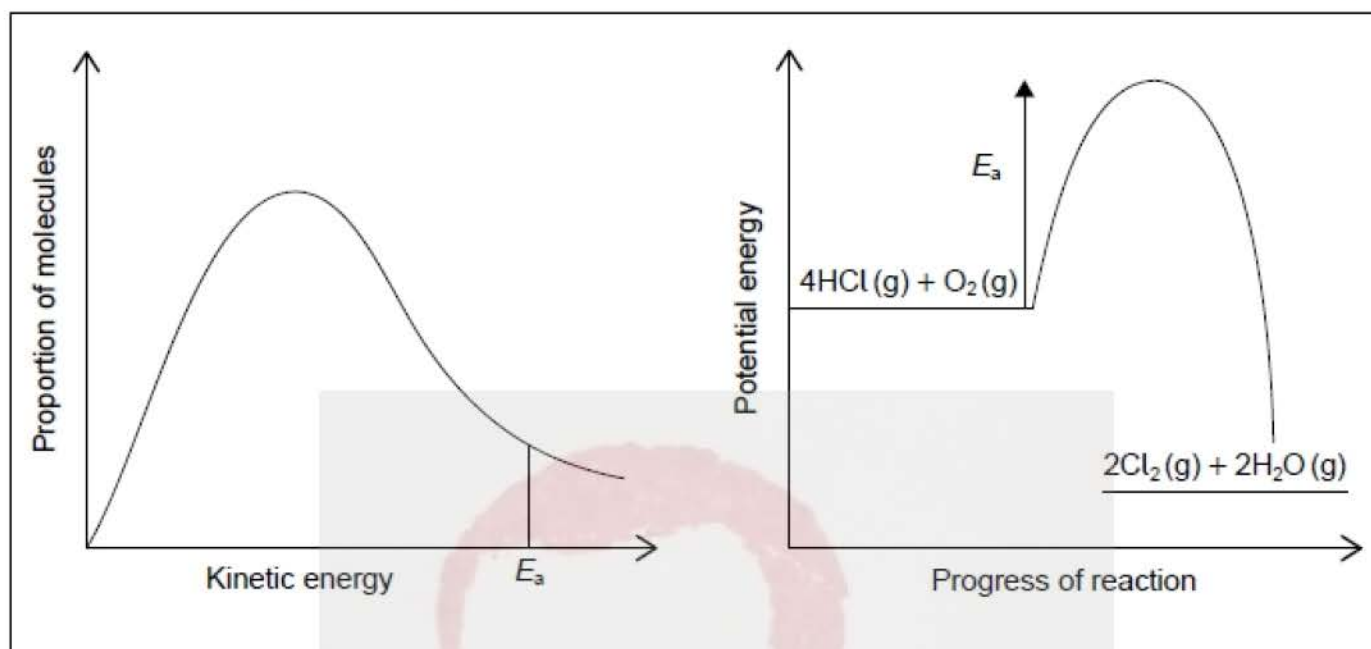
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- (iii) The diagram shows the Maxwell–Boltzmann distribution and potential energy profile for the reaction without a catalyst.

Annotate both charts to show the activation energy for the catalysed reaction, using the label $E_{a(\text{cat})}$.

[2]



- (iv) Explain how the catalyst increases the rate of the reaction.

[2]

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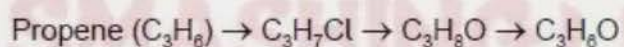
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Topic Chem 6 Q# 101/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q4./ www.SmashingScience.org :o)

3. Propene is an important starting material for many products. The following shows some compounds which can be made from propene, C_3H_6 .



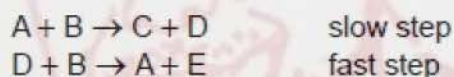
- (b) An experiment was carried out to determine the order of reaction between one of the isomers of C_3H_7Cl and aqueous sodium hydroxide. The following results were obtained.

Experiment	$[C_3H_7Cl] / \text{mol dm}^{-3}$	$[OH^-] / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.05	0.10	3.1×10^{-4}
2	0.10	0.20	1.3×10^{-3}
3	0.15	0.10	9.2×10^{-4}

- (i) Determine the rate expression from the results, explaining your method. [3]

Topic Chem 6 Q# 102/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q10/ www.SmashingScience.org :o)

10. The following mechanism is proposed for a reaction:



- (a) Classify substances B and D as reactant, product, catalyst, or intermediate, based on the proposed mechanism. [2]

B:

.....

D:

.....

- (b) Deduce the rate expression. [1]



- (c) Calculate the initial rate of reaction for experiment 2, if measured under the same conditions.

[1]

Experiment	[A] / mol dm ⁻³	[B] / mol dm ⁻³	Initial rate / mol dm ⁻³ s ⁻¹
1	0.200	0.200	1.20
2	0.300	0.200	

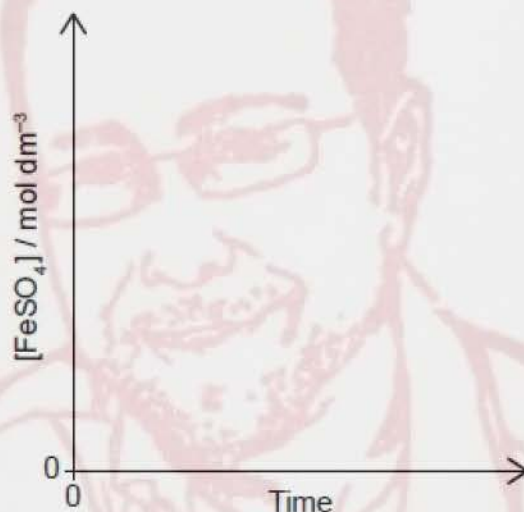
Topic Chem 6 Q# 103/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

1. 3.26 g of iron powder are added to 80.0 cm³ of 0.200 mol dm⁻³ copper(II) sulfate solution. The following reaction occurs:



- (c) (i) Sketch a graph of the concentration of iron(II) sulfate, FeSO₄, against time as the reaction proceeds.

[2]



- (ii) Outline how the initial rate of reaction can be determined from the graph in part (c)(i).

[2]

- (iii) Explain, using the collision theory, why replacing the iron powder with a piece of iron of the same mass slows down the rate of the reaction.

[2]



4. Calcium carbonate reacts with hydrochloric acid.



- (a) Outline **two** ways in which the progress of the reaction can be monitored. No practical details are required.

[2]

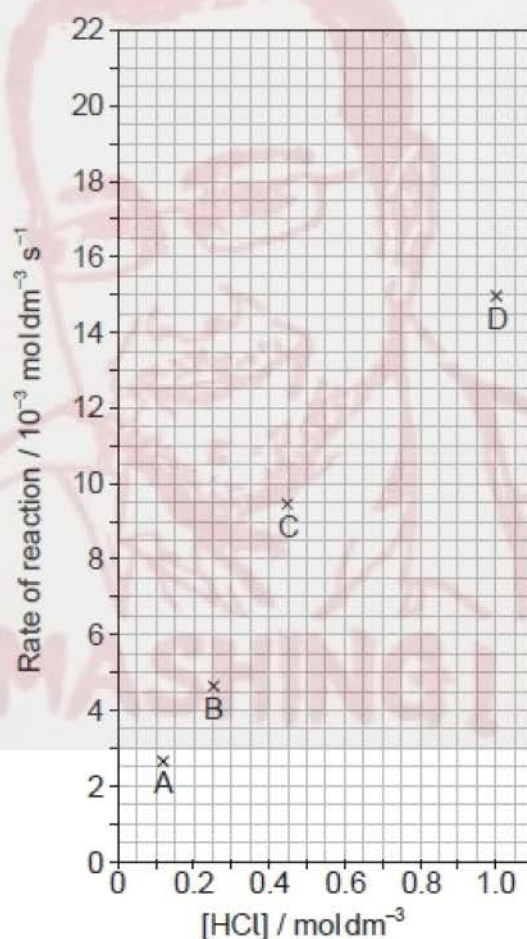
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- (b) The results of a series of experiments in which the concentration of HCl was varied are shown below.



- (i) Suggest why point D is so far out of line assuming human error is not the cause. [1]

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- (ii) Draw the best fit line for the reaction excluding point D. [1]

- (iii) Suggest the relationship that points A, B and C show between the concentration of the acid and the rate of reaction. [1]

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- (iv) Deduce the rate expression for the reaction. [1]

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- (v) Calculate the rate constant of the reaction, stating its units. [2]

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- (c) Predict from your line of best fit the rate of reaction when the concentration of HCl is 1.00 mol dm^{-3} . [1]

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(d) Describe how the activation energy of this reaction could be determined.

[3]

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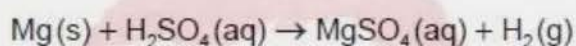
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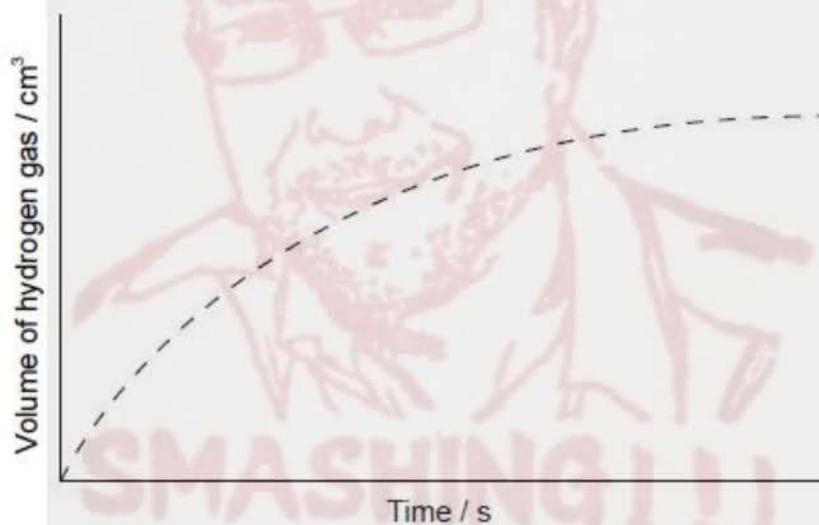
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Topic Chem 6 Q# 105/ IB Chem/2017/s/TZ 2/Paper 2/Higher Level/Q5/ www.SmashingScience.org :o)

5. (a) Magnesium reacts with sulfuric acid:



The graph shows the results of an experiment using excess magnesium ribbon and dilute sulfuric acid.



(i) Outline why the rate of the reaction decreases with time.

[1]

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(ii) Sketch, on the same graph, the expected results if the experiment were repeated using powdered magnesium, keeping its mass and all other variables unchanged.

[1]

(b) Nitrogen dioxide and carbon monoxide react according to the following equation:

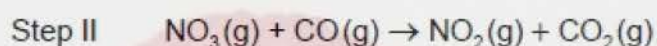
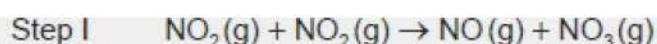


Experimental data shows the reaction is second order with respect to NO_2 and zero order with respect to CO .

(i) State the rate expression for the reaction. [1]

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(ii) The following mechanism is proposed for the reaction.



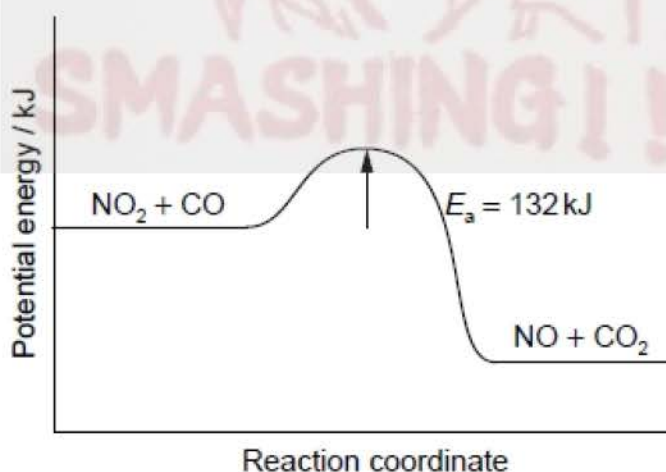
Identify the rate determining step giving your reason. [1]

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.....

(iii) State one method that can be used to measure the rate for this reaction. [1]

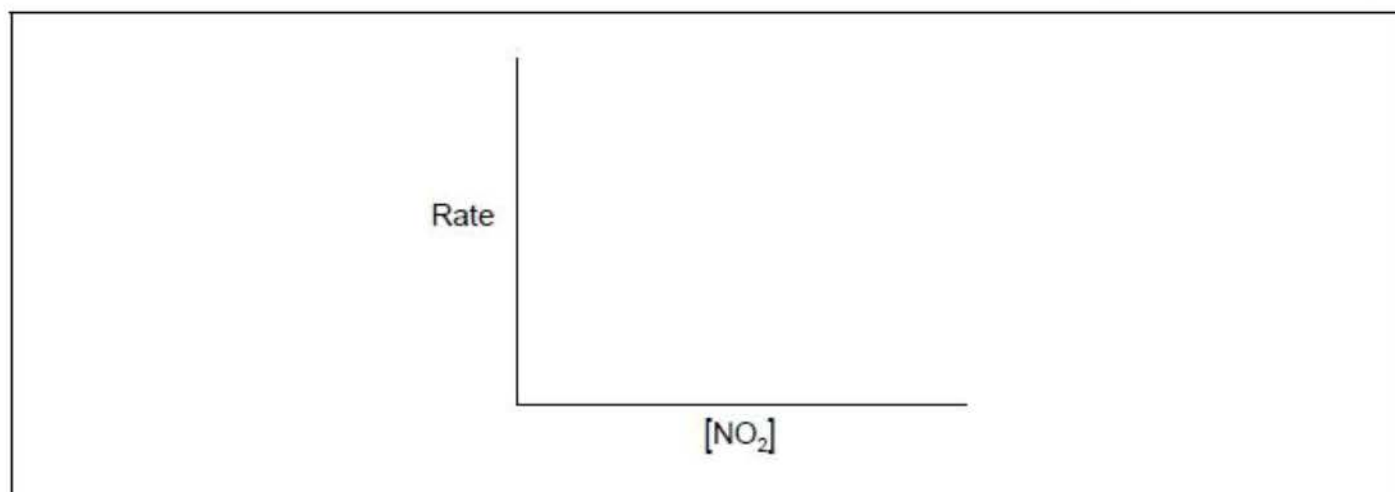
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(iv) Calculate the activation energy for the reverse reaction. [1]



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- (v) Sketch the relationship between the rate of reaction and the concentration of NO_2 . [1]



- (c) The Arrhenius equation, $k = Ae^{\frac{-E_a}{RT}}$, gives the relationship between the rate constant and temperature.

State how temperature affects activation energy.

[1]

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- (d) State the equation for the reaction of NO_2 in the atmosphere to produce acid deposition.

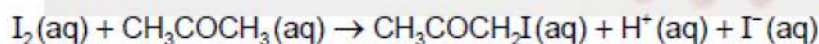
[1]

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Topic Chem 6 Q# 106/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

1. The rate of the acid-catalysed iodination of propanone can be followed by measuring how the concentration of iodine changes with time.



The general form of the rate equation is:

$$\text{Rate} = [\text{H}_3\text{CCOCH}_3(\text{aq})]^m \times [\text{I}_2(\text{aq})]^n \times [\text{H}^+(\text{aq})]^p$$

The reaction is first order with respect to propanone.

- (a) (i) Suggest how the change of iodine concentration could be followed.

[1]

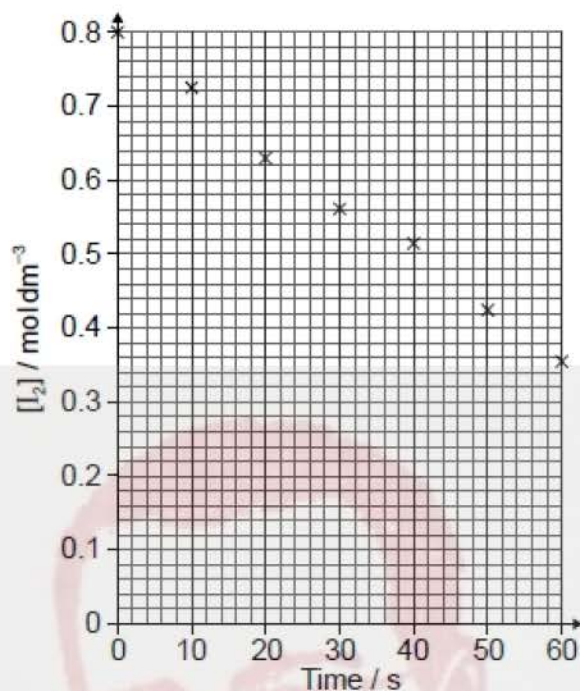
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- (ii) A student produced these results with $[H^+] = 0.15 \text{ mol dm}^{-3}$. Propanone and acid were in excess and iodine was the limiting reagent.

Determine the relative rate of reaction when $[H^+] = 0.15 \text{ mol dm}^{-3}$.

[2]



- (b) The student then carried out the experiment at other acid concentrations with all other conditions remaining unchanged.

$[H^+] / \text{mol dm}^{-3}$	Relative rate of reaction
0.05	0.0025
0.10	0.0051
0.20	0.0100

Determine the relationship between the rate of reaction and the concentration of acid and the order of reaction with respect to hydrogen ions.

[2]

Relationship:

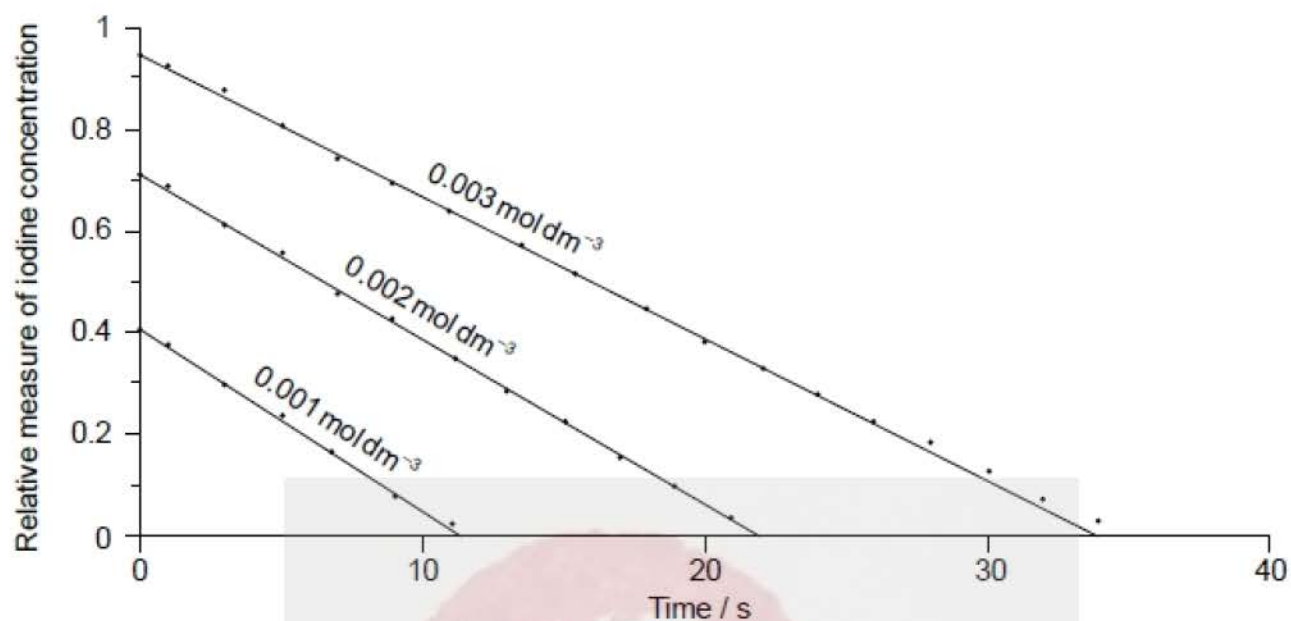
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Order of reaction with respect to $[H^+]$:

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- (c) When the concentration of iodine is varied, while keeping the concentrations of acid and propanone constant, the following graphs are obtained.



Deduce, giving your reason, the order of reaction with respect to iodine.

[2]

Order with respect to iodine:

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Reason:

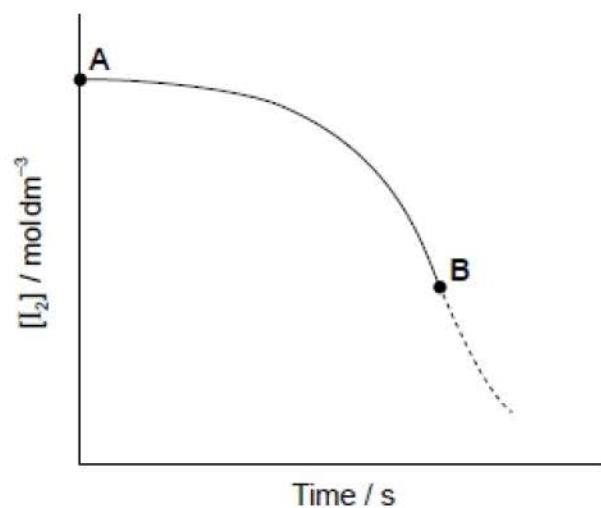
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(d) When the reaction is carried out in the absence of acid the following graph is obtained.



Discuss the shape of the graph between A and B.

[2]

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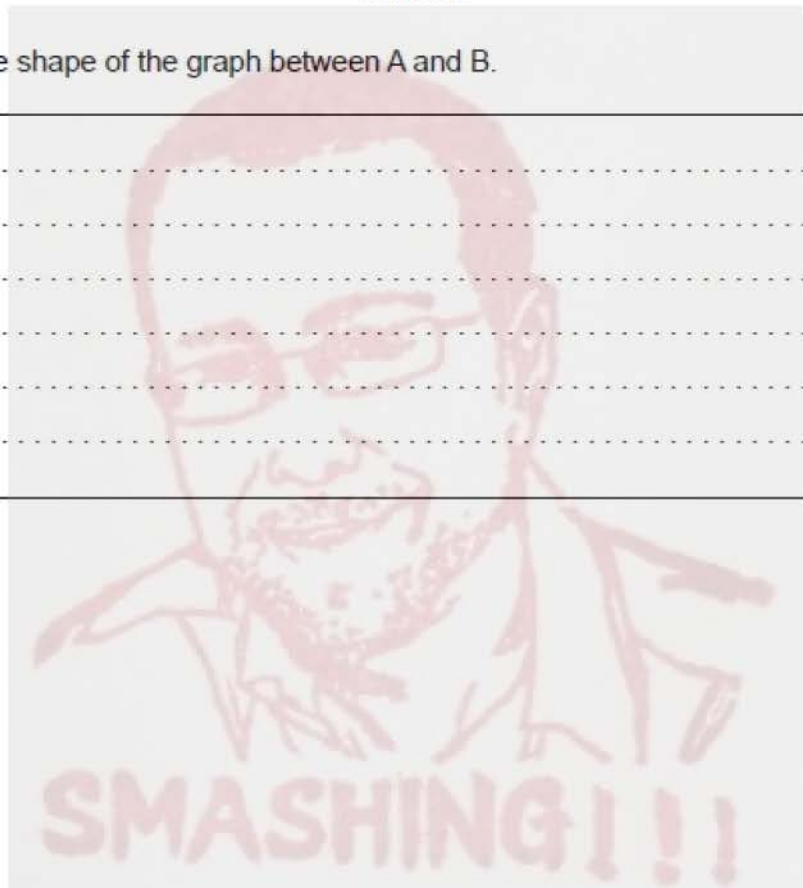
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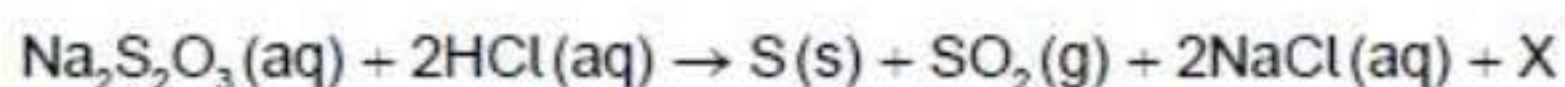
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3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.



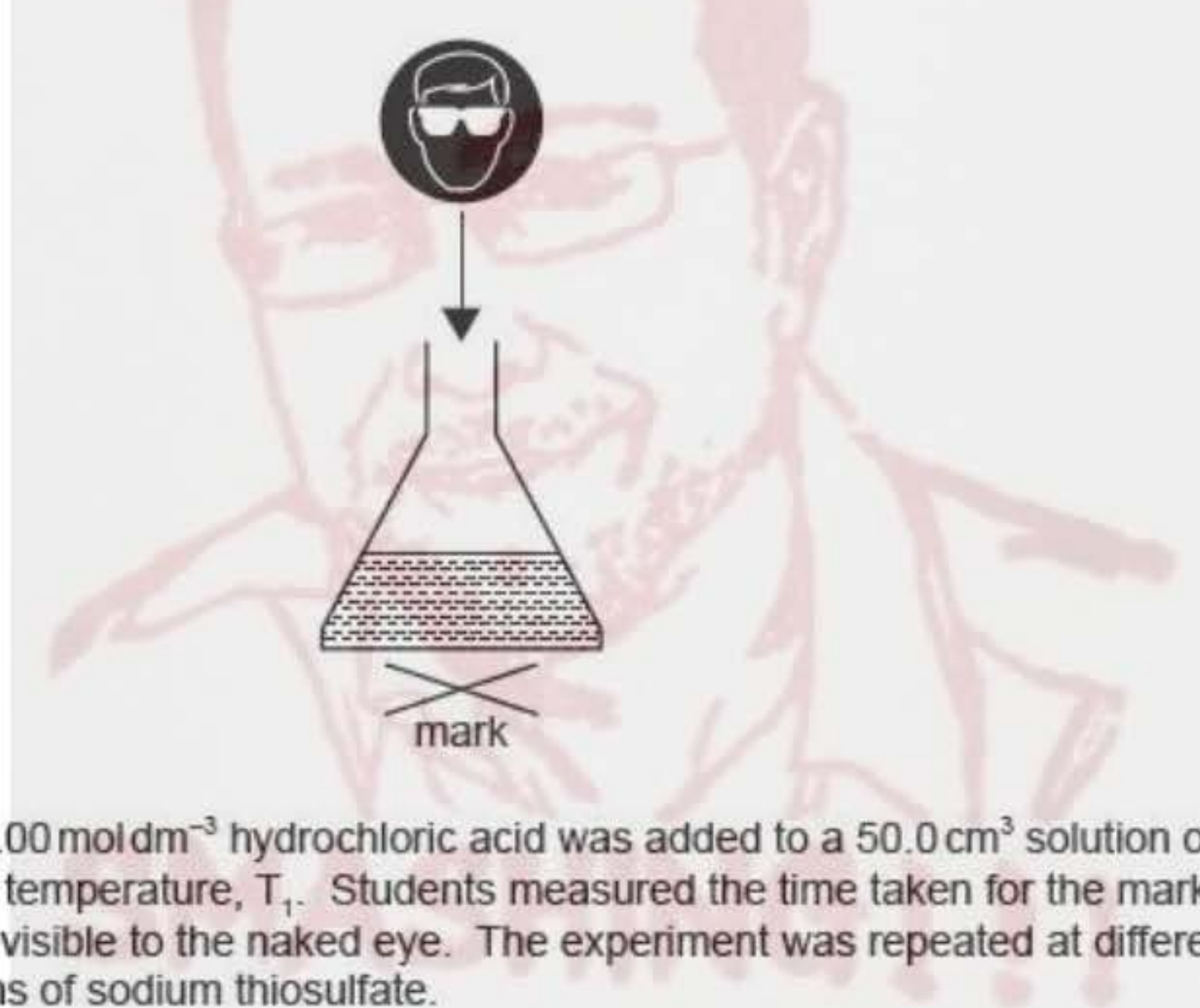
- (a) Identify the formula and state symbol of X.

[1]

- (b) Suggest why the experiment should be carried out in a fume hood or in a well-ventilated laboratory.

[1]

- (c) The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.



10.0 cm³ of 2.00 mol dm⁻³ hydrochloric acid was added to a 50.0 cm³ solution of sodium thiosulfate at temperature, T₁. Students measured the time taken for the mark to be no longer visible to the naked eye. The experiment was repeated at different concentrations of sodium thiosulfate.

Experiment	[Na ₂ S ₂ O ₃ (aq)] / mol dm ⁻³	Time, t, for mark to disappear / s ± 1 s	$\frac{1}{t} / 10^{-3} \text{ s}^{-1}$
1	0.150	23	43.5
2	0.120	27	37.0
3	0.090	36	27.8
4	0.060	60	16.7
5	0.030	111	9.0

* The reciprocal of the time in seconds can be used as a measure of the rate of reaction.

[Source: Adapted from <http://www.flinnsci.com/>]



Show that the hydrochloric acid added to the flask in experiment 1 is in excess.

[2]

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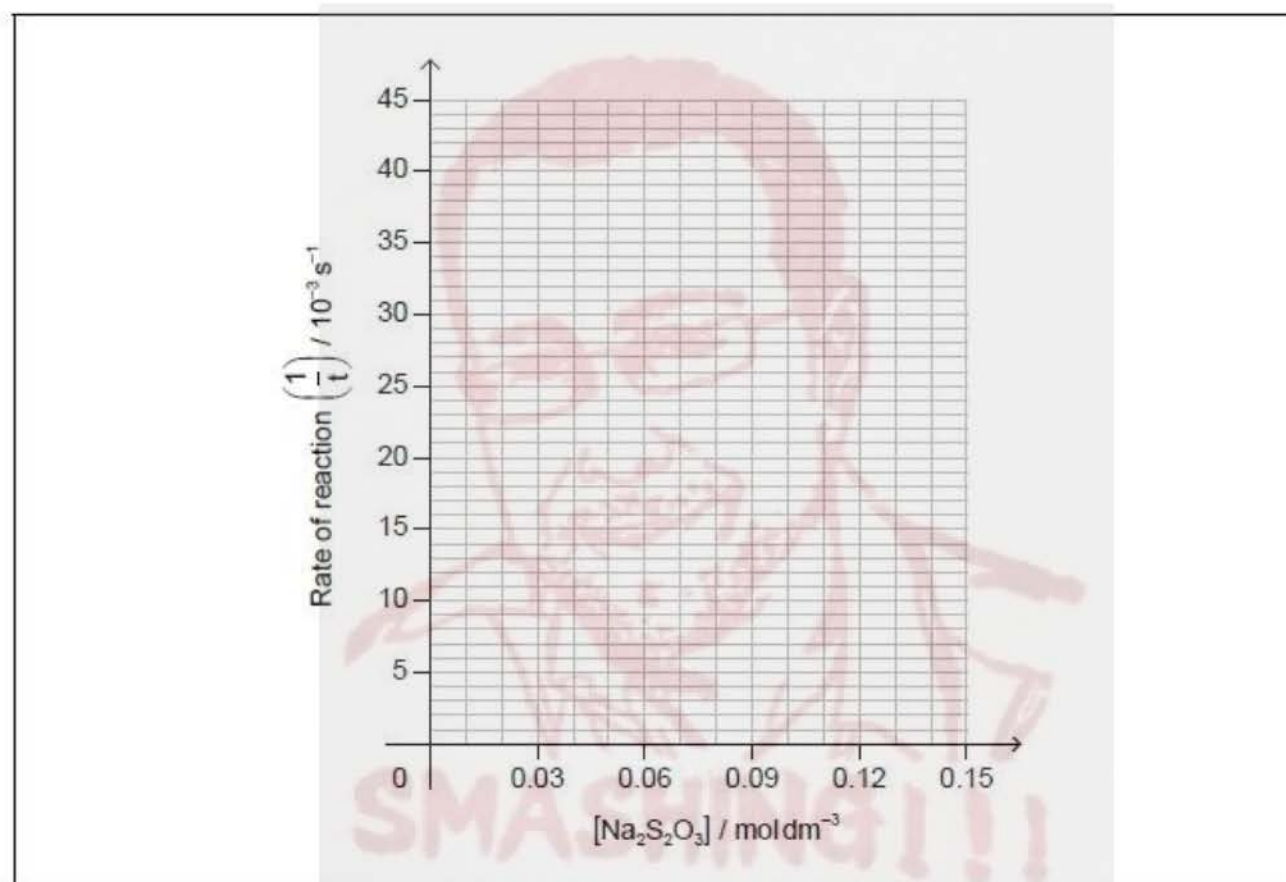
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- (d) Draw the best fit line of $\frac{1}{t}$ against concentration of sodium thiosulfate on the axes provided.

[2]



- (e) (i) Using the graph, explain the order of reaction with respect to sodium thiosulfate.

[2]

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- (ii) In a different experiment, this reaction was found to be first order with respect to hydrochloric acid. Deduce the overall rate expression for the reaction.

[1]

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- (f) A student decided to carry out another experiment using $0.075 \text{ mol dm}^{-3}$ solution of sodium thiosulfate under the same conditions. Determine the time taken for the mark to be no longer visible.

[2]

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- (g) An additional experiment was carried out at a higher temperature, T_2 .

- (i) On the same axes, sketch Maxwell–Boltzmann energy distribution curves at the two temperatures T_1 and T_2 , where $T_2 > T_1$.

[2]



(ii) Explain why a higher temperature causes the rate of reaction to increase.

[2]

(h) Suggest one reason why the values of rates of reactions obtained at higher temperatures may be less accurate.

[1]

Topic Chem 6 Q# 108/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q4/ www.SmashingScience.org :o)

(e) Describe what you understand by the term *frequency (pre-exponential) factor, A*.

[1]

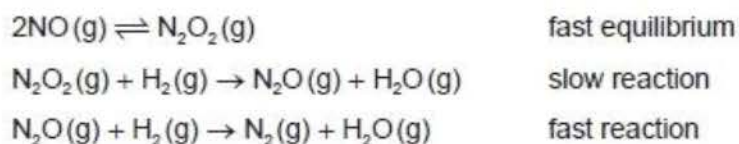
(f) The activation energy, E_a , for the reaction of 1-iodoethane with sodium hydroxide is 87.0 kJ mol^{-1} , and the frequency (pre-exponential) factor, A , is $2.10 \times 10^{11} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$.

Calculate the rate constant, k , of the reaction at 25°C , indicating the units of k , and giving a reason for your choice.

[2]



3. The reaction between hydrogen and nitrogen monoxide is thought to proceed by the mechanism shown below.



- (a) (i) State the equation for the overall reaction. [1]

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- (ii) Deduce the rate expression consistent with this mechanism. [1]

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- (iii) Explain how you would attempt to confirm this rate expression, giving the results you would expect. [3]

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- (iv) State, giving your reason, whether confirmation of the rate expression would prove that the mechanism given is correct.

[1]

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- (v) Suggest how the rate of this reaction could be measured experimentally.

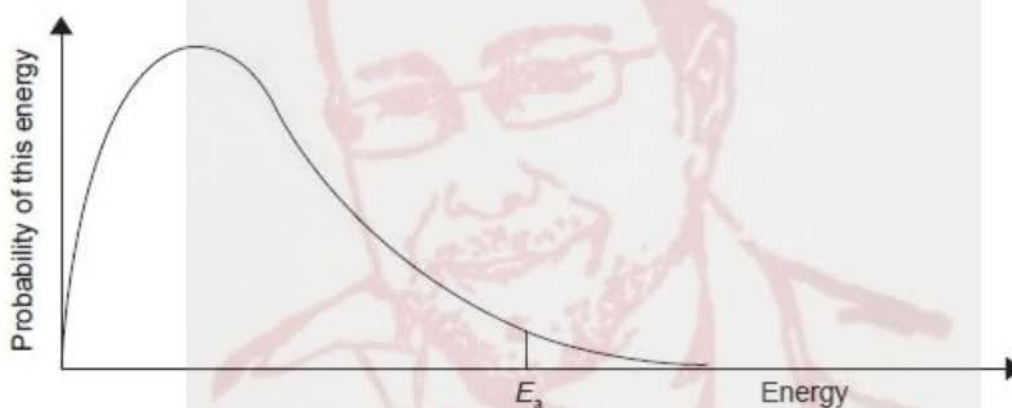
[1]

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(b)

- (iii) Sketch and label a second Maxwell-Boltzmann energy distribution curve representing the same system but at a higher temperature, T_{higher} .

[1]



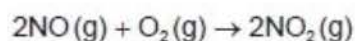
- (iv) Explain why an increase in temperature increases the rate of this reaction.

[2]

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(c) The oxidation of nitrogen monoxide takes place as follows:



The following experimental data was obtained at 101.3 kPa and 298 K.

Experiment	Initial [NO] / mol dm ⁻³	Initial [O ₂] / mol dm ⁻³	Initial rate / mol dm ⁻³ s ⁻¹
1	2.30×10^{-2}	1.15×10^{-2}	1.05×10^{-3}
2	2.30×10^{-2}	2.30×10^{-2}	2.09×10^{-3}
3	4.60×10^{-2}	4.60×10^{-2}	1.68×10^{-2}

(i) Deduce the orders of reaction with respect to O₂ and NO. [2]

Order with respect to O₂:

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Order with respect to NO:

.....

(ii) State the rate expression for the reaction. [1]

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(iii) Calculate the value of the rate constant, *k*, and include its units. [2]

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- (iv) Suggest a mechanism that is consistent with the rate expression, indicating the rate-determining step.

[3]

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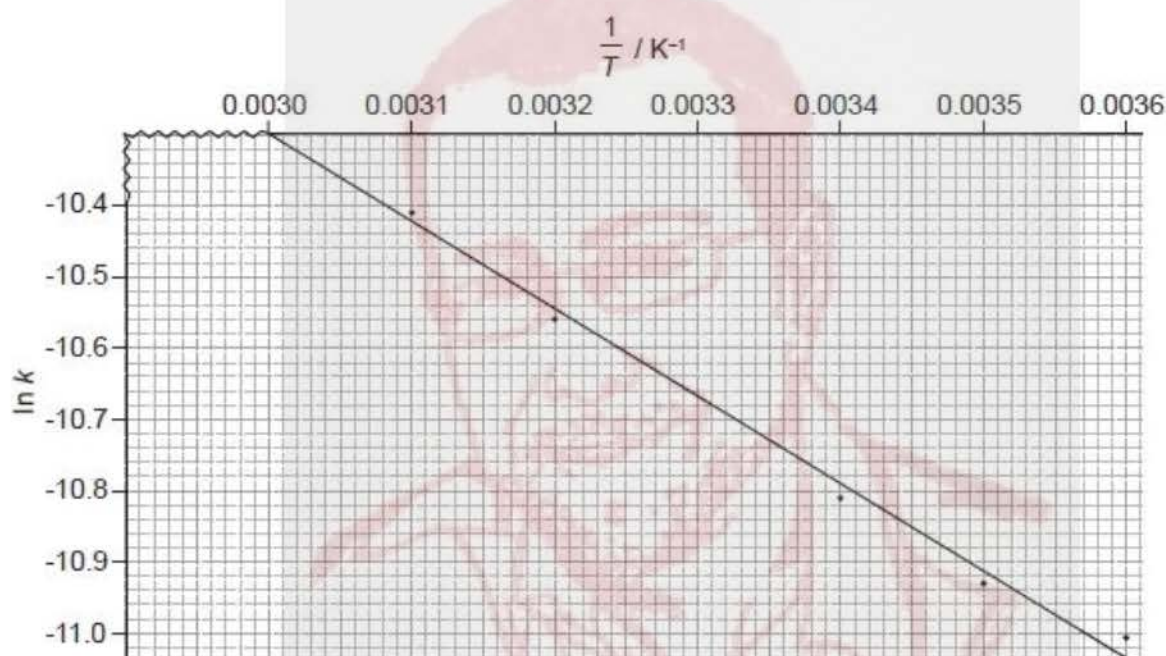
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Topic Chem 6 Q# 111/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q1/ www.SmashingScience.org :o)

- (f) The student found by further experimentation that oxidation of ascorbic acid follows first-order kinetics. The graph of $\ln k$ against $\frac{1}{T}$ is shown below. Determine the activation energy to **three** significant figures, including units.

[3]



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2. (a) Define the term *rate of reaction*.

[1]

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(b) Explain why increasing the particle size of a solid reactant decreases the rate of reaction.

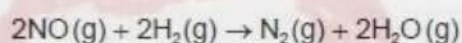
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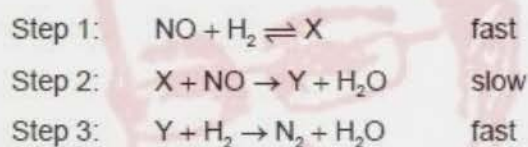
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(c) Nitrogen(II) oxide reacts with hydrogen according to the equation below.



A suggested mechanism for this reaction is:



(i) Identify the rate-determining step.

[1]

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(ii) A student hypothesized that the order of reaction with respect to H_2 is 2. Evaluate this hypothesis.

[2]

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- (c) (i) Determine the orders of reaction of the reactants and the overall rate expression for the reaction between 2-bromobutane and aqueous sodium hydroxide using the data in the table.

Experiment	[NaOH] / mol dm ⁻³	[C ₄ H ₉ Br] / mol dm ⁻³	Rate / mol dm ⁻³ s ⁻¹
1	1.00	1.00	1.66 × 10 ⁻³
2	0.50	1.00	8.31 × 10 ⁻⁴
3	0.25	0.25	1.02 × 10 ⁻⁴
4	1.00	0.50	8.29 × 10 ⁻⁴

[2]

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- (ii) Determine the rate constant, k , with its units, using the data from experiment 3.

[2]

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- (iii) Identify the molecularity of the rate-determining step in this reaction.

[1]

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3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, $\text{SO}_3(\text{g})$.

(a) Define the term *rate of reaction*.

[1]

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(b) Describe the collision theory.

[3]

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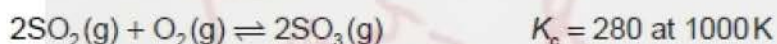
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5. This reaction is used in the manufacture of sulfuric acid.



- (e) 0.200 mol sulfur dioxide, 0.300 mol oxygen and 0.500 mol sulfur trioxide were mixed in a 1.00 dm^3 flask at 1000K.

Predict the direction of the reaction showing your working.

[3]

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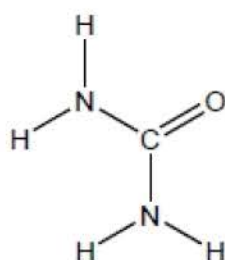
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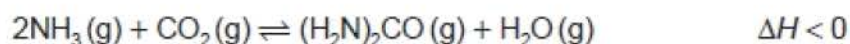
1. Urea, $(\text{H}_2\text{N})_2\text{CO}$, is excreted by mammals and can be used as a fertilizer.



- (b) The structural formula of urea is shown.



- (d) Urea can also be made by the direct combination of ammonia and carbon dioxide gases.



- (i) State the equilibrium constant expression, K_c . [1]

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.....	

- (ii) Predict, with a reason, the effect on the equilibrium constant, K_c , when the temperature is increased. [1]

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- (iii) Determine an approximate order of magnitude for K_c , using sections 1 and 2 of the data booklet. Assume ΔG° for the forward reaction is approximately +50 kJ at 298 K. [2]

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(d) The equilibrium for a mixture of NO_2 and N_2O_4 gases is represented as:



At 100°C , the equilibrium constant, K_c , is 0.21.

- (i) At a given time, the concentration of $\text{NO}_2(\text{g})$ and $\text{N}_2\text{O}_4(\text{g})$ were 0.52 and 0.10 mol dm^{-3} respectively.

Deduce, showing your reasoning, if the forward or the reverse reaction is favoured at this time.

[2]

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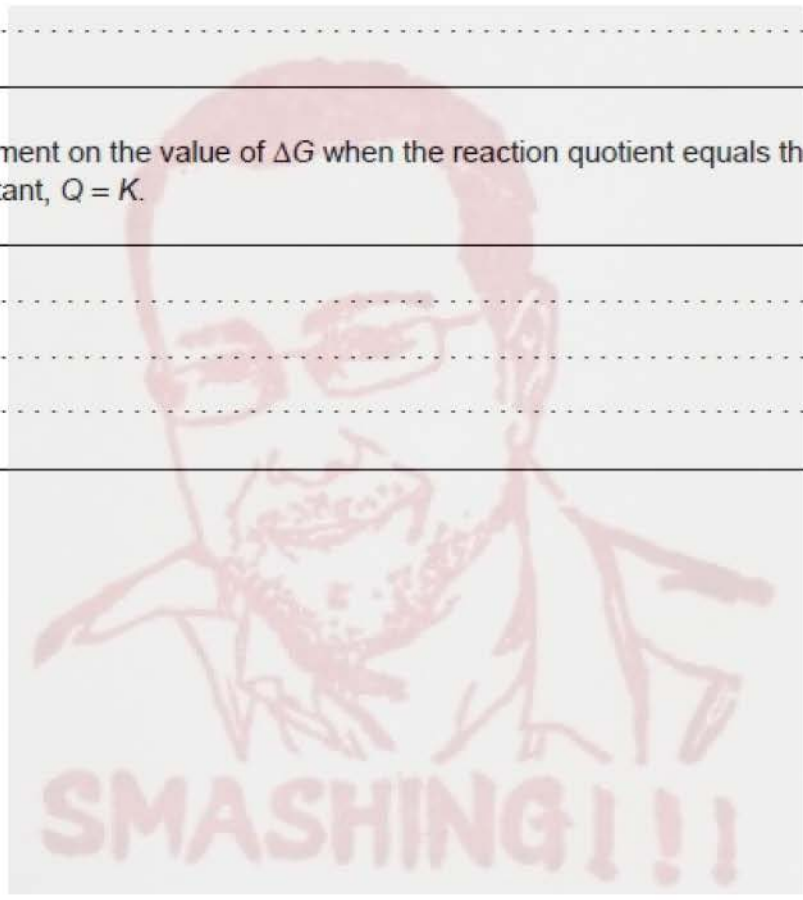
- (ii) Comment on the value of ΔG when the reaction quotient equals the equilibrium constant, $Q = K$.

[2]

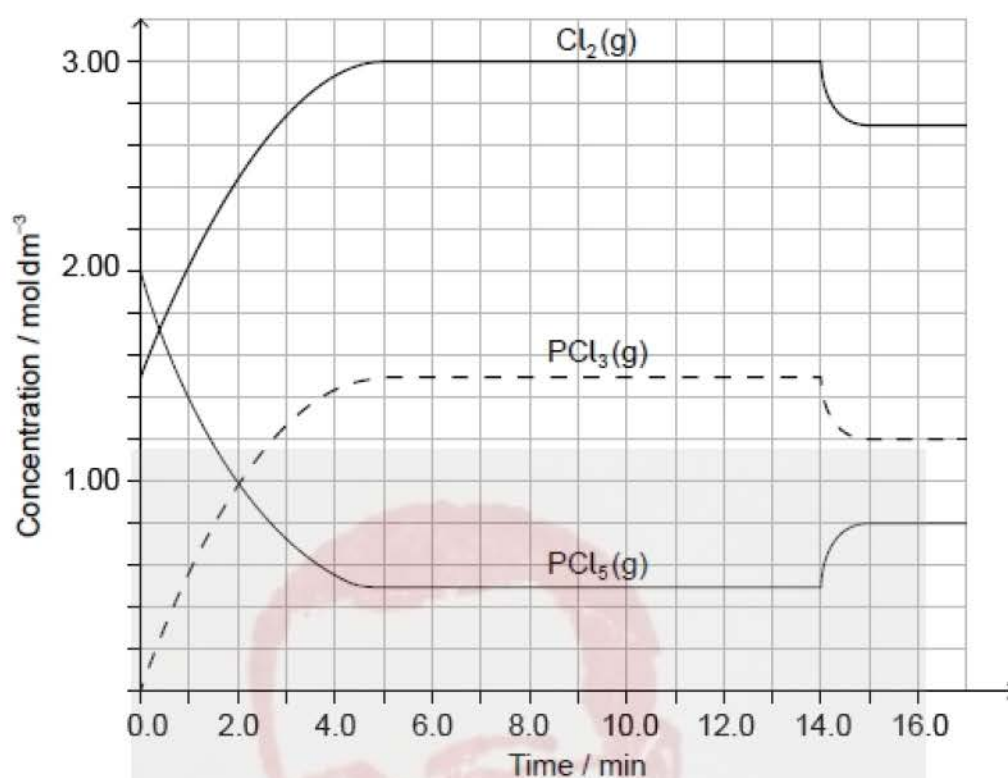
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3. $\text{PCl}_5(\text{g})$ and $\text{Cl}_2(\text{g})$ were placed in a sealed flask and allowed to reach equilibrium at 200°C . The enthalpy change, ΔH , for the decomposition of $\text{PCl}_5(\text{g})$ is positive.



[Source: Source: <http://education.alberta.ca/media>]

- (a) (i) Deduce the equilibrium constant expression, K_c , for the decomposition of $\text{PCl}_5(\text{g})$.

[1]

.....

.....

- (ii) Deduce, giving a reason, the factor responsible for establishing the new equilibrium after 14 minutes.

[2]

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1. Ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(a) Ethane-1,2-diol can be formed according to the following reaction.



- (i) Deduce the equilibrium constant expression, K_c , for this reaction. [1]

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- (ii) State how increasing the pressure of the reaction mixture at constant temperature will affect the position of equilibrium and the value of K_c . [2]

Position of equilibrium:

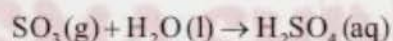
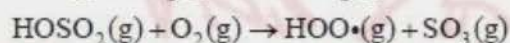
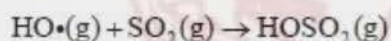
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K_c :

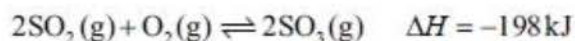
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2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4 . This acid is formed from the sulfur dioxide pollutant, SO_2 .

A mechanism proposed for its formation is:



- (b) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:



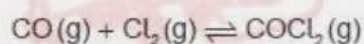
Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below.

[3]

Change	Shift	Reason
Increase in temperature		
Increase in pressure		
Addition of a catalyst to the mixture		

Topic Chem 7 Q# 121/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

2. Phosgene, COCl_2 , is usually produced by the reaction between carbon monoxide and chlorine according to the equation:



- (a) (i) Deduce the equilibrium constant expression, K_c , for this reaction.

[1]

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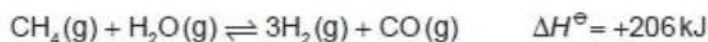
- (ii) At exactly 600°C the value of the equilibrium constant is 0.200. Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, for the reaction, in kJ, using sections 1 and 2 of the data booklet. State your answer to **three** significant figures.

[3]

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7. (a) The following reaction is used in industry to obtain hydrogen from natural gas by partial oxidation with steam.



- (i) Describe the effect, if any, of each of the following changes on the equilibrium amount of hydrogen, giving a reason in each case. [4]

Increasing the pressure, at constant temperature:

.....

Increasing the temperature, at constant pressure:

.....

- (ii) Discuss the effects of adding a solid catalyst to the mixture of methane and steam, at constant pressure and temperature. [3]

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- (iii) Deduce the equilibrium constant expression, K_c , for the reaction. [1]

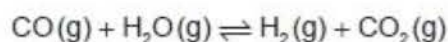
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- (iv) Identify which of the changes in part (a) (i) will affect the value of K_c and whether the value will increase or decrease. [1]

.....



- (b) The equilibrium constant, K_c , for the reaction



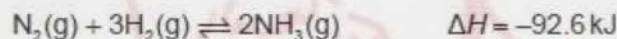
was found to be 10.0 at 420°C.

1.00 mol of CO(g) and 1.00 mol of H₂O(g) are mixed in a 1.00 dm³ container at 420°C. Calculate the equilibrium concentration of each component in the mixture, showing your working.

[3]

Topic Chem 7 Q# 123/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/

7. When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.



The above equation is needed in question (d)(i)

- (d) (i) Deduce the equilibrium constant expression, K_c , for the reaction on page 10. [1]

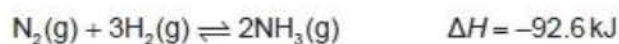
- (ii) When 1.00 mol of nitrogen and 3.00 mol of hydrogen were allowed to reach equilibrium in a 1.00 dm³ container at a temperature of 500 °C and a pressure of 1000 atm, the equilibrium mixture contained 1.46 mol of ammonia.

Calculate the value of K_c at 500 °C.

[2]



7. When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.



- (a) (i) Outline **two** characteristics of a reversible reaction in a state of dynamic equilibrium.

[2]

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- (ii) Predict, with a reason, how each of the following changes affects the position of equilibrium.

[2]

The volume of the container is increased.

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Ammonia is removed from the equilibrium mixture.

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- (iii) Define the term *activation energy*, E_a .

[1]

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- (b) Ammonia is manufactured by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the rate of reaction. [2]

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- (c) Typical conditions used in the Haber process are 500°C and 200 atm, resulting in approximately 15% yield of ammonia.

- (i) Explain why a temperature lower than 500°C is **not** used. [2]

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- (ii) Outline why a pressure higher than 200 atm is **not** often used. [1]

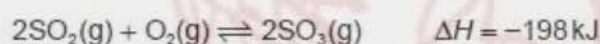
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Topic Chem 7 Q# 125/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, SO₃(g).

- (c) The Contact process involves this homogeneous equilibrium:



- (i) State and explain how increasing the pressure of the reaction mixture affects the yield of SO₃. [2]

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- (ii) 2.00 mol of $\text{SO}_2(\text{g})$ are mixed with 3.00 mol of $\text{O}_2(\text{g})$ in a 1.00 dm^3 container until equilibrium is reached. At equilibrium there are 0.80 mol of $\text{SO}_3(\text{g})$.

Determine the equilibrium constant (K_c) assuming all gases are at the same temperature and pressure.

[4]

[illegible]

- (iii) State the effect of increasing temperature on the value of K_c for this reaction.

[1]

.....

- (d) Outline the economic importance of using a catalyst in the Contact process.

[2]

[illegible]

Topic Chem 8 Q# 126/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q7./ www.SmashingScience.org :o)

6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

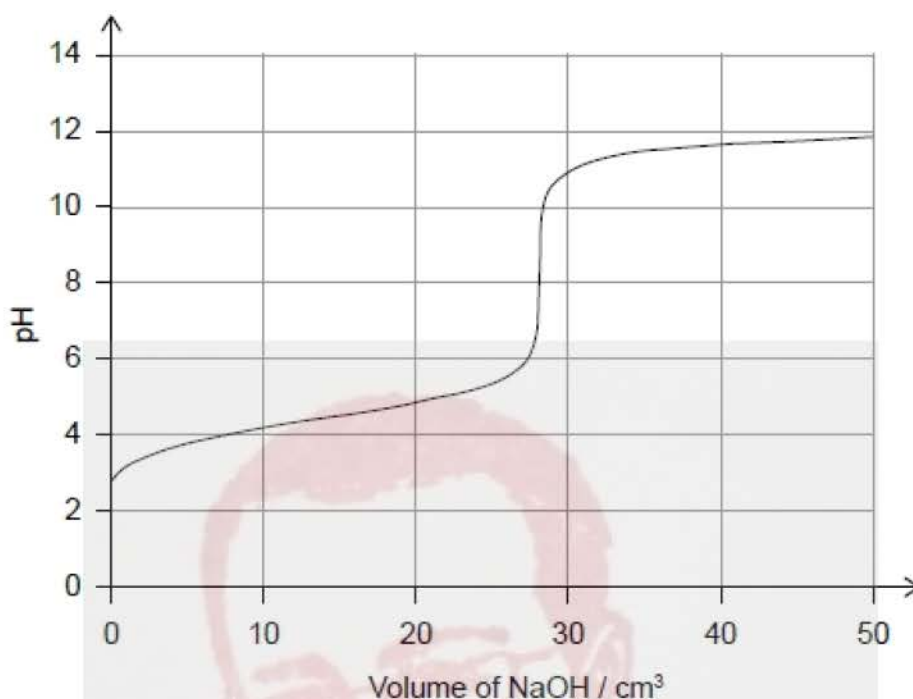
- (iv) Examine the relationship between the Brønsted–Lowry and Lewis definitions of a base, referring to the ligands in the complex ion $[\text{CuCl}_4]^{2-}$.

[2]

[illegible]

5. Another common acid found in food is ethanoic acid.

- (a) A sample of ethanoic acid was titrated with sodium hydroxide solution, and the following pH curve obtained.



Annotate the graph to show the buffer region and the volume of sodium hydroxide at the equivalence point.

[2]

- (b) (i) Identify the most suitable indicator for the titration using section 22 of the data booklet.

[1]

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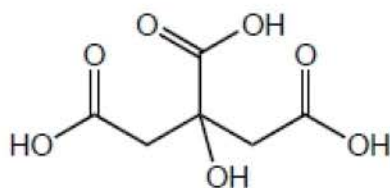
- (ii) Describe, using a suitable equation, how the buffer solution formed during the titration resists pH changes when a small amount of acid is added.

[2]

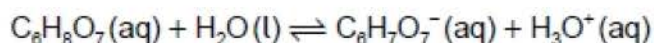
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4. A molecule of citric acid, $C_6H_8O_7$, is shown.



The equation for the first dissociation of citric acid in water is



(a) (i) Identify a conjugate acid–base pair in the equation. [1]

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.....

(ii) The value of K_a at 298 K for the first dissociation is 5.01×10^{-4} .
State, giving a reason, the strength of citric acid. [1]

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.....

(iii) The dissociation of citric acid is an endothermic process. State the effect on the hydrogen ion concentration, $[H^+]$, and on K_a , of increasing the temperature. [2]

Effect on $[H^+]$	Effect on K_a
.....	

(iv) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in kJ mol^{-1} , for the first dissociation of citric acid at 298 K, using section 1 of the data booklet. [1]

.....

.....



(v) Comment on the spontaneity of the reaction at 298 K.

[1]

(b) Outline **two** laboratory methods of distinguishing between solutions of citric acid and hydrochloric acid of equal concentration, stating the expected observations.

[2]

Topic **Chem 8 Q# 129/** IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q6/ www.SmashingScience.org :o)

6. Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is a weak acid and ethylamine, $\text{CH}_3\text{CH}_2\text{NH}_2$, is a weak base.

(a) (i) State the equation for the reaction of each substance with water.

[2]

Butanoic acid:

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.....

Ethylamine:

.....
.....

(ii) Draw a diagram showing the delocalization of electrons in the conjugate base of butanoic acid.

[1]



- (b) (i) A $0.250 \text{ mol dm}^{-3}$ aqueous solution of butanoic acid has a concentration of hydrogen ions, $[\text{H}^+]$, of $0.00192 \text{ mol dm}^{-3}$. Calculate the concentration of hydroxide ions, $[\text{OH}^-]$, in the solution at 298 K.

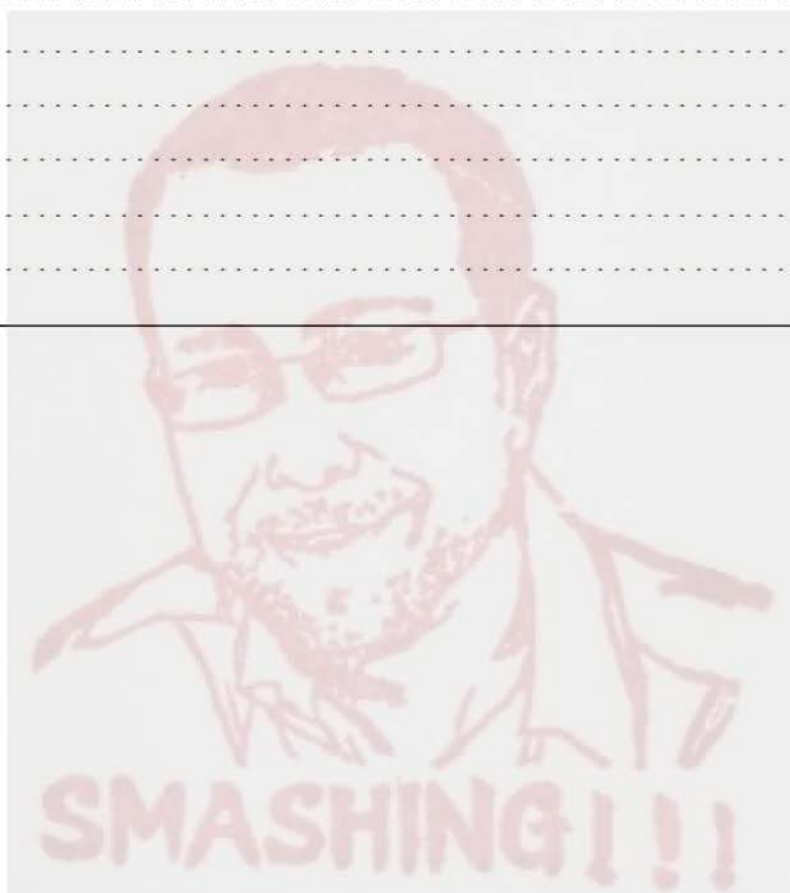
[1]

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- (ii) Determine the pH of a $0.250 \text{ mol dm}^{-3}$ aqueous solution of ethylamine at 298 K, using section 21 of the data booklet.

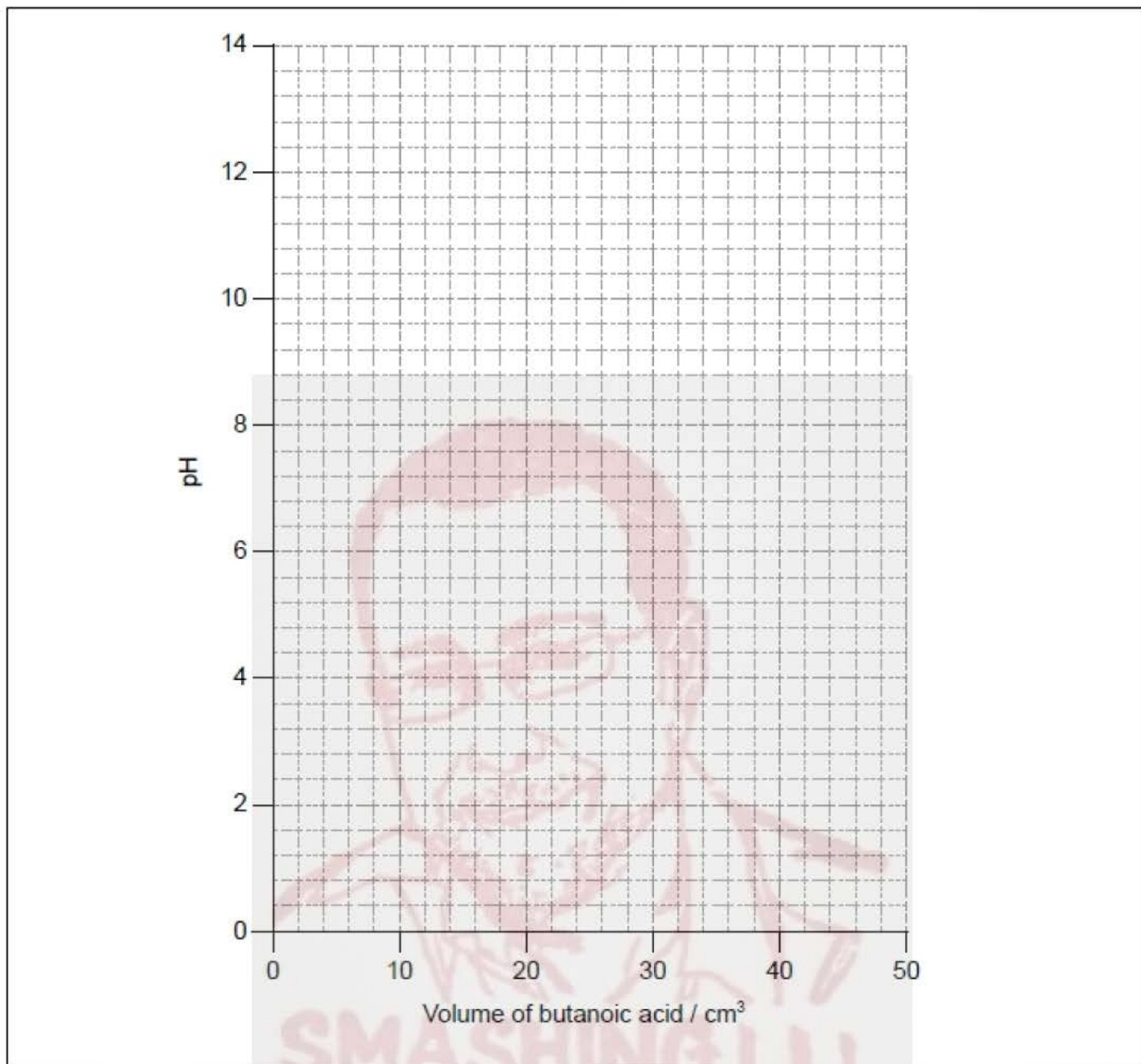
[3]

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- (c) Sketch the pH curve for the titration of 25.0 cm^3 of ethylamine aqueous solution with 50.0 cm^3 of butanoic acid aqueous solution of equal concentration. No calculations are required.

[3]



Topic Chem 8 Q# 130/ IB Chem/2018/s/TZ 1/Paper 2/Higher Level/Q5/ www.SmashingScience.org :o)

5. Limescale, $\text{CaCO}_3(\text{s})$, can be removed from water kettles by using vinegar, a dilute solution of ethanoic acid, $\text{CH}_3\text{COOH}(\text{aq})$.

- (a) Predict, giving a reason, a difference between the reactions of the same concentrations of hydrochloric acid and ethanoic acid with samples of calcium carbonate.

[2]

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- (b) Dissolved carbon dioxide causes unpolluted rain to have a pH of approximately 5, but other dissolved gases can result in a much lower pH. State one environmental effect of acid rain. [1]

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- (c) Write an equation to show ammonia, NH_3 , acting as a Brønsted–Lowry base and a different equation to show it acting as a Lewis base. [2]

Brønsted–Lowry base:

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.....

Lewis base:

.....

.....

- (d) Determine the pH of $0.010 \text{ mol dm}^{-3}$ 2,2-dimethylpropanoic acid solution.

$$K_a(\text{2,2-dimethylpropanoic acid}) = 9.333 \times 10^{-6} \quad [2]$$

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SMASHING!!!

- (e) Explain, using appropriate equations, how a suitably concentrated solution formed by the partial neutralization of 2,2-dimethylpropanoic acid with sodium hydroxide acts as a buffer solution. [2]

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- (f) Calcium carbide reacts with water to form ethyne and calcium hydroxide.

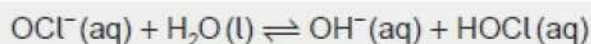


Estimate the pH of the resultant solution.

[1]

8. Soluble acids and bases ionize in water.

- (a) Sodium hypochlorite ionizes in water.



- (i) Identify the amphiprotic species.

[1]

- (ii) Identify one conjugate acid-base pair in the reaction.

[1]

Acid	Base

- (b) A solution containing 0.510g of an unknown monoprotic acid, HA, was titrated with 0.100 mol dm⁻³ NaOH(aq). 25.0 cm³ was required to reach the equivalence point.

- (i) Calculate the amount, in mol, of NaOH(aq) used.

[1]

- (ii) Calculate the molar mass of the acid.

[1]



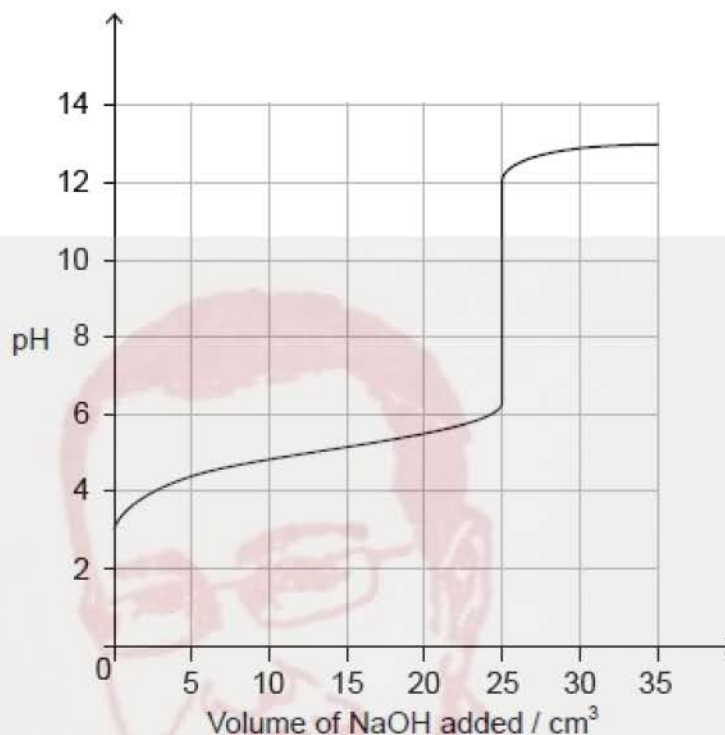
(iii) Calculate $[H^+]$ in the NaOH solution.

[1]

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(iv) The following curve was obtained using a pH probe.



State, giving a reason, the strength of the acid.

[1]

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.....

(v) State a technique other than a pH titration that can be used to detect the equivalence point.

[1]

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.....

(vi) Deduce the pK_a for this acid.

[1]

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- (c) The pK_a of an anthocyanin is 4.35. Determine the pH of a $1.60 \times 10^{-3} \text{ mol dm}^{-3}$ solution to two decimal places.

[3]

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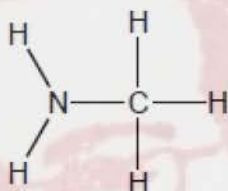
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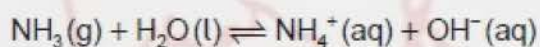
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Topic **Chem 8 Q# 133**/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q5 DATA Booklet T22/
www.SmashingScience.org :o)

5. Two hydrides of nitrogen are ammonia and hydrazine, N_2H_4 . One derivative of ammonia is methanamine whose molecular structure is shown below.



- (c) Ammonia reacts reversibly with water.



Explain the effect of adding $H^+(aq)$ ions on the position of the equilibrium.

[2]

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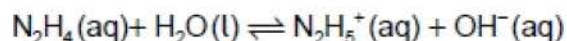
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- (d) (i) Hydrazine reacts with water in a similar way to ammonia. (The association of a molecule of hydrazine with a second H^+ is so small it can be neglected.)



$$\text{p}K_{\text{b}}(\text{hydrazine}) = 5.77$$

Calculate the pH of a $0.0100 \text{ mol dm}^{-3}$ solution of hydrazine.

[3]

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- (ii) Suggest a suitable indicator for the titration of hydrazine solution with dilute sulfuric acid using section 22 of the data booklet.

[1]

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- (e) Outline, using an ionic equation, what is observed when magnesium powder is added to a solution of ammonium chloride.

[2]

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.....

.....



2. The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined by titration with a standard solution of sodium hydroxide, NaOH(aq).

(a) Distinguish between a weak acid and a strong acid.

[1]

Weak acid:

.....

Strong acid:

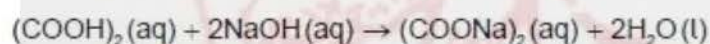
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(b) Suggest why it is more convenient to express acidity using the pH scale instead of using the concentration of hydrogen ions.

[1]

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.....
.....

(c) 5.00 g of an impure sample of hydrated ethanedioic acid, $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a $0.100 \text{ mol dm}^{-3}$ solution of sodium hydroxide using a suitable indicator.



The mean value of the titre was 14.0 cm^3 .

(i) Suggest a suitable indicator for this titration. Use section 22 of the data booklet.

[1]

.....



7. This question is about the weak acid methanoic acid, HCOOH .

- (a) Calculate the pH of $0.0100 \text{ mol dm}^{-3}$ methanoic acid stating any assumption you make.
 $K_a = 1.6 \times 10^{-4}$.

[3]

Calculation:

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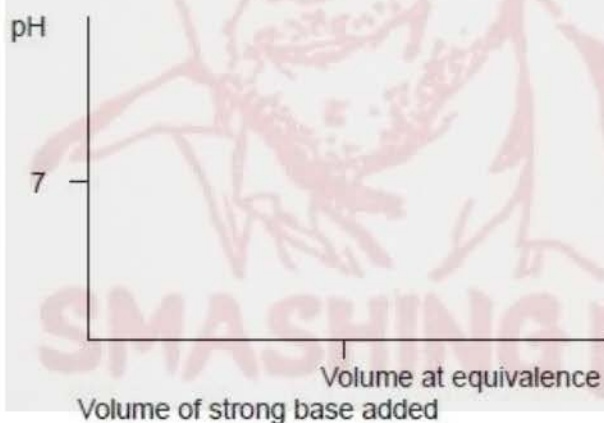
Assumption:

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.....

- (b) (i) Sketch a graph of pH against volume of a strong base added to a weak acid showing how you would determine $\text{p}K_a$ for the weak acid.

[2]



- (ii) Explain, using an equation, why the pH increases very little in the buffer region when a small amount of alkali is added.

[2]

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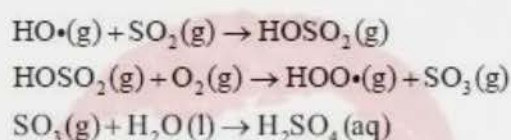
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Topic **Chem 8 Q# 136/** IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4 . This acid is formed from the sulfur dioxide pollutant, SO_2 .

A mechanism proposed for its formation is:



- (a) State what the symbol ($\cdot$) represents in the species shown in this mechanism.

[1]

.....

.....

- (d) Other compounds present in acid rain are formed from nitrogen dioxide, NO_2 . Formulate an equation for the reaction of nitrogen dioxide with water.

[1]

.....



3. A 0.12 mol dm^{-3} sodium methanoate solution dissociates completely into its ions.

- (a) Formulate the equation, including state symbols, for the equilibrium reaction of the hydrolysis of the methanoate anion. [1]

.....

Sections 1 and 21 of the data booklet may be used for parts (b) to (e).

- (b) Calculate the value of K_a , the acid dissociation constant at 298K, for an aqueous solution of methanoic acid. [1]

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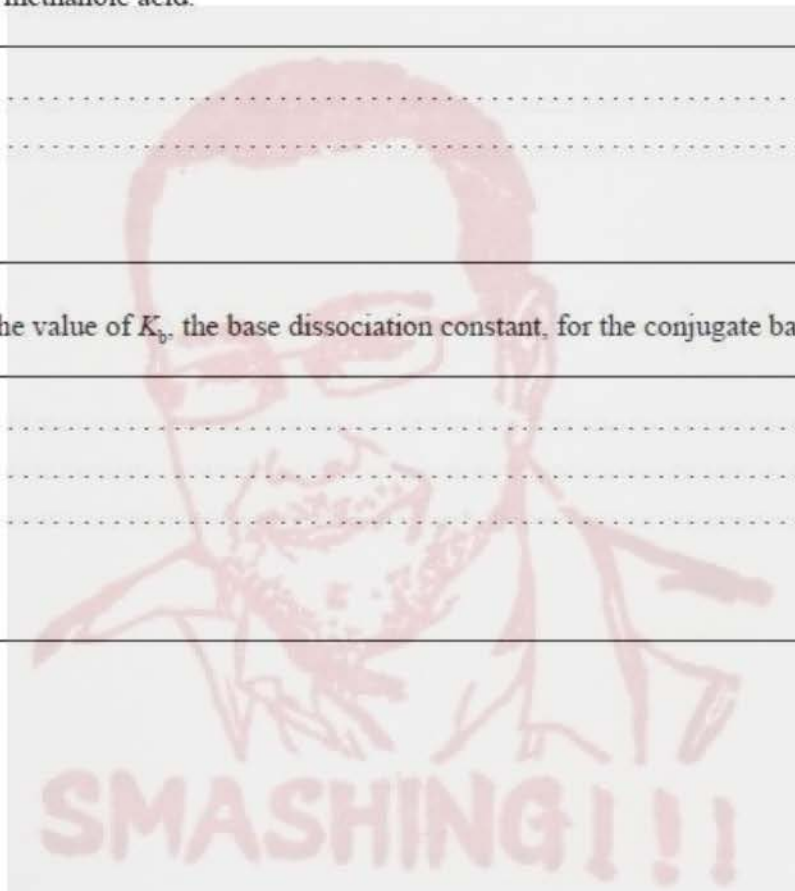
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- (c) Calculate the value of K_b , the base dissociation constant, for the conjugate base. [1]

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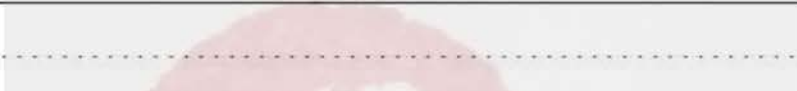
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- (d) Determine the concentration, in mol dm^{-3} , of hydroxide ion, $[\text{OH}^-(\text{aq})]$, in the original 0.12 mol dm^{-3} sodium methanoate solution, mentioning **one** assumption made. [3]

- (e) Calculate the pH of the 0.12 mol dm^{-3} sodium methanoate solution. [2]



Topic **Chem 8 Q# 138**/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q2/ www.SmashingScience.org :o)

- (d) Phenylamine can act as a weak base. Calculate the pH of a $0.0100 \text{ mol dm}^{-3}$ solution of phenylamine at 298 K using section 21 of the data booklet. [4]



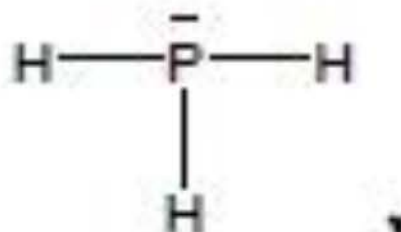
SMASHING!!!

Topic Chem 8 Q# 139/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q1(a) Not with 1(a)(

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 .

It's Lewis structure is this:



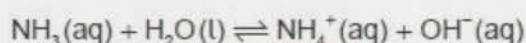


- (iii) Deduce, giving your reason, whether phosphine would act as a Lewis acid, a Lewis base, or neither.

[1]

.....

- (vi) Ammonia acts as a weak Brønsted–Lowry base when dissolved in water.



Outline what is meant by the terms “weak” and “Brønsted–Lowry base”.

[2]

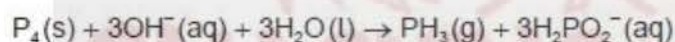
Weak:

.....

Brønsted–Lowry base:

.....

- (b) Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium hydroxide. The equation for the reaction is:



- (ii) The ion H_2PO_2^- is amphoteric. Outline what is meant by amphoteric, giving the formulas of **both** species it is converted to when it behaves in this manner.

[2]

.....



- (iv) State the equation for the reaction of this oxide of phosphorus with water. [1]

.....

.....

- (v) Suggest why oxides of phosphorus are not major contributors to acid deposition. [1]

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.....

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- (vi) The levels of sulfur dioxide, a major contributor to acid deposition, can be minimized by either pre-combustion and post-combustion methods. Outline **one** technique of each method. [2]

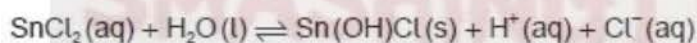
Pre-combustion:	.....
	
Post-combustion:	.....
	
	

Topic Chem 8 Q# 140/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.

(a)

- (iii) Tin(II) chloride reacts with water to precipitate the insoluble basic chloride, Sn(OH)Cl.



- Suggest why tin(II) chloride is usually dissolved in dilute hydrochloric acid. [1]

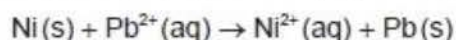
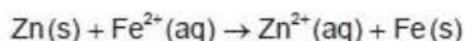
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(d) Consider the following spontaneous reactions.



- (i) Deduce the order of **increasing** reactivity of the metals based on the reactions above.

[2]

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- (ii) Identify the strongest oxidizing agent in the reactions above.

[1]

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- (e) Deduce the half-equations for the formation of the major product at the positive electrode (anode) when the following aqueous solutions are electrolysed.

[2]

Dilute sodium chloride:

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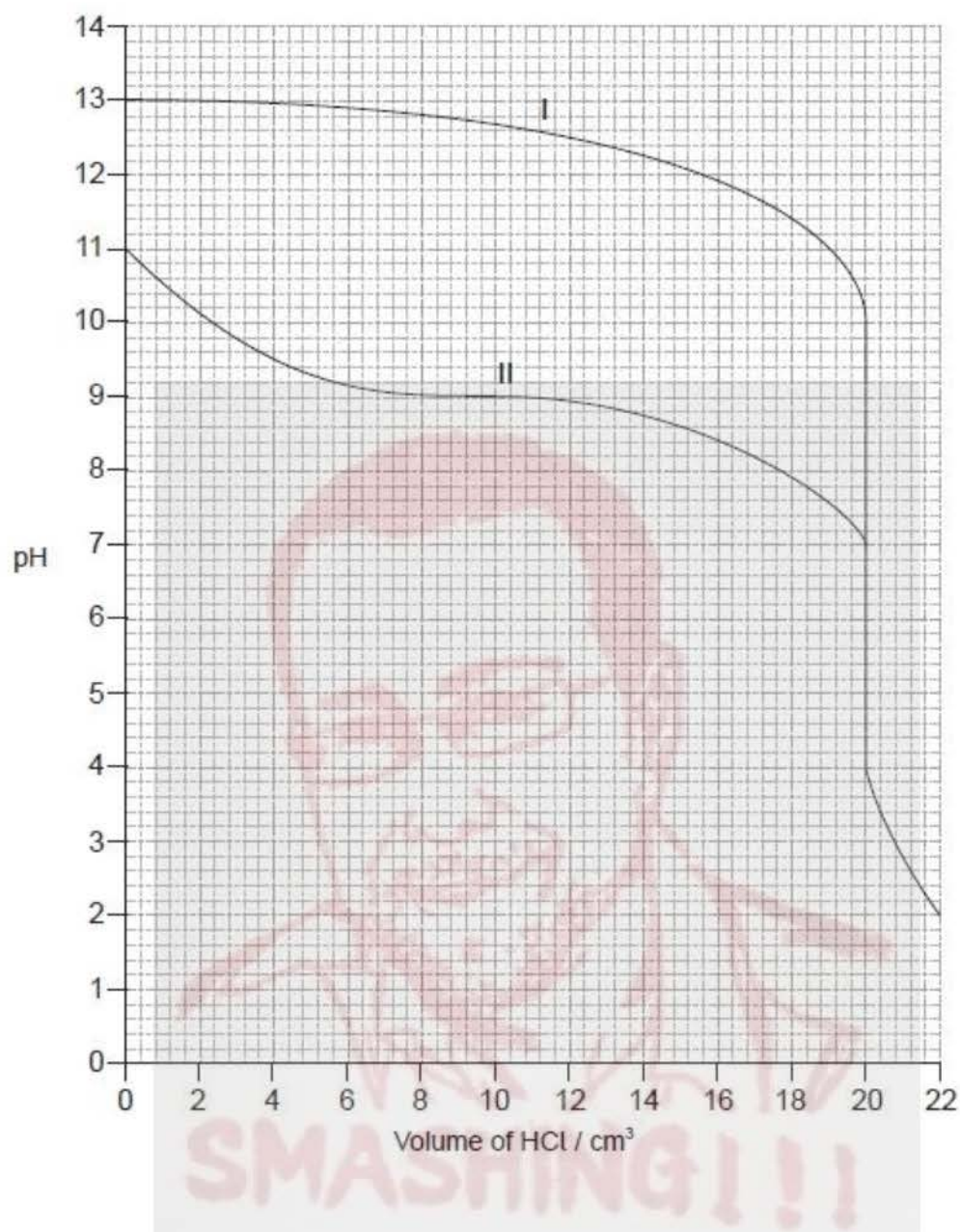
Concentrated sodium chloride:

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.....



8. (a) 20.0 cm^3 aqueous solutions of two bases, each with a concentration of 0.100 mol dm^{-3} were separately titrated with 0.100 mol dm^{-3} hydrochloric acid, HCl(aq) , and the following graph was obtained.



- (i) Deduce the pH at the equivalence points for base I and base II. [2]

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- (ii) Suggest why the titration curve for base I is different from base II. [1]

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- (iii) State the formulas of **two** possible bases which could be used as base I. [1]

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- (iv) Calculate, using data from the graph, the dissociation constant, K_b , of base II, showing your working. [3]

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- (v) Suggest an indicator that can be used for both titrations. [1]

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- (b) (i) State what is meant by the term buffer solution. [2]

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- (ii) Calculate the pH of a solution prepared by mixing 40.0 cm³ of 0.200 mol dm⁻³ NH₃ (aq) and 40.0 cm³ of 0.100 mol dm⁻³ HCl (aq), showing your working. (pK_b NH₃ = 4.75 at 298 K) [3]

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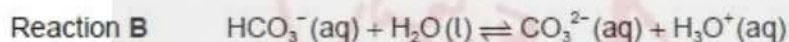
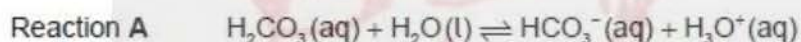
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- (c) The equations of two acid-base reactions are given below.



- (i) Explain whether HCO₃⁻ (aq) behaves as an acid or a base in each of the reactions A and B. [2]

Reaction A:

.....

.....

Reaction B:

.....

.....

- (ii) Deduce **two** conjugate acid-base pairs from reactions A and B. [2]

	Acid	Base
Conjugate acid-base pair 1		
Conjugate acid-base pair 2		



(d) Nitric acid, HNO_3 , and nitrous acid, HNO_2 , are described as strong and weak acids respectively.

(i) Distinguish between *strong* and *weak* acids.

[1]

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.....
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(ii) A 1.00 g sample of solid magnesium carbonate, MgCO_3 , is added to separate solutions of HNO_3 and HNO_2 of the same concentration and temperature. State **one** similarity and **one** difference in the observations made in these reactions.

[2]

Similarity:	.....
	
Difference:	.....
	

(iii) A solution of HNO_3 has a pH of 1, while a solution of HNO_2 has a pH of 5. Determine the ratio of the hydrogen ion concentration in HNO_3 : HNO_2 .

[1]

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Topic **Chem 8 Q# 143**/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q2/ www.SmashingScience.org :o)

(b) $\text{Cu}^{2+}(\text{aq})$ reacts with ammonia to form the complex ion $[\text{Cu}(\text{NH}_3)_4]^{2+}$. Explain this reaction in terms of acid-base theory, and outline the bonding in the complex formed between Cu^{2+} and NH_3 .

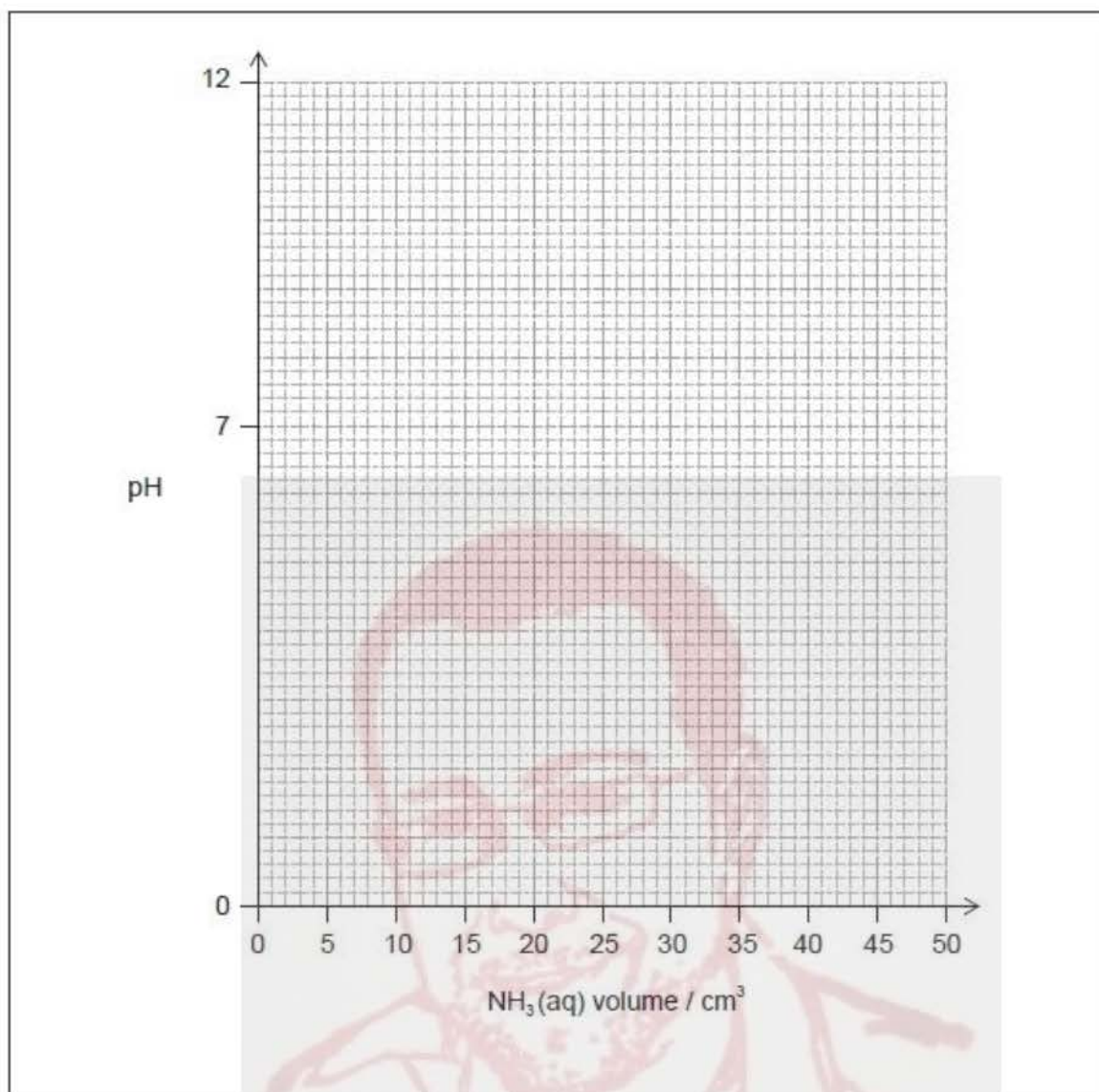
[3]

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- (g) (i) Sketch the pH titration curve obtained when 50.0 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ NH}_3(\text{aq})$ is added to 25.0 cm^3 of $0.100 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$.

[3]



- (ii) Identify an indicator from table 16 of the data booklet that could be used for this titration.

[1]

.....

4. A buffer solution with a pH of 3.87 contains 7.41 g dm^{-3} of propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, together with an unknown quantity of sodium propanoate, $\text{CH}_3\text{CH}_2\text{COONa}$.

(a) Define the term *buffer solution*.

[2]

.....

(b) Explain, using appropriate equations, how this solution acts as a buffer solution.

[2]

.....

(c) Calculate the concentration, in mol dm^{-3} , of sodium propanoate in this buffer solution. The $\text{p}K_a$ of propanoic acid is 4.87 at 298 K.

[4]

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8. Acids can be described as strong or weak.

- (a) (i) Outline the difference in dissociation between strong and weak acids of the same concentration.

[1]

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- (ii) Describe **three** tests that can be carried out in the laboratory, and the expected results, to distinguish between $0.10 \text{ mol dm}^{-3} \text{ HCl (aq)}$ and $0.10 \text{ mol dm}^{-3} \text{ CH}_3\text{COOH (aq)}$.

[3]

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- (b) Calculate the pH, using table 15 of the data booklet, of a solution of ethanoic acid made by dissolving 1.40 g of the acid in distilled water to make a 500 cm^3 solution.

[4]

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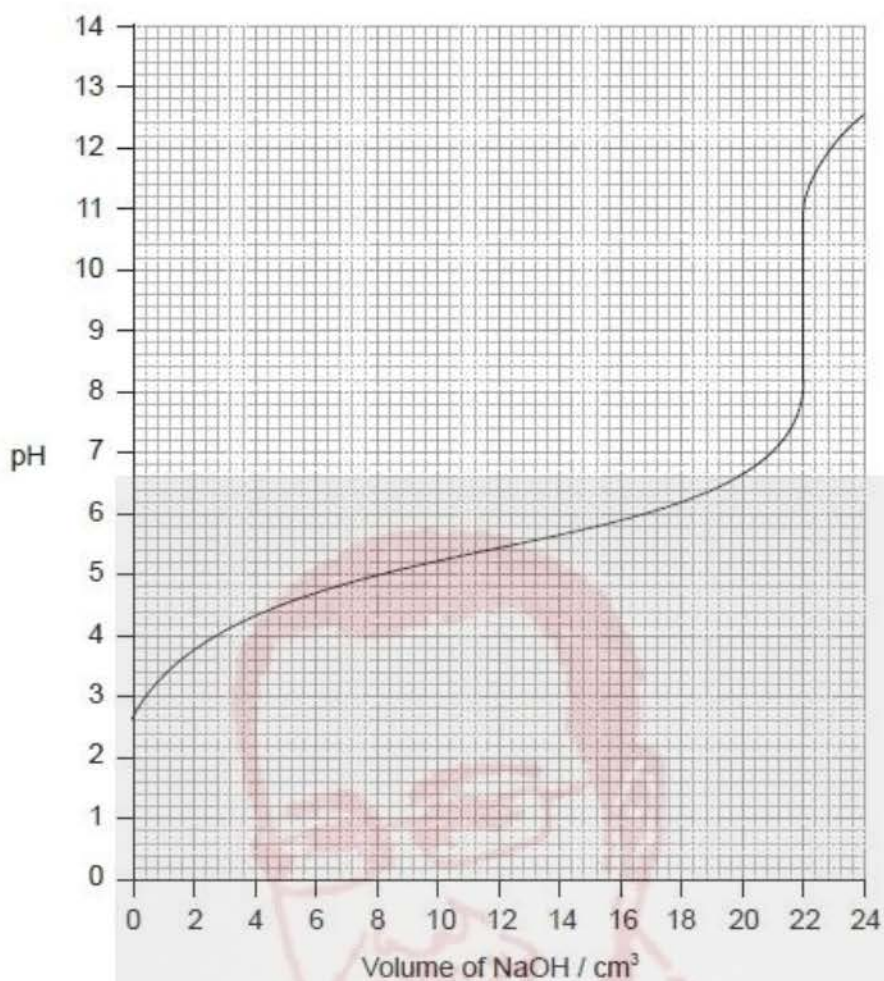
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- (c) (i) Determine the pH at the equivalence point of the titration and the pK_a of an unknown acid using the acid-base titration curve below.

[3]



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- (ii) Identify, using table 16 of the data booklet, a suitable indicator to show the end-point of this titration.

[1]

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- (iii) Describe how an indicator, that is a weak acid, works. Use Le Chatelier's principle in your answer.

[2]

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- (d) (i) State the formula of the conjugate base of chloroethanoic acid, CH_2ClCOOH .

[1]

.....

- (ii) Identify, with a reason, whether chloroethanoic acid is weaker or stronger than ethanoic acid using table 15 of the data booklet.

[1]

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- (iii) Determine the pH of the solution resulting when 100 cm^3 of 0.50 mol dm^{-3} CH_2ClCOOH is mixed with 200 cm^3 of 0.10 mol dm^{-3} NaOH .

[4]

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- (c) Predict and explain the pH of the following aqueous solutions, using equations to support your answer.

[4]

Ammonium chloride, $\text{NH}_4\text{Cl}(\text{aq})$:

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Sodium methanoate, $\text{HCOONa}(\text{aq})$:

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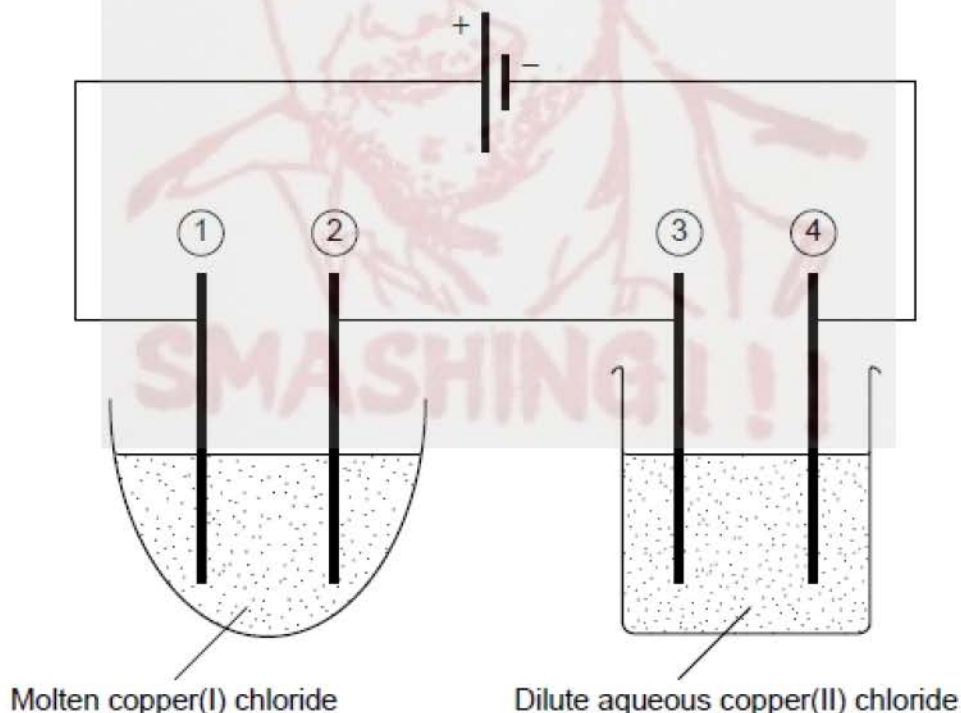
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6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

- (ii) Copper(II) chloride is used as a catalyst in the production of chlorine from hydrogen chloride.



- (c) Two electrolysis cells were assembled using graphite electrodes and connected in series as shown.



- (i) State how current is conducted through the wires and through the electrolyte. [2]

Wires:

.....

Electrolyte:

.....

- (ii) Write the half-equation for the formation of gas bubbles at electrode 1. [1]

.....

.....

- (iii) Bubbles of gas were also observed at another electrode. Identify the electrode and the gas. [1]

Electrode number (on diagram):

.....

Name of gas:

.....

- (iv) Deduce the half-equation for the formation of the gas identified in (c)(iii). [1]

.....

.....



- (e) Copper(I) chloride undergoes a disproportionation reaction, producing copper(II) chloride and copper.



- (i) Calculate the cell potential at 298 K for the disproportionation reaction, in V, using section 24 of the data booklet.

[1]

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- (ii) Comment on the spontaneity of the disproportionation reaction at 298 K.

[1]

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- (iii) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, to two significant figures, for the disproportionation at 298 K. Use your answer from (e)(i) and sections 1 and 2 of the data booklet.

[1]

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- (iv) Suggest, giving a reason, whether the entropy of the system increases or decreases during the disproportionation.

[1]

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- (v) Deduce, giving a reason, the sign of the standard enthalpy change, $\Delta H^\ominus$, for the disproportionation reaction at 298 K.

[1]

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- (vi) Predict, giving a reason, the effect of increasing temperature on the stability of copper(I) chloride solution.

[1]

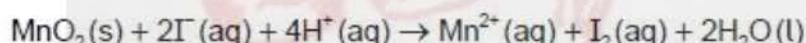
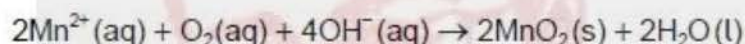
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Topic Chem 9 Q# 149/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q3./ www.SmashingScience.org :o)

2. The biochemical oxygen demand of a water sample can be determined by the following series of reactions. The final step is titration of the sample with sodium thiosulfate solution, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.



A student analysed two 300.0 cm^3 samples of water taken from the school pond: one immediately (day 0), and the other after leaving it sealed in a dark cupboard for five days (day 5). The following results were obtained for the titration of the samples with $0.0100\text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.

Sample	Titre / $\text{cm}^3 \pm 0.1\text{ cm}^3$
Day 0	25.8
Day 5	20.1

- (a) (i) Determine the mole ratio of $\text{S}_2\text{O}_3^{2-}$ to O_2 , using the balanced equations.

[1]

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.....



(ii) Calculate the number of moles of oxygen in the day 0 sample.

[2]

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.....

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(iii) The day 5 sample contained 5.03×10^{-5} moles of oxygen.

Determine the 5-day biochemical oxygen demand of the pond, in mg dm^{-3} ("parts per million", ppm).

[2]

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Topic Chem 9 Q# 150/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q6/ www.SmashingScience.org :o)

6. Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is a weak acid and ethylamine, $\text{CH}_3\text{CH}_2\text{NH}_2$, is a weak base.

(iii) Deduce the average oxidation state of carbon in butanoic acid.

[1]

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.....

Topic Chem 9 Q# 151/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. Bromine can form the bromate(V) ion, BrO_3^- .

(d) (i) Bromate(V) ions act as oxidizing agents in acidic conditions to form bromide ions.

Deduce the half-equation for this reduction reaction.

[2]

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.....



- (ii) Bromate(V) ions oxidize iron(II) ions, Fe^{2+} , to iron(III) ions, Fe^{3+} .

Deduce the equation for this redox reaction.

[1]

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.....

- (iii) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in J, of the redox reaction in (ii), using sections 1 and 24 of the data booklet.

$$E^\ominus (\text{BrO}_3^- / \text{Br}^-) = +1.44 \text{ V}$$

[2]

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.....
.....

Topic Chem 9 Q# 152/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q1/ www.SmashingScience.org :o)

1. 3.26 g of iron powder are added to 80.0 cm^3 of $0.200 \text{ mol dm}^{-3}$ copper(II) sulfate solution. The following reaction occurs:



- (d) A student electrolyzed aqueous iron(II) sulfate, $\text{FeSO}_4(\text{aq})$, using platinum electrodes. State half-equations for the reactions at the electrodes, using section 24 of the data booklet.

[2]

Anode (positive electrode):

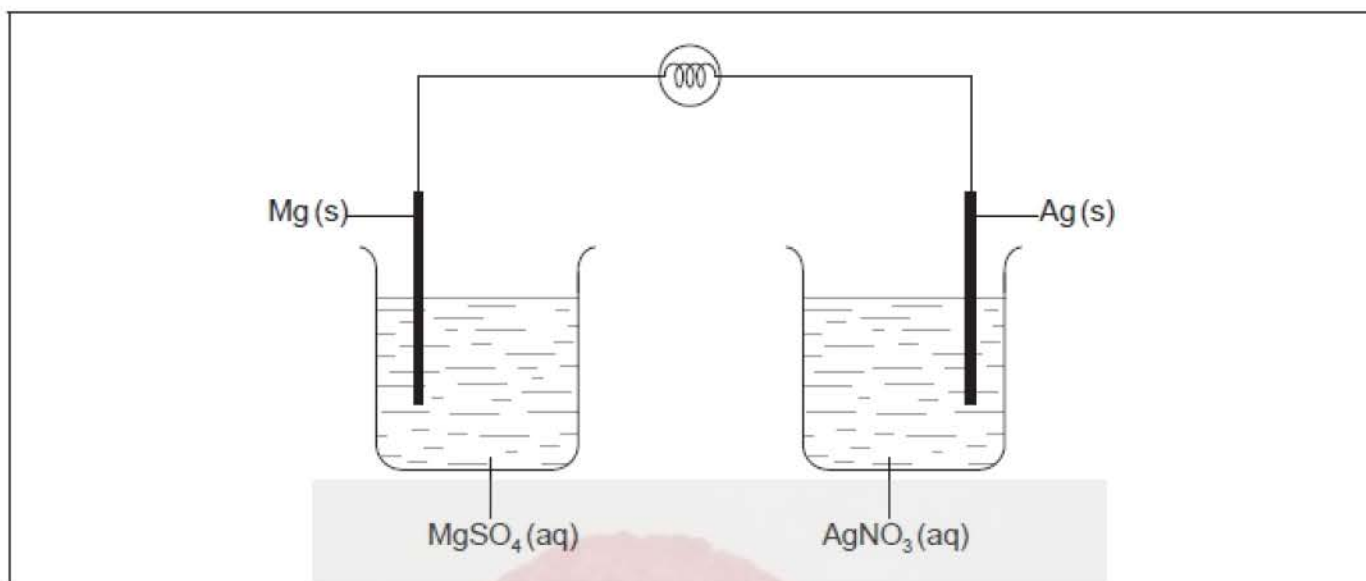
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Cathode (negative electrode):

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.....



6. The diagram shows an incomplete voltaic cell with a light bulb in the circuit.



- (a) Identify the missing component of the cell and its function. [2]

.....

.....

- (b) Deduce the half-equations for the reaction at each electrode when current flows. [2]

Positive electrode (cathode):

.....

Negative electrode (anode):

.....

- (c) Annotate the diagram with the location and direction of electron movement when current flows. [1]

- (d) Calculate the cell potential, in V, using section 24 of the data booklet. [1]

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- (e) Determine the loss in mass of one electrode if the mass of the other electrode increases by 0.10 g.

[2]

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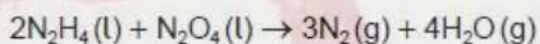
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Topic Chem 9 Q# 154/ IB Chem/2017/s/TZ 2/Paper 2/Higher Level/Q4/ www.SmashingScience.org :o)

4. Bonds can be formed in many ways.

- (a) The landing module for the Apollo mission used rocket fuel made from a mixture of hydrazine, N_2H_4 , and dinitrogen tetroxide, N_2O_4 .



- (iii) Determine the oxidation state of nitrogen in the two reactants.

[1]

N_2H_4 :

.....

N_2O_4 :

.....

- (iv) Deduce, giving a reason, which species is the reducing agent.

[1]

.....

SMASHING!!!

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Topic Chem 9 Q# 155/ IB Chem/2017/s/TZ 2/Paper 2/Higher Level/Q2/ www.SmashingScience.org :o)

2. (a) An acidic sample of a waste solution containing $\text{Sn}^{2+}(\text{aq})$ reacted completely with $\text{K}_2\text{Cr}_2\text{O}_7$ solution to form $\text{Sn}^{4+}(\text{aq})$.

- (i) State the oxidation half-equation.

[1]

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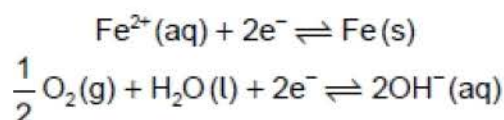
- (ii) Deduce the overall redox equation for the reaction between acidic $\text{Sn}^{2+}(\text{aq})$ and $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$, using section 24 of the data booklet. [1]

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- (b) (i) Corrosion of iron is similar to the processes that occur in a voltaic cell. The initial steps involve the following half-equations:



Calculate $E^{\ominus}$, in V, for the spontaneous reaction using section 24 of the data booklet. [1]

.....

.....

- (ii) Calculate the Gibbs free energy, $\Delta G^{\ominus}$, in kJ, which is released by the corrosion of 1 mole of iron. Use section 1 of the data booklet. [2]

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.....

- (c) Zinc is used to galvanize iron pipes, forming a protective coating. Outline how this process prevents corrosion of the iron pipes. [1]

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.....

Topic Chem 9 Q# 156/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q4/ www.SmashingScience.org :o)

4. Millerite, a nickel sulfide mineral, is an important source of nickel. The first step in extracting nickel is to roast the ore in air.

- (a) Formulate an equation for the oxidation of nickel(II) sulfide to nickel(II) oxide. [1]

.....

.....

.....

- (b) The nickel obtained from another ore, nickeliferous limonite, is contaminated with iron. Both nickel and iron react with carbon monoxide gas to form gaseous complexes, tetracarbonylnickel, $\text{Ni}(\text{CO})_4(\text{g})$, and pentacarbonyliron, $\text{Fe}(\text{CO})_5(\text{g})$. Suggest why the nickel can be separated from the iron successfully using carbon monoxide.

[1]

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Topic Chem 9 Q# 157/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. Vanadium has a number of different oxidation states.

- (a) Determine the oxidation state of vanadium in each of the following species.

[2]

V_2O_5:	.....
VO^{2+}:	.....

- (b) Electrode potentials for the reactions of vanadium and other species are shown below.

$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$	-0.26V
$\text{VO}^{2+}(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.34V
$\text{VO}_2^+(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+1.0V
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76V
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13V
$\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17V
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80V
$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^- \rightleftharpoons \text{Cl}^-(\text{aq})$	+1.36V



3. Vanadium has a number of different oxidation states.

(a) Determine the oxidation state of vanadium in each of the following species. [2]



.....



.....

(b) Electrode potentials for the reactions of vanadium and other species are shown below.

$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	-0.26V
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34V
$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$	+1.0V
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	-0.76V
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	-0.13V
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons H_2SO_3(aq) + H_2O(l)$	+0.17V
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80V
$\frac{1}{2}Cl_2(g) + e^- \rightleftharpoons Cl^-(aq)$	+1.36V

(i) Identify, from the table, a non-vanadium species that can reduce $VO^{2+}(aq)$ to $V^{3+}(aq)$ but no further. [1]

.....

(ii) Identify, from the table, a non-vanadium species that could convert $VO_2^+(aq)$ to $V^{2+}(aq)$. [1]

.....



- (c) (i) Formulate an equation for the reaction between $\text{VO}^{2+}(\text{aq})$ and $\text{V}^{2+}(\text{aq})$ in acidic solution to form $\text{V}^{3+}(\text{aq})$.

[1]

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- (ii) Comment on the spontaneity of this reaction by calculating a value for $\Delta G^\ominus$ using the data given in (b) and in section 1 of the data booklet.

[3]

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Topic Chem 9 Q# 158/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q4/ www.SmashingScience.org :o)

- (i) Magnesium chloride can be electrolysed.

- (i) Deduce the half-equations for the reactions at each electrode when **molten** magnesium chloride is electrolysed, showing the state symbols of the products. The melting points of magnesium and magnesium chloride are 922 K and 987 K respectively.

[2]

Anode (positive electrode):

.....

Cathode (negative electrode):

.....

- (ii) Identify the type of reaction occurring at the cathode (negative electrode).

[1]

.....



- (iii) State the products when a very **dilute** aqueous solution of magnesium chloride is electrolysed. [2]

Anode (positive electrode):

.....

Cathode (negative electrode):

.....

Topic **Chem 9 Q# 159/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q4/ www.SmashingScience.org :o)

- (j) Standard electrode potentials are measured relative to the standard hydrogen electrode. Describe a standard hydrogen electrode. [2]

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.....
.....

- (k) A magnesium half-cell, $\text{Mg(s)}/\text{Mg}^{2+}(\text{aq})$, can be connected to a copper half-cell, $\text{Cu(s)}/\text{Cu}^{2+}(\text{aq})$.

- (i) Formulate an equation for the spontaneous reaction that occurs when the circuit is completed. [1]

.....
.....

- (ii) Determine the standard cell potential, in V, for the cell. Refer to section 24 of the data booklet. [1]

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- (iii) Predict, giving a reason, the change in cell potential when the concentration of copper ions increases. [2]

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1. Ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(c) Determine the average oxidation state of carbon in ethene and in ethane-1,2-diol. [2]

Ethene:

.....

Ethane-1,2-diol:

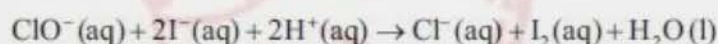
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1. Two IB students carried out a project on the chemistry of bleach.

- (a) The bleach contained a solution of sodium hypochlorite, $\text{NaClO}(\text{aq})$. The students determined experimentally the concentration of hypochlorite ions, ClO^- , in the bleach:

Experimental procedure:

- The bleach solution was first diluted by adding 25.00 cm^3 of the bleach to a 250 cm^3 volumetric flask. The solution was filled to the graduation mark with deionized water.
- 25.00 cm^3 of this solution was then reacted with excess iodide in acid.



- The iodine formed was titrated with $0.100 \text{ mol dm}^{-3}$ sodium thiosulfate solution, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$, using starch indicator.



The following data were recorded for the titration:

	First titre	Second titre	Third titre
Final burette reading of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ (in $\text{cm}^3 \pm 0.05$)	23.95	46.00	22.15
Initial burette reading of $0.100 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ (in $\text{cm}^3 \pm 0.05$)	0.00	23.95	0.00



(b) Some of the group 17 elements, the halogens, show variable valency.

(i) Deduce the oxidation states of chlorine and iodine in the following species. [1]

NaClO_2

.....

I_2

.....

(ii) Deduce, with a reason, the oxidizing agent in the reaction of hypochlorite ions with iodide ions in part (a). [1]

.....
.....
.....

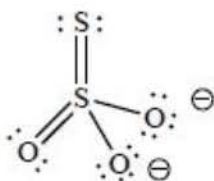
(iii) From a health and safety perspective, suggest why it is not a good idea to use hydrochloric acid when acidifying the bleach. [1]

.....
.....

SMASHING!!!



- (iv) The thiosulfate ion, $\text{S}_2\text{O}_3^{2-}$, is an interesting example of oxidation states. The sulfur atoms can be considered to have an oxidation state of +6 on one atom and -2 on the other atom. Discuss this statement in terms of your understanding of oxidation state. [2]

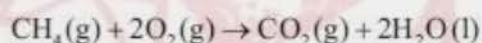


Lewis (electron dot) structure of thiosulfate

- (c) The various changes that have been made to the definitions of oxidation and reduction show how scientists often broaden similarities to general principles.

Combustion is also a redox type of reaction.

With reference to the combustion reaction of methane, explore two different definitions of oxidation, choosing one which is valid and one which may be considered not valid. [2]

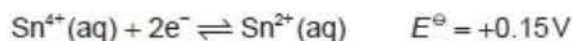


Valid:

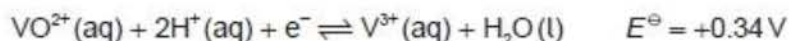
Not valid:



(b) Tin can also exist in the +4 oxidation state.



Vanadium can be reduced from an oxidation state of +4 to +3 according to the equation:



- (i) Calculate the cell potential, $E^{\ominus}$, and the standard free energy, $\Delta G^{\ominus}$, change for the reaction between the VO^{2+} and Sn^{2+} ions, using sections 1 and 2 of the data booklet.

[2]

$E^{\ominus}$:

.....
.....

$\Delta G^{\ominus}$:

.....
.....

- (ii) Deduce, giving your reason, whether a reaction between $\text{Sn}^{2+}(\text{aq})$ and $\text{VO}^{2+}(\text{aq})$ would be spontaneous.

[1]

.....
.....
.....

Topic **Chem 9 Q# 163**/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 .

(b)

- (iii) State the oxidation state of phosphorus in P_4 and $\text{H}_2\text{PO}_2^{-}$.

[2]

P_4 :

.....

$\text{H}_2\text{PO}_2^{-}$:

.....

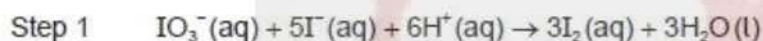


- (iv) Oxidation is now defined in terms of change of oxidation number. Explore how earlier definitions of oxidation and reduction may have led to conflicting answers for the conversion of P_4 to $H_2PO_2^-$ and the way in which the use of oxidation numbers has resolved this.

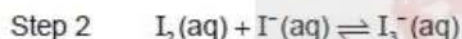
[3]

Topic Chem 9 Q# 164/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

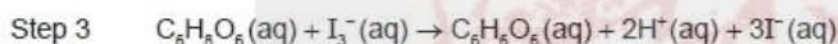
1. A student used the technique of titration to determine the concentration of ascorbic acid ($C_6H_8O_6$) in a sample of orange juice. Excess potassium iodide, $KI(aq)$, was added to acidified orange juice. The resulting solution was titrated with potassium iodate, $KIO_3(aq)$, in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.



Iodine is only slightly soluble in water, but in the presence of excess iodide ions, $I^-(aq)$, it forms the soluble tri-iodide ion, $I_3^-(aq)$.



Ascorbic acid reacts with tri-iodide ions as follows.



- (a) (i) Deduce the changes in oxidation number of iodine in step 1.

[2]

IO_3^- to I_2 :

I^- to I_2 :

- (ii) Identify the oxidizing and reducing agents in step 1.

[1]

Oxidizing agent:

Reducing agent:



- (d) (i) The dichromate ion, $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$, and the iodide ion, $\text{I}^-(\text{aq})$, react together in the presence of an acid to form $\text{Cr}^{3+}(\text{aq})$ and $\text{IO}_3^-(\text{aq})$ ions. Deduce the half-equation for the reaction of I^- to IO_3^- and the overall equation for this reaction. [2]

Half-equation:

.....

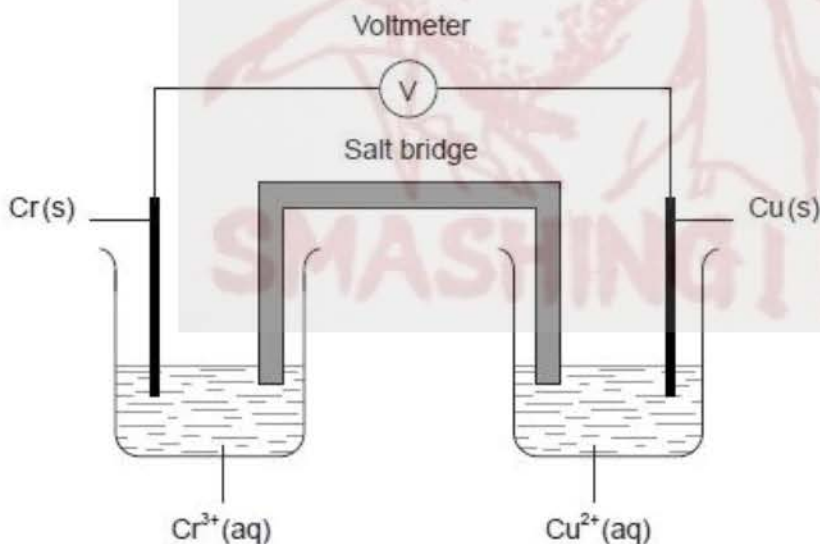
Overall equation:

.....

- (ii) Explain in terms of oxidation numbers whether iodine is oxidized or reduced in part (d) (i). [1]

.....

- (e) A voltaic cell is constructed as follows. One half-cell contains a chromium electrode immersed in a solution containing $\text{Cr}^{3+}(\text{aq})$ ions. The other half-cell contains a copper electrode immersed in a solution containing $\text{Cu}^{2+}(\text{aq})$ ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.



- (i) Define the term *standard electrode potential*. [1]

.....



- (ii) Calculate the cell potential, in V, under standard conditions, for this voltaic cell, using table 14 of the data booklet and $E^{\ominus}_{\text{Cr}^{3+}/\text{Cr}} = -0.74 \text{ V}$. [1]

.....
.....

- (iii) Predict the balanced equation for the spontaneous reaction which will produce a current in this voltaic cell. [1]

.....
.....

- (iv) Identify the negative and the positive electrodes in this cell. [1]

.....
.....

- (v) Predict the direction of movement of electrons in the external circuit. [1]

.....
.....

- (vi) State the directions in which the negative ions (anions) and the positive ions (cations) flow in the salt bridge. [1]

.....
.....
.....



6. Electrolysis is an important industrial process used to obtain very reactive elements from their common ores.

- (a) Molten magnesium chloride can be electrolysed using inert graphite electrodes at 800 °C.

Deduce the half-equations, including state symbols, for the reactions occurring at each electrode. (The melting points of MgCl_2 and Mg are 714 °C and 649 °C respectively.)

[3]

Positive electrode (anode):

.....

Negative electrode (cathode):

.....

- (b) Aluminium can also be obtained by electrolysis. Suggest **one** reason why aluminium is often used instead of iron by engineers.

[1]

.....
.....

Topic Chem 9 Q# 168/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7/ www.SmashingScience.org :o)

The structure of ethanol is $\text{CH}_3\text{CH}_2\text{OH}$ and for ethanal it is CH_3CHO



- (ii) Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

.....

Ethanal:

.....

- (iii) Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

.....
.....

- (iv) Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI). [2]

.....
.....
.....

Topic Chem 9 Q# 169/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6/ www.SmashingScience.org :o)

- (d) (i) Bromine can be produced by the electrolysis of **molten** sodium bromide. Deduce the half-equation for the reaction at each electrode. [2]

Positive electrode (anode):

.....

Negative electrode (cathode):

.....

- (ii) Predict the products formed at the electrodes during the electrolysis of concentrated **aqueous** sodium bromide. [2]

Positive electrode (anode):

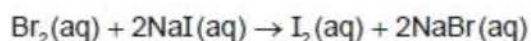
.....

Negative electrode (cathode):

.....



(e) Bromine reacts with aqueous sodium iodide.



Identify the oxidizing agent in this reaction.

[1]

(f) (i) Define the term *standard electrode potential*, $E^\ominus$.

[1]

(ii) Draw a labelled diagram for the voltaic cell in which the following reaction occurs.



Include in your answer the direction of electron flow and the polarity of the electrodes.

[4]

(iii) A student measures a voltage of 2.65 V in the voltaic cell formed between magnesium and copper half-cells using a digital voltmeter.

State the random uncertainty of this value, in V, and the number of significant figures in the answer.

[2]

Random uncertainty:

.....

Significant figures:

.....



(iv) Outline how the student can reduce the random error in her results.

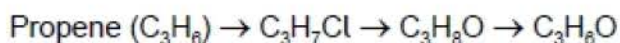
[1]

.....

.....

Topic Chem 10 Q# 171/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q4. NOT with Q3b(i)

3. Propene is an important starting material for many products. The following shows some compounds which can be made from propene, C_3H_6 .



(a) Consider the conversion of propene to C_3H_7Cl .

(i) State the type of reaction.

[1]

.....

(ii) State the IUPAC name of the major product.

[1]

.....

(iii) Outline why it is the major product.

[1]

.....

.....

(iv) Write an equation for the reaction of the major product with aqueous sodium hydroxide to produce a C_3H_8O compound, showing structural formulas.

[1]

.....

.....

(b) An experiment was carried out to determine the order of reaction between one of the isomers of C_3H_7Cl and aqueous sodium hydroxide. The following results were obtained.

Experiment	$[C_3H_7Cl] / \text{mol dm}^{-3}$	$[OH^-] / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.05	0.10	3.1×10^{-4}
2	0.10	0.20	1.3×10^{-3}
3	0.15	0.10	9.2×10^{-4}

The rate equation for this reaction is: $\text{Rate} = k [C_3H_7Cl][OH^-]$



- (ii) Deduce the type of mechanism for the reaction of this isomer of C_3H_7Cl with aqueous sodium hydroxide.

[1]

.....

- (iii) Sketch the mechanism using curly arrows to represent the movement of electrons. [4]

- (d) (i) State the reagents for the conversion of the compound C_3H_8O formed in (a)(iv) into C_3H_6O .

[1]

.....
.....

- (ii) Explain why the compound C_3H_8O , produced in (a)(iv), has a higher boiling point than compound C_3H_8O , produced in d(i).

[2]

.....
.....
.....
.....

- (e) Propene is often polymerized. Draw a section of the resulting polymer, showing two repeating units.

[1]



9. Halogenoalkanes undergo nucleophilic substitution reactions with sodium hydroxide.

- (a) State a reason why most halogenoalkanes are more reactive than alkanes. [1]

.....
.....

- (b) Classify 1-bromopropane as a primary, secondary or tertiary halogenoalkane, giving a reason. [1]

.....
.....
.....

- (c) Explain the mechanism of the reaction between 1-bromopropane with aqueous sodium hydroxide using curly arrows to represent the movement of electron pairs. [4]

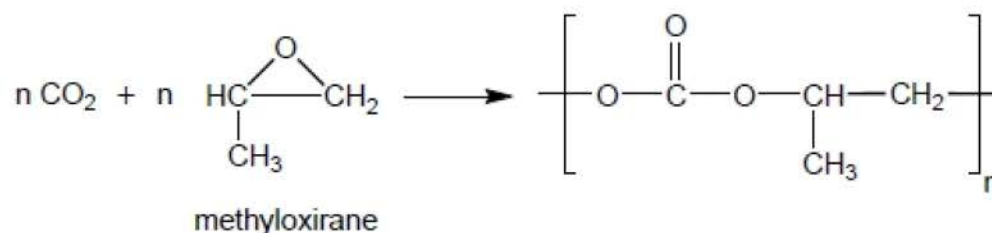
- (d) State, giving your reason, whether the hydroxide ion acts as a Lewis acid, a Lewis base, or neither in the nucleophilic substitution. [1]

.....
.....

- (e) Suggest **two** advantages of understanding organic reaction mechanisms. [2]

.....
.....
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.....
.....

8. Carbon dioxide contributes significantly to global warming. It can be used as a raw material with methyloxirane to form polymers.



- (a) Suggest why the three-membered ring in methyloxirane is unstable. [1]

.....

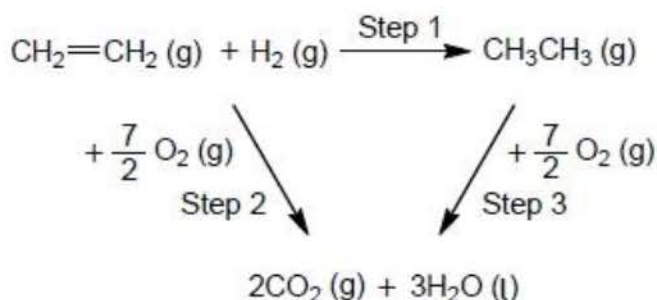
- (b) (i) Draw two structural isomers of methyloxirane. [2]

- (ii) State, giving a reason, whether methyloxirane can form *cis-trans* isomers. [1]

.....



7. Consider the following Hess's law cycle:



(a) Identify the type of reaction in step 1.

[1]

6. Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is a weak acid and ethylamine, $\text{CH}_3\text{CH}_2\text{NH}_2$, is a weak base.

(d) Explain why butanoic acid is a liquid at room temperature while ethylamine is a gas at room temperature.

[2]

6. Butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, is a weak acid and ethylamine, $\text{CH}_3\text{CH}_2\text{NH}_2$, is a weak base.

(e) (i) State a suitable reagent for the reduction of butanoic acid.

[1]

(ii) Deduce the product of the complete reduction reaction in (e)(i).

[1]



7. This question is about the reactions of halogenoalkanes.

- (a) Compare and contrast the mechanisms by which 1-chlorobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$, and 2-chloro-2-methylpropane, $(\text{CH}_3)_3\text{CCl}$, react with aqueous sodium hydroxide, giving **two** similarities and **one** difference. [3]

Two similarities:

.....

.....

.....

.....

One difference:

.....

.....

.....

- (b) Outline why the rate of reaction of the similar bromo-compounds is faster. [1]

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.....

.....

- (c) (i) State the organic product of the reaction between 1-chlorobutane, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$, and aqueous sodium hydroxide. [1]

.....

.....

- (ii) Suggest how this product could be synthesized in one step from butanoic acid. [1]

.....

.....



- (iii) Deduce the name of the class of compound formed when the product of (c)(i) reacts with butanoic acid.

[1]

.....

.....

Topic **Chem 10 Q# 178**/ IB Chem/2018/s/TZ 1/Paper 2/Higher Level/Q3/ www.SmashingScience.org :o)

3. This question is about ethene, C_2H_4 , and ethyne, C_2H_2 .

- (a) (i) Ethyne, like ethene, undergoes hydrogenation to form ethane. State the conditions required.

[2]

.....

.....

.....

.....

- (ii) Outline the formation of polyethene from ethene by drawing three repeating units of the polymer.

[1]

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.....

.....

- (b) Ethyne reacts with chlorine in a similar way to ethene. Formulate equations for the following reactions.

[2]

One mole of ethyne reacts with one mole of chlorine:

.....

.....

One mole of benzene reacts with one mole of chlorine:

.....

.....



6. The photochemical chlorination of methane can occur at low temperature.

- (a) Using relevant equations, show the initiation and the propagation steps for this reaction.

[3]

Initiation:

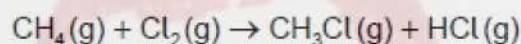
.....

Propagation:

.....

.....

- (b) The overall equation for monochlorination of methane is:



Calculate the standard enthalpy change for the reaction, $\Delta H^\ominus$, using section 12 of the data booklet.

[2]

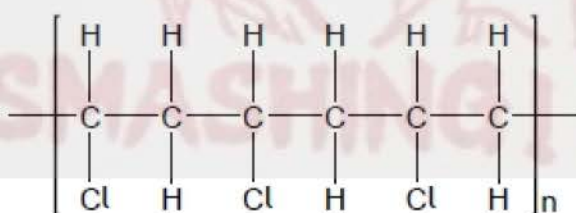
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- (c) Polyvinyl chloride (PVC) is a polymer with the following structure.



State the structural formula for the monomer of PVC.

[1]

.....

.....

.....



(v) Identify one organic functional group that can react with acidified $K_2Cr_2O_7(aq)$.

[1]

.....

Topic Chem 10 Q# 181/ IB Chem/2017/s/TZ 1/Paper 2/Higher Level/Q7/ www.SmashingScience.org :o)

7. Benzene is an aromatic hydrocarbon.

(a) Discuss the physical evidence for the structure of benzene.

[2]

.....
.....
.....
.....

(b) State the typical reactions that benzene and cyclohexene undergo with bromine.

[1]

Benzene:
.....

Cyclohexene:
.....

(c) State the reagents used to convert benzene to nitrobenzene and the formula of the electrophile formed.

[2]

.....
.....
.....

(d) Explain the mechanism for the nitration of benzene, using curly arrows to show the movement of electron pairs.

[4]

- (e) State the reagents used in the two-stage conversion of nitrobenzene to aniline. [2]

.....

.....

.....

Topic Chem 10 Q# 182/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

6. One structural isomer of C_4H_9Br is a chiral molecule.

- (a) Draw the three-dimensional shape of each enantiomer of this isomer showing their spatial relationship to each other. [2]

- (b) When one enantiomer undergoes substitution by alkaline hydrolysis approximately 75 % of the product molecules show inversion of configuration. Comment on the mechanisms that occur. [2]

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- (c) Suggest why the rate of alkaline hydrolysis of an enantiomer of iodopropane is greater than that of an enantiomer of bromopropane. [1]

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.....



5. Propane and propene are members of different homologous series.

(a) Draw the full structural formulas of propane and propene.

[1]

Propane:

Propene:

(c) Both propane and propene react with bromine.

(i) State an equation and the condition required for the reaction of 1 mol of propane with 1 mol of bromine.

[2]

(ii) State an equation for the reaction of 1 mol of propene with 1 mol of bromine.

[1]

(iii) State the type of each reaction with bromine.

[1]

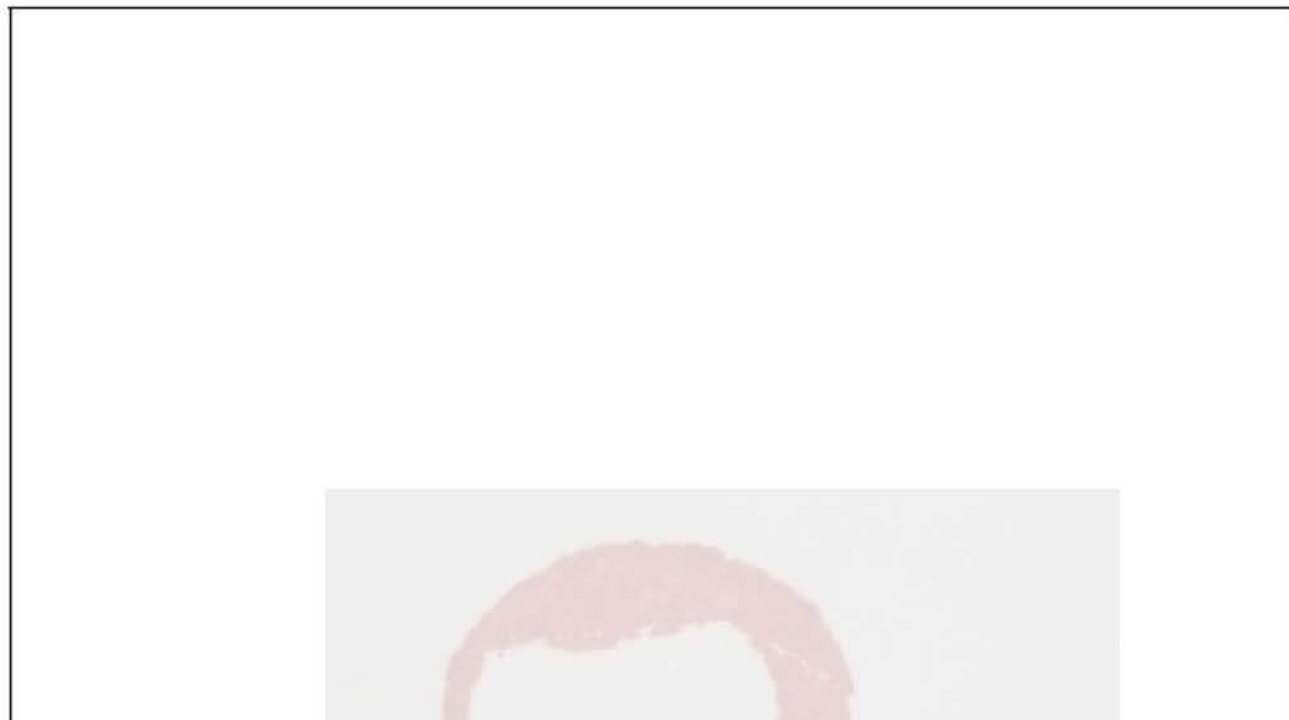
Propane:

Propene:



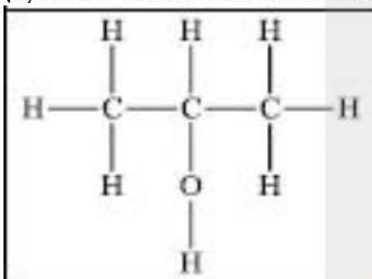
- (d) Construct the mechanism of the formation of 2-bromopropane from hydrogen bromide and propene using curly arrows to denote the movement of electrons.

[3]



Topic **Chem 10 Q# 184**/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7/ www.SmashingScience.org :o)

- (d) X is an alcohol with the following formula:



Y is an isomer of X but has a different functional group

- (v) Both X and Y are soluble in water. Deduce whether or not both X and Y show hydrogen bonding with water molecules, representing any hydrogen bonding present by means of a diagram.

[2]



- (iv) Compare and contrast the bonding types formed by nitrogen in $[\text{PtCl}_2(\text{NH}_3)_2]$. [2]

Similarity:

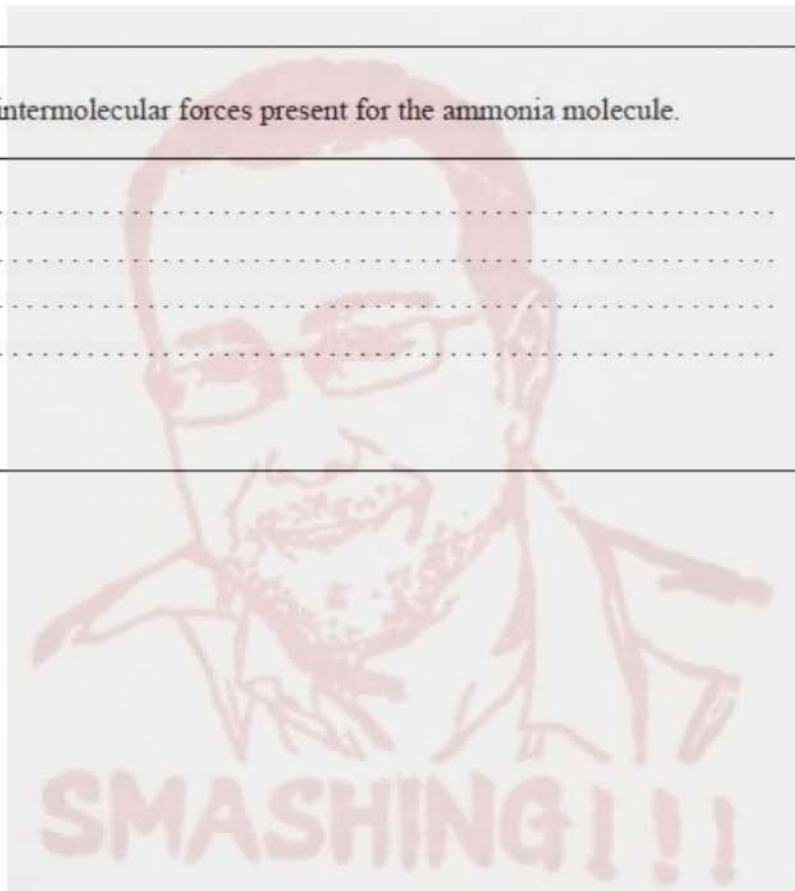
.....
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Difference:

.....
.....

- (v) Deduce all of the intermolecular forces present for the ammonia molecule. [2]

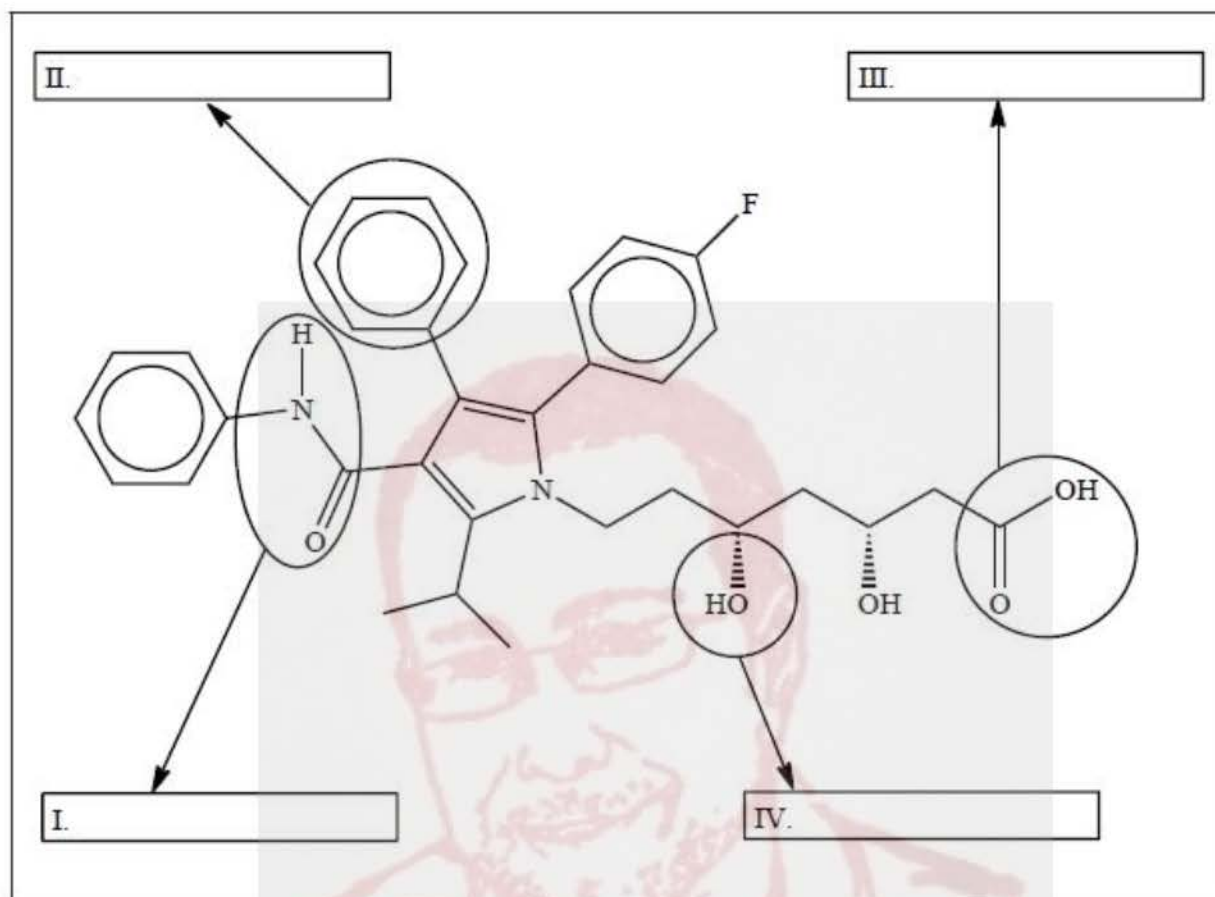
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7. The biopharmaceutical industry is now a global contributor to the world economy.

- (a) Atorvastatin, a drug used to lower cholesterol, recently gained attention from the global media.

Atorvastatin has the structure shown below.



Identify the four functional groups, I, II, III and IV.

[2]

(b) Bute is a chemical with the following molecular formula:
C₁₉H₂₀N₂O₂

- (iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute. [1]

.....

.....

.....

- (d) The two isomers of $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ are crystalline. One of the isomers is widely used as a drug in the treatment of cancer.

(i) Draw both isomers of the complex.

[1]



(ii) Explain the polarity of each isomer, using a diagram for each isomer to support your answer.

[2]

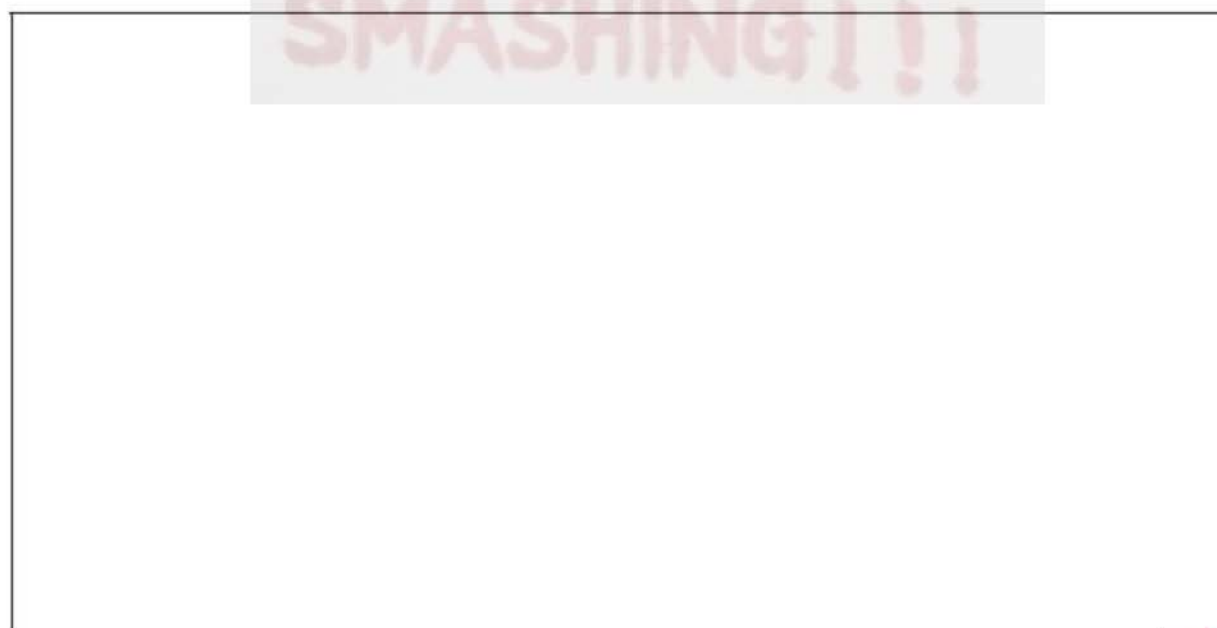


Topic Chem 10 Q# 187/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

4. 1-iodoethane reacts with sodium hydroxide.

(a) Explain the mechanism of this reaction, using curly arrows to represent the movement of electron pairs and showing any stereochemical features of the reaction mechanism.

[4]



- (b) State the rate expression for this reaction and identify the molecularity of the rate-determining step (RDS). [2]

Rate expression:

.....

Molecularity of RDS:

.....

- (c) Suggest why polar, aprotic solvents are more suitable for S_N2 reactions whereas polar, protic solvents favour S_N1 reactions. [2]

S_N2 :

.....
.....
.....
.....

S_N1 :

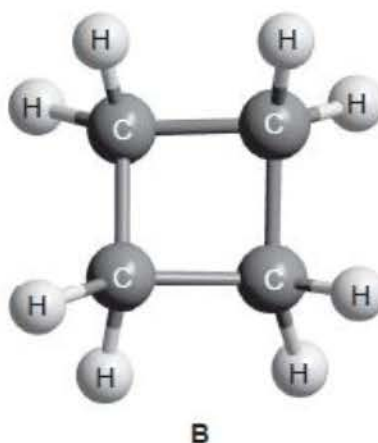
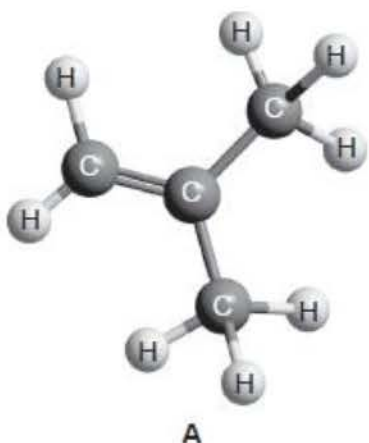
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- (d) Deduce, with a reason, if water or DMF (N,N-Dimethylformamide, $\text{HCON}(\text{CH}_3)_2$) is a better solvent for this reaction. [1]

.....
.....



5. Compound A and compound B are hydrocarbons.



- (a) (i) State the term that is used to describe molecules that are related to each other in the same way as compound A and compound B.

[1]

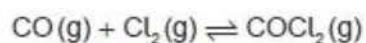
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- (ii) Suggest a chemical test to distinguish between compound A and compound B, giving the observation you would expect for each.

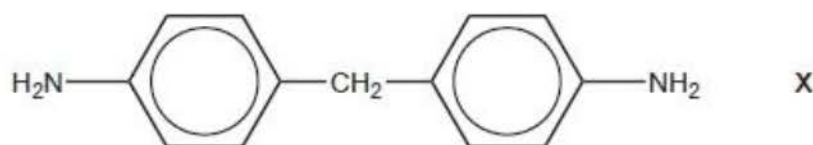
[2]

Test:	..... .....
Observation with A:	..... .....
Observation with B:	..... .....

2. Phosgene, COCl_2 , is usually produced by the reaction between carbon monoxide and chlorine according to the equation:



- (b) One important industrial use of phosgene is the production of polyurethanes. Phosgene is reacted with diamine X, derived from phenylamine.



- (i) Classify diamine X as a primary, secondary or tertiary amine. [1]

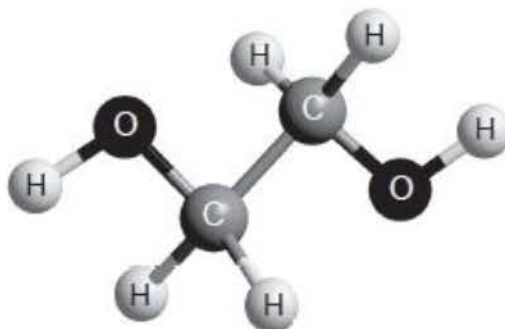
- (ii) Phenylamine, $C_6H_5NH_2$, is produced by the reduction of nitrobenzene, $C_6H_5NO_2$. Suggest how this conversion can be carried out. [2]

- (iii) Nitrobenzene can be obtained by nitrating benzene using a mixture of concentrated nitric and sulfuric acids. Formulate the equation for the equilibrium established when these two acids are mixed. [1]

- (iv) Deduce the mechanism for the nitration of benzene, using curly arrows to indicate the movement of electron pairs. [4]



- (c) The other monomer used in the production of polyurethane is compound **Z** shown below.



- (i) State the name, applying IUPAC rules, of compound **Z** and the class of compounds to which it belongs.

[2]

Name:

.....

Class:

.....

Topic Chem 10 Q# 190/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

9. (a) A 0.842 g sample of a liquid halogenoalkane, RBr(l) , was heated under reflux with $1.35 \times 10^{-2} \text{ mol}$ of aqueous sodium hydroxide, NaOH(aq) . After cooling the mixture, the excess NaOH was titrated with hydrochloric acid, HCl(aq) , and required $7.36 \times 10^{-3} \text{ mol}$ of the acid.

- (i) State the equation for the substitution reaction of the halogenoalkane with sodium hydroxide.

[1]

.....
.....

- (ii) Calculate the amount, in mol, of sodium hydroxide that reacted with the halogenoalkane.

[1]

.....
.....



(iii) Calculate the molar mass of the halogenoalkane.

[1]

.....
.....
.....
.....

(iv) Given that each molecule of the halogenoalkane contains one bromine atom, determine its molecular formula.

[1]

.....
.....
.....

(v) Deduce the structural formulas of **four** structural isomers of the halogenoalkane based on the molecular formula **and** label each isomer as primary, secondary or tertiary.

[4]

(If you have not been able to determine the molecular formula in part (a) (iv), use $C_5H_{11}Br$ to deduce the four structural isomers.)



(b) The reaction between a primary halogenoalkane drawn in part (a) (v) and potassium cyanide follows a S_N2 mechanism.

(i) State the importance of this reaction in organic synthesis.

[1]

.....
.....

- (ii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs.

[4]

- (iii) The organic product obtained in part (b) (ii) can be reduced to form an amine. State an equation for this reaction and a suitable catalyst.

[2]

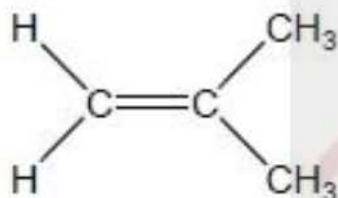
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(d) This molecule is needed in the question that follows it:



- (ii) Under certain conditions, the major product obtained in the elimination reaction can undergo polymerization. Identify the type of polymerization and draw a section of the polymer consisting of **two** repeating units.

[2]

Type of polymerization:

.....

Section of polymer:



- (d) Ethane can react with chlorine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions.

[4]

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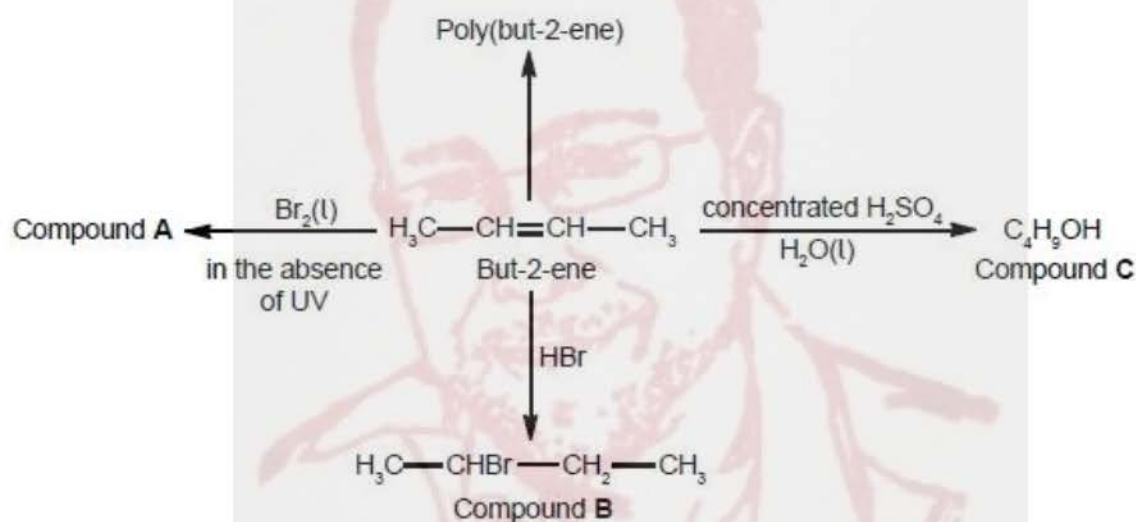
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Topic Chem 10 Q# 191/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/

10. Some reactions of but-2-ene are given below.



- (a) (i) Deduce the full structural formula of compound A.

[1]

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- (ii) Apply IUPAC rules to name compound A.

[1]

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- (iii) Describe the colour change observed when excess but-2-ene reacts with bromine to form compound A.

[1]

.....
.....

- (b) (i) Outline **two** reasons why the polymerization of alkenes is of economic importance. [2]

.....
.....
.....
.....

- (ii) Identify the structure of the repeating unit of poly(but-2-ene).

[1]

- (c) (i) Compound C, C_4H_9OH , can also be formed by reacting compound B, $CH_3CHBrCH_2CH_3$, with aqueous potassium hydroxide. This reaction proceeds by both S_N1 and S_N2 mechanisms. Explain the S_N2 mechanism, using curly arrows to represent the movement of electron pairs.

[4]

SMASHING!!!



(ii) Explain why the hydroxide ion is a better nucleophile than water.

[2]

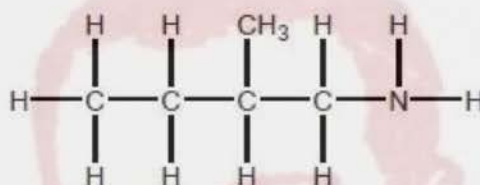
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(d) (i) Compound **B**, $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$, also reacts with potassium cyanide.
Apply IUPAC rules to name the organic product formed.

[1]

.....

(ii) The organic product of the reaction in part (d) (i) can be reduced to:



State the **two** reagents required.

[1]

.....

(iii) Deduce the full structural formula of the organic product formed when the compound in part (d) (ii) reacts with ethanoic acid in the presence of an acid catalyst.

[1]

SMASHING!!!



(e) Compound **C**, C_4H_9OH , can be oxidized by acidified potassium dichromate(VI) to form compound **F**.

(i) State the name of the functional group present in compound **F**. [1]

.....

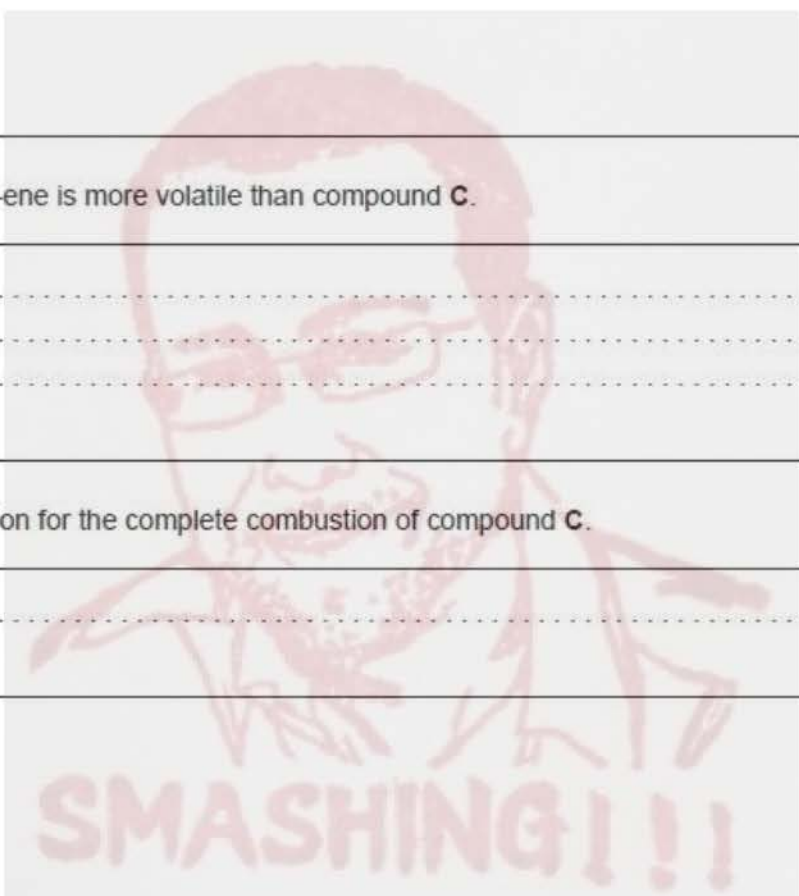
(ii) Deduce the structural formula of an alcohol which is a structural isomer of compound **C** and **cannot** be oxidized by acidified potassium dichromate(VI). [1]

(f) Explain why but-2-ene is more volatile than compound **C**. [2]

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.....

(g) Deduce the equation for the complete combustion of compound **C**. [1]

.....



- (h) But-2-ene can exist as two geometrical isomers. Geometrical isomerism is a form of stereoisomerism.

(i) Define the term *stereoisomers*. [1]

.....
.....

(ii) State the conditions needed for a compound to show geometrical isomerism. [2]

.....
.....
.....
.....

(iii) Draw the structures of the two geometrical isomers of but-2-ene, clearly identifying each as *cis* or *trans*. [2]

SMASHING!!!



5. (a) State two features of a homologous series.

[2]

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(b) Ethane, a member of the homologous series of alkanes, can react with bromine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions.

[4]

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5. Ethanol has many industrial uses.

(a) State an equation for the formation of ethanol from ethene and the necessary reaction conditions.

[3]

Equation:

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Conditions:

.....

.....



- (d) State the equation for the acid-catalysed reaction of ethanol with propanoic acid and state the name of the organic product. [2]

Equation:

.....
.....

Name of the organic product:

.....

- (e) (i) A polyester can be formed when ethane-1,2-diol reacts with benzene-1,4-dicarboxylic acid. [2]
Deduce the structure of the repeating unit and state the other product formed.

Repeating unit:

Other product:

.....

- (ii) State the type of polymerization that occurs. [1]

.....



6. Bromomethane was used as a pesticide until it was found to be ozone-depleting.

- (a) State the equation for the reaction between methane and bromine to form bromomethane. [1]

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.....

- (b) (i) Explain, using equations, the complete free-radical mechanism for the reaction of methane with bromine, including necessary reaction conditions. [4]

.....

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- (ii) Bromomethane reacts with aqueous sodium hydroxide. State the organic product of this reaction. [1]

.....

- (c) Explain why the rate of the reaction between iodomethane, CH_3I , and $\text{NaOH}(\text{aq})$ is faster than the rate of the reaction between CH_3Br and $\text{NaOH}(\text{aq})$. [2]

.....

.....

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7. (a) (i) Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

Ethanal:

.....
.....

Ethanoic acid:

.....
.....

- (b) Ethanol can be made by reacting aqueous sodium hydroxide with bromoethane. Explain the mechanism for this reaction, using curly arrows to represent the movement of electron pairs. [4]

- (d) 2-bromobutane exists as optical isomers.
(i) State the essential feature of optical isomers. [1]

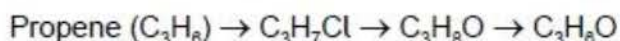
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SMASHING!!!

- (ii) Outline how a polarimeter can distinguish between these isomers. [2]

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.....



3. Propene is an important starting material for many products. The following shows some compounds which can be made from propene, C_3H_6 .



- (b) An experiment was carried out to determine the order of reaction between one of the isomers of C_3H_7Cl and aqueous sodium hydroxide. The following results were obtained.

Experiment	$[C_3H_7Cl] / \text{mol dm}^{-3}$	$[OH^-] / \text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.05	0.10	3.1×10^{-4}
2	0.10	0.20	1.3×10^{-3}
3	0.15	0.10	9.2×10^{-4}

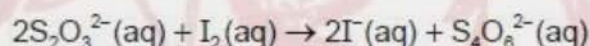
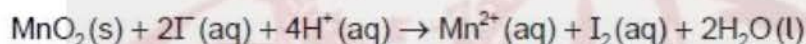
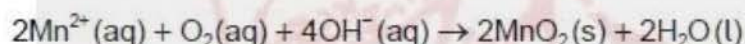
C_3H_6O mentioned in this question has a molecular formula of CH_3COCH_3

- (iii) Explain why the 1H NMR spectrum of C_3H_6O , produced in (d)(i), shows only one signal.

[1]

Topic Chem 11 Q# 197/ IB Chem/2019/w/TZ0/Paper 2/Higher Level/Q3./ www.SmashingScience.org :o)

2. The biochemical oxygen demand of a water sample can be determined by the following series of reactions. The final step is titration of the sample with sodium thiosulfate solution, $Na_2S_2O_3(aq)$.



A student analysed two 300.0 cm^3 samples of water taken from the school pond: one immediately (day 0), and the other after leaving it sealed in a dark cupboard for five days (day 5). The following results were obtained for the titration of the samples with $0.0100 \text{ mol dm}^{-3} Na_2S_2O_3(aq)$.

Sample	Titre / $\text{cm}^3 \pm 0.1 \text{ cm}^3$
Day 0	25.8
Day 5	20.1



(b) (i) Calculate the percentage uncertainty of the day 5 titre.

[1]

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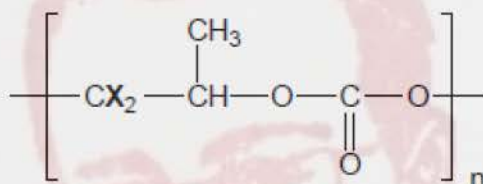
(ii) Suggest a modification to the procedure that would make the results more reliable. [1]

.....
.....

Topic Chem 11 Q# 198/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q8/ www.SmashingScience.org :o)

(c) Predict the chemical shift and splitting pattern of the signal produced by the hydrogen atoms labelled X in the ^1H NMR spectrum of the polymer. Use section 27 of the data booklet.

[2]



Chemical shift:

Splitting pattern:

Topic Chem 11 Q# 199/ IB Chem/2018/w/TZ 0/Paper 2/Higher Level/Q2 NOT With 2(a)

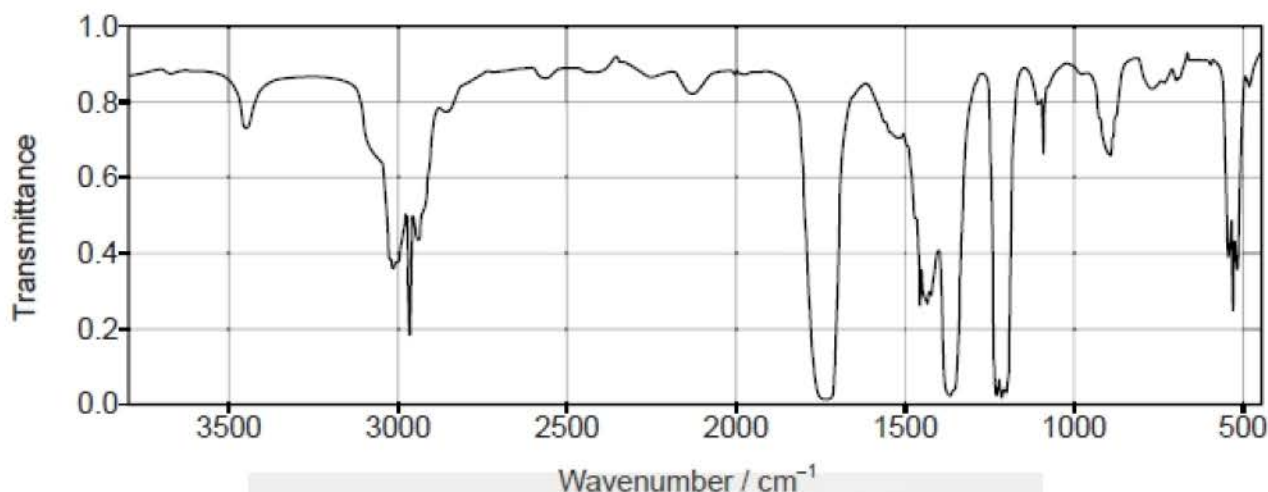
2. An organic compound containing carbon, hydrogen and oxygen has 62.02 % carbon and 10.43 % hydrogen by mass.

It's empirical formula is $\text{C}_3\text{H}_6\text{O}$



- (b) The infrared spectrum of the compound is shown. Deduce the functional group of the compound.

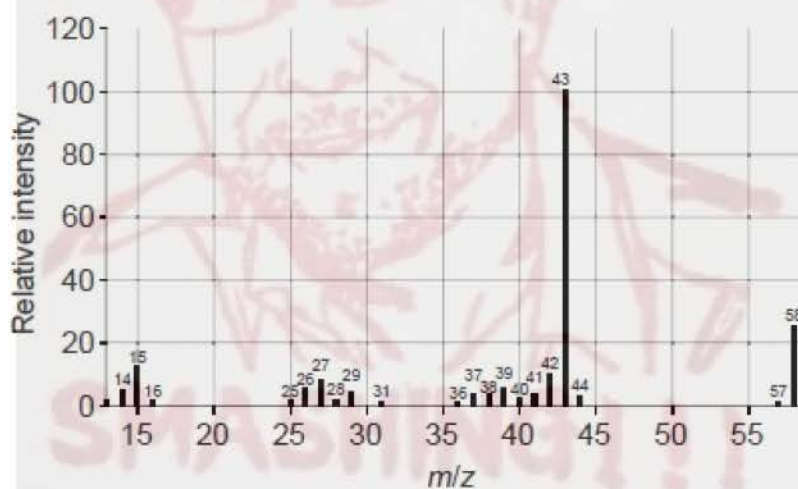
[1]



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899]

- (c) The mass spectrum of the compound is shown. Deduce the relative molecular mass of the compound.

[1]



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899]

- (d) The compound could not be oxidized using acidified potassium dichromate(VI).

Deduce the structural formula of the compound.

[1]

1. 3.26 g of iron powder are added to 80.0 cm³ of 0.200 mol dm⁻³ copper(II) sulfate solution. The following reaction occurs:



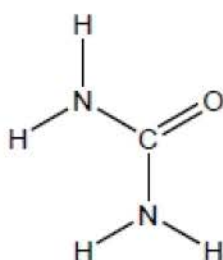
- (b) (i) The reaction was carried out in a calorimeter. The maximum temperature rise of the solution was 7.5 °C.
- (iii) The only significant uncertainty is in the temperature measurement.

Determine the absolute uncertainty in the calculated value of ΔH if the uncertainty in the temperature rise was $\pm 0.2^\circ\text{C}$. [2]

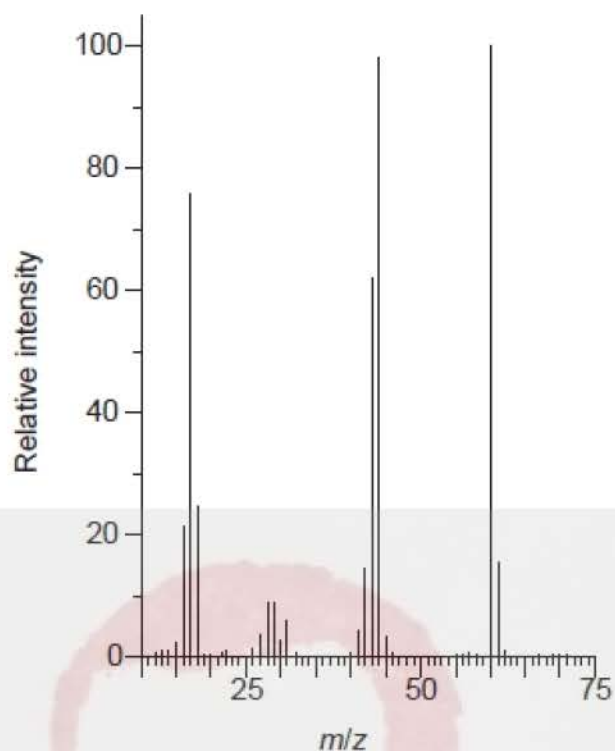
- (g) Outline why repeating quantitative measurements is important. [1]

- (b) Describe how the relative atomic mass of a sample of calcium could be determined from its mass spectrum. [2]

1. Urea, (H₂N)₂CO, is excreted by mammals and can be used as a fertilizer.
- (b) The structural formula of urea is shown.



(j) The mass spectrum of urea is shown below.



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in *NIST Chemistry WebBook*, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, doi:10.18434/T4D303, (retrieved May 31, 2018).]

Identify the species responsible for the peaks at $m/z = 60$ and 44.

[2]

60:

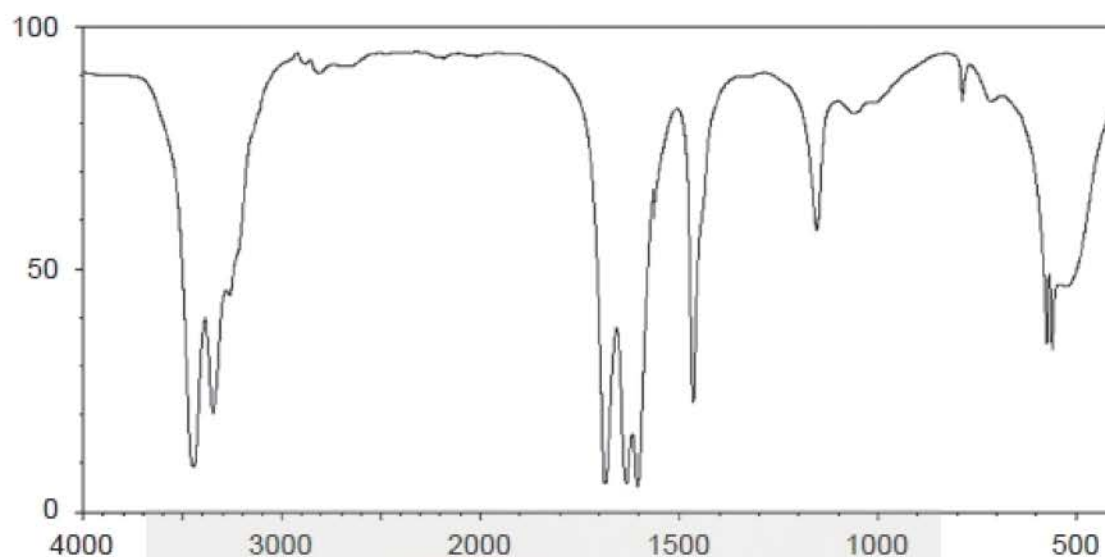
.....

44:

.....



(k) The IR spectrum of urea is shown below.



[Source: SDBS, National Institute of Advanced Industrial Science and Technology]

Identify the bonds causing the absorptions at 3450 cm⁻¹ and 1700 cm⁻¹ using section 26 of the data booklet.

[2]

3450 cm⁻¹:

.....

1700 cm⁻¹:

.....

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- (l) (i) Predict the number of signals in the ^1H NMR spectrum of urea. [1]

.....

- (ii) Predict the splitting pattern of the ^1H NMR spectrum of urea. [1]

.....

- (iii) Outline why TMS (tetramethylsilane) may be added to the sample to carry out ^1H NMR spectroscopy and why it is particularly suited to this role. [2]

.....

Topic Chem 11 Q# 204/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

- (f) Predict the ^1H NMR data for ethanedioic acid and ethane-1,2-diol by completing the table. [2]

	Number of signals	Splitting pattern
Ethanedioic acid:		
Ethane-1,2-diol:		Not required

Topic Chem 11 Q# 205/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7/ www.SmashingScience.org :o)

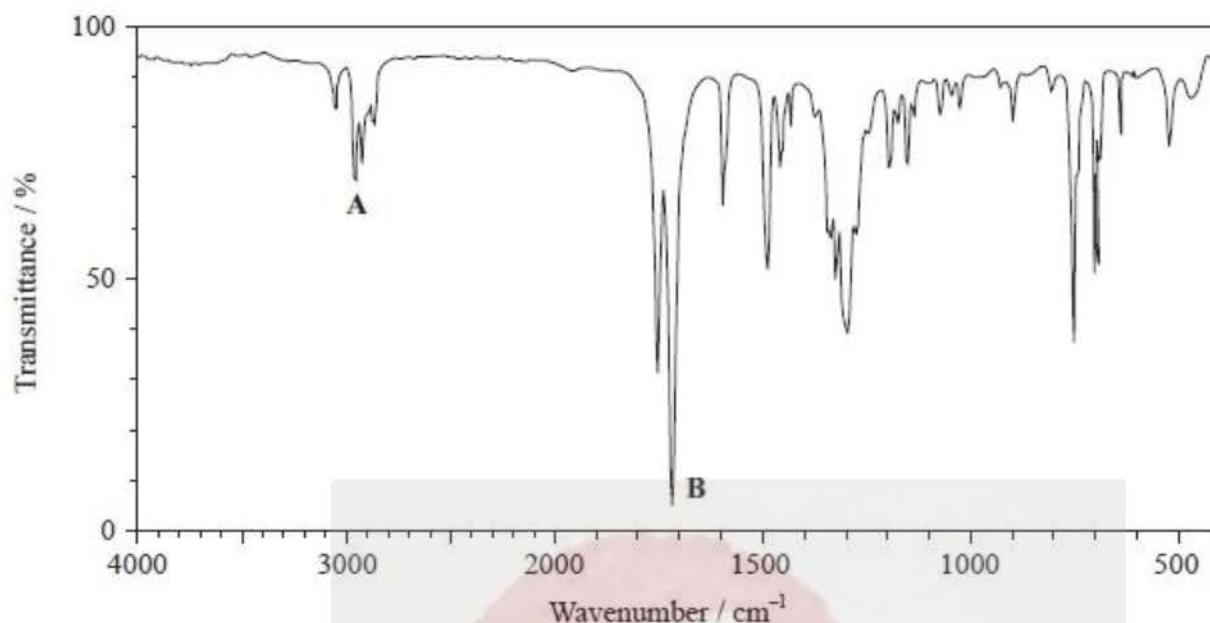
(b) Bute is a chemical with the following molecular formula:

$\text{C}_{19}\text{H}_{20}\text{N}_2\text{O}_2$



It has an unsaturation index of 9/ www.SmashingScience.org :o)

(iv) The infrared (IR) spectrum of bute is shown below.



[Source: SDBS web: www.sdb.srioddb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Using information from section 26 of the data booklet, identify the bonds corresponding to A and B.

[1]

A:
B:

(v) Based on analysis of the IR spectrum, predict, with an explanation, one bond containing oxygen and one bond containing nitrogen that could not be present in the structure.

[2]

Bond containing oxygen not present in structure:

.....

Bond containing nitrogen not present in structure:

.....

Explanation:

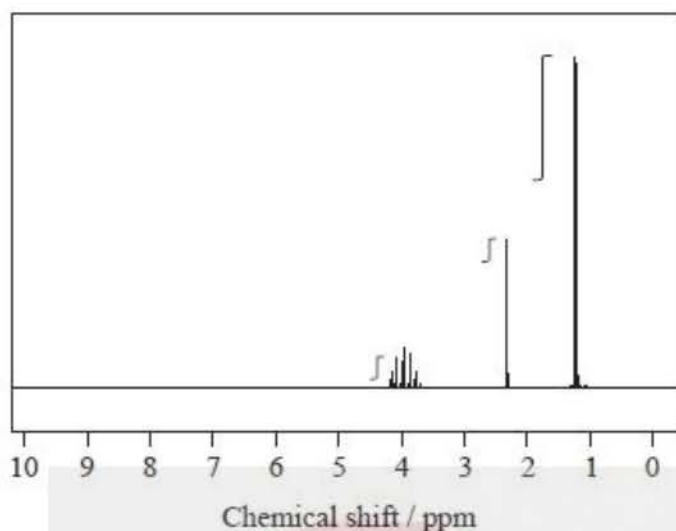
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- (c) An alcohol, X, of molecular formula C_3H_8O , used as a disinfectant in hospitals, has the following 1H NMR spectrum:



[Source: SDBS web: www.sdb.srioddb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the 1H NMR spectrum of X have chemical shift values centred at $\delta = 4.0$, 2.3 and 1.2 ppm.

- (i) From the integration trace, estimate the ratio of hydrogen atoms in different chemical environments. [1]

.....
.....

- (ii) Deduce the full structural formula of X. [1]

SMASHING!!!

- (iii) Y is an isomer of X containing a different functional group. State the condensed structural formula of Y. [1]

.....

.....

- (iv) Compare and contrast the expected mass spectra of X and Y using section 28 of the data booklet. [2]

One similarity:

.....

.....

One difference:

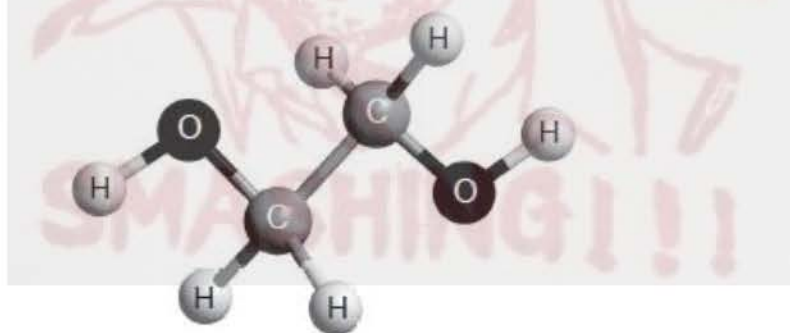
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Topic Chem 11 Q# 206/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q2/ www.SmashingScience.org :o)

- (c) The other monomer used in the production of polyurethane is compound Z shown below.



- (ii) Deduce the number of signals you would expect to find in the ^1H NMR spectrum of compound Z, giving your reasons. [1]

.....

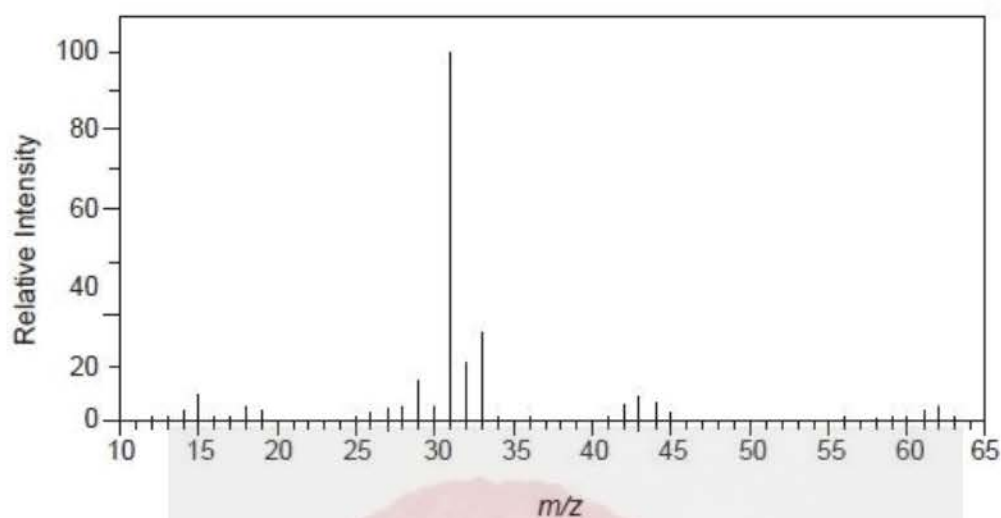
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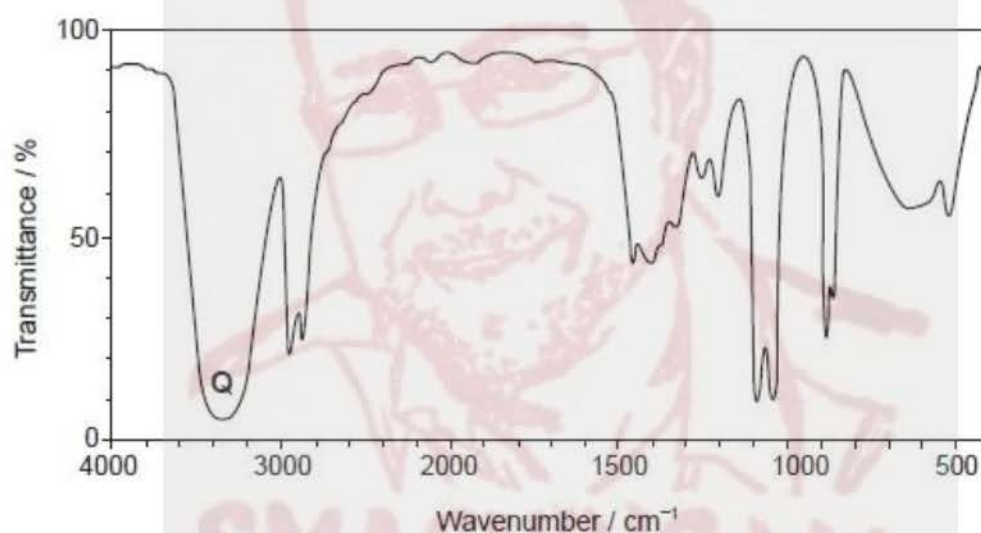
The mass spectrum and infrared (IR) spectrum of compound **Z** are shown below:

Mass spectrum



[Source: <http://sdfs.db.aist.go.jp>]

IR spectrum



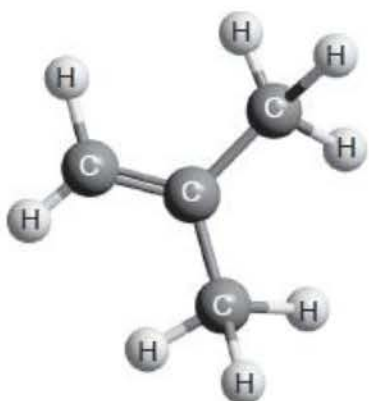
- (iii) Identify the species causing the large peak at $m/z = 31$ in the mass spectrum. [1]

.....

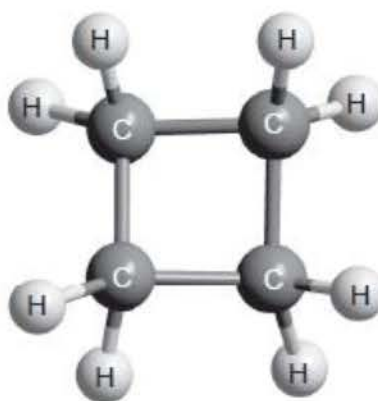
- (iv) Identify the bond that produces the peak labelled **Q** on the IR spectrum, using section 26 of the data booklet. [1]

.....

5. Compound **A** and compound **B** are hydrocarbons.



A



B

- (b) Outline how you could use the IR spectra of compounds **A** and **B** and section 26 of the data booklet to identify them.

[1]

.....

- (c) Two signals occur in the ^1H NMR spectrum of compound **A**. Deduce their expected chemical shift and their splitting pattern, using section 27 of the data booklet.

[2]

Signal	1	2
Chemical shift / ppm		
Splitting pattern		



1. A student used the technique of titration to determine the concentration of ascorbic acid ($C_6H_8O_6$) in a sample of orange juice. Excess potassium iodide, $KI(aq)$, was added to acidified orange juice. The resulting solution was titrated with potassium iodate, $KIO_3(aq)$, in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.
- (c) The concentration of KIO_3 used in the titration was $2.00 \times 10^{-3} \text{ mol dm}^{-3}$. The titration produced the following results.

	Titration 1	Titration 2	Titration 3
Final volume of $KIO_3 (\pm 0.05 \text{ cm}^3)$	7.10	14.40	21.60
Initial volume of $KIO_3 (\pm 0.05 \text{ cm}^3)$	0.00	7.10	14.40
Volume added of $KIO_3 (\pm 0.10 \text{ cm}^3)$	7.10	7.30	7.20
Mean volume added of $KIO_3 (\pm 0.10 \text{ cm}^3)$	7.20		

- (i) Calculate the percentage uncertainty associated with the mean volume of $KIO_3(aq)$.

[1]

.....

.....

.....

- (ii) The colour of orange juice interfered with the blue-black colour at the equivalence point. State the name of this type of error and suggest how this can be minimized.

[2]

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.....

.....



- (e) In the operation of a mass spectrometer, the first stage is vaporization and the last is detection. State the names of the other three stages and outline what happens in each one.

[3]

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Topic Chem X 93 Q# 210/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/

9. (a) Consider the structure and bonding in MgCl_2 and PCl_3 .

- (i) State and explain the electrical conductivities of these two chloride compounds in their liquid state.

[3]

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.....

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.....

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- (ii) Suggest, giving your reasons, the approximate pH values of the solutions formed by adding each chloride compound separately to distilled water.

[4]

MgCl_2 :

.....

.....

.....

PCl_3 :

.....

.....

.....



4. (a) The monomers hexanedioic acid and 1,6-diaminohexane react together to form a synthetic polymer.

Deduce the structural formula of each monomer.

[2]

- (b) State the type of polymerization reaction that occurs between these two monomers and identify the structural feature needed in the monomers.

[2]

Type:
.....

Structural feature:
.....
.....

- (c) Draw the structure of the linkage formed in this polymer, and identify the other product of this polymerization reaction.

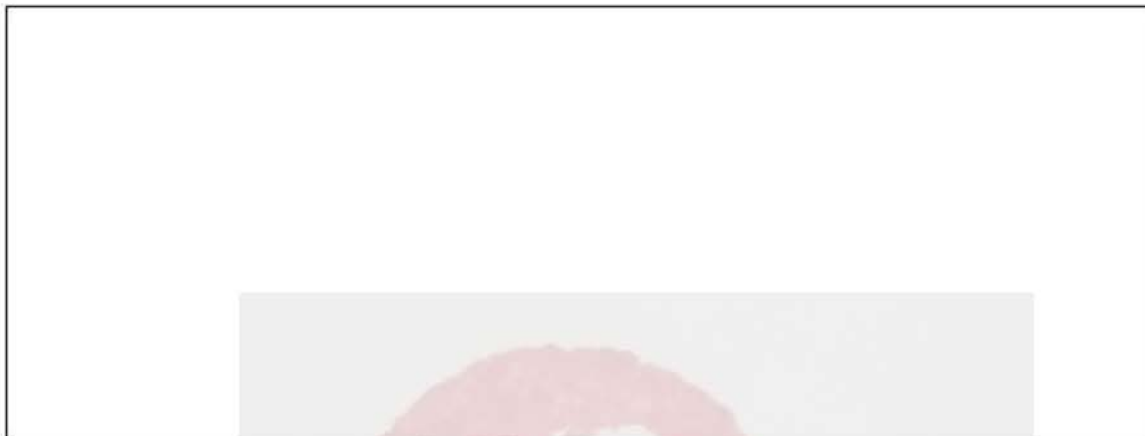
[2]

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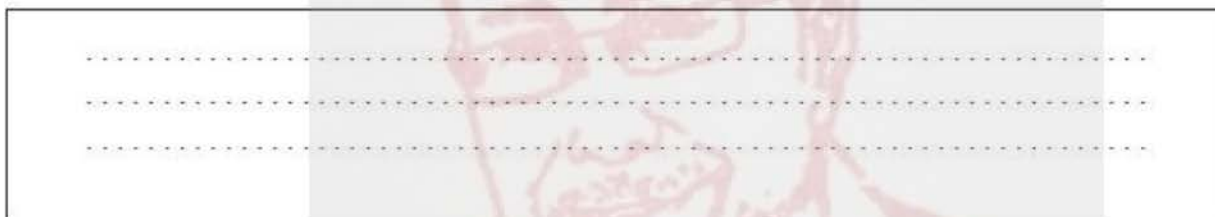


- (c) The reaction between the primary halogenoalkane, obtained in part (a) (v), and hot, concentrated alcoholic NaOH is an example of an elimination reaction.

- (i) Explain the mechanism of the elimination reaction using curly arrows to represent the movement of electron pairs. [4]



- (e) Describe, using an equation, the elimination of HBr from 2-bromobutane, stating the reagent used. [2]



Mark Scheme

Topic Chem 1 Q# 1/ IB Chem/2019/w/TZ0/P2/Higher Level/Q8./

7.	a	i	$\text{C}(\text{NH}_2)_3\text{NO}_3(\text{s}) \rightarrow 2\text{N}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g}) + \text{C}(\text{s}) \checkmark$		1
7.	a	ii	moles of gas = $5 \times \frac{10.0 \text{ g}}{122.11 \text{ g mol}^{-1}} = 0.409 \text{ «mol»} \checkmark$		1
7.	a	iii	$p = \frac{0.409 \text{ mol} \times 8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times (127 + 273) \text{ K}}{10.0 \text{ dm}^3} = 136 \text{ «kPa»} \checkmark$		1
7.	a	iv	Any two of: nitrogen non-polar/London/dispersion forces AND water polar/H-bonding $\checkmark$ water has «much» stronger intermolecular forces $\checkmark$ water molecules attract/condense/occupy smaller volume «and therefore deviate from ideal behaviour» $\checkmark$		2 max
7.	b		$2\text{Na}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g}) \checkmark$ hydrogen explosive OR highly exothermic reaction OR sodium reacts violently with water OR forms strong alkali $\checkmark$	Accept the equation of combustion of hydrogen. Do not accept just "sodium is reactive/dangerous".	2

Topic Chem 1 Q# 2/ IB Chem/2019/w/TZ0/P2/Higher Level/Q7./

6.	b		mass of H_2O = $18.360 \text{ g} - 17.917 \text{ g} = 0.443 \text{ «g»}$ AND mass of CuCl_2 = $17.917 \text{ g} - 16.221 \text{ g} = 1.696 \text{ «g»} \checkmark$ moles of H_2O = $\frac{0.443 \text{ g}}{18.02 \text{ g mol}^{-1}} = 0.0246 \text{ «mol»}$ OR moles of CuCl_2 = $\frac{1.696 \text{ g}}{134.46 \text{ g mol}^{-1}} = 0.0126 \text{ «mol»} \checkmark$ «water : copper(II) chloride = 1.95 : 1» «x =» 2 $\checkmark$	Award [3] for correct final answer. Accept «x =» 1.95.	3
----	---	--	--	---	---

Topic Chem 1 Q# 3/ IB Chem/2018/w/TZ 0/P2/Higher Level/

5.	a		all «species» are in same phase $\checkmark$	Accept "all species are in same state". Accept "all species are gases".	1
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Topic Chem 1 Q# 4/ IB Chem/2018/w/TZ 0/P2/Higher Level/

2.	a		«in 100 g sample» $\frac{62.02 \text{ g}}{12.01 \text{ g mol}^{-1}}$ AND $\frac{10.43 \text{ g}}{1.01 \text{ g mol}^{-1}}$ OR «in 100 g sample» 5.164 mol C AND 10.33 mol H $\checkmark$ 27.55 % OR 1.722 mol O $\checkmark$ «empirical formula» $\text{C}_3\text{H}_5\text{O} \checkmark$		3
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Topic Chem 1 Q# 5/ IB Chem/2018/w/TZ 0/P2/Higher Level/

1.	a	i	$n_{\text{CuSO}_4} = 0.0800 \text{ dm}^3 \times 0.200 \text{ mol dm}^{-3} = 0.0160 \text{ mol}$ AND $n_{\text{Fe}} = \frac{3.26 \text{ g}}{55.85 \text{ g mol}^{-1}} = 0.0584 \text{ mol}$ ✓ CuSO ₄ is the limiting reactant ✓	Do not award M2 if mole calculation is not shown.	2
1.	a	ii	ALTERNATIVE 1: $0.0160 \text{ mol} \times 63.55 \text{ g mol}^{-1} = 1.02 \text{ g}$ ✓ $\frac{0.872 \text{ g}}{1.02 \text{ g}} \times 100 = 85.5 \%$ ✓ ALTERNATIVE 2: $\frac{0.872 \text{ g}}{63.55 \text{ g mol}^{-1}} = 0.0137 \text{ mol}$ ✓ $\frac{0.0137 \text{ mol}}{0.0160 \text{ mol}} \times 100 = 85.6 \%$ ✓	Accept answers in the range 85–86 %. Award [2] for correct final answer.	2

Topic Chem 1 Q# 6/ IB Chem/2018/s/TZ 2/P2/Higher Level/

1.	a		$n(\text{H}_2\text{SO}_4) = 0.0500 \text{ dm}^3 \times 0.100 \text{ mol dm}^{-3} = 0.00500/5.00 \times 10^{-3} \text{ mol}$ ✓		1
1.	b		$\text{H}_2\text{SO}_4(\text{aq}) + \text{Mg}(\text{OH})_2(\text{s}) \rightarrow \text{MgSO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ ✓	Accept an ionic equation.	1
1.	c		$n(\text{H}_2\text{SO}_4) = \frac{1}{2} \times n(\text{NaOH}) = \frac{1}{2} (0.02080 \text{ dm}^3 \times 0.1133 \text{ mol dm}^{-3})$ $0.001178/1.178 \times 10^{-3} \text{ mol}$ ✓		1
1.	d		$n(\text{H}_2\text{SO}_4) \text{ reacted} = 0.00500 - 0.001178 = 0.00382/3.82 \times 10^{-3} \text{ mol}$ ✓		1
1.	e		$n(\text{Mg}(\text{OH})_2) = n(\text{H}_2\text{SO}_4) = 0.00382/3.82 \times 10^{-3} \text{ mol}$ ✓ $m(\text{Mg}(\text{OH})_2) = 0.00382 \text{ mol} \times 58.33 \text{ g mol}^{-1} = 0.223 \text{ g}$ ✓	Award [2] for correct final answer.	2
1.	f		$\% \text{ Mg}(\text{OH})_2 = \frac{0.223 \text{ g}}{1.24 \text{ g}} \times 100 = 18.0 \%$ ✓	Answer must show three significant figures.	1

Topic Chem 1 Q# 7/ IB Chem/2018/s/TZ 1/P2/Higher Level/

1.	a	i	$\text{molar mass of urea} = 4 \times 1.01 + 2 \times 14.01 + 12.01 + 16.00 = 60.07 \text{ g mol}^{-1}$ ✓ $\% \text{ nitrogen} = \frac{2 \times 14.01}{60.07} \times 100 = 46.65 \%$ ✓	Award [2] for correct final answer. Award [1 max] for final answer not to two decimal places.	2
1.	a	ii	«cost» increases AND lower N % «means higher cost of transportation per unit of nitrogen» OR «cost» increases AND inefficient/too much/about half mass not nitrogen ✓	Accept other reasonable explanations. Do not accept answers referring to safety/explosions.	1
1.	c		$n(\text{KNO}_3) = 0.0500 \text{ dm}^3 \times 0.100 \text{ mol dm}^{-3} = 5.00 \times 10^{-3} \text{ mol}$ ✓ $\text{mass of urea} = 5.00 \times 10^{-3} \text{ mol} \times 60.07 \text{ g mol}^{-1} = 0.300 \text{ g}$ ✓	Award [2] for correct final answer.	2
1.	d	iii	$\ln K = \frac{-\Delta G^\ominus}{RT} = \frac{-50 \times 10^3 \text{ J}}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K}} = -20$ ✓ $K_c = 2 \times 10^{-9}$ OR 1.69×10^{-9} OR 10^{-9} ✓	Accept range of 20–20.2 for M1. Award [2] for correct final answer.	2



1.	f		$2(\text{H}_2\text{N})_2\text{CO}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 4\text{H}_2\text{O}(\text{l}) + 2\text{CO}_2(\text{g}) + 2\text{N}_2(\text{g})$ correct coefficients on LHS ✓ correct coefficients on RHS ✓	Accept $(\text{H}_2\text{N})_2\text{CO}(\text{s}) + \frac{3}{2}\text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g}) + \text{N}_2(\text{g})$. Accept any correct ratio.	2
1.	g		$V = \frac{0.600 \text{ g}}{60.07 \text{ g mol}^{-1}} \times 22700 \text{ cm}^3 \text{ mol}^{-1} = 227 \text{ cm}^3$ ✓		1

Topic Chem 1 Q# 8/ IB Chem/2017/s/TZ 2/P2/Higher Level/

2	a	iii	$[\text{K}_2\text{Cr}_2\text{O}_7] = \frac{13.239 \text{ g}}{294.20 \text{ g mol}^{-1} \times 0.100 \text{ dm}^3} = 0.450 \text{ mol dm}^{-3}$ ✓		1
2	a	iv	$n(\text{Sn}^{2+}) = 0.450 \text{ mol dm}^{-3} \times 0.01324 \text{ dm}^3 \times \frac{3 \text{ mol}}{1 \text{ mol}} = 0.0179 \text{ mol}$ ✓ $[\text{Sn}^{2+}] = \frac{0.0179 \text{ mol}}{0.0100 \text{ dm}^3} = 1.79 \text{ mol dm}^{-3}$ ✓	Award [2] for correct final answer.	2

Topic Chem 1 Q# 9/ IB Chem/2017/s/TZ 2/P2/Higher Level/

1.	a	i	$n(\text{Ag}) = \frac{3.275 \text{ g}}{107.87 \text{ g mol}^{-1}} = 0.03036 \text{ mol}$ AND $n(\text{O}) = \frac{3.760 \text{ g} - 3.275 \text{ g}}{16.00 \text{ g mol}^{-1}} = \frac{0.485}{16.00} = 0.03031 \text{ mol}$ ✓ $\frac{0.03036}{0.03031} \approx 1$ / ratio of Ag to O approximately 1 : 1, so AgO ✓	Accept other valid methods for M1. Award [1 max] for correct empirical formula if method not shown.	2
1	a	ii	temperature too low OR heating time too short OR oxide not decomposed completely ✓ heat sample to constant mass «for three or more trials» ✓	Accept "not heated strongly enough". If M1 as per markscheme, M2 can only be scored for constant mass technique. Accept "soot deposition" (M1) and any suitable way to reduce it (M2). Accept "absorbs moisture «from atmosphere» (M1) and "cool in desiccator" (M2). Award [1 max] for reference to "impurity" AND design improvement.	2

Topic Chem 1 Q# 10/ IB Chem/2017/s/TZ 2/P2/Higher Level/

1	b		A_r closer to 107/less than 108 «so more ^{107}Ag » OR A_r less than the average of (107 + 109) «so more ^{107}Ag » ✓	Accept calculation that gives greater than 50% ^{107}Ag .	1
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1	c	i	Flask containing	Colour of solution	Product formula	Do not accept name for the products. Accept $\text{Na}^+ + \text{OH}^-$ for NaOH. Ignore coefficients in front of formula.	3
			Na_2O	blue	NaOH ✓		
			P_4O_{10}	AND yellow ✓	H_3PO_4 ✓		
1	c	ii	«molten» Na_2O has mobile ions/charged particles AND conducts electricity ✓ «molten» P_4O_{10} does not have mobile ions/charged particles AND does not conduct electricity/is poor conductor of electricity ✓			Do not award marks without concept of mobile charges being present. Award [1 max] if type of bonding or electrical conductivity correctly identified in each compound. Do not accept answers based on electrons. Award [1 max] if reference made to solution.	2
1	d		electrons in discrete/specific/certain/different shells/energy levels ✓ energy levels converge/get closer together at higher energies OR energy levels converge with distance from the nucleus ✓			Accept appropriate diagram for either M1, M2 or both. Do not give marks for answers that refer to the lines in the spectrum.	2

Topic Chem 1 Q# 11/ IB Chem/2017/s/TZ 1/P2/Higher Level/

6.	c	i	$\text{C} = \frac{24.27}{12.01} = 2.021$ AND $\text{H} = \frac{4.08}{1.01} = 4.04$ AND $\text{Cl} = \frac{71.65}{35.45} = 2.021$ ✓ «hence» CH_2Cl ✓	Accept $\frac{24.27}{12.01} : \frac{4.08}{1.01} : \frac{71.65}{35.45}$ Do not accept $\text{C}_2\text{H}_4\text{Cl}_2$. Award [2] for correct final answer.	2
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Topic Chem 1 Q# 12/ IB Chem/2017/s/TZ 1/P2/Higher Level/

5.	h	i	total mass of oxygen « $8.0 \times 10^{-3} \text{ g dm}^{-3} \times 1000 \text{ dm}^3$ » = 8.0 «g» $n(\text{O}_2) = \frac{8.0 \text{ g}}{32.00 \text{ g mol}^{-1}} = 0.25 \text{ «mol»}$ OR $n(\text{N}_2\text{H}_4) = n(\text{O}_2)$ ✓ «mass of hydrazine = $0.25 \text{ mol} \times 32.06 \text{ g mol}^{-1}$ » = 8.0 «g» ✓	Award [3] for correct final answer.	3
5.	h	ii	$n(\text{N}_2\text{H}_4) = n(\text{O}_2) = \frac{8.0 \text{ g}}{32.00 \text{ g mol}^{-1}} = 0.25 \text{ «mol»}$ «volume of nitrogen = $0.25 \text{ mol} \times 24.8 \text{ dm}^3 \text{ mol}^{-1}$ » = 6.2 «dm ³ » ✓	Award [1] for correct final answer.	1

Topic Chem 1 Q# 13/ IB Chem/2017/s/TZ 1/P2/Higher Level/

2.	h	i	$\text{TiCl}_4(\text{l}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{TiO}_2(\text{s}) + 4\text{HCl}(\text{aq})$ correct products ✓ correct balancing ✓	Accept ionic equation. Award M2 if products are HCl and a compound of Ti and O.	2
2.	h	ii	HCl causes breathing/respiratory problems OR HCl is an irritant OR HCl is toxic OR HCl has acidic vapour OR HCl is corrosive ✓	Accept TiO_2 causes breathing problems/is an irritant. Accept "harmful" for both HCl and TiO_2 . Accept "smoke is asphyxiant".	1

Topic Chem 1 Q# 14/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

2.	a		Weak acid: partially dissociated/ionized «in solution/water» AND Strong acid: «assumed to be almost» completely/100% dissociated/ionized «in solution/water» ✓	Accept answers relating to pH, conductivity, reactivity if solutions of equal concentrations stated.	1
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Question	Answers	Notes	Total
2. b	«log scale» reduces a wide range of numbers to a small range OR simple/easy to use OR converts exponential expressions into a linear scale/simple numbers ✓	<i>Do not accept "easy for calculations".</i>	1
2. c i	phenolphthalein OR phenol red ✓		1
2. c ii	$n(\text{NaOH}) = \left(\frac{14.0}{1000}\right) \text{dm}^3 \times 0.100 \text{mol dm}^{-3} = 1.40 \times 10^{-3} \text{mol} \checkmark$		1
2. c iii	$\frac{1}{2} \times 1.40 \times 10^{-3} = 7.00 \times 10^{-4} \text{mol} \checkmark$		1

Question	Answers	Notes	Total
2. c iv	ALTERNATIVE 1: «mass of pure hydrated ethanedioic acid in each titration = $7.00 \times 10^{-4} \text{mol} \times 126.08 \text{g mol}^{-1} = 0.0883 / 8.83 \times 10^{-2} \text{g} \checkmark$ mass of sample in each titration = $\frac{25}{1000} \times 5.00 \text{g} = 0.125 \text{g} \checkmark$ «% purity = $\frac{0.0883 \text{g}}{0.125 \text{g}} \times 100 = 70.6 \text{ \%} \checkmark$ ALTERNATIVE 2: «mol of pure hydrated ethanedioic acid in 1 dm³ solution = $7.00 \times 10^{-4} \times \frac{1000}{25} = 2.80 \times 10^{-2} \text{mol} \checkmark$ «mass of pure hydrated ethanedioic acid in sample = $2.80 \times 10^{-2} \text{mol} \times 126.08 \text{g mol}^{-1} = 3.53 \text{g} \checkmark$ «% purity = $\frac{3.53 \text{g}}{5.00 \text{g}} \times 100 = 70.6 \text{ \%} \checkmark$ ALTERNATIVE 3: mol of hydrated ethanedioic acid (assuming sample to be pure) = $\frac{5.00 \text{g}}{126.08 \text{g mol}^{-1}} = 0.03966 \text{mol} \checkmark$ actual amount of hydrated ethanedioic acid = $7.00 \times 10^{-4} \times \frac{1000}{25} = 2.80 \times 10^{-2} \text{mol} \checkmark$ «% purity = $\frac{2.80 \times 10^{-2}}{0.03966} \times 100 = 70.6 \text{ \%} \checkmark$	<i>Award suitable part marks for alternative methods.</i> <i>Award [3] for correct final answer.</i> <i>Award [2 max] for 50.4% if anhydrous ethanedioic acid assumed.</i>	3

Topic Chem 1 Q# 15/ IB Chem/2016/s/TZ0SP/P2 Section A/Higer Level/

b i	$n_{\text{C}} : \left(\frac{73.99}{12.01}\right) = 6.161(\text{mol})$ and $n_{\text{H}} : \left(\frac{6.55}{1.01}\right) = 6.49(\text{mol})$ and $n_{\text{N}} : \left(\frac{9.09}{14.01}\right) = 0.649(\text{mol})$ and $n_{\text{O}} : \left(\frac{10.37}{16.00}\right) = 0.6481(\text{mol}) \checkmark$ $n_{\text{C}} : n_{\text{H}} : n_{\text{N}} : n_{\text{O}} = 9.5 : 10 : 1 : 1 \checkmark$ Empirical formula: $\text{C}_{10}\text{H}_{20}\text{N}_2\text{O}_2 \checkmark$	<i>Award [2 max] for correct final answer without working.</i>	3
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Topic Chem 1 Q# 16/ IB Chem/2016/s/TZ0SP/P2 Section A/Higer Level/

Question	Answers	Notes	Total
1. a i	$\langle(22.05 + 22.15)(0.5) \rightarrow 22.10 \text{ cm}^3 \rangle \checkmark$		1
a ii	$\left(\frac{22.10 \times 0.100}{1000}\right) = 2.21 \times 10^{-3} / 0.00221 \text{ mol} \checkmark$		1
a iii	$\left(\frac{0.5 \times 2.21 \times 10^{-3} \times 1000}{25.00}\right) = 4.42 \times 10^{-2} / 0.0442 \text{ mol dm}^{-3} \checkmark$		1
a iv	$\langle 4.42 \times 10^{-2} \times 10 \Rightarrow 4.42 \times 10^{-1} / 0.442 \text{ mol dm}^{-3} \rangle \checkmark$		1

Topic Chem 1 Q# 17/ IB Chem/2016/s/TZ1/P2 Section A/Higer Level/

1. b i	P_4 is a molecule «comprising 4P atoms» AND 4P is four/separate «P» atoms OR P_4 represents «4P» atoms bonded together AND 4P represents «4» separate/non-bonded «P» atoms ✓		1
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1.	c	i	$\left(\frac{2.478}{4 \times 30.97}\right) \rightarrow 0.02000 \text{ mol} \checkmark$		1
1.	c	ii	$n(\text{NaOH}) = 0.1000 \times 5.00 \rightarrow 0.500 \text{ mol} \text{ AND } P_4/\text{phosphorus is limiting reagent} \checkmark$	Accept $n(\text{H}_2\text{O}) = \frac{100}{18} = 5.50 \text{ AND } P_4 \text{ is limiting reagent.}$	1
1.	c	iii	amount in excess $\rightarrow 0.500 - (3 \times 0.02000) \rightarrow 0.440 \text{ mol} \checkmark$		1
1.	c	iv	$22.7 \times 1000 \times 0.02000 \rightarrow 454 \text{ cm}^3 \checkmark$	Accept methods employing $pV = nRT$, with p as either 100 (454 cm ³) or 101.3 kPa (448 cm ³). Do not accept answers in dm ³ .	1

Question	Answers	Notes	Total
1. d ii	$n(\text{P}) = \frac{43.6}{30.97} \rightarrow 1.41 \text{ mol} \checkmark$ $n(\text{O}) = \frac{100 - 43.6}{16.00} \rightarrow 3.53 \text{ mol} \checkmark$ $\frac{n(\text{O})}{n(\text{P})} = \frac{3.53}{1.41} = 2.50 \text{ so empirical formula is } P_2O_5 \checkmark$	Accept other methods where the working is shown.	3
1. d iii	$\frac{285}{141.9} = 2.00$, so molecular formula $= 2 \times P_2O_5 \rightarrow P_4O_{10} \checkmark$		1

Topic Chem 1 Q# 18/ IB Chem/2015/w/TZ0/P2 Section A/Higher Level/

1. (a) (i) IO_3^- to I_2 : V/+5 to 0;
 I^- to I_2 : -I/-1 to 0;
 Accept change in oxidation number -5 and +1.
 Penalize incorrect notation such as 5+ or 5 once only. [2]
- (ii) Oxidizing agent: IO_3^- /iodate **and** Reducing agent: I^- /iodide; [1]
- (b) $0.250 \times 2.00 \times 10^{-3} / 5.00 \times 10^{-4}$ (mol of KIO_3);
 $(5.00 \times 10^{-4} \times 214.00 =) 0.107 \text{ (g)}$;
 Award [2] for the correct final answer. [2]
- (c) (i) 1.4 (%);
 Accept 1 (%). [1]
- (ii) systematic;
 dilute the orange juice;
 Accept other valid suggestions, eg. compare with a standard (showing colour at equivalence) / look at mixture through a yellow filter / add more starch (for a sharper colour change) / filter orange juice (through charcoal).
 Do not accept repeat titrations or alternative indicator. [2]
- (iii) $1.44 \times 10^{-5} \text{ (mol)}$; [1]
- (d) $\text{IO}_3^- : 3\text{C}_6\text{H}_8\text{O}_6$ / 1:3 mole ratio;
 $(1.44 \times 10^{-5} \text{ mol} \times 3 =) 4.32 \times 10^{-5} \text{ (mol)}$;
 Award [2] for the correct final answer.
 Award [1 max] for " $4.80 \times 10^{-6} \text{ (mol)}$ " obtained from reversed ratio, 3:1. [2]
- (e) $(4.32 \times 10^{-5} \times 176.14 =) 7.61 \times 10^{-3} \text{ (g)}$;
 Accept $M_r = 176$ and mass $= 7.60 \times 10^{-3} \text{ (g)}$. [1]



- (f) $\text{gradient} = -\frac{E_a}{R} / -1233(\text{K})$;
Accept value from -1200 to -1260 (K).

$$E_a = (1233 \times 8.31) = 1.02 \times 10^4 \text{ J mol}^{-1} / 10.2 \text{ kJ mol}^{-1}$$

correct E_a value;

correct units;

Allow value in range $9.97 - 10.5 \text{ kJ mol}^{-1}$.

Answer must be given to three significant figures.

Award [3] for correct final answer **and** units.

Accept J or kJ instead of J mol^{-1} or kJ mol^{-1} .

[3]

Topic Chem 1 Q# 19/ IB Chem/2015/s/TZ1/P2 Section A/Higher Level/

1. (a) $\left(\frac{12.70 + 12.50}{2} \right) = 12.60(\text{cm}^3)$;

$$(0.01260 \times 0.100) = 1.26 \times 10^{-3}(\text{mol})$$

Award [2] for correct final answer.

[2]

(b) (i) $\left(\frac{1.26 \times 10^{-3}}{2} \right) = 6.30 \times 10^{-4}(\text{mol})$;

[1]

(ii) $(6.30 \times 10^{-4} \times 10) = 6.30 \times 10^{-3}(\text{mol})$;

[1]

(iii) $\left(\frac{0.795}{6.30 \times 10^{-3}} \right) = 126(\text{g mol}^{-1})$;

[1]

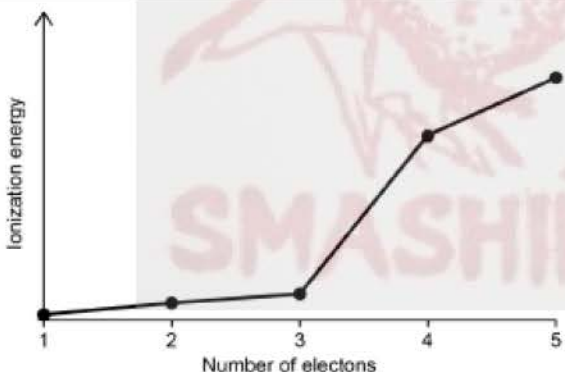
(iv) $M_r(\text{C}_2\text{H}_2\text{O}_4) = 90.04$ and $M_r(\text{H}_2\text{O}) = 18.02$;
 $x = 2$;

[2]

Accept integer values for M_r 's of 90 and 18 and any reasonable calculation.

Award [1 max] if no working shown.

Topic Chem 2 Q# 20/ IB Chem/2018/w/TZ 0/P2/Higher Level/

4.	c	 Sketch showing: largest increase between third and fourth ionization energies ✓ $IE_1 < IE_2 < IE_3 < IE_4 < IE_5$ ✓	2
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Topic Chem 2 Q# 21/ IB Chem/2017/s/TZ 2/P2/Higher Level/

4	c	Any two of: IE ₄ : electron in lower/inner shell/energy level OR IE ₄ : more stable/full electron shell ✓ IE ₄ : electron closer to nucleus OR IE ₄ : electron more tightly held by nucleus ✓ IE ₄ : less shielding by complete inner shells ✓	Accept "increase in effective nuclear charge" for M2.	2 max
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Topic Chem 2 Q# 22/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question	Answers	Notes	Total
4. a	$^{26}_{12}\text{Mg}$ ✓		1
4. b	$\langle A_r \rangle = \frac{24 \times 78.60 + 25 \times 10.11 + 26 \times 11.29}{100}$ ✓ $\langle A_r \rangle = 24.3269 \Rightarrow 24.33$ ✓	Award [2] for correct final answer. Do not accept data booklet value (24.31).	2
4. c	contamination with sodium/other «compounds» ✓		1
4. d i	energy levels are closer together at high energy / high frequency / short wavelength ✓		1
4. d ii	ionisation energy ✓		1

Topic Chem 2 Q# 23/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

d i	$[\text{Ne}]3s^2 3p^4$ ✓	Electrons must be given as superscript.	1
d ii	$\begin{array}{|c|c|c|c|c|} \hline 1 & 1 & 1 & 1 & 1 \\ \hline 1s^2 & 2s^2 & 2p^6 & 3s^2 & 3p^4 \\ \hline \end{array}$ ✓		1

Topic Chem 2 Q# 24/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

e	ionic radius of nitrogen is $146\text{pm}/146 \times 10^{-12}\text{m}$ which is greater than atomic radius which is $71\text{pm}/71 \times 10^{-12}\text{m}$ due to increased repulsion between electrons ✓	Values must be given to score mark.	1
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Topic Chem 2 Q# 25/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

4. e i	First: 4s AND Second: 4s AND Third: 3d AND Fourth: 3d ✓	Do not apply ECF from (c).	1
4. e ii	«in the same sub-shell and a» decrease in electron-electron repulsion OR «in the same sub-shell and» as more electrons removed, the pull of the nucleus/positive ions holds the remaining electrons more tightly ✓	Do not accept "greater nuclear charge/ effective nuclear charge".	1
4. e iii	electron 5 is lost from the 3d orbital OR electron 5 is lost from the valence shell ✓ electron 6 is lost from a 3p orbital OR electron 6 is lost from a «complete» inner shell ✓ 3p orbital/complete inner shell experiences a much larger effective nuclear charge OR 3p orbital/complete inner shell is less well shielded OR 3p orbital/complete inner shell is nearer the nucleus ✓	Award [1 max] (for M1/M2) (ECF) if candidate recognises electrons 5 and 6 are from different levels.	3
4. e iv	28 ✓		1

Topic Chem 2 Q# 26/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

(g) $79.91 = 79x + 81(1 - x)$;

Award M1 for any suitable calculation.

(abundance ^{79}Br) = 54.5 %;

Award [2] for correct final answer.

[2]

Topic Chem 3 Q# 27/ IB Chem/2019/w/TZ0/P2/Higher Level/Q7./

6. a i	$[\text{Ar}] 3d^{10}$ OR $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓		1
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6.	f	i	«ligands cause» d-orbitals «to» split ✓ light absorbed as electrons transit to higher energy level «in d–d transitions» OR light absorbed as electrons promoted ✓ energy gap corresponds to «orange» light in visible region of spectrum ✓ colour observed is complementary ✓		3 max
6.	f	ii	full «3»d sub-level/orbitals OR no d–d transition possible «and therefore no colour» ✓		1

Topic Chem 3 Q# 28/ IB Chem/2018/w/TZ 0/P2/Higher Level/

4.	a		nuclear charge/number of protons/ Z_{eff} increases «causing a stronger pull on the outer electrons» ✓ same number of shells/«outer» energy level/shielding ✓	Accept "atomic number" for "number of protons".	2
4.	b		isoelectronic/same electronic configuration/«both» have 2.8 ✓ more protons in Na^+ ✓		2

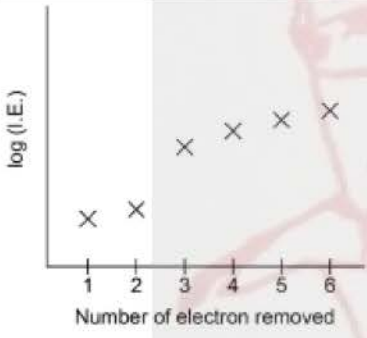
Topic Chem 3 Q# 29/ IB Chem/2018/w/TZ 0/P2/Higher Level/

3.	a	i	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ OR [Ar] $4s^2 3d^{10} 4p^5$ ✓	Accept 3d before 4s.	1
3.	a	ii		Accept double-headed arrows.	1
3.	b	i	Structure I – follows octet rule: Structure II – does not follow octet rule: 	Accept dots, crosses or lines to represent electron pairs.	2
3.	b	ii	«structure I» formal charge on Br = +2 OR «structure II» formal charge on Br = 0/+1 ✓ structure II is preferred AND it produces formal charge closer to 0 ✓	Ignore any reference to formal charge on oxygen.	2



3.	c		Geometry: trigonal/pyramidal ✓ Reason: three bonds AND one lone pair OR four electron domains ✓ O–Br–O angle: 107° ✓	Accept "charge centres" for "electron domains". Accept answers in the range 104–109°.	3
3.	d	i	$\text{BrO}_3^-(\text{aq}) + 6\text{e}^- + 6\text{H}^+(\text{aq}) \rightarrow \text{Br}^-(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$ correct reactants and products ✓ balanced equation ✓	Accept reversible arrows.	2
3.	d	ii	$\text{BrO}_3^-(\text{aq}) + 6\text{Fe}^{2+}(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow \text{Br}^-(\text{aq}) + 3\text{H}_2\text{O}(\text{l}) + 6\text{Fe}^{3+}(\text{aq})$ ✓		1
3.	d	iii	$E^\circ_{\text{reaction}} = +1.44 \text{ V} - 0.77 \text{ V} = +0.67 \text{ V}$ ✓ $\Delta G^\circ = -nFE^\circ_{\text{reaction}} = -6 \times 96500 \text{ C mol}^{-1} \times 0.67 \text{ V} = -3.9 \times 10^5 \text{ J}$ ✓		2
3.	e		both are paramagnetic ✓ «both» contain unpaired electrons ✓	Accept orbital diagrams for both ions showing unpaired electrons.	2

Topic Chem 3 Q# 30/ IB Chem/2018/s/TZ 1/P2/Higher Level/

2.	c		«promoted» electrons fall back to lower energy level ✓ energy difference between levels is different ✓	Accept "Na and Ca have different nuclear charge" for M2.	2
2.	e		 general increase ✓ only one discontinuity between "IE2" and "IE3" ✓		2

Topic Chem 3 Q# 31/ IB Chem/2018/s/TZ 1/P2/Higher Level/

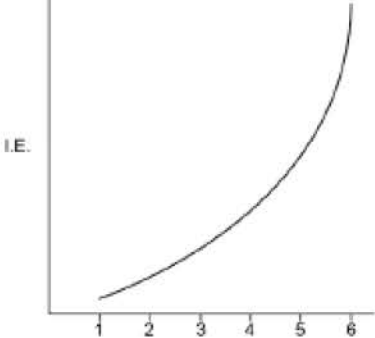
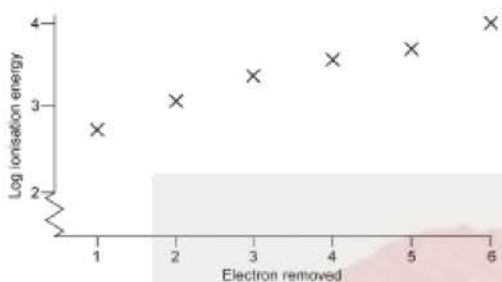
1.	h		lone/non-bonding electron pairs «on nitrogen/oxygen/ligand» given to/shared with metal ion ✓ co-ordinate/dative/covalent bonds ✓		2
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Topic Chem 3 Q# 32/ IB Chem/2017/s/TZ 2/P2/Higher Level/

Topic: Chem 1: Q1: Q2, 15 Chem/2017/3, 12/2/17, Higher Level														
1	c	i	<table><tr><td>Flask containing</td><td>Colour of solution</td><td>Product formula</td></tr><tr><td>Na₂O</td><td>blue</td><td>NaOH ✓</td></tr><tr><td>P₄O₁₀</td><td>AND yellow ✓</td><td>H₃PO₄ ✓</td></tr></table>	Flask containing	Colour of solution	Product formula	Na ₂ O	blue	NaOH ✓	P ₄ O ₁₀	AND yellow ✓	H ₃ PO ₄ ✓	Do not accept name for the products. Accept "Na⁺ + OH⁻" for NaOH. Ignore coefficients in front of formula.	3
Flask containing	Colour of solution	Product formula												
Na ₂ O	blue	NaOH ✓												
P ₄ O ₁₀	AND yellow ✓	H ₃ PO ₄ ✓												



Topic Chem 3 Q# 33/ IB Chem/2017/s/TZ 1/P2/Higher Level/

2.	d	iii	  regular increase for first five AND sharp increase to the 6th ✓	A log graph is acceptable. Accept log plot on given axes (without amendment of y-axis). Award mark if gradient of 5 to 6 is greater than "best fit line" of 1 to 5.	1
2.	e		pair of electrons provided by the ligand ✓	Do not accept "dative" or "co-ordinate bonding" alone.	1
2.	f		partially filled d-orbitals ✓ «ligands cause» d-orbitals «to» split ✓ light is absorbed as electrons transit to a higher energy level «in d-d transitions» OR light is absorbed as electrons are promoted ✓ energy gap corresponds to light in the visible region of the spectrum ✓ colour observed is the complementary colour ✓		4 max

Topic Chem 3 Q# 34/ IB Chem/2017/s/TZ 1/P2/Higher Level/

2.	b		$\frac{(46 \times 7.98) + (47 \times 7.32) + (48 \times 73.99) + (49 \times 5.46) + (50 \times 5.25)}{100}$ = 47.93 ✓	Answer must have two decimal places with a value from 47.90 to 48.00. Award [2] for correct final answer. Award [0] for 47.87 (data booklet value).	2
2.	c		Protons: 22 AND Neutrons: 26 AND Electrons: 22 ✓		1
2.	d	i	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^2$ ✓		1

Topic Chem 3 Q# 35/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

4.	e	$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(s)$ OR $MgO(s) + H_2O(l) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$ ✓	Accept ⇌.	1
4.	f	from basic to acidic ✓ through amphoteric ✓	Accept "alkali/alkaline" for "basic". Accept "oxides of Na and Mg: basic AND oxide of Al: amphoteric" for M1. Accept "oxides of non-metals/Si to Cl acidic" for M2. Do not accept just "become more acidic".	2
4.	g	Mg_3N_2 ✓	Accept MgO_2 , $Mg(OH)_2$, $Mg(NO_3)_2$, $MgCO_3$.	1

Topic Chem 3 Q# 36/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

2.	f	coordinate/dative/covalent bond from O to «transition» metal «ion» OR acts as a Lewis base/nucleophile ✓ can occupy two positions OR provide two electron pairs from different «O» atoms OR form two «coordinate/dative/covalent» bonds «with the metal ion» OR chelate «metal/ion» ✓		2
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Topic Chem 3 Q# 37/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

4.	c		$1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$ OR $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$ ✓ incomplete d «sub-» level/orbital/shell «in its compounds/ions» ✓		2
4.	d	i	give/donate a lone/non-bonding electron pair ✓	Accept "through the formation of a dative/ coordinate bond". Accept "by acting as Lewis bases". Do not accept "act as ligands".	1

Question	Answers	Notes	Total
4. d ii	«more chlorido ligands» smaller energy gap between split d-orbitals OR Cl^- is lower than H_2O in spectrochemical series OR Cl^- is a weaker ligand/has lower charge density ✓ the absorption will move to longer wavelengths OR the absorption wavelength will increase ✓	Do not accept answers in terms of change of frequency.	2

Topic Chem 3 Q# 38/ IB CHEM/2015/w/TZ0/P2 Section B/Higher Level/

(e) (i)

Na and Mg: basic

Al: amphoteric

Do not accept amphiprotic.

Si to Cl: acidic

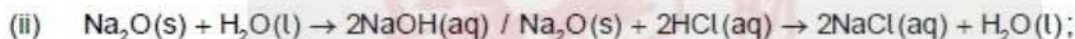
Ar: no oxide ;;

Award [2] for three or four correct, award [1] for two correct.

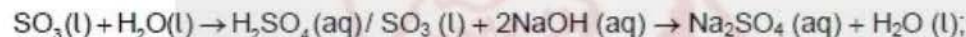
Award [1] for stating oxides become more acidic towards the right/chlorine or more basic towards the left/sodium.

Do not penalize incorrect formulas of oxides.

[2]



Accept a correct equation with any acid or acidic oxide.



[2]

Accept a correct equation with any metal hydroxide, metal oxide, metal carbonate or metal hydrogen carbonate.

Do not accept equation with SO_2 .

Ignore state symbols.

Accept ionic equations for M1 and/or M2.

Topic Chem 3 Q# 39/ IB Chem/2015/w/TZ0/P2 Section A/Higher Level/

5. (a) (i) ability of an atom to attract (a pair of) electrons in a covalent bond/molecule / ability of an atom to attract a shared pair of electrons;
Do not accept element/nucleus instead of atom.

[1]

(ii) do not form bonds/compounds / do not share electrons / have (full/stable) octet / have full/stable outer shell;
Accept (chemically) inert / do not react / stable electron arrangements/ configurations.

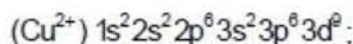
[1]

(c) Na^+ has one less energy level/shell compared to Na atom / Na^+ has 2 energy levels/shells compared to 3 in Na atom;
(compared to Na atom) effective nuclear charge greater in Na^+ (so valence electrons attracted more strongly to nucleus) / (compared to Na atom) more protons than electrons in Na^+ (so valence electrons attracted more strongly to nucleus);

[1 max]



2. (a) (Cu) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ / $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$;
Do not accept [Ar] $4s^1 3d^{10}$.



Do not accept [Ar] $3d^9$.

[2]

- (c) d orbitals are split (into two sets of different energies);
(frequency/wavelength of visible) light absorbed by electrons moving between d levels/orbitals;
colour due to remaining frequencies/complementary colour transmitted;
Cu²⁺ has unpaired electrons/partially filled d sub-level / Zn²⁺ has filled d sub-level;

Accept d-d transitions possible between orbitals for M2.

[4]

- (b) (i) Na, Mg (oxides): basic

Al (oxide): amphoteric

Do not accept amphiprotic.

Si to Cl (oxides): acidic

[2]

Award [2] for all three listed sets correct.

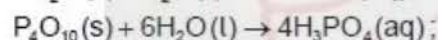
Award [1] for one or two listed sets correct.

Award [1] for stating oxides become more acidic towards right/Cl or more basic towards left/Na.

Do not penalize if reference is to Ar instead of Cl.

Do not penalize for incorrect formulas of oxides.

- (ii) $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq})$;

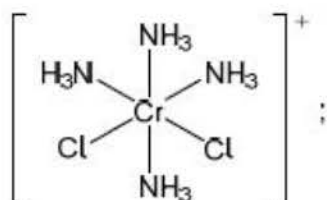
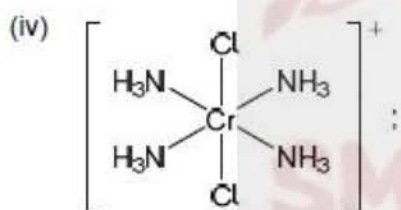


Ignore state symbols.

Accept $\text{P}_2\text{O}_5(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_3\text{PO}_4(\text{aq})$.

Do not award marks if incorrect formulas of the oxides are used.

[2]



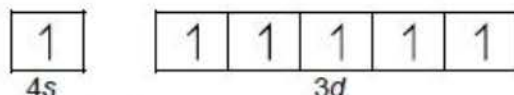
[2]

Accept any other octahedral arrangement of ligands.

Ignore missing square brackets and charge.



8. (a) (i)



[1]

Accept full-arrows.

Accept boxes in reverse order or at different energy levels.

Do not award the mark if sub-levels are incorrectly labelled or if no boxes are drawn.

(ii) (electrostatic) attraction between (lattice of) cations/positive/ Cr^{3+} ions and delocalized electrons;

[1]

(iii) (delocalized electrons allows) the layers/rows of cations/positive/ Cr^{3+} ions to slide past each other (without disrupting the metallic bonding);
Accept atoms instead of ions.

[1]

(c) (i) III / +3;

[1]

Do not accept incorrect notation such as 3+/3.

(ii) ligand has lone/non-bonding electron pair /
dative (covalent)/coordinate/coordination bond forms;

ligand is Lewis base / ion is Lewis acid;

[2]

(iii) partially filled/incomplete d sub levels/orbitals;
d orbitals split into two levels;
energy difference is in visible part of spectrum / electrons absorb visible light/one colour/frequency/wavelength;
electron transitions occur from lower to higher energy level (within d sub-level);
complementary colour/colour not absorbed is seen;
Do not accept complementary colour "emitted".

[4 max]

Topic Chem 3 Q# 44/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

(e) Cl has 7 valence electrons **and** is in group 7;
Accept "group 17" as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3;

[2]

Topic Chem 3 Q# 45/ IB Chem/2015/s/TZ1/P2 Section A/Higher Level/

2. (a) $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq})$;

Accept $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{Na}^+(\text{aq}) + 2\text{OH}^-(\text{aq})$.

$\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq})$;

Accept $\text{P}_2\text{O}_5(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_3\text{PO}_4(\text{aq})$.

Accept $\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}^+(\text{aq}) + 4\text{H}_2\text{PO}_4^-(\text{aq})$.

Ignore state symbols.

[2]

Topic Chem 3 Q# 46/ IB Chem/2015/s/TZ1/P2 Section A/Higher Level/

4. (a) $1\text{s}^22\text{s}^22\text{p}^63\text{s}^23\text{p}^63\text{d}^{10}4\text{s}^1$ / $1\text{s}^22\text{s}^22\text{p}^63\text{s}^23\text{p}^64\text{s}^13\text{d}^{10}$;

[1]

(b) Physical:

^{63}Cu lower boiling point/melting point/density/greater rate of diffusion than ^{65}Cu ;

Accept converse argument.

Do not accept "different mass".

Chemical:

(properties identical because) same electron configuration/arrangement of electrons;

Accept "same number of protons **and** electrons".

Do not accept "same number of electrons" OR "same valence (electrons)" OR "same atomic number" only.

[2]

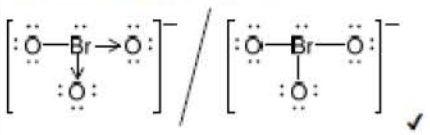
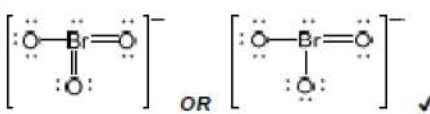


6.	f	iii	octahedral AND 90° «180° for axial» ✓	Accept square-based bi-pyramid.	1
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Topic Chem 4 Q# 48/ IB Chem/2019/w/TZ0/P2/Higher Level/Q2./

1.	a		$\ddot{\text{O}}=\ddot{\text{O}} \quad \ddot{\text{O}}=\ddot{\text{O}}-\ddot{\text{O}}:$ $\checkmark \quad \checkmark$	Coordinate bond may be represented by an arrow. Do not accept delocalized structure for ozone.	2
1.	b		resonance «structures» OR delocalization of «the double/pi bond» electrons ✓ 121 «pm» < length < 148 «pm» ✓	Accept any length between these two values.	2
1.	c		any value from 110°–119° ✓		1
1.	d		«bond» in O ₂ stronger than in O ₃ ✓ ozone absorbs lower frequency/energy «radiation than oxygen» OR ozone absorbs longer wavelength «radiation than oxygen» ✓	Accept ozone «layer» absorbs a range of frequencies.	2
1.	e	i	steps 1 AND 3 ✓		1
1.	e	ii	ALTERNATIVE 1: for oxygen: $E = \frac{498\,000 \text{ J mol}^{-1}}{6.02 \times 10^{23} \text{ mol}^{-1}} = 8.27 \times 10^{-19} \text{ «J»} \checkmark$ $\lambda = \frac{6.63 \times 10^{-34} \text{ J s} \times 3.00 \times 10^8 \text{ m s}^{-1}}{8.27 \times 10^{-19} \text{ J}} = 2.40 \times 10^{-7} \text{ «m»} \checkmark$ ALTERNATIVE 2: for ozone: similar calculation using 200 < bond enthalpy < 400 for ozone, such as $E = \frac{300\,000 \text{ J mol}^{-1}}{6.02 \times 10^{23} \text{ mol}^{-1}} = 4.98 \times 10^{-19} \text{ «J»} \checkmark$ $\lambda = \frac{6.63 \times 10^{-34} \text{ J s} \times 3.00 \times 10^8 \text{ m s}^{-1}}{4.98 \times 10^{-19} \text{ J}} = 3.99 \times 10^{-7} \text{ «m»} \checkmark$	Award [2] for correct final answer.	2
1.	f		$\bullet\text{NO} + \text{O}_3 \rightarrow \bullet\text{NO}_2 + \text{O}_2 \checkmark$ $\bullet\text{NO}_2 + \text{O}_3 \rightarrow \bullet\text{NO} + 2\text{O}_2 \checkmark$	Accept $\bullet\text{NO}_2 \rightarrow \bullet\text{NO} + \bullet\text{O}$ AND $\bullet\text{O} + \text{O}_3 \rightarrow 2\text{O}_2$ for M2.	2



3.	b	i	Structure I – follows octet rule:  Structure II – does not follow octet rule: 	Accept dots, crosses or lines to represent electron pairs.	2
3.	b	ii	«structure I» formal charge on Br = +2 OR «structure II» formal charge on Br = 0/+1 ✓ structure II is preferred AND it produces formal charge closer to 0 ✓	Ignore any reference to formal charge on oxygen.	2
3.	c		Geometry: trigonal/pyramidal ✓ Reason: three bonds AND one lone pair OR four electron domains ✓ O–Br–O angle: 107° ✓	Accept “charge centres” for “electron domains”. Accept answers in the range 104–109°.	3

QUESTION	ANSWERS	MARKS	TOTAL		
7.	a	i	polar bonds «between H and group 16 elements» OR difference in electronegativities «between H and group 16 element» ✓ uneven distribution of charge/electron cloud OR non-linear/bent/V-shaped/angular shape «due to lone pairs» OR polar bonds/dipoles do not cancel out ✓	M2: Do not accept "net/overall dipole moment" without further explanation. Accept "non-symmetrical «shape/distribution of charge»".	2
7.	a	ii	number of electrons increases ✓ London/dispersion/instantaneous induced dipole-induced dipole forces increase ✓	M1: Accept "M_r/A_r increases" or "molecules become larger in size/mass/surface area".	2
7.	b		Electron domain geometry: tetrahedral ✓ Molecular geometry: bent/V-shaped/angular ✓	Both marks can be awarded for clear diagrams. Electron domain geometry requires a 3-D diagram showing the tetrahedral arrangement.	2



7.	c	i	<table><tr><td>Structure:</td><td>I</td><td>II</td><td></td></tr><tr><td>O atom labelled (1)</td><td>0</td><td>«+» 1</td><td>✓</td></tr><tr><td>O atom labelled (2)</td><td>0</td><td>-1</td><td>✓</td></tr></table>	Structure:	I	II		O atom labelled (1)	0	«+» 1	✓	O atom labelled (2)	0	-1	✓	Award [1] for any two correctly filled cells.	2
Structure:	I	II															
O atom labelled (1)	0	«+» 1	✓														
O atom labelled (2)	0	-1	✓														
7.	c	ii	structure I AND no formal charges OR structure I AND no charge transfer «between atoms» ✓		1												
7.	d		O ₃ has bond between single and double bond AND O ₂ has double bond OR O ₃ has bond order of 1.5 AND O ₂ has bond order of 2 OR bond in O ₃ is weaker/longer than in O ₂ ✓ O ₃ requires longer wavelength ✓	M1: Do not accept "ozone has one single and one double bond".	2												
7.	e		CO ₂ «non-polar» «weak» London/dispersion forces/instantaneous induced dipole-induced dipole forces between molecules ✓ SiO ₂ network/lattice/3D/giant «covalent» structure ✓	M1: The concept of "between" is essential.	2												

Topic Chem 4 Q# 51/ IB Chem/2018/s/TZ 1/P2/Higher Level/

3.	d		equal C—C bond «lengths/strengths» OR regular hexagon OR «all» C—C have bond order of 1.5 OR «all» C—C intermediate between single and double bonds ✓	Accept "all C—C—C bond angles are equal".	1
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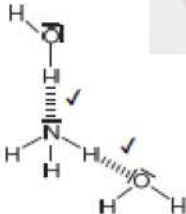
Topic Chem 4 Q# 52/ IB Chem/2018/s/TZ 1/P2/Higher Level/

2.	a		electrostatic attraction AND oppositely charged ions ✓		1
2.	b		multiply relative intensity by «m/z» value of isotope OR find the frequency of each isotope ✓ sum of the values of products/multiplication «from each isotope» OR find/calculate the weighted average ✓	Award [1 max] for stating "m/z values of isotopes AND relative abundance/intensity" but not stating these need to be multiplied.	2
2.	c		«promoted» electrons fall back to lower energy level ✓ energy difference between levels is different ✓	Accept "Na and Ca have different nuclear charge" for M2.	2
2.	d	i	Any two of: stronger metallic bonding ✓ smaller ionic/atomic radius ✓ two electrons per atom are delocalized OR greater ionic charge ✓ greater atomic mass ✓	Do not accept just "heavier" or "more massive" without reference to atomic mass.	2
2.	d	ii	delocalized/mobile electrons «free to move» ✓		1

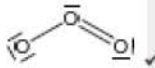
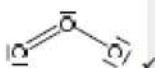


2.	e		general increase ✓ only one discontinuity between "IE2" and "IE3" ✓		2
2.	f		pH > 7 ✓	Accept any specific pH value or range of values above 7 and below 14.	1
2.	g	i	σ (σ): overlap «of atomic orbitals» along the axial/internuclear axis OR head-on/end-to-end overlap «of atomic orbitals» ✓ π (π): overlap «of p-orbitals» above and below the internuclear axis OR sideways overlap «of p-orbitals» ✓	Award marks for suitable diagrams.	2
2.	g	ii	σ (σ): 3 AND π (π): 2 ✓		1

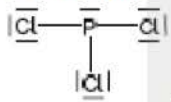
Topic Chem 4 Q# 53/ IB Chem/2018/s/TZ 1/P2/Higher Level/

1.	b		<table><tr><td></td><td>Electron geometry</td><td>Molecular geometry</td></tr><tr><td>Nitrogen</td><td>tetrahedral ✓</td><td>trigonal pyramidal ✓</td></tr><tr><td>Carbon</td><td>trigonal planar ✓</td><td>trigonal planar</td></tr></table>		Electron geometry	Molecular geometry	Nitrogen	tetrahedral ✓	trigonal pyramidal ✓	Carbon	trigonal planar ✓	trigonal planar	Note: Urea's structure is more complex than that predicted from VSEPR theory.	3
	Electron geometry	Molecular geometry												
Nitrogen	tetrahedral ✓	trigonal pyramidal ✓												
Carbon	trigonal planar ✓	trigonal planar												
1.	e	i	Any one of: urea has greater molar mass ✓ urea has greater electron density/greater London/dispersion ✓ urea has more hydrogen bonding ✓ urea is more polar/has greater dipole moment ✓	Accept "urea has larger size/greater van der Waals forces". Do not accept "urea has greater intermolecular forces/IMF".	1									
1.	e	ii		Award [1] for each correct interaction. If lone pairs are shown on N or O, then the lone pair on N or one of the lone pairs on O MUST be involved in the H-bond. Penalize solid line to represent H-bonding only once.	2									
1.	i		lone pairs on nitrogen atoms can be donated to/shared with C–N bond OR C–N bond partial double bond character OR delocalization «of electrons occurs across molecule» OR slight positive charge on C due to C=O polarity reduces C–N bond length ✓		1									

Topic Chem 4 Q# 54/ IB Chem/2017/s/TZ 2/P2/Higher Level/

4.	a	i	triple bond in nitrogen «molecule» AND single bond in hydrazine ✓ triple bond is stronger than single bond OR more shared «pairs of» electrons make bond stronger/attract nuclei more ✓	Accept bond enthalpy values from data booklet (158 and 945 kJ mol ⁻¹).	2
4	a	ii	hydrogen bonding «between molecules, dinitrogen tetraoxide does not» ✓		1
4	b	i	lone pair on p orbital «of O atom» overlaps/delocalizes with pi electrons «from double bond» ✓ both O—O bonds have equal bond length OR both O—O bonds have same/1.5 bond order OR both O—O are intermediate between O—O AND O=O ✓ both O—O bonds have equal bond energy ✓	Accept "p/pi/π electrons are delocalized/not localized".	3
4	b	ii	ALTERNATIVE 1:  FC: -1 AND +1 AND 0 ✓ ALTERNATIVE 2:  FC: 0 AND +1 AND -1 ✓	Accept any combination of lines, dots or crosses to represent electrons. Do not accept structure that represents 1.5 bonds. Do not penalize missing lone pairs if already penalized in 3(b). If resonance structure is incorrect, no ECF. Any one of the structures with correct formal charges for [2 max].	2

Topic Chem 4 Q# 55/ IB Chem/2017/s/TZ 2/P2/Higher Level/

3	b		Lewis structure:  Molecular geometry: trigonal/triangular pyramidal ✓ Bond angles: < 109.5° ✓	Penalize missing lone pairs once only between this question and 4(b)(ii). Accept any combination of lines, dots or crosses to represent electrons. Do not apply ECF. Do not accept answer equal to or less than 90°. Literature value is 100.1°.	3
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Topic Chem 4 Q# 56/ IB Chem/2017/s/TZ 2/P2/Higher Level/

1	c	ii	«molten» Na ₂ O has mobile ions/charged particles AND conducts electricity ✓ «molten» P ₄ O ₁₀ does not have mobile ions/charged particles AND does not conduct electricity/is poor conductor of electricity ✓	Do not award marks without concept of mobile charges being present. Award [1 max] if type of bonding or electrical conductivity correctly identified in each compound. Do not accept answers based on electrons. Award [1 max] if reference made to solution.	2
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Topic Chem 4 Q# 57/ IB Chem/2017/s/TZ 1/P2/Higher Level/

8.	a	$\text{NO}^\bullet (\text{g}) + \text{O}_3 (\text{g}) \rightarrow \text{NO}_2^\bullet (\text{g}) + \text{O}_2 (\text{g}) \checkmark$ $\text{NO}_2^\bullet (\text{g}) + \text{O}^\bullet (\text{g}) \rightarrow \text{NO}^\bullet (\text{g}) + \text{O}_2 (\text{g})$ OR $\text{NO}_2^\bullet (\text{g}) + \text{O}_3 (\text{g}) \rightarrow \text{NO}^\bullet (\text{g}) + 2\text{O}_2 (\text{g}) \checkmark$	Allow representation of radicals without • if consistent throughout.	2
8.	b	«loss of ozone» allows UV radiation to penetrate atmosphere/reach earth $\checkmark$ UV radiation causes skin cancer OR UV radiation causes tissue damage $\checkmark$		2

Topic Chem 4 Q# 58/ IB Chem/2017/s/TZ 1/P2/Higher Level/

5.	a	107° $\checkmark$	Accept 100° to <109.5°. Literature value = 105.8°	1
5.	b	tetrahedral $\checkmark$ $\text{sp}^3 \checkmark$	No ECF allowed.	2

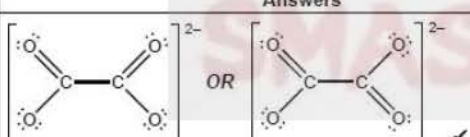
Topic Chem 4 Q# 59/ IB Chem/2017/s/TZ 1/P2/Higher Level/

2.	a	electrostatic attraction $\checkmark$ between «a lattice of» metal/positive ions/cations AND «a sea of» delocalized electrons $\checkmark$	Accept "mobile electrons". Do not accept "metal atoms/nuclei".	2
2.	d	ii vanadium has smaller ionic radius «leading to stronger metallic bonding» $\checkmark$	Accept vanadium has «one» more valence electron«s» «leading to stronger metallic bonding». Accept "atomic" for "ionic".	1
2.	d	iv titanium atoms/ions distort the regular arrangement of atoms/ions OR titanium atoms/ions are a different size to aluminium «atoms/ions» $\checkmark$ prevent layers sliding over each other $\checkmark$	Accept diagram showing different sizes of atoms/ions.	2
2.	g	i ionic OR «electrostatic» attraction between oppositely charged ions $\checkmark$		1
2.	g	ii «simple» molecular structure OR weak«er» intermolecular bonds OR weak«er» bonds between molecules $\checkmark$	Accept specific examples of weak bonds such as London/dispersion and van der Waals. Do not accept "covalent".	1

Topic Chem 4 Q# 60/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

4.	h	«3-D/giant» regularly repeating arrangement «of ions» OR lattice «of ions» $\checkmark$ electrostatic attraction between oppositely charged ions OR electrostatic attraction between Mg^{2+} and O^{2-} ions $\checkmark$	Accept "giant" for M1 unless "giant covalent" stated. Do not accept "ionic" without description.	2
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Topic Chem 4 Q# 61/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question	Answers	Notes	Total
2. d		Accept single negative charges on two O atoms singly bonded to C. Do not accept resonance structures. Allow any combination of dots/crosses or lines to represent electron pairs.	1
2. e	electrons delocalized «across the O–C–O system» OR resonance occurs $\checkmark$ 122 «pm» < C–O < 143 «pm» $\checkmark$	Accept delocalized π -bond(s). No ECF from (d). Accept any answer in range 123 «pm» to 142 «pm». Accept "bond intermediate between single and double bond" or "bond order 1.5".	2



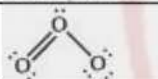
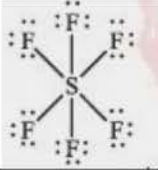
Topic Chem 4 Q# 62/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

5.	b	i	Sigma (σ):  OR  ✓		2									
			Pi (π):  ✓											
5.	b	ii	<table><tr><td></td><td>Number of sigma (σ) bonds</td><td>Number of pi (π) bonds</td></tr><tr><td>Propane</td><td>10</td><td>0</td></tr><tr><td>Propene</td><td>8</td><td>1</td></tr></table> ✓✓		Number of sigma (σ) bonds	Number of pi (π) bonds	Propane	10	0	Propene	8	1	Award [1] for two or three correct answers. Award [2] for all four correct.	2
	Number of sigma (σ) bonds	Number of pi (π) bonds												
Propane	10	0												
Propene	8	1												

Topic Chem 4 Q# 63/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question		Answers	Notes	Total
1.	d	ethane-1,2-diol can hydrogen bond to other molecules «and ethene cannot» OR ethane-1,2-diol has «significantly» greater van der Waals forces ✓ hydrogen bonding is «significantly» stronger than other intermolecular forces ✓	Accept converse arguments. Award [0] if answer implies covalent bonds are broken.	2

Topic Chem 4 Q# 64/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

Question			Answers			Notes	Total	
6.	a	i	Lewis (electron dot) structure			<i>Lines, x's or dots may be used to represent electron pairs. Charges may be included in Lewis structures of ozone but are not required.</i>	2	
			Ozone					
	a	ii		Electron domain geometry	Molecular geometry	<i>Award [1 max] for either both electron domain geometries correct OR for either both molecular geometries correct.</i>	2	
			Ozone	trigonal/triangular planar	v-shaped/bent/angular ✓			
			Sulfur hexafluoride	octahedral/square bipyramidal	octahedral/square bipyramidal ✓			
	a	iii	sulfur hexafluoride/SF ₆ ✓				1	
	a	iv	<i>Ozone: Accept any angle greater than 115° but less than 120° and Sulfur hexafluoride: 90° (and 180°) ✓</i>				<i>Experimental value of bond angle in O₃ is 117°</i>	1

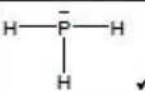
Question			Answers	Notes	Total																				
6.	a	v		Double-headed arrow not necessary for mark. Lines, x's or dots may be used to represent electron pairs.	1																				
	b	i	<table><tr><th></th><th>Lewis (electron dot) structure</th><th>FC of O on LHS</th><th>FC of central N</th><th>FC of N on RHS</th></tr><tr><td>A</td><td>:$\ddot{\text{O}}=\text{N}=\ddot{\text{N}}:$</td><td>0</td><td>+1</td><td>-1</td></tr><tr><td>B</td><td>:$\ddot{\text{O}}-\text{N}\equiv\text{N}:$</td><td>-1</td><td>+1</td><td>0</td></tr><tr><td>C</td><td>:$\text{O}\equiv\text{N}-\ddot{\text{N}}:$</td><td>+1</td><td>+1</td><td>-2</td></tr></table>		Lewis (electron dot) structure	FC of O on LHS	FC of central N	FC of N on RHS	A	: $\ddot{\text{O}}=\text{N}=\ddot{\text{N}}:$	0	+1	-1	B	: $\ddot{\text{O}}-\text{N}\equiv\text{N}:$	-1	+1	0	C	: $\text{O}\equiv\text{N}-\ddot{\text{N}}:$	+1	+1	-2	Award [2] for all nine FCs correct, [1] for six to eight FCs correct.	2
	Lewis (electron dot) structure	FC of O on LHS	FC of central N	FC of N on RHS																					
A	: $\ddot{\text{O}}=\text{N}=\ddot{\text{N}}:$	0	+1	-1																					
B	: $\ddot{\text{O}}-\text{N}\equiv\text{N}:$	-1	+1	0																					
C	: $\text{O}\equiv\text{N}-\ddot{\text{N}}:$	+1	+1	-2																					
	b	ii	smallest FC difference for A or B, so either is preferred ✓ however B is preferred as oxygen is more electronegative than nitrogen, even though FC per se ignores electronegativity ✓	Reason required for M1. OWTTE	2																				

Question	Answers	Notes	Total
6. d i	O₂ has a double bond ✓ O₃ has intermediate bonds between double and single bonds OR O₃ has a bond order of 1½ ✓ bond in O₃ is stronger therefore I needs more energy ✓	Do not award mark for I on its own with no justification.	3
d ii	C-Cl (bond) breaks since weakest bond ✓ $\text{CCl}_2\text{F}_2 \xrightarrow{h\nu} \cdot\text{CClF}_2 + \text{Cl}\cdot$ ✓ $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$ ✓ $\text{ClO}\cdot + \text{O}\cdot \rightarrow \text{O}_3 + \text{Cl}\cdot$ ✓ $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{Cl}\cdot + 2\text{O}_2$ ✓	Allow representation of radicals without $\cdot$ as long as consistent throughout.	5

Topic Chem 4 Q# 65/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

Question	Answers	Notes	Total
3. c i	ALTERNATIVE 1: σ-bond from N to N AND from N to O ✓ π-bond from N to N ✓ delocalized π-bond/π-electrons «extending over the oxygen and both nitrogens» ✓ ALTERNATIVE 2: both have 2 σ-bonds «from N to N and from N to O» AND π-bond from N to N ✓ one structure has second π-bond from N to N and the other has π-bond from N to O ✓ delocalized π-bond/π-electrons ✓	Award [1 max] if candidate has identified both/either structure having 2 σ-bonds and 2 π-bonds.	3
3. c ii	more than one possible position for a multiple/π-/pi- bond ✓	Accept "more than one possible Lewis structure". Accept reference to delocalisation if M3 not awarded in c (i). Accept reference to fractional bond orders.	1

Topic Chem 4 Q# 66/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

Question	Answers	Notes	Total
1. a i	 ✓	Accept structures using dots and/or crosses to indicate bonds and/or lone pair.	1
1. a ii	sp ³ ✓	Do not allow ECF from a (i).	1
1. a iii	Lewis base AND has a lone pair of electrons «to donate» ✓		1
1. a iv	non-polar AND P and H have the same electronegativity ✓	Accept "similar electronegativities". Accept "polar" if there is a reference to a small difference in electronegativity and apply ECF in 1 a (v).	1
1. a v	PH₃ has London «dispersion» forces ✓ NH₃ forms H-bonds ✓ H-bonds are stronger OR London forces are weaker ✓	Accept van der Waals' forces, dispersion forces and instantaneous dipole – induced dipole forces. Accept "dipole-dipole forces" as molecule is polar. H-bonds in NH ₃ (only) must be mentioned to score [2]. Do not award M2 or M3 if: • implies covalent bond is the H-bond • implies covalent bonds break. Accept "dipole-dipole forces are weaker".	2 max
1. a vi	Weak: only partially dissociated/ionized «in dilute aqueous solution» ✓ Brensted–Lowry base: an acceptor of protons/H⁺/hydrogen ions ✓	Accept reaction with water is reversible/an equilibrium. Accept "water is partially dissociated «by the weak base»".	2
1. b i	P₄ is a molecule «comprising 4P atoms» AND 4P is four/separate «P» atoms OR P₄ represents «4P» atoms bonded together AND 4P represents «4» separate/non-bonded «P» atoms ✓		1

(c) (i)		NF_4^+	N_2H_2	N_2H_4
	Hybridization	sp^3	sp^2	sp^3

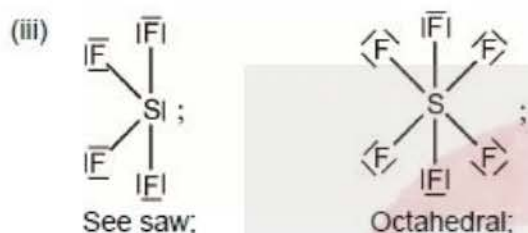
[3]

Do not penalize if it is not superscript.

- (ii) *sigma bond*: overlapping of orbitals end to end/head on / overlapping of orbitals along internuclear axis;
Accept "axial overlapping of orbitals".

pi bond: side-ways/parallel overlapping of p orbitals (above and below internuclear axis);
Accept "overlapping of p orbitals above and below the internuclear axis".
Accept suitable labelled diagrams.

[2]



[4]

Accept any combination of lines, dots or crosses to represent electron pairs.

Penalize missing lone pairs on fluorine atoms once only.

For SF_4 , lone pair on S required for the mark.

Do not allow ECF for a wrong Lewis structure.

Accept saw horse/distorted tetrahedron instead of see-saw.

- (d) (i) $CH_3CH_2CH_3 < CH_3CHO < CH_3CH_2OH < CH_3COOH$;;
Award [2] for correct order.
Award [1] for $CH_3COOH > CH_3CH_2OH > CH_3CHO > CH_3CH_2CH_3$ as compounds are not listed in order of increasing boiling point.
Award [1] if one error in the order.

[2]

- (ii) $CH_3CH_2CH_3$ /London/dispersion/instantaneous induced dipole-induced dipole forces
 CH_3CHO dipole-dipole forces (and London/dispersion forces)
 CH_3CH_2OH H-bonding (and dipole-dipole and London/dispersion forces)
 CH_3COOH H-bonding (and dipole-dipole and London/dispersion forces);;
Award [2] for all four correct.
Award [1] for two or three correct.

H-bonding strongest / London/dispersion forces weakest / dipole-dipole stronger than London/dispersion / dipole-dipole weaker than H-bonding;

Accept van der Waals' forces for London/dispersion forces.

CH_3COOH forms more/stronger H-bonds than CH_3CH_2OH / CH_3COOH is more polar than CH_3CH_2OH ;
Accept CH_3COOH has more electrons/higher molar mass than CH_3CH_2OH .

[4]

- (e) ionization **and** (bombardment) by high energy/fast moving electrons/electron gun (to form positive ions);
acceleration **and** passing through electric field/potential difference/oppositely charged plates;
deflection **and** passing through magnetic field/electromagnet;
Award [1] for naming 3 processes (ionization, acceleration, deflection) in the correct order with incorrect details.

[3]



- (b) ($Li \rightarrow Cs$) atomic/ionic radius increases;
force of attraction between metal ions and delocalized electrons decreases;
Accept metallic bonding gets weaker.

($F \rightarrow I$) London/dispersion/instantaneous induced dipole-induced dipole forces increase;
Accept vdW/van der Waals' forces for London/dispersion forces.

with increasing number of electrons/molar mass/surface area/size of electron cloud;

[3 max]

Do not accept "with increasing size" or "with increasing mass" only.

- (c) (i)



Penalize lone pairs missing on Br and F once only.

Accept any combination of lines, dots or crosses to represent electron pairs.

[2]

- (ii)

PBr ₃	SF ₄
Shape: trigonal pyramidal; Accept triangular pyramidal. No ECF for shape if Lewis structure is incorrect.	Shape: see-saw/K-shaped; Accept distorted tetrahedral.
Bond angle: Any value $99^\circ < 109^\circ$; Literature value = 101° . No ECF for angle if shape is incorrect. Do not award mark for correct angles if shape is incorrect.	Bond angle: Any two for [1] of: (F _{eq} -S-F _{eq}): Any value $100^\circ < 120^\circ$ Literature value = 103° (F _{ax} -S-F _{ax}): Any value $175^\circ < 185^\circ$ Literature value = $179^\circ/180^\circ$ (F _{ax} -S-F _{eq}): Any value $85^\circ < 95^\circ$ Literature value = 89°

[4]

- (iii) P-Br and S-F bonds are polar / bonds in both molecules are polar;
non-symmetrical distribution of electron cloud / polar bonds/dipoles do not cancel because of non-symmetrical shape;
M2 may also be scored with a suitable diagram showing the vectorial addition of the individual S-F dipole moments to show a net dipole moment centred along the axis between the F_{eq}-S-F_{eq} bond.

[2]



- (d) (i) *EITHER*
(electrostatic) attraction between (positively charged) nuclei and a pair of electrons;
formed as a result of electron sharing (between the carbon and hydrogen nuclei);

OR

sigma bond formed by overlap of atomic orbitals;
s orbital from H and p/sp² from carbon;

[2]

- (ii) α : sp³ and β : sp²;
Accept if numbers are given as subscripts.

[1]

- (iii) σ bond:
end-on / axial overlap of two orbitals;

π bond:
sideways overlap of two (parallel) p orbitals;

[2]

Accept suitable diagrams for both marks.

- (iv) 11 σ and 3 π ;

[1]

Topic Chem 4 Q# 70/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

- (b) (i) chromium(III) oxide;
Do not award the mark for chromium oxide.

[1]

- (ii) (electrostatic) attraction between positive and negative ions/oppositely charged ions/Cr³⁺ and O²⁻;
formed as a result of electron transfer from chromium atoms to oxygen atoms / OWTTE;
Ignore reference to number of electrons transferred or charges of ion for M2.

[2]

- (iii) ions are not free to move (when solid) / ions in rigid lattice / OWTTE;

[1]

Topic Chem 4 Q# 71/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

- (f) *Sigma bonds:*

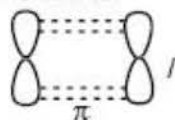


result from head-on/end-on overlap of orbitals / OWTTE;

Accept axial overlap of orbitals.

Accept "symmetric orbital" with respect to same plane / OWTTE.

Pi bonds:



result from sideways overlap of orbitals / OWTTE;

Accept "antisymmetric orbitals" with respect to (defining) plane (containing at least one atom) / OWTTE.

[2]



(g) Allotropes:

Any **three** allotropes for [1] from:

diamond

graphite

fullerene

graphene;

Allow (carbon) nanotubes for graphene.

Accept C_{60} / C_{70} /buckminsterfullerene/bucky balls for fullerene.

Structures:

Any three for [3] from:

Diamond:

tetrahedral arrangement of (carbon) atoms/each carbon bonded to four others / sp^3 and 3D/covalent network structure;

Graphite:

each carbon bonded to three others (in a trigonal planar arrangement) / sp^2 and 2D / layers of (carbon) atoms;

Fullerene:

each (carbon) atom bonded to three others (in a trigonal arrangement) / sp^2 and joined in a ball/cage/sphere/connected hexagons and pentagons;

Accept "trigonal planar" for "each carbon atom bonded to three others" part in M4.

Graphene:

each carbon bonded to three others (in a trigonal arrangement) / sp^2 and 2D structure;

[4]

Topic Chem 4 Q# 73/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

(e) Cl has 7 valence electrons **and** is in group 7;

Accept "group 17" as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3;

[2]

(f)

Molecule	Shape	Bond angle	Polarity
SCl_2	bent/angular/ v-shaped	$< 109.5^\circ$ Accept $100^\circ - 108^\circ$. Literature value is 103° .	polar
$SClF_5$	Octahedral Accept square bipyramidal.	90° (180°)	polar

...

[3]

Do not accept ECF for bond angles and polarities from incorrect shapes.

Award [3] for all six correct.

Award [2] for four or five correct.

Award [1] for two or three correct.

Topic Chem 4 Q# 74/ IB Chem/2015/s/TZ1/P2 Section A/Higher Level/

(b) (i) Na_2O ionic **and** P_4O_{10} covalent (within molecule);

Na_2O in giant/3D/network/lattice structure with strong (ionic) bonds **and**

P_4O_{10} has a (simple) molecular structure/weak intermolecular forces (between molecules);

Award [1] for stating that bonds require more energy to break in Na_2O than in P_4O_{10} .

[2]

(ii)

	Phosphorus(V) oxide	Sodium oxide
Solid state	no	no
Molten state	no	yes

..

[2]

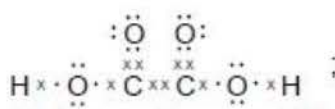
Award [2] for four correct.

Award [1] for two or three correct.



- (c) electrostatic attraction;
between (a lattice of) cations/positive ions **and** delocalized/sea of electrons; [2]
Do not award any mark for only stating "metallic bonding".

- (c) hydrogen bonding; [1]

- (d)  [1]

*Mark cannot be scored if lone pairs are missing on oxygens.
Accept any combination of lines, dots or crosses to represent electron pairs.*

- (e) Acid:
one double and one single bond / one shorter and one longer bond;
Accept "two double and two single".

Conjugate base:
two 1.5 bonds / both bonds same length;
Accept "four / all".

electrons delocalized / resonance forms;
Award marks for suitable diagrams.

[3]

6.	a	ii	$\Delta H^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants}) \checkmark$ $\Delta H^\circ = 2(-241.8 \text{ kJ mol}^{-1}) - 4(-92.3 \text{ kJ mol}^{-1}) = -114.4 \text{ kJ} \checkmark$	<i>Award [2] for correct final answer.</i>	2
6.	d		enthalpy of solution = lattice enthalpy + enthalpies of hydration «of Cu^{2+} and Cl^- » $\checkmark$ « $+2824 \text{ kJ mol}^{-1} - 2161 \text{ kJ mol}^{-1} - 2(359 \text{ kJ mol}^{-1}) = -55 \text{ kJ mol}^{-1}$ » $\checkmark$	<i>Accept enthalpy cycle.</i> <i>Award [2] for correct final answer.</i>	2

3.	c	i	$2\text{C}_3\text{H}_8\text{O}(\text{l}) + 9\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 8\text{H}_2\text{O}(\text{g})$ OR $\text{C}_3\text{H}_8\text{O}(\text{l}) + 4.5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \checkmark$		1
3.	c	ii	<u>bonds broken</u> : $7(\text{C-H}) + \text{C-O} + \text{O-H} + 2(\text{C-C}) + 4.5(\text{O=O})$ OR $7(414 \text{ kJ mol}^{-1}) + 358 \text{ kJ mol}^{-1} + 463 \text{ kJ mol}^{-1} + 2(346 \text{ kJ mol}^{-1}) + 4.5(498 \text{ kJ mol}^{-1}) / 6652 \text{ kJ} \checkmark$ <u>bonds formed</u> : $6(\text{C=O}) + 8(\text{O-H})$ OR $6(804 \text{ kJ mol}^{-1}) + 8(463 \text{ kJ mol}^{-1}) / 8528 \text{ kJ} \checkmark$ « $\Delta H = \text{bonds broken} - \text{bonds formed} = 6652 - 8528 = -1876 \text{ kJ mol}^{-1}$ » $\checkmark$	<i>Award [3] for correct final answer.</i>	3

7.	b		« $(-286 \text{ kJ}) + (-1411 \text{ kJ}) = -1697 \text{ kJ}$ » $\checkmark$		1
7.	c		« $-1697 \text{ kJ} + 1561 \text{ kJ} = -136 \text{ kJ}$ » OR « $\Delta H^\circ = \Delta H_f^\circ (\text{products}) - \Delta H_f^\circ (\text{reactants}) = -84 \text{ kJ} - 52 \text{ kJ} = -136 \text{ kJ}$ » $\checkmark$		1



7.	d	Accurate: no approximations were made in the cycle OR values are specific to the compounds OR Hess's law is a statement of conservation of energy OR method is based on a law OR data in table has small uncertainties ✓ Approximate: values were experimentally determined/had uncertainties OR each value has been determined to only three/four significant figures OR different sources have «slightly» different values for enthalpy of combustion OR law is valid until disproved OR law of conservation of energy is now conservation of mass-energy OR small difference between two quite large terms «leads to high percentage uncertainty» ✓		2
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Topic Chem 5 Q# 80/ IB Chem/2018/w/TZ 0/P2/Higher Level/

5.	b	negative AND fewer moles/molecules «of gas» in the products ✓		1
5.	c	$\Delta G^\ominus = -RT \ln K_c = -8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 1000 \text{ K} \times \ln 280$ OR $\Delta G^\ominus = -4.7 \times 10^4 \text{ «J»} \checkmark$ $\text{«}\Delta G^\ominus \text{»} = -47 \text{ «kJ»} \checkmark$	Award [2] for correct final answer.	2
5.	d	$\Delta G^\ominus < 0$ /spontaneous AND $\Delta S^\ominus < 0$ /unfavourable ✓ exothermic AND $\Delta H^\ominus$ «must be» negative/favourable ✓		2

Topic Chem 5 Q# 81/ IB Chem/2018/w/TZ 0/P2/Higher Level/

4.	d	Fe^{2+} AND smaller size/radius OR Fe^{2+} AND higher charge density ✓ stronger interaction with «polar» water molecules ✓	M1 not needed for M2.	2
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1.	b	i	ALTERNATIVE 1: $q = 80.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 7.5 \text{ K} = 2.5 \times 10^3 \text{ J} / 2.5 \text{ kJ} \checkmark$ $\text{«per mol of CuSO}_4 = \frac{-2.5 \text{ kJ}}{0.0160 \text{ mol}} = -1.6 \times 10^2 \text{ kJ mol}^{-1}\text{»}$ $\text{«for the reaction» } \Delta H = -1.6 \times 10^2 \text{ kJ} \checkmark$ ALTERNATIVE 2: $q = 80.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 7.5 \text{ K} = 2.5 \times 10^3 \text{ J} / 2.5 \text{ kJ} \checkmark$ $\text{«} n_{\text{Cu}} = \frac{0.872}{63.55} = 0.0137 \text{ mol} \text{»}$ $\text{«per mol of CuSO}_4 = \frac{-2.5 \text{ kJ}}{0.0137 \text{ mol}} = -1.8 \times 10^2 \text{ kJ mol}^{-1}\text{»}$ $\text{«for the reaction» } \Delta H = -1.8 \times 10^2 \text{ kJ} \checkmark$	Award [2] for correct final answer.	2
1.	b	ii	density «of solution» is 1.00 g cm^{-3} OR specific heat capacity «of solution» is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$/that of «pure» water OR reaction goes to completion OR iron/CuSO₄ does not react with other substances $\checkmark$	The mark for "reaction goes to completion" can only be awarded if 0.0160 mol was used in part (b)(i). Do not accept "heat loss".	1

3.	c	i	$\Delta H^\circ = \text{bonds broken} - \text{bonds formed} \checkmark$ $\text{«} \Delta H^\circ = 3(\text{C}\equiv\text{C}) - 6(\text{C}\equiv\text{C})_{\text{benzene}} / 3 \times 839 - 6 \times 507 / 2517 - 3042 = \text{»}$ $-525 \text{ kJ} \checkmark$	Award [2] for correct final answer. Award [1 max] for "+525 kJ". Award [1 max] for: $\text{«} \Delta H^\circ = 3(\text{C}\equiv\text{C}) - 3(\text{C}-\text{C}) - 3(\text{C}=\text{C}) / 3 \times 839 - 3 \times 346 - 3 \times 614 / 2517 - 2880 = \text{»} -363 \text{ kJ}.$	2
3.	c	ii	$\Delta H^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants}) \checkmark$ $\text{«} \Delta H^\circ = 49 \text{ kJ} - 3 \times 228 \text{ kJ} = \text{»} -635 \text{ kJ} \checkmark$	Award [2] for correct final answer. Award [1 max] for "+635 kJ".	2
3.	c	iii	ΔH_f° values are specific to the compound OR bond enthalpy values are averages «from many different compounds» $\checkmark$ condensation from gas to liquid is exothermic $\checkmark$	Accept "benzene is in two different states «one liquid the other gas»" for M2.	2
3.	c	iv	$\text{«} \Delta S^\circ = 173 - 3 \times 201 = \text{»} -430 \text{ J K}^{-1} \checkmark$		1
3.	c	v	$T = 25 + 273 = 298 \text{ K} \checkmark$ $\Delta G^\circ = -635 \text{ kJ} - 298 \text{ K} \times (-0.430 \text{ kJ K}^{-1}) = -507 \text{ kJ} \checkmark$ $\Delta G^\circ < 0 \text{ AND spontaneous} \checkmark$	$\Delta G^\circ < 0$ may be inferred from the calculation.	3



Topic Chem 5 Q# 84/ IB Chem/2017/s/TZ 2/P2/Higher Level/

9.	a	i	$\Delta H = 177.0 - \frac{189.2}{2} - 285.5 \text{ «kJ»} \checkmark$ $\Delta H = -203.1 \text{ «kJ»} \checkmark$	Accept other methods for correct manipulation of the three equations. Award [2] for correct final answer.	2
	a	ii	$203.1 \text{ «kJ»} = 0.850 \text{ «kg»} \times 4.18 \text{ «kJ kg}^{-1} \text{ K}^{-1}\text{»} \times \Delta T \text{ «K»}$ OR $\Delta T = 57.2 \text{ «K»} \checkmark$ $T_{\text{final}} = (57.2 + 21.8)^\circ\text{C} = 79.0^\circ\text{C} / 352.0 \text{ «K»} \checkmark$ If 200.0 kJ was used: $200.0 \text{ «kJ»} = 0.850 \text{ «kg»} \times 4.18 \text{ «kJ kg}^{-1} \text{ K}^{-1}\text{»} \times \Delta T \text{ «K»}$ OR $\Delta T = 56.3 \text{ «K»} \checkmark$ $T_{\text{final}} = (56.3 + 21.8)^\circ\text{C} = 78.1^\circ\text{C} / 351.1 \text{ «K»} \checkmark$	Award [2] for correct final answer. Accept two, three or four significant figures. Unit, if specified, must be consistent with value stated.	2
	b	i	$\Delta S^\circ = 270 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} - 267 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} - 131 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} \checkmark$ $\Delta S^\circ = -128 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} \checkmark$	Award [2] for correct final answer.	2
	b	ii	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ > 0$ OR $\Delta H^\circ > T\Delta S^\circ \checkmark$ $T \text{ above} = \frac{-124.4 \text{ «kJ mol}^{-1}\text{»}}{-0.128 \text{ «kJ K}^{-1} \text{ mol}^{-1}\text{»}} = 972 \text{ «K»} \checkmark$	Award [2] for correct final answer. Accept 699 °C. Do not award M2 for any negative T value.	2

Topic Chem 5 Q# 85/ IB Chem/2017/s/TZ 1/P2/Higher Level/

4.	c	i	$\Sigma S^\circ_{\text{RHS}} = 313.4 \text{ «J K}^{-1}\text{»}$ AND $\Sigma S^\circ_{\text{LHS}} = (4 \times 187.6) + 29.9 \text{ «J K}^{-1}\text{»} = 820.3 \text{ «J K}^{-1}\text{»} \checkmark$ $\Delta S^\circ = \Sigma S^\circ_{\text{RHS}} - \Sigma S^\circ_{\text{LHS}} = 313.4 - 820.3 = -506.9 \text{ «J K}^{-1}\text{»} \checkmark$	Award [2] for correct final answer.	2
4.	c	ii	$\Delta H^\circ = -833.0 - 4 \times (-110.5) = -191 \text{ «kJ»} \checkmark$		1
4.	c	iii	$\Delta G = 0$ «forward and backward reactions are equally favourable» $\checkmark$ $\Delta G = 0, T = \frac{\Delta H}{\Delta S}, T = \frac{191 \text{ kJ}}{0.5069 \text{ kJ K}^{-1}} = 377 \text{ «K»} \checkmark$ $\text{temperature} = 104^\circ\text{C} \checkmark$	Award [3] for correct final answer. Use of -500 J K ⁻¹ and -200 kJ gives 127 °C. Award [2 max] for T < 104 °C. Accept $\Delta G < 0$ and T > 104 °C.	3
4.	d		CO is toxic/poisonous OR Ni(CO) ₄ decomposition deposits nickel in the lungs OR tetracarbonylnickel is toxic/poisonous OR tetracarbonylnickel is highly flammable «auto-ignition temperature of 60 °C» $\checkmark$		1

Topic Chem 5 Q# 86/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

1.	a	iii	$\text{Bonds broken: } 2\text{C}\equiv\text{O} + 3(\text{H}-\text{H}) / 2(1077 \text{ kJ mol}^{-1}) + 3(436 \text{ kJ mol}^{-1}) / 3462 \text{ «kJ»} \checkmark$ $\text{Bonds formed: } 2(\text{C}-\text{O}) + 2(\text{O}-\text{H}) + 4(\text{C}-\text{H}) + (\text{C}-\text{C}) / 2(358 \text{ kJ mol}^{-1}) + 2(463 \text{ kJ mol}^{-1}) + 4(414 \text{ kJ mol}^{-1}) + 346 \text{ kJ mol}^{-1} / 3644 \text{ «kJ»} \checkmark$ $\text{«Enthalpy change} = \text{bonds broken} - \text{bonds formed} = 3462 \text{ kJ} - 3644 \text{ kJ} = -182 \text{ «kJ»} \checkmark$	Award [3] for correct final answer. Award [2 max] for «-» 182 «kJ».	3
1.	b	i	$\Delta H = \Sigma \Delta H_f^\circ \text{ products} - \Sigma \Delta H_f^\circ \text{ reactants} = -454.8 \text{ kJ mol}^{-1} - 2(-110.5 \text{ kJ mol}^{-1}) = -233.8 \text{ «kJ»} \checkmark$		1
1.	b	ii	in (a)(iii) gas is formed and in (b)(i) liquid is formed OR products are in different states OR conversion of gas to liquid is exothermic OR conversion of liquid to gas is endothermic OR enthalpy of vapourisation needs to be taken into account $\checkmark$	Accept product is «now» a liquid. Accept answers referring to bond enthalpies being means/averages.	1



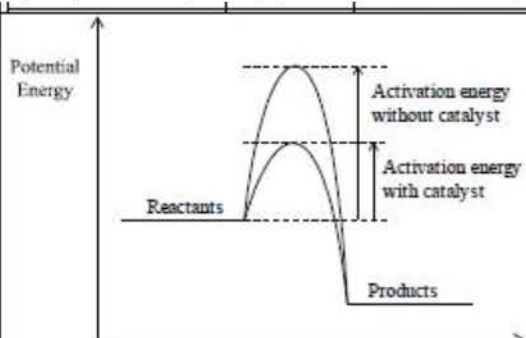
Question	Answers	Notes	Total
1. b iii	« ΔS is negative because five mols of» gases becomes «one mol of» liquid OR increase in complexity of product «compared to reactants» OR product more ordered «than reactants» ✓	Accept "fewer moles of <u>gas</u> " but not "fewer molecules".	1
1. b iv	$\Delta S = \left(\frac{-620.1}{1000} \right) \text{ «kJ K}^{-1}\text{»} \checkmark$ $\Delta G = -233.8 \text{ kJ} - (298 \text{ K} \left(\frac{-620.1}{1000} \right) \text{ kJ K}^{-1}) = -49.0 \text{ «kJ»} \checkmark$	Award [2] for correct final answer. Award [1 max] for «+» 185×10^3 . If -244.0 kJ used, answer is: $\Delta G = -244.0 \text{ kJ} - (298 \text{ K} \left(\frac{-620.1}{1000} \right) \text{ kJ K}^{-1}) = -59.2 \text{ «kJ»}$ Award [2] for correct final answer.	2
1. b v	increasing T makes ΔG larger/more positive/less negative OR $-T\Delta S$ will increase ✓		1

Topic Chem 5 Q# 87/ IB Chem/2016/s/TZoSP/P2 Section A/Higher Level/

c i	$\text{CH}_4(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) + 2\text{O}_3(\text{g}) \checkmark$		1
c ii	$\Delta H^\circ = \{ [(-393.5) + (2)(-241.8) + (2)(+142.3)] - [(-74.0)] \} = -660.8 \text{ «kJ mol}^{-1}\text{»} \checkmark$		1
c iii	standard enthalpy change of formation/ ΔH_f° of an element «in most stable form» is always zero ✓		1
c iv	$\Delta S^\circ = \{ [(+213.8) + (2)(+188.8) + (2)(+237.6)] - [(+186) + (5)(+205.0)] \} = -144.4 \text{ «J K}^{-1} \text{ mol}^{-1}\text{»} \checkmark$		1
c v	$\Delta G^\circ = \left\{ \Delta H^\circ - T\Delta S^\circ = (-660.8) - (298) \left(\frac{-144.4}{1000} \right) \right\} = -617.8 \text{ «kJ mol}^{-1}\text{»} \checkmark$		1
c vi	spontaneous since negative $\Delta G^\circ \checkmark$		1

Question	Answers	Notes	Total
6. d i	O_2 has a double bond ✓ O_3 has intermediate bonds between double and single bonds OR O_3 has a bond order of $1\frac{1}{2}$ ✓ bond in O_2 is stronger therefore I needs more energy ✓	Do not award mark for I on its own with no justification.	3
d ii	C-Cl (bond) breaks since weakest bond ✓ $\text{CCl}_2\text{F}_2 \xrightarrow{\text{h}\nu} \cdot\text{CClF}_2 + \text{Cl}\cdot \checkmark$ $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2 \checkmark$ $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{O}_2 + \text{Cl}\cdot \checkmark$ $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{Cl}\cdot + 2\text{O}_2 \checkmark$	Allow representation of radicals without $\cdot$ as long as consistent throughout.	5

Topic Chem 5 Q# 88/ IB Chem/2016/s/TZoSP/P2 Section A/Higher Level/

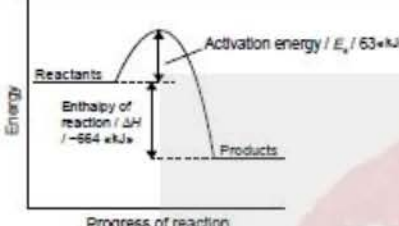
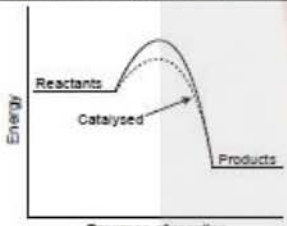
c	 correct positions of reactants and products ✓ correct profile with labels showing activation energy with and without a catalyst ✓		2
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Topic Chem 5 Q# 89/ IB Chem/2016/s/TZoSP/P2 Section A/Higher Level/

Question	Answers	Notes	Total
5. a	only water/H ₂ O produced (<so non-polluting>) ✓		1
b	Bond breaking: $(1)(\text{H-H}) + (4)(\text{C-H}) + (1)(\text{C=C})$ OR $(1)(436) + (4)(414) + (1)(614) = 2706 \text{ kJ mol}^{-1}$ ✓ Bond formation: $(6)(\text{C-H}) + (1)(\text{C-C})$ OR $(6)(414) + (1)(346) = 2830 \text{ kJ mol}^{-1}$ ✓ $(+2706 - 2830) = -124 \text{ kJ mol}^{-1}$ ✓	Award [2 max] for $+124 \text{ kJ mol}^{-1}$. Award [3] for correct final answer.	3

Topic Chem 5 Q# 90/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

Question	Answers	Notes	Total
3. b i	 products lower than reactants AND enthalpy of reaction correctly marked and labelled with name or value ✓ activation energy correctly marked and labelled with name or value ✓	Accept other clear ways of indicating energy/enthalpy changes.	2
3. b ii	 lower dotted curve, between same reactants and products levels, labelled "Catalysed" ✓		1

Topic Chem 5 Q# 91/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

1. d i	$\text{temperature rise } \Delta = \frac{750 \times 1.00}{0.2000 \times 1.00} = 3750 \text{ }^{\circ}\text{C/K}$ ✓	Do not accept -3750.	1
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Topic Chem 5 Q# 92/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

4. a i	same charge AND same/similar ionic radius ✓		1
4. a ii	enthalpy of hydration $\Delta = -1483 + 2(-359) = -2201 \text{ kJ mol}^{-1}$ ✓ enthalpy of solution $\Delta = 2170 - 2201 = -31 \text{ kJ mol}^{-1}$ ✓	Award [2] for correct final answer. Award [1 max] for $+31 \text{ kJ mol}^{-1}$. Award [1 max] for ± 4371.	2

Topic Chem 5 Q# 93/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

2. a iii	$\Delta H^{\circ} = -220.1 - (-110.5)$ ✓ $\Delta H^{\circ} = -109.6 \text{ kJ}$ ✓	Award [2] for correct final answer. Award [1] for -330.6, or $+109.6 \text{ kJ}$.	2
2. a iv	$\Delta G^{\circ} = -109.6 - (298 \times \Delta S^{\circ}) = +11.7 \text{ kJ}$ ✓ $\Delta S^{\circ} = - \frac{(11.7 + 109.6) \times 10^3}{298} = -407 \text{ J K}^{-1}$ ✓	Award [2] for correct final answer. Award [2] for -470 J K^{-1} (result from given values). Do not penalize wrong value for T if already done in (a)(ii). Award [1 max] for -0.407 kJ K^{-1}. Award [1 max] for -138.9 J K^{-1}.	2



6. (a) possible to get iron **and** 3:1 ratio of the two equations;
The ratio may be shown in combining the equations/calculating overall ΔG / -29 (kJ).
 possible to get iron **and** resultant ΔG is negative / -29 (kJ); [2]
"Possible to get iron" needs only to be stated once.
Do not accept "possible to get iron" without any reason.
Do not accept "it is not possible to get iron because ΔG is positive".
- (b) (i) $\Delta G^\ominus = [-1582 + 2 \times 10] - [-742];$
 $\Delta G^\ominus = -820 (\text{kJ mol}^{-1});$ [2]
Award [2] for the correct final answer.
- (ii) $(\Delta S^\ominus = [50.9 + 2(34.8)] - [87.5 + 2(28.3)]) = -23.6 (\text{JK}^{-1} \text{mol}^{-1});$ [1]
- (iii) $\Delta G^\ominus = [-825.2 - (298 \times (-0.0236))];$
 $\Delta G^\ominus = -818 (\text{kJ mol}^{-1}) / -8.18 \times 10^5 (\text{J mol}^{-1});$ [2]
Award [2] for the correct final answer.
Award [0] if b(i) is repeated here.

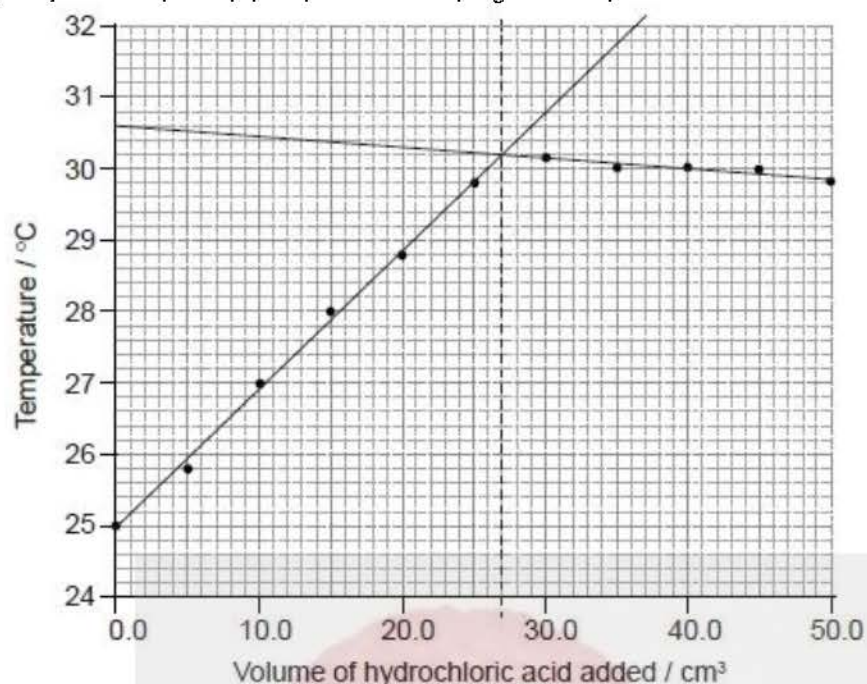
3. (a) $\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g});$ [1]
Ignore state symbols.
- (b) bonds broken: $2(\text{C}-\text{C})/694 + 8(\text{C}-\text{H})/3304 + 5(\text{O}=\text{O})/2490 / 6488 (\text{kJ});$
 bonds made: $6(\text{C}=\text{O})/4476 + 8(\text{O}-\text{H})/3712 / 8188 (\text{kJ});$
 $(6488 - 8188) = -1700 (\text{kJ mol}^{-1});$ [3]
Ignore signs in M1 and M2.
Award [3] for the correct final answer.
Award [2] for +1700 (kJ mol⁻¹).
Accept values from 2016 data booklet to give 6494 (kJ) for M1, 8528 (kJ) for M2, and -2034 (kJ) for M3.

3. (a) $(-239.0 - [-110.5]) = -128.5 (\text{kJ mol}^{-1});$ [1]
- (b) $(-166.0 - [-137.2]) = -28.8 (\text{kJ mol}^{-1});$ [1]
- (c)
$$\left(\Delta G^\ominus = -28.8 = -128.5 - \left[\frac{298 \times \Delta S^\ominus}{1000} \right] \right)$$

 $(\Delta S^\ominus =) -335 (\text{J mol}^{-1} \text{K}^{-1});$ [1]
- (d) $\Delta S^\ominus = \sum S^\ominus_{\text{products}} - \sum S^\ominus_{\text{reactants}} / -335 = 126.8 - 197.6 - 2S^\ominus_{\text{H}_2};$
 $S^\ominus_{\text{H}_2} = (+)132 (\text{J mol}^{-1} \text{K}^{-1});$ [2]
Award [2] for correct final answer.
Award [1 max] for $S^\ominus_{\text{H}_2} = (+)264 (\text{J mol}^{-1} \text{K}^{-1})$.



1. (a) (i)



drawing best-fit straight lines to show volume;
There should be approximately the same number of points above and below for both lines.

27.0 (cm³);

[2]

Accept any value in the range 26.0 to 28.0 (cm³) if consistent with student's annotation on the graph.

Accept ECF for volumes in the range 27.0–30.0 cm³ if it corresponds to maximum temperature of line drawn.

Volume should be given to one decimal place.

(ii)
$$([HCl]) = \frac{1.00 \times 0.0250}{0.0270};$$

$$= 0.926 \text{ mol dm}^{-3};$$

[2]

Volume of 26.0 gives $[HCl] = 0.962 \text{ mol dm}^{-3}$. Volume of 28.0 gives $[HCl] = 0.893 \text{ mol dm}^{-3}$.

Award [2] for correct final answer with units.

Award [1 max] for correct concentration without units.

Accept M, mol L⁻¹, mol/dm³ as units.



- (b) (i) $(30.2 - 25.0) = (+)5.2(^{\circ}\text{C/K})$; [1]

Any accepted value must be consistent with student's annotation on the graph but do not accept $\Delta T < 5.1$.

Accept $(+)5.6(^{\circ}\text{C/K})$ (ie, taking into account heat loss and using T when volume = 0.0 cm^3).

(ii) $Q = (m \times c \times \Delta T = (25.0 + 27.0) \times 4.18 \times 5.2 = 1130.272\text{ J} = 1.13(\text{kJ})$;

$n = (1.00 \times 0.0250 =) 0.0250(\text{mol})$;

$\Delta H = \left(-\frac{Q}{n} = -45210.88\text{ J mol}^{-1} = -45(\text{kJ mol}^{-1})\right)$; [3]

Award [3] for correct final answer.

Award [2] for $+45(\text{kJ mol}^{-1})$.

Apply ECF for M3 even if both m and ΔT are incorrect in M1.

Accept use of $c = 4.2\text{ J g}^{-1}\text{K}^{-1}$.

(iii) $\left(\left|\frac{-45 - (-58)}{(-58)}\right| \times 100 = \right) 22(\%)$; [1]

Answer must be given to two significant figures.

Ignore sign.

- (iv) heat losses; [2]
better (thermal) insulation / using a polystyrene cup / putting a lid on the beaker;

Accept other suitable methods for better thermal insulation but do not accept just "use a calorimeter" without reference to insulation.

Topic Chem 5 Q# 98/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

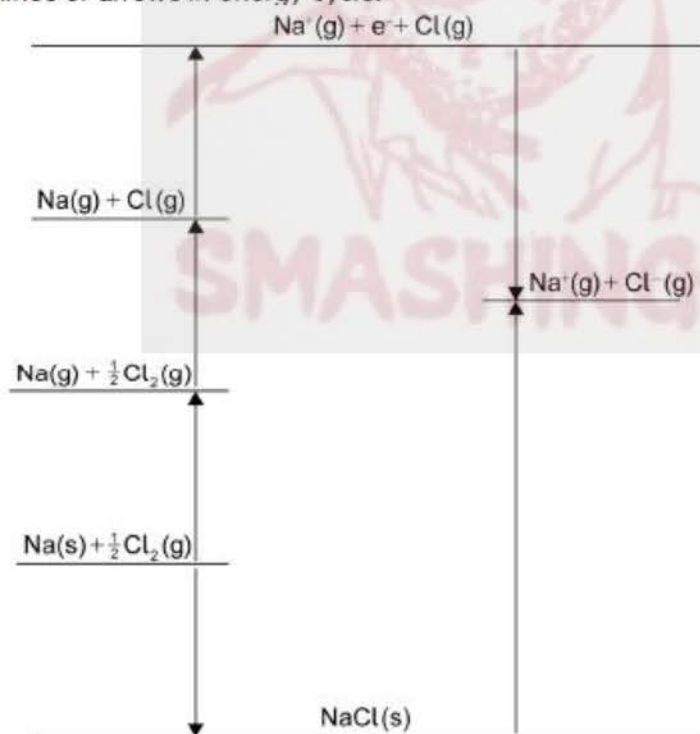
(g) atomization of chlorine = $\frac{1}{2}$ bond enthalpy / $\frac{1}{2} 243 / 121.5(\text{kJ mol}^{-1})$;

correct values for ionization Na ($+496\text{ kJ mol}^{-1}$) and electron affinity Cl (-349 kJ mol^{-1})

and lattice enthalpy of NaCl ($+790\text{ kJ mol}^{-1} / +769\text{ kJ mol}^{-1}$);

Born-Haber energy cycle;

Accept lines or arrows in energy cycle.



$\Delta H_f^{\ominus}(\text{NaCl(s)}) = -413.5 / -413 / -414(\text{kJ mol}^{-1})$;

Accept $-392.5 / -392 / -393$ if $+769$ used for lattice enthalpy.

Award [4] for correct final answer.

[4]



- (b) (i) energy needed to break (1 mol of) a bond in the gaseous state/phase;
(averaged over) similar compounds;
Do not accept "similar bonds" instead of "similar compounds".
Concept of "similar" is important for M2. [2]

- (ii) $\text{CH}_3\text{CH}_2\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$;
Bonds broken:
 $347 + (5 \times 413) + 358 + 464 + (3 \times 498) / 4728 \text{ (kJ)} /$
 $\text{C}-\text{C} + 5\text{C}-\text{H} + \text{C}-\text{O} + \text{O}-\text{H} + 3\text{O}=\text{O}$;
Bonds made:
 $(4 \times 746) + (6 \times 464) = 5768 \text{ (kJ)} / 4\text{C}=\text{O} + 6\text{O}-\text{H}$;
 $\Delta H = (4728 - 5768) = -1040 \text{ (kJ mol}^{-1}) / \text{bonds broken} - \text{bonds formed}$; [4]
Award [4] for correct final answer.
Award [3] for (+)1040 (kJ mol⁻¹).

- (c) heat loss (to the surroundings); [1]

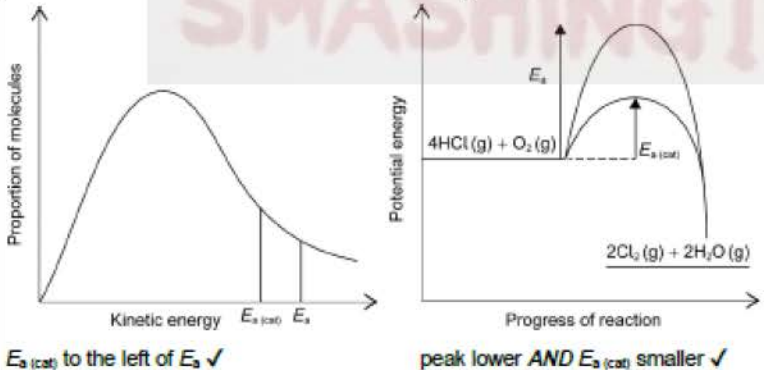
- (f) (i) $3\text{C(s)} + 3\text{H}_2\text{(g)} + \text{O}_2\text{(g)} \rightarrow \text{CH}_3\text{CH}_2\text{COOH(l)}$;
 $\Delta H_f^\ominus = \sum \Delta H_c^\ominus(\text{reactants}) - \sum \Delta H_c^\ominus(\text{products})$;
Accept any suitable energy cycle.
 $\sum \Delta H_c^\ominus(\text{reactants}) = 3 \times (-394) + 3 \times (-286) / -2040 \text{ (kJ mol}^{-1})$;
 $(\Delta H_f^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) = -513 \text{ (kJ mol}^{-1})$;

OR
 $\text{CH}_3\text{CH}_2\text{COOH(l)} + 3.5\text{O}_2\text{(g)} \rightarrow 3\text{CO}_2\text{(g)} + 3\text{H}_2\text{O(g)}$;
 $\Delta H_c^\ominus = \sum \Delta H_f^\ominus(\text{products}) - \sum \Delta H_f^\ominus(\text{reactants})$;
 $\sum \Delta H_f^\ominus(\text{products}) = 3 \times (-394) + 3 \times (-286) / -2040 \text{ (kJ mol}^{-1})$;
 $(\Delta H_c^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) = -513 \text{ (kJ mol}^{-1})$; [4]

Ignore state symbols.
Award [4] for correct final answer.

- (ii) negative;
reduction in the number of gaseous molecules; [2]

Topic Chem 6 Q# 100/ IB Chem/2019/w/TZ0/P2/Higher Level/Q7/

6.	a	iii	 $E_{a(\text{cat})}$ to the left of E_a ✓ peak lower AND $E_{a(\text{cat})}$ smaller ✓	2
6.	a	iv	«catalyst provides an» alternative pathway ✓ «with» lower E_a OR higher proportion of/more particles with «kinetic» $E \geq E_{a(\text{cat})}$ «than E_a» ✓	2

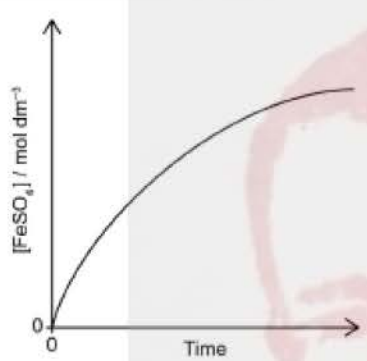
Topic Chem 6 Q# 101/ IB Chem/2019/w/TZ0/P2/Higher Level/Q4./

3.	b	i	Rate = $k [\text{C}_3\text{H}_7\text{Cl}] [\text{OH}^-]$ ✓ «[OH ⁻] held constant and» [C ₃ H ₇ Cl] triples AND rate triples «so first order wrt C ₃ H ₇ Cl» ✓ [C ₃ H ₇ Cl] doubles AND [OH ⁻] doubles AND rate quadruples «so first order wrt OH ⁻ » ✓		3
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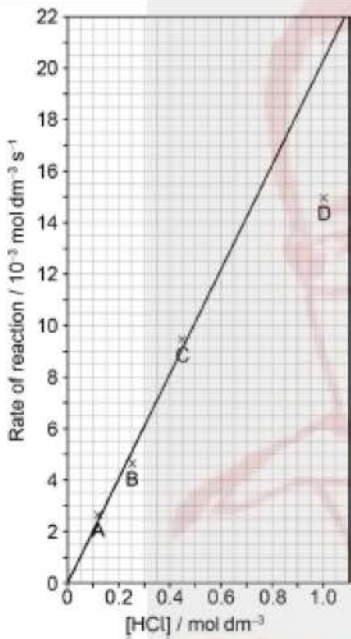
Topic Chem 6 Q# 102/ IB Chem/2018/w/TZ 0/P2/Higher Level/Q10

10.	a		B: reactant ✓ D: intermediate ✓		2
10.	b		rate = $k [\text{A}][\text{B}]$ ✓		1
10.	c		1.80 «mol dm ⁻³ s ⁻¹ » ✓		1

Topic Chem 6 Q# 103/ IB Chem/2018/w/TZ 0/P2/Higher Level/

1.	c	i	 initial concentration is zero AND concentration increases with time ✓ decreasing gradient as reaction proceeds ✓		2
1.	c	ii	«draw a» tangent to the curve at time = 0 ✓ «rate equals» gradient/slope «of the tangent» ✓	Accept suitable diagram.	2
1.	c	iii	piece has smaller surface area ✓ lower frequency of collisions OR fewer collisions per second/unit time ✓	Accept "chance/probability" instead of "frequency". Do not accept just "fewer collisions".	2

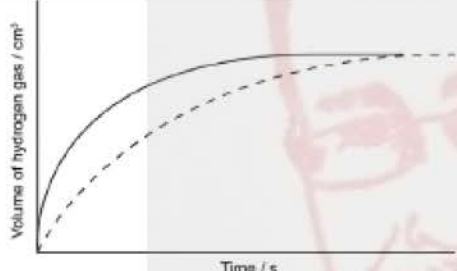
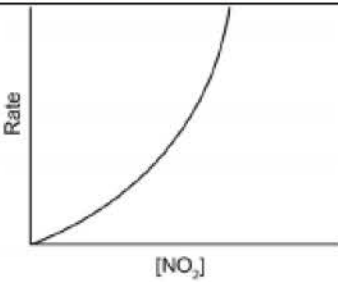


4.	a		Any two of: loss of mass «of reaction mixture/CO ₂ » ✓ «increase in» volume of gas produced ✓ change of conductivity ✓ change of pH ✓ change in temperature ✓	Do not accept "disappearance of calcium carbonate". Do not accept "gas bubbles". Do not accept "colour change" or "indicator".	2
4.	b	i	reaction is fast at high concentration AND may be difficult to measure accurately OR so many bubbles of CO ₂ produced that inhibit contact of HCl (aq) with CaCO ₃ (s) OR insufficient change in conductivity/pH at high concentrations OR calcium carbonate has been used up/is limiting reagent/ there is not enough calcium carbonate «to react with the high concentration of HCl» OR HCl is in excess OR so many bubbles of CO ₂ produced that inhibit contact of HCl (aq) with CaCO ₃ (s) ✓		1
4.	b	ii	 Rate of reaction / $10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$ [HCl] / mol dm^{-3} straight line going through the origin AND as close to A, B, C as is reasonably possible ✓		1
4.	b	iii	«directly» proportional ✓	Accept "first order" or "linear". Do not accept "rate increases as concentration increases" or "positive correlation".	1
4.	b	iv	rate = $k [\text{H}^+]$ ✓	Accept "rate = $k [\text{HCl}]$ ".	1
4.	b	v	0.02 ✓ s^{-1} ✓		2
4.	c		$20.5 \times 10^{-3} \text{ «mol dm}^{-3} \text{ s}^{-1}\text{»}$	Accept any answer in the range 19.5–21.5.	1

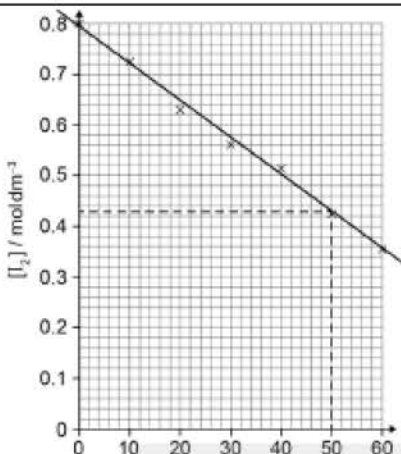


4.	d		ALTERNATIVE 1: carry out reaction at several temperatures ✓ plot $\frac{1}{T}$ against log rate constant ✓ $E_a = -\text{gradient} \times R$ ✓ ALTERNATIVE 2: carry out reaction at two temperatures ✓ determine two rate constants OR determine the temperature coefficient of the rate ✓ use the formula $\ln \frac{k_1}{k_2} = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$ ✓	Accept "gradient" = $\frac{-E_a}{R}$ for M3. Award both M2 and M3 for the formula $\ln \frac{\text{rate}_1}{\text{rate}_2} = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$. Accept any variation of the formula, such as $\frac{\text{rate}_1}{\text{rate}_2} = e^{\frac{E_a}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right)}$.	3
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Topic Chem 6 Q# 105/ IB Chem/2017/s/TZ 2/P2/Higher Level/

5.	a	i	concentration of acid decreases OR surface area of magnesium decreases ✓	Accept "less frequency/chance/rate/probability/likelihood of collisions". Do not accept just "less acid" or "less magnesium". Do not accept "concentration of reagents decrease".	1
5	a	ii	 curve starting from origin with steeper gradient AND reaching same maximum volume ✓		1
5	b	i	«rate» = $k [\text{NO}_2]^2$ ✓	Accept rate = $k [\text{NO}_2]^2 [\text{CO}]^0$.	1
5	b	ii	«step» I AND CO does not appear in the rate law expression OR «step» I AND only «2 molecules of» NO_2 appears in rate expression ✓	Do not allow ECF from (i).	1
5	b	iii	«IR or UV-vis» spectroscopy OR colorimetry OR colour change «over time» ✓	Accept GC/gas chromatography.	1
5	b	iv	« $E_{a(\text{rev})}$ » = $226 + 132$ = 358 «kJ» ✓	Do not accept -358.	1
5	b	v	 Rate [NO_2]	Curve must go through origin.	1
5	c		activation energy is independent of temperature ✓	Accept "no relationship".	1
5	d		$2\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HNO}_3(\text{aq}) + \text{HNO}_2(\text{aq})$ OR $4\text{NO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) \rightarrow 4\text{HNO}_3(\text{aq})$ ✓	Accept ionized forms of the acids.	1

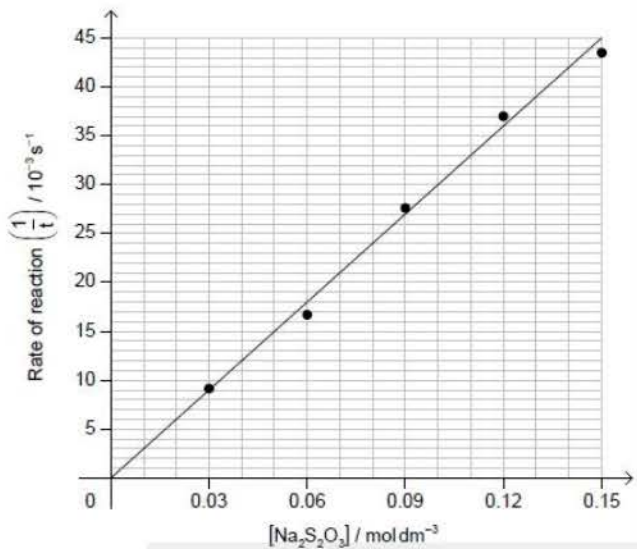
Topic Chem 6 Q# 106/ IB Chem/2017/s/TZ 1/P2/Higher Level/

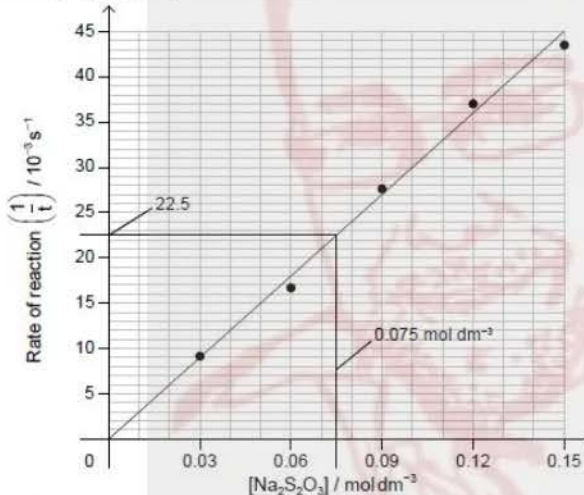
1.	a	i	use a colorimeter/monitor the change in colour OR take samples AND quench AND titrate «with thiosulfate» ✓	Accept change in pH. Accept change in conductivity. Accept other suitable methods. Method must imply "change".	1
1	a	ii	 best fit line ✓ relative rate of reaction = « $\frac{-\Delta y}{\Delta x} = \frac{-(0.43 - 0.80)}{50} = » 0.0074 / 7.4 \times 10^{-3}$ ✓	Best fit line required for M1. M2 is independent of M1. Accept range from 0.0070 to 0.0080.	2
1	b		Relationship: rate of reaction is «directly» proportional to $[H^+]$ OR rate of reaction $\propto [H^+]$ ✓ Order of reaction with respect to $[H^+]$: first ✓	Accept "doubling the concentration doubles the rate". Do not accept "rate increases as concentration increases".	2
1.	c		zero order ✓ rate of reaction is the same for all concentrations of iodine ✓	Accept "all graphs have same/similar gradient".	2
1.	d		slow rate of reaction which gradually increases ✓ as H^+ ions are produced «to catalyse the reaction» OR reaction is autocatalytic ✓	M1 should mention "rate of reaction".	2

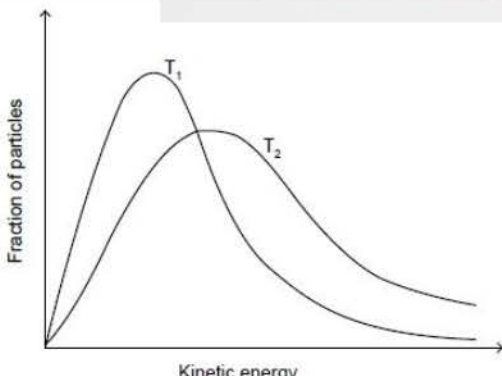
Topic Chem 6 Q# 107/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question			Answers	Notes	Total
3.	a		H ₂ O AND (l) ✓	Do not accept H ₂ O (aq).	1
3.	b		SO ₂ (g) is an irritant/causes breathing problems OR SO ₂ (g) is poisonous/toxic ✓	Accept SO ₂ (g) is acidic but do not accept "causes acid rain". Accept SO ₂ (g) is harmful. Accept SO ₂ (g) has a foul/pungent smell.	1
3.	c		$n(\text{HCl}) = \frac{10.0}{1000} \text{ dm}^3 \times 2.00 \text{ mol dm}^{-3} = 0.0200 / 2.00 \times 10^{-2} \text{ «mol»}$ AND $n(\text{Na}_2\text{S}_2\text{O}_3) = \frac{50}{1000} \text{ dm}^3 \times 0.150 \text{ mol} \times \text{dm}^{-3} = 0.00750 / 7.50 \times 10^{-3} \text{ «mol»} \checkmark$ $0.0200 \text{ «mol»} > 0.0150 \text{ «mol»}$ OR $2.00 \times 10^{-2} \text{ «mol»} > 2 \times 7.50 \times 10^{-3} \text{ «mol»}$ OR $\frac{1}{2} \times 2.00 \times 10^{-2} \text{ «mol»} > 7.50 \times 10^{-3} \text{ «mol»} \checkmark$	Accept answers based on volume of solutions required for complete reaction. Award [2] for second marking point. Do not award M2 unless factor of 2 (or half) is used.	2



Question	Answers	Notes	Total
3. d	 five points plotted correctly ✓ best fit line drawn with ruler, going through the origin ✓		2

Question	Answers	Notes	Total
3. e i	first order ✓ «because» $[\text{Na}_2\text{S}_2\text{O}_3]$ is «directly» proportional to rate of reaction « $\frac{1}{t}$ » ✓	Do not accept "linear" for M2.	2
3. e ii	rate = $k [\text{Na}_2\text{S}_2\text{O}_3][\text{HCl}]$ ✓		1
3. f	 22.5 × 10⁻³ «s⁻¹» ✓ «Time = $\frac{1}{22.5 \times 10^{-3}}$ » = 44.4 «s» ✓	Award [2] for correct final answer. Accept value based on candidate's graph. Award M2 as ECF from M1. Award [1 max] for methods involving taking mean of appropriate pairs of $\frac{1}{t}$ values. Award [0] for taking mean of pairs of time values. Award [2] for answers between 42.4 and 46.4 «s».	2

Question	Answers	Notes	Total
3. g i	 correctly labelled axes ✓ peak of T_2 curve lower AND to the right of T_1 curve ✓	Accept "probability «density» / number of particles / N / fraction" on y-axis. Accept "kinetic E/KE/ E_k " but not just "Energy/E" on x-axis.	2



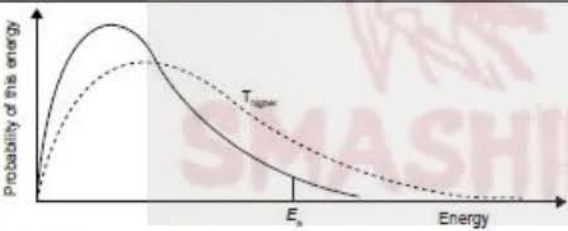
Question	Answers	Notes	Total
3. g ii	greater proportion of molecules have $E \geq E_a$ or $E > E_a$ OR greater area under curve to the right of the E_a ✓ greater frequency of collisions «between molecules» OR more collisions per unit time/second ✓	Accept more molecules have energy greater than E_a . Do not accept just "particles have greater kinetic energy". Accept "rate/chance/probability/likelihood" instead of "frequency". Accept suitably shaded/annotated diagram. Do not accept just "more collisions".	2
3. h	shorter reaction time so larger «%» error in timing/seeing when mark disappears ✓	Accept cooling of reaction mixture during course of reaction.	1

Topic Chem 6 Q# 108/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

e	A is indicative of frequency of collisions and probability that collisions have proper orientations ✓		1
f	$k = \left\langle \exp \left[\frac{(-87.0 \times 1000)}{(8.31 \times 298)} + \ln(2.10 \times 10^{11}) \right] \right\rangle = 1.2 \times 10^{-4}$ ✓ S_N2 implies second-order so $\text{mol}^{-1} \text{dm}^3 \text{s}^{-1}$ ✓		2

Topic Chem 6 Q# 109/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

3. a i	$2\text{NO}(\text{g}) + 2\text{H}_2(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$ ✓		1
3. a ii	rate = $k[\text{NO}]^2[\text{H}_2]$ ✓		1
3. a iii	test the effect «on the reaction rate» of varying each concentration «independently» OR test the effect of varying $[\text{NO}]$ «on rate», whilst keeping $[\text{H}_2]$ constant AND test effect of varying $[\text{H}_2]$ «on rate», whilst keeping $[\text{NO}]$ constant ✓ rate proportional to $[\text{NO}]^2$ OR doubling $[\text{NO}]$ quadruples rate ✓ rate proportional to $[\text{H}_2]$ OR doubling $[\text{H}_2]$ doubles rate ✓	Remember to refer back to a (ii) for ECF. If only one species in rate expression, third mark can be awarded for zero order discussion.	3
3. a iv	no AND different mechanisms could give the same rate expression OR no AND mechanisms can only be disproved OR no AND just suggest it is consistent with the mechanism given OR no AND does not give information about what occurs after RDS ✓		1
3. a v	change of pressure «at constant volume and temperature» with time OR change of volume «at constant pressure and temperature» with time ✓	Accept other methods where rate can be monitored with time.	1

Question	Answers	Notes	Total
3. b iii	 second curve at a higher temperature is correctly drawn (maximum lower and to right of original) ✓		1
3. b iv	greater proportion of molecules have $E \geq E_a$ or $E > E_a$ OR greater area under curve to the right of the E_a ✓ greater frequency of collisions «between molecules» OR more collisions per unit time/second ✓	Do not accept just particles have greater kinetic energy. Do not accept just "more collisions".	2



- (c) (i) Order with respect to O_2 : first (order);
Order with respect to NO : second (order); [2]
- (ii) (rate =) $k [NO]^2 [O_2]$; [1]
- (iii) $172.6 / 173$;
 $mol^{-2} dm^6 s^{-1}$; [2]
Accept $M^{-2} s^{-1} / mol^{-2} L^2 s^{-1}$.
- (iv) $NO + NO \rightleftharpoons N_2O_2$ (fast);
 $N_2O_2 + O_2 \rightarrow 2NO_2$ (slow);
second step is rate determining step;

OR

$NO + O_2 \rightleftharpoons O + NO_2$ (fast);
 $O + NO \rightarrow NO_2$ (slow);
second step is rate determining step;

OR

$NO + O_2 \rightleftharpoons NO_3$ (fast);
 $NO_3 + NO \rightarrow 2NO_2$ (slow);
second step is rate determining step;
Accept single arrow instead of reversible sign.
Accept fast/slow next to the equations.

Do **not** accept the following mechanisms:

$NO + NO \rightleftharpoons NO_2 + N$ (fast)
 $N + O_2 \rightarrow NO_2$ (slow)

OR

$NO + NO + O_2 \rightleftharpoons N_2O_4$ (slow)
 $N_2O_4 \rightarrow 2NO_2$ (fast)

[3]

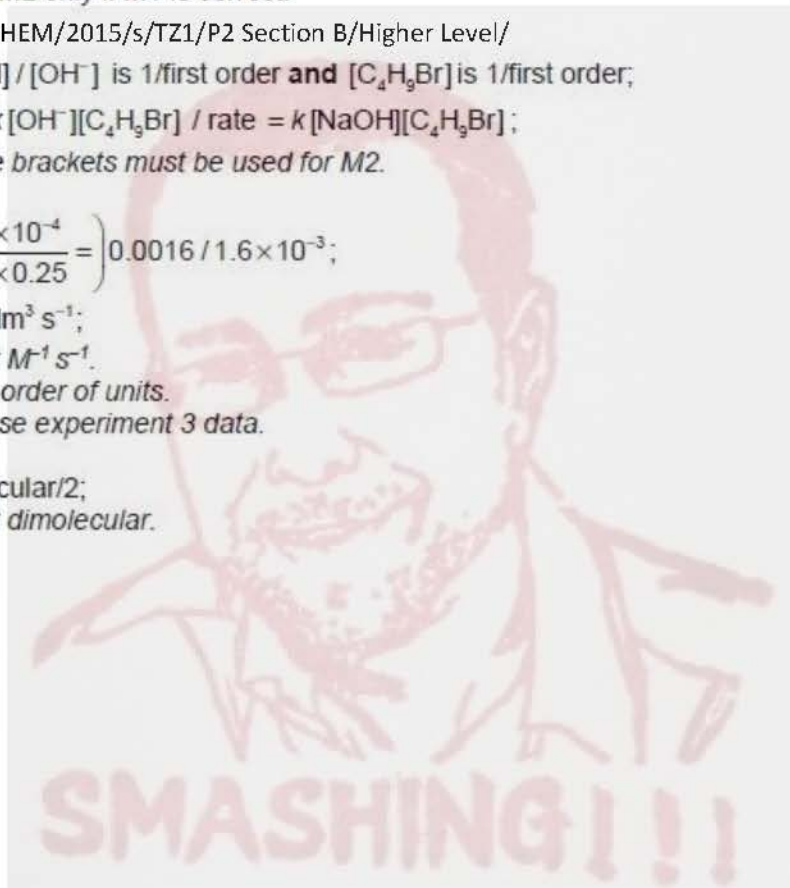
- (f) gradient = $-\frac{E_a}{R} / -1233(K)$;
Accept value from -1200 to $-1260 (K)$.
 $E_a = (1233 \times 8.31 =) 1.02 \times 10^4 J mol^{-1} / 10.2 kJ mol^{-1}$
correct E_a value;
correct units;
Allow value in range $9.97 - 10.5 kJ mol^{-1}$.
Answer must be given to three significant figures.
Award [3] for correct final answer **and** units.
Accept J or kJ instead of $J mol^{-1}$ or $kJ mol^{-1}$.

[3]



2. (a) change in concentration of reactant/product with time / rate of change of concentration; [1]
 Accept "increase" instead of "change" for product and "decrease" instead of "change" for reactant.
 Accept "mass/amount/volume" instead of "concentration".
 Do not accept substance.
- (b) surface area decreases; [2]
 frequency/probability of collisions decreases;
 Accept number of collisions per unit time decreases.
- (c) (i) step 2 / $X + NO \rightarrow Y + H_2O$ / slow; [1]
- (ii) invalid / unlikely as order most likely one (with respect to hydrogen); [2]
 rate = $k[NO]^2[H_2]$ / H_2 only involved once in the formation of the intermediate before the slow step / OWTTE;
 Award M2 only if M1 is correct.

- (c) (i) $[NaOH] / [OH^-]$ is 1/first order **and** $[C_4H_9Br]$ is 1/first order; [2]
 rate = $k[OH^-][C_4H_9Br]$ / rate = $k[NaOH][C_4H_9Br]$;
 Square brackets must be used for M2.
- (ii) $\left(\frac{1.02 \times 10^{-4}}{0.25 \times 0.25} \right) 0.0016 / 1.6 \times 10^{-3};$ [2]
 $mol^{-1} dm^3 s^{-1};$
 Accept $M^{-1} s^{-1}$.
 Ignore order of units.
 Must use experiment 3 data.
- (iii) bimolecular/2; [1]
 Accept dimolecular.



3. (a) change in concentration of reactant/product with time / rate of change of concentration; [1]
 Accept "increase" instead of "change" for product and "decrease" instead of "change" for reactant.
 Accept "mass/amount/volume" instead of "concentration".
 Do not accept substance.
- (b) collision frequency;
 two particles must collide;
 particles must have sufficient energy to overcome the activation energy/ $E \geq E_a$;
 Concept of activation energy must be mentioned.
 appropriate collision geometry/orientation; [3 max]
- (c) (i) increases yield;
 (equilibrium shifts to the right/products as) more gaseous moles in reactants/on left / fewer gaseous moles in products/on right; [2]
- (ii) $Eqm[O_2] = 2.6(\text{mol dm}^{-3})$;
 $Eqm[SO_2] = 1.2(\text{mol dm}^{-3})$;
 $K_c = \frac{[SO_3]^2}{[SO_2]^2 [O_2]}$;
 $K_c = 0.17$; [4]
 Award [4] for correct final answer.
 Ignore units.
- (iii) (K_c) decreases; [1]
- (d) catalyst increases rate of reaction / equilibrium reached faster / increases yield of product per unit time;
 reduces costs / reduces energy needed; [2]
 Do not accept just "increases the yield".

5.	e	«reaction quotient/Q =» $\frac{[SO_3]^2}{[SO_2]^2 [O_2]} = \frac{0.500^2}{0.200^2 \times 0.300} / 20.8 \checkmark$ reaction quotient/Q/20.8/answer < $K_c/280$ OR mixture needs more product for the number to equal $K_c \checkmark$ reaction proceeds to the right/products $\checkmark$	Do not award M3 without valid reasoning.	3
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1.	d	i	$K_c = \frac{[(H_2N)_2CO] \times [H_2O]}{[NH_3]^2 \times [CO_2]} \checkmark$	1
1.	d	ii	«K_c» decreases AND reaction is exothermic OR «K_c» decreases AND ΔH is negative OR «K_c» decreases AND reverse/endothermic reaction is favoured $\checkmark$	1



1.	d	iii	$\ln K = \frac{-\Delta G^\ominus}{RT} = \frac{-50 \times 10^3 \text{ J}}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K}} = -20 \checkmark$ $K_c = 2 \times 10^{-9}$ OR 1.69×10^{-9} OR $10^{-9} \checkmark$	Accept range of 20-20.2 for M1. Award [2] for correct final answer.	2
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Topic Chem 7 Q# 117/ IB Chem/2017/s/TZ 2/P2/Higher Level/

4	d	i	$Q_c = \frac{0.10}{0.52^2} = 0.37 \checkmark$ reaction proceeds to the left/ $\text{NO}_2(\text{g})$ «until $Q = K_c$ » OR reverse reaction «favoured» $\checkmark$	Do not award M2 without a calculation for M1 but remember to apply ECF.	2
4	d	ii	$\Delta G = 0 \checkmark$ reaction at equilibrium OR rate of forward and reverse reaction is the same OR constant macroscopic properties $\checkmark$		2

Topic Chem 7 Q# 118/ IB Chem/2017/s/TZ 2/P2/Higher Level/

3.	a	i	$K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} \checkmark$		1
3	a	ii	decrease in temperature $\checkmark$ endothermic «reaction» AND «equilibrium» shifts to the left/reactants OR endothermic «reaction» AND K_c decreases OR endothermic «reaction» AND concentration of PCl_5 increased/concentration of PCl_3 and Cl_2 decreased OR «equilibrium» shifts in the exothermic direction $\checkmark$	Do not accept "temperature change". Accept " ΔH positive" in place of "endothermic". Accept "products" instead of " PCl_3 and Cl_2 ".	2

Topic Chem 7 Q# 119/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question	Answers	Notes	Total
1. a i	$K_c = \frac{[\text{HOCH}_2\text{CH}_2\text{OH}]}{[\text{CO}]^2 \times [\text{H}_2]^3} \checkmark$		1
1. a ii	Position of equilibrium: moves to right OR favours product $\checkmark$ K_c : no change OR is a constant at constant temperature $\checkmark$		2

Topic Chem 7 Q# 120/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

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Question	Answers	Notes	Total
2. a i	$K_c = \frac{[\text{COCl}_2]}{[\text{CO}][\text{Cl}_2]}$ ✓		1
2. a ii	$T = 800 + 273 = 873\text{K}$ ✓ $\Delta G^\circ = -8.31 \times 873 \times \ln(0.200)$ OR $\Delta G^\circ = - \rightarrow 11878 \text{ J}$ ✓ $\Delta G^\circ = - \rightarrow 11.7 \text{ kJ}$ ✓	Accept 11.5 to 12.0. Award final mark only if correct sig fig. Award [3] for correct final answer.	3

7. (a) (i) Increasing the pressure, at constant temperature:
decreases;
more (gas) molecules/moles on the right / fewer (gas) molecules/moles on the left;

Increasing the temperature, at constant pressure:
increases;
(forward) reaction is endothermic;

[4]

- (ii) equilibrium reached faster;
no change in the concentration of reactants/products/yield (at equilibrium) /
position of equilibrium is not affected;
rates of forward and reverse reactions increase (equally);
reduces activation energy;
no change in K_c ;

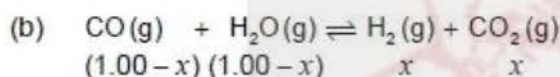
[3 max]

(iii) $K_c = \frac{[\text{H}_2]^3 [\text{CO}]}{[\text{CH}_4][\text{H}_2\text{O}]}$;

[1]

- (iv) (increasing) temperature and (K_c) increases;
Award [0] if both temperature and pressure stated.

[1]



$$K_c = 10.0 = \frac{x^2}{(1.00 - x)^2} \quad / \sqrt{10.0} = \frac{x}{(1.00 - x)};$$

$$x = 0.760 / (1.00 - x) = 0.240;$$

$[\text{CO}] = 0.240(\text{mol dm}^{-3})$ and $[\text{H}_2\text{O}] = 0.240(\text{mol dm}^{-3})$ and $[\text{H}_2] = 0.760(\text{mol dm}^{-3})$
and $[\text{CO}_2] = 0.760(\text{mol dm}^{-3})$;

[3]

(d) (i) $K_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})] \times [\text{H}_2(\text{g})]^3}$;

[1]

Ignore state symbols.

Concentrations must be represented by square brackets.

- (ii) moles at equilibrium: nitrogen 0.27, hydrogen 0.81 / concentrations at equilibrium: nitrogen $0.27(\text{mol dm}^{-3})$, hydrogen $0.81(\text{mol dm}^{-3})$ (and ammonia 1.46 mol dm^{-3});

$$K_c = 15;$$

[2]

Actual calculation gives $K_c = 14.86$.

Award [2] for correct final answer.

Award [1 max] if $K_c = \frac{1.46^2}{3^3 \times 1} = 0.079$



7. (a) (i) rates of forward **and** reverse reactions are equal / opposing changes occur at equal rates;
the concentrations of all reactants **and** products remain constant / macroscopic properties remain constant;
closed/isolated system;
Accept "the same" for "equal" in M1 and for "constant" in M2. [2 max]
- (ii) The volume of the container is increased:
position of equilibrium shifts to the left/reactants **and** fewer moles of gas on the right hand side/pressure decreases / OWTTE;

Ammonia is removed from the equilibrium mixture:
position of equilibrium shifts to the right/products **and** $[\text{NH}_3]$ decreases so $[\text{N}_2]$ and $[\text{H}_2]$ must also decrease to keep K_c constant
OR
position of equilibrium shifts to the right/products **and** rate of reverse reaction decreases / OWTTE; [2]
Award [1 max] if both predicted changes are correct.
Do not accept "to increase $[\text{NH}_3]$ " or reference to LCP without explanation.
- (iii) minimum energy needed (by reactants/colliding particles) to react/start/initiate a reaction; [1]
Accept "energy difference between reactants and transition state".
- (b) rate increases;
more effective/successful collisions per unit time / greater proportion of collisions effective;

alternative pathway **and** a lower activation energy
OR
lowers activation energy so that more particles have enough energy to react; [2 max]
Do not accept just "lowers/reduces the activation energy".
Accept "provides a surface for reacting/reactants/reaction".
- (c) (i) slower rate / OWTTE;
uneconomic / OWTTE; [2]
- (ii) high cost for building/maintaining plant / high energy cost of compressor / OWTTE; [1]
Do not accept "high pressure is expensive" without justification.
Accept high pressure requires high energy.

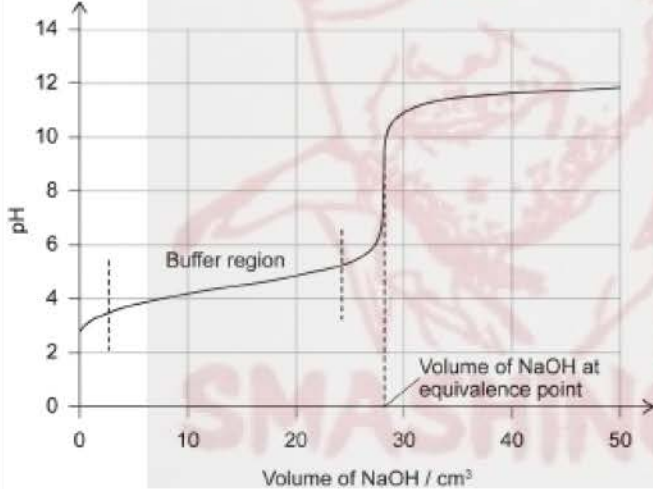


- (c) (i) increases yield;
(equilibrium shifts to the right/products as) more gaseous moles in reactants/on left / fewer gaseous moles in products/on right; [2]
- (ii) $\text{Eqm}[\text{O}_2] = 2.6(\text{mol dm}^{-3})$;
 $\text{Eqm}[\text{SO}_2] = 1.2(\text{mol dm}^{-3})$;
 $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]}$;
 $K_c = 0.17$; [4]
Award [4] for correct final answer.
Ignore units.
- (iii) (K_c) decreases; [1]
- (d) catalyst increases rate of reaction / equilibrium reached faster / increases yield of product per unit time;
 reduces costs / reduces energy needed; [2]
Do not accept just "increases the yield".

Topic Chem 8 Q# 126/ IB Chem/2019/w/TZ0/P2/Higher Level/Q7./

6.	f	iv	Any two of: ligand/chloride ion Lewis base AND donates e-pair ✓ not Brønsted–Lowry base AND does not accept proton/ H^+ ✓ Lewis definition extends/broader than Brønsted–Lowry definition ✓	2 max
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Topic Chem 8 Q# 127/ IB Chem/2019/w/TZ0/P2/Higher Level/Q6./

5.	a		 buffer region on graph ✓ equivalence point/V_{eq} on graph ✓	Construction lines not required.	2
5.	b	i	phenolphthalein ✓	Accept phenol red.	1



5.	b	ii	ALTERNATIVE 1: $\text{H}^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq}) \rightarrow \text{CH}_3\text{COOH}(\text{aq}) \checkmark$ added acid neutralised by ethanoate ions OR «weak» $\text{CH}_3\text{COOH}(\text{aq})$/ethanoic acid replaces $\text{H}^+(\text{aq})$ OR $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ ratio virtually/mostly unchanged $\checkmark$ ALTERNATIVE 2: $\text{CH}_3\text{COOH}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq}) \checkmark$ equilibrium shifts to the ethanoic acid side OR $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ ratio virtually/mostly unchanged $\checkmark$		2
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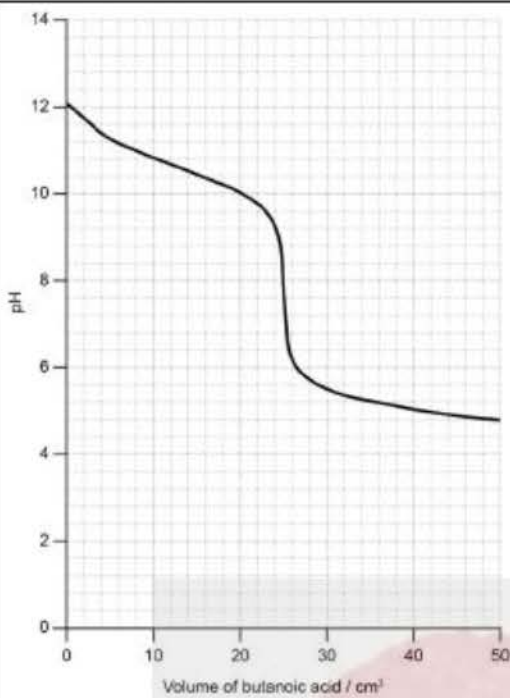
Topic Chem 8 Q# 128/ IB Chem/2019/w/TZ0/P2/Higher Level/Q5./

4.	a	i	$\text{C}_6\text{H}_5\text{O}_7^-$ AND $\text{C}_6\text{H}_7\text{O}_7^-$ OR H_2O AND H_3O^+ ✓		1				
4.	a	ii	weak acid AND partially dissociated OR weak acid AND equilibrium lies to left OR weak acid AND $K_a < 1$ ✓		1				
4.	a	iii	<table><tr><td>Effect on $[\text{H}^+]$</td><td>Effect on K_a</td></tr><tr><td>increases ✓</td><td>increases ✓</td></tr></table>	Effect on $[\text{H}^+]$	Effect on K_a	increases ✓	increases ✓		2
Effect on $[\text{H}^+]$	Effect on K_a								
increases ✓	increases ✓								
4.	a	iv	« $\Delta G^\ominus = -RT \ln K = -8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K} \times \ln(5.01 \times 10^{-4}) \div 1000 \Rightarrow 18.8$ « kJ mol^{-1} » ✓		1				
4.	a	v	non-spontaneous AND $\Delta G^\ominus$ positive ✓		1				
4.	b		Any two of: «electrical» conductivity AND HCl greater ✓ pH AND citric acid higher ✓ titrate with strong base AND pH at equivalence higher for citric acid ✓ add reactive metal/carbonate/hydrogen carbonate AND stronger effervescence/faster reaction with HCl ✓ titration AND volume of alkali for complete neutralisation greater for citric acid ✓	Accept "add universal indicator AND HCl more red/pink" for M2. Accept any acid reaction AND HCl greater rise in temperature. Accept specific examples throughout. Do not accept "smell" or "taste".	2 max				
			titrate with strong base AND more than one equivalence point for complete neutralisation of citric acid ✓ titrate with strong base AND buffer zone with citric acid ✓						



6.	a	i	<i>Butanoic acid:</i> $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH (aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^- \text{ (aq)} + \text{H}_3\text{O}^+ \text{ (aq)} \checkmark$ <i>Ethylamine:</i> $\text{CH}_3\text{CH}_2\text{NH}_2 \text{ (aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{CH}_3\text{CH}_2\text{NH}_3^+ \text{ (aq)} + \text{OH}^- \text{ (aq)} \checkmark$		2
6.	a	ii	$\text{CH}_3\text{CH}_2\text{CH}_2-\text{C} \begin{array}{l} \nearrow \text{O} \\ \searrow \text{O}^- \end{array}$ Diagram showing: dotted line along O—C—O AND negative charge	Accept correct diagrams with pi clouds.	1
6.	a	iii	-1 ✓		1
6.	b	i	$\llcorner = \frac{1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}}{0.00192 \text{ mol dm}^{-3}} \llcorner = 5.21 \times 10^{-12} \llcorner \text{ mol dm}^{-3} \llcorner \checkmark$		1
6.	b	ii	$\llcorner \text{p}K_b = 3.35, K_b = 10^{-3.35} = 4.5 \times 10^{-4} \llcorner$ $\llcorner \text{C}_2\text{H}_5\text{NH}_2 + \text{H}_2\text{O} \rightleftharpoons \text{C}_2\text{H}_5\text{NH}_3^+ + \text{OH}^- \llcorner$ $K_b = \frac{[\text{OH}^-][\text{CH}_3\text{CH}_2\text{NH}_3^+]}{[\text{CH}_3\text{CH}_2\text{NH}_2]}$ OR $\llcorner K_b \llcorner = 4.5 \times 10^{-4} = \frac{[\text{OH}^-][\text{CH}_3\text{CH}_2\text{NH}_3^+]}{0.250}$ OR $\llcorner K_b \llcorner = 4.5 \times 10^{-4} = \frac{x^2}{0.250} \checkmark$ $\llcorner x = [\text{OH}^-] \llcorner = 0.011 \llcorner \text{ mol dm}^{-3} \llcorner \checkmark$ $\llcorner \text{pH} = -\log \frac{1.00 \times 10^{-14}}{0.011} \llcorner = 12.04$ OR $\llcorner \text{pH} = 14.00 - (-\log 0.011) \llcorner = 12.04 \checkmark$	Award [3] for correct final answer.	3



6.	c	 decreasing pH curve ✓ pH close to 7 (6–8) at volume of 25 cm³ butanoic acid ✓ weak acid/base shape with no flat «strong acid/base» parts on the curve ✓	3
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Topic Chem 8 Q# 130/ IB Chem/2018/s/TZ 1/P2/Higher Level/

5.	a	slower rate with ethanoic acid OR smaller temperature rise with ethanoic acid ✓ [H⁺] lower OR ethanoic acid is weak OR ethanoic acid is partially dissociated ✓	Accept experimental observations such as "slower bubbling" or "feels less warm".	2
5.	b	Any one of: corrosion of materials/metals/carbonate materials ✓ destruction of plant/aquatic life ✓ «indirect» effect on human health ✓	Accept "lowering pH of oceans/lakes/waterways".	1
5.	c	Brønsted–Lowry base: $\text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+$ ✓ Lewis base: $\text{NH}_3 + \text{BF}_3 \rightarrow \text{H}_3\text{NBF}_3$ ✓	Accept "AlCl₃ as an example of Lewis acid". Accept other valid equations such as $\text{Cu}^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4]^{2+}$.	2
5.	d	$[\text{H}^+] \ll \sqrt{K_a \times [\text{C}_2\text{H}_5\text{O}_2]} = \sqrt{9.333 \times 10^{-6} \times 0.010} = 3.055 \times 10^{-4} \text{ mol dm}^{-3}$ ✓ «pH =» 3.51 ✓	Accept "pH = 3.52". Award [2] for correct final answer. Accept other calculation methods.	2



5.	e	$(\text{CH}_3)_3\text{CCOOH (aq)} + \text{OH}^- \text{(aq)} \rightarrow (\text{CH}_3)_3\text{CCOO}^- \text{(aq)} + \text{H}_2\text{O (l)}$ OR $(\text{CH}_3)_3\text{CCOOH (aq)} + \text{OH}^- \text{(aq)} \rightleftharpoons (\text{CH}_3)_3\text{CCOO}^- \text{(aq)} + \text{H}_2\text{O (l)}$ AND addition of alkali causes equilibrium to move to right ✓ $(\text{CH}_3)_3\text{CCOO}^- \text{(aq)} + \text{H}^+ \text{(aq)} \rightarrow (\text{CH}_3)_3\text{CCOOH (aq)}$ OR $(\text{CH}_3)_3\text{CCOO}^- \text{(aq)} + \text{H}^+ \text{(aq)} \rightleftharpoons (\text{CH}_3)_3\text{CCOOH (aq)}$ AND addition of acid causes equilibrium to move to right ✓	Accept "HA" for the acid. Award [1 max] for correct explanations of buffering with addition of acid AND base without equilibrium equations.	2
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Topic Chem 8 Q# 131/ IB Chem/2018/s/TZ 1/P2/Higher Level/

2.	f	pH > 7 ✓	Accept any specific pH value or range of values above 7 and below 14.	1
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Topic Chem 8 Q# 132/ IB Chem/2017/s/TZ 2/P2/Higher Level/

8.	a	i	H ₂ O/water ✓		Accept "hydroxide ion/OH ⁻ ".	1								
	a	ii	<table><tr><td>Acid</td><td>Base</td></tr><tr><td>HOCl AND OCl⁻</td><td></td></tr><tr><td>OR</td><td></td></tr><tr><td>H₂O AND OH⁻ ✓</td><td></td></tr></table>		Acid	Base	HOCl AND OCl ⁻		OR		H ₂ O AND OH ⁻ ✓			1
Acid	Base													
HOCl AND OCl ⁻														
OR														
H ₂ O AND OH ⁻ ✓														
	b	i	«0.100 mol dm ⁻³ × 0.0250 dm ³ » = 0.00250 «mol» ✓			1								
	b	ii	« $M = \frac{0.510 \text{ g}}{0.00250 \text{ mol}}$ » =» 204 «g mol ⁻¹ » ✓			1								
	b	iii	«1.00 × 10 ⁻¹⁴ = [H ⁺] × 0.100» 1.00 × 10 ⁻¹³ «mol dm ⁻³ » ✓			1								
	b	iv	weak AND pH at equivalence greater than 7 OR weak acid AND forms a buffer region ✓			1								
	b	v	calorimetry OR measurement of heat/temperature OR conductivity measurement ✓		Accept "indicator" but not "universal indicator".	1								
	b	vi	«pK _a = pH at half-equivalence =» 5.0			1								
	c		$K_a = 10^{-4.35} / 4.46683 \times 10^{-5} \checkmark$ $[\text{H}_3\text{O}^+] = \sqrt{4.46683 \times 10^{-5} \times 1.60 \times 10^{-3}} / \sqrt{7.1469 \times 10^{-8} / 2.6734 \times 10^{-4}} \text{ «mol dm}^{-3}\text{»} \checkmark$ $\text{pH} = \text{«-log } \sqrt{7.1469 \times 10^{-8}} \text{»} = 3.57 \checkmark$		Award [3] for correct final answer to two decimal places. If quadratic equation used, then: $[\text{H}_3\text{O}^+] = 2.459 \times 10^{-4} \text{ «mol dm}^{-3}\text{»}$ and pH = 3.61	3								



Topic Chem 8 Q# 133/ IB Chem/2017/s/TZ 1/P2/Higher Level/

5.	a		107° ✓	Accept 100° to <109.5°. Literature value = 105.8°	1
5.	b		tetrahedral ✓ sp ³ ✓	No ECF allowed.	2
5.	c		removes/reacts with OH ⁻ ✓ moves to the right/products «to replace OH ⁻ ions» ✓	Accept ionic equation for M1.	2
5.	d	i	$K_b = 10^{-5.77} / 1.698 \times 10^{-6}$ OR $K_b = \frac{[N_2H_5^+] \times [OH^-]}{[N_2H_4]}$ ✓ $[OH^-]^2 = 1.698 \times 10^{-6} \times 0.0100 = 1.698 \times 10^{-8}$ OR $[OH^-] = \sqrt{1.698 \times 10^{-8}} = 1.303 \times 10^{-4} \text{ mol dm}^{-3}$ ✓ $pH = -\log_{10} \frac{1 \times 10^{-14}}{1.3 \times 10^{-4}} = 10.1$ ✓	Award [3] for correct final answer. Give appropriate credit for other methods containing errors that do not yield correct final answer.	3
5.	d	ii	methyl red OR bromocresol green OR bromophenol blue OR methyl orange ✓		1
5.	e		bubbles OR gas OR magnesium disappears ✓ $2NH_4^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + 2NH_3(aq) + H_2(g)$ ✓	Do not accept "hydrogen" without reference to observed changes. Accept "smell of ammonia". Accept $2H^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + H_2(g)$ Equation must be ionic.	2
5.	f		bonds broken: E(N-N) + 4E(N-H) OR 158 «kJ mol ⁻¹ » + 4 × 391 «kJ mol ⁻¹ » / 1722 «kJ» ✓ bonds formed: E(N≡N) + 2E(H-H) OR 945 «kJ mol ⁻¹ » + 2 × 436 «kJ mol ⁻¹ » / 1817 «kJ» ✓ «ΔH = bonds broken – bonds formed = 1722 – 1817 = -95 «kJ» ✓	Award [3] for correct final answer. Award [2 max] for +95 «kJ».	3

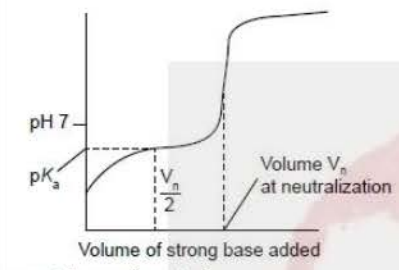
Topic Chem 8 Q# 134/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

2.	a		Weak acid: partially dissociated/ionized «in solution/water» AND Strong acid: «assumed to be almost» completely/100% dissociated/ionized «in solution/water» ✓	Accept answers relating to pH, conductivity, reactivity if solutions of equal concentrations stated.	1
Question		Answers		Notes	Total
2.	b		«log scale» reduces a wide range of numbers to a small range OR simple/easy to use OR converts exponential expressions into a linear scale/simple numbers ✓	Do not accept "easy for calculations".	1
2.	c	i	phenolphthalein OR phenol red ✓		1



Topic Chem 8 Q# 135/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question	Answers	Notes	Total
7. a	Calculation: ALTERNATIVE 1: $[H^+] = (K_a \times [HA])^{1/2} / (1.6 \times 10^{-4} \times 0.0100)^{1/2} / 1.3 \times 10^{-3} \text{ mol dm}^{-3} \checkmark$ $pH = -\log_{10}[H^+] \approx 2.9 \checkmark$ ALTERNATIVE 2: $pH = 0.5(pK_a - \log_{10}[HA]) \checkmark$ $pH = 2.9 \checkmark$ Assumption: ionisation is $\ll 0.0100$ so $0.0100 - [A^-] \approx 0.0100$ OR $[HA]_{eqm} = [HA]_{initial}$ OR all H^+ ions in the solution come from the acid «and not from the self-ionisation of water» OR $[H^+] = [HCOO^-] \checkmark$	Award [2] for correct final answer. Do not accept partial dissociation.	3

Question	Answers	Notes	Total
b i	 Volume of strong base added correct shape of graph $\checkmark$ pH at half neutralization/equivalence $\checkmark$	M1: must show buffer region at $pH < 7$ and equivalence at $pH > 7$. Accept graph starting from where two axes meet as pH scale is not specified.	2
b ii	ALTERNATIVE 1: $HCOOH \rightleftharpoons HCOO^- + H^+ \checkmark$ H^+ ions consumed in reaction with OH^- are produced again as equilibrium moves to the right «so $[H^+]$ remains almost unchanged» $\checkmark$ ALTERNATIVE 2: $HCOOH + OH^- \rightleftharpoons HCOO^- + H_2O \checkmark$ added OH^- are neutralized by $HCOOH$ OR strong base replaced by weak base $\checkmark$	Accept HA or any other weak acid in equations. Equilibrium sign must be included in equation for M1.	2

Topic Chem 8 Q# 136/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

Question	Answer	Notes	Total
2. a	radical / unpaired electron $\checkmark$		1
Question	Answers	Notes	Total
d	$2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq) \checkmark$	Ignore state symbols.	1

Topic Chem 8 Q# 137/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

3. a	$HCOO^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + HCOOH(aq) \checkmark$	Equilibrium sign must be given for mark.	1
b	$K_a = 1.8 \times 10^{-4} \checkmark$		1
c	$K_b = \left(\frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-4}} \right) = 5.6 \times 10^{-11} \checkmark$		1
d	$K_b = \frac{x^2}{0.12} = 5.6 \times 10^{-11} \checkmark$ $[OH^-(aq)] = 2.6 \times 10^{-6} \text{ mol dm}^{-3} \checkmark$ Assumption: $0.12 - x \approx 0.12 \checkmark$	Award [2] for correct final answer of $[OH^-(aq)]$. Accept any other reasonable assumption.	3
e	$pOH = (-\log(2.6 \times 10^{-6})) \rightarrow 5.59 \checkmark$ $pH = (14.00 - 5.59) \rightarrow 8.41 \checkmark$	Award [2] for correct final answer.	2



Topic Chem 8 Q# 138/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

2.	d		$K_b = \frac{[\text{OH}^-]^2}{[\text{C}_6\text{H}_5\text{NH}_2]} = 10^{-9.13} / 7.413 \times 10^{-10} \checkmark$ $[\text{OH}^-] = \sqrt{0.0100 \times 10^{-9.13}} = 2.72 \times 10^{-6} \checkmark$ $[\text{H}^+] = \frac{1 \times 10^{-14}}{2.72 \times 10^{-6}} = 3.67 \times 10^{-9}$ OR $\text{pOH} = 5.57 \checkmark$ $\text{pH} = -\log[\text{H}^+] = 8.44 \checkmark$	Accept other approaches to the calculation. Award [4] for correct final answer. Accept any answer from 8.4 to 8.5.	4
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Topic Chem 8 Q# 139/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/Q1(a)

1.	a	iii	Lewis base AND has a lone pair of electrons «to donate» ✓		1
1.	a	vi	Weak: only partially dissociated/ionized «in dilute aqueous solution» ✓ Bronsted–Lowry base: an acceptor of protons/H ⁺ /hydrogen ions ✓	Accept reaction with water is reversible/an equilibrium. Accept “water is partially dissociated «by the weak base»”.	2
1.	b	i	P ₄ is a molecule «comprising 4P atoms» AND 4P is four/separate «P» atoms OR P ₄ represents «4P» atoms bonded together AND 4P represents «4» separate/non-bonded «P» atoms ✓		1

Question	Answers	Notes	Total
1. b ii	can act as both a «Bronsted–Lowry» acid and a «Bronsted–Lowry» base OR can accept and/or donate a hydrogen ion/proton/H ⁺ ✓ HPO ₄ ²⁻ AND H ₃ PO ₄ ✓		2

Topic Chem 8 Q# 140/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

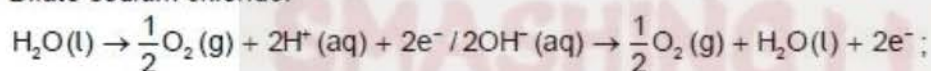
4.	a	iii	hydrochloric acid shifts equilibrium to left OR hydrochloric acid prevents the basic chloride forming/precipitating ✓	Accept “hydrochloric acid reacts with «basic» chloride” OR “hydrochloric acid suppresses salt hydrolysis”.	1
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Topic Chem 8 Q# 141/ IB CHEM/2015/w/TZ0/P2 Section B/Higher Level/

- (d) (i) Pb < Ni < Fe < Zn;; [2]
Award [2] for the correct order.
Award [1] for Zn > Fe > Ni > Pb as metals not listed in order of increasing reactivity.
Award [1] if one error in the order.

- (ii) Pb²⁺/ lead(II) (ions); [1]
Do not accept Pb/lead.

- (e) Dilute sodium chloride:



Concentrated sodium chloride:



Award [1 max] if equations are given the wrong way round.

Accept e instead of e⁻.

Ignore state symbols and equilibrium sign.

Accept correct half-equations balanced with different coefficients.



8. (a) (i) base I: 7.0;
base II: 5.5; [2]
- (ii) base I: strong base **and** base II: weak base; [1]
- (iii) NaOH **and** KOH; [1]
Accept LiOH.

- (iv) (from the graph: initial pH = 11, pOH = 3) $[\text{OH}^-] = 10^{-3} (\text{mol dm}^{-3})$;

$$K_b = \frac{10^{-3} \times 10^{-3}}{0.100 - x} / \frac{10^{-3} \times 10^{-3}}{0.100};$$

$$K_b = 1.0 \times 10^{-5};$$

OR

at half-equivalence point, pH = 9.0 = pK_a for base II;

$$\text{p}K_b = 14.0 - 9.0 = 5.0;$$

Award M1 and M2 for stating: "at half-equivalence point pOH = 5 = pK_b for base II".

$$K_b = 1.0 \times 10^{-5};$$

Accept other valid methods of working.

Accept a slightly different value of pK_b and so K_b if the student uses the pH at the end point, rather than the initial or half-neutralisation values.

- (v) methyl red; [1]
Do not accept bromocresol green (since from table 16 data booklet pH range, 3.8 is too low).

- (b) (i) resists change in pH;
on addition of small amounts of acid and base; [2]

- (ii) (after mixing) $[\text{NH}_3] = [\text{NH}_4^+] / n\text{NH}_3 = n\text{NH}_4^+ / n = 4.00 \times 10^{-3} \text{ mol};$

$$[\text{OH}^-] = K_b \frac{[\text{base}]}{[\text{salt}]} / \text{pOH} = \text{p}K_b = 4.75;$$

$$\text{pH} = 9.25;$$

Award [1 max] if no working shown.

Accept other valid methods of working.

- (c) (i) Reaction A: base **and** accepts a proton/H⁺;
Accept donates a pair of electrons. [2]
- Reaction B: acid **and** donates a proton/H⁺;

Award [1] if acid and base identified correctly without a reason.

- (ii)
- | | Acid | | Base |
|------------------------------|--------------------------------|------------|---------------------------------|
| Conjugate acid-base pair 1/2 | H ₂ CO ₃ | and | HCO ₃ ⁻ ; |
| Conjugate acid-base pair 2/1 | HCO ₃ ⁻ | and | CO ₃ ²⁻ ; |
| Conjugate acid-base pair 1/2 | H ₃ O ⁺ | and | H ₂ O; |

[2 max]



- (d) (i) **strong acid:** (assumed to be) completely/100% dissociated/ionized **and**
weak acid: partially dissociated/ionized; [1]
- (ii) **Similarity:** bubbling/effervescence/gas / heat/increase in temperature / solid dissolves;
Difference: strong acid more vigorous / faster reaction / greater temperature increase; [2]
 Accept converse statements for weak acid.
- (iii) $10^4(: 1) / 10^{-1} : 10^{-5} / 1 : 10^{-4}$; [1]
 Do not accept inverse ratio, $1 : 10^4$.

Topic Chem 8 Q# 143/ IB Chem/2015/w/TZ0/P2 Section A/Higher Level/

- (b) (NH₃) Lewis base **and** (Cu²⁺) Lewis acid;
 NH₃/ligand donates an electron pair (to Cu²⁺) / Cu²⁺ accepts an electron pair (from NH₃);
 forming coordinate/dative (covalent) bond; [3]
 Accept coordination bond.
 Do not accept just covalent bond.

Topic Chem 8 Q# 144/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

- (e) (i) electron pair donor; [1]
 Accept lone pair donor.
- (ii) proton acceptor **and** partially/slightly ionized; [1]
 Accept "proton acceptor **and** partially/slightly dissociated".

(iii)

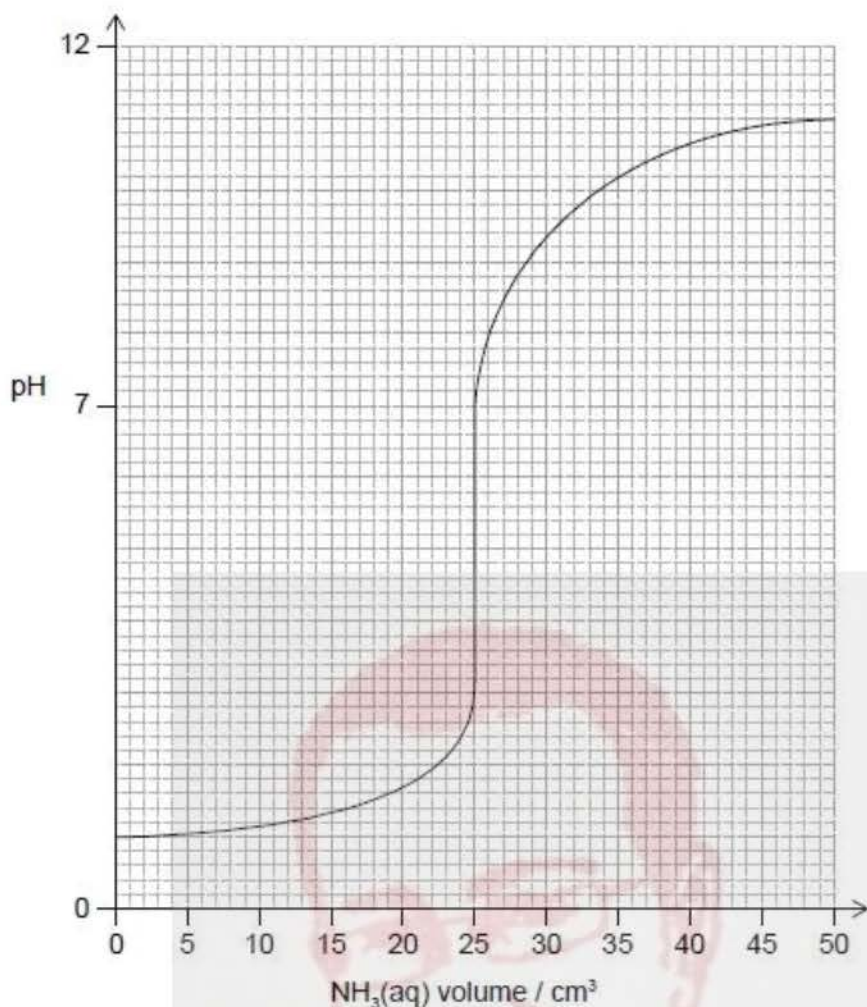
Acid		Conjugate base
CH ₃ NH ₃ ⁺	and	CH ₃ NH ₂ ;
H ₂ O	and	OH ⁻ ;

Award [1 max] for two correct acids OR two correct conjugate bases.

- (f) $K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} = 1.8 \times 10^{-5} / 10^{-4.75}$;
 $[\text{NH}_4^+] = [\text{OH}^-]$ **and** $[\text{NH}_3] \approx 1.00 \times 10^{-1} \text{ (mol dm}^{-3}\text{)}$;
 $[\text{OH}^-] = (\sqrt{1.8 \times 10^{-5}}) = 1.3 \times 10^{-3} \text{ (mol dm}^{-3}\text{)} / \text{pOH} = 2.89$;
 $\text{pH} = (14.0 - 2.89) = 11.1$; [4]
 Award [4] for correct final answer.



(g) (i)



For volume = 0: pH = 1;

vertical jump should be positioned in volume range 24 cm³ to 26 cm³ and include pH range between 3 to 6;

For volume = 50: pH between 8 to 11;

[3]

(ii) methyl orange / bromophenol blue / bromocresol green / methyl red;

[1]

Topic Chem 8 Q# 145/ IB Chem/2015/s/TZ2/P2 Section A/Higher Level/

4. (a) a solution that resists changes in pH / changes pH slightly / OWTTE;
when small amounts of an acid/H⁺ or a base/alkali/OH⁻ are added;

[2]

(b) addition of acid:

$\text{CH}_3\text{CH}_2\text{COO}^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{CH}_3\text{CH}_2\text{COOH}(\text{aq})$ / propanoate ions combine with H⁺ ions to form undissociated propanoic acid;

addition of base:

$\text{CH}_3\text{CH}_2\text{COOH}(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{CH}_3\text{CH}_2\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$ / addition of OH⁻ removes H⁺ and more propanoic acid dissociates/ionizes;

[2]

Ignore state symbols.

Accept reversible arrows.

Award [1 max] if correct equations are given without reference to addition of acid or alkali.



(c) $K_a = \frac{[H^+(aq)][CH_3CH_2COO^-(aq)]}{[CH_3CH_2COOH(aq)]}$ / $pH = pK_a + \log\left(\frac{[base]}{[acid]}\right)$;
 $K_a = 1.3 \times 10^{-5} / 10^{-4.87}$ **and** $[H^+] = 1.3 \times 10^{-4} / 10^{-3.87} (\text{mol dm}^{-3})$ /
 $\log\left(\frac{[CH_3CH_2COO^-]}{[CH_3CH_2COOH]}\right) = 3.87 - 4.87 = -1$;
 $\left([CH_3CH_2COOH] = \frac{7.41}{74.09} = \right) 0.100 / 1.00 \times 10^{-1} (\text{mol dm}^{-3})$;
 $[CH_3CH_2COONa] = 0.010 / 1.0 \times 10^{-2} (\text{mol dm}^{-3})$;

[4]

Award [4] for correct final answer.

Accept corresponding use of $[H_3O]^+$ for $[H^+]$, [acid] for $[CH_3CH_2COOH]$, and [base] or [salt] for $[CH_3CH_2COO^-]$ throughout.

Topic **Chem 8 Q# 146/** IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

8. (a) (i) weak acids dissociate only partially **and** strong acids (are assumed to) dissociate fully;

[1]

- (ii) measuring electrical conductivity **and** strong acids have greater electrical conductivity/weak acids have lower electrical conductivity;
Do not accept conductivity for electrical conductivity.
Accept explanation in terms of lightbulb in circuit.

measure pH/use universal indicator **and** pH higher for weak acid/pH lower for strong acid;

conduct titration with a strong base **and** equivalence point higher for weak acid / buffer region for weak acid;

adding a reactive metal/carbonate/hydrogen carbonate **and** stronger effervescence/faster reaction with strong acids;
Accept converse argument.
Accept correct example.

adding a strong base **and** strong acid would increase more in temperature/weak acids increase less in temperature;
Accept correct example.

[3 max]

Award [1 max] for three suitable tests without correct results.
Accept specific examples with given strong acid and weak acid.
*Accept "addition of $AgNO_3(aq)$ **and** white precipitate with $HCl(aq)$ ".*
Do not accept "smell".

SMASHING!!!



- (b) $\frac{1.40}{60.06} = 0.0233 \text{ (mol)}$ and $\frac{0.0233}{0.500} = 0.0466 \text{ (mol dm}^{-3}\text{)}$;
 $(pK_a = 4.76) K_a = 1.7 \times 10^{-5}$;
 $[H^+] = \sqrt{K_a[HA]} = 8.9 \times 10^{-4}$;
 Accept 9.0×10^{-4} .
 $pH = 3.05$;
 Award [4] for correct final answer.
 Accept alternative methods.

[4]

- (c) (i) Equivalence point: pH of 9.5;
 Accept values between 9 and 10.

$pK_a = pH$ at half equivalence point;

$pK_a = 5.4$;

Accept any value between 5.2 and 5.6.

Award [2] for M2 and M3 if correct pK_a given without explanation.

[3]

- (ii) phenolphthalein;

[1]

- (iii) $HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$ and HIn and In^- have different colours;
 Ignore state symbols.

equilibrium shifts depending on addition of H^+ and OH^- / more HIn in acid/low pH / more In^- in alkali/high pH;

[2]

- (d) (i) CH_2ClCOO^- ;

[1]

- (ii) stronger because pK_a of chloroethanoic acid is $< pK_a$ of ethanoic acid;

[1]

- (iii) Concentration of acid: $\frac{0.030}{0.300} = 0.10 \text{ (mol dm}^{-3}\text{)}$;

Concentration of base/salt: $\frac{0.020}{0.300} = 0.067 \text{ (mol dm}^{-3}\text{)}$;

$$[H^+] = \frac{K_a \times [HA]}{[A^-]} = \frac{1.3 \times 10^{-3} \times 0.10}{0.067} = 1.9 \times 10^{-3} \text{ (mol dm}^{-3}\text{)};$$

$pH = 2.72$;

[4]

Award [4] for correct final answer.

Accept 2.69, 2.70 or 2.7.

Alternative for M3 and M4 if Henderson-Hasselbalch equation used:

$$M3: pH = pK_a + \log \frac{[base]}{[acid]} = 2.87 + \log \left(\frac{0.067}{0.10} \right)$$

$$M4: pH = 2.70$$

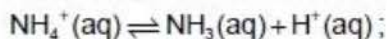
Award [1 max] for $n_{acid} (= 100 \times 0.50 \div 1000) = 0.050 \text{ mol}$ and

$n_{base} (= 200 \times 0.10 \div 1000) = 0.020 \text{ mol}$.



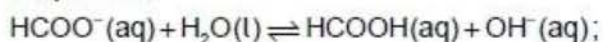
(c) Ammonium chloride:

Accept any value in the range: $3 < \text{pH} < 7$;



Sodium methanoate:

$7 < \text{pH} < 11$;



[4]

Award [1 max] for both M1 and M3 combined if stated "pH < 7/acidic for ammonium chloride and pH > 7/alkaline/basic for sodium methanoate".

Accept alternative suitable equations.

Award [1 max] for two correct explanations, such as "salt of weak acid and strong base" or "salt of weak base and strong acid", without equations.

Penalize missing equilibrium sign once only.

Ignore state symbols.

Topic Chem 9 Q# 148/ IB Chem/2019/w/TZ0/P2/Higher Level/Q7./

6.	c	i	Wires: «delocalized» electrons «flow» ✓ Electrolyte: «mobile» ions «flow» ✓		2
6.	c	ii	$2\text{Cl}^- \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$ OR $\text{Cl}^- \rightarrow \frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^-$ ✓	Accept e for e ⁻ .	1
6.	c	iii	«electrode» 3 AND oxygen/O ₂ ✓	Accept chlorine/Cl ₂ .	1
6.	c	iv	$2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^-$ ✓	Accept $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$. Accept $4\text{OH}^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^-$	1
6.	e	i	$E^\circ = +0.52 - 0.15 = +0.37 \text{ V}$ ✓		1
6.	e	ii	spontaneous AND E° positive ✓		1
6.	e	iii	$\Delta G^\circ = -nFE = -1 \text{ mol} \times 96\,500 \text{ C mol}^{-1} \times 0.37 \text{ V} = -36\,000 \text{ J} = -36 \text{ kJ}$ ✓	Accept "-18 kJ mol ⁻¹ «per mole of Cu ²⁺ »". Do not accept values of n other than 1. Apply SF in this question. Accept J/kJ or J mol ⁻¹ /kJ mol ⁻¹ for units.	1
6.	e	iv	2 mol (aq) → 1 mol (aq) AND decreases ✓	Accept "solid formed from aqueous solution AND decreases". Do not accept 2 mol → 1 mol without (aq).	1
6.	e	v	$\Delta G^\circ < 0$ AND $\Delta S^\circ < 0$ AND $\Delta H^\circ < 0$ OR $\Delta G^\circ + T\Delta S^\circ < 0$ AND $\Delta H^\circ < 0$ ✓		1
6.	e	vi	TΔS more negative «reducing spontaneity» AND stability increases ✓	Accept calculation showing non-spontaneity at 433 K.	1



Topic Chem 9 Q# 149/ IB Chem/2019/w/TZ0/P2/Higher Level/Q3./

2.	a	i	4:1 ✓		1
2.	a	ii	$n_{S_2O_8^{2-}} = 0.0258 \text{ dm}^3 \times 0.010 \text{ mol dm}^{-3} = 2.58 \times 10^{-4} \text{ «mol»} \checkmark$ $\ll \frac{2.58 \times 10^{-4} \text{ mol}}{4} = 6.45 \times 10^{-5} \text{ «mol»} \checkmark$	Award [2] for correct final answer.	2
2.	a	iii	$\ll \text{difference in moles per dm}^3 = (6.45 \times 10^{-5} - 5.03 \times 10^{-5}) \times \frac{1000}{300.0} = 4.73 \times 10^{-5} \text{ «mol dm}^{-3}\text{»} \checkmark$ $\ll \text{convert to mg per dm}^3: 4.73 \times 10^{-5} \text{ mol dm}^{-3} \times 32.00 \text{ g mol}^{-1} \times 1000 \text{ mg g}^{-1} = 1.51 \text{ «ppm/mg dm}^{-3}\text{»} \checkmark$	Award [2] for correct final answer.	2

Topic Chem 9 Q# 150/ IB Chem/2018/w/TZ 0/P2/Higher Level/

6.	a	iii	-1 ✓		1
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Topic Chem 9 Q# 151/ IB Chem/2018/w/TZ 0/P2/Higher Level/

3.	d	i	$\text{BrO}_3^- (\text{aq}) + 6\text{e}^- + 6\text{H}^+ (\text{aq}) \rightarrow \text{Br}^- (\text{aq}) + 3\text{H}_2\text{O} (\text{l})$ correct reactants and products ✓ balanced equation ✓	Accept reversible arrows.	2
3.	d	ii	$\text{BrO}_3^- (\text{aq}) + 6\text{Fe}^{2+} (\text{aq}) + 6\text{H}^+ (\text{aq}) \rightarrow \text{Br}^- (\text{aq}) + 3\text{H}_2\text{O} (\text{l}) + 6\text{Fe}^{3+} (\text{aq}) \checkmark$		1
3.	d	iii	$E^\circ_{\text{reaction}} = +1.44 \text{ V} - 0.77 \text{ V} = 0.67 \text{ «V»} \checkmark$ $\Delta G^\circ = -nFE^\circ_{\text{reaction}} = -6 \times 96500 \text{ C mol}^{-1} \times 0.67 \text{ V} = -3.9 \times 10^5 \text{ «J»} \checkmark$		2

Topic Chem 9 Q# 152/ IB Chem/2018/w/TZ 0/P2/Higher Level/Q1

1.	d		Anode (positive electrode): $2\text{H}_2\text{O} (\text{l}) \rightarrow \text{O}_2 (\text{g}) + 4\text{H}^+ (\text{aq}) + 4\text{e}^- \checkmark$ Cathode (negative electrode): $2\text{H}_2\text{O} (\text{l}) + 2\text{e}^- \rightarrow \text{H}_2 (\text{g}) + 2\text{OH}^- (\text{aq})$ OR $2\text{H}^+ (\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2 (\text{g}) \checkmark$	Accept $4\text{OH}^- (\text{aq}) \rightarrow \text{O}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l}) + 4\text{e}^-$ OR $\text{Fe}^{2+} (\text{aq}) \rightarrow \text{Fe}^{3+} (\text{aq}) + \text{e}^-$ for M1. Accept $\text{Fe}^{2+} (\text{aq}) + 2\text{e}^- \rightarrow \text{Fe} (\text{s})$ OR $\text{SO}_4^{2-} (\text{aq}) + 4\text{H}^+ (\text{aq}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{SO}_3 (\text{aq}) + \text{H}_2\text{O} (\text{l})$ for M2.	2
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Topic Chem 9 Q# 153/ IB Chem/2018/s/TZ 1/P2/Higher Level/

6.	a		salt bridge ✓ movement of ions OR balance charge ✓	Do not accept "to complete circuit" unless ion movement is mentioned for M2.	2
6.	b		Positive electrode (cathode): $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$ ✓ Negative electrode (anode): $\text{Mg}(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$ ✓	Award [1 max] if correct equations given at wrong electrodes.	2
6.	c		in external wire from left to right ✓		1
6.	d		$E = +0.80 \text{ V} - (-2.37 \text{ V}) = +3.17 \text{ V}$ ✓		1
6.	e		«moles of silver = $\frac{0.10 \text{ g}}{107.87 \text{ g mol}^{-1}}$ » moles of magnesium = $\frac{0.5 \times 0.10 \text{ g}}{107.87 \text{ g mol}^{-1}}$ ✓ «loss in mass of magnesium = $\frac{24.31 \text{ g mol}^{-1} \times 0.5 \times 0.10 \text{ g}}{107.87 \text{ g mol}^{-1}} = 0.011 \text{ g}$ » ✓	Award [2] for correct final answer.	2

Topic Chem 9 Q# 154/ IB Chem/2017/s/TZ 2/P2/Higher Level/

4	a	iii	N_2H_4 -2 AND N_2O_4 +4 ✓		1
4	a	iv	N_2H_4 AND oxidized/oxidation state increases OR N_2H_4 AND loses hydrogen OR N_2H_4 AND reduces/removes oxygen from N_2O_4 ✓	Accept " N_2H_4 AND gives electrons «to N_2O_4 »".	1

Topic Chem 9 Q# 155/ IB Chem/2017/s/TZ 2/P2/Higher Level/

2.	a	i	$\text{Sn}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + 2\text{e}^-$ ✓	Accept equilibrium sign. Accept $\text{Sn}^{2+}(\text{aq}) - 2\text{e}^- \rightarrow \text{Sn}^{4+}(\text{aq})$	1
2	b	i	$E^\ominus = +0.85 \text{ V}$ ✓	Accept 0.85 V.	1
2	b	ii	$\Delta G^\ominus = -nFE^\ominus = -2 \text{ mol e}^- \times 96500 \text{ C mol}^{-1} \times 0.85 \text{ V}$ ✓ $\Delta G^\ominus = -164 \text{ kJ}$ ✓	Accept " $+164 \text{ kJ}$ " as question states energy released. Award [1 max] for "+" or "- 82 kJ". Do not accept answer in J.	2
2	c		Zn/zinc is a stronger reducing agent than Fe/iron OR Zn/zinc is oxidized instead of Fe/iron OR Zn/zinc is the sacrificial anode ✓	Accept "Zn is more reactive than Fe". Accept "Zn oxide layer limits further corrosion". Do not accept "Zn layer limits further corrosion".	1



Topic Chem 9 Q# 156/ IB Chem/2017/s/TZ 1/P2/Higher Level/

4.	a		$2\text{NiS (s)} + 3\text{O}_2\text{ (g)} \rightarrow 2\text{NiO (s)} + 2\text{SO}_2\text{ (g)}$ ✓		1
4.	b		formation of «gaseous» pentacarbonyliron is slower OR «gaseous» complexes form at different rates OR gases have different rates of diffusion «due to difference in masses» OR difference in thermal stability of «gaseous» complexes OR difference in boiling points of «gaseous» complexes OR difference in solubility of «gaseous» complexes OR difference in surface affinity «onto solid absorbent» OR difference in chemical properties of «gaseous» complexes ✓	Accept any other valid answer.	1

Topic Chem 9 Q# 157/ IB Chem/2017/s/TZ 1/P2/Higher Level/

3.	a		V_2O_5 : +5 ✓ VO^{2+} : +4 ✓	Do not penalize incorrect notation twice.	2
3.	b	i	$\text{H}_2\text{SO}_3\text{ (aq)}$ OR Pb (s) ✓		1
3.	b	ii	Zn (s) ✓		1
3.	c	i	$\text{VO}^{2+}\text{ (aq)} + \text{V}^{2+}\text{ (aq)} + 2\text{H}^+\text{ (aq)} \rightarrow 2\text{V}^{3+}\text{ (aq)} + \text{H}_2\text{O (l)}$ ✓	Accept equilibrium sign.	1
3.	c	ii	$E^\ominus \llcorner +0.34\text{ V} - (-0.26\text{ V}) \llcorner +0.60\text{ «V»}$ ✓ $\Delta G^\ominus \llcorner -nFE^\ominus \llcorner -9.85 \times 10^4\text{ C mol}^{-1} \times 0.60\text{ J C}^{-1} \llcorner -57\,900\text{ «J mol}^{-1}\text{»} / -57.9\text{ «kJ mol}^{-1}\text{»}$ ✓ spontaneous as $\Delta G^\ominus$ is negative ✓	Do not award M3 as a stand-alone answer. Accept "spontaneous" for M3 if answer given for M2 is negative. Accept "spontaneous as $E^\ominus$ is positive" for M3.	3

Topic Chem 9 Q# 158/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

4.	i	iii	Anode (positive electrode): oxygen/ O_2 OR hydrogen ion/proton/ H^+ AND oxygen/ O_2 ✓ Cathode (negative electrode): hydrogen/ H_2 OR hydroxide «ion»/ OH^- AND hydrogen/ H_2 ✓	Award [1 max] if correct products given at wrong electrodes.	2
4.	j		Any two of: «inert» Pt electrode OR platinum black conductor ✓ $1\text{ mol dm}^{-3}\text{ H}^+\text{ (aq)}$ ✓ $\text{H}_2\text{ (g)}$ at 100 kPa ✓	Accept 1 atm $\text{H}_2\text{ (g)}$. Accept 1 bar $\text{H}_2\text{ (g)}$. Accept a labelled diagram. Ignore temperature if it is specified.	2 max
4.	k	i	$\text{Mg (s)} + \text{Cu}^{2+}\text{ (aq)} \rightarrow \text{Mg}^{2+}\text{ (aq)} + \text{Cu (s)}$ ✓		1
4.	k	ii	$\llcorner +0.34\text{ V} - (-2.37\text{ V}) \llcorner +2.71\text{ «V»}$ ✓		1
4.	k	iii	cell potential increases ✓ reaction «in Q4(k)(i)» moves to the right OR potential of the copper half-cell increases/becomes more positive ✓	Accept correct answers based on the Nernst equation.	2

Topic Chem 9 Q# 159/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

4.	k	i	$\text{Mg (s)} + \text{Cu}^{2+}\text{ (aq)} \rightarrow \text{Mg}^{2+}\text{ (aq)} + \text{Cu (s)}$ ✓		1
4.	k	ii	$\llcorner +0.34\text{ V} - (-2.37\text{ V}) \llcorner +2.71\text{ «V»}$ ✓		1
4.	k	iii	cell potential increases ✓ reaction «in Q4(k)(i)» moves to the right OR potential of the copper half-cell increases/becomes more positive ✓	Accept correct answers based on the Nernst equation.	2

Topic Chem 9 Q# 160/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

1.	c		Ethene: -2 ✓ Ethane-1,2-diol: -1 ✓	Do not accept 2-, 1- respectively.	2
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Topic Chem 9 Q# 161/ IB Chem/2016/s/TZoSP/P2 Section A/Higher Level/

b	i	NaClO : +1 (for chlorine) and I_2 : 0 (for iodine) ✓		1
b	ii	ClO^- since chlorine reduced/gains electrons OR ClO^- since oxidation state of chlorine changes from +1 to -1/decreases OR ClO^- since it loses oxygen / causes iodide to be oxidized ✓		1
b	iii	produces chlorine (gas)/ Cl_2 (on reaction with ClO^-) which is toxic ✓	OWTTE	1
b	iv	oxidation states are not real OR oxidation states are just used for electron book-keeping purposes ✓ average oxidation state of sulfur calculated to be +2 ✓ but the two sulfurs are bonded differently/in different environments in thiosulfate so have different oxidation states ✓	OWTTE	2 max

Question	Answers	Notes	Total
c	Valid: addition of oxygen signifies an oxidation reaction so C is oxidized OR loss of hydrogen signifies an oxidation reaction so C is oxidized OR oxidation state of C changes from -4 to +4/increases ✓ Not valid: loss of electrons might suggest formation of ionic product but not valid since CO_2 is covalent OR loss of electrons might suggest formation of ionic product but not valid since reaction only involves neutral molecules ✓	OWTTE	2

Topic Chem 9 Q# 162/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

4.	b	i	$E^\circ \leftarrow -0.34 - 0.15 = -0.19 \text{ V}$ ✓ $\Delta G^\circ \leftarrow -nFE^\circ \leftarrow -2 \times 96500 \times 0.19 = -36870 / -37000 \text{ kJ} / -37 \text{ kJ}$ ✓	Accept -18335 kJ or -18 kJ as equation not specified.	2
4.	b	ii	yes AND ΔG° is negative OR yes AND E° for the cell is positive OR yes AND $\text{Sn}^{2+}(\text{aq})$ is a stronger reducing agent than $\text{V}^{2+}(\text{aq})$ OR yes AND E° for $\text{Sn}^{4+}(\text{aq})$ is more negative than E° for $\text{VO}^{2+}(\text{aq})$ OR yes AND $\text{VO}^{2+}(\text{aq})$ is a stronger oxidizing agent than $\text{Sn}^{4+}(\text{aq})$ OR yes AND E° for $\text{VO}^{2+}(\text{aq})$ is more positive than E° for $\text{Sn}^{4+}(\text{aq})$ ✓	Do not accept reference to anti-clockwise rule.	1

Topic Chem 9 Q# 163/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

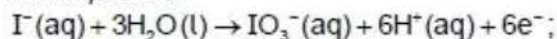
1.	b	iii	P_4 : 0 ✓ H_2PO_2^- : +1 ✓	Do not accept 1 or 1+ for H_2PO_2^- .	2
1.	b	iv	oxygen gained, so could be oxidation ✓ hydrogen gained, so could be reduction OR negative charge (on product/ H_2PO_2^-)/gain of electrons, so could be reduction ✓ oxidation number increases so must be oxidation ✓	Award [1 max] for M1 and M2 if candidate displays knowledge of at least two of these definitions but does not apply them to the reaction. Do not award M3 for "oxidation number changes".	3

Topic Chem 9 Q# 164/ IB Chem/2015/w/TZ0/P2 Section A/Higher Level/

1. (a) (i) IO_3^- to I_2 : V/+5 to 0;
 I^- to I_2 : -1/-1 to 0; [2]
 Accept change in oxidation number -5 and +1.
 Penalize incorrect notation such as 5+ or 5 once only.
- (ii) Oxidizing agent: IO_3^- /iodate and Reducing agent: I^- /iodide; [1]



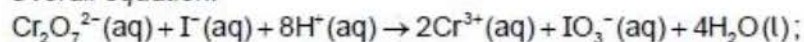
(d) (i) Half equation:



Accept e instead of e⁻.

Accept reversible arrows.

Overall equation:



[2]

Ignore state symbols.

(ii) oxidized **and** increase (in oxidation number) of 6/from -1/-I to +5/+V;

[1]

(e) (i) potential (of reduction half-reaction) under standard conditions measured relative to standard hydrogen electrode/SHE / OWTTE;

[1]

Accept "solute concentration of 1 mol dm⁻³" or "1 bar/1 atm (pressure) for gases" instead of "standard conditions".

Accept voltage/emf for potential.

(ii) (+)1.08 (V);

[1]

(iii) $2\text{Cr}(\text{s}) + 3\text{Cu}^{2+}(\text{aq}) \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 3\text{Cu}(\text{s});$

[1]

Ignore state symbols.

Do not accept reversible arrows.

(iv) Negative electrode: chromium/Cr **and** Positive electrode: copper/Cu;

[1]

Accept "Cr is the anode **and** Cu the cathode".

(v) from chromium/Cr to copper/Cu;

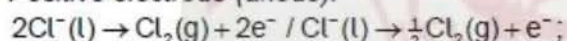
[1]

Accept "from negative electrode/anode to positive electrode/cathode" if electrodes correctly identified in (iv).

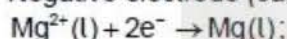
(vi) negative ions/anions towards the chromium(III) solution **and** positive ions/cations towards the copper(II) solution / OWTTE;

[1]

6. (a) Positive electrode (anode):



Negative electrode (cathode):



Accept e instead of e⁻.

Award [1 max] for correct half-equations given at the wrong electrode.

Penalize use of reversible arrows once only.

correct state symbols in both equations;

[3]

(b) aluminium/Al is less dense (compared to iron/Fe) / Al is more ductile or malleable / aluminium forms a protective oxide layer / Al does not corrode / iron/Fe rusts / OWTTE;

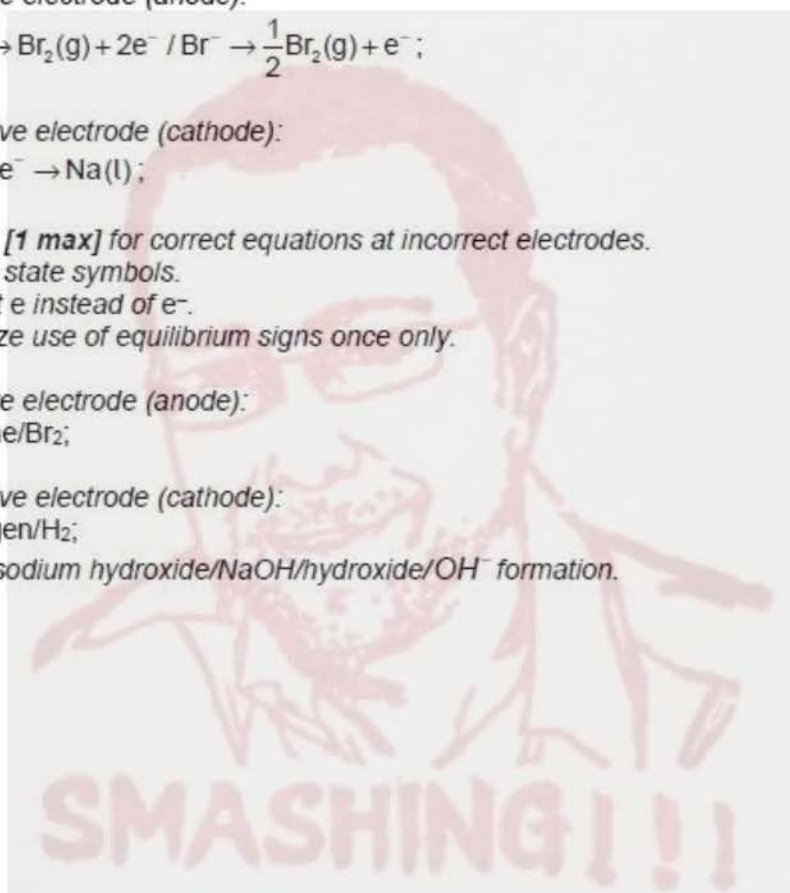
[1]

Do not accept "Al is lighter" OR "less expensive" OR "Al can be recycled".



- (ii) Ethanol: $-2/-II$;
Ethanal: $-1/-I$;
Do not accept 2-, 1- but penalize once only. [2]
- (iii) $CH_3CH_2OH \rightarrow CH_3CHO + 2H^+ + 2e^-$; [1]
Half-equation required. Do not accept $C_2H_5OH + 2[O] \rightarrow CH_3CHO + H_2O$.
Accept e for e^- .
Accept e^- for e^- .
- (iv) $3CH_3CH_2OH(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 2Cr^{3+}(aq) + 3CH_3CHO(l) + 7H_2O(l)$
correct reactants and products;
correct balancing; [2]
M2 can only be scored if M1 correct.
Ignore state symbols.

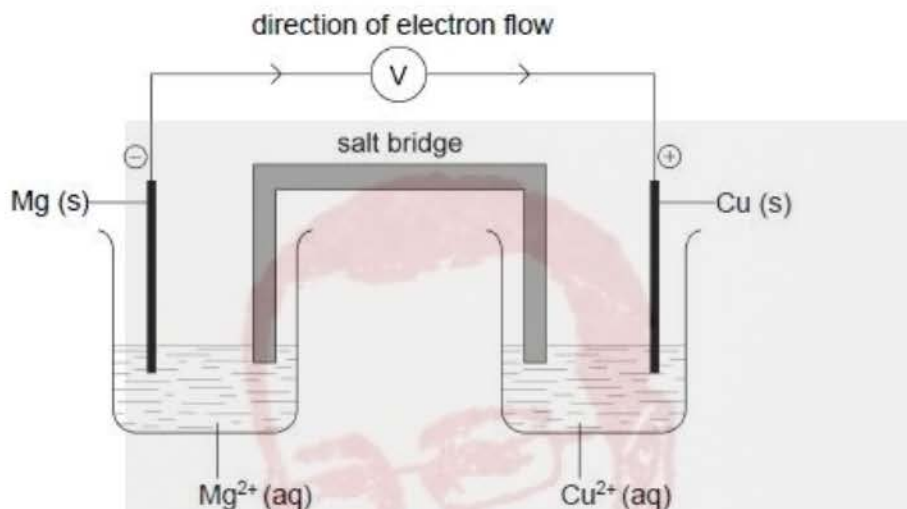
- (d) (i) Positive electrode (anode):
 $2Br^- \rightarrow Br_2(g) + 2e^-$ / $Br^- \rightarrow \frac{1}{2}Br_2(g) + e^-$;
Negative electrode (cathode):
 $Na^+ + e^- \rightarrow Na(l)$; [2]
Award [1 max] for correct equations at incorrect electrodes.
Ignore state symbols.
Accept e instead of e^- .
Penalize use of equilibrium signs once only.
- (ii) Positive electrode (anode):
bromine/ Br_2 ;
Negative electrode (cathode):
hydrogen/ H_2 ; [2]
Allow sodium hydroxide/ $NaOH$ /hydroxide/ OH^- formation.



- (e) bromine/ Br_2 ; [1]
Do not accept bromide/ Br^- .

- (f) (i) potential of reduction half-reaction under standard conditions measured relative to standard hydrogen electrode/SHE / potential under standard conditions relative to standard hydrogen electrode/SHE; [1]
Instead of standard state allow either solute concentration of 1 mol dm^{-3} or $100 \text{ kPa}/1.00 \times 10^5 \text{ Pa}$ for gases.
Allow 1 bar for $100 \text{ kPa}/1.00 \times 10^5 \text{ Pa}$.
Allow 1 atm.
Allow voltage instead of potential.

(ii)



correct diagram including (voltmeter), 4 correct species (state symbols not required) and connecting wires;
No credit if wires to electrodes immersed in the solutions.
Accept ammeter/meter/lamp instead of voltmeter.

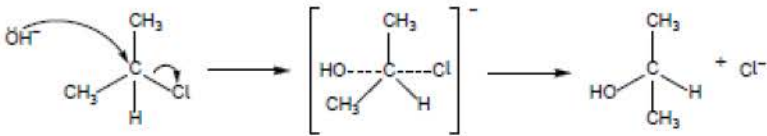
labelled salt bridge;
Accept an appropriate salt (name or formula) instead of salt bridge (eg, potassium nitrate).

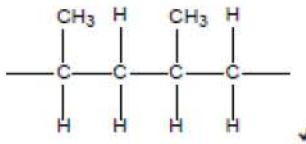
correctly labelled electrodes as +/cathode **and** -/anode;
flow of electrons from Mg to Cu in external circuit; [4]

- (iii) Random uncertainty: $(\pm) 0.01 \text{ (V)}$; [2]
Significant figures: 3;

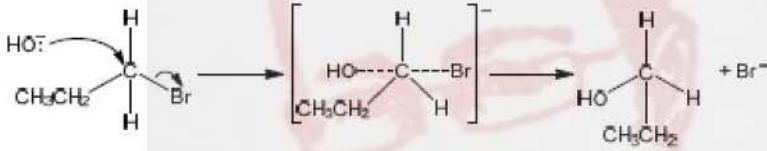
- (iv) repeat readings **and** take an average / use more precise equipment; [1]



3.	a	i	«electrophilic» addition ✓	Do not accept "nucleophilic addition" or "free radical addition". Do not accept "halogenation".	1
3.	a	ii	2-chloropropane ✓		1
3.	a	iii	secondary carbocation/carbocation «ion» is more stable OR carbocation/carbocation «ion» stabilized by two/more alkyl groups ✓		1
3.	a	iv	$\text{CH}_3\text{CHClCH}_3 (\text{l}) + \text{OH}^- (\text{aq}) \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_3 (\text{aq}) + \text{Cl}^- (\text{aq})$ OR $\text{CH}_3\text{CHClCH}_3 (\text{l}) + \text{NaOH} (\text{aq}) \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_3 (\text{aq}) + \text{NaCl} (\text{aq})$ ✓		1
3.	b	i	Rate = $k [\text{C}_3\text{H}_7\text{Cl}] [\text{OH}^-]$ ✓ «[OH ⁻] held constant and» [C ₃ H ₇ Cl] triples AND rate triples «so first order wrt C ₃ H ₇ Cl» ✓ [C ₃ H ₇ Cl] doubles AND [OH ⁻] doubles AND rate quadruples «so first order wrt OH ⁻ » ✓		3
3.	b	ii	S _N 2 ✓	Accept 'bimolecular nucleophilic substitution.'	1
3.	a	i	«electrophilic» addition ✓	Do not accept "nucleophilic addition" or "free radical addition". Do not accept "halogenation".	1
3.	a	ii	2-chloropropane ✓		1
3.	a	iii	secondary carbocation/carbocation «ion» is more stable OR carbocation/carbocation «ion» stabilized by two/more alkyl groups ✓		1
3.	a	iv	$\text{CH}_3\text{CHClCH}_3 (\text{l}) + \text{OH}^- (\text{aq}) \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_3 (\text{aq}) + \text{Cl}^- (\text{aq})$ OR $\text{CH}_3\text{CHClCH}_3 (\text{l}) + \text{NaOH} (\text{aq}) \rightarrow \text{CH}_3\text{CH}(\text{OH})\text{CH}_3 (\text{aq}) + \text{NaCl} (\text{aq})$ ✓		1
3.	b	i	Rate = $k [\text{C}_3\text{H}_7\text{Cl}] [\text{OH}^-]$ ✓ «[OH ⁻] held constant and» [C ₃ H ₇ Cl] triples AND rate triples «so first order wrt C ₃ H ₇ Cl» ✓ [C ₃ H ₇ Cl] doubles AND [OH ⁻] doubles AND rate quadruples «so first order wrt OH ⁻ » ✓		3
3.	b	ii	S _N 2 ✓	Accept 'bimolecular nucleophilic substitution.'	1
3.	b	iii	 curly arrow going from lone pair on O/negative charge on OH⁻ to C ✓ curly arrow showing C—Cl bond breaking ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓ formation of CH₃CH(OH)CH₃ AND Cl⁻ ✓	Do not allow arrow originating on H in OH⁻. Allow curly arrow going from bond between C and Cl to Cl in either reactant or transition state. Do not award M3 if OH—C bond is represented. Accept formation of NaCl instead of Cl⁻.	4

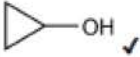
3.	d	i	$\text{K}_2\text{Cr}_2\text{O}_7/\text{Cr}_2\text{O}_7^{2-}$ «potassium» dichromate «(VI)» AND acidified/ H^+ OR «acidified potassium» manganate(VII) / « H^+ and» KMnO_4 / « H^+ and» MnO_4^- ✓	Accept " H_2SO_4 " or " H_3PO_4 " for " H^+ ". Do not accept HCl. Accept "permanganate" for "manganate(VII)".	1
3.	d	ii	$\text{C}_3\text{H}_8\text{O}$ /propan-2-ol: hydrogen-bonding AND $\text{C}_3\text{H}_6\text{O}$ /propanone: no hydrogen bonding/«only» dipole–dipole/dispersion forces ✓ hydrogen bonding stronger «than dipole–dipole» ✓		2
3.	e			Continuation bonds must be shown. Methyl groups may be drawn on opposite sides of the chain or head to tail. Ignore square brackets and "n".	1

Topic Chem 10 Q# 172/ IB Chem/2018/w/TZ 0/P2/Higher Level/

9.	a		polarity/polar «molecule/bond» OR carbon–halogen bond is weaker than C–H bond ✓		1
9.	b		primary AND Br/bromine is attached to a carbon bonded to two hydrogens OR primary AND Br/bromine is attached to a carbon bonded to one C/R/alkyl «group» ✓	Accept "primary AND Br/bromine is attached to the first carbon in the chain".	1
9.	c		 curly arrow going from lone pair/negative charge on O in HO^- to C ✓ curly arrow showing Br leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓ formation of organic product $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ AND Br^- ✓	Do not allow curly arrow originating on H in HO^- . Accept curly arrow either going from bond between C and Br to Br in 1-bromopropane or in the transition state. Do not penalize if HO and Br are not at 180° to each other. Do not award M3 if OH–C bond is represented.	4
9.	d		«Lewis» base AND donates a pair of electrons ✓		1
9.	e		Any two of: choose «most» appropriate reaction «for preparing the target compound» ✓ design/discover new reactions/reagents ✓ apply this knowledge to other areas of chemistry/science ✓ «retro-»synthesis «more effective» ✓ control/predict «desired» products ✓ control rate of reaction «more effectively» ✓ satisfy intellectual curiosity ✓ predicting how changing reagents/conditions might affect reaction ✓ suggesting intermediates/transition states ✓	Accept other reasonable answers.	2 max



Topic Chem 10 Q# 173/ IB Chem/2018/w/TZ 0/P2/Higher Level/

8.	a		angle between bonds is 60°/strained/smaller than 109.5° ✓		1
8.	b	i	Any two of: CH ₃ COCH ₃ ✓ CH ₃ CH ₂ CHO ✓ CH ₂ =CHCH ₂ OH ✓ CH ₃ OCH=CH ₂ ✓  ✓  ✓	Accept displayed or condensed structural formulas or skeletal formulas. Accept CH(OH)=CHCH ₃ and CH ₂ =C(OH)CH ₃ .	2
8.	b	ii	no AND only one «axial/methyl/CH ₃ » substituent «at the ring» OR no AND two «axial» substituents required «for cis/trans-isomers» ✓	Accept "no AND «O in the ring and» one carbon has two H atoms".	1

Topic Chem 10 Q# 174/ IB Chem/2018/w/TZ 0/P2/Higher Level/

7.	a		«electrophilic» addition/A _E OR reduction ✓	Accept "hydrogenation".	1
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Topic Chem 10 Q# 175/ IB Chem/2018/w/TZ 0/P2/Higher Level/

6.	d		Any two of: butanoic acid forms more/stronger hydrogen bonds ✓ butanoic acid forms stronger London/dispersion forces ✓ butanoic acid forms stronger dipole–dipole interaction/force ✓	Accept "butanoic acid forms dimers". Accept "butanoic acid has larger M _r /hydrocarbon chain/number of electrons" for M2. Accept "butanoic acid has larger «permanent» dipole/more polar" for M3.	2 max
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Topic Chem 10 Q# 176/ IB Chem/2018/w/TZ 0/P2/Higher Level/

6.	e	i	lithium aluminium hydride/LiAlH ₄ ✓		1
6.	e	ii	butan-1-ol/1-butanol/CH ₃ CH ₂ CH ₂ CH ₂ OH ✓		1

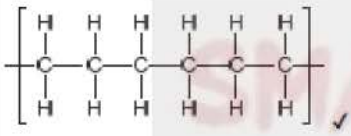
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Topic Chem 10 Q# 177/ IB Chem/2018/s/TZ 1/P2/Higher Level/

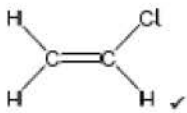
7.	a	Any two similarities: heterolytic bond breaking OR chloride ions leave ✓ nucleophilic/OH⁻ substitution ✓ both first order with regard to [halogenoalkane] ✓ One difference: CH₃CH₂CH₂CH₂Cl is second order/bimolecular/S_N2 AND (CH₃)₃CCl is first order/unimolecular/S_N1 OR CH₃CH₂CH₂CH₂Cl rate depends on [OH⁻] AND (CH₃)₃CCl does not OR CH₃CH₂CH₂CH₂Cl is one step AND (CH₃)₃CCl is two steps OR (CH₃)₃CCl involves an intermediate AND CH₃CH₂CH₂CH₂Cl does not OR CH₃CH₂CH₂CH₂Cl has inversion of configuration AND (CH₃)₃CCl has c. 50 : 50 retention and inversion ✓	Do not accept "produces alcohol" or "produces NaCl". Accept "substitution in 1-chlorobutane and «some» elimination in 2-chloro-2-methylpropane".	3	
7.	b	C–Br bond weaker than C–Cl bond ✓	Accept "Br⁻ is a better leaving group". Do not accept "bromine is more reactive". Do not accept "C–Br bond is longer than C–Cl" alone.	1	
7.	c	i	butan-1-ol/CH ₃ CH ₂ CH ₂ CH ₂ OH ✓	Do not accept "butanol" for "butan-1-ol". Accept "1-butanol". Do not penalize for name if correct formula is drawn.	1
7.	c	ii	«reduction with» lithium aluminium hydride/LiAlH ₄ ✓	Do not accept "sodium borohydride/NaBH ₄ ".	1
7.	c	iii	ester ✓		1

Topic Chem 10 Q# 178/ IB Chem/2018/s/TZ 1/P2/Higher Level/

3.	a	i	nickel/Ni «catalyst» ✓ high pressure OR heat ✓	Accept these other catalysts: Pt, Pd, Ir, Rh, Co, Ti. Accept "high temperature" or a stated temperature such as "150 °C".	2
3.	a	ii		Ignore square brackets and "n". Connecting line at end of carbons must be shown.	1
3.	b		ethyne: C₂H₂ + Cl₂ → CHClCHCl ✓ benzene: C₆H₆ + Cl₂ → C₆H₅Cl + HCl ✓	Accept "C ₂ H ₂ Cl ₂ ".	2



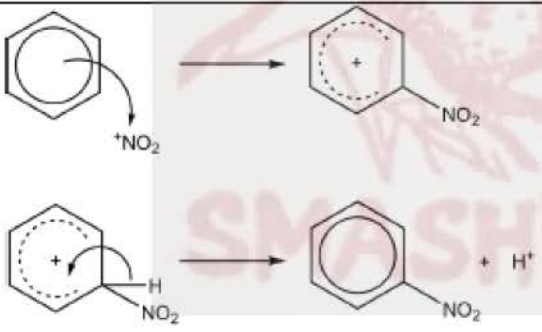
Topic Chem 10 Q# 179/ IB Chem/2017/s/TZ 2/P2/Higher Level/

6.	a	Initiation: $\text{Cl}-\text{Cl} \rightarrow \text{Cl}\cdot + \text{Cl}\cdot \checkmark$ Propagation: $\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{Cl}-\text{H} + \cdot\text{CH}_3 \checkmark$ $\text{Cl}-\text{Cl} + \cdot\text{CH}_3 \rightarrow \text{Cl}-\text{CH}_3 + \text{Cl}\cdot \checkmark$	Do not penalize missing electron dot on radicals if consistent throughout. Accept Cl_2, HCl and CH_3Cl without showing bonds. Do not accept hydrogen radical, $\text{H}\cdot$ or H, but apply ECF to other propagation steps.	3
6	b	$\Delta H^\ominus = -82.0 \text{ kJ} - 92.3 \text{ kJ} - (-74.0 \text{ kJ}) \checkmark$ $\Delta H^\ominus = -100.3 \text{ kJ} \checkmark$	Award [2] for correct final answer.	2
6	c	$\text{H}_2\text{C}=\text{CHCl}$ OR 	Accept "CH_2CHCl" or "CHClCH_2". Do not accept "$\text{C}_2\text{H}_3\text{Cl}$".	1

Topic Chem 10 Q# 180/ IB Chem/2017/s/TZ 2/P2/Higher Level/

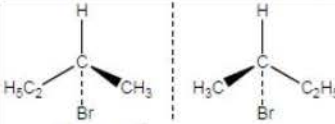
2	a	v	hydroxyl/OH OR aldehyde/CHO $\checkmark$	Accept "hydroxy/alcohol" for "hydroxyl". Accept amino/amine/NH_2.	1
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Topic Chem 10 Q# 181/ IB Chem/2017/s/TZ 1/P2/Higher Level/

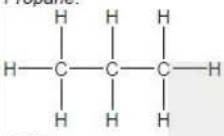
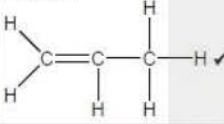
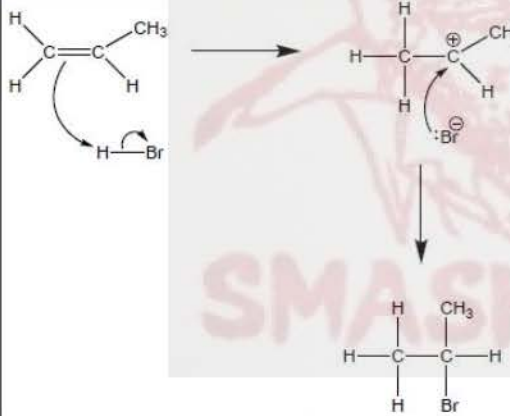
7.	a	Any two of: planar «X-ray» $\checkmark$ C to C bond lengths all equal OR C to C bonds intermediate in length between C-C and C=C $\checkmark$ all C-C-C bond angles equal $\checkmark$		2 max
7.	b	benzene: «electrophilic» substitution/S_E AND cyclohexene: «electrophilic» addition/A_E $\checkmark$	Accept correct equations.	1
7.	c	«concentrated» nitric AND sulfuric acids $\checkmark$ $^+\text{NO}_2$ $\checkmark$	Accept NO_2^+ .	2
7.	d	 curly arrow going from benzene ring to N of $^+\text{NO}_2/\text{NO}_2^+$ $\checkmark$ carbocation with correct formula and positive charge on ring $\checkmark$ curly arrow going from C-H bond to benzene ring of cation $\checkmark$ formation of organic product AND H^+ $\checkmark$	Accept mechanism with corresponding Kekulé structures. Do not accept a circle in M2 or M3. Accept first arrow starting either inside the circle or on the circle. M2 may be awarded from correct diagram for M3. M4: Accept $\text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{SO}_4$ if HSO_4^- used in M3.	4
7.	e	Fe/Zn/Sn AND $\text{HCl}/\text{H}_2\text{SO}_4/\text{CH}_3\text{COOH}$ $\checkmark$ NaOH/KOH $\checkmark$	Accept other suitable metals and acids. Accept other suitable bases. Award [1 max] for single-step reducing agents (such as H_2/Pt, Na_2S etc.). Accept formulas or names.	2



Topic Chem 10 Q# 182/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question			Answers	Notes	Total
6.	a		 correct isomer ✓ mirror image shown clearly ✓		2
6.	b		S_N2 would give inversion of configuration «almost 100%» OR S_N1 would give «approximately» 50% of each ✓ so mechanism is a mixture of both mechanisms ✓		2
6.	c		C–I bond «longer, so» weaker «than C–Br bond» OR I[–] is a better leaving group than Br[–] ✓		1

Topic Chem 10 Q# 183/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

Question			Answers	Notes	Total
5.	a		Propane:  AND Propene: 		1
5.	c	i	C₃H₈ + Br₂ → C₃H₇Br + HBr ✓ «sun»light/UV/hν OR high temperature ✓	Do not accept "reflux" for M2.	2
5.	c	ii	C ₃ H ₈ + Br ₂ → C ₃ H ₇ Br ₂ ✓		1
5.	c	iii	Propane: «free radical» substitution / S_R AND Propene: «electrophilic» addition / A_E ✓		1
5.	d		 curly arrow going from C=C to H of HBr and curly arrow showing Br leaving ✓ representation of carbocation ✓ curly arrow going from lone pair/negative charge on Br[–] to C⁺ ✓	Award [2 max] for formation of 1-bromopropane.	3

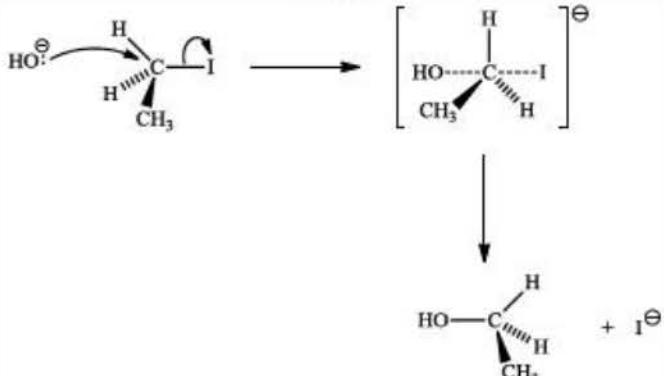


Question	Answers	Notes	Total
c v	both X and Y will exhibit hydrogen bonding with water molecules ✓ diagrams showing hydrogen bonding ✓ X: $\begin{array}{c} \text{CH}_3 \\ | \\ \text{H}-\text{C}-\text{O} \cdots \text{H}-\text{O} \cdots \\ | \quad | \\ \text{CH}_3 \quad \text{H} \end{array}$ OR $\begin{array}{c} \text{CH}_3 \\ | \\ \text{H}-\text{C}-\text{O} \cdots \text{H} \cdots \text{O}-\text{H} \\ | \\ \text{CH}_3 \end{array}$ Y: $\begin{array}{c} \text{H}_3\text{C}-\text{O} \cdots \text{CH}_2\text{CH}_3 \\ | \\ \text{H} \\ | \\ \text{:O}-\text{H} \end{array}$		2

d iv	<i>Similarity:</i> both involve shared pair of electrons / both are covalent ✓ <i>Difference:</i> Pr-N: pair of electrons comes from nitrogen / coordinate bond and N-H: one electron comes from each bonded atom ✓		2
d v	London / dispersion / instantaneous induced dipole-induced dipole ✓ dipole-dipole ✓ hydrogen bonding ✓	Award [2] for all three correct, [1] for any two correct.	2 max

Question	Answers	Notes	Total
7. a	I: carboxamide ✓ II: phenyl ✓ III: carboxyl / carboxy ✓ IV: hydroxyl ✓	Award [2] for all four correct, [1] for two or three correct. Do not allow benzene. Do not allow carboxylic/alkanoic acid. Do not allow alcohol or hydroxide.	2 max
b iii	$\langle (0.5)(40 - 20 - 2) \rangle 9$ ✓		1

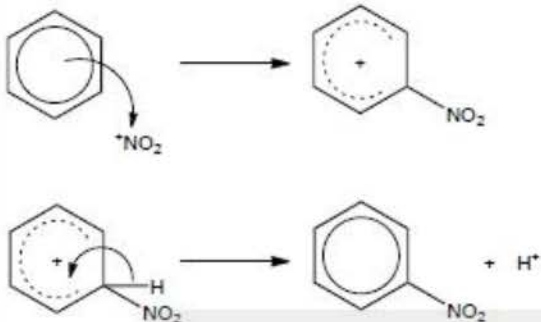
Question	Answers	Notes	Total
7. d i	$\begin{array}{c} \text{Cl} \quad \text{NH}_3 \\ \diagdown \quad \diagup \\ \text{Pt} \\ \diagup \quad \diagdown \\ \text{Cl} \quad \text{NH}_3 \end{array}$ and $\begin{array}{c} \text{H}_3\text{N} \quad \text{Cl} \\ \diagdown \quad \diagup \\ \text{Pt} \\ \diagup \quad \diagdown \\ \text{Cl} \quad \text{NH}_3 \end{array}$ Cisplatin Transplatin ✓	Names of complexes are not required. Complexes may be drawn without tapered bonds.	1
d ii	$\begin{array}{c} \text{Cl} \quad \text{NH}_3 \\ \diagdown \quad \diagup \\ \text{Pt} \\ \diagup \quad \diagdown \\ \text{Cl} \quad \text{NH}_3 \end{array}$ and $\begin{array}{c} \text{H}_3\text{N} \quad \text{Cl} \\ \diagdown \quad \diagup \\ \text{Pt} \\ \diagup \quad \diagdown \\ \text{Cl} \quad \text{NH}_3 \end{array}$ Cisplatin Transplatin ✓ M-O Cis: polar and trans: non-polar ✓		2

Question	Answers	Notes	Total
4. a	 curly arrow going from lone pair/negative charge on O in HO⁻ to C ✓ curly arrow showing I leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds at 180° to each other ✓ formation of organic product CH₃CH₂OH and I⁻ ✓	Do not allow curly arrow originating on H in HO⁻. Accept curly arrow going from bond between C and I to I in 1-iodoethane or in the transition state. Do not allow arrow originating from C to C-I bond. Do not award M3 if OH—C bond is represented. Inversion of configuration must be shown to score M4.	4
b	Rate expression: rate = k[OH⁻][CH₃CH₂I] ✓ Molecularity of RDS: bimolecular ✓		2

Question	Answers	Notes	Total
c	S_N2: polar, protic solvents decrease nucleophilic reactivity due to hydrogen bonding OR polar, protic solvents have a cage of solvent molecules surrounding anionic nucleophile resulting in increased stabilization <so are slower> OR polar, aprotic solvents have no hydrogen bonding so S_N2 reactions are favoured since nucleophiles do not solvate effectively so have an enhanced/pronounced effect on nucleophilicity of anionic nucleophiles <so are faster> ✓ S_N1: polar, protic solvents favour S_N1 reactions since the carbocation <intermediate> is solvated by ion-dipole interactions by the polar solvent ✓		2
d	DMF since aprotic solvent so favours S _N 2 ✓		1

5. a i	structural/functional isomers ✓		1
5. a ii	Test: react with bromine/Br₂ in the dark OR react with bromine water/Br₂(aq) in the dark ✓ A: from yellow/orange/brown to colourless AND B: colour remains/slowly decolourized ✓	Accept other correct reagents, such as manganate(VII) or iodine solutions, and descriptions of the corresponding changes observed. Accept "decolourized" for A and "not decolourized/unchanged" for B. Do not accept "clear/transparent" instead of "colourless".	2

2. b i	primary ✓		1
2. b ii	ALTERNATIVE 1: heat with tin/Sn AND hydrochloric acid/HCl ✓ aqueous alkali/OH⁻(aq) ✓ ALTERNATIVE 2: hydrogen/H₂ ✓ nickel/Ni catalyst ✓	Accept specific equations having correct reactants. Do not accept LiAlH₄ or NaBH₄. Accept Pt or Pd catalyst. Accept equations having correct reactants.	2

Question			Answers	Notes	Total
2.	b	iii	$\text{HNO}_3 + 2\text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + 2\text{HSO}_4^- + \text{H}_3\text{O}^+ \checkmark$	Accept: $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + \text{HSO}_4^- + \text{H}_2\text{O}$ Accept $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$. Accept equivalent two step reactions in which sulfuric acid first behaves as a strong acid and protonates the nitric acid, before behaving as a dehydrating agent removing water from it.	1
2.	b	iv	 curly arrow going from benzene ring to N of $\text{NO}_2^+/\text{NO}_2^+$ ✓ carbocation with correct formula and positive charge on ring ✓ curly arrow going from C-H bond to benzene ring of cation ✓ formation of organic product nitrobenzene AND H^+ ✓	Accept mechanism with corresponding Kekulé structures. Do not accept a circle in M2 or M3. Accept first arrow starting either inside the circle or on the circle. M2 may be awarded from correct diagram for M3. M4: Accept $\text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{SO}_4$ if HSO_4^- used in M3.	4
Question			Answers	Notes	Total
2.	c	i	Name: ethane-1,2-diol ✓ Class: alcohol ✓	Accept ethan-1,2-diol / 1,2-ethanediol. Do not accept "diol" for Class.	2

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9. (a) (i) $\text{RBr}(\text{l}) + \text{NaOH}(\text{aq}) \rightarrow \text{ROH}(\text{aq}) + \text{NaBr}(\text{aq})$ /
 $\text{RBr}(\text{l}) + \text{OH}^-(\text{aq}) \rightarrow \text{ROH}(\text{aq}) + \text{Br}^-(\text{aq})$;
 Ignore state symbols. [1]
- (ii) $(1.35 \times 10^{-2} - 7.36 \times 10^{-3}) = 6.14 \times 10^{-3}$ / $6.1 \times 10^{-3} (\text{mol})$; [1]
- (iii) $(\text{molar mass} = \frac{0.842}{6.14 \times 10^{-3}} =) 137 (\text{g mol}^{-1})$; [1]
 Accept 138.
- (iv) $(137 - 80 = 57 \text{ which corresponds to } \text{C}_4\text{H}_9, \text{ hence molecular formula})$
 $\text{C}_4\text{H}_9\text{Br}$; [1]
 Accept correct structural formula of one of the isomers as molecular formula.
 Do not accept ECF from 9a(iii) for an impossible molecular formula, such as $\text{C}_4\text{H}_{10}\text{Br}$.

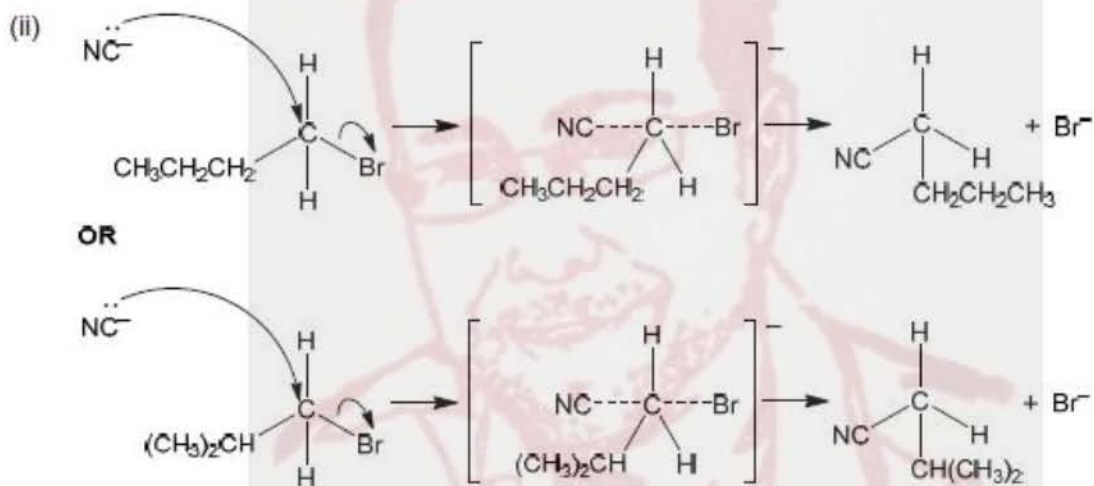


- (v) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ **and** primary;
 $(\text{CH}_3)_2\text{CHCH}_2\text{Br}$ **and** primary;
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$ **and** secondary;
 $(\text{CH}_3)_3\text{CBr}$ **and** tertiary;
 If primary, secondary or tertiary not stated, award [3] for four correct, [2] for three correct and [1] for two correct structural formulas.
 Penalize missing hydrogens once only.
 Accept either full or condensed structural formulas.

If $\text{C}_5\text{H}_{11}\text{Br}$ was used, accept any correct structural formulas.

- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ **and** primary;
 $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2\text{Br}$ **and** primary;
 $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{Br}$ **and** primary;
 $(\text{CH}_3)_3\text{CCH}_2\text{Br}$ **and** primary;
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_2\text{CH}_3$ **and** secondary;
 $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{CH}_3$ **and** secondary;
 $\text{CH}_3\text{CHBrCH}(\text{CH}_3)_2$ **and** secondary;
 $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)_2\text{Br}$ **and** tertiary; [4]
 If primary, secondary or tertiary not stated, award [3] for four correct, [2] for three correct and [1] for two correct structural formulas.
 Penalize missing hydrogens once only.
 Accept either full or condensed structural formulas.

- (b) (i) increase in carbon chain; [1]



curly arrow going from lone pair/negative charge on NC^- to C;
 curly arrow showing Br leaving;
 Accept curly arrow either going from bond between C and Br to Br in 1-bromobutane/1-bromo-2-methylpropane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;
 Do not penalize if NC and Br are not at 180° to each other.

Products: $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CN}/(\text{CH}_3)_2\text{CHCH}_2\text{CN}$ **and** Br^-/KBr ; [4]
 Penalize missing hydrogens and/or incorrect bond linkages (eg $\text{CN}-\text{C}$ instead of $\text{NC}-\text{C}$) only once in this question.
 Remember to apply ECF from part (a)(v).

- (iii) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CN} + 2\text{H}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$
OR
 $(\text{CH}_3)_2\text{CHCH}_2\text{CN} + 2\text{H}_2 \rightarrow (\text{CH}_3)_2\text{CHCH}_2\text{CH}_2\text{NH}_2$;

Ni / Co / Ru;
 Accept Pt/Pd/Cu/Rh.
 Accept either chemical symbol or name.

[2]



- (c) (ii) addition;
 $\text{--CH(C}_2\text{H}_5\text{)--CH}_2\text{--CH(C}_2\text{H}_5\text{)--CH}_2\text{-- / --C(CH}_3\text{)}_2\text{--CH}_2\text{--C(CH}_3\text{)}_2\text{--CH}_2\text{--}$;
 Continuation bonds required for the mark.

[2]

- (d) Initiation:
 $\text{Cl}_2 \xrightarrow{\text{UV/hf/hv/heat}} 2\text{Cl}\cdot$;
 Reference to UV light or high temperatures must be included.

Propagation:
 $\text{Cl}\cdot + \text{C}_2\text{H}_6 \rightarrow \text{C}_2\text{H}_5\cdot + \text{HCl}$;
 $\text{C}_2\text{H}_5\cdot + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}\cdot$;

Termination:
 $\text{Cl}\cdot + \text{Cl}\cdot \rightarrow \text{Cl}_2$ / $\text{C}_2\text{H}_5\cdot + \text{Cl}\cdot \rightarrow \text{C}_2\text{H}_5\text{Cl}$ / $\text{C}_2\text{H}_5\cdot + \text{C}_2\text{H}_5\cdot \rightarrow \text{C}_4\text{H}_{10}$;

[4]

Accept representation of radical without $\cdot$ (eg, Cl, C₂H₅) if consistent throughout mechanism.

Accept further chlorination.

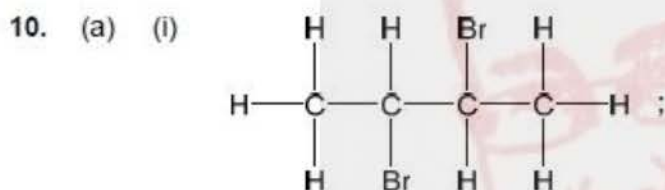
Award [3 max] if initiation, propagation **and** termination are not stated or are incorrectly labelled for equations.

Accept correct description of processes without equations.

Award [3 max] if Br used correctly instead of Cl.

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Penalize missing hydrogens only once in Question 10.



[1]

Accept bromine atoms cis to each other.

- (ii) 2,3-dibromobutane;
 Do not penalize the incorrect use of spaces, comma or hyphen.

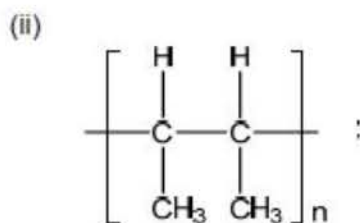
[1]

- (iii) red/brown/orange/yellow to colourless/decolourized;
 Do not accept clear.
 Do not accept just "decolorized".

[1]

- (b) (i) (synthesis of) plastics/polymers/organic materials not naturally available / synthetic materials;
 wide range of uses/physical properties / versatile;
 large industry / many tons of plastics consumed by society / OWTTE;
 Do not accept "useful" for M2.
 Award [1 max] if specific addition polymer and its use is given.
 Penalize reference to condensation polymers once only.

[2 max]



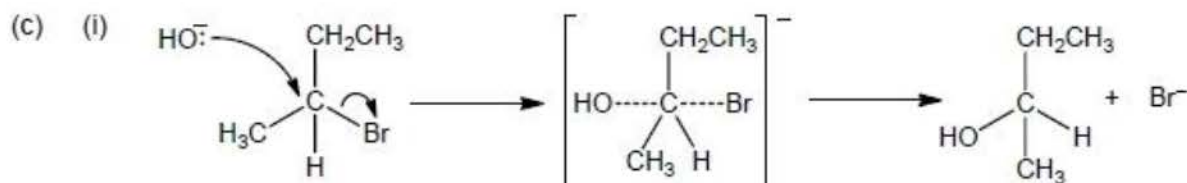
[1]

Ignore n.

Brackets are not required for the mark, but continuation bonds are.

Do not penalize if methyl groups are trans to each other.





curly arrow going from lone pair/negative charge on O in HO^- to C;
Do not accept curly arrow originating on H in HO^- .

curly arrow showing Br leaving;

Accept curly arrow either going from bond between C and Br to Br in 2-bromobutane or in the transition state.

Accept if arrow goes from C-Br bond to/or beyond Br.

representation of transition state showing negative charge, square brackets and partial bonds;

Do not penalize if HO and Br are not at 180° to each other.

Do not award M3 if $\text{OH}\cdots\text{C}$ bond is represented.

formation of organic product $\text{CH}_3\text{CHOHCH}_2\text{CH}_3$ and KBr/Br^- ;

[4]

- (ii) OH^- has a negative charge/higher electron density;
stronger attraction to the carbon atom with the partial positive charge / OWTTE;
Do not accept just stronger attraction.
Reference to carbon atom needed for M2.

[2]

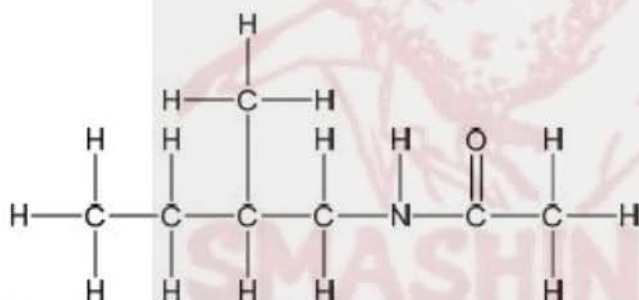
- (d) (i) 2-methylbutanenitrile;
Accept small errors in spelling.
Accept 2-cyanobutane.
Do not accept butan-2-nitrile.

[1]

- (ii) hydrogen/ H_2 and nickel/Ni;
Accept other suitable metal catalysts such as platinum/Pt, palladium/Pd.

[1]

(iii)

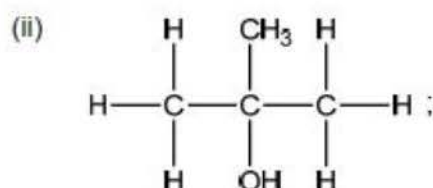


Accept condensed CH_3 branch in structural formula as this was present in structure given in question.

[1]

- (e) (i) carbonyl;
Accept ketone.

[1]



Accept condensed or full structural formula.

[1]

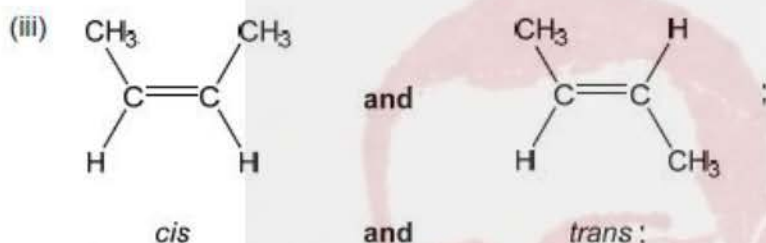


- (f) hydrogen bonding in compound **C**;
dipole-dipole forces in **C** / **C** is more polar;
C has greater molar mass/more dispersion/London/instantaneous induced dipole-induced dipole forces/van der Waal forces;
Accept converse argument.
Award [1 max] for stronger intermolecular forces. [2 max]

- (g) $\text{C}_4\text{H}_9\text{OH}(\text{l}) + 6\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 5\text{H}_2\text{O}(\text{l})$;
Ignore state symbols. [1]

- (h) (i) compounds with the same structural formula **and** different arrangement in space/3D structures;
Accept molecular formula instead of structural formula.
Do not accept "similar" instead of "same". [1]

- (ii) restricted rotation around a (double) bond;
carbon atoms of the $\text{C}=\text{C}$ /carbon-carbon double bond (in alkene)/carbon atoms of the $\text{C}-\text{C}$ /carbon-carbon single bond (in cycloalkane) must have two different atoms/groups of atoms / OWTTE;
Do not accept "functional groups" for "groups of atoms" in M2. [2]



Award [1 max] if cis and trans isomers are correctly drawn and identified for alkene other than but-2-ene.

Award [1 max] if student draws and labels one structure correctly but not the other. [2]

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5. (a) same functional group;
same general formula;
(successive members) differ by CH_2 ;
similar chemical properties;
gradation in physical properties;
Do not accept "same" instead of "similar", or vice-versa. [2 max]

- (b) Initiation:
 $\text{Br}_2 \xrightarrow{\text{UV}/h\nu} 2\text{Br}\cdot$;
Reference to UV light or high temperatures must be included.
Propagation:
 $\text{Br}\cdot + \text{C}_2\text{H}_6 \rightarrow \text{C}_2\text{H}_5\cdot + \text{HBr}$;
 $\text{C}_2\text{H}_5\cdot + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{Br}\cdot$;
Termination:
 $\text{Br}\cdot + \text{Br}\cdot \rightarrow \text{Br}_2$ / $\text{C}_2\text{H}_5\cdot + \text{Br}\cdot \rightarrow \text{C}_2\text{H}_5\text{Br}$ / $\text{C}_2\text{H}_5\cdot + \text{C}_2\text{H}_5\cdot \rightarrow \text{C}_4\text{H}_{10}$;
Accept representation of radical without $\cdot$ (eg, Br, C_2H_5) if consistent throughout mechanism.
Penalize reference to heterolytic fission once only.
Award [0] to any mechanism involving ions.
Accept further bromination.
*Award [3 max] if initiation, propagation **and** termination are not stated or are incorrectly labelled for equations.*
Accept correct description of processes without equations. [4]



5. (a) Equation:
 $\text{CH}_2\text{CH}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH} / \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH};$

Conditions:

(concentrated) sulfuric acid/ H_2SO_4 ;

Do not accept dilute sulfuric acid.

Accept phosphoric acid/ H_3PO_4 (on pellets of silicon dioxide) (for industrial preparation).

heat / high temperature;

Do not accept warm.

Accept high pressure (for industrial preparation) for M3 only if H_3PO_4 is given for M2.

[3]

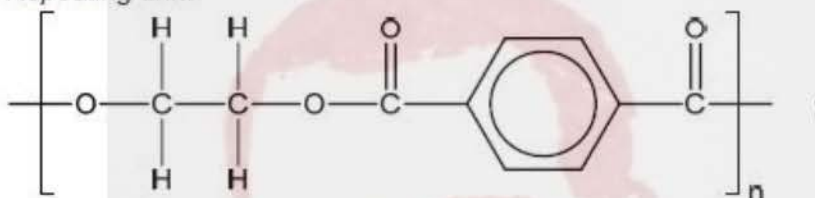
- (d) $\text{CH}_3\text{CH}_2\text{OH} + \text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{OOCCH}_2\text{CH}_3 + \text{H}_2\text{O};$

ethyl propanoate;

Do not penalize if equilibrium arrow missing.

[2]

- (e) (i) Repeating unit:



Continuation lines must be shown.

Ignore brackets and n .

Accept condensed formulas such as CH_2 and C_6H_4 .

Other product:

H_2O /water;

[2]

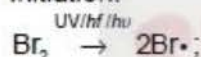
- (ii) condensation;

[1]

6. (a) $\text{CH}_4 + \text{Br}_2 \rightarrow \text{CH}_3\text{Br} + \text{HBr};$

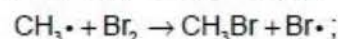
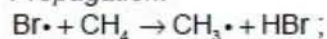
[1]

- (b) (i) Initiation:



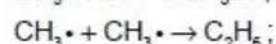
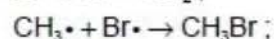
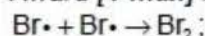
Reference to UV/light or high temperatures must be included.

Propagation:



Termination:

Award [1 max] for any one of:



[4 max]

Allow representation of radical without $\cdot$ (eg Br , CH_3) if consistent throughout mechanism.

Award [3 max] if initiation, propagation and termination are not stated or are incorrectly labelled for equations.

- (ii) methanol/ CH_3OH ;

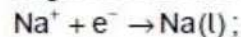
[1]



- (c) C–I bond is weaker than the C–Br bond so more easily broken;
C–I bond is longer than the C–Br bond / I larger than Br so bonding electrons not as tightly held / I⁻ is better leaving group than Br⁻; [2]

- (d) (i) *Positive electrode (anode):*
 $2\text{Br}^- \rightarrow \text{Br}_2(\text{g}) + 2\text{e}^-$ / $\text{Br}^- \rightarrow \frac{1}{2}\text{Br}_2(\text{g}) + \text{e}^-$;

Negative electrode (cathode):



[2]

Award [1 max] for correct equations at incorrect electrodes.

Ignore state symbols.

Accept e instead of e⁻.

Penalize use of equilibrium signs once only.

- (ii) *Positive electrode (anode):*
bromine/Br₂;

Negative electrode (cathode):

hydrogen/H₂;

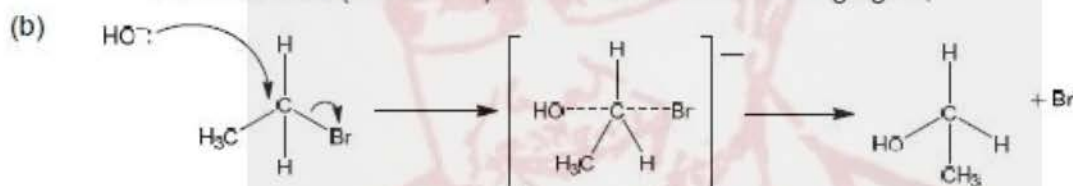
Allow sodium hydroxide/NaOH/hydroxide/OH⁻ formation.

[2]

Topic Chem 10 Q# 195/ IB CHEM/2015/s/TZ1/P2 Section B/Higher Level/

7. (a) (i) *Ethanal: distill off product as it forms;*
Accept distillation.
Ethanoic acid: (heat under) reflux / use excess oxidizing agent;

[2]



curly arrow going from lone pair/negative charge on O in HO⁻ to C;
Do not allow curly arrow originating on H in HO⁻.

curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in bromoethane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;

Do not penalize if HO and Br are not at 180° to each other.

Do not award M3 if OH—C bond is represented.

formation of organic product CH₃CH₂OH and Br⁻;

Award [3 max] for correct S_N1 mechanism.

[4]

- (d) (i) chiral/asymmetric carbon / carbon attached to 4 different groups / non-super imposable mirror images;

[1]

- (ii) enantiomers rotate plane of (plane-) polarized light;
in opposite directions (by equal amounts);

[2]

Topic Chem 11 Q# 196/ IB Chem/2019/w/TZ0/P2/Higher Level/Q4./

3.	d	iii	only one hydrogen environment OR methyl groups symmetrical «around carbonyl group» ✓	Accept «all hydrogens belong to methyl groups «which are in identical positions»».	1
----	---	-----	--	--	---

Topic Chem 11 Q# 197/ IB Chem/2019/w/TZ0/P2/Higher Level/Q3./

2.	b	i	$\llcorner \frac{100 \times 0.1 \text{ cm}^3}{20.1 \text{ cm}^3} = \llcorner 0.5 \llcorner \% \llcorner \checkmark$		1
2.	b	ii	repetition / take several samples «and average» $\checkmark$		1

Topic Chem 11 Q# 198/ IB Chem/2018/w/TZ 0/P2/Higher Level/

8.	c		Chemical shift: 3.7–4.8 «ppm» $\checkmark$ Splitting pattern: doublet $\checkmark$		2
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Topic Chem 11 Q# 199/ IB Chem/2018/w/TZ 0/P2/Higher Level/

2.	b		«absorption at wavenumber 1700–1750 cm ⁻¹ » C=O/carbonyl $\checkmark$	Do not accept "ketone" or "aldehyde".	1
2.	c		«m/z =» 58 $\checkmark$		1
2.	d		$ \begin{array}{c} \text{H} & \text{O} & \text{H} \\ | & || & | \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ | & & | \\ \text{H} & & \text{H} \end{array} $ CH ₃ COCH ₃ / $\checkmark$		1

Topic Chem 11 Q# 200/ IB Chem/2018/w/TZ 0/P2/Higher Level/

1.	b	iii	ALTERNATIVE 1: $\llcorner 0.2^\circ\text{C} \times \frac{100}{7.5^\circ\text{C}} = \llcorner 3\% / 0.03 \llcorner \checkmark$ $\llcorner 0.03 \times 160 \text{ kJ} = \llcorner \pm 5 \llcorner \text{kJ} \llcorner \checkmark$ ALTERNATIVE 2: $\llcorner 0.2^\circ\text{C} \times \frac{100}{7.5^\circ\text{C}} = \llcorner 3\% / 0.03 \llcorner \checkmark$ $\llcorner 0.03 \times 180 \text{ kJ} = \llcorner \pm 5 \llcorner \text{kJ} \llcorner \checkmark$	Accept values in the range 4.1–5.5 «kJ». Award [2] for correct final answer.	2
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Topic Chem 11 Q# 201/ IB Chem/2018/s/TZ 2/P2/Higher Level/

1.	g		to reduce random errors OR to increase precision $\checkmark$	Accept "to ensure reliability".	1
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Topic Chem 11 Q# 202/ IB Chem/2018/s/TZ 1/P2/Higher Level/

2.	b		multiply relative intensity by «m/z» value of isotope OR find the frequency of each isotope $\checkmark$ sum of the values of products/multiplication «from each isotope» OR find/calculate the weighted average $\checkmark$	Award [1 max] for stating "m/z values of isotopes AND relative abundance/intensity" but not stating these need to be multiplied.	2
----	---	--	--	--	---

Topic Chem 11 Q# 203/ IB Chem/2018/s/TZ 1/P2/Higher Level/

1.	j		60: CON ₂ H ₄ ⁺ $\checkmark$ 44: CONH ₂ ⁺ $\checkmark$	Accept "molecular ion".	2
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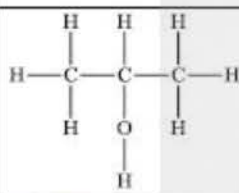
1.	k		3450 cm ⁻¹ : N-H ✓ 1700 cm ⁻¹ : C=O ✓	Do not accept "O-H" for 3450 cm ⁻¹ .	2
1.	l	i	1 ✓		1
1.	l	ii	singlet ✓	Accept "no splitting".	1
1.	l	iii	acts as internal standard OR acts as reference point ✓ one strong signal OR 12 H atoms in same environment OR signal is well away from other absorptions ✓	Accept "inert" or "readily removed" or "non-toxic" for M1.	2

Topic Chem 11 Q# 204/ IB Chem/2016/w/TZ0/P2 Section A/Higher Level/

1.	f		Number of signals	Splitting pattern	Accept "none/no splitting" for singlet.	2
		Ethanedioic acid:	1	AND singlet ✓		
		Ethane-1,2-diol:	2 ✓	Not required		

Topic Chem 11 Q# 205/ IB Chem/2016/s/TZ0SP/P2 Section A/Higher Level/

b	iv	A: C-H and B: C=O ✓	1
b	v	O-H and N-H ✓ frequencies/stretches due to O-H and N-H occur above 3200 cm ⁻¹ which are not present in IR of bute ✓	2
c	i	1:1:6 ✓	1

Question	Answers	Notes	Total
7. c ii			1
c iii	CH ₃ OCH ₂ CH ₃ ✓		1
c iv	Similarity: both have fragment corresponding to (M _r - 15) ⁺ / m/z = 45 ✓ Difference: X has fragment corresponding to (M _r - 17) ⁺ / m/z = 43 OR X has fragment corresponding to (M _r - 43) ⁺ / m/z = 17 OR Y has fragment corresponding to (M _r - 31) ⁺ / m/z = 29 OR Y has fragment corresponding to (M _r - 29) ⁺ / m/z = 31 ✓	Allow "both have same molecular ion peak/M" / both have m/z = 60". However in practice the molecular ion peak is of low abundance and difficult to observe for propan-2-ol.	2

Topic Chem 11 Q# 206/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

2. c ii	two AND two hydrogen environments in the molecule OR two AND both CH ₂ and OH present ✓		1
2. c iii	"CH ₂ OH ✓	Accept CH ₃ O ⁺ . Accept [-CH ₂ OH] ⁺ and [-CH ₂ O] ⁺ . Do not accept answers in which the charge is missing.	1
2. c iv	oxygen-hydrogen bonds/O-H in hydroxyls ✓		1

Topic Chem 11 Q# 207/ IB Chem/2016/s/TZ1/P2 Section A/Higher Level/

5.	b	compound A would absorb at 1620–1680 cm^{-1} ✓				Accept any value in range 1620 – 1680 cm^{-1} .	1															
5.	c	<table><tr><td>Signal</td><td>1/2</td><td></td><td>2/1</td><td></td></tr><tr><td>Chemical shift / ppm</td><td>0.9 – 1.0</td><td>AND</td><td>4.5 – 6.0</td><td>✓</td></tr><tr><td>Splitting pattern</td><td>singlet</td><td>AND</td><td>singlet</td><td>✓</td></tr></table>				Signal	1/2		2/1		Chemical shift / ppm	0.9 – 1.0	AND	4.5 – 6.0	✓	Splitting pattern	singlet	AND	singlet	✓	Accept 0.9 to 2.0 for the first signal as the C=C affects the CH_3 shift (actually 1.7).	
Signal	1/2		2/1																			
Chemical shift / ppm	0.9 – 1.0	AND	4.5 – 6.0	✓																		
Splitting pattern	singlet	AND	singlet	✓																		
						Accept "none/no splitting" for both splitting patterns.	2															
						Award [1 max] for the correct deduction (both shift and splitting) of signal 1 or 2.																

(c) (i) 1.4 (%); [1]
Accept 1 (%).

(ii) systematic; [2]
dilute the orange juice;
Accept other valid suggestions, eg. compare with a standard (showing colour at equivalence) / look at mixture through a yellow filter / add more starch (for a sharper colour change) / filter orange juice (through charcoal).
Do not accept repeat titrations or alternative indicator.

(iii) 1.44×10^{-5} (mol); [1]

(c) (i)

	NF_4^+	N_2H_2	N_2H_4
Hybridization	sp^3 ;	sp^2 ;	sp^3 ;

 [3]

Do not penalize if it is not superscript.

(ii) sigma bond: overlapping of orbitals end to end/head on / overlapping of orbitals along internuclear axis; [2]
Accept "axial overlapping of orbitals".

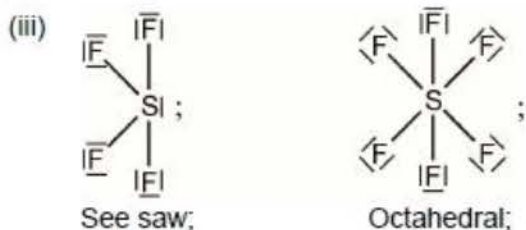
pi bond: side-ways/parallel overlapping of p orbitals (above and below internuclear axis);
Accept "overlapping of p orbitals above and below the internuclear axis".
Accept suitable labelled diagrams.

(iii) ; See saw; [4]
; Octahedral;

Accept any combination of lines, dots or crosses to represent electron pairs.
Penalize missing lone pairs on fluorine atoms once only.
For SF_4 , lone pair on S required for the mark.
Do not allow ECF for a wrong Lewis structure.
Accept saw horse/distorted tetrahedron instead of see-saw.

(d) (i) $CH_3CH_2CH_3 < CH_3CHO < CH_3CH_2OH < CH_3COOH$;; [2]
Award [2] for correct order.
Award [1] for $CH_3COOH > CH_3CH_2OH > CH_3CHO > CH_3CH_2CH_3$ as compounds are not listed in order of increasing boiling point.
Award [1] if one error in the order.





[4]

Accept any combination of lines, dots or crosses to represent electron pairs.

Penalize missing lone pairs on fluorine atoms once only.

For SF_4 , lone pair on S required for the mark.

Do not allow ECF for a wrong Lewis structure.

Accept saw horse/distorted tetrahedron instead of see-saw.

- (d) (i) $\text{CH}_3\text{CH}_2\text{CH}_3 < \text{CH}_3\text{CHO} < \text{CH}_3\text{CH}_2\text{OH} < \text{CH}_3\text{COOH}$;;

[2]

Award [2] for correct order.

Award [1] for $\text{CH}_3\text{COOH} > \text{CH}_3\text{CH}_2\text{OH} > \text{CH}_3\text{CHO} > \text{CH}_3\text{CH}_2\text{CH}_3$ as compounds are not listed in order of increasing boiling point.

Award [1] if one error in the order.

- (ii) $\text{CH}_3\text{CH}_2\text{CH}_3$ /London/dispersion/instantaneous induced dipole-induced dipole forces
 CH_3CHO dipole-dipole forces (and London/dispersion forces)
 $\text{CH}_3\text{CH}_2\text{OH}$ H-bonding (and dipole-dipole and London/dispersion forces)
 CH_3COOH H-bonding (and dipole-dipole and London/dispersion forces);;
 Award [2] for all four correct.
 Award [1] for two or three correct.

H-bonding strongest / London/dispersion forces weakest / dipole-dipole stronger than London/dispersion / dipole-dipole weaker than H-bonding;

Accept van der Waals' forces for London/dispersion forces.

CH_3COOH forms more/stronger H-bonds than $\text{CH}_3\text{CH}_2\text{OH}$ / CH_3COOH is more polar than $\text{CH}_3\text{CH}_2\text{OH}$;
 Accept CH_3COOH has more electrons/higher molar mass than $\text{CH}_3\text{CH}_2\text{OH}$.

[4]

- (e) ionization **and** (bombardment) by high energy/fast moving electrons/electron gun (to form positive ions);
 acceleration **and** passing through electric field/potential difference/oppositely charged plates;
 deflection **and** passing through magnetic field/electromagnet;
 Award [1] for naming 3 processes (ionization, acceleration, deflection) in the correct order with incorrect details.

[3]



9. (a) (i) MgCl_2 conducts electricity **and** PCl_3 does not;
 MgCl_2 is ionic **and** PCl_3 is covalent/molecular;
 ions/charged particles can move in MgCl_2 / no free charged particles in PCl_3 ; [3]
Award [1 max] if all three points correct for one substance but not other.

- (ii) MgCl_2 :
 $4 \leq \text{pH} \leq 6.9$;
 high charge density/high charge **and** small size of Mg^{2+} makes $[\text{Mg}(\text{H}_2\text{O})_6]^{2+}$
 hydrolyse / polarizes water to produce H^+ ;

PCl_3 :
 $0 \leq \text{pH} \leq 4$;
 (reacts with water to) form $\text{HCl}/\text{H}_3\text{PO}_3$; [4]
Do not accept H_3PO_4 .

- (b) (i) Na , Mg (oxides): basic

Al (oxide): amphoteric
Do not accept amphiprotic.

Si to Cl (oxides): acidic [2]

*Award [2] for all three listed sets correct.
 Award [1] for one or two listed sets correct.
 Award [1] for stating oxides become more acidic towards right/ Cl or more basic towards left/ Na .
 Do not penalize if reference is to Ar instead of Cl .
 Do not penalize for incorrect formulas of oxides.*

- (ii) $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq})$;
 $\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq})$; [2]
*Ignore state symbols.
 Accept $\text{P}_2\text{O}_5(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_3\text{PO}_4(\text{aq})$.
 Do not award marks if incorrect formulas of the oxides are used.*

- (c) (i)



*Penalize lone pairs missing on Br and F once only.
 Accept any combination of lines, dots or crosses to represent electron pairs.*



- (ii)
- | PBr ₃ | SF ₄ |
|---|--|
| Shape:
trigonal pyramidal;
Accept triangular pyramidal.

No ECF for shape if Lewis structure is incorrect. | Shape:
see-saw/K-shaped;
Accept distorted tetrahedral. |
| Bond angle:
Any value $99^\circ < 109^\circ$;
Literature value = 101° .

No ECF for angle if shape is incorrect.
Do not award mark for correct angles if shape is incorrect. | Bond angle:
Any two for [1] of:
(F _{eq} -S-F _{eq}): Any value $100^\circ < 120^\circ$
Literature value = 103°

(F _{ax} -S-F _{ax}): Any value $175^\circ < 185^\circ$
Literature value = $179^\circ / 180^\circ$

(F _{ax} -S-F _{eq}): Any value $85^\circ < 95^\circ$
Literature value = 89°

[4] |
- (iii) P-Br and S-F bonds are polar / bonds in both molecules are polar;
 non-symmetrical distribution of electron cloud / polar bonds/dipoles do not cancel because of non-symmetrical shape;
 M2 may also be scored with a suitable diagram showing the vectorial addition of the individual S-F dipole moments to show a net dipole moment centred along the axis between the F_{eq}-S-F_{eq} bond. [2]
- (d) (i) EITHER
 (electrostatic) attraction between (positively charged) nuclei and a pair of electrons;
 formed as a result of electron sharing (between the carbon and hydrogen nuclei);
 OR
 sigma bond formed by overlap of atomic orbitals;
 s orbital from H and p/sp² from carbon; [2]
- (ii) α : sp³ and β : sp²;
 Accept if numbers are given as subscripts. [1]
- (iii) σ bond:
 end-on / axial overlap of two orbitals;
 π bond:
 sideways overlap of two (parallel) p orbitals; [2]
 Accept suitable diagrams for both marks.
- (iv) 11 σ and 3 π ; [1]



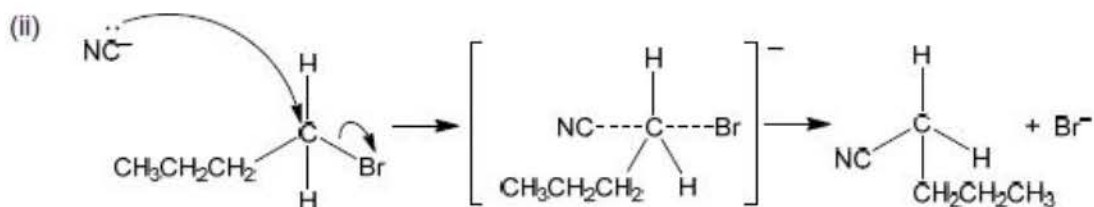
4. (a) $\text{HOOC}(\text{CH}_2)_4\text{COOH}$;
Accept $\text{COOH}(\text{CH}_2)_4\text{COOH}$ but not $\text{COOH}(\text{CH}_2)_4\text{HOOC}$ or $\text{HOOC}(\text{CH}_2)_4\text{HOOC}$.
 $\text{H}_2\text{N}(\text{CH}_2)_6\text{NH}_2$;
Accept $\text{NH}_2(\text{CH}_2)_6\text{NH}_2$ but not $\text{H}_2\text{N}(\text{CH}_2)_6\text{H}_2\text{N}$ or $\text{NH}_2(\text{CH}_2)_6\text{H}_2\text{N}$.
Accept full or condensed structural formulas. [2]
- (b) Type: condensation (polymerization);
Structural feature: two functional groups on each monomer; [2]
- (c) $\begin{array}{c} \text{O} \quad \text{H} \\ \parallel \quad | \\ \text{---C---N---} \end{array}$
Accept ---CONH--- ;
Accept this group if correctly identified as part of polymer chain.
water/ H_2O ; [2]

9. (a) (i) $\text{RBr}(\text{l}) + \text{NaOH}(\text{aq}) \rightarrow \text{ROH}(\text{aq}) + \text{NaBr}(\text{aq})$ /
 $\text{RBr}(\text{l}) + \text{OH}^-(\text{aq}) \rightarrow \text{ROH}(\text{aq}) + \text{Br}^-(\text{aq})$;
Ignore state symbols. [1]
- (ii) $(1.35 \times 10^{-2} - 7.36 \times 10^{-3}) = 6.14 \times 10^{-3} / 6.1 \times 10^{-3} (\text{mol})$; [1]
- (iii) $(\text{molar mass} = \frac{0.842}{6.14 \times 10^{-3}} =) 137 (\text{g mol}^{-1})$;
Accept 138. [1]
- (iv) $(137 - 80 = 57 \text{ which corresponds to } \text{C}_4\text{H}_9, \text{ hence molecular formula})$
 $\text{C}_4\text{H}_9\text{Br}$;
Accept correct structural formula of one of the isomers as molecular formula.
Do not accept ECF from 9a(iii) for an impossible molecular formula, such as $\text{C}_4\text{H}_{10}\text{Br}$. [1]
- (v) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ and primary;
 $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2\text{Br}$ and primary;
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$ and secondary;
 $(\text{CH}_3)_3\text{CBr}$ and tertiary;
If primary, secondary or tertiary not stated, award [3] for four correct, [2] for three correct and [1] for two correct structural formulas.
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas.
- If $\text{C}_5\text{H}_{11}\text{Br}$ was used, accept any correct structural formulas.
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ and primary;
 $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2\text{CH}_2\text{Br}$ and primary;
 $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_2\text{Br}$ and primary;
 $(\text{CH}_3)_3\text{CCCH}_2\text{Br}$ and primary;
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_2\text{CH}_3$ and secondary;
 $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{CH}_3$ and secondary;
 $\text{CH}_3\text{CHBrCH}(\text{CH}_3)_2$ and secondary;
 $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)_2\text{Br}$ and tertiary;
If primary, secondary or tertiary not stated, award [3] for four correct, [2] for three correct and [1] for two correct structural formulas.
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas. [4]

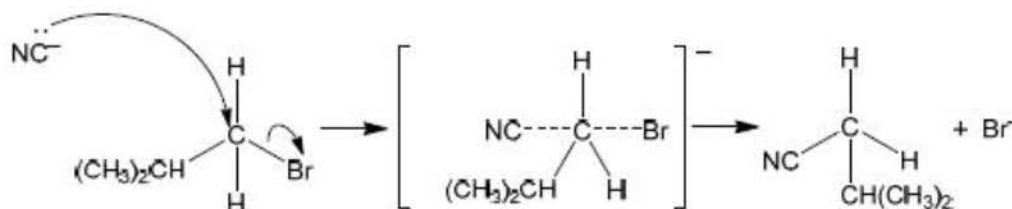


(b) (i) increase in carbon chain;

[1]



OR



curly arrow going from lone pair/negative charge on NC^- to C;

curly arrow showing Br leaving;

Accept curly arrow either going from bond between C and Br to Br in 1-bromobutane/1-bromo-2-methylpropane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;

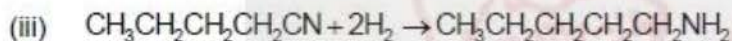
Do not penalize if NC and Br are not at 180° to each other.

Products: $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CN}/(\text{CH}_3)_2\text{CHCH}_2\text{CN}$ and Br^-/KBr ;

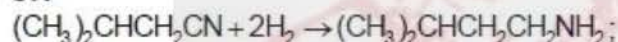
Penalize missing hydrogens and/or incorrect bond linkages (eg $\text{CN}-\text{C}$ instead of $\text{NC}-\text{C}$) only once in this question.

Remember to apply ECF from part (a)(v).

[4]



OR



Ni / Co / Ru;

Accept Pt/Pd/Cu/Rh.

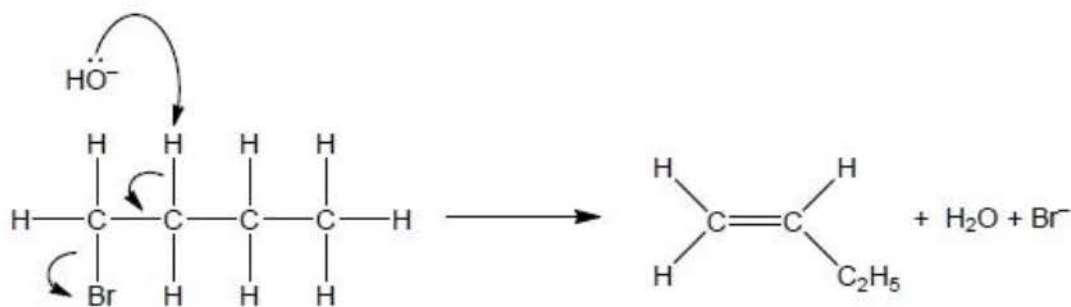
Accept either chemical symbol or name.

[2]

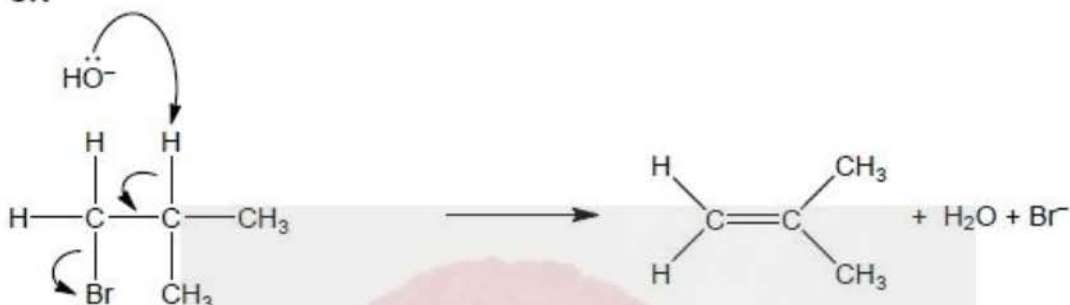
SMASHING!!!



(c) (i)



OR



curly arrow going from lone pair/negative charge on O in OH⁻ to H on C;
Do not allow curly arrow originating on H in OH⁻.

curly arrow going from CH bond to form C=C bond;
curly arrow showing Br leaving;

H₂C=CHCH₂CH₃ + H₂O + Br⁻ / H₂C=C(CH₃)₂ + H₂O + Br⁻;

Accept NaBr for Br⁻.

Remember to apply ECF from part (a)(v).

Do not penalize if mechanism shown with a secondary bromoalkane.

Do not penalize incorrect side-chain.

Penalize missing hydrogens only once in this question.

[4]

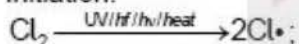
(ii) addition;

-CH(C₂H₅)-CH₂-CH(C₂H₅)-CH₂- / -C(CH₃)₂-CH₂-C(CH₃)₂-CH₂-;

Continuation bonds required for the mark.

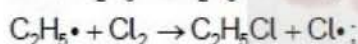
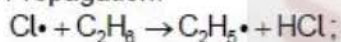
[2]

(d) Initiation:

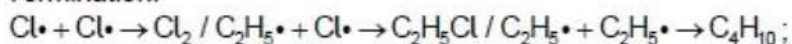


Reference to UV light or high temperatures must be included.

Propagation:



Termination:



Accept representation of radical without $\cdot$ (eg, Cl, C₂H₅) if consistent throughout mechanism.

Accept further chlorination.

Award [3 max] if initiation, propagation **and** termination are not stated or are incorrectly labelled for equations.

Accept correct description of processes without equations.

Award [3 max] if Br used correctly instead of Cl.

[4]

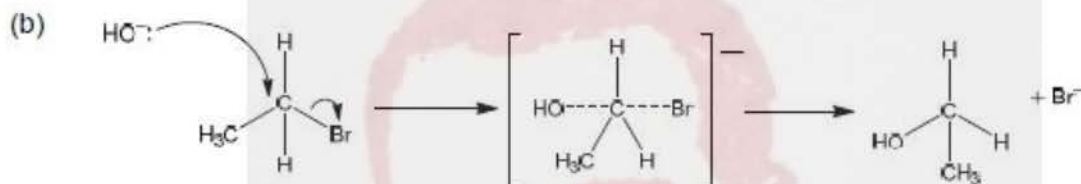


7. (a) (i) *Ethanal*: distill off product as it forms;
Accept distillation.
Ethanoic acid: (heat under) reflux / use excess oxidizing agent; [2]

- (ii) *Ethanol*: -2/-II;
Ethanal: -1/-I;
Do not accept 2-, 1- but penalize once only. [2]

- (iii) $\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} + 2\text{H}^+ + 2\text{e}^-$; [1]
Half-equation required. Do not accept $\text{C}_2\text{H}_5\text{OH} + 2[\text{O}] \rightarrow \text{CH}_3\text{CHO} + \text{H}_2\text{O}$.
Accept e for e^- .

- (iv) $3\text{CH}_3\text{CH}_2\text{OH}(\text{aq}) + \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 8\text{H}^+(\text{aq}) \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 3\text{CH}_3\text{CHO}(\text{l}) + 7\text{H}_2\text{O}(\text{l})$
 correct reactants and products;
 correct balancing; [2]
M2 can only be scored if M1 correct.
Ignore state symbols.



curly arrow going from lone pair/negative charge on O in HO^- to C;
Do not allow curly arrow originating on H in HO^- .

curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in bromoethane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;
Do not penalize if HO and Br are not at 180° to each other.
Do not award M3 if $\text{OH} \cdots \text{C}$ bond is represented.

formation of organic product $\text{CH}_3\text{CH}_2\text{OH}$ and Br^- ; [4]
Award [3 max] for correct $\text{S}_{\text{N}}2$ mechanism.

- (c) (i) $[\text{NaOH}] / [\text{OH}^-]$ is 1/first order **and** $[\text{C}_4\text{H}_9\text{Br}]$ is 1/first order; [2]
 $\text{rate} = k [\text{OH}^-][\text{C}_4\text{H}_9\text{Br}]$ / $\text{rate} = k [\text{NaOH}][\text{C}_4\text{H}_9\text{Br}]$;
Square brackets must be used for M2.

- (ii) $\left(\frac{1.02 \times 10^{-4}}{0.25 \times 0.25} \right) 0.0016 / 1.6 \times 10^{-3}$; [2]
 $\text{mol}^{-1} \text{dm}^3 \text{s}^{-1}$;
Accept $\text{M}^{-1} \text{s}^{-1}$.
Ignore order of units.
Must use experiment 3 data.

- (iii) bimolecular/2; [1]
Accept dimolecular.



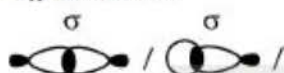
(d) (i) chiral/asymmetric carbon / carbon attached to 4 different groups / non-super imposable mirror images; [1]

(ii) enantiomers rotate plane of (plane-) polarized light; in opposite directions (by equal amounts); [2]

(e) $\text{CH}_3\text{CHBrCH}_2\text{CH}_3 + \text{OH}^- \rightarrow \text{CH}_3\text{CHCHCH}_3 + \text{H}_2\text{O} + \text{Br}^-$ /
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_3 + \text{OH}^- \rightarrow \text{CH}_2\text{CHCH}_2\text{CH}_3 + \text{H}_2\text{O} + \text{Br}^-$ /
 $\text{CH}_3\text{CHBrCH}_2\text{CH}_3 + \text{CH}_3\text{CH}_2\text{O}^- \rightarrow \text{CH}_3\text{CHCHCH}_3 + \text{CH}_3\text{CH}_2\text{OH} + \text{Br}^-$;
 Accept equations with NaOH.

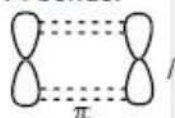
alcoholic sodium hydroxide / ethanolic OH^- ; [2]

(f) *Sigma bonds:*



result from head-on/end-on overlap of orbitals / OWTTE;
 Accept axial overlap of orbitals.
 Accept "symmetric orbital" with respect to same plane / OWTTE.

Pi bonds:



result from sideways overlap of orbitals / OWTTE;
 Accept "antisymmetric orbitals" with respect to (defining) plane (containing at least one atom) / OWTTE.

(g) $79.91 = 79x + 81(1 - x)$;
 Award M1 for any suitable calculation.
 (abundance ^{79}Br =) 54.5 %;
 Award [2] for correct final answer. [2]





1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1 H 1.01	Atomic number Element Relative atomic mass												2 He 4.00						
3 Li 6.94	4 Be 9.01													5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31													13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.90		
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29		
55 Cs 132.91	56 Ba 137.33	57+ La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)		
87 Fr (223)	88 Ra (226)	89+ Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (269)	109 Mt (278)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Uut (286)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (294)		

58 Ce	59 Pr	60 Nd	61 Pm (145)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
140.12	140.91	144.24	(145)	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05	174.97
90 Th	91 Pa	92 U	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)
232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)