IB DIPLOMA CHEMISTRY HIGHER LEVEL

IB HL Paper 2

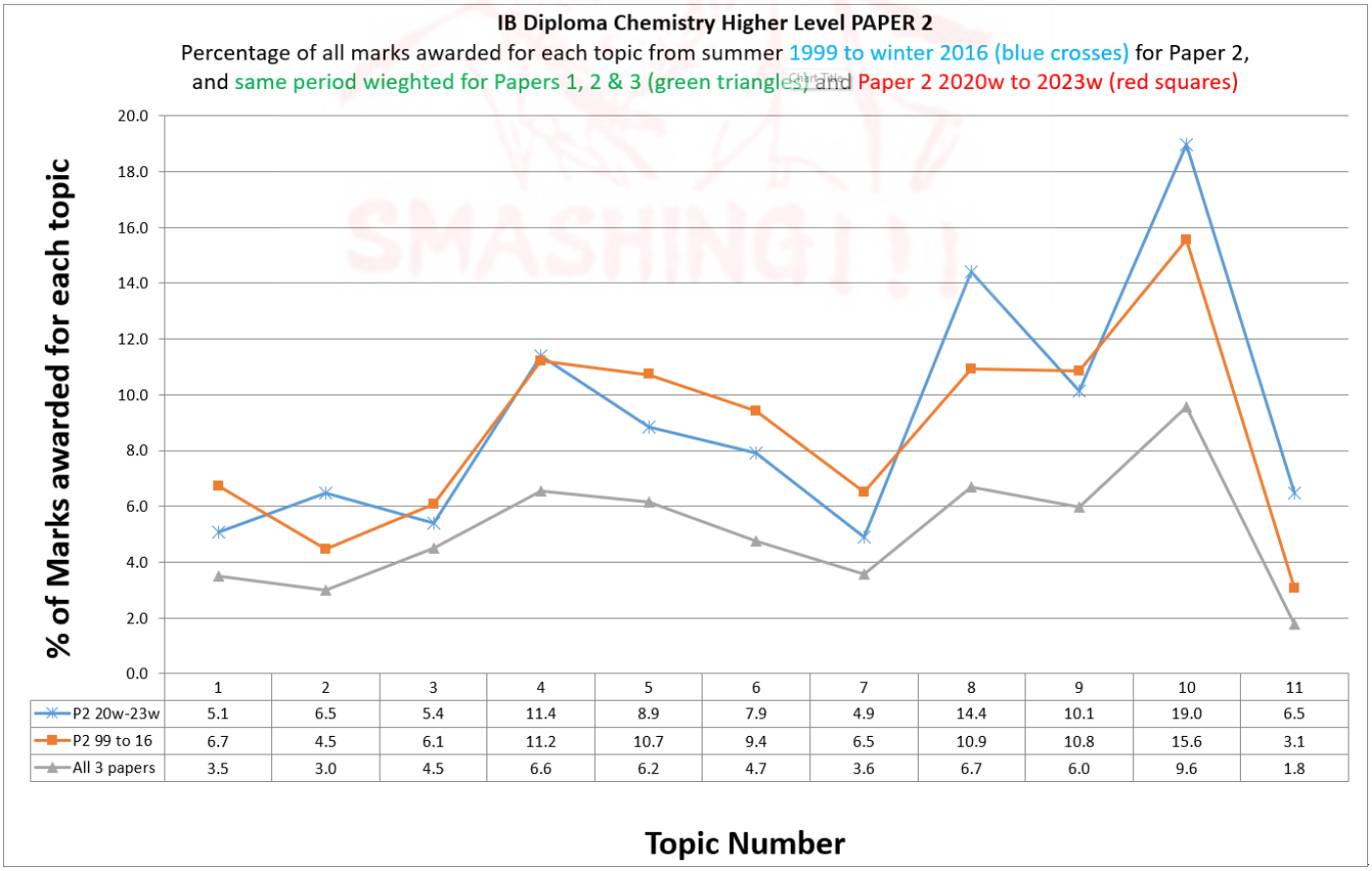
Past Exam Questions

Organised by Topic Number

Winter 2020 to Winter 2023 (7 Papers)

Name: _____

Class: _____



	1	2	3	4	5	6	7	8	9	10	11
P2 20w-23w	5.1	6.5	5.4	11.4	8.9	7.9	4.9	14.4	10.1	19.0	6.5
P2 99 to 16	6.7	4.5	6.1	11.2	10.7	9.4	6.5	10.9	10.8	15.6	3.1
All 3 papers	3.5	3.0	4.5	6.6	6.2	4.7	3.6	6.7	6.0	9.6	1.8

Contents

For a digital version of this document scan the code below, or go here:
https://www.smashingscience.org/ib-chemistry-hl-sl

A note on the topic numbers used here:

IB Chemistry topic numbers from 12 onwards have been merged with their SL counterparts, so "Topic 3" in this booklet includes marks for both IB Chemistry Topic 3 (Periodicity) and Topic 13 (The periodic table—the transition metals). For more information see the syllabus ("Chemistry Guide: First Assessment 2016"). For exams in 2025 and later changes to the ordering of the syllabus have been made which are not addressed here.

Organising your months in 2024

April

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

May

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

June

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

July

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

August

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

September

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

October

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

November

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

December

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Organising your weeks –

Week Starting	Wk #	Events	Topic Focus
29-Apr	1		
6-May	2		
13-May	3		
20-May	4		
27-May	5		
3-Jun	6		
10-Jun	7		
17-Jun	8		
24-Jun	9		
1-Jul	10		
8-Jul	11		
15-Jul	12		
22-Jul	13		
29-Jul	14		
5-Aug	15		
12-Aug	16		
19-Aug	17		
26-Aug	18		
2-Sep	19		
9-Sep	20		
16-Sep	21		
23-Sep	22		
30-Sep	23		
7-Oct	24		
14-Oct	25		
21-Oct	26		
28-Oct	27		
4-Nov	28		
11-Nov	29		
18-Nov	30		

Planning your days V1.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
	8:00 pm							
	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v2.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
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	8:00 pm							
	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v3.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
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	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v4.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
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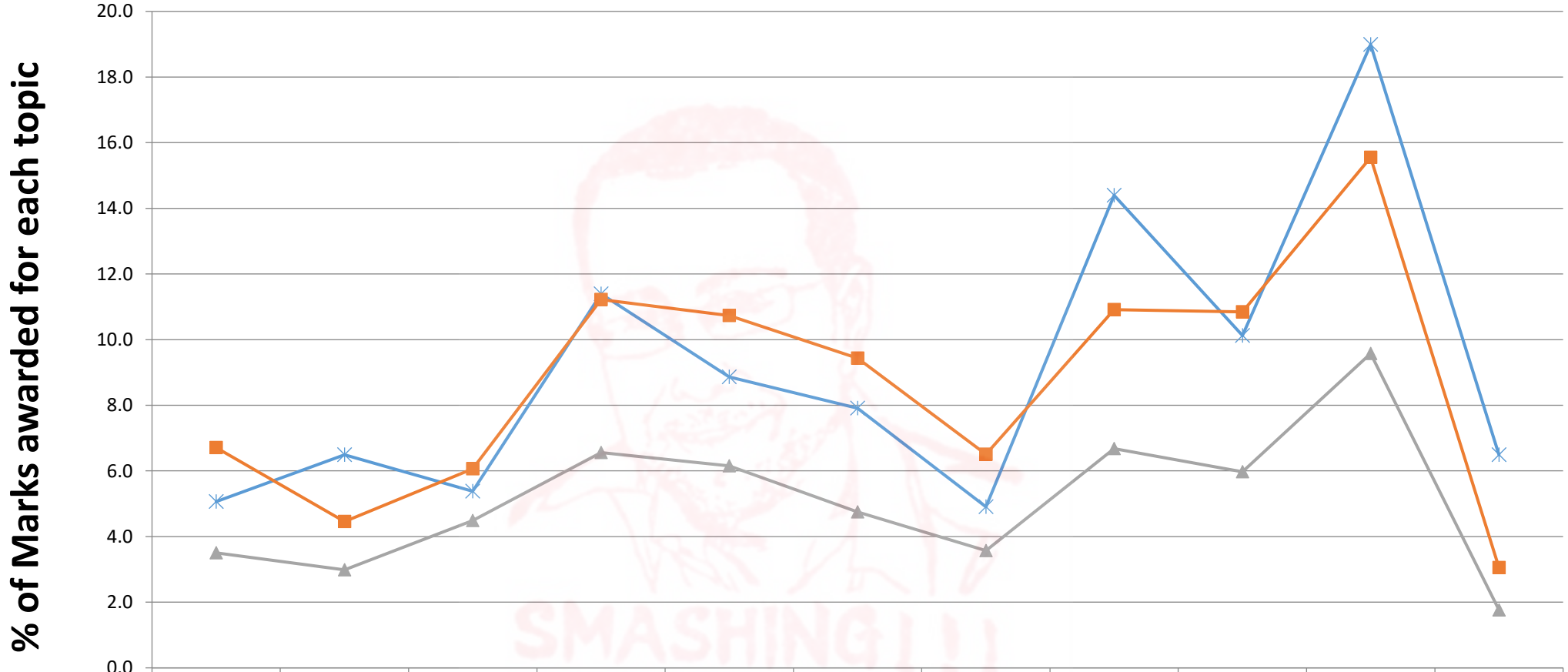
	10:00 pm							
	10:30 pm							

IB Diploma Chemistry Higher Level PAPER 2

Percentage of all marks awarded for each topic from summer 1999 to winter 2016 (blue crosses) for Paper 2, and same period wieghted for Papers 1, 2 & 3 (green triangles) and Paper 2 2020w to 2023w (red squares)



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All 3 papers	3.5	3.0	4.5	6.6	6.2	4.7	3.6	6.7	6.0	9.6	1.8

Topic **Chem Q# 1/** IB Chem/**2020/s**/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)
Entire exam paper was not published

Topic Chem 1 Stoichiometric relationships Q# 2/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. Methanoic acid can be converted into methyl methanoate, $HCOOCH_3$.

(b) 1.72 g of methyl methanoate is produced from 2.83 g of methanoic acid and excess of the other reagent. Determine the percentage yield. [2]

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Topic **Chem 1 Q# 3/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Methanoic acid (HCOOH) is the first member of the homologous series of carboxylic acids.

(b) Calculate the percentage, by mass, of oxygen in methanoic acid. [2]

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Topic **Chem 1 Q# 4/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Double salts are substances with two cations and one anion. A hydrated sulfate containing two cations has this percentage composition.

Element	Percentage (%)
Nitrogen (N)	7.09
Hydrogen (H)	5.11
Sulfur (S)	16.22
Cobalt (Co)	14.91
Oxygen (O)	—

(ii) Calculate the percentage of oxygen present in the double salt. [1]

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(iii) Determine the empirical formula of the double salt. Use section 6 of the data booklet. [3]

(iv) The molar mass of the empirical formula is the same as the molar mass of the formula unit. Deduce the formula unit of the hydrated double salt. [1]

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(b) 1.20 g of the double salt was dissolved in water and an excess of aqueous barium chloride was added, precipitating all the sulfate ions as barium sulfate.

(i) Formulate an ionic equation, including state symbols, for the reaction of barium ions with sulfate ions. [1]

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(ii) Calculate the mass of barium sulfate precipitate. Use your answer to part (a)(iii) and section 6 of the data booklet. (If you did not obtain an answer for part (a)(iii), use 400.0 g mol^{-1} as M_r for the double salt, but this is not the correct value.) [2]

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Topic **Chem 1 Q# 5/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Lignite, a type of coal, contains about 0.40 % sulfur by mass.

(a) Calculate the amount, in mol, of sulfur dioxide produced when 500.0 g of lignite undergoes combustion. [2]

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

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Topic **Chem 1 Q# 6/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(a) Calculate the percentage by mass of nitrogen in ammonium nitrate. Use section 6 of the data booklet. [1]

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Topic **Chem 1 Q# 7/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. When heated in air, magnesium ribbon reacts with oxygen to form magnesium oxide.

(a) (i) Write a balanced equation for the reaction that occurs. [1]

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(b) The reaction in (a)(i) was carried out in a crucible with a lid and the following data was recorded:

Mass of crucible and lid = 47.372 ±0.001 g

Mass of crucible, lid and magnesium ribbon before heating = 53.726 ±0.001 g

Mass of crucible, lid and product after heating = 56.941 ±0.001 g

(i) Calculate the amount of magnesium, in mol, that was used. [1]

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(iii) Assume the reaction in (a)(i) is the only one occurring and it goes to completion, but some product has been lost from the crucible. Deduce the percentage yield of magnesium oxide in the crucible. [2]

(c) When magnesium is burnt in air, some of it reacts with nitrogen to form magnesium nitride according to the equation:

$$3\,Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$$

(i) Evaluate whether this, rather than the loss of product, could explain the yield found in (b)(iii). [1]

(ii) Suggest an explanation, other than product being lost from the crucible or reacting with nitrogen, that could explain the yield found in (b)(iii). [1]

(d) The presence of magnesium nitride can be demonstrated by adding water to the product. It is hydrolysed to form magnesium hydroxide and ammonia.

(i) Calculate coefficients that balance the equation for the following reaction. [1]

$$\_\_\ Mg_3N_2(s) + \_\_\ H_2O(l) \rightarrow \_\_\ Mg(OH)_2(s) + \_\_\ NH_3(aq)$$

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A 4.406 g sample of a compound containing only C, H and O was burnt in excess oxygen. 8.802 g of CO_2 and 3.604 g of H_2O were produced.

(a) Determine the empirical formula of the compound using section 6 of the data booklet. [3]

(b) Determine the molecular formula of this compound if its molar mass is 88.12 g mol^{-1}. If you did not obtain an answer in (a) use CS, but this is not the correct answer. [1]

3. Magnetite, Fe_3O_4, is another ore of iron that contains both Fe^{2+} and Fe^{3+}.

(a) Deduce the ratio of Fe^{2+}:Fe^{3+} in Fe_3O_4. [1]

(b) 2.67 g of manganese(IV) oxide was added to 200.0 cm^3 of 2.00 mol dm^{-3} HCl.

$$MnO_2(s) + 4HCl(aq) \rightarrow Cl_2(g) + 2H_2O(l) + MnCl_2(aq)$$

(i) Calculate the amount, in mol, of manganese(IV) oxide added. [1]

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(ii) Determine the limiting reactant, showing your calculations. [2]

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

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(iv) Calculate the volume of chlorine, in dm^3, produced if the reaction is conducted at standard temperature and pressure (STP). Use section 2 of the data booklet. [1]

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Topic Chem 2 Atomic structure Q# 11/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5.

www.SmashingScience.org :o)

5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(h) Outline how the first ionization energy of beryllium could be found from its atomic emission spectrum. [1]

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4. Carbon disulfide, CS_2, undergoes gas phase hydrolysis according to the overall equation

$$CS_2(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 2H_2S(g)$$

(c) Sulfur has a number of natural isotopes and a sample of sulfur was enriched in $^{36}_{16}S$, to produce a mixture with the following composition:

Isotope	Percent
$^{32}_{16}S$	90 %
$^{33}_{16}S$	1 %
$^{34}_{16}S$	4 %
$^{36}_{16}S$	5 %

(i) Calculate the relative atomic mass of this enriched sample, correct to two decimal places. [2]

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(ii) In naturally occurring sulfur, the relative abundance of $^{36}_{16}S$ is only 0.0100 %. Calculate the number of atoms of this isotope that would be present in 1.00 g of natural sulfur. Use sections 2 and 6 of the data booklet. [2]

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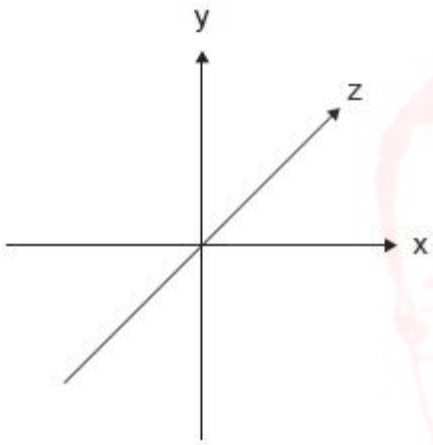
2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(a) (i) Annotate and label the ground state orbital diagram of boron, using arrows to represent electrons. [1]

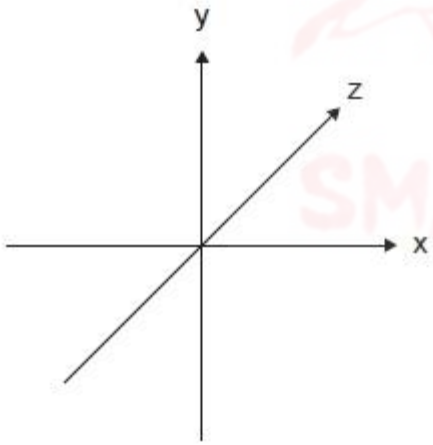
[He] ☐ ☐ ☐ ☐

Orbital label: _____ _____

(ii) Sketch the shapes of the occupied orbitals identified in part (a)(i). [2]



Orbital type: .....



Orbital type: .....

3. Consider the following reaction:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$

(a) State the ground-state electron configuration for Fe^{2+}. [1]

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(c) Predict, with a reason, whether Cu or Cu^{2+} has the greater ionization energy. [1]

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(d) Determine the frequency, in s^{-1}, of a photon that will cause the first ionization of copper. Use sections 1, 2 and 8 of the data booklet. [2]

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(e) Outline the magnetic properties of iron by referring to its electron configuration. [2]

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(ii) This reaction can be done with a copper catalyst. State the ground-state electron configuration for copper. [1]

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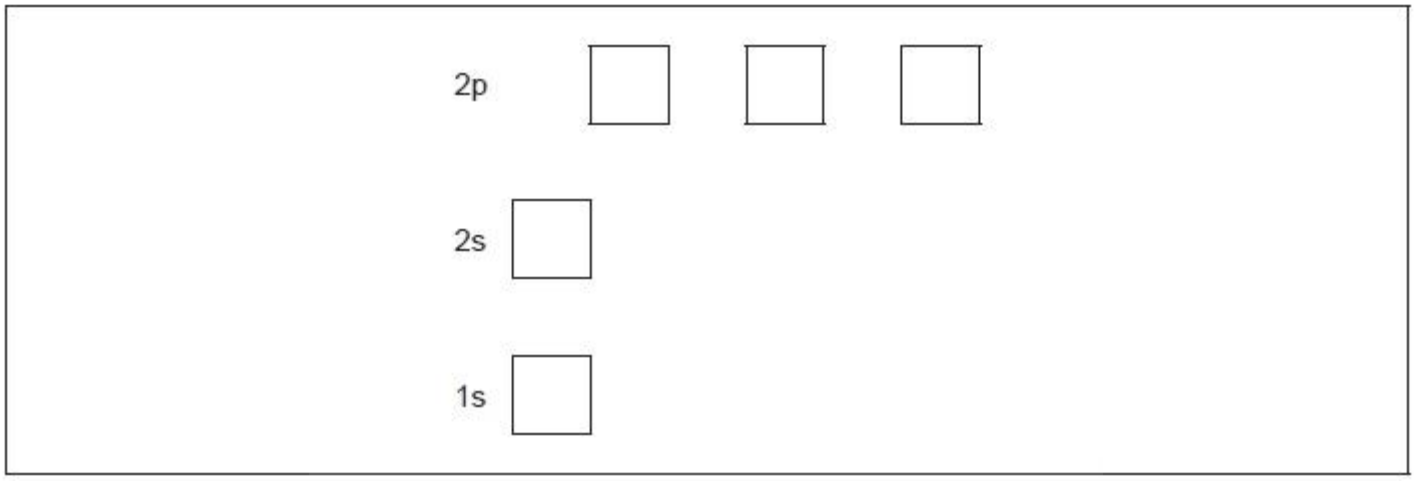
6. Nitric acid is usually produced by the oxidation of ammonia.

(a) (i) Draw arrows in the boxes to represent the electron configuration of a nitrogen atom. [1]



(e) Most nitride ions are $^{14}N^{3-}$.

(i) State the number of subatomic particles in this ion. [1]

Protons: .....

Neutrons: .....

Electrons: .....

(ii) Some nitride ions are $^{15}N^{3-}$. State the term that describes the relationship between $^{14}N^{3-}$ and $^{15}N^{3-}$. [1]

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(iii) The nitride ion and the magnesium ion are isoelectronic (they have the same electron configuration). Determine, giving a reason, which has the greater ionic radius. [1]

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(iv) Suggest, giving a reason, whether magnesium or nitrogen would have the greater sixth ionization energy. [1]

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(f) Suggest **two** reasons why atoms are no longer regarded as the indivisible units of matter. [2]

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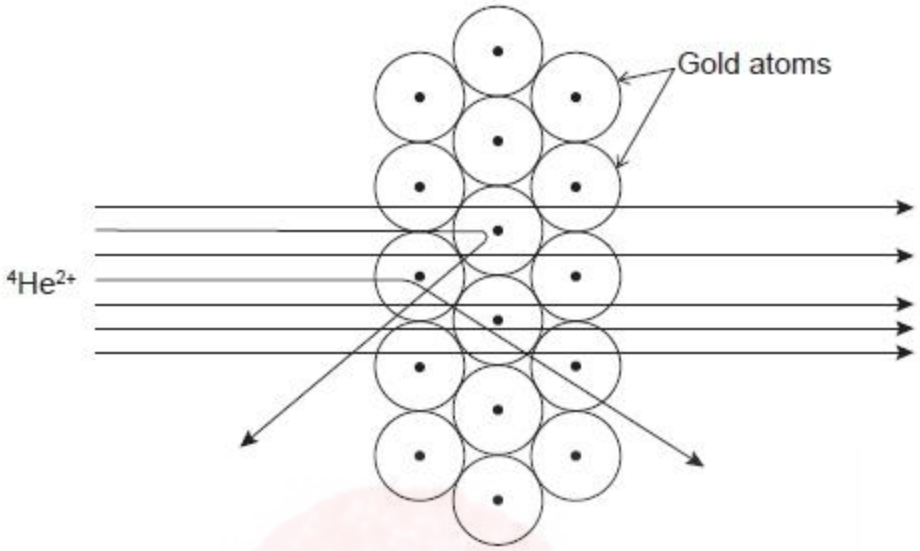
9. Fast moving helium nuclei ($^4He^{2+}$) were fired at a thin piece of gold foil with most passing undeflected but a few deviating largely from their path. The diagram illustrates this historic experiment.



(a) Suggest what can be concluded about the gold atom from this experiment. [2]

Most $^4He^{2+}$ passing straight through:

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Very few $^4He^{2+}$ deviating largely from their path:

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(b) (i) Subsequent experiments showed electrons existing in energy levels occupying various orbital shapes.

Draw diagrams of 1s, 2s and 2p. [2]

1s	2s	2p

(ii) State the electron configuration of copper. [1]

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Topic **Chem 2 Q# 19/** IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Electron transitions are related to trends in the periodic table.

(b) Sodium emits yellow light with a frequency of 5.09×10^{14} Hz when electrons transition from 3p to 3s orbitals.

Calculate the energy difference, in J, between these two orbitals using sections 1 and 2 of the data booklet. [1]

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Topic **Chem 2 Q# 20/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. Magnetite, Fe_3O_4, is another ore of iron that contains both Fe^{2+} and Fe^{3+}.

(b) Iron exists as several isotopes.

(i) State the type of spectroscopy that could be used to determine their relative abundances. [1]

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(ii) State the number of protons, neutrons and electrons in each species. [2]

	Protons	Neutrons	Electrons
$^{54}_{26}Fe$	. . . . .	. . . . .	. . . . .
$^{56}_{26}Fe^{3+}$	. . . . .	. . . . .	. . . . .

Topic **Chem 2 Q# 21/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(d) Iron (II) sulfide, FeS, is ionically bonded.

(iii) State the full electron configuration of the sulfide ion. [1]

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(iv) Outline, in terms of their electronic structures, why the ionic radius of the sulfide ion is greater than that of the oxide ion. [1]

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Topic **Chem 2 Q# 22/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. The electron configuration of copper makes it a useful metal.

(a) Determine the frequency of a photon that will cause the first ionization of copper. Use sections 1, 2 and 8 of the data booklet. [2]

Topic **Chem 2 Q# 23/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Chlorine undergoes many reactions.

(a) (i) State the full electron configuration of the chlorine atom. [1]

(ii) State, giving a reason, whether the chlorine atom or the chloride ion has a larger radius. [1]

(iii) Outline why the chlorine atom has a smaller atomic radius than the sulfur atom. [2]

Topic Chem 3 Periodicity Q# 24/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5.

www.SmashingScience.org :o)

5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(e) Iron (III) chloride also exists as a dimer in the vapour phase, but iron, unlike beryllium, is a transition element.

(i) Outline, in terms of its electronic structure, what identifies a transition element. [1]

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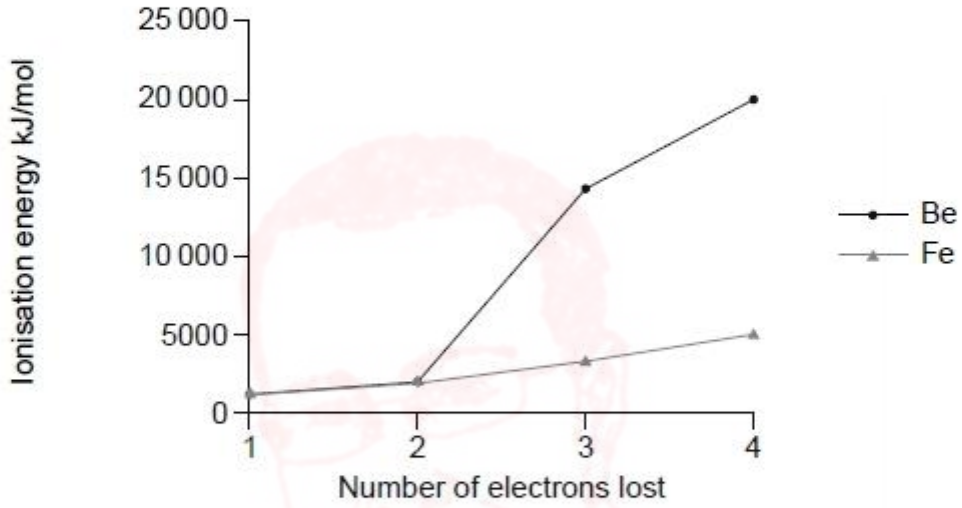
(ii) The first four ionization energies of beryllium and iron are shown.



One common property of transition elements is that they have variable oxidation states. Discuss, referring to the graph, why iron, but not beryllium, displays this characteristic. [3]

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(g) Explain, in terms of nuclear charge, electron subshells and the shielding provided by filled electron shells, why the first ionization energy increases from Li to Be, but decreases from Be to B. [4]

Topic **Chem 3 Q# 25/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

9. (a) Explain why a colorimeter set at a wavelength of 500 nm is not suitable to investigate reactions of Zn^{2+} compounds. Use section 3 of the data booklet. [2]

Topic **Chem 3 Q# 26/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(b) Explain the decrease in first ionization energy from Li to Cs, group 1. [2]

(e) $Mg(OH)^+$ is a complex ion, but Mg is not regarded as a transition metal. Contrast Mg with manganese, Mn, in terms of one characteristic chemical property of transition metals, other than complex ion formation. [2]

Property: .....

Comparison: .....

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(ii) Identify a metal, in the same period as magnesium, that does **not** form a basic oxide. [1]

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(iii) Copper is a transition metal that forms different coloured complexes. A complex $[Cu(H_2O)_6]^{2+}(aq)$ changes colour when excess $Cl^-(aq)$ is added.

Explain the cause of this colour change, using sections 3 and 15 from the data booklet. [3]

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Topic **Chem 3 Q# 30/** IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Electron transitions are related to trends in the periodic table.

(a) Explain the general increase in trend in the first ionization energies of the period 3 elements, Na to Ar. [2]

Topic **Chem 3 Q# 31/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

(f) Outline why, unlike typical transition metals, zinc compounds are not coloured. [1]

(g) Transition metals like iron can form complex ions. Discuss the bonding between transition metals and their ligands in terms of acid-base theory. [2]

Topic **Chem 3 Q# 32/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(b) Justify why sulfur is classified as a non-metal by giving **two** of its chemical properties. [2]

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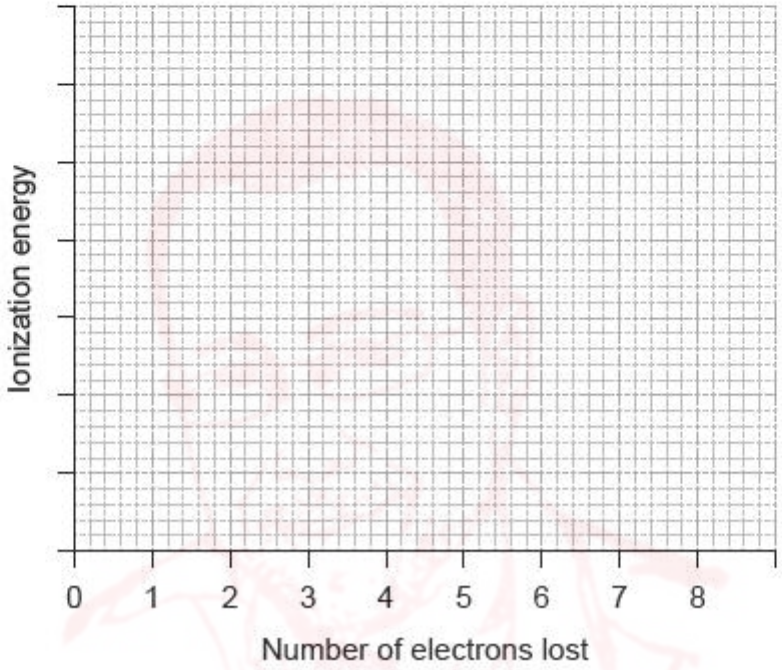
(c) Sketch the first eight successive ionisation energies of sulfur. [2]



Topic **Chem 3 Q# 33/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. The electron configuration of copper makes it a useful metal.

(b) Explain why a copper(II) solution is blue, using section 17 of the data booklet. [3]

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5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(a) Beryllium has a crystalline structure.

(ii) Outline the electrostatic attraction in the beryllium crystal structure. [1]

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(c) Beryllium forms a chloride, $BeCl_2$.

(i) Draw the Lewis (electron dot) structure of the $BeCl_2$ molecule. [1]

(ii) Outline how the Lewis (electron dot) structure of the $BeCl_2$ molecule differs from most Lewis (electron dot) structures. [1]

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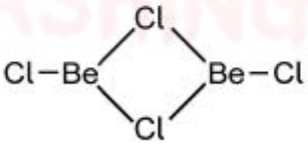
(d) Beryllium chloride, $BeCl_2$, partially dimerizes in the gas phase to produce this molecule:



(i) Identify the hybridization of the beryllium atom in the dimer, Be_2Cl_4. [1]

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Topic **Chem 4 Q# 35/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4. Carbon disulfide, CS_2, undergoes gas phase hydrolysis according to the overall equation

$$CS_2(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 2H_2S(g)$$

(b) Deduce the molecular geometries of CS_2 and H_2S, and the reason why they are different. [2]

Molecular geometry CS_2: .....

Molecular geometry H_2S: .....

Reason for difference: .....

.....

Topic **Chem 4 Q# 36/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

(b) Nitrogen (II) oxide radicals (NO•) catalyse the decomposition of ozone (O_3).

(i) Formulate equations showing how NO• acts as a catalyst in this reaction. [2]

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Chlorine also forms free radicals; the bond enthalpy for Cl_2 is 4.02×10^{-19} J.

(ii) Calculate the minimum frequency of light needed to break this bond. Use sections 1 and 2 of the data booklet. [1]

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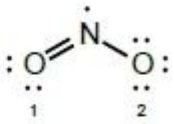
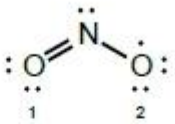
(iii) Calculate the formal charge on each atom in the **two** Lewis structures of the NO_2• (g) radical. [1]

	Structure A	Structure B
		
Oxygen 1	.....	.....
Nitrogen	.....	.....
Oxygen 2	.....	.....

(iv) Lewis structure A is more stable. Suggest, giving **one** reason, whether the formal charge model supports this. [1]

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Topic **Chem 4 Q# 37/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

(iii) Explain the polarity of the S—O bond. Use section 8 of the data booklet. [2]

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5. Double salts are substances with two cations and one anion. A hydrated sulfate containing two cations has this percentage composition.

Element	Percentage (%)
Nitrogen (N)	7.09
Hydrogen (H)	5.11
Sulfur (S)	16.22
Cobalt (Co)	14.91
Oxygen (O)	—

(a) (i) Draw **one** Lewis (electron dot) structure of the sulfate ion. [1]

2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(c) (i) State the electron domain geometry of the ammonia molecule. [1]

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(ii) Deduce the Lewis (electron dot) structure of ammonia and sketch its 3D molecular shape. [2]

Lewis structure:

3D molecular shape:

(iii) Explain, with reference to the forces between molecules, why ammonia has a higher boiling point than phosphine (PH_3). [3]

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Topic **Chem 4 Q# 40/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Lignite, a type of coal, contains about 0.40 % sulfur by mass.

(c) Deduce the Lewis (electron dot) structure for sulfur dioxide. [1]

(f) SF_4Cl_2 can form two isomers, one which is polar and another non-polar. Deduce the 3-dimensional representations of both isomers of SF_4Cl_2. [2]

Non-polar isomer:

Polar isomer:

(v) Deduce the Lewis (electron dot) structure, including formal charges, and shape for dinitrogen monoxide showing nitrogen as the central atom. [3]

Lewis structure:

Shape: .....

6. Nitric acid is usually produced by the oxidation of ammonia.

(ii) Deduce a Lewis (electron dot) structure of the nitric acid molecule, HNO_3, that obeys the octet rule, showing any non-zero formal charges on the atoms. [2]

(iii) Explain the relative lengths of the three bonds between N and O in nitric acid. [3]

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(d) Iodomethane is used to prepare CH_3MgI. It can also be converted into methanol:

$$CH_3I + HO^- \rightarrow CH_3OH + I^-$$

(iv) The polarity of the carbon–halogen bond, C–X, facilitates attack by HO^-. Outline, giving a reason, how the bond polarity changes going down group 17. [1]

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(g) State the types of bonding in magnesium, oxygen and magnesium oxide, and how the valence electrons produce these types of bonding. [4]

Substance	Bond type	How the valence electrons produce these bonds
Magnesium	. . . . .	. . . . .
Oxygen	. . . . .	. . . . .
Magnesium oxide	. . . . .	. . . . .

3. White phosphorus is an allotrope of phosphorus and exists as P_4.

(a) (i) Sketch the Lewis (electron dot) structure of the P_4 molecule, containing only single bonds. [1]

(ii) Write an equation for the reaction of white phosphorus (P_4) with chlorine gas to form phosphorus trichloride (PCl_3). [1]

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(b) (i) Deduce the electron domain and molecular geometry using VSEPR theory, and estimate the Cl–P–Cl bond angle in PCl_3. [3]

Electron domain geometry:

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Molecular geometry:

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Bond angle:

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(ii) Outline the reason why PCl_5 is a non-polar molecule, while PCl_4F is polar. [3]

PCl_5 is non-polar:

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PCl_4F is polar:

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10. Hybridization of hydrocarbons affects their reactivity.

(a) (i) Distinguish between a sigma and pi bond. [2]

Sigma (σ) bond:

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Pi (π) bond:

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7. Oxygen exists as two allotropes, diatomic oxygen, O_2, and ozone, O_3.

(a) (i) Draw a Lewis (electron dot) structure for ozone. [1]

(ii) Discuss the relative length of the two O–O bonds in ozone. [2]

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2. Iron (II) sulfide reacts with hydrochloric acid to form hydrogen sulfide, H_2S.

(a) (i) Draw the Lewis (electron dot) structure of hydrogen sulfide. [1]

(ii) Predict the shape of the hydrogen sulfide molecule. [1]

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Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(a) Outline why metals, like iron, can conduct electricity. [1]

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(Question 1 continued)

(d) Iron (II) sulfide, FeS, is ionically bonded.

(i) Describe the bonding in this type of solid. [2]

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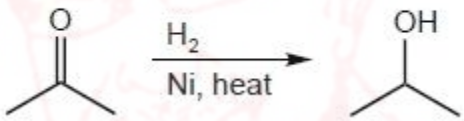
(v) Suggest why chemists find it convenient to classify bonding into ionic, covalent and metallic. [1]

(f) Explain why the addition of small amounts of carbon to iron makes the metal harder. [2]

Topic **Chem 4 Q# 50/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4. Nickel catalyses the conversion of propanone to propan-2-ol.



(c) Discuss, referring to intermolecular forces present, the relative volatility of propanone and propan-2-ol. [3]

(d)

(Question 4 continued)

(v) Describe the bonding in metals. [2]

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(vi) Nickel alloys are used in aircraft gas turbines. Suggest a physical property altered by the addition of another metal to nickel. [1]

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2. Compound **A** is in equilibrium with compound **B**.

(a) Predict the electron domain and molecular geometries around the **oxygen** atom of molecule **A** using VSEPR. [2]

Electron domain geometry:

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Molecular geometry:

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(b) State the type of hybridization shown by the central carbon atom in molecule **B**. [1]

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(c) State the number of sigma (σ) and pi (π) bonds around the central carbon atom in molecule **B**. [1]

σ-bonds:

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π-bonds:

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(e) CCl_2F_2 is a common chlorofluorocarbon, CFC.

(i) Calculate the percentage by mass of chlorine in CCl_2F_2. [2]

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(ii) Comment on how international cooperation has contributed to the lowering of CFC emissions responsible for ozone depletion. [1]

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(iii) CFCs produce chlorine radicals. Write two successive propagation steps to show how chlorine radicals catalyse the depletion of ozone. [2]

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4. Carbon disulfide, CS_2, undergoes gas phase hydrolysis according to the overall equation

$$CS_2(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 2H_2S(g)$$

(a) (i) Calculate the enthalpy change in this reaction from section 12 of the data booklet and the given values: [2]

	$CS_2(g)$	$H_2S(g)$
$\Delta H_f^\ominus$	$+88.7\,kJ\,mol^{-1}$	$-20.6\,kJ\,mol^{-1}$

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(ii) Outline why you would expect the entropy change for this reaction to be quite small. [1]

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Topic **Chem 5 Q# 54/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(c) Bond enthalpies are a useful way of finding approximate enthalpy changes for reactions.

(i) Determine the enthalpy change, $\Delta H^\ominus$, of this reaction, using section 11 of the data booklet. [3]

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(iii) Bond enthalpies are usually only approximate values. Identify which of the bond enthalpies you have just used is actually an exact value, and give a reason for your choice. [1]

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(e) Calculate the standard entropy change, $\Delta S^{\ominus}$, of the reaction. Use data from section 12 of the data booklet and the given values: [1]

	$H_2(g)$	HCOOH (g)
$S^{\ominus}$	$130.7\,J\,mol^{-1}\,K^{-1}$	$251.0\,J\,mol^{-1}\,K^{-1}$

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Topic **Chem 5 Q# 55/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. The element sulfur has many industrial uses.

(a) (i) Determine the standard enthalpy of reaction ($\Delta H_r^{\ominus}$), in kJ mol^{-1}, for the oxidation of SO_2 to SO_3. [1]

Substance	Enthalpy of formation, $\Delta H_f^{\ominus}$ (kJ mol^{-1})
SO_2	−296.8
SO_3	−395.8

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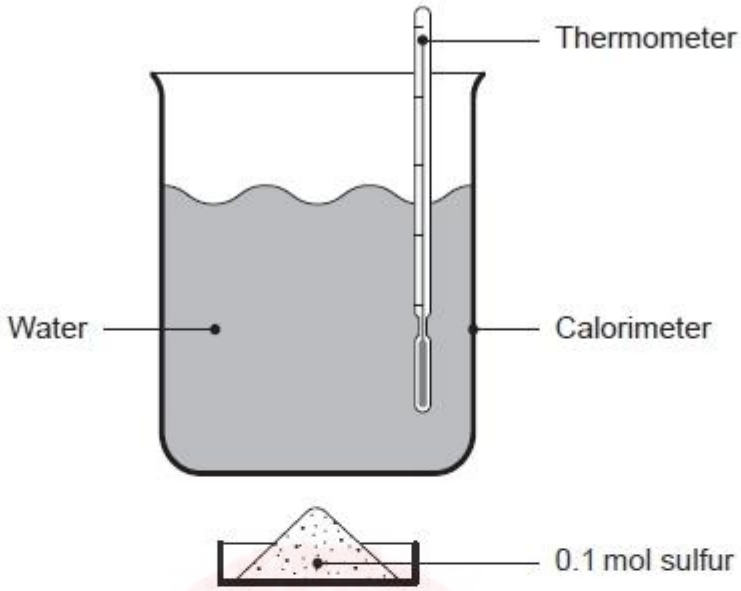
(b) The combustion of 0.1 moles of sulfur (S) was demonstrated in a school laboratory using the following apparatus in a fume cupboard.



(i) Calculate the enthalpy of combustion of sulfur, ΔH_c, in kJ mol^{-1} from this data. Use sections 1 and 2 of the data booklet. [2]

Mass of water (g) ±0.01	50.00
Initial temperature of water (°C) ±0.5	20.0
Final temperature of water (°C) ±0.5	35.0

Topic **Chem 5 Q# 56/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(d) Cold packs contain ammonium nitrate and water separated by a membrane.

(i) The mass of the contents of the cold pack is 25.32 g and its initial temperature is 25.2 °C. Once the contents are mixed, the temperature drops to 0.8 °C.

Calculate the energy, in J, absorbed by the dissolution of ammonium nitrate in water within the cold pack. Assume the specific heat capacity of the solution is $4.18\,J\,g^{-1}\,K^{-1}$. Use section 1 of the data booklet. [1]

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(ii) Determine the mass of ammonium nitrate in the cold pack using your answer obtained in (d)(i) and sections 6 and 19 of the data booklet.

If you did not obtain an answer in (d)(i), use 3.11×10^3 J, although this is not the correct answer. [2]

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(iii) The absolute uncertainty in mass of the contents of the cold pack is ±0.01 g and in each temperature reading is ±0.2 °C. Using your answer in (d)(ii), calculate the absolute uncertainty in the mass of ammonium nitrate in the cold pack.

If you did not obtain an answer in (d)(ii), use 6.55 g, although this is not the correct answer. [3]

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(iv) The cold pack contains 9.50 g of ammonium nitrate. Calculate the percentage error in the experimentally determined mass of ammonium nitrate obtained in (d)(ii).

If you did not obtain an answer in (d)(ii), use 6.55 g, although this is not the correct answer. [1]

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(v) Calculate the standard entropy change, $\Delta S^{\ominus}$, for the dissolution of ammonium nitrate. [1]

$S^{\ominus}NH_4NO_3(s) = 151.1\ J\ mol^{-1}\ K^{-1}$

$S^{\ominus}NH_4NO_3(aq) = 259.8\ J\ mol^{-1}\ K^{-1}$

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(vi) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for the dissolution of ammonium nitrate at 298 K. Use sections 1 and 19 of the data booklet as well as your answer for question part (d)(v).

If you did not obtain an answer in (d)(v), use 102.3 J mol^{-1} K^{-1}, although this is not the correct answer. [1]

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(f) Solid ammonium nitrate can decompose to gaseous dinitrogen monoxide and liquid water.

(i) Write the chemical equation for this decomposition. [1]

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(ii) Calculate the volume of dinitrogen monoxide produced at STP when a 5.00 g sample of ammonium nitrate decomposes. Use section 2 of the data booklet. [2]

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(iii) Calculate the standard enthalpy change, $\Delta H^{\ominus}$, of the reaction. Use section 12 of the data booklet. [2]

$\Delta H_f^{\ominus}$ ammonium nitrate = −366 kJ mol^{-1}

$\Delta H_f^{\ominus}$ dinitrogen monoxide = 82 kJ mol^{-1}

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(iv) Predict, with a reason, the signs for the entropy change, $\Delta S^{\ominus}$, and Gibbs free energy change, $\Delta G^{\ominus}$, of the reaction. [2]

Entropy change: . . . . . .

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Gibbs free energy change: . . . . . .

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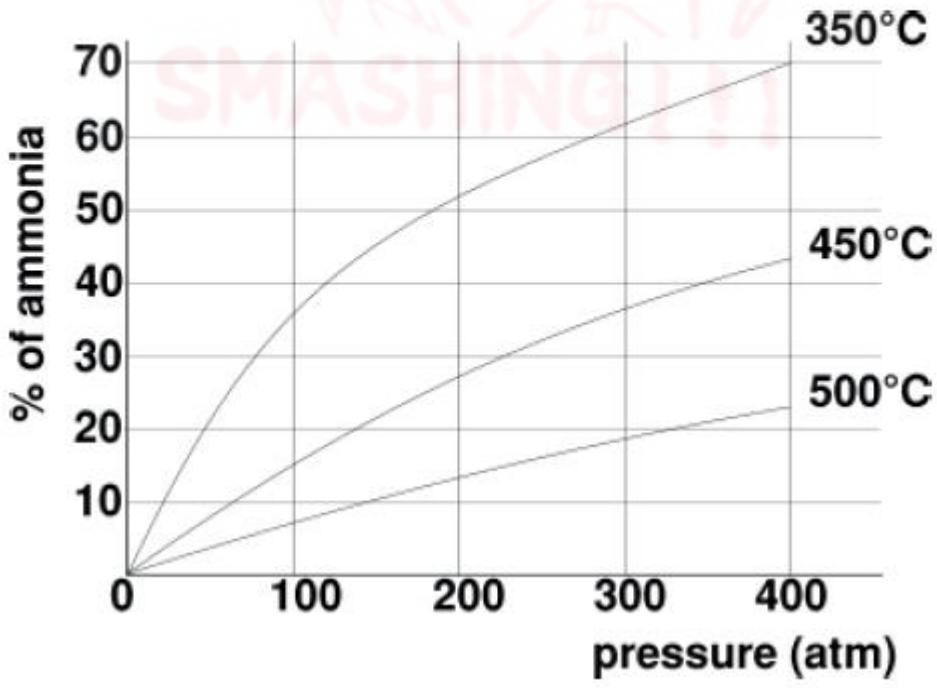
Topic **Chem 5 Q# 57/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. Ammonia is produced by the Haber–Bosch process which involves the equilibrium:

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$$

The percentage of ammonia at equilibrium under various conditions is shown:



(b) One factor affecting the position of equilibrium is the enthalpy change of the reaction.

(i) Determine the enthalpy change, ΔH, for the Haber–Bosch process, in kJ.
Use Section 11 of the data booklet. [3]

(ii) Outline why the value obtained in (b)(i) might differ from a value calculated using ΔH_f data. [1]

(c) The standard free energy change, $\Delta G^{\ominus}$, for the Haber–Bosch process is –33.0 kJ at 298 K.

(i) State, giving a reason, whether the reaction is spontaneous or not at 298 K. [1]

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(ii) Calculate the value of the equilibrium constant, *K*, at 298 K. Use sections 1 and 2 of the data booklet. [2]

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(iii) Calculate the entropy change for the Haber–Bosch process, in $J\,mol^{-1}\,K^{-1}$ at 298 K. Use your answer to (b)(i) and section 1 of the data booklet. [2]

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(iv) Outline, with reference to the reaction equation, why this sign for the entropy change is expected. [1]

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Topic **Chem 5 Q# 58/** IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. White phosphorus is an allotrope of phosphorus and exists as P_4.

(c) An equilibrium exists between PCl_3 and PCl_5.

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

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

$$\Delta H^{\ominus}_f PCl_3(g) = -306.4\,kJ\,mol^{-1}$$

$$\Delta H^{\ominus}_f PCl_5(g) = -398.9\,kJ\,mol^{-1}$$ [1]

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(ii) Calculate the entropy change, ΔS, in $JK^{-1}mol^{-1}$, for this reaction.

Substance	Entropy $JK^{-1}mol^{-1}$
$PCl_3(g)$	311.7
$PCl_5(g)$	364.5
$Cl_2(g)$	223.0

[1]

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(iii) Calculate the Gibbs free energy change (ΔG), in $kJ\,mol^{-1}$, for this reaction at 25 °C. Use section 1 of the data booklet.

If you did not obtain an answer in c(i) or c(ii) use $-87.6\,kJ\,mol^{-1}$ and $-150.5\,J\,mol^{-1}K^{-1}$ respectively, but these are not the correct answers. [2]

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Topic **Chem 5 Q# 59/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7. Oxygen exists as two allotropes, diatomic oxygen, O_2, and ozone, O_3.

(b) Explain why there are frequencies of UV light that will dissociate O_3 but not O_2. [2]

(c) Explain, using equations, how the presence of CCl_2F_2 results in a chain reaction that decreases the concentration of ozone in the stratosphere. [2]

Topic **Chem 5 Q# 60/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. Magnetite, Fe_3O_4, is another ore of iron that contains both Fe^{2+} and Fe^{3+}.

(c) Iron has a relatively small specific heat capacity; the temperature of a 50 g sample rises by 44.4 °C when it absorbs 1 kJ of heat energy.

Determine the specific heat capacity of iron, in $J\,g^{-1}K^{-1}$. Use section 1 of the data booklet. [1]

3. An equation for the combustion of propane is given below.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

(a) Determine the standard enthalpy change, $\Delta H^{\ominus}$, for this reaction, using section 11 of the data booklet. [3]

(b) Calculate the standard enthalpy change, $\Delta H^{\ominus}$, for this reaction using section 12 of the data booklet. [2]

(Question 3 continued)

(c) Predict, giving a reason, whether the entropy change, $\Delta S^{\ominus}$, for this reaction is negative or positive. [1]

(d) Calculate $\Delta S^{\ominus}$ for the reaction in JK^{-1}, using section 12 of the data booklet.

The standard molar entropy for oxygen gas is $205\,JK^{-1}mol^{-1}$. [2]

(e) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, **in kJ**, for the reaction at 5 °C, using your answers to (b) and (d). Use section 1 of the data booklet.

(If you did not obtain an answer to (b) or (d) use values of −1952 kJ and $+113\,JK^{-1}$ respectively, although these are not the correct answers.) [2]

Topic Chem 6 Chemical kinetics Q# 62/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q6.
www.SmashingScience.org :o)

(c) Chemists have a "rule of thumb" that raising the temperature by 10 °C doubles the reaction rate. Deduce the activation energy, in $kJ\,mol^{-1}$, assuming that a rise in temperature from 25 °C to 35 °C doubled the rate of this reaction. Use sections 1 and 2 of the data booklet. [3]

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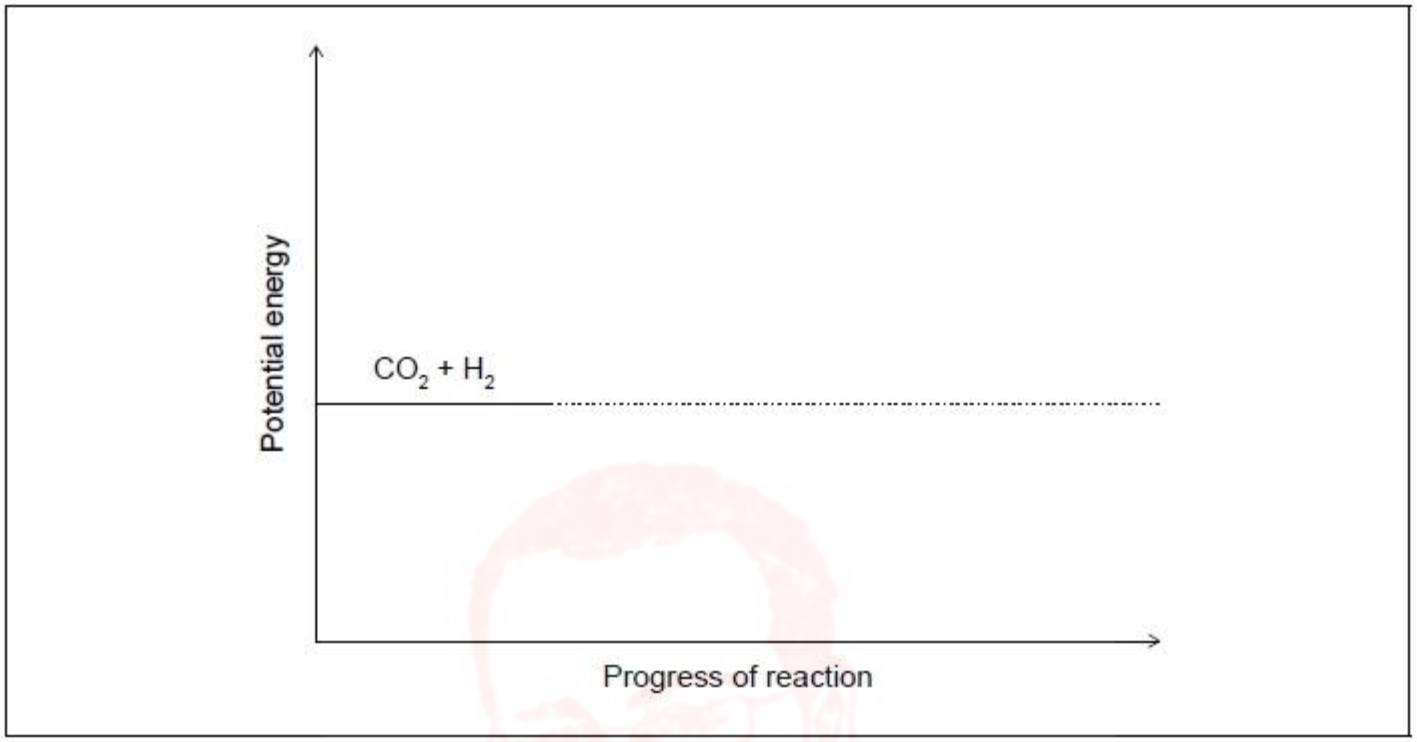
Topic **Chem 6 Q# 63/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(f) The conversion of carbon dioxide to methanoic acid is usually carried out over an iridium-based catalyst.

(i) Sketch, on the axes provided, energy profiles of the reaction both with and without a catalyst, indicating ΔH and the activation energies. [3]



(ii) State **one** change, other than carrying out the reaction over a catalyst at high temperature, that would increase the reaction rate. [1]

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Topic **Chem 6 Q# 64/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(e) (i) The Haber process requires a catalyst. State how a catalyst functions. [1]

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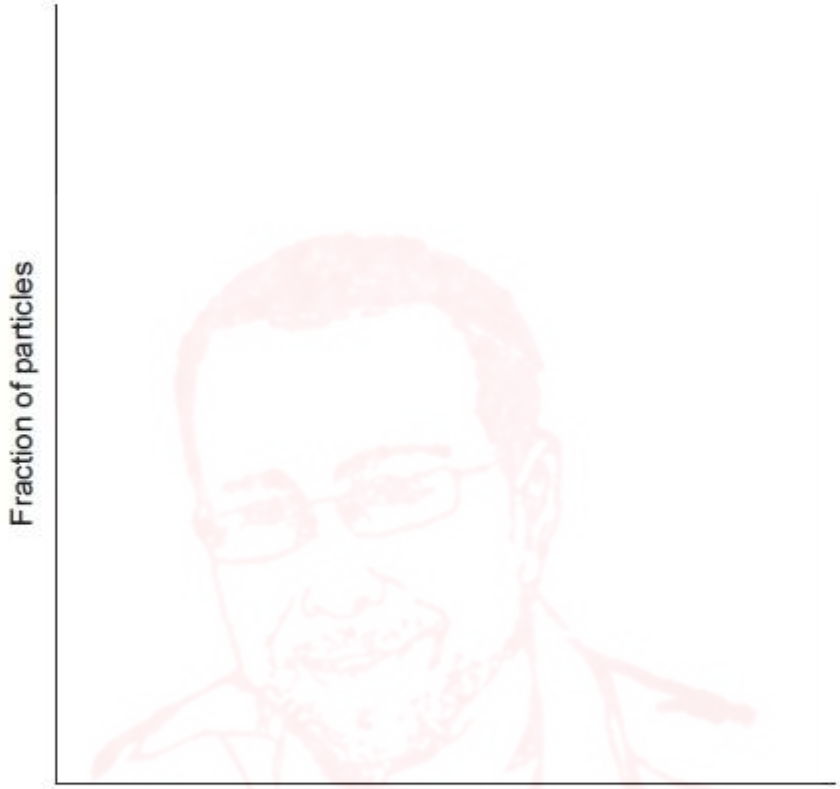
(ii) Sketch a Maxwell–Boltzmann distribution curve showing the activation energies with and without a catalyst. [2]



(iii) Suggest how the progress of the reaction could be monitored. [1]

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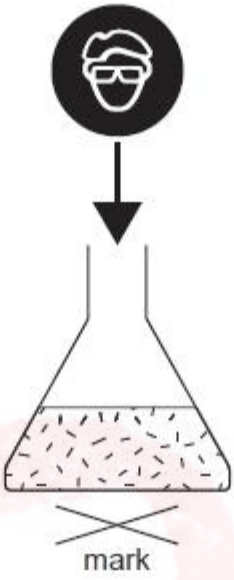
Topic **Chem 6 Q# 65/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Lignite, a type of coal, contains about 0.40 % sulfur by mass.

(d) Sodium thiosulfate reacts with hydrochloric acid as shown:

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow S(s) + SO_2(aq) + 2NaCl(aq) + H_2O(l)$$

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



Suggest **two** variables, other than concentration, that should be controlled when comparing relative rates at different temperatures. [2]

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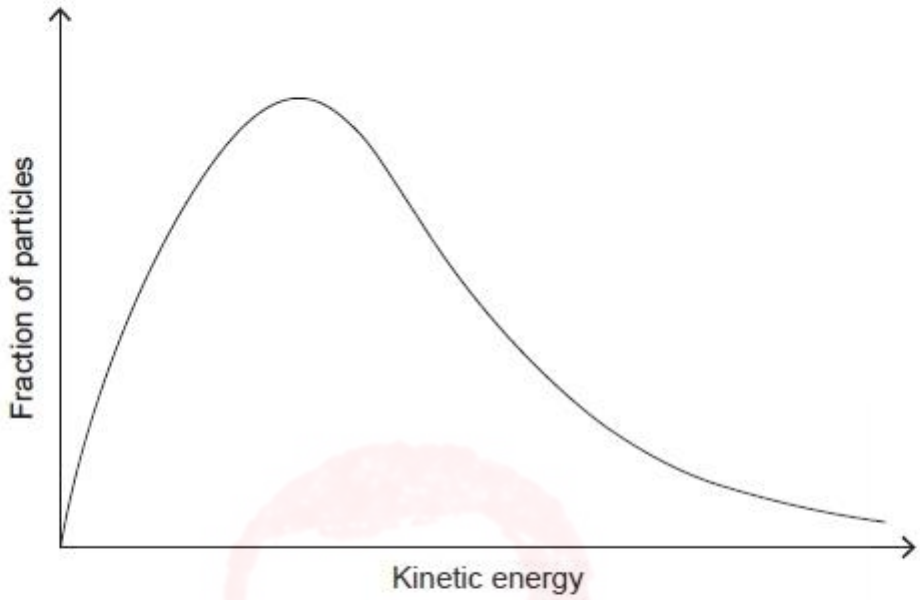
(iii) Annotate the Maxwell–Boltzmann distribution curve showing the activation energies, E_a, for the catalysed and uncatalysed reactions. [1]



(iv) Explain, referring to the Maxwell–Boltzmann distribution curve, the effect of a catalyst on a chemical reaction. [1]

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Topic **Chem 6 Q# 67/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

(d) Iodomethane is used to prepare CH_3MgI. It can also be converted into methanol:

$$CH_3I + HO^- \rightarrow CH_3OH + I^-$$

(ii) Outline the requirements for a collision between reactants to yield products. [2]

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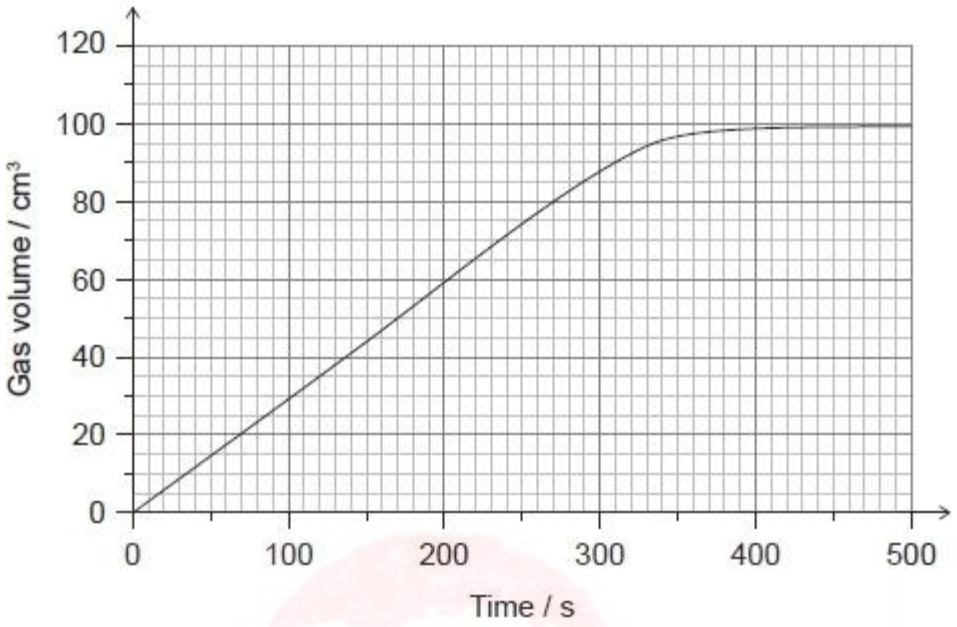
(c) A graph of the volume of gas produced by reacting magnesium with a large excess of 1 mol dm^{-3} hydrochloric acid is shown.



(i) Use the graph to deduce the dependence of the reaction rate on the amount of Mg. [1]

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(ii) The reaction is first order with respect to HCl. Calculate the time taken, in seconds (s), for half of the Mg to dissolve when [HCl] = 0.5 mol dm^{-3}. [1]

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(iii) Carbonates also react with HCl and the rate can be determined by graphing the mass loss. Suggest why this method is less suitable for the reaction of Mg with HCl. [1]

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Topic **Chem 6 Q# 69/** IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q10. www.SmashingScience.org :o)

10. Hybridization of hydrocarbons affects their reactivity.

(c) Experiments were carried out to investigate the mechanism of reaction between 2-chloropentane and aqueous sodium hydroxide.

Experiment	[NaOH] (mol dm^{-3})	[$C_5H_{11}Cl$] (mol dm^{-3})	Initial rate (mol dm^{-3} s^{-1})
1	0.20	0.10	2.50×10^{-2}
2	0.20	0.15	3.75×10^{-2}
3	0.40	0.20	1.00×10^{-1}
4	0.60	0.25	

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

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(ii) Deduce the units of the rate constant. [1]

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(iii) Determine the initial rate of reaction in experiment 4. [2]

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6. When dinitrogen pentoxide, N_2O_5, is heated the colourless gas undergoes thermal decomposition to produce brown nitrogen dioxide:

$$N_2O_5(g) \rightarrow 2NO_2(g) + \frac{1}{2} O_2(g)$$

(a) Suggest how the extent of decomposition could be measured. [1]

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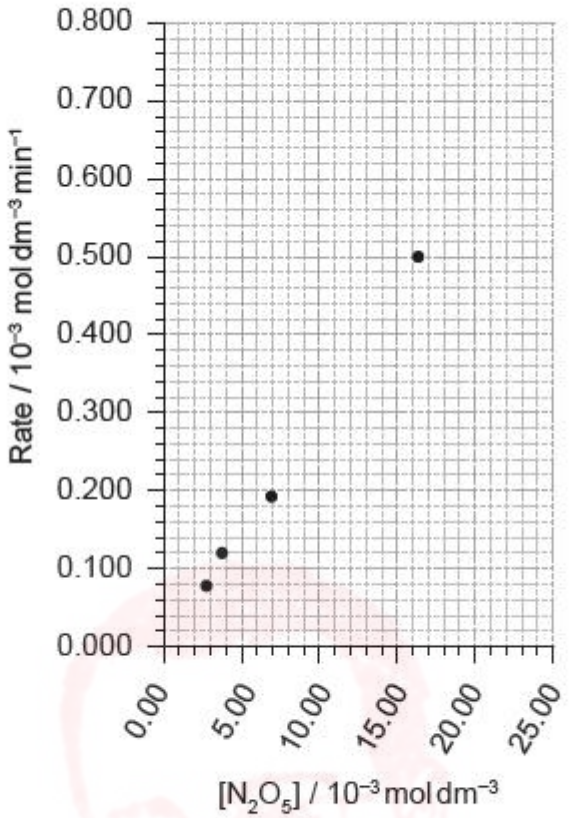
(b) Data for the decomposition at constant temperature is given.

$[N_2O_5]$ / 10^{-3} mol dm^{-3}	Rate / 10^{-3} mol dm^{-3} min^{-1}
2.74	0.078
3.68	0.121
6.89	0.197
16.27	0.498
24.30	0.710

(i) Plot the missing point on the graph and draw the best-fit line. [2]



(ii) Outline why increasing the concentration of N_2O_5 increases the rate of reaction. [1]

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(iii) Write the rate expression for this reaction. [1]

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(iv) Calculate the value of the rate constant, k, giving its units. [3]

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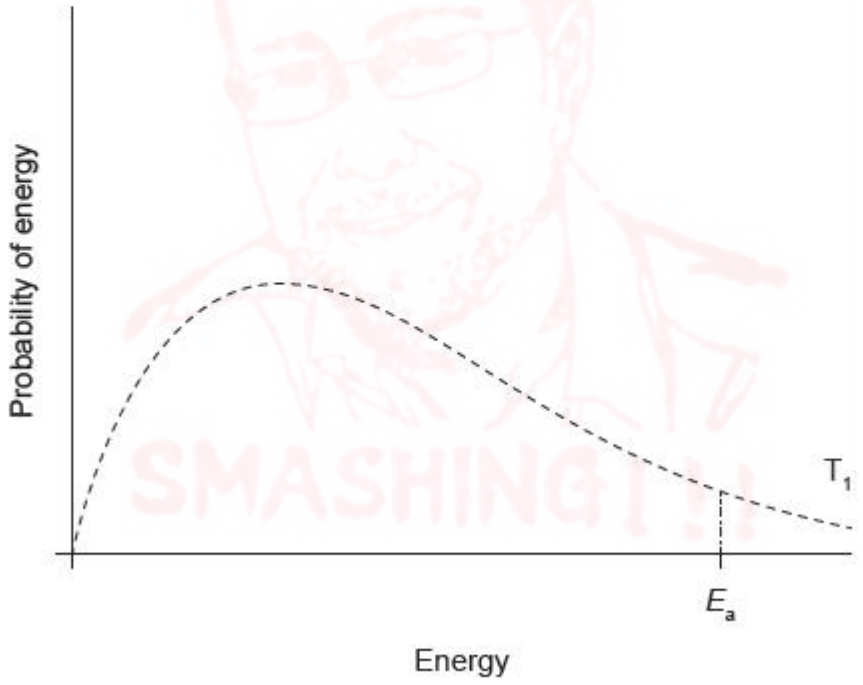
Topic **Chem 6 Q# 71/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4. Hydrogen peroxide can react with methane and oxygen to form methanol. This reaction can occur below 50°C if a gold nanoparticle catalyst is used.

(a) The diagram shows the Maxwell-Boltzmann curve for the uncatalyzed reaction.

Draw a distribution curve at a lower temperature (T_2) **and** show on the diagram how the addition of a catalyst enables the reaction to take place more rapidly than at T_1. [2]



(Question 4 continued)

(d) Consider the first stage of the reaction.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

(i) Determine the enthalpy change, ΔH, in kJ. Use section 11 of the data booklet.

Bond enthalpy of CO = 1077 kJ mol^{-1}. [3]

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(ii) State **one** reason why you would expect the value of ΔH calculated from the $\Delta H_f^{\ominus}$ values, given in section 12 of data booklet, to differ from your answer to (d)(i). [1]

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(Question 4 continued)

(e) Now consider the second stage of the reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(l) \quad \Delta H^{\ominus} = -129\,kJ$$

(i) The equilibrium constant, K_c, has a value of 1.01 at 298 K.

Calculate $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, for this reaction. Use sections 1 and 2 of the data booklet. [2]

(ii) Calculate a value for the entropy change, $\Delta S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$ at 298 K. Use your answers to (e)(i) and section 1 of the data booklet.

If you did not get answers to (e)(i) use −1 kJ, but this is not the correct answer. [2]

(iii) Justify the sign of ΔS with reference to the equation. [1]

(Question 4 continued)

(iv) Predict, giving a reason, how a change in temperature from 298 K to 273 K would affect the spontaneity of the reaction. [1]

7. Nitrogen monoxide reacts with oxygen gas to form nitrogen dioxide.

(a) The following experimental data was obtained.

Experiment	Initial [NO] / mol dm^{-3}	Initial [O_2] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.0100	0.0300	2.13×10^{-2}
2	0.0100	0.0600	4.26×10^{-2}
3	0.0300	0.0300	1.92×10^{-1}

Deduce the partial order of reaction with respect to nitrogen monoxide and oxygen. [2]

NO:

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O_2:

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(Question 7 continued)

(b) Deduce, giving a reason, whether the following mechanism is possible.

First step:	$2NO(g) \rightarrow N_2O_2(g)$	slow
Second step:	$N_2O_2(g) + O_2(g) \rightleftharpoons 2NO_2(g)$	fast

[1]

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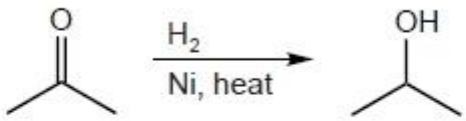
4. Nickel catalyses the conversion of propanone to propan-2-ol.



(a) Outline how a catalyst increases the rate of reaction. [1]

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(b) Explain why an increase in temperature increases the rate of reaction. [2]

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Topic Chem 7 Equilibrium Q# 74/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4.

www.SmashingScience.org :o)

4. Carbon disulfide, CS_2, undergoes gas phase hydrolysis according to the overall equation

$$CS_2(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 2H_2S(g)$$

(iii) Neglecting any entropy change, use your answer to 4(a)(i), section 1 and section 2 of the data booklet to estimate the equilibrium constant, K_c, at 500 K.

(If you did not obtain an answer to 4(a)(i), use a value of $-50.0\,kJ\,mol^{-1}$, although this is not the correct answer.) [2]

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(iv) The concentrations of the species involved at equilibrium are:

$CS_2(g)$	$H_2O(g)$	$CO_2(g)$	$H_2S(g)$
$0.0400\,mol\,dm^{-3}$	$0.100\,mol\,dm^{-3}$	$x\,mol\,dm^{-3}$	$2x\,mol\,dm^{-3}$

Calculate the numerical value of x, the concentration of carbon dioxide at equilibrium, using your answer from 4(a)(iii).

(If you did not obtain an answer to 4(a)(iii), then use a value of 1.68×10^5, although this is not the correct answer.) [2]

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Topic **Chem 7 Q# 75/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)
NOT with 2023/w/TZ0/Paper 2/Higher Level/Q2(c)

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(b) State the equilibrium constant expression for this reaction. [1]

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The enthalpy change, which was calculated in part (c) for this reaction is +5 kJ mol^{-1}

(d) Suggest why temperature has a very small effect on the value of the equilibrium constant. [1]

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Topic **Chem 7 Q# 76/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(d) (i) Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H_r^{\ominus} = -92.0\,kJ\,mol^{-1}$$

Outline what is meant by dynamic equilibrium. [1]

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(ii) Deduce the K_c expression for the reaction in part (d)(i). [1]

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(iii) Determine the entropy change, $\Delta S^{\ominus}$ for the forward reaction to **four** significant figures, using the data given. [2]

Substance	Entropy ($S^{\ominus}$) J K^{-1} mol^{-1}
H_2	130.7
N_2	191.6
NH_3	192.8

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(iv) Calculate the temperature, in K, below which this reaction becomes spontaneous. Use section 1 of the data booklet. (If you were unable to obtain an answer for part (d)(iii) use $-210.0\,J\,K^{-1}\,mol^{-1}$, but this is not the correct value.) [2]

(v) The value of K_c for this reaction is 6.84×10^{-5} at 500 °C. Suggest, with a reason, how lowering the temperature affects the value of K_c. [1]

(vi) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction. Use sections 1 and 2 of the data booklet. [2]

Topic **Chem 7 Q# 77/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(vii) Calculate the value of the equilibrium constant for the dissolution of ammonium nitrate at 298 K using the answer to question part (d)(vi) and section 1 of the data booklet.

$$NH_4NO_3(s) \rightleftharpoons NH_4NO_3(aq)$$

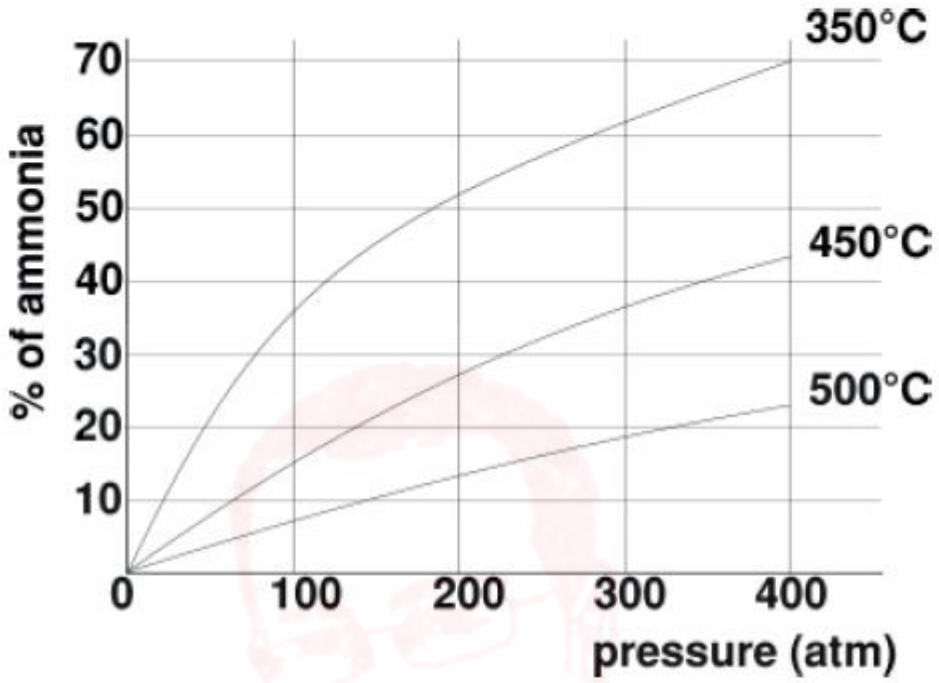
If you did not obtain an answer in (d)(vi), use −7.84 kJ/mol, although this is not the correct answer. [2]

(viii) Deduce, with a reason, the position of the equilibrium. [1]

3. Ammonia is produced by the Haber–Bosch process which involves the equilibrium:

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$$

The percentage of ammonia at equilibrium under various conditions is shown:



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

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(ii) State how the use of a catalyst affects the position of the equilibrium. [1]

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(iii) With reference to the reaction quotient, Q, explain why the percentage yield increases as the pressure is increased at constant temperature. [3]

(b) One factor affecting the position of equilibrium is the enthalpy change of the reaction.

(i) Determine the enthalpy change, ΔH, for the Haber–Bosch process, in kJ.

The answer to the enthalpy change of the forward reaction in (b)(i) is -93 kJ

(iii) Demonstrate that your answer to (b)(i) is consistent with the effect of an increase in temperature on the percentage yield, as shown in the graph. [2]

Topic **Chem 7 Q# 79/** IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. White phosphorus is an allotrope of phosphorus and exists as P_4.

(c) An equilibrium exists between PCl_3 and PCl_5.

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

(iv) Determine the equilibrium constant, K, for this reaction at 25 °C, referring to section 1 of the data booklet.

If you did not obtain an answer in (c)(iii), use $\Delta G = -43.5\,\text{kJ mol}^{-1}$, but this is not the correct answer. [2]

(v) State the equilibrium constant expression, K_c, for this reaction. [1]

(vi) State, with a reason, the effect of an increase in temperature on the position of this equilibrium. [1]

Topic **Chem 7 Q# 80/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

(d) Consider the first stage of the reaction.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

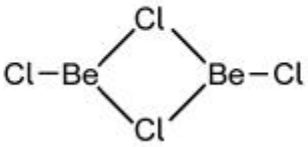
(iii) State the expression for K_c for this stage of the reaction. [1]

(iv) State and explain the effect of increasing temperature on the value of K_c. [1]

5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(c) Beryllium forms a chloride, $BeCl_2$.

(d) Beryllium chloride, $BeCl_2$, partially dimerizes in the gas phase to produce this molecule:



(ii) Describe the interactions between the $BeCl_2$ monomers to form the dimer in Lewis' acid-base terms. [1]

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Topic **Chem 8 Q# 82/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Methanoic acid (HCOOH) is the first member of the homologous series of carboxylic acids.

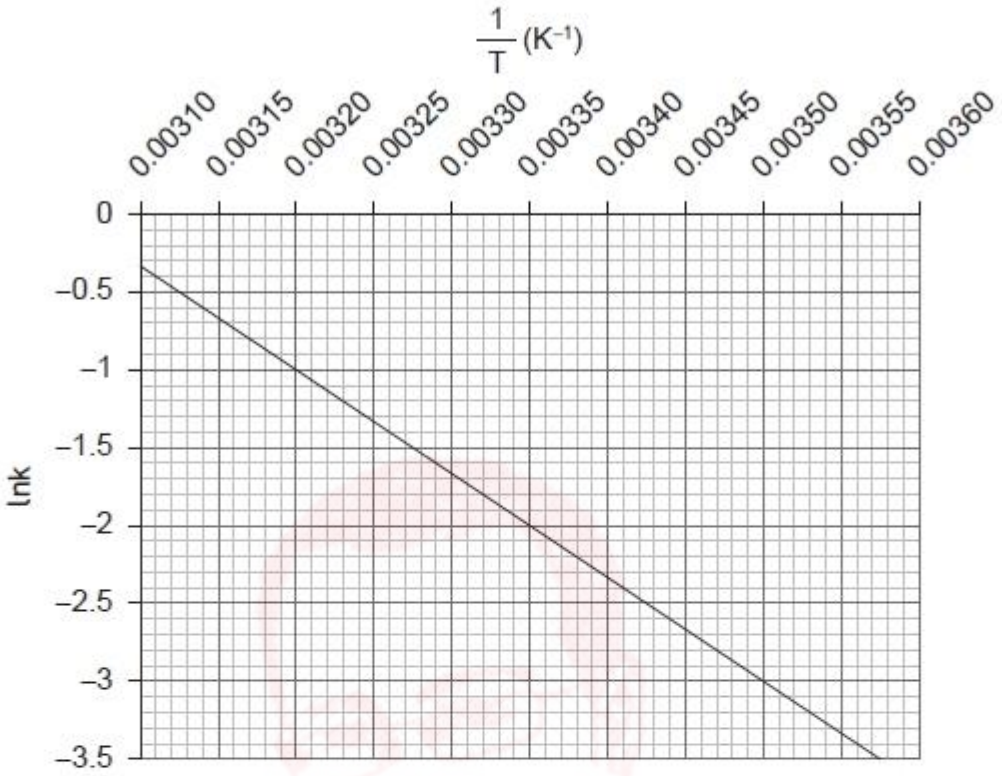
(d) Methanoic acid acts as a weak monobasic acid in aqueous solution.

(i) $2.00\,dm^3$ of a solution of methanoic acid was prepared, and $25.0\,cm^3$ of this was found to require exactly $20.7\,cm^3$ of $0.100\,mol\,dm^{-3}$ aqueous sodium hydroxide to completely convert it to sodium methanoate, HCOONa. Calculate the mass of methanoic acid used to make the solution. [2]

(ii) Determine the pH of the methanoic acid solution. Use section 21 of the data booklet. [3]

(iii) Predict, using an equation, whether the pH of the solution of sodium methanoate formed would be greater than, less than or equal to 7. [2]

8. A series of experiments were carried out at different temperatures and the rate of reaction, in mol dm^{-3} s^{-1}, was determined for each. The rate constant for the reaction of propanone (CH_3COCH_3) with iodine (I_2) was calculated and the processed data is represented in the following graph.



Determine the activation energy for this reaction, stating the units. Use sections 1 and 2 of the data booklet. [3]

(ii) Formulate equations showing how SO_2 and SO_3 lead to acid deposition. [1]

SO_2: .....

SO_3: .....

Answer **all** questions. Answers must be written within the answer boxes provided.

1. This question is about acid–base properties.

(a) (i) Deduce the ionic equation, including state symbols, for the reaction of hydrogen chloride gas with water. [2]

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(ii) Calculate the pH of 0.50 mol dm^{-3} hydrochloric acid. [1]

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(iii) Explain why a solution of ethanoic acid has a higher pH than hydrochloric acid of the same concentration. [1]

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(iv) A pH probe can be used to distinguish between the acids in part (a)(iii). Identify another simple instrumental method that could be used in a school laboratory to distinguish between the two acids. [1]

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(v) Outline how the instrumental method identified in part (a)(iv) distinguishes between the acids in part (a)(iii). [1]

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(b) Outline **one** chemical test, other than an indicator, that can distinguish between the two acids in part (a)(iii), and the expected result. [1]

Chemical test: .....

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Expected result: .....

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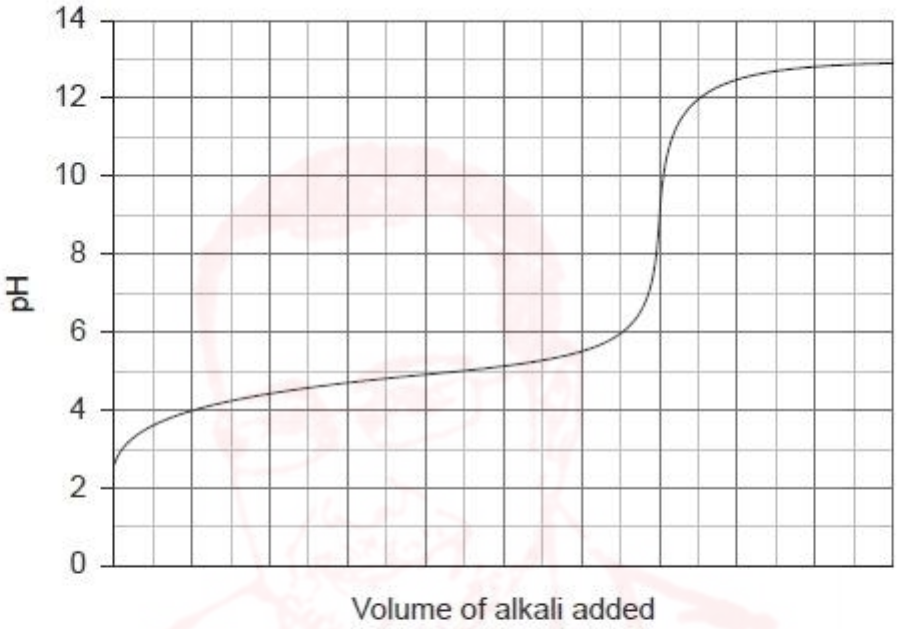
(c) A neutralization curve for a weak acid, HA, and a strong base is given.



(i) Estimate the pK_a of HA. [1]

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(ii) Explain, using an equation, why adding a strong base to the weak acid, HA, leads to very little change in pH in the buffer zone of the graph. [2]

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In a separate experiment, 80 cm^3 of 0.1 mol dm^{-3} ammonia, $NH_3(aq)$, was added to 40 cm^3 of 0.1 mol dm^{-3} hydrochloric acid, $HCl(aq)$.

(iii) Determine the final pH of the solution. Use section 21 of the data booklet. [4]

Topic **Chem 8 Q# 86/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Lignite, a type of coal, contains about 0.40 % sulfur by mass.

(b) Write an equation that shows how sulfur dioxide can produce acid rain. [1]

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(e) Discuss **two** different ways to reduce the environmental impact of energy production from coal. [2]

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Topic **Chem 8 Q# 87/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(b) State, with a reason, whether the ammonium ion is a Brønsted-Lowry acid or base. [1]

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(c) A 0.20 mol dm^{-3} solution of ammonium nitrate is prepared.

(i) Calculate the pH of an ammonium nitrate solution with $[H_3O^+] = 1.07 \times 10^{-5}$ mol dm^{-3}. Use section 1 of the data booklet. [1]

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(ii) Ammonium nitrate is neutralized with sodium hydroxide. Write the equation for the reaction. [1]

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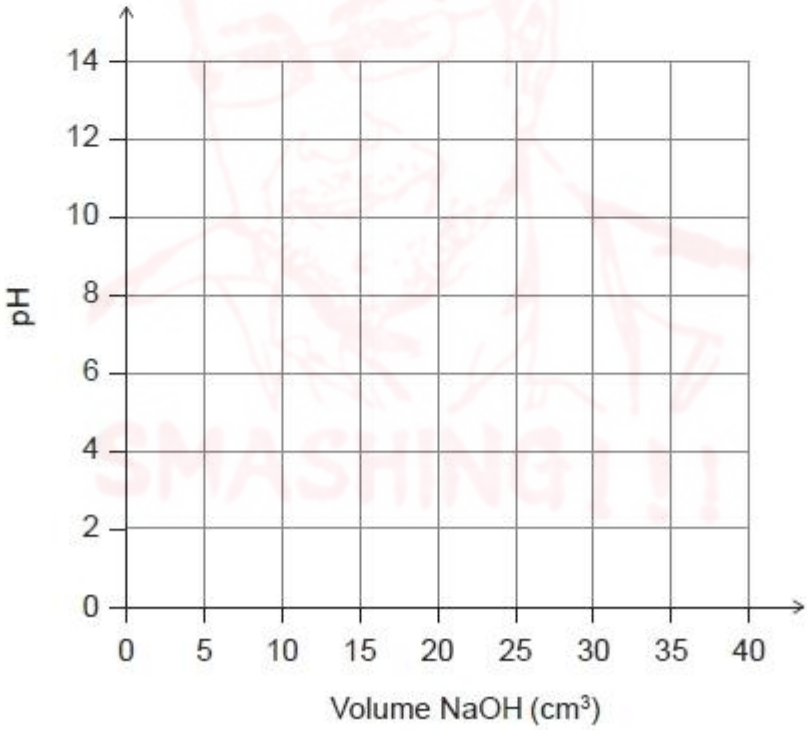
(iii) A 20.00 cm^3 sample of the 0.20 mol dm^{-3} solution of ammonium nitrate is titrated with a 0.20 mol dm^{-3} solution of sodium hydroxide. Determine the pH at the equivalence point, to **two** decimal places using section 1 and 21 of the data booklet. [4]

(iv) Sketch the pH curve that would result from the titration of a 0.20 mol dm^{-3} solution of ammonium nitrate with sodium hydroxide. [2]



(v) State, with a reason, if bromothymol blue is an appropriate indicator for this titration. Use section 22 of the data booklet. [1]

4. Ammonia is soluble in water and forms an alkaline solution:

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + HO^-(aq)$$

(a) State the relationship between NH_4^+ and NH_3 in terms of the Brønsted–Lowry theory. [1]

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(b) Determine the concentration, in mol dm^{-3}, of the solution formed when 900.0 dm^3 of $NH_3(g)$ at 300.0 K and 100.0 kPa, is dissolved in water to form 2.00 dm^3 of solution. Use sections 1 and 2 of the data booklet. [2]

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(c) (i) Calculate the concentration of hydroxide ions in an ammonia solution with pH = 9.3. Use sections 1 and 2 of the data booklet. [1]

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(ii) Calculate the concentration, in mol dm^{-3}, of ammonia molecules in the solution with pH = 9.3. Use section 21 of the data booklet. [2]

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(iii) An aqueous solution containing high concentrations of both NH_3 and NH_4^+ acts as an acid-base buffer solution as a result of the equilibrium:

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

Referring to this equilibrium, outline why adding a small volume of strong acid would leave the pH of the buffer solution almost unchanged. [2]

(d) Magnesium salts form slightly acidic solutions owing to equilibria such as:

$$Mg^{2+}(aq) + H_2O(l) \rightleftharpoons Mg(OH)^+(aq) + H^+(aq)$$

Comment on the role of Mg^{2+} in forming the $Mg(OH)^+$ ion, in acid-base terms. [2]

Topic **Chem 8 Q# 89/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

(d) The presence of magnesium nitride can be demonstrated by adding water to the product. It is hydrolysed to form magnesium hydroxide and ammonia.

$$\_\_ Mg_3N_2(s) + \_\_ H_2O(l) \rightarrow \_\_ Mg(OH)_2(s) + \_\_ NH_3(aq)$$

(ii) Ammonia is added to water that contains a few drops of an indicator. Identify an indicator that would change colour. Use sections 21 and 22 of the data booklet. [1]

5. Phosphoric acid, H_3PO_4 can form three different salts depending on the extent of neutralisation by sodium hydroxide.

(a) Formulate an equation for the reaction of one mole of phosphoric acid with one mole of sodium hydroxide. [1]

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(b) Formulate **two** equations to show the amphiprotic nature of $H_2PO_4^-$. [2]

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(c) Calculate the concentration of H_3PO_4 if 25.00 cm^3 is completely neutralised by the addition of 28.40 cm^3 of 0.5000 mol dm^{-3} NaOH. [2]

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(d) Outline the reasons that sodium hydroxide is considered a Brønsted–Lowry and Lewis base. [1]

Brønsted–Lowry base:

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Lewis Base:

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4. 1-chloropentane reacts with aqueous sodium hydroxide.

(a) (i) Identify the type of reaction. [1]

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(ii) Outline the role of the hydroxide ion in this reaction. [1]

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(iii) Suggest, with a reason, why 1-iodopentane reacts faster than 1-chloropentane under the same conditions. Use section 11 of the data booklet for consistency. [2]

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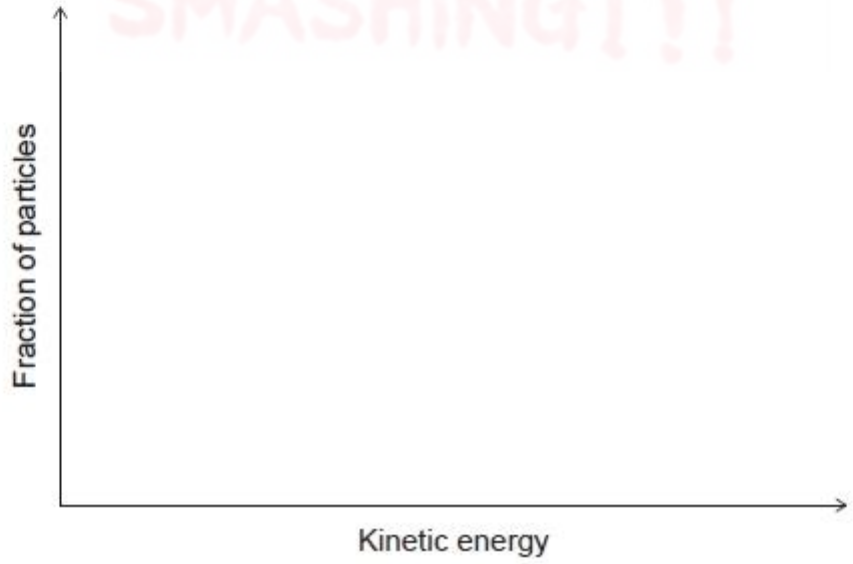
(b) The reaction was repeated at a lower temperature.

Sketch labelled Maxwell–Boltzmann energy distribution curves at the original temperature (T_1) and the new lower temperature (T_2). [2]



11. 50.00 cm^3 of 0.75 mol dm^{-3} sodium hydroxide was added in 1.00 cm^3 portions to 22.50 cm^3 of 0.50 mol dm^{-3} chloroethanoic acid.

(a) Calculate the initial pH before any sodium hydroxide was added, using section 21 of the data booklet. [2]

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(b) The concentration of excess sodium hydroxide was 0.362 mol dm^{-3}. Calculate the pH of the solution at the end of the experiment. [1]

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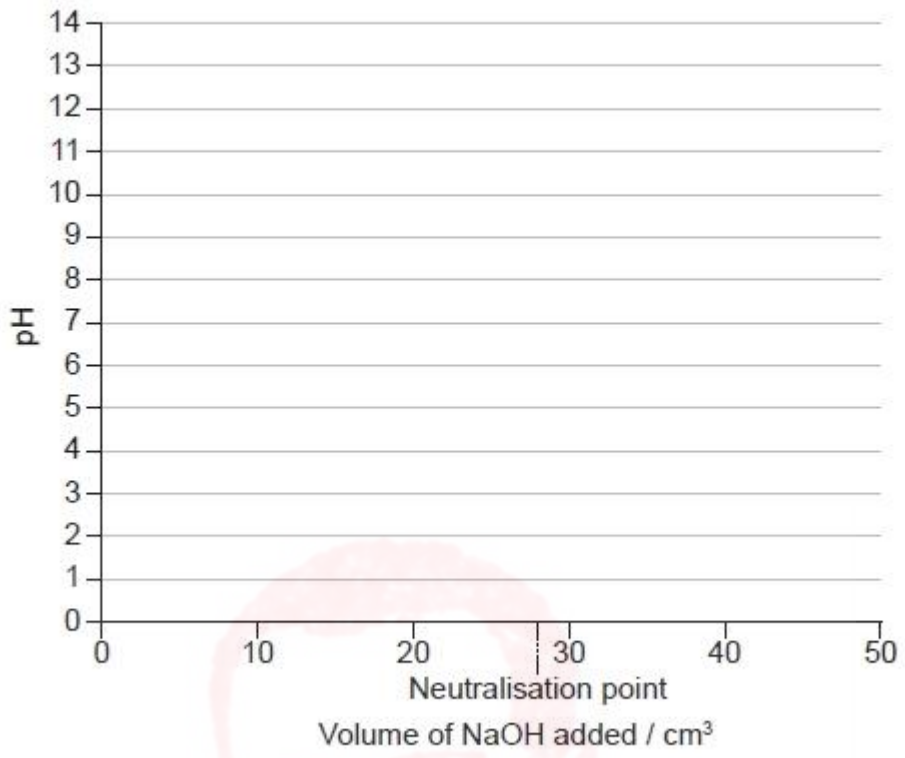
(c) Sketch the neutralisation curve obtained **and** label the equivalence point. [3]



8. Propanoic acid, CH_3CH_2COOH, is a weak organic acid.

(a) Calculate the pH of 0.00100 mol dm^{-3} propanoic acid solution. Use section 21 of the data booklet. [3]

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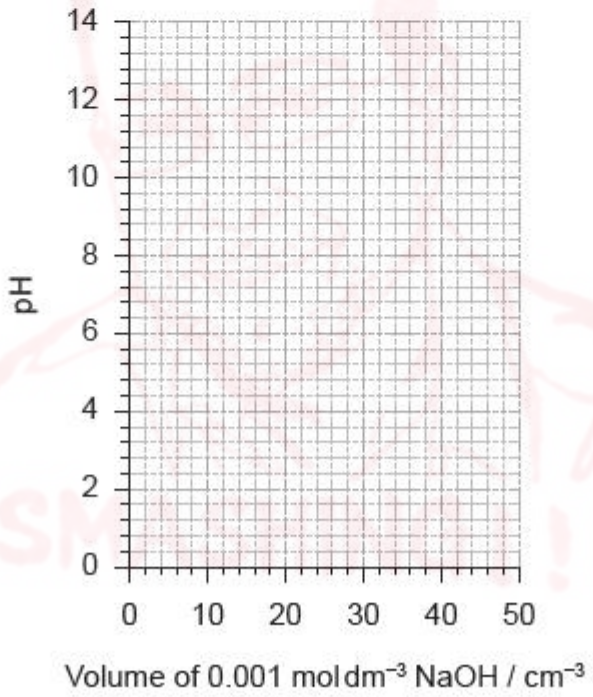
(b) Sketch the general shape of the variation of pH when 50 cm^3 of 0.001 mol dm^{-3} NaOH (aq) is gradually added to 25 cm^3 of 0.001 mol dm^{-3} CH_3CH_2COOH (aq). [3]



2. Iron (II) sulfide reacts with hydrochloric acid to form hydrogen sulfide, H_2S.

(b) In aqueous solution, hydrogen sulfide acts as an acid.

(i) State the formula of its conjugate base. [1]

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(ii) Saturated aqueous hydrogen sulfide has a concentration of 0.10 mol dm^{-3} and a pH of 4.0. Demonstrate whether it is a strong or weak acid. [1]

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(iii) Calculate the hydroxide ion concentration in saturated aqueous hydrogen sulfide. [1]

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(c) A gaseous sample of nitrogen, contaminated only with hydrogen sulfide, was reacted with excess sodium hydroxide solution at constant temperature. The volume of the gas changed from 550 cm^3 to 525 cm^3.

Determine the mole percentage of hydrogen sulfide in the sample, stating one assumption you made. [3]

Mole percentage H_2S:

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Assumption:

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Topic **Chem 8 Q# 95/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(e) The first step in the extraction of iron from iron (II) sulfide is to roast it in air to form iron (III) oxide and sulfur dioxide.

(iii) Suggest why this process might raise environmental concerns. [1]

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Topic **Chem 8 Q# 96/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. A student performs a titration to determine the concentration of ethanoic acid, CH_3COOH, in vinegar using potassium hydroxide.

(a) Write a balanced equation for the reaction. [1]

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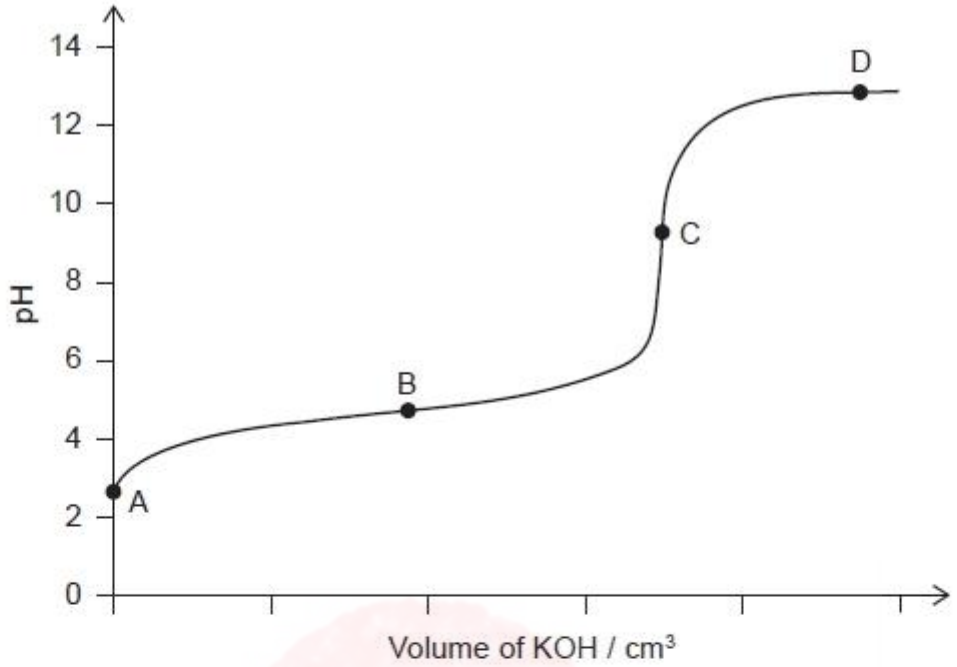
(b) The pH curve for the reaction is given.



(i) Identify the **major** species, other than water and potassium ions, at these points. [2]

B:

. . . . . .

C:

. . . . . .

(ii) State a suitable indicator for this titration. Use section 22 of the data booklet. [1]

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(iii) Suggest, giving a reason, which point on the curve is considered a buffer region. [1]

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(c) State the K_a expression for ethanoic acid. [1]

(d) Calculate the K_b of the conjugate base of ethanoic acid using sections 2 and 21 of the data booklet. [1]

(e) In a titration, 25.00 cm^3 of vinegar required 20.75 cm^3 of 1.00 mol dm^{-3} potassium hydroxide to reach the end-point.

Calculate the concentration of ethanoic acid in the vinegar. [2]

Topic **Chem 8 Q# 97/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

(b) 2.67 g of manganese(IV) oxide was added to 200.0 cm^3 of 2.00 mol dm^{-3} HCl.

$$MnO_2(s) + 4HCl(aq) \rightarrow Cl_2(g) + 2H_2O(l) + MnCl_2(aq)$$

(c) Chlorine gas reacts with water to produce hypochlorous acid and hydrochloric acid.

$$Cl_2(g) + H_2O(l) \rightleftharpoons HClO(aq) + HCl(aq)$$

(i) Hypochlorous acid is considered a weak acid. Outline what is meant by the term weak acid. [1]

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(ii) State the formula of the conjugate base of hypochlorous acid. [1]

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(iii) Calculate the concentration of $H^+(aq)$ in a $HClO(aq)$ solution with a pH = 3.61. [1]

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Topic Chem 9 Redox processes Q# 98/ IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5.

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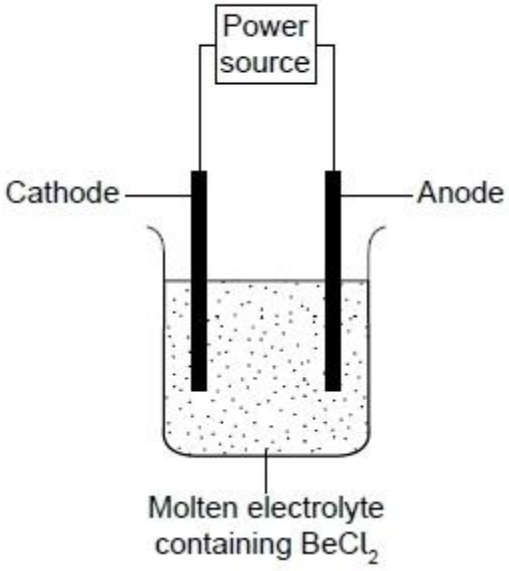
5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(b) The production of beryllium is illustrated in the diagram.



(i) Outline why molten $BeCl_2$ is considered an electrolyte. [1]

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(ii) Identify the electrode at which beryllium will be produced **and** the polarity of that electrode. [1]

Electrode: . . . . . .

Polarity: . . . . . .

(iii) Write a balanced equation for the reaction occurring at the other electrode, to the one you identified in 5(b)(ii). [1]

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(iv) Calculate the mass of beryllium that would be produced by the passage of 1.00×10^6 coulomb of electrical charge. Use sections 2 and 6 of the data booklet. [2]

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(f) The standard electrode potential, E°, of

$$Be^{2+}(aq) + 2e^- \rightleftharpoons Be(s)$$

is −1.85 V.

(i) Calculate the cell potential for the reaction

$$Be(s) + 2H_2O(l) \rightarrow Be^{2+}(aq) + 2OH^-(aq) + H_2(g)$$

Use section 24 of the data booklet. [1]

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(ii) Deduce, giving a reason, whether this reaction is thermodynamically spontaneous. [1]

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Topic **Chem 9 Q# 99/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(g) Determine the oxidation state of carbon in methanoic acid. [1]

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4. Redox reactions can be used to produce electricity.

(a) State the oxidation state of sulfur in copper(II) sulfate. [1]

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(b) A voltaic cell was constructed using a copper(II) sulfate/copper half-cell and a zinc sulfate/zinc half-cell.

(i) Outline why electrons flow from zinc to copper when these half cells are connected with a wire. Use section 25 of the data booklet. [1]

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(ii) Formulate equations for the reactions taking place at each electrode. [2]

Anode (negative electrode): . . . . . .

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Cathode (positive electrode): . . . . . .

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(c) (i) Calculate the standard cell potential for the voltaic cell in part (b). Use section 24 of the data booklet. [1]

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(ii) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction. Use section 1 of the data booklet. (If you did not answer part (c)(i) use 1.05 V, but this is not the correct value.) [2]

. . . . . .

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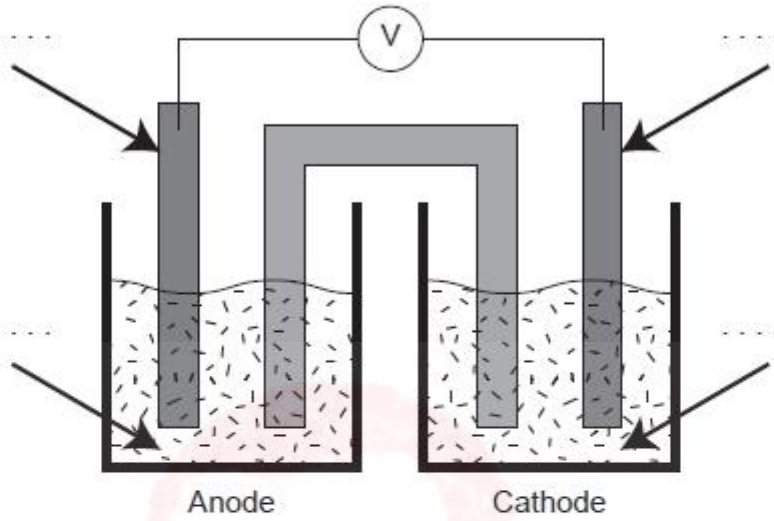
(f) The diagram shows an unlabelled voltaic cell for the reaction:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$



(i) Label the diagram with the species from the equation and the direction of electron flow. [2]

(ii) Write the half-equation for the reaction occurring at the anode (negative electrode). [1]

(iii) The diagram includes a salt bridge that is filled with a saturated solution of KNO_3. Outline the function of the salt bridge. [1]

(iv) Predict the movement of **all** ionic species through the salt bridge. [2]

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(v) Calculate the standard cell potential, in V, for this cell. Use section 24 of the data booklet. [1]

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(vi) Calculate the standard free energy change, **in kJ**, for the cell. Use your answer in (f)(v) and sections 1 and 2 of the data booklet.

If you did not obtain an answer in (f)(v), use 0.68 V, although this is not the correct answer. [1]

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Topic **Chem 9 Q# 102/** IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(e) Predict, using the given values, the reaction that would take place at the anode and cathode for the electrolysis of an aqueous solution of ammonium nitrate using graphite electrodes. [2]

	$E^{\ominus}$ / V
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$	+ 1.23
$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$	+ 0.96
$H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)$	0.00

Anode: .....

.....

Cathode: .....

.....

2. Magnesium is a reactive metal often found in alloys.

(a) Suggest an experiment that shows that magnesium is more reactive than zinc, giving the observation that would confirm this. [2]

(b) Magnesium is sometimes used as a sacrificial anode to protect steel from corrosion.

(i) Calculate the standard potential, in V, of a cell formed by magnesium and steel half-cells. Use section 24 of the data booklet and assume steel has the standard electrode potential of iron. [1]

(ii) Calculate the free energy change, $\Delta G^{\ominus}$, in kJ, of the cell reaction. Use sections 1 and 2 of the data booklet. [2]

(iii) This cell causes the electrolytic reduction of water on the steel. State the half-equation for this reduction. [1]

(d) The presence of magnesium nitride can be demonstrated by adding water to the product. It is hydrolysed to form magnesium hydroxide and ammonia.

$$\_\_\ Mg_3N_2(s) + \_\_\ H_2O(l) \rightarrow \_\_\ Mg(OH)_2(s) + \_\_\ NH_3(aq)$$

(iii) Determine the oxidation state of nitrogen in Mg_3N_2 and in NH_3. [1]

Mg_3N_2: .....

NH_3: .....

(iv) Deduce, giving reasons, whether the reaction of magnesium nitride with water is an acid–base reaction, a redox reaction, neither or both. [2]

Acid–base: ☐ Yes ☐ No

Reason: .....

.....

.....

Redox: ☐ Yes ☐ No

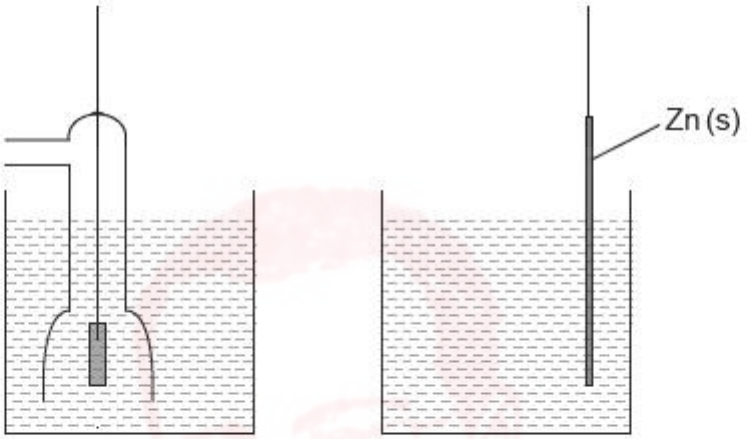
Reason: .....

.....

.....

8. The standard electrode potential of zinc can be measured using a standard hydrogen electrode (SHE).

Draw and annotate the diagram to show the complete apparatus required to measure the standard electrode potential of zinc. [4]



6. Biochemical oxygen demand (BOD) can be determined by the Winkler Method.

(a) Outline what is measured by BOD. [1]

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(b) A student dissolved $0.1240 \pm 0.0001\,g$ of $Na_2S_2O_3$ to make $1000.0 \pm 0.4\,cm^3$ of solution to use in the Winkler Method.

Determine the percentage uncertainty in the molar concentration. [2]

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(c) A $25.00\,cm^3$ sample of water was treated according to the Winkler Method.

Step I: $2Mn^{2+}(aq) + O_2(g) + 4OH^-(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$

Step II: $MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$

Step III: $2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

The iodine produced was titrated with $37.50\,cm^3$ of $5.000 \times 10^{-4}\,mol\,dm^{-3}$ $Na_2S_2O_3$.

(i) Calculate the amount, in moles of $Na_2S_2O_3$ used in the titration. [1]

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(ii) Deduce the mole ratio of O_2 consumed in step I to $S_2O_3^{2-}$ used in step III. [1]

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(iii) Calculate the concentration of dissolved oxygen, in mol dm^{-3}, in the sample. [2]

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(iv) The three steps of the Winkler Method are redox reactions.

Deduce the reduction half-equation for step II. [1]

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(v) Suggest a reason that the Winkler Method used to measure biochemical oxygen demand (BOD) must be done at constant temperature. [1]

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Topic **Chem 9 Q# 107/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3. Magnetite, Fe_3O_4, is another ore of iron that contains both Fe^{2+} and Fe^{3+}.

(d) A voltaic cell is set up between the $Fe^{2+}(aq) \mid Fe(s)$ and $Fe^{3+}(aq) \mid Fe^{2+}(aq)$ half-cells.

Deduce the equation and the cell potential of the spontaneous reaction. Use section 24 of the data booklet. [2]

Equation:

. . . . . .

. . . . . .

Cell potential:

. . . . . .

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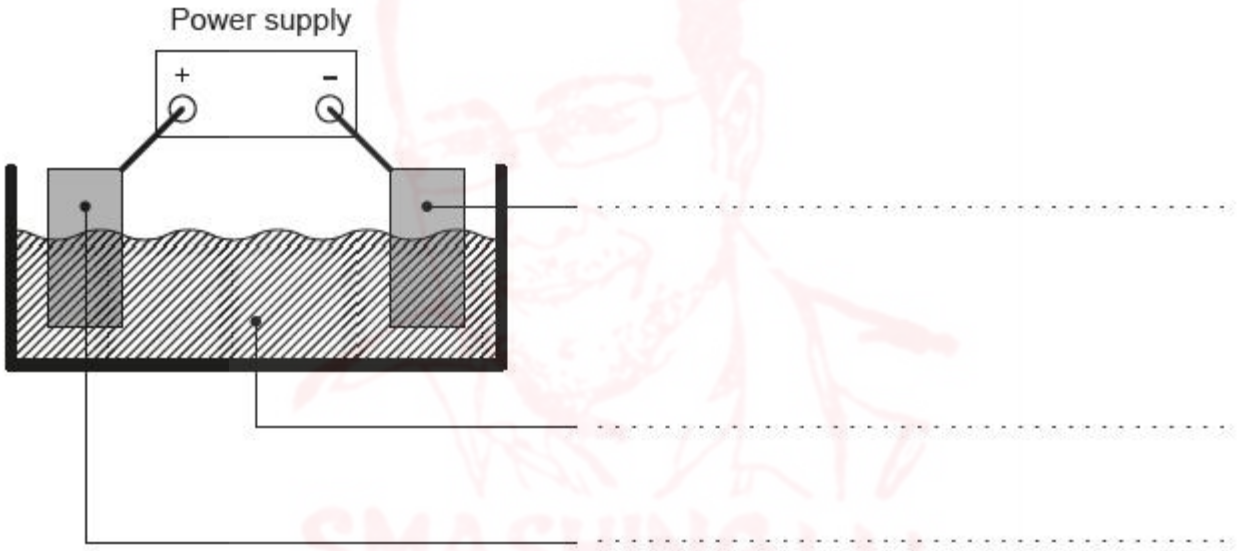
(e) The figure shows an apparatus that could be used to electroplate iron with zinc. Label the figure with the required substances. [2]



Topic **Chem 9 Q# 142/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(Question 1 continued)

(e) The first step in the extraction of iron from iron (II) sulfide is to roast it in air to form iron (III) oxide and sulfur dioxide.

(i) Write the equation for this reaction. [1]

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(ii) Deduce the change in the oxidation state of sulfur. [1]

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Topic **Chem 9 Q# 108/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

(c) Copper plating can be used to improve the conductivity of an object.

State, giving your reason, at which electrode the object being electroplated should be placed. [1]

. . . . . .

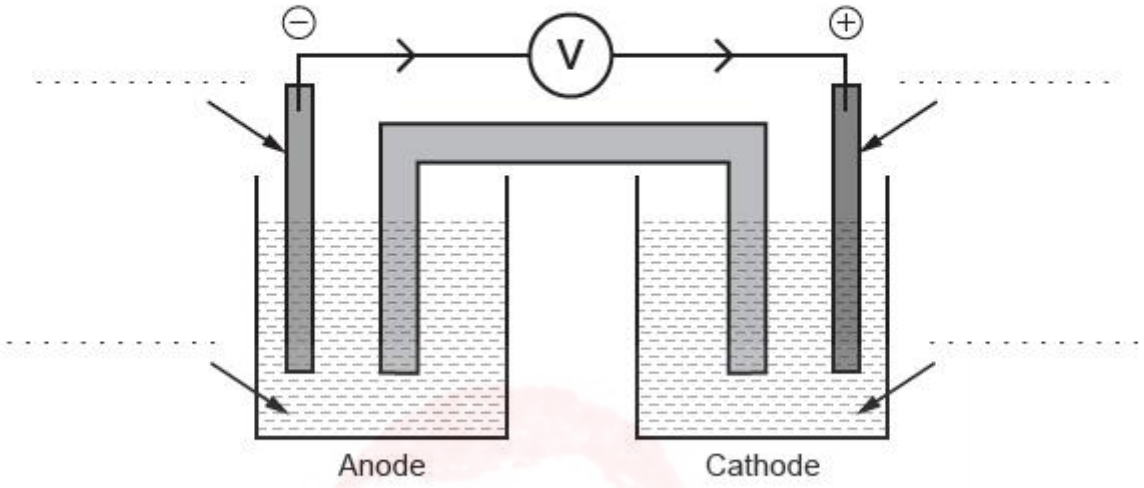
. . . . . .

. . . . . .

(d) (i) The diagram shows an unlabelled voltaic cell for the reaction.

$$Pb^{2+}(aq) + Ni(s) \rightarrow Ni^{2+}(aq) + Pb(s)$$

Label the diagram with the species in the equation. [1]



(ii) Calculate the standard cell potential, in V, for the cell at 298 K. Use section 24 of the data booklet. [1]

. . . . . .

. . . . . .

(iii) Calculate the standard free energy change, $\Delta G^{\ominus}$, **in kJ**, for the cell using sections 1 and 2 of the data booklet. [1]

. . . . . .

. . . . . .

(iv) Suggest a metal that could replace nickel in a new half-cell and reverse the electron flow. Use section 25 of the data booklet. [1]

. . . . . .

(b) 2.67 g of manganese(IV) oxide was added to 200.0 cm^3 of 2.00 mol dm^{-3} HCl.

$$MnO_2(s) + 4HCl(aq) \rightarrow Cl_2(g) + 2H_2O(l) + MnCl_2(aq)$$

(v) State the oxidation state of manganese in MnO_2 and $MnCl_2$. [2]

MnO_2:

. . . . . .

$MnCl_2$:

. . . . . .

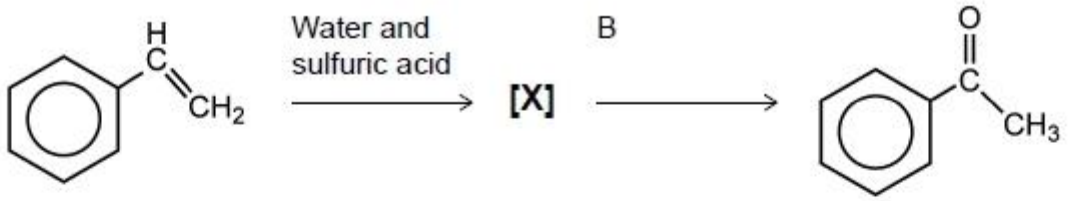
(vi) Deduce, referring to oxidation states, whether MnO_2 is an oxidizing or reducing agent. [1]

. . . . . .

. . . . . .

6. Phenylethanone is a fragrant compound that occurs naturally in fruits such as bananas and apples.

(a) Phenylethanone may be synthesised in a two-stage process from phenylethene:



(i) Draw the structural formula of the intermediate compound **[X]**. [1]

(ii) Outline why the intermediate compound, **[X]**, can exhibit stereoisomerism. [1]

. . . . . .

. . . . . .

(iii) State the reagent required for the second stage of the synthesis, B. [1]

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. . . . . .

(iv) Determine the compound that will be formed as a minor product in this two-stage synthesis, and outline why this will occur. [2]

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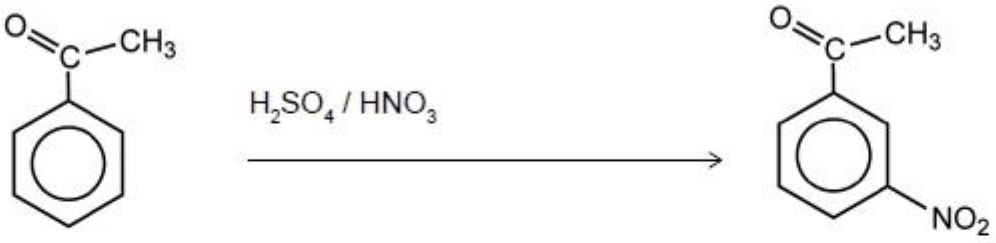
(b) When heated with a mixture of concentrated sulfuric and nitric acids, phenylethanone is nitrated, in a similar manner to benzene, to form 3-nitrophenylethanone.



(i) Write the formula of the electrophile produced in this acid mixture. [1]

. . . . . .

. . . . . .

(ii) Explain the mechanism of the reaction between phenylethanone and the nitrating agent, using curly arrows to represent the movement of electron pairs. [4]

3. Methanoic acid can be converted into methyl methanoate, $HCOOCH_3$.

(a) State the name of the reagent and catalyst required. [2]

Reagent: .....

Catalyst: .....

(d) State the class of compounds to which methyl methanoate belongs. [1]

.....

.....

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(a) Explain why this process has been extensively investigated in recent years. [2]

.....

.....

.....

.....

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Methanoic acid (HCOOH) is the first member of the homologous series of carboxylic acids.

(a) Outline what is meant by the term "homologous series". [1]

.....

.....

.....

(c) Methanoic acid and ethanal (CH_3CHO) both contain a carbonyl group and have similar molar masses.

(i) Explain why, in terms of the strongest intermolecular forces between the molecules, ethanal has a much lower boiling point than methanoic acid. [2]

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(ii) Outline why ethanal and methanoic acid are both fully miscible with water. [1]

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(iii) Predict, giving an explanation, the relative electrical conductivity of solutions of methanoic acid, ethanal and hydrochloric acid of the same concentration. [3]

Relative electrical conductivity: _____ < _____ < _____

Explanation: . . . . . .

. . . . . .

. . . . . .

. . . . . .

(d) Methanoic acid acts as a weak monobasic acid in aqueous solution.

(iv) Explain why the two carbon–oxygen bonds in the methanoate ion are of equal length, and compare their length to the carbon–oxygen bonds in methanoic acid. [2]

. . . . . .

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3. Alkanes form a homologous series.

(a) (i) Outline the meaning of homologous series. [1]

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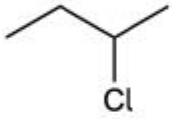
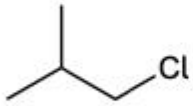
. . . . . .

(ii) State the preferred IUPAC name for the following compounds. [2]

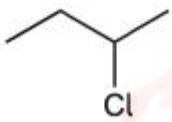


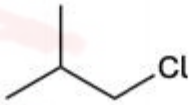
IUPAC name: . . . . . .



IUPAC name: . . . . . .

(iii) Identify **one** chiral carbon atom present in one of the following structures with an asterisk (*). [1]





(iv) But-2-ene can be polymerized. Draw a section of the resulting polymer showing **two** repeating units. [1]

(b) Chloroethane can be converted into ethanoic acid in a two-step process.

Identify reagents for each step. [2]

Step 1: .....

.....

Step 2: .....

.....

(c) (i) Identify the type of reaction that takes place in step 1 of part (b). [1]

. . . . . .

(ii) Sketch the mechanism of the reaction for step 1 in part (b), using curly arrows to show the movement of electron pairs. [4]

(iii) Identify the products formed from the reaction of ethanol and ethanoic acid in the presence of an acid catalyst. [1]

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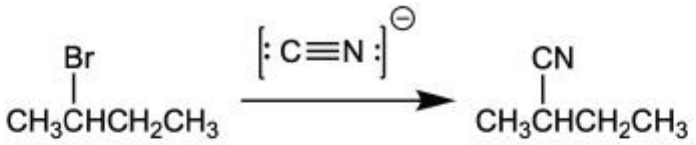
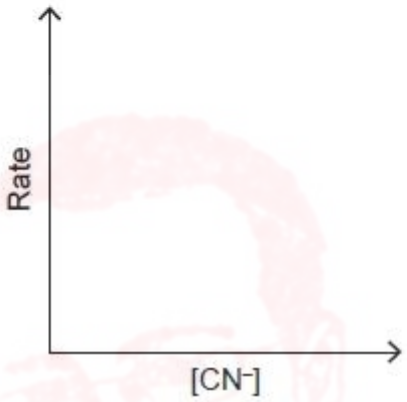
6. 2-Bromobutane can react with cyanide, CN^-, in a nucleophilic substitution reaction.

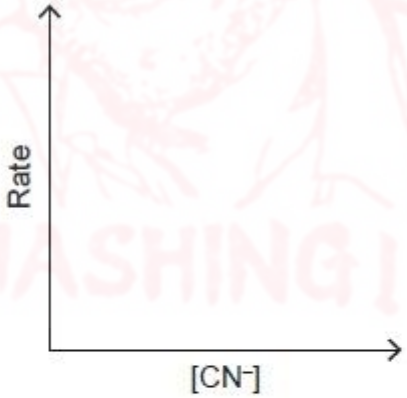


(a) This reaction could proceed through either S_N1 or S_N2 mechanisms depending on the reaction conditions. Sketch a graph of the rate versus nucleophile concentration, $[CN^-]$, for each of the mechanisms. [2]

S_N1 mechanism:



S_N2 mechanism:



(b) Suggest, with a reason, whether the reaction follows an S_N1 or S_N2 mechanism if only one stereoisomer was obtained as a product. [1]

. . . . . .

. . . . . .

(c) State an instrument that could be used to determine whether the product was a single enantiomer or a racemic mixture. [1]

. . . . . .

(d) S_N1 and S_N2 reactions are better conducted using different types of solvents. Identify **two** properties of a solvent most suited for the mechanism proposed in (b). [1]

. . . . . .

. . . . . .

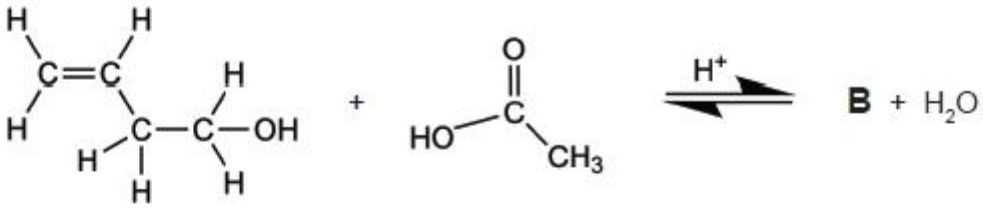
(e) State, with a reason, how the rate of reaction of cyanide with 2-chlorobutane differs from its rate of reaction with 2-bromobutane under the same conditions. [1]

. . . . . .

. . . . . .

(f) 2-Bromobutane reacts with hydroxide via the same mechanism identified in (b). Explain this mechanism using curly arrows to represent the movement of electron pairs. [3]

4. An organic compound, **A**, reacts with ethanoic acid to produce **B** using concentrated sulfuric acid as a catalyst.



A ethanoic acid

(a) (i) Deduce the structural and empirical formulas of **B**. [3]

Structural formula:

Empirical formula: .....

(ii) Explain, with reference to Le Châtelier's principle, the effect of using dilute rather than concentrated sulfuric acid as the catalyst on the yield of the reaction. [2]

.....

.....

.....

.....

(iii) Explain, with reference to intermolecular forces, why **B** is more volatile than **A**. [2]

. . . . . .

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(b) Compound **A** can also react with bromine. Describe the change observed if **A** is reacted with bromine. [1]

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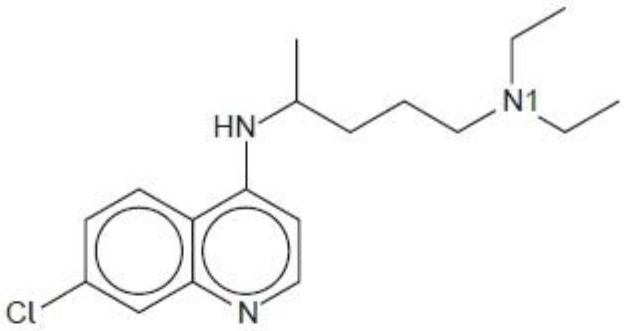
2. Chloroquine is a medication used to prevent and treat malaria.



(a) Draw a circle around the secondary amino group in chloroquine. [1]

(b) State the number of sp^2 hybridized carbons in chloroquine. [1]

. . . . . .

(c) Determine the index of hydrogen deficiency, IHD, of chloroquine. [1]

. . . . . .

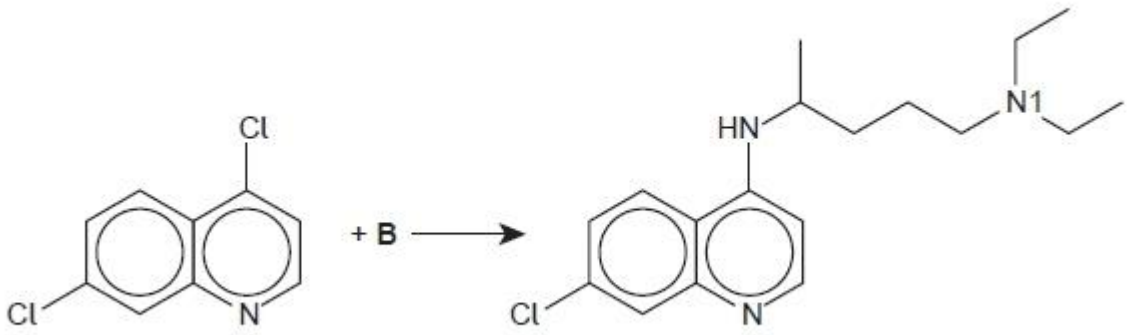
. . . . . .

(d) Compare, giving a reason, the length of the carbon-nitrogen bond in the ring to the length of the carbon-N1 bond. [1]

. . . . . .

. . . . . .

(e) Chloroquine can be synthesized by reacting 4,7-dichloroquinoline with another reactant, **B**.



4,7-dichloroquinoline **chloroquine**

(i) Deduce the structure of **B**. [2]

Topic **Chem 10 Q# 119/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. Nitric acid is usually produced by the oxidation of ammonia.

(b) A mixture of nitric acid and sulfuric acid can be used to convert benzene to nitrobenzene, $C_6H_5NO_2$.

(i) Write an equation for the reaction between the acids to produce the electrophile, NO_2^+. [1]

. . . . . .

. . . . . .

. . . . . .

(ii) Draw the structural formula of the carbocation intermediate produced when this electrophile attacks benzene. [1]

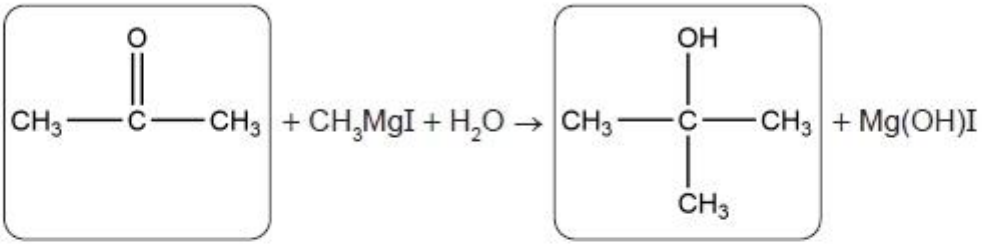
(iii) Deduce the number of signals that you would expect in the ^1H NMR spectrum of nitrobenzene and the relative areas of these. [2]

Number of signals: . . . . . .

Relative areas: . . . . . .

5. Organomagnesium compounds can react with carbonyl compounds. One overall equation is:

Compound A **Compound B**



(a) (i) State the name of Compound B, applying International Union of Pure and Applied Chemistry (IUPAC) rules. [1]

. . . . . .

. . . . . .

(ii) Compound A and Compound B are both liquids at room temperature and pressure. Identify the strongest intermolecular force between molecules of Compound A. [1]

. . . . . .

. . . . . .

(iii) State the number of σ (sigma) and π (pi) bonds in Compound A. [1]

σ: . . . . . π: . . . . . .

(iv) Deduce the hybridization of the central carbon atom in Compound A. [1]

. . . . . .

(v) Identify the isomer of Compound B that exists as optical isomers (enantiomers). [1]

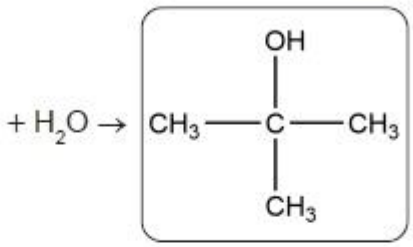
. . . . . .

. . . . . .

(b) Compound B can also be prepared by reacting an alkene with water.

(i) Draw the structural formula of the alkene required. [1]

Compound B



(ii) Explain why the reaction produces more $(CH_3)_3COH$ than $(CH_3)_2CHCH_2OH$. [2]

. . . . . .

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(iii) Deduce the structural formula of the repeating unit of the polymer formed from this alkene. [1]

(c) Deduce what would be observed when Compound B is warmed with acidified aqueous potassium dichromate (VI). [1]

. . . . . .

. . . . . .

. . . . . .

(d) Iodomethane is used to prepare CH_3MgI. It can also be converted into methanol:

$$CH_3I + HO^- \rightarrow CH_3OH + I^-$$

(i) Identify the type of reaction. [1]

. . . . . .

. . . . . .

(iii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs. [3]

7. Alkanes undergo combustion and substitution.

(a) Determine the molar enthalpy of combustion of an alkane if 8.75×10^{-4} moles are burned, raising the temperature of 20.0 g of water by 57.3 °C. [2]

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(b) Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane. [3]

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10. Hybridization of hydrocarbons affects their reactivity.

(ii) Identify the hybridization of carbon in ethane, ethene and ethyne. [1]

	Ethane	Ethene	Ethyne
Hybridization of carbon	.....	.....	.....

(b) (i) State, giving a reason, if but-1-ene exhibits cis-trans isomerism. [1]

.....

.....

.....

.....

(ii) State the type of reaction which occurs between but-1-ene and hydrogen iodide at room temperature. [1]

.....

(iii) Explain the mechanism of the reaction between but-1-ene with hydrogen iodide, using curly arrows to represent the movement of electron pairs. [4]

(iv) State, giving a reason, if the product of this reaction exhibits stereoisomerism. [1]

. . . . . .

. . . . . .

. . . . . .

(c) Experiments were carried out to investigate the mechanism of reaction between 2-chloropentane and aqueous sodium hydroxide.

Experiment	[NaOH] ($mol\,dm^{-3}$)	[$C_5H_{11}Cl$] ($mol\,dm^{-3}$)	Initial rate ($mol\,dm^{-3}\,s^{-1}$)
1	0.20	0.10	2.50×10^{-2}
2	0.20	0.15	3.75×10^{-2}
3	0.40	0.20	1.00×10^{-1}
4	0.60	0.25	

(d) Deduce, with a reason, the mechanism of the reaction between 2-chloropentane and sodium hydroxide. [1]

(e) Discuss the reason benzene is more reactive with an electrophile than a nucleophile. [2]

Topic **Chem 10 Q# 123/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Ethanol is obtained by the hydration of ethene, C_2H_4.

(a) (i) State the class of compound to which ethene belongs. [1]

(ii) State the molecular formula of the next member of the homologous series to which ethene belongs. [1]

(c) Suggest **two** possible products of the incomplete combustion of ethene that would not be formed by complete combustion. [1]

. . . . . .

. . . . . .

(d) A white solid was formed when ethene was subjected to high pressure.

Deduce the type of reaction that occurred. [1]

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(e) Alternative synthetic routes exist to produce alcohols.

(i) Sketch the mechanism for the reaction of propene with hydrogen bromide using curly arrows. [3]

(ii) Explain why the major organic product is 2-bromopropane and not 1-bromopropane. [2]

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(iii) 2-bromopropane can be converted directly to propan-2-ol. Identify the reagent required. [1]

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. . . . . .

(iv) Propan-2-ol can also be formed in one step from a compound containing a carbonyl group.

State the name of this compound and the type of reaction that occurs. [2]

Name of carbonyl compound:

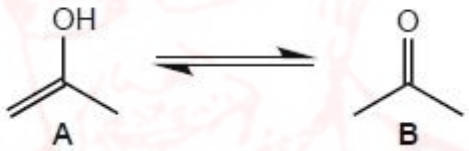
. . . . . .

Type of reaction:

. . . . . .

Topic **Chem 10 Q# 124/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2. Compound **A** is in equilibrium with compound **B**.



(e) Compound **A** and **B** are isomers. Draw two other structural isomers with the formula C_3H_6O. [2]

(f) (i) The equilibrium constant, K_c, for the conversion of **A** to **B** is 1.0×10^8 in water at 298 K.

Deduce, giving a reason, which compound, **A** or **B**, is present in greater concentration when equilibrium is reached. [1]

. . . . . .

. . . . . .

. . . . . .

(ii) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, **in kJ mol^{-1}**, for the reaction (**A** to **B**) at 298 K. Use sections 1 and 2 of the data booklet. [1]

. . . . . .

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(g) Propanone can be synthesized in two steps from propene.

(i) Suggest the synthetic route including all the necessary reactants and steps. [3]

(ii) Suggest why propanal is a minor product obtained from the synthetic route in (g)(i). [2]

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Topic **Chem 10 Q# 125/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

(d) (i) State the type of reaction occurring when ethane reacts with chlorine to produce chloroethane. [1]

. . . . . .

(ii) Predict, giving a reason, whether ethane or chloroethane is more reactive. [1]

. . . . . .

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(iii) Explain the mechanism of the reaction between chloroethane and aqueous sodium hydroxide, NaOH(aq), using curly arrows to represent the movement of electron pairs. [3]

5. Beryllium is a low-density metal that is used in specialized lightweight alloys.

(a) Beryllium has a crystalline structure.

(i) State the technique that would be used to determine the crystal structure of beryllium. [1]

. . . . . .

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Topic **Chem 11 Q# 127/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

(c) The conversion of methanoic acid to methyl methanoate can be followed by changes in spectra.

(i) State **one** similarity and **one** difference you would expect in the infrared (IR) spectra of methanoic acid and methyl methanoate in the region of 1500–3500 cm^{-1}. Use section 26 of the data booklet. [2]

Similarity: . . . . . .

. . . . . .

Difference: . . . . . .

. . . . . .

(ii) Deduce, referring to the integration trace, whether the ^{1}H NMR spectrum shown is that of methanoic acid or methyl methanoate. [1]

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Topic **Chem 11 Q# 128/** IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)
NOT with 2023/w/TZ0/Paper 2/Higher Level/Q2(c)

2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium

$$CO_2(g) + H_2(g) \rightleftharpoons HCOOH(g)$$

(c) Bond enthalpies are a useful way of finding approximate enthalpy changes for reactions.

(i) Determine the enthalpy change, $\Delta H^\ominus$, of this reaction, using section 11 of the data booklet.

Answer fir (c)(i) which is needed for (c)(ii):

«bond breaking» C=O + H-H / 804 + 436 / 1240 «kJ» ✓

«bond forming» C-H + C-O + O-H / 414 + 358 + 463 / 1235 «kJ» ✓

$\Delta H^\ominus$ «= 1240 – 1235» = «+»5 «kJ mol^{-1}» ✓

(ii) Assuming a 0.1 % uncertainty for each bond enthalpy, determine the resultant percentage uncertainty of the calculated enthalpy change of the reaction. [2]

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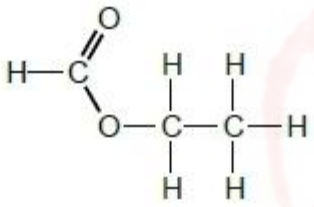
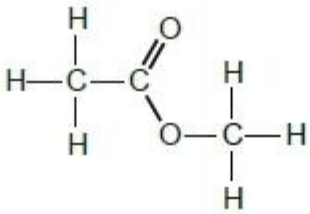
Topic **Chem 11 Q# 129/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7. The structural formulae of two esters of formula $C_3H_6O_2$ are shown.

Ethyl methanoate



Methyl ethanoate



(a) (i) Deduce the number of signals you would expect to find in the ^{1}H NMR spectrum of each compound. [1]

Name	Number of signals
Ethyl methanoate	. . . . .
Methyl ethanoate	. . . . .

(ii) Outline why infrared spectroscopy is not used to differentiate between the two esters. [1]

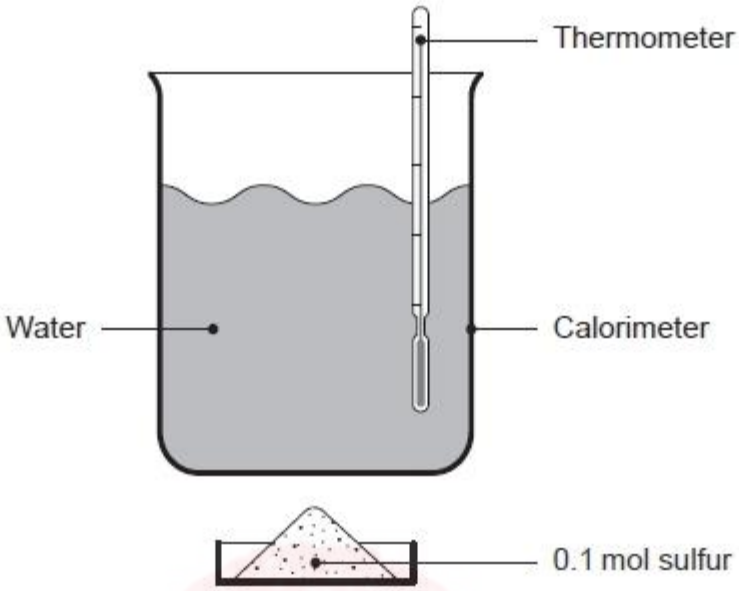
. . . . . .

. . . . . .

Topic **Chem 11 Q# 130/** IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. The element sulfur has many industrial uses.

(b) The combustion of 0.1 moles of sulfur (S) was demonstrated in a school laboratory using the following apparatus in a fume cupboard.



(ii) Suggest the major source of systematic error in this experiment and an improvement to reduce this error. [2]

Source of systematic error: .....

.....

Improvement: .....

.....

(iii) Calculate the percentage uncertainty in the temperature change to **two** significant figures. [1]

.....

.....

.....

(iv) Suggest **one** way of reducing the percentage uncertainty in this experiment. [1]

.....

.....

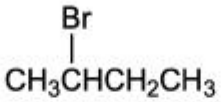
.....

(v) Calculate the overall percentage error of this experiment. Use part (b)(i) and section 13 of the data booklet. (If you did not obtain an answer for part (b)(i) use $-50.0\,kJ\,mol^{-1}$, but this is not the correct value.) [1]

.....

.....

(g) (i) Deduce the number of signals and the ratio of areas under the signals in the ^{1}H NMR spectrum of 2-bromobutane. [2]



Number of signals:

. . . . . .

Ratio of areas:

. . . . . .

(ii) Identify the splitting pattern of the signal of the hydrogen atoms on the circled carbon atoms in 2-bromobutane. [2]

Splitting pattern of the signal of the hydrogen atoms in circle **A**:

. . . . . .

Splitting pattern of the signal of the hydrogen atoms in circle **B**:

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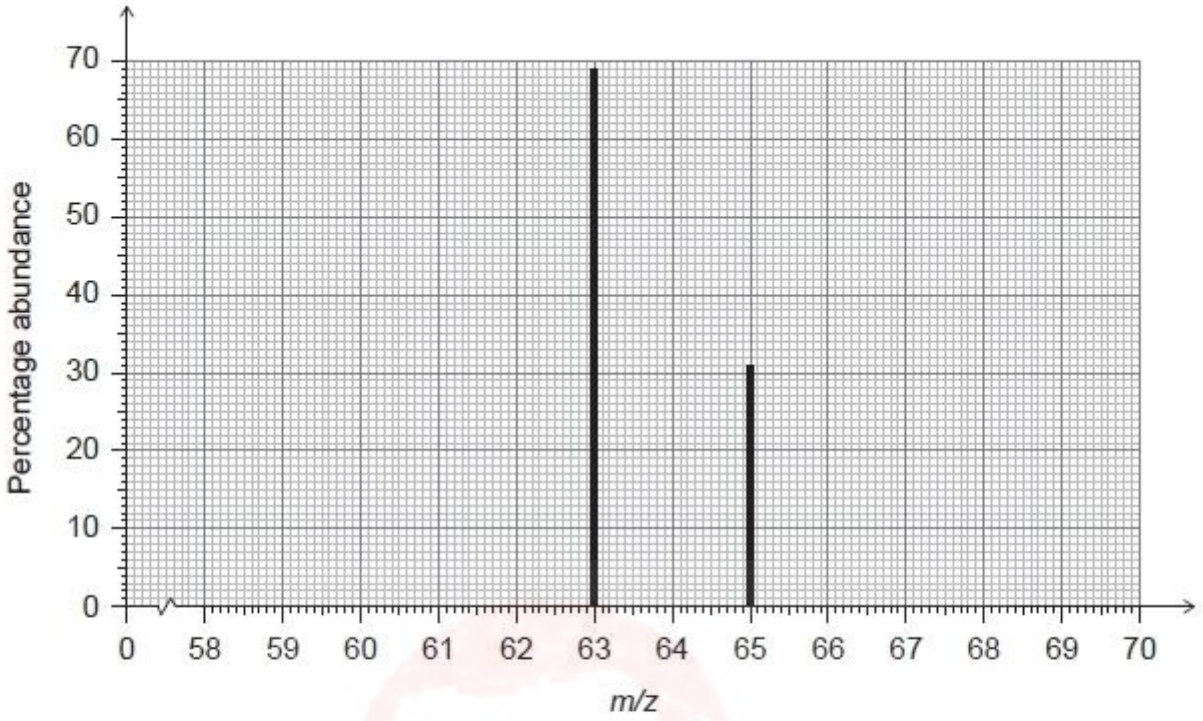
3. Consider the following reaction:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$

(b) The mass spectrum for copper is shown:



Show how a relative atomic mass of copper of 63.62 can be obtained from this mass spectrum. [1]

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Topic **Chem 11 Q# 133/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6. Nitric acid is usually produced by the oxidation of ammonia.

(iv) State a technique used to determine the length of the bonds between N and O in solid HNO_3. [1]

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Topic **Chem 11 Q# 134/** IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. When heated in air, magnesium ribbon reacts with oxygen to form magnesium oxide.

(b) The reaction in (a)(i) was carried out in a crucible with a lid and the following data was recorded:

Mass of crucible and lid = 47.372 ±0.001 g

Mass of crucible, lid and magnesium ribbon before heating = 53.726 ±0.001 g

Mass of crucible, lid and product after heating = 56.941 ±0.001 g

(ii) Determine the percentage uncertainty of the mass of product after heating. [2]

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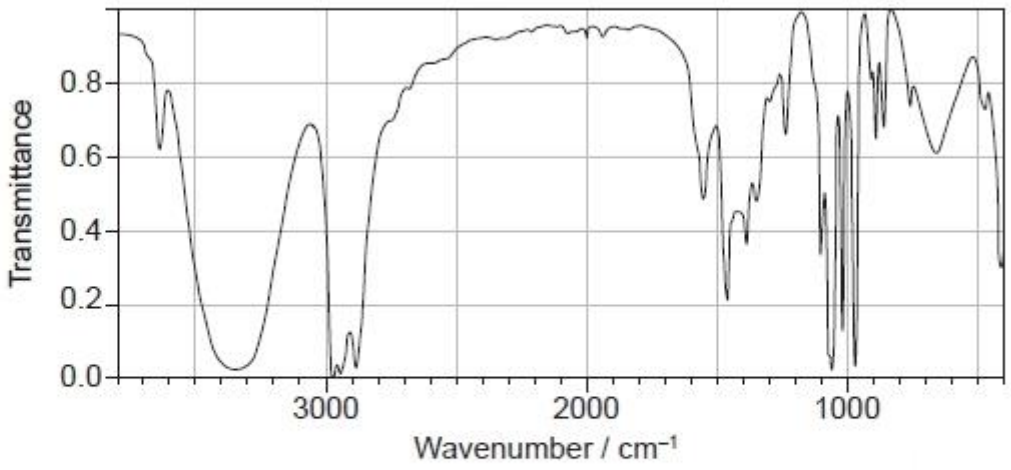
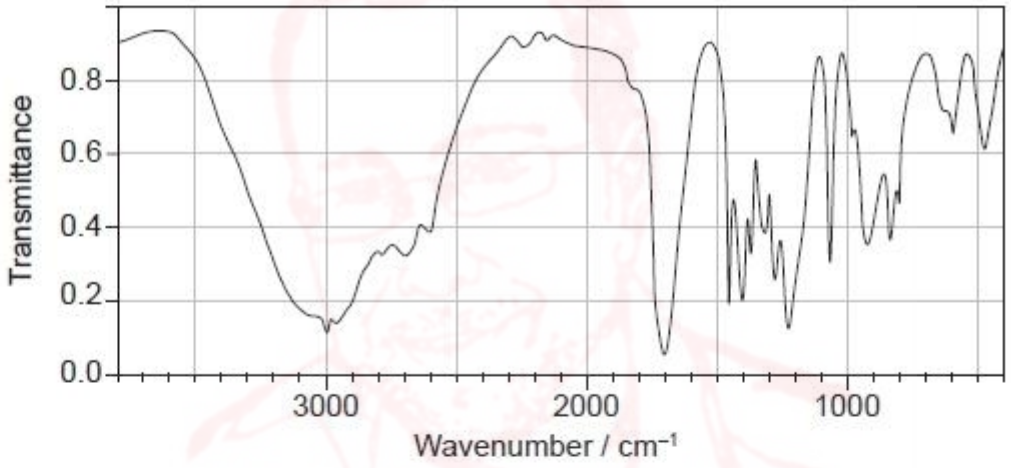
The following spectrums show the Infrared spectra of propan-1-ol, propanal and propanoic acid.

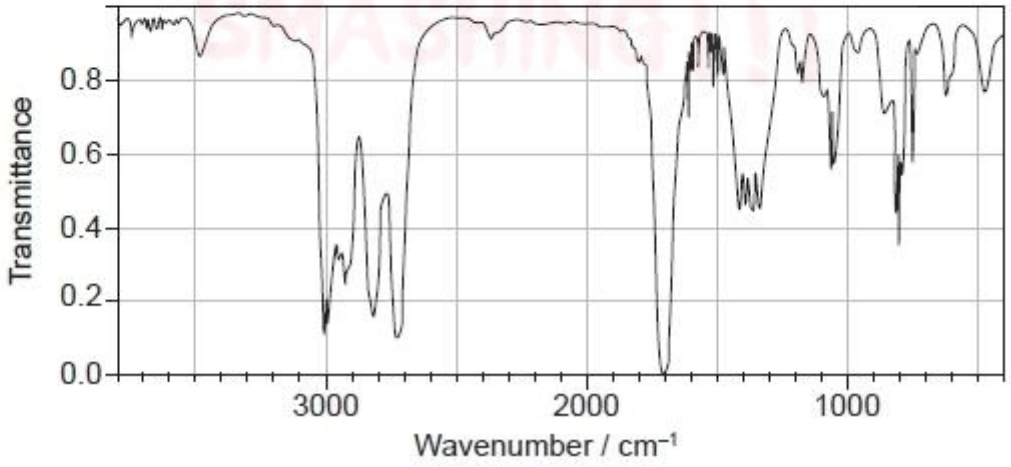
Spectrum A



Spectrum B



Spectrum C



(c) Identify each compound from the spectra given, use absorptions from the range of 1700 cm^{-1} to 3500 cm^{-1}. Explain the reason for your choice, referring to section 26 of the data booklet. [3]

Spectrum	Identity	Reason
A	....	....
B	....	....
C	....	....

(d) Predict the number of ^1H NMR signals, and splitting pattern of the $-CH_3$ seen for propanone (CH_3COCH_3) and propanal (CH_3CH_2CHO). [2]

Spectrum	Number of signals	Splitting pattern of $-CH_3$
propanone	.....	.....
propanal	.....	.....

(e) Predict the fragment that is responsible for a *m/z* of 31 in the mass spectrum of propan-1-ol. Use section 28 of the data booklet. [1]

.....

Topic **Chem 11 Q# 136/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. Ethanol is obtained by the hydration of ethene, C_2H_4.

(b) (i) Justify why ethene has only a single signal in its ^1H NMR spectrum. [1]

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(ii) Deduce the chemical shift of this signal. Use section 27 of the data booklet. [1]

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Topic **Chem 11 Q# 137/** IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron may be extracted from iron (II) sulfide, FeS.

(d) Iron (II) sulfide, FeS, is ionically bonded.

(ii) State a technique that could be used to determine the crystal structure of the solid compound. [1]

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Topic **Chem 11 Q# 138/** IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5. A student performs a titration to determine the concentration of ethanoic acid, CH_3COOH, in vinegar using potassium hydroxide.

(f) Potassium hydroxide solutions can react with carbon dioxide from the air. The solution was made one day prior to using it in the titration.

(i) State the type of error that would result from the student's approach. [1]

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(ii) Predict, giving a reason, the effect of this error on the calculated concentration of ethanoic acid in 5(e). [2]

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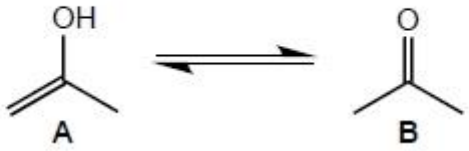
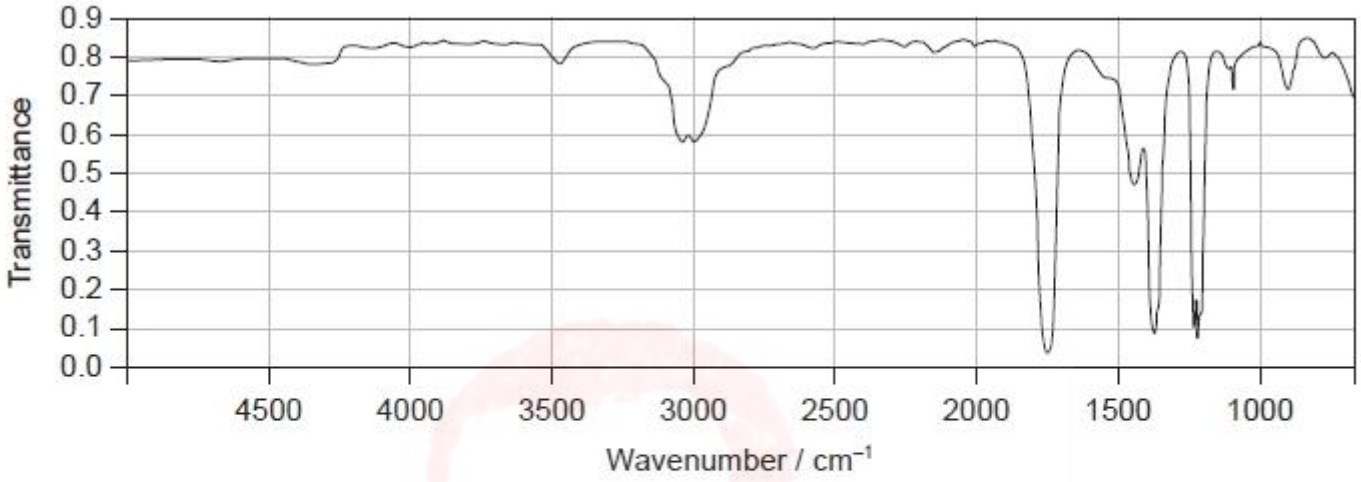
2. Compound **A** is in equilibrium with compound **B**.



(d) The IR spectrum of one of the compounds is shown:



Deduce, giving a reason, the compound producing this spectrum. [1]

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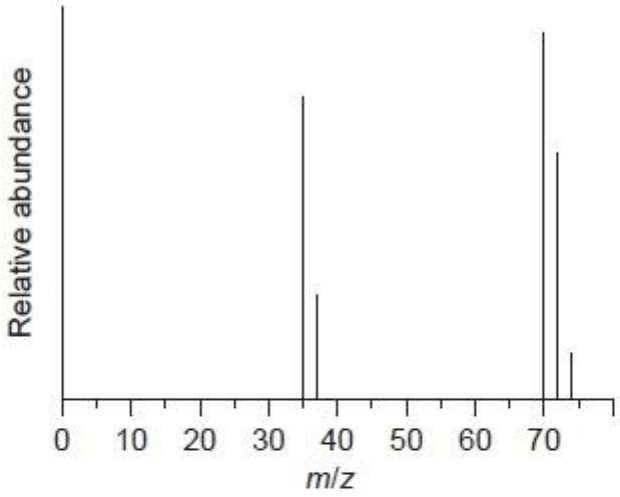
Answer **all** questions. Answers must be written within the answer boxes provided.

1. Chlorine undergoes many reactions.

(Question 1 continued)

(iv) The mass spectrum of chlorine is shown.



Outline the reason for the two peaks at $m/z = 35$ and 37. [1]

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(v) Explain the presence and relative abundance of the peak at $m/z = 74$. [2]

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(iv) Ethoxyethane (diethyl ether) can be used as a solvent for this conversion. Draw the structural formula of ethoxyethane. [1]

(v) Deduce the number of signals and chemical shifts with splitting patterns in the ^{1}H NMR spectrum of ethoxyethane. Use section 27 of the data booklet. [3]

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Mark Scheme

Q# 1/ Chem IB Chem/**2020/s**/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)
Was not published

Q# 2/ Chem 1 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3	b		*ALTERNATIVE 1* expected yield «=2.83 × $\frac{60.06}{46.03}$» = 3.69 «g» ✓ percentage yield «=100 × $\frac{1.72}{3.69}$» = 46.6 «%» ✓ *ALTERNATIVE 2* «amount of methanoic acid used = $\frac{2.83}{46.03}$ =» 0.0615 «mol» ✓ «expected amount of methyl methanoate = 0.0615 mol» «actual amount of methyl methanoate = $\frac{1.72}{60.06}$ = 0.0286 mol» percentage yield «=$\frac{0.0286}{0.0615}$ × 100» = 46.5% ✓	*Award [2] for correct final answer.* *Award [0] for 60.8% (simple ratio of starting and final masses).*	2

Q# 3/ Chem 1 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1	b		M_r «= 12.01 + (2 x 1.01) + (2 x 16.00) »= 46.03 ✓ «M_r of O in molecule = 2 x 16.00 = 32.00» «percentage O = 100 × $\frac{32.00}{46.03}$ » = 69.52% ✓	*Award [2] for correct final answer.*	2

Q# 4/ Chem 1 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	(a)	(ii)	«100-(7.09+5.11+16.22+14.91) =» 56.67 «%» ✓		1

5.	(a)	(iii)	n(N): 7.09g/14.01g mol^{-1}, n(H): 5.11g/1.01 g mol^{-1}, n(S): 16.22g/32.07 g mol^{-1}, n(Co): 14.91g/58.93 g mol^{-1} and n(O): 56.67g/16.00 g mol^{-1} *OR* n(N): 0.506, n(H): 5.06, n(S): 0.506, n(Co): 0.253 and n(O): 3.54 ✓ 0.506/0.253, 5.06/0.253, 0.506/0.253, 0.253/0.253, 3.54/0.253 *OR* 2.00, 20.0, 2.00, 1.00 14.00 ✓ $N_2H_{20}S_2CoO_{14}$ ✓	*Award [3] for the correct final formula.*	3
5.	(a)	(iv)	$(NH_4)_2Co(SO_4)_2{\cdot}6H_2O$ *OR* $Co(NH_4)_2(SO_4)_2{\cdot}6H_2O$ ✓	*Accept $(NH_4)_2Co(SO_4)_2(H_2O)_6$.*	1
5.	(b)	(i)	$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightleftharpoons BaSO_4(s)$ ✓	*Accept single arrow in place of equilibrium sign.*	1
5.	(b)	(ii)	«1.20g/395.29 g mol^{-1} salt = 2 x 3.04 x10^{-3} «mol» SO_4^{2-} =» 6.08 x x10^{-3} «mol» ✓ «233.40 g mol^{-1} x 6.08 x10^{-3} =» 1.42«g» ✓ *OR* «(1.20g/400) x 2 g mol^{-1} =» 6.00 x 10^{-3} «mol» ✓ «233.40 g mol^{-1} x 6.00 x10^{-3} =» 1.40«g» ✓	*Award [2] for correct final answer.* *Accept x2 in any step.* *Award [1] for half the answer, 0.70«g».*	2

Q# 5/ Chem 1 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	(a)		«0.40% × 500.0g = » 2.0 «g» ✓ «2.0 g × $\frac{1\ mol\ S}{32.07\ g}$ = 0.062 $mol\ of\ S$» = 0.062 «mol of SO_2» ✓	*Award [2] for correct final answer.* *Accept 0.063 «mol».*	2

Q# 6/ Chem 1 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(a)		«$\%N = \frac{2\times14.01\ g\ mol^{-1}}{(2\times14.01\ g\ mol^{-1}+4\times1.01\ g\ mol^{-1}+3\times16.00\ g\ mol^{-1})} \times 100\%$ =» 35.00«%» ✓		1

Q# 7/ Chem 1 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	a	i	$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$ ✓	*Do not accept equilibrium arrows.* *Ignore state symbols.*	1
1.	b	i	$\langle\langle \frac{53.726\ g - 47.372\ g}{24.31\ g\ mol^{-1}} = \frac{6.354\ g}{24.31\ g\ mol^{-1}} \rangle\rangle$ = 0.2614 «mol» ✓		1
1.	b	iii	$\langle\langle 0.2614\ mol \times (24.31\ g\ mol^{-1} + 16.00\ g\ mol^{-1}) = 0.2614\ mol \times 40.31\ g\ mol^{-1} \rangle\rangle$ = 10.536 «g» ✓ $\langle\langle 100 \times \frac{9.569\ g}{10.536 g} = 90.822 \rangle\rangle$ = 91 «%» ✓	*Award 0.2614 mol x 40.31 g mol^{-1}.* *Accept alternative methods to arrive at the correct answer.* *Accept final answer in the range 90.5-91.5%.* *[2] for correct final answer.*	2
1.	c	i	yes *AND* «each Mg combines with $^2/_3$ N, so» mass increase would be 14x$^2/_3$ which is less than expected increase of 16x *OR* 3 mol Mg would form 101g of Mg_3N_2 but would form 3 x MgO = 121 g of MgO *OR* 0.2614 mol forms 10.536 g of MgO, but would form 8.796 g of Mg_3N_2 ✓	*Accept Yes **AND** "the mass of N/N_2 that combines with each g/mole of Mg is lower than that of O/O_2"* *Accept YES **AND** "molar mass of nitrogen less than of oxygen".*	1
1.	c	ii	incomplete reaction *OR* Mg was partially oxidised already *OR* impurity present that evaporated/did not react ✓	*Accept "crucible weighed before fully cooled".* *Accept answers relating to a higher atomic mass impurity consuming less O/O_2.* *Accept "non-stoichiometric compounds formed".* *Do not accept "human error", "wrongly calibrated balance" or other non-chemical reasons.* *If answer to (b)(iii) is >100%, accept appropriate reasons, such as product absorbed moisture before being weighed.*	1
1.	d	i	«1» $Mg_3N_2(s) + 6\ H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(aq)$ ✓		1

Q# 8/ Chem 1 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	a		«$\frac{8.802\ g}{44.01\ g\ mol^{-1}}$ =» 0.2000 «mol of C/CO_2» ***AND*** «$\frac{3.604\ g}{18.02\ g\ mol^{-1}}$ =» 0.2000 «mol of H_2O» / 0.4000 «mol of H» ***OR*** «$\frac{8.802\ g}{44.01\ g\ mol^{-1}}$ $\times 12.01\ g\ mol^{-1}$ =» 2.402 «g of C» ***OR*** «$\frac{3.604\ g}{18.02\ g\ mol^{-1}}$ $\times 2 \times 1.01\ g\ mol^{-1}$ =» 0.404 «g of H» ✓ «4.406 g – 2.806 g» = 1.600 «g of O» ✓ «$\frac{2.402\ g}{12.01\ g\ mol^{-1}}$ = 0.2000 mol C; $\frac{0.404\ g}{1.01\ g\ mol^{-1}}$ = 0.400 mol H; $\frac{1.600\ g}{16.00\ g\ mol^{-1}}$ = 0.1000 mol O» C_2H_4O ✓	*Award **[3]** for correct final answer.*	3
1.	b		«$\frac{88.12\ g\ mol^{-1}}{44.06\ g\ mol^{-1}}$ = 2» $C_4H_8O_2$ ✓	*C_2S_2 if CS used.*	1

Q# 9/ Chem 1 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	a		1:2 ✓	*Accept 2 Fe3+: 1 Fe2+* *Do not accept 2:1 only*	1

Q# 10/ Chem 1 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	b	i	«$\frac{2.67\ g}{86.94\ g\ mol^{-1}}$ =» 0.0307 «mol» ✓		1
1.	b	ii	«n_{HCl} = 2.00 mol dm^{-3} x 0.2000 dm^3» = 0.400 mol ✓ «$\frac{0.400}{4}$ =» 0.100 mol ***AND*** MnO_2 is the limiting reactant ✓	*Accept other valid methods of determining the limiting reactant in M2.*	2
1.	b	iii	«0.0307 mol × 4 = 0.123 mol» «0.400 mol – 0.123 mol =» 0.277 «mol» ✓		1
1.	b	iv	«0.0307 mol × 22.7 $dm^3\ mol^{-1}$ =» 0.697 «dm^3» ✓	*Accept methods employing $pV = nRT$.*	1

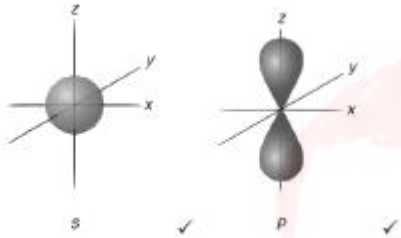
Q# 11/ Chem 2 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5	h		frequency /wavelength of «the radiation at» convergence limit «is proportional to the ionization energy» ✓	*Accept highest frequency/shortest wavelength.*	1

Q# 12/ Chem 2 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4	c	i	0.9x32 + 0.01x33 + 0.04x34 + 0.05x36 ✓ «A_r =» 32.29 ✓	*Award [2] for correct final answer.* *Do not accept 32.07 which is the data booklet value.* *M2 can only be awarded for answer with two decimal places.*	2
4	c	ii	amount of $^{36}_{16}S$ «= $\frac{0.0100}{100} \times \frac{1.00}{32.07}$ » = 3.12×10^{-6} «mol»✓ number of atoms «= 3.12×10^{-6} mol × 6.02×10^{23} mol^{-1}» = 1.88×10^{18} ✓	*Award [2] for correct final answer.*	2

Q# 13/ Chem 2 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(a)	(i)	 arrows *AND identifies 2s AND 2p sub orbitals* ✓	*Accept "hooks" to represent the electrons.*	1
2.	(a)	(ii)	 ✓ ✓	$P_{x,y}$ or $_z$ *can be used.* *M2 cannot be awarded if labels of orbital types are missing or incorrect* *Node of p orbital must be at the origin*	2

Q# 14/ Chem 2 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	(a)		$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ *OR* $[Ar]3d^6$ ✓		1
3.	(c)		Cu^{2+} *AND* fewer shielding electrons/less electron-electron repulsion «from same nuclear charge» *OR* Cu^{2+} *AND* larger effective nuclear charge *OR* Cu^{2+} *AND* more energy required to remove electron from positive ion than neutral parent atom *OR* Cu^{2+} *AND* smaller radius *OR* Cu^{2+} *AND* electron is being lost from a lower energy/inner/3d orbital ✓		1

3.	(d)		*Alternative 1* «$E = 745\ kJ\ mol^{-1} \times \frac{1\ mol}{6.02 \times 10^{23} atoms} =$ » 1.24×10^{-21}«$kJ\ atom^{-1}$» ✓ «$E = h\nu$» «$1.24 \times 10^{-21} kJ \times \frac{1000\ J}{1\ kJ} = 6.63 \times 10^{-34} Js \times \nu$» «$\nu =$ » 1.87×10^{15}«s^{-1}» ✓ *Alternative 2* «$E=h\nu$» «$745 \times 10^3\ J\ mol^{-1} = 6.63 \times 10^{-34}\ J\ s \times \upsilon$ » «$\upsilon =$» 1.12×10^{39}«$s^{-1}\ mol^{-1}$» ✓ « $= \frac{1.12 \times 10^{39} s^{-1}}{6.02 \times 10^{23}}$» $= 1.87 \times 10^{16}$«s^{-1}» ✓	*Award [2] for correct final answer.*	2
3.	(e)		«iron atoms have 4» unpaired electrons ✓ aligns with a magnetic field/paramagnetic *OR* has a magnetic moment *OR* ferromagnetic ✓	*For M1 accept diagrams showing unpaired electrons.*	2

Q# 15/ Chem 2 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(e)	(ii)	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ / $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ *OR* $[Ar]4s^1 3d^{10}$ / $[Ar]3d^{10} 4s^1$ ✓		1

Q# 16/ Chem 2 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

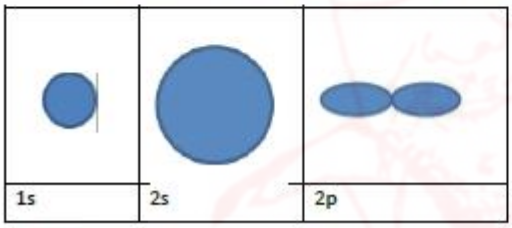
6.	a	i	2p ↑ ↑ ↑ 2s ↑↓ 1s ↑↓ ✓	*Accept all 2p electrons pointing downwards.* *Accept half arrows instead of full arrows.*	1

Q# 17/ Chem 2 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	e	i	*Protons:* 7 ***AND*** *Neutrons:* 7 ***AND*** *Electrons:* 10 ✓		1
1.	e	ii	isotope«s» ✓		1
1.	e	iii	nitride ***AND*** smaller nuclear charge/number of protons/atomic number ✓		1
1.	e	iv	nitrogen ***AND*** electron lost from first *«energy»* level/s sub-level/s-orbital ***AND*** magnesium from p sub-level/p-orbital/second *«energy»* level *OR* nitrogen ***AND*** electron lost from lower level «than magnesium» ✓	*Accept "nitrogen **AND** electron lost closer to the nucleus «than magnesium»".*	1

1.	f		*Any two of:* subatomic particles «discovered» *OR* particles smaller/with masses less than atoms «discovered» *OR* «existence of» isotopes «same number of protons, different number of neutrons»✓ charged particles obtained from «neutral» atoms *OR* atoms can gain or lose electrons «and become charged» ✓ atom «discovered» to have structure ✓ fission *OR* atoms can be split ✓	*Accept atoms can undergo fusion «to produce heavier atoms».* *Accept specific examples of particles.* *Award [2] for "atom shown to have a nucleus with electrons around it" as both M1 and M3.*	2

Q# 18/ Chem 2 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

9.	a		*Most $^4He^{2+}$ passing straight through:* most of the atom is empty space ***OR*** the space between nuclei is much larger than $^4He^{2+}$ particles ***OR*** nucleus/centre is «very» small «compared to the size of the atom» ✓ *Very few $^4He^{2+}$ deviating largely from their path:* nucleus/centre is positive «and repels $^4He^{2+}$ particles» ***OR*** nucleus/centre is «more» dense/heavy «than $^4He^{2+}$ particles and deflects them» ***OR*** nucleus/centre is «very» small «compared to the size of the atom» ✓	*Do **not** accept the same reason for both **M1** and **M2**.* *Accept "most of the atom is an electron cloud" for **M1**.* *Do **not** accept only "nucleus repels $^4He^{2+}$ particles" for **M2**.*	2
9.	b	i	 1s ***AND*** 2s as spheres ✓ one or more 2p orbital(s) as figure(s) of 8 shape(s) of any orientation (p_x, p_y p_z) ✓		2
9.	b	ii	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ ***OR*** $[Ar]\ 4s^1 3d^{10}$ ✓	*Accept configuration with 3d before 4s.*	1

Q# 19/ Chem 2 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	b		«$\Delta E = h\nu = 6.63 \times 10^{-34}$ J s × 5.09×10^{14} s^{-1} =» 3.37×10^{-19} «J» ✓		1

Q# 20/ Chem 2 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	b	i	mass «spectroscopy»/MS ✓		
3.	b	ii	<table><tr><th></th><th>Protons</th><th></th><th>Neutrons</th><th></th><th>Electrons</th><th></th></tr><tr><td></td><td>26</td><td rowspan="2">AND</td><td>28</td><td rowspan="2">AND</td><td>26</td><td>✓</td></tr><tr><td></td><td>26</td><td>30</td><td>23</td><td>✓</td></tr></table>	*Award [1 max] for 4 correct values.*	2

Q# 21/ Chem 2 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	d	iii	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ ✓	*Do not accept "[Ne] $3s^2\ 3p^6$".*	1
1.	d	iv	«valence» electrons further from nucleus/extra electron shell/ electrons in third/3s/3p level «not second/2s/2p»✓	*Accept 2,8 (for O^{2-}) and 2,8,8 (for S^{2-})*	1
1.	d	v	allows them to explain the properties of different compounds/substances *OR* enables them to generalise about substances *OR* enables them to make predictions ✓	*Accept other valid answers.*	1
1.	e	i	$4FeS(s) + 7O_2(g) \rightarrow 2Fe_2O_3(s) + 4SO_2(g)$ ✓	*Accept any correct ratio.*	1
1.	e	ii	+6 *OR* −2 to +4 ✓	*Accept "6/VI".* *Accept "−II, 4/+4/IV".* Do not accept 2- to 4+.	1
1.	e	iii	sulfur dioxide/SO_2 causes acid rain ✓	*Accept sulfur dioxide/SO_2/dust causes respiratory problems* *Do not accept just "causes respiratory problems" or "causes acid rain".*	1
1.	f		disrupts the regular arrangement «of iron atoms/ions» *OR* carbon different size «to iron atoms/ions» ✓ prevents layers/atoms sliding over each other ✓		2

Q# 22/ Chem 2 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	a		«$E = \frac{745\,000\ J\ mol^{-1}}{6.02 \times 10^{23}\ mol^{-1}}$ =» 1.24×10^{-18} J ✓ «$E = h\nu$» «$1.24 \times 10^{-18}\ J = 6.63 \times 10^{-34}\ J\ s \times \nu$» $\nu = 1.87 \times 10^{15}$ «s^{-1}/Hz» ✓	*Award [2] for correct final answer.* *Award [1] for 1.12x10^{39} «Hz».*	2

Q# 23/ Chem 2 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

Question			Answers	Notes	Total
1.	a	i	$1s^2 2s^2 2p^6 3s^2 3p^5$ ✓	*Do not accept condensed electron configuration.*	1
1.	a	ii	Cl^- *AND* more «electron–electron» repulsion ✓	*Accept Cl^- AND has an extra electron.*	1
1.	a	iii	Cl has a greater nuclear charge/number of protons/Z_{eff} «causing a stronger pull on the outer electrons» ✓ same number of shells *OR* same «outer» energy level *OR* similar shielding ✓		2

Q# 24/ Chem 3 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5	e	i	has a partially filled d sub-shell «in a common oxidation state» ✓		1
5	e	ii	IE values of Fe gradually increase *AND* IE values of Be show a sudden rise ✓ first and second ionization energies close together therefore do not form a +1 oxidation state / singly charged ion ✓ further IEs of Fe are close to second IE, so the oxidation state/number of electrons Fe loses can vary «according to the oxidizing agents present» ✓	*Accept Be always loses 2 electrons / forms Be^{2+} / only has +2 oxidation state for M2.*	3
5	g		nuclear charge / number of protons increases «for both» ✓ Li and Be «outer electrons have» same subshell/shielding ✓ electron in B lost from p-subshell whereas that in Be lost from s-subshell ✓ «outer electron in» B/p-subshell experiences greater shielding / has higher energy ✓	*Do not accept explanations invoking distance of electrons from nucleus.*	4

Q# 25/ Chem 3 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

9.	(a)		Zn^{2+} does not form coloured compounds/ has a complete d subshell/orbital ✓ 500 nm/«the setting on the colorimeter» in visible region *AND* no absorbance will be seen ✓		2

Q# 26/ Chem 3 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(b)		valence electron further from nucleus/«atomic» radius larger «down the group» ✓ «electron» more shielded/ less attractive force/easier to remove ✓		2

Q# 27/ Chem 3 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	e		*ALTERNATIVE 1* *Property:* variable oxidation state ✓ *Comparison:* Mn compounds can exist in different valencies/oxidation states *AND* Mg has a valency/oxidation state of +2 in all its compounds ✓ *ALTERNATIVE 2* *Property:* coloured ions/compounds/complexes ✓ *Comparison:* Mn ions/compounds/complexes coloured *AND* Mg ions/compounds white/«as solids»/colourless «in aqueous solution» ✓ *ALTERNATIVE 3* *Property:* catalytic activity ✓ *Comparison:* «many» Mn compounds act as catalysts *AND* Mg compounds do not «generally» catalyse reactions ✓	*Accept valency.* *Accept for second statement "Mg «always» has the same oxidation state".* *Accept Mn forms coloured ions/compounds/complexes and Mg does not.* *For any property accept a correct specific example, for example manganate(VII) is purple.* *Do not accept differences in atomic structure, such as partially filled d sub-levels, but award ECF for a correct discussion.*	2

Q# 28/ Chem 3 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	a	ii	aluminium/Al ✓		1

Q# 29/ Chem 3 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

9.	b	iii	chloride is lower in the spectrochemical series ✓ «ligand cause» decreased/lesser splitting «in d-orbitals compared to H_2O»✓ frequency/energy of light absorbed is decreased ***OR*** wavelength of light absorbed is increased ✓	*Accept chloride a weaker ligand than water/produces a smaller energy difference than water for **M1**.* *Award **[2 max]** for mentioning splitting of orbitals is changed **AND** frequency/ wavelength/energy of light absorbed are different/changed without mentioning correct decrease or increase.*	3

Q# 30/ Chem 3 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

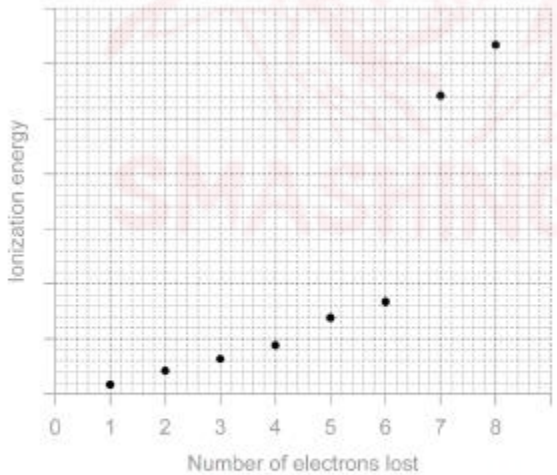
2.	a		increasing number of protons ***OR*** increasing nuclear charge ✓ «atomic» radius/size decreases ***OR*** same number of shells/electrons occupy same shell ***OR*** similar shielding «by inner electrons» ✓		2

Q# 31/ Chem 3 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	f		« Zn^{2+}» has a full d-shell *OR* does not form « ions with» an incomplete d-shell	*Do not accept "Zn is not a transition metal".* *Do not accept zinc atoms for zinc ions.*	1

3.	g		ligands donate pairs of electrons to metal ions *OR* forms coordinate covalent/dative bond✓ ligands are Lewis bases *AND* metal «ions» are Lewis acids ✓		2

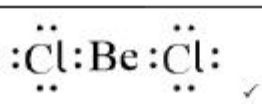
Q# 32/ Chem 3 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	b		*Any two of:* forms acidic oxides «rather than basic oxides» ✓ forms covalent/bonds compounds «with other non-metals» ✓ forms anions «rather than cations» ✓ behaves as an oxidizing agent «rather than a reducing agent» ✓	*Award [1 max] for 2 correct non-chemical properties such as non-conductor, high ionisation energy, high electronegativity, low electron affinity if no marks for chemical properties are awarded.*	2
1.	c		 two regions of small increases ***AND*** a large increase between them✓ large increase from 6th to 7th ✓	*Accept line/curve showing these trends.*	2

Q# 33/ Chem 3 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	b		orange light is absorbed «and the complementary colour is observed» ✓ *Any TWO from:* partially filled d-orbitals ✓ «ligands/water cause» d-orbitals «to» split ✓ light is absorbed as electrons move to a higher energy orbital «in d–d transitions» *OR* light is absorbed as electrons are promoted ✓ energy gap corresponds to «orange» light in the visible region of the spectrum ✓		3

Q# 34/ Chem 4 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

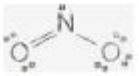
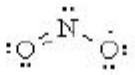
5	a	ii	«between a lattice of» cations ***AND*** delocalized electrons ✓	*Do not accept metallic bonding on its own.* *Accept "sea of electrons" instead of "delocalized electrons".*	1
5	b	i	«contains» mobile/free moving ions ✓	*Accept has ions that can carry an «electric» current/charge.*	1
5	b	ii	*Electrode:* cathode ***AND*** *Polarity:* negative ✓		1
5	c	i	 ✓		1
5	c	ii	«Be» does not have complete valence shell ✓	*Accept incomplete octet / exception to octet rule / electron deficient.*	1
5	d	i	sp^2 ✓	*Accept the "2" as a subscript or normal character.*	1
5	g		nuclear charge / number of protons increases «for both» ✓ Li and Be «outer electrons have» same subshell/shielding ✓ electron in B lost from p-subshell whereas that in Be lost from s-subshell ✓ «outer electron in» B/p-subshell experiences greater shielding / has higher energy ✓	*Do not accept explanations invoking distance of electrons from nucleus.*	4
5	h		frequency /wavelength of «the radiation at» convergence limit «is proportional to the ionization energy» ✓	*Accept highest frequency/shortest wavelength.*	1

Q# 35/ Chem 4 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4	b		*Molecular geometry CS_2:* linear ***AND*** *Molecular geometry H_2S:* bent/V-shaped ✓ *Reason for difference:* «central atom in» H_2S has «two» lone/non-bonding «electron» pairs *OR* CS_2 has two ***AND*** H_2S has four electron domains/negative charge centres «around central atom» ✓	*Do not accept diagrams for M1 or M2.* *Accept central atom sp hybridized in CS_2 **AND** sp^3 hybridized in H_2S for M2.*	2

Q# 36/ Chem 4 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q9. www.SmashingScience.org :o)

9.	(b)	(i)	«$O_3(g) \rightarrow O_2(g) + O^{\bullet}(g)$» $NO^{\bullet}(g) + O_3(g) \rightarrow NO_2^{\bullet}(g) + O_2(g)$ ✓ $NO_2^{\bullet}(g) + O_3(g) \rightarrow NO^{\bullet}(g) + 2O_2(g)$ *OR* $NO_2^{\bullet}(g) + O^{\bullet}(g) \rightarrow NO^{\bullet}(g) + O_2(g)$ ✓	*Accept radicals without • if consistent throughout.*	2

9.	(b)	(ii)	«$v = E/h$ = 4.02 x 10^{-19}/6.63 x 10^{-34} =» 6.06 x 10^{14} «Hz» ✓		1
9.	(b)	(iii)	 1 2  1 2 ✓		1

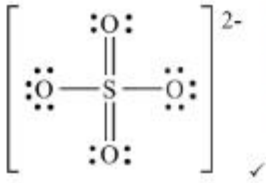
	Structure A	Structure B
Oxygen 1	0	0
Nitrogen	+1	0
Oxygen 2	-1	0

9.	(b)	(iv)	No *AND* Structure B has all atoms of formal charge 0✓		1

Q# 37/ Chem 4 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	(a)	(iii)	significant/large/0.8 difference in electronegativity/oxygen more electronegative ✓ oxygen «dipole partially» negative/sulfur «dipole partially» positive *OR* oxygen more negative/higher electron density «around it than sulfur»✓	Accept suitable diagram showing the O–S dipole.	2

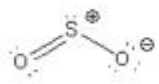
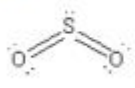
Q# 38/ Chem 4 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

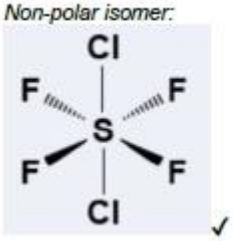
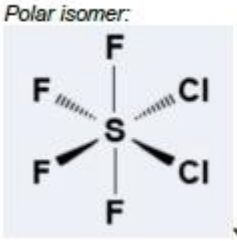
5.	(a)	(i)	 ✓	*Accept any combination of dots, crosses and lines.* *Double bonds do not have to be opposite each other.* *Do not penalise missing square brackets.*	1

Q# 39/ Chem 4 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

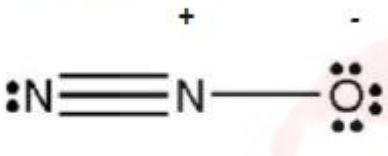
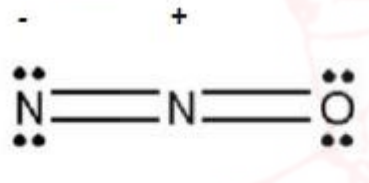
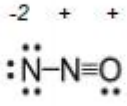
2.	(c)	(i)	tetrahedral ✓		1
2.	(c)	(ii)	 ✓ ✓	*Accept a combination of dots /crosses /lines in the Lewis structure* *Lone pair not required for shape*	2
2.	(c)	(iii)	ammonia has intermolecular/IMF hydrogen bonds «phosphine does not» ✓ phosphine «and ammonia» dipole-dipole/London dispersion forces/instantaneous dipole attractions/Van der Waals forces ✓ hydrogen bonds stronger ✓	*Accept converse argument.* *Award 1 for* stating that NH_3 is more polar than phosphine so the dipole-dipole forces are stronger	3

Q# 40/ Chem 4 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

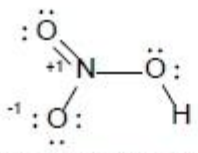
5.	(c)		 *OR*  ✓	*Do not penalise missing formal charges.*	1

5.	(f)		*Non-polar isomer:*  ✓ *Polar isomer:*  ✓	*Accept other methods of clearly representing 3D structure.*	2

Q# 41/ Chem 4 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(f)	(v)	*Alternative 1* *Lewis structure:*  ✓ +/1+/+1 on central N atom ***AND*** -/1-/-1 on O atom ✓ *Alternative 2* *Lewis structure:*  ✓ +/1+/+1 on central N atom ***AND*** -/1-/-1 on other N atom ✓ *Shape:* linear ✓	*Accept*  . *Formal charges are not needed for M1.* *Allow ECF for both formal charge and shape.* *Only award M3 if the shape corresponds to that expected for the Lewis structure given.*	3

Q# 42/ Chem 4 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	a	ii	 bonds and non-bonding pairs correct ✓ formal charges correct ✓	*Accept dots, crosses or lines to represent electron pairs.* *Do not accept resonance structures with delocalised bonds/electrons.* *Accept + and – sign respectively.* *Do not accept a bond between nitrogen and hydrogen.* *For an incorrect Lewis structure, allow ECF for non-zero formal charges.*	2
6.	a	iii	*Any three of:* two N-O same length/order ✓ delocalization/resonance ✓ N-OH longer «than N-O» *OR* N-OH bond order 1 ***AND*** N-O bond order 1½ ✓	*Award [2 max] if bond strength, rather than bond length discussed.* *Accept N-O between single and double bond **AND** N-OH single bond.*	3

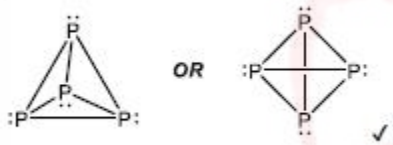
Q# 43/ Chem 4 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	d	iv	decreases/less polar ***AND*** electronegativity «of the halogen» decreases ✓	*Accept "decreases" **AND** a correct comparison of the electronegativity of two halogens.* *Accept "decreases" **AND** "attraction for valence electrons decreases".*	1

Q# 44/ Chem 4 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	g		<table><tr><th>Substance</th><th>Bond type</th><th>How the valence electrons produce these bonds</th></tr><tr><td>Magnesium</td><td>metallic ***AND***</td><td>delocalized «throughout lattice attracted to cations» ✓ *Accept reference to "sea"/flux of electrons «attracted to cations»*</td></tr><tr><td>Oxygen</td><td>covalent ***AND***</td><td>shared «between atoms» ✓</td></tr><tr><td>Magnesium oxide</td><td>ionic ✓</td><td>transferred «from magnesium to oxygen» ***OR*** lost by magnesium ***AND*** gained by oxygen ✓</td></tr></table>	*Award [1] for all bonding types correct.* *Award [1] for each correct description.* *Apply ECF for M2 only once.*	4

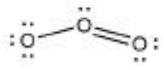
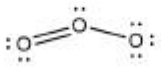
Q# 45/ Chem 4 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	a	i	 ***OR*** ✓	*Accept any diagram with each P joined to the other three.* *Accept any combination of dots, crosses and lines.*	1
3.	a	ii	$P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(l)$ ✓		1
3.	b	i	*Electron domain geometry:* tetrahedral ✓ *Molecular geometry:* trigonal pyramidal ✓ *Bond angle:* 100«°» ✓	*Accept any value or range within the range 91–108«°» for **M3**.*	3
3.	b	ii	*PCl_5 is non-polar:* symmetrical ***OR*** dipoles cancel ✓ *PCl_4F is polar:* P–Cl has a different bond polarity than P–F ✓ non-symmetrical «dipoles» ***OR*** dipoles do not cancel ✓	*Accept F more electronegative than /different electronegativity to Cl for **M2**.*	3

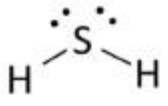
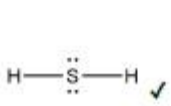
Q# 46/ Chem 4 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q10. www.SmashingScience.org :o)

10.	a	i	*Sigma (σ) bond:* overlap «of atomic orbitals» along the axial / intermolecular axis / electron density is between nuclei ***OR*** head-on/end-to-end overlap «of atomic orbitals» ✓ *Pi (π) bond:* overlap «of p-orbitals» above and below the internuclear axis/electron density above and below internuclear axis ***OR*** sideways overlap «of p-orbitals» ✓	*Accept a suitable diagram.*	2

Q# 47/ Chem 4 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7.	a	i	 OR  ✓	*Accept any combination of lines, dots or crosses to represent electrons.* *Do not accept structures that represent 1.5 bonds.*	1
7.	a	ii	both equal ✓ delocalization/resonance ✓	*Accept bond length between 121 and 148 pm/ that of single O-O bond and double O=O bond for M1.*	2

Q# 48/ Chem 4 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	a	i	 OR  ✓	*Accept any combination of lines, dots or crosses to represent electrons.*	1
2.	a	ii	bent/non-linear/angular/v-shaped✓		1

Q# 49/ Chem 4 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	a		mobile/delocalized <<sea of >> electrons		1
1.	d	i	electrostatic attraction ✓ between oppositely charged ions/between Fe^{2+} and S^{2-} ✓		2
1.	d	v	allows them to explain the properties of different compounds/substances *OR* enables them to generalise about substances *OR* enables them to make predictions ✓	*Accept other valid answers.*	1
1.	f		disrupts the regular arrangement «of iron atoms/ions» *OR* carbon different size «to iron atoms/ions» ✓ prevents layers/atoms sliding over each other ✓		2

Q# 50/ Chem 4 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	c		hydrogen bonding/bonds «and dipole–dipole and London/dispersion forces are present in» propan-2-ol ✓ dipole–dipole «and London/dispersion are present in» propanone ✓ propan-2-ol less volatile ***AND*** hydrogen bonding/bonds stronger «than dipole–dipole » *OR* propan-2-ol less volatile ***AND*** «sum of all» intermolecular forces stronger ✓		3
4.	d	v	electrostatic attraction ✓ between «a lattice of» metal/positive ions/cations ***AND*** «a sea of» delocalized electrons ✓	*Accept "mobile/free electrons".*	2

4.	d	vi	*Any of:* malleability/hardness *OR* «tensile» strength/ductility *OR* density *OR* thermal/electrical conductivity *OR* melting point *OR* thermal expansion ✓	*Do not accept corrosion/reactivity or any chemical property.* *Accept other specific physical properties.*	1

Q# 51/ Chem 4 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	a		*Electron domain geometry:* tetrahedral ✓ *Molecular geometry:* bent/V-shaped ✓		2
2.	b		sp^2 ✓		1
2.	c		σ-bonds: 3 *AND* π-bonds: 1 ✓		1
2.	d		B *AND* C=O absorption/1750 «cm^{-1}» *OR* B *AND* absence of O–H /3200–3600 «cm^{-1} absorption» ✓	*Accept any value between 1700–1750 cm^{-1}.*	1

Q# 52/ Chem 4 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	e	i	«*M*(CCl_2F_2) =» 120.91 «g mol^{-1}» ✓ $\frac{2 \times 35.45\,g\,mol^{-1}}{120.91\,g\,mol^{-1}} \times 100\,\% =$» 58.64 «%» ✓	*Award [2] for correct final answer.*	2
1.	e	ii	*Any of:* research «collaboration» for alternative technologies «to replace CFCs» *OR* technologies «developed»/data could be shared *OR* political pressure/Montreal Protocol/governments passing legislations ✓	*Do not accept just "collaboration".* *Do not accept any reference to CFC as greenhouse gas or product of fossil fuel combustion.* *Accept reference to specific measures, such as agreement on banning use/manufacture of CFCs.*	1
1.	e	iii	$O_3 + Cl\cdot \rightarrow O_2 + ClO\cdot$ ✓ $ClO\cdot + O\cdot \rightarrow O_2 + Cl\cdot$ *OR* $ClO\cdot + O_3 \rightarrow Cl\cdot + 2O_2$ ✓	*Penalize missing/incorrect radical dot (·) once only.*	2

Q# 53/ Chem 5 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4	a	i	«$\Sigma \Delta H^\ominus_f$ (reactants) =» +88.7 + 2(-241.8) / -394.9 «kJ mol^{-1}» *AND* «$\Sigma \Delta H^\ominus_f$ (products) =» -393.5 + 2(-20.6) / -434.7 «kJ mol^{-1}» ✓ $\Delta H^\ominus$ «= -434.7 – (-394.9)» = -39.8 «kJ mol^{-1}» ✓	*Award [2] for correct final answer.* *Award [1] for +48.2 «kJ mol^{-1}» (obtained using -285.8 kJ mol^{-1} for $H_2O(l)$).*	2
4	a	ii	moles «of gas» same on both sides of equation ✓		1

Q# 54/ Chem 5 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2	b		«$K_c = \frac{[HCOOH]}{[CO_2][H_2]}$» ✓		1
2	c	i	*ALTERNATIVE 1* «bond breaking» C=O + H-H / 804 + 436 / 1240 «kJ» ✓ «bond forming» C-H + C-O + O-H / 414 + 358 + 463 / 1235 «kJ» ✓ $\Delta H^\ominus$ «= 1240 – 1235» = «+»5 «kJ mol^{-1}» ✓ *ALTERNATIVE 2* «bond breaking» 2C=O + H-H / 2(804) + 436 / 2044 «kJ» ✓ «bond forming» C=O + C-H + C-O + O-H / 804 + 414 + 358 + 463 / 2039 «kJ» ✓ $\Delta H^\ominus$ «= 2044 – 2039» = «+»5 «kJ mol^{-1}» ✓	*Award [3] for correct final answer.*	3
2	c	ii	*ALTERNATIVE 1* sum of absolute uncertainties «= 0.804 + 0.436 + 0.414 + 0.358 + 0.463 =» 2.475 «kJ mol^{-1}» ✓ percentage uncertainty «= $100 \times \frac{2.475}{5}$ = 49.5% =» 50 «%» ✓ *ALTERNATIVE 2* sum of absolute uncertainties «= 3(0.804) + 0.436 + 0.414 + 0.358 + 0.463 =» 4.083 «kJ mol^{-1}» ✓ percentage uncertainty «= $100 \times \frac{4.083}{5}$ = 81.7%» = 80 «%» ✓	*Award [2] for correct final answer.*	2
2	c	iii	H-H *AND* it can only occur in the H_2 molecule ✓	*Accept H-H AND does not require averaging.*	1
2	d		enthalpy change is very small ✓		1
2	e		$\Delta S^\ominus$«= $\sum S^\ominus$(products)−$\sum S^\ominus$(reactants) = 251.0 J mol^{-1} K^{-1} – 130.7 J mol^{-1} K^{-1} - 213.8 J mol^{-1} K^{-1}» = -93.5 «J mol^{-1} K^{-1}» ✓		1

Q# 55/ Chem 5 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	(a)	(i)	«$\Delta H^\ominus rxn = \sum \Delta H^\ominus f$ (Products) – $\sum \Delta H^\ominus f$ (Reactants) =» -395.8 - (-296.8)» = –99.0«kJ mol^{-1}» ✓		1
6.	(b)	(i)	«q = -mcΔT = 50.00g x 4.18J K^{-1}g^{-1} x (35.0-20.0)°C =» -3140.0 «J» ✓ «(3140/0.1)/1000 =» -31.4 «kJ mol^{-1}» ✓	*Award [1 max] for +31.4 kJ mol^{-1}* *Award [2] for correct final answer.*	2

Q# 56/ Chem 5 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(d)	(i)	«$q = mc\Delta T$ = 25.32 g × 4.18 J g^{-1}K^{-1} × (25.2°C – 0.8°C) =» 2580 «J» ✓	*Do not accept a negative value.*	1
1.	(d)	(ii)	«$2.58 \times 10^3\ J \times \frac{1\ kJ}{1000\ J} \times \frac{1\ mol}{25.69\ kJ}$ =» 0.100 «mol» ✓ «0.100 mol × 80.06 g mol^{-1} =» 8.01 «g» ✓	*Award [2] for the correct final answer.* *Accept range of 8.0 – 8.1 g.* *If 3.11 x 10^3 J used then answer is 9.69 g.*	2

1.	(d)	(iii)	«fractional / % uncertainty in ΔT =» $\frac{0.4}{24.4}$ / 0.02 / 2«%» ✓ «fractional / % uncertainty in m =» $\frac{0.01}{25.32}$ / 0.0004 / 0.04«%» *OR* fractional / % uncertainty in m is much smaller than uncertainty in ΔT ✓ «2% x 8.01 g =» 0.2 «g» ✓	*Award [3] for correct final answer.* *Accept range of 0.1 g – 0.2 «g».* *If 6.55 g used then the answer is 0.1 «g».*	3
1.	(d)	(iv)	«% error = $\left\|\frac{9.50\ g - 8.01\ g}{9.50\ g}\right\| \times 100\ \%$ =» 15.7«%» ✓	*Accept range 14.7 – 15.8«%».* *If 6.55 g used then answer is 31.1«%».*	1
1.	(d)	(v)	«$\Delta S° = 259.8\ J\ mol^{-1}\ K^{-1} - 151.1\ J\ mol^{-1}\ K^{-1}$ =» 108.7 «J mol^{-1} K^{-1}» ✓		1
1.	(d)	(vi)	«$\Delta G° = \Delta H° - T\Delta S° = 25.69\ kJ\ mol^{-1} - 298\ K\ \left(108.7\ J\ mol^{-1}\ K^{-1} \times \frac{1\ kJ}{1000\ J}\right)$ = – 6.70 «kJ mol^{-1}» ✓	*If 102.3 J mol^{-1} K^{-1} is used then answer is –4.80 kJ mol^{-1}.*	1
1.	(d)	(vii)	«$\Delta G° = -RT \ln K$» «$-6.70\ kJ \times \frac{1000\ J}{kJ} = -8.31\ J\ K^{-1}(298\ K)\ \ln K$» «ln$K$ =» 2.71 ✓ «$K = e^{2.71}$ = » 15.0 ✓	*Award [2] for correct final answer.* *If –7.84 kJ is used then answer is 23.7.*	2
1.	(d)	(viii)	product/right/solution/NH_4NO_3(aq) is favoured *AND* K>1 ✓	*Accept K large.* *Accept other valid ways of justifying equilibrium position such as ΔG<0/ spontaneous/ΔH<0 AND ΔS>0.*	1
1.	(f)	(i)	$NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(l)$ ✓		1
1.	(f)	(ii)	«5.00 g ÷ 80.06 g mol^{-1} =» 0.0625 mol «NH_4NO_3» ✓ «1:1 mol ratio» «$0.0625\ mol\ N_2O \times \frac{22.7\ dm^3}{mol}$ =» 1.42 «dm^3» ✓	*Award [2] for correct final answer.* *Accept range 1.36 – 1.43 «dm^3».* *Accept calculations based on PV=nRT.*	2
Question			Answers	Notes	Total
1.	(f)	(iii)	2 x – 285.8 «kJ mol^{-1}» ✓ «1mol (82 kJ mol^{-1}) + 2mol (– 285.8 kJ mol^{-1}) – 1mol (– 366 kJ mol^{-1}) =» –124 «kJ» ✓	*Award [2] for correct final answer.*	2
1.	(f)	(iv)	*Entropy change:* positive *AND* formation of gas «and liquid from solid» ✓ *Gibbs free energy change:* negative *AND* increase in entropy/ΔS positive *AND* exothermic reaction/ΔH negative ✓		2

Q# 57/ Chem 5 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	b	i	*bonds broken*: N≡N + 3(H-H) /«1 mol×»945 «kJ mol^{-1}» + 3«mol»×436 «kJ mol^{-1}» / 945 «kJ» + 1308 «kJ» / 2253 «kJ» ✓ *bonds formed*: 6(N-H) / 6«mol»×391 «kJ mol^{-1}» / 2346 «kJ» ✓ ΔH = «2253 kJ - 2346 kJ = » -93 «kJ» ✓	*Award [2 max] for (+)93 «kJ».*	3
3.	b	ii	«N-H» bond enthalpy is an average «and may not be the precise value in NH_3» ✓	*Accept ΔH_f data are more accurate / are not average values.*	1

3.	c	i	spontaneous ***AND*** $\Delta G < 0$ ✓		1
3.	c	ii	$\ln K = \langle\langle -\frac{\Delta G}{R.T} = \rangle\rangle \; -\frac{-33000}{8.31 \times 298}$ / «+»13.3 ✓ $K = 6.13 \times 10^5$ ✓	*Award [2] for correct final answer.* *Accept answers in the range 4.4×10^5 to 6.2×10^5 (arises from rounding of ln K).*	2
3.	c	iii	ΔG = «$\Delta H - T\Delta S$ =» -93000 «J» - 298«K» × ΔS = -33000 ✓ $\Delta S = \langle\langle \frac{-93000\text{ J} - (-33000\text{ J})}{298\text{ K}} \rangle\rangle$ = -201 «J mol^{-1} K^{-1}» ✓	*Do not penalize failure to convert kJ to J in both (c)(ii) and (c)(iii).* *Award [2] for correct final answer* *Award [1 max] for (+) 201 «J mol^{-1} K^{-1}».* *Award [2] for –101 or –100.5 «J mol^{-1} K^{-1}».*	2
3	c	iv	«forward reaction involves» decrease in number of moles «of gas» ✓		1

Q# 58/ Chem 5 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	c	i	«–398.9 kJ mol^{-1} – (–306.4 kJ mol^{-1}) =» –92.5 «kJ mol^{-1}» ✓		1
3.	c	ii	«ΔS = 364.5 J K^{-1} mol^{-1} – (311.7 J K^{-1} mol^{-1} + 223.0 J K^{-1} mol^{-1}) =» –170.2 «J K^{-1} mol^{-1}» ✓		1
3.	c	iii	«ΔS =» –0.1702 «kJ mol^{-1} K^{-1}» ***OR*** 298 «K» ✓ «ΔG = –92.5 kJ mol^{-1} – (298 K × –0.1702 kJ mol^{-1} K^{-1}) =» –41.8 «kJ mol^{-1}» ✓	*Award [2] for correct final answer.* *If –87.6 and –150.5 are used then –42.8.*	2

Q# 59/ Chem 5 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7.	b		bond in O_3 is weaker *OR* O_3 bond order 1.5/< 2 ✓ lower frequency/longer wavelength «UV light» has enough energy to break the O–O bond in O_3 «but not that in O_2» ✓	*Do not accept bond in O_3 is longer for M1.* *Accept "lower frequency/longer wavelength «UV light» has lower energy".*	2
7.	c		$CCl_2F_2(g) \rightarrow {}^{\bullet}CClF_2(g) + Cl^{\bullet}(g)$ ✓ $Cl^{\bullet}(g) + O_3(g) \rightarrow O_2(g) + ClO^{\bullet}(g)$ ***AND*** $ClO^{\bullet}(g) + O_3(g) \rightarrow 2O_2(g) + Cl^{\bullet}(g)$ ✓	*Do not penalize missing radical.* *Accept:for M2:* $Cl^{\bullet}(g) + O_3(g) \rightarrow O_2(g) + ClO^{\bullet}(g)$ ***AND*** $ClO^{\bullet}(g) + O(g) \rightarrow O_2(g) + Cl^{\bullet}(g)$	2

Q# 60/ Chem 5 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	c		specific heat capacity « $= \frac{q}{m \times \Delta T} / \frac{1000\text{ J}}{50\text{ g} \times 44\text{ K}}$ » = 0.45 «J g^{-1} K^{-1}» ✓		1

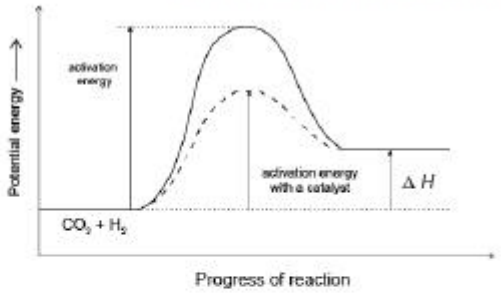
Q# 61/ Chem 5 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	a		*Bonds broken*: 8(C–H) + 2(C–C) + 5(O=O) / 8 × 414 «kJ mol^{-1}» + 2 × 346 «kJ mol^{-1}» + 5 × 498 «kJ mol^{-1}» / 6494 «kJ» ✓ *Bonds formed*: 6(C=O) + 8(O–H) / 6 × 804 «kJ mol^{-1}» + 8 × 463 «kJ mol^{-1}» / 8528 «kJ» ✓ «Enthalpy change = bonds broken – bonds formed = 6494 kJ – 8528 kJ =» –2034 «kJ» ✓	*Award [3] for correct final answer.*	3
3.	b		4(–241.8 «kJ») ***AND*** 3(–393.5 «kJ») ***AND*** «1»(–105 «kJ») ✓ «$\Delta H^{\ominus}$ = 4(–241.8 «kJ») + 3(–393.5 «kJ») – «1»(–105 «kJ») =» –2043 «kJ» ✓	*Award [2] for correct final answer.* *Award [1 max] for –2219 «kJ».*	2
3.	c		positive ***AND*** more moles «of gas» in products ✓		1
3.	d		4 × 188.8 «J K^{-1}» ***AND*** 3 × 213.8 «J K^{-1}» ***AND*** «1 ×» 270 «J K^{-1}» ***AND*** 5 × 205 «J K^{-1}» ✓ «$\Delta S^{\ominus}$ = 4(188.8 J K^{-1}) + 3(213.8 J K^{-1}) – [1(270 J K^{-1}) + 5(205 J K^{-1})] =» 102 «J K^{-1}» ✓	*Award [2] for correct final answer.*	2
3.	e		«T = 5 + 273 =» 278 K ✓ «$\Delta G^{\ominus}$ = –2043 kJ – (278 K × 0.102 kJ K^{-1}) =» –2071 «kJ» ✓	*Award [2] for correct final answer.*	2

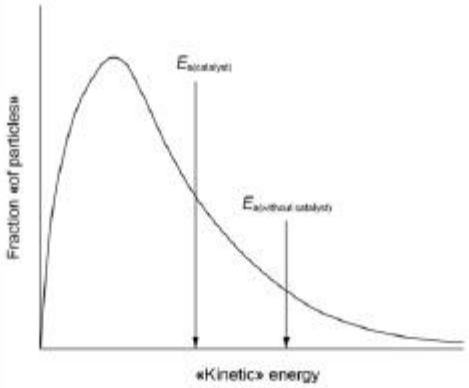
Q# 62/ Chem 6 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6	c		*k1/k2 = 2 OR k1/k2 = 0.5* ✓ $\langle\langle ln\frac{k_1}{k_2} = ln2 = \frac{E_a}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right) = \frac{E_a}{8.31}\left(\frac{1}{298}-\frac{1}{308}\right)\rangle\rangle$ «E_a = 8.31 J mol^{-1}K^{-1} $\left(\frac{308\text{ K} \times 298\text{ K}}{10\text{ K}}\right)$ ln2» = 8.31 x 9178 x ln2 ✓ E_a «= 52868 J mol^{-1} » = 52.9 «kJ mol^{-1}» ✓	*Award [3] for correct final answer.* *Accept answers in the range 50 to 55 kJ mol^{-1}.* *Accept k_1 at 298 K and k_2 at 308 K, if ratio inverted.* *Accept other methods of calculation.* *Award [2] for 0.504 kJ mol^{-1} (not converting temperatures to Kelvin).*	3

Q# 63/ Chem 6 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2	f	i	 two curves, each passing through a maximum ***AND*** same finishing point ✓ endothermic enthalpy change labelled ✓ both activation energies correctly labelled ✓	*Do not penalize curve showing multiple steps for the catalysis in M1.* *Accept double-headed arrows or lines in M2 and M3.* *Accept E_{cat} for catalysed E_a in M3.* *Award [1 max] for one curve drawn and correctly labelled.*	3
2	f	ii	increase pressure ✓	*Accept increase «reactant» concentration but not increase amount of reactant.*	1

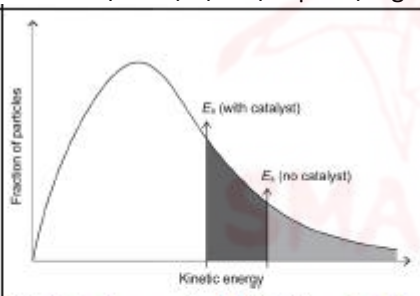
Q# 64/ Chem 6 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(e)	(i)	alternate pathway ***AND*** lowers activation energy/E_a ✓		1
2.	(e)	(ii)	 correct shape curve starting at the origin, without touching the x axis at high energy. ✓ (E_a) catalysed <(E_a) uncatalysed on x axis. ✓	*Ignore any shading under the curve.*	2
2.	(e)	(iii)	change in ***AND*** volume ***OR*** pressure ***OR*** temperature ***OR*** concentration of H_2/N_2 /reactants/NH_3 /product ✓	*Do not accept pH.* *Accept any valid method.*	1

Q# 65/ Chem 6 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	(d)		*Any two of:* depth/volume «of solution» ✓ colour/darkness/thickness/size/background of mark ✓ intensity of lighting in the lab ✓	*Accept same size flask.* *Accept position of observation/person observing.* *Accept same equipment/apparatus.* *Do not accept catalyst/particle size/pressure/time.*	2 max

Q# 66/ Chem 6 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(e)	(iii)	 both E_a values marked ***AND*** left one labelled catalysed ✓		1
2.	(e)	(iv)	increases rate ***AND*** there is a greater area under the curve past activation energy ***OR*** increases rate ***AND*** greater proportion of/more molecules have «kinetic» $E \geq E_a$ «(cat) than E_a (uncat)» ✓	*Do not award a mark for general statements about catalysts such as "provides alternative pathway" or "lowers E_a".*	1

Q# 67/ Chem 6 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	d	ii	energy/E ≥ activation energy/E_a ✓ correct orientation «of reacting particles» ***OR*** correct geometry «of reacting particles» ✓		2

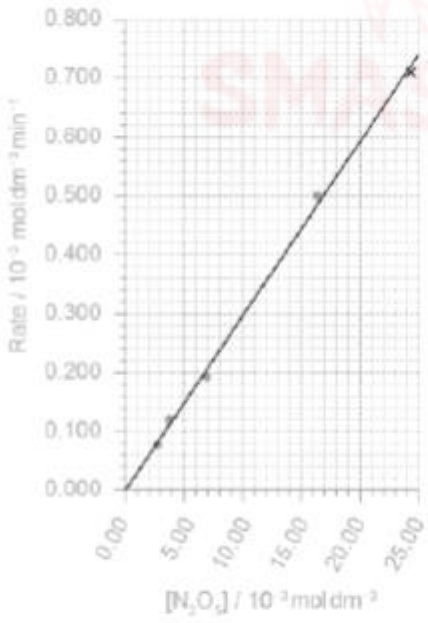
Q# 68/ Chem 6 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	c	i	independent / not dependent ✓	*Accept "zero order in Mg".*	1
2.	c	ii	«2×170 s» = 340 «s» ✓	*Accept 320 – 360 «s».* *Accept 400 – 450 «s» based on no more gas being produced after 400 to 450s.*	1
2.	c	iii	«relative/percentage» decrease in mass is «too» small/«much» less ✓	*Accept "«relative/percentage» uncertainty in mass loss «too» great".* *OR "density/molar mass of H_2 is «much» less than CO_2".*	1

Q# 69/ Chem 6 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q10. www.SmashingScience.org :o)

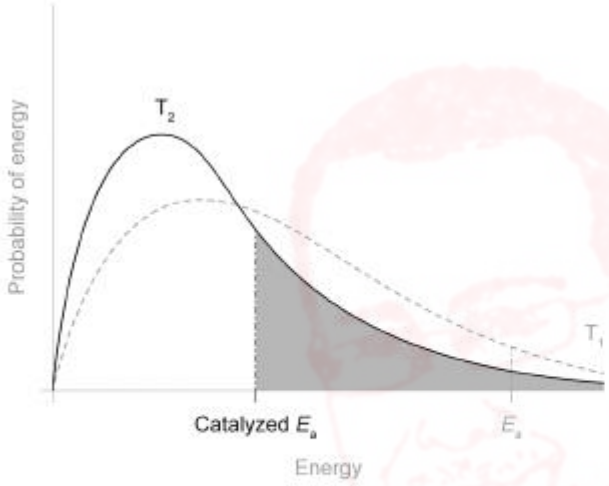
10.	c	i	«rate =» k[NaOH][$C_5H_{11}Cl$] ✓		1
10.	c	ii	$mol^{-1}\ dm^3\ s^{-1}$ ✓		1
10.	c	iii	**ALTERNATIVE 1:** «k = » 1.25 «$mol^{-1}\ dm^3\ s^{-1}$» ✓ «rate = 1.25 $mol^{-1}\ dm^3\ s^{-1}$ × 0.60 $mol\ dm^{-3}$ × 0.25 $mol\ dm^{-3}$» 1.9 x 10^{-1} «$mol\ dm^{-3}\ s^{-1}$» ✓ **ALTERNATIVE 2:** «[NaOH] exp. 4 is 3 × exp. 1» «[$C_5H_{11}Cl$] exp. 4 is 2.5 × exp. 1» «exp. 4 will be » 7.5× faster ✓ 1.9 x 10^{-1} «$mol\ dm^{-3}\ s^{-1}$» ✓	*Award **[2]** for correct final answer.*	2

Q# 70/ Chem 6 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	a		use colorimeter *OR* change in colour *OR* change in volume *OR* change in pressure ✓	*Accept suitable instruments, e.g. pressure probe/oxygen sensor.*	1
6.	b	i	 point correct ✓ straight line passing close to all points ***AND*** through origin ✓	*Accept free hand drawn line as long as attempt to be linear and meets criteria for M2.*	2

6.	b	ii	greater frequency of collisions «as concentration increases» *OR* more collisions per unit time «as concentration increases» ✓	*Accept "rate/chance/probability/likelihood" instead of "frequency".* *Do not accept just "more collisions".*	1
6.	b	iii	rate = $k[N_2O_5]$ ✓		1
6.	b	iv	$k = \frac{\Delta \text{ rate}}{\Delta [N_2O_5]}$ ✓ $«k = \frac{0.75 \times 10^{-3} «\text{mol dm}^{-3}\ \text{min}^{-1}»}{25 \times 10^{-3} «\text{mol dm}^{-3}»} = » 0.030 «\text{min}^{-1}»$ ✓ min^{-1} ✓	*M1 can be awarded from correct M2 if not explicitly stated.* *Accept k = gradient.* *Accept values in the range 0.028–0.032.* *Award [3] for correct final answer.*	3

Q# 71/ Chem 6 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	a		 curve higher *AND* to left of T_1 ✓ new/catalysed E_a marked *AND* to the left of E_a of curve T_1 ✓	*Do not penalize curve missing a label, not passing exactly through the origin, or crossing x-axis after Ea.* *Do not award M1 if curve drawn shows significantly more/less molecules/greater/smaller area under curve than curve 1.* *Accept E_a drawn to T_1 instead of curve drawn as long as to left of marked E_a.*	2
4.	b		methanoic acid/HCOOH/CHOOH *OR* methanal/HCHO ✓	*Accept "carbon dioxide/CO_2".*	1
4.	c	i	$CH_4(g) + H_2O(g) \rightleftharpoons CH_3OH(l) + H_2(g)$ ✓	*Accept arrow instead of equilibrium sign.*	1
4.	c	ii	amount of methane = $« \frac{8.00\ \text{g}}{16.05\ \text{g mol}^{-1}} = » 0.498 «\text{mol}»$ ✓ amount of hydrogen = amount of methane / 0.498 «mol» ✓ volume of hydrogen = «0.498 mol × 22.7 $\text{dm}^3\ \text{mol}^{-1} = » 11.3 «\text{dm}^3»$ ✓	*Award [3] for final correct answer.* *Award [2 max] for 11.4 «dm3 due to rounding of mass to 16/moles to 0.5. »*	3
4.	d	i	Σbonds broken = 4 × 414 «kJ» + 2 × 463 «kJ» / 2582 «kJ» ✓ Σbonds formed = 1077 «kJ» + 3 × 436 «kJ» / 2385 «kJ» ✓ ΔH «= Σbonds broken − Σbonds formed =(2582 kJ − 2385 kJ)» = «+»197«kJ» ✓	*Award [3] for final correct answer.* Award *[2 Max]* for final answer of −197 «kJ»	3
4.	d	ii	bond energies are average values «not specific to the compound» ✓		1

4.	e	i	«$\Delta G^\ominus = -RT\ln K_c$» $\Delta G^\ominus$ = – 8.31 «J K^{-1} mol^{-1}» × 298 «K» × ln (1.01) / –24.6 «J mol^{-1}» ✓ = –0.0246 «kJ mol^{-1}» ✓	*Award [2] for correct final answer.* *Award [1 max] for +0.0246 «kJ mol^{-1}».*	2
4.	e	ii	«$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$» $\Delta G^\ominus$ = –129 «kJ mol^{-1}» – (298 «K» × ΔS) = –0.0246 «kJ mol^{-1}» ✓ $\Delta S^\ominus$ = « $\frac{(-129\ \text{kJ mol}^{-1} + 0.0246\ \text{kJ mol}^{-1}) \times 10^3}{298\ \text{K}}$ = » –433 «J K^{-1} mol^{-1}» ✓	*Award [2] for correct final answer.* *Award [1 max] for "–0.433 «kJ K^{-1} mol^{-1}»".* *Award [1 max] for "433" or "+433" «J K^{-1} mol^{-1}».* *Award [2] for –430 «J K^{-1} mol^{-1}» (result from given values).*	2
4.	e	iii	«negative as» product is liquid and reactants gases *OR* fewer moles of gas in product ✓		1
4.	e	iv	reaction «more» spontaneous/ΔG negative/less positive ***AND*** effect of negative entropy decreases/TΔS increases/is less negative/more positive *OR* reaction «more» spontaneous/ΔG negative/less positive ***AND*** reaction exothermic «so K_c increases » ✓	*Award mark if correct calculation shown.*	1

Q# 72/ Chem 6 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7.	a		*NO*: second ✓ O_2: first ✓		2
7.	b		not possible ***AND*** «proposed» mechanism does not match experimental rate law *OR* not possible ***AND*** «proposed» mechanism shows zero/not first order with respect to oxygen ✓		1

Q# 73/ Chem 6 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	a		provides an alternative pathway/mechanism ***AND*** lower E_a ✓	*Accept description of how catalyst lowers E_a (e.g. "reactants adsorb on surface «of catalyst»", "reactant bonds weaken «when adsorbed»").*	1
4.	b		more/greater proportion of molecules with $E \geq E_a$ ✓ greater frequency/probability/chance of collisions «between the molecules» *OR* more collision per unit of time/second ✓		2

Q# 74/ Chem 7 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4	a	iii	ΔG° «= ΔH° - T.ΔS°» = -39.8 «kJ mol^{-1}» ✓ ≪ $\ln K_c = -\frac{\Delta G^\circ}{R.T} = \frac{39800\ J mol^{-1}}{8.31\ JK^{-1}mol^{-1} \times 500\ K} = 9.58$ ≫ K_c = 1.45 x 10^4 ✓	*Award [2] for correct final answer.* *Using –50.0 kJ mol^{-1} gives K_c = 1.68 x 10^5.* *If student obtained +48.2 kJ mol^{-1} for 4(a) then ECF gives K_c = 9.16 x 10^{-6}.*	2
4	a	iv	K_c ≪= 1.45 × 10^4 = $\frac{[CO_2] \times [H_2S]^2}{[CS_2] \times [H_2O]^2}$ ≫ = $\frac{X \times (2X)^2}{0.0400 \times (0.100)^2} / \frac{4X^3}{4.00 \times 10^{-4}}$ ✓ X ≪= $\sqrt[3]{1.45}$ ≫= 1.13 ≪ mol dm^{-3} ≫ ✓	*Award [2] for correct final answer.* *Students who obtain K ~1 in 4(a)iii will obtain answers ~0.046 by ECF.* *Using 1.68 x 10^5 gives 2.56 «mol dm^{-3}».*	2

Q# 75/ Chem 7 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2	b		«K_c = » $\frac{[HCOOH]}{[CO_2][H_2]}$ ✓		1
2	d		enthalpy change is very small ✓		1

Q# 76/ Chem 7 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(d)	(i)	«in a closed system» the rate of the forward reaction equals the rate of the reverse reaction. ✓		1
2.	(d)	(ii)	$[NH_3]^2/([N_2][H_2]^3)$ ✓		1
2.	(d)	(iii)	$\Delta S^\ominus = \Delta S^\ominus_{(products)} - \Delta S^\ominus_{(reactants)}$ *OR* (2 × 192.8«J mol^{-1} K^{-1}») – (3 × 130.7 «J mol^{-1} K^{-1}» + 191.6 «J mol^{-1} K^{-1}»)✓ -198.1 «J K^{-1} mol^{-1}» ✓	*Award [2] for correct final answer with four significant figures.*	2
2.	(d)	(iv)	«$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$» $\Delta S^\ominus$ = -0.1981 kJ K^{-1} mol^{-1} ***AND*** $\Delta H^\ominus$ = –92.0 kJ mol^{-1}✓ «0 kJ mol^{-1} = (-92.0 kJ mol^{-1}) - (T K × -0.1981 kJ K^{-1}mol^{-1})» 464«K» ✓ Alternate: $\Delta S^\ominus$ = –0.2100 kJ K^{-1} mol^{-1} ***AND*** $\Delta H^\ominus$ = –92.0 kJ mol^{-1}✓ «0 kJ mol^{-1} = (-92.0 kJ mol^{-1}) - (T K× -0.2100 kJ K^{-1}mol^{-1})» 438«K» ✓	*M1 for conversion to common units for $\Delta H^\ominus$ and $\Delta S^\ominus$.* *Award [2] for correct final answer.*	2
2.	(d)	(v)	«reaction» exothermic ***AND*** K_c increases «as equilibrium moves right» ✓		1
2.	(d)	(vi)	«$\Delta G^\ominus = -RT\ln K_c$» «$\Delta G^\ominus$ = (–8.31J K^{-1} mol^{-1} × 773K × ln 6.84 x10^{-5})/1000 =» «+» 61.6 «kJ mol^{-1}» ✓ *OR* «$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$» «$\Delta G^\ominus$ = –92.0 kJ mol^{-1} – 773 K × (–0.1981 kJ K^{-1} mol^{-1}) =» +61.1 «kJ mol^{-1}» ✓	*Award [2] for the correct final answer.*	2

Q# 77/ Chem 7 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(d)	(vii)	«$\Delta G^\circ = -RT\ln K$» «$-6.70\ kJ \times \frac{1000\ J}{kJ} = -8.31\ J\ K^{-1}(298\ K)\ \ln K$» «ln$K$ =» 2.71 ✓ «$K = e^{2.71}$ = » 15.0 ✓	*Award [2] for correct final answer.* *If –7.84 kJ is used then answer is 23.7.*	2
1.	(d)	(viii)	product/right/solution/NH_4NO_3(aq) is favoured ***AND*** K>1 ✓	*Accept K large.* *Accept other valid ways of justifying equilibrium position such as* ΔG<0/ *spontaneous/*ΔH<0 AND ΔS>0.	1

Q# 78/ Chem 7 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	a	i	$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$ ✓		1
3.	a	ii	same/unaffected/unchanged ✓		1
3.	a	iii	increasing pressure increases «all» concentrations *OR* increasing pressure decreases volume ✓ Q becomes less than K_c *OR* affects the lower line/denominator of Q expression more than upper line/numerator ✓ «for Q to once again equal K_c,» ratio of products to reactants increases *OR* «for Q to once again equal K_c,» equilibrium shifts to right/products ✓	*Award [2 max] for answers that do not refer to Q.*	3
3.	b	iii	increased temperature decreases yield «as shown on graph» ✓ shifts equilibrium in endothermic/reverse direction ✓		2

Q# 79/ Chem 7 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	c	iv	«$\Delta G = -41.8\ kJ\ mol^{-1} = -\frac{8.31\ J\ mol^{-1}\ K^{-1}}{1000} \times 298\ K \times \ln K$» ***OR*** «$\Delta G = -41800\ J\ mol^{-1} = -8.31\ J\ mol^{-1} K^{-1} \times 298\ K \times \ln K$» «$\ln K =$ =» 16.9 ✓ «$K = e^{16.9}$ =» 2.19×10^7 ✓	*Award **[2]** for correct final answer.* *Accept range of 1.80×10^6–2.60×10^7.* *If −43.5 is used then 4.25×10^7.*	2
3.	c	v	«K_c =» $\frac{[PCl_5]}{[PCl_3]\,[Cl_2]}$ ✓		1
3.	c	vi	«shifts» left/towards reactants ***AND*** «forward reaction is» exothermic/ΔH is negative ✓		1

Q# 80/ Chem 7 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	d	iii	$K_c = \frac{[CO][H_2]^3}{[CH_4][H_2O]}$ ✓		1
4.	d	iv	K_c increases ***AND*** «forward» reaction endothermic ✓		1

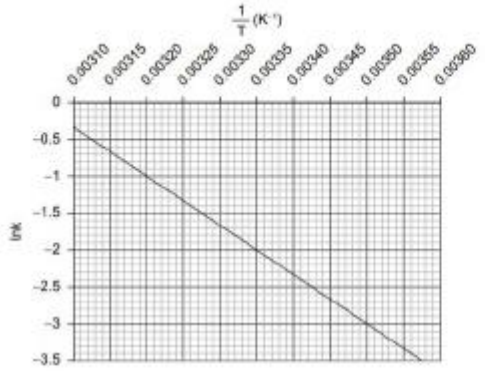
Q# 81/ Chem 8 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5	d	ii	chlorine «on one monomer» acts as a Lewis base ***AND*** beryllium «on the other monomer» acts as a Lewis acid ✓		1

Q# 82/ Chem 8 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1	d	i	[HCOOH] «=0.100 $mol\,dm^{-3} \times \frac{20.7\ cm^3}{25.0\ cm^3}$» = 0.0828 «mol dm^{-3}» ✓ mass HCOOH «=2.00 dm^3 x 0.0828 mol dm^{-3} x 46.03 g mol^{-1}» = 7.62 «g» ✓	*Accept answers in the range 7.60-7.65.* *Award [0] for 0.096 g - mass of acid in 25 cm^3.*	2
1	d	ii	$K_a = 10^{-3.75}/1.78 \times 10^{-4}$ ✓ $[H^+]$ «= $\sqrt{1.78 \times 10^{-4} \times 0.0828} = \sqrt{1.47 \times 10^{-5}}$ =» 3.84×10^{-3} «mol dm^{-3}» ✓ pH = 2.42 ✓	*Award [3] for correct final answer.* *Accept alternative methods of calculation.* *Accept answers in the range 2.35 - 2.45.*	3
1	d	iii	$NaHCOO(aq) + H_2O(l) \rightleftharpoons HCOOH(aq) + NaOH(aq)$ *OR* $HCOO^-(aq) + H_2O(l) \rightleftharpoons HCOOH(aq) + OH^-(aq)$ ✓ methanoate ion acts as «Brønsted-Lowry» base ***AND*** pH >7 *OR* sodium hydroxide/NaOH/hydroxide ion/OH^- makes solution alkaline ***AND*** pH >7 ✓	*Accept arrows rather than equilibrium signs for M1.* *Do not accept the equation for the titration reaction for M1.* *Accept sodium methanoate is formed from a strong base and weak acid **AND** pH >7 for M2.* *The reason for M2 can be implied in the equation written without being separately stated.*	2

Q# 83/ Chem 8 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q8. www.SmashingScience.org :o)

8.			 «two construction lines shown on the graph, and slope calculated: «(–1.0 – (–3.0))/(0.0032 – 0.0035) =» –6700 ✓ «gradient x R = -E_a» «6700 x 8.31J K^{-1} mol^{-1} /1000=» 56 *OR* «6700 x 8.31J K^{-1} mol^{-1} =» 56000 ✓ kJ «mol^{-1}» ✓ *OR* J «mol^{-1}»✓	*Accept range 6400-7000 for M1.* *Accept range 53-59 or 53000-59000 for M2.* *Accept the unit as kJ or J without reference to per mol.* *Award [2] for final answer without units.* *Accept use of* ln k1/k2 = -Ea/R (1/T2-1/T1).	3

Q# 84/ Chem 8 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	(a)	(ii)	$SO_{2\,(aq)} + H_2O(l) \rightleftharpoons H_2SO_{3\,(aq)}$ ***AND*** $SO_{3\,(aq)} + H_2O\,(l) \rightarrow H_2SO_{4\,(aq)}$ ✓	Accept single arrow for the first equation.	1

Q# 85/ Chem 8 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(a)	(i)	$H_2O_{(l)} + HCl_{(g)} \rightarrow Cl^-_{(aq)} + H_3O^+_{(aq)}$ ✓✓	*One for the equation and one for the state symbols.* *Do not accept* $H_2O_{(l)} + H^+_{(g)} \rightarrow H_3O^+_{(aq)}$ *Do not accept equilibrium sign.*	2
1.	(a)	(ii)	«pH = $-\log_{10}[H^+] = -\log_{10}0.5$ =» 0.30 ✓		1
1.	(a)	(iii)	«Ethanoic acid» *partially ionizes/dissociates/OWTTE* *OR* *lower [H+]* ✓	*Do not accept weak acid only.* *Accept converse argument.*	1
1.	(a)	(iv)	conductivity/conductance meter/probe *OR* ammeter «with power supply» ✓	*Ignore any reference to indicators or any chemical methods.* *Accept Cl^- or ethanoate ion selective probe.*	1
1.	(a)	(v)	HCl higher conductivity «due to higher [ion]» ✓	*Accept explanation if alternative given in a(iv).* *Accept converse argument.* *Apply ECF for incorrect method.*	1

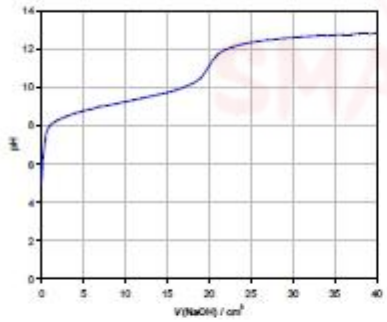
1.	(b)		Chemical test: use of carbonate/hydrogen carbonate/named metal ***AND*** Expected result: more bubbles per unit time/disappears faster/faster reaction in $HCl_{(aq)}$ ✓ ***OR*** Chemical test: add alkali/hydroxide/metal oxide ***AND*** Expected result: higher temperature rise with HCl ✓ ***OR*** Chemical test: add silver nitrate «solution»/$AgNO_3$«(aq)» ***AND*** Expected result: white precipitate/ppt. with HCl ✓	*Do not accept just metal.* *Accept active metal.* *Accept greater temperature change in place of more bubbles.*	1
1.	(c)	(i)	4.8 ✓	*Accept 4.7–4.9*	1
1.	(c)	(ii)	***ALTERNATIVE 1*** $HA + OH^- \rightleftharpoons A^- + H_2O$✓ added OH^- neutralized by HA ***OR*** strong base «OH^-» replaced by weak base «A^-»✓ ***ALTERNATIVE 2*** $HA \rightleftharpoons A^- + H^+$ ✓ added OH^- neutralized by H^+ ***OR*** strong base «OH^-» replaced by weak base «A^-»✓	*Must show* $\rightleftharpoons$ *for M1* *Accept molecular equation.* *Allow reference to Châtelier principle for M2*	2
1.	(c)	(iii)	$n(NH_3)_{init}$ = «0.08 dm^3 × 0.1 mol dm^{-3} =» 0.008 mol ***AND*** $n(HCl)_{init}$ = «0.04 dm^3 × 0.1 mol dm^{-3} =» 0.004 mol ✓ $n(NH_3)_{frn}$ = «0.008 mol – 0.004 mol =» 0.004 mol ***AND*** $n(NH_4^+)_{frn}$ = 0.004 mol ✓ «V_{frn} = 0.08 dm^3 + 0.04 dm^3 = 0.12 dm^3» «$c(NH_3)_{frn} = c(NH_4^+)_{frn}$ = 0.004 mol/0.12 dm^3 = 0.033 mol dm^{-3}» $pK_a(NH_4^+)$ = «14 – $pK_b(NH_3)$ = 14 – 4.75 =» 9.25 ✓ pH = «9.25 + log(0.033/0.033) =» 9.25 ***OR*** pH = «9.25 + log(0.004/0.004) =» 9.25 ✓	*Award [4] for the correct final answer.* *Accept alternate working.*	4

Q# 86/ Chem 8 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	(b)		$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ ***OR*** $SO_2(g) + ½O_2(g) \rightarrow SO_3(g)$ ***AND*** $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ ***OR*** $SO_2(g) + ½O_2(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ ✓	*Accept ionized forms of acids.*	1

5.	(e)		*Any two of:* remove sulfur from coal ✓ add lime during combustion ✓ not allow sulfur oxides to be released into the environment ✓ reduce proportion/percentage of energy/power produced by «the combustion of» coal ✓	*Accept any valid method to wash coal and remove sulfur content for M1.* *Accept any valid combustion/post-combustion method to remove sulfur oxides.* *Accept any suggestion that would reduce the amount of coal that is burnt or would reduce the damage caused.* *Do not accept answers that only reduce production of SO_2/CO_2 from other fuels.* *Accept "improve efficiency of energy production from coal".* *Accept "use coal of lower sulfur content" OR "cleaner coal".*	**2 max**

Q# 87/ Chem 8 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(b)		«Brønsted-Lowry» acid ***AND*** can donate a proton/H^+ *OR* «Brønsted-Lowry» acid ***AND*** cannot accept proton/H^+ ✓		**1**
1.	(c)	(i)	«pH = – log (1.07×10^{-5}) =» 4.97 ✓		**1**
1.	(c)	(ii)	$NH_4^+(aq) + OH^-(aq) \rightarrow NH_3(aq) + H_2O(l)$ *OR* $NH_4NO_3(aq) + NaOH(aq) \rightarrow NH_3(aq) + H_2O(l) + NaNO_3(aq)$ ✓	*Accept NH_4OH instead of $NH_3 + H_2O$.*	**1**
1.	(c)	(iii)	«n(NH_4NO_3) = 0.20 mol dm^{-3} × 0.02000 dm^3 =» 0.0040 «mol NH_4NO_3» ✓ «[NH_3] at equivalence point = $\frac{0.0040\ mol}{0.04000\ dm^3}$ =» 0.10 «mol dm^{-3}» ✓ «$K_b = 10^{-pKb} = 10^{-4.75} = 1.8 \times 10^{-5}$» «$[OH^-] = \sqrt{K_b[NH_3]} = \sqrt{1.8 \times 10^{-5}(0.10)}$ =» 0.0013 «mol dm^{-3}» ✓ «pOH = – log (0.0013) = 2.89» «pH = 14.00 – pOH =» 11.11 ✓	*Award [4] for correct final answer.* *Accept a range of 11.11 – 11.14.*	**4**
1.	(c)	(iv)	 non-symmetrical sigmoidal curve, starting pH 2–7 ***AND*** terminating pH>12 ✓ equivalence point pH approximately 11 ***AND*** at a volume 20 cm^3 ✓		**2**

1.	(c)	(v)	no *AND* the end point is not in the sharp part of the curve *OR* no *AND* the equivalence point does not fall within the end-point/pH range of the indicator *OR* no *AND* there is a large difference in volume between end point and equivalence point *OR* no *AND* no sharp rise in pH «near equivalence point» ✓		1

Q# 88/ Chem 8 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	a		conjugate «acid and base» ✓		1
4.	b		amount of ammonia $\langle\langle = \frac{P.V}{R.T} = \frac{100.0\ kPa \times 900.0\ dm^3}{8.31\ J\ K^{-1}mol^{-1} \times 300.0\ K} \rangle\rangle$ = 36.1 «mol» ✓ concentration $\langle\langle = \frac{n}{V} = \frac{36.1}{2.00} \rangle\rangle$ = 18.1 «mol dm^{-3}» ✓	*Award [2] for correct final answer.*	2
4.	c	i	$[OH^-]$ $\langle\langle = \frac{K_w}{[H^+]} = \frac{10^{-14}}{10^{-9.3}} = 10^{-4.7} \rangle\rangle$ = 2.0×10^{-5} $\langle\langle mol\ dm^{-3} \rangle\rangle$ ✓		1
4.	c	ii	$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} / \frac{10^{-4.7} \times 10^{-4.7}}{[NH_3]}$ $\langle\langle = 10^{-4.75} \rangle\rangle$ ✓ $[NH_3]$ = $\langle\langle = \frac{10^{-9.4}}{10^{-4.75}} = 10^{-4.65} \rangle\rangle$ = 2.24×10^{-5} «mol dm^{-3}» ✓	*Accept other methods of carrying out the calculation.* *Award [2] for correct answer.*	2
4.	c	iii	equilibrium shifts to right/H^+ reacts with NH_3 ✓ «as large excess» ratio $[NH_3]$:$[NH_4^+]$ «and hence pH» almost unchanged ✓	*Accept "strong acid/H^+ converted to a weak acid/NH_4^+ «and hence pH almost unchanged».*	2
4.	d		Lewis acid ✓ accepts «a lone» electron pair «from the hydroxide ion» ✓	*Do not accept electron acceptor without mention of electron pair.*	2

Q# 89/ Chem 8 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

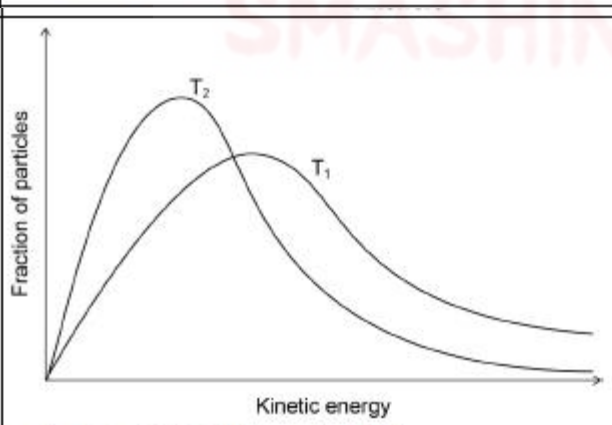
1.	d	ii	phenol red ✓	*Accept bromothymol blue or phenolphthalein.*	1

Q# 90/ Chem 8 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

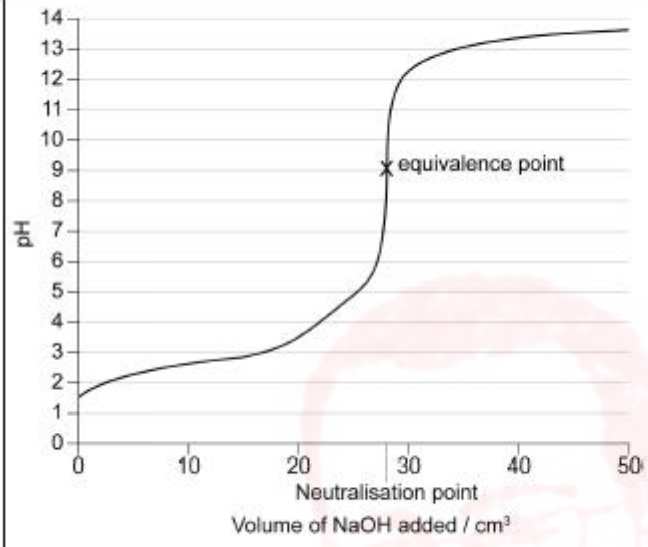
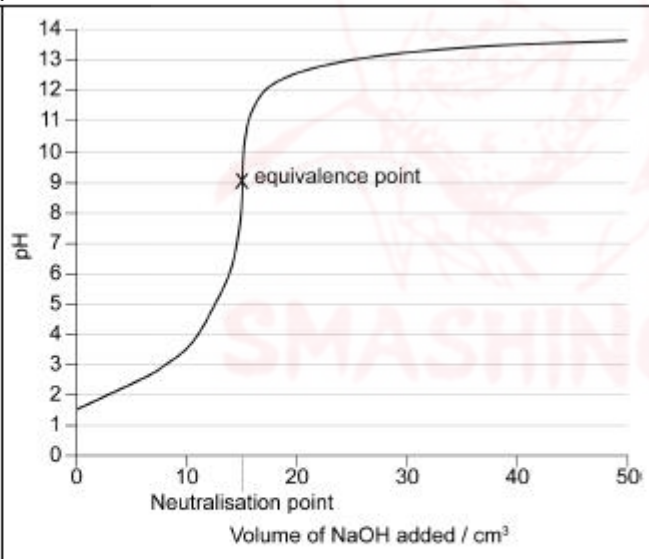
5.	a		H_3PO_4 (aq) + NaOH (aq) → NaH_2PO_4 (aq) + H_2O (l) ✓	*Accept net ionic equation.*	1

5.	b		$H_2PO_4^-(aq) + H^+(aq) \rightarrow H_3PO_4(aq)$ ✓ $H_2PO_4^-(aq) + OH^-(aq) \rightarrow HPO_4^{2-}(aq) + H_2O(l)$ ✓	*Accept reactions of $H_2PO_4^-$ with any acidic, basic or amphiprotic species, such as H_3O^+, NH_3 or H_2O.* *Accept $H_2PO_4^-(aq) \rightarrow HPO_4^{2-}(aq) + H^+(aq)$ for **M2**.*	2
5.	c		«NaOH $\frac{28.40\ cm^3}{1000}$ × 0.5000 mol dm^{-3} = 0.01420 mol» « $\frac{0.01420\ mol}{3}$ =» 0.004733 «mol» ✓ « $\frac{0.004733\ mol}{\frac{25.00\ cm^3}{1000}}$ =» 0.1893 «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.*	2
5.	d		*Brønsted–Lowry base:* proton acceptor ***AND*** *Lewis Base:* e^- pair donor/nucleophile ✓		1

Q# 91/ Chem 8 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

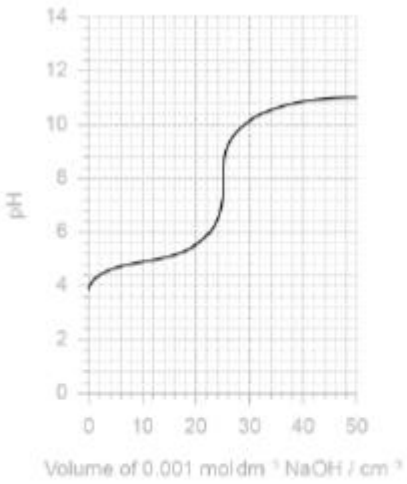
4.	a	i	«nucleophilic» substitution/S_N2 ✓	*Do not accept if "electrophilic" or "free radical" substitution is stated.*	1
4.	a	ii	«acts as a» nucleophile/Lewis base ***OR*** donates/provides lone pair «of electrons» ***OR*** attacks the «partially» positive carbon ✓		1
4.	a	iii	bond enthalpy C–I lower than C–Cl ***OR*** C–I bond weaker than C–Cl ✓ «weaker bond» broken more easily/with less energy ***OR*** lower E_a «for weaker bonds» ✓	*Accept the bond enthalpy values for C–I and C–Cl for **M1**.*	2
4.	b		 peak at T_1 to right of ***AND*** lower than T_2 ✓ lines begin at origin ***AND*** T_1 must finish above T_2 ✓		2

Q# 92/ Chem 8 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q11. www.SmashingScience.org :o)

11.	a		«$Ka = 10^{-2.87} = 1.35 \times 10^{-3}$» «$1.35 \times 10^{-3} = \frac{[\text{chloroethanoate}] \times [H^+]}{0.50\ \text{mol dm}^{-3}} = \frac{x^2}{0.50\ \text{mol dm}^{-3}}$» «$x = [H^+] = \sqrt{1.4 \times 10^{-3} \times 0.50}$ =» 2.6×10^{-2} «mol dm^{-3}» ✓ «$pH = -\log[H^+] = -\log(2.6 \times 10^{-2})$ =» 1.59 ✓	*Accept final answer in range 1.58-1.60.* *Award **[2]** for correct final answer.*	2
11.	b		«$pOH = -\log(0.362) = 0.441$» «$pH = 14.000 - 0.441$ =» 13.559 ✓		1
11.	c		 ***OR***  starts at 1.6 ***AND*** finishes at 13.6 ✓ approximately vertical at the correct volume of alkali added ✓ equivalence point labelled ***AND*** above pH 7 ✓	*Accept any range from 1.1-1.9 **AND** 13.1-13.9 for **M1** or ECF from 11c(i) and 11c(ii).* *Award **M2** for vertical climb at 28cm^3 **OR** 15 cm^3.* *Equivalence point must be labelled for **M3**.*	3

Q# 93/ Chem 8 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q8. www.SmashingScience.org :o)

8.	a		$K_a = 10^{-4.87} / 1.35 \times 10^{-5}$ ✓ $[H^+] = \sqrt{1.35 \times 10^{-5} \times 0.001} = \sqrt{1.35 \times 10^{-8}}$ =» 1.16×10^{-4} «mol dm^{-3}» ✓ pH = 3.94 ✓	*Accept alternative methods of calculation.* *Award [3] for correct final answer.* *Award [3] for 3.96 {answer if solved by quadratic}.*	3

8.	b		 *Any three of:* correct "S" shape ✓ equivalence point at 25 cm^3 ✓ final pH tends to 11 ✓ pH at equivalence point >7 ✓ starting pH between 3.8 - 4 ✓ pH at half equivalence approx. 5 ✓	*Do not penalize for incorrect points. Award any 3 correct.*	3

Q# 94/ Chem 8 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	b	i	HS^- ✓		1
2.	b	ii	weak ***AND*** strong acid of this concentration/$[H^+] = 0.1$ mol dm^{-3} would have pH = 1 *OR* weak ***AND*** $[H^+] = 10^{-4} < 0.1$ «therefore only fraction of acid dissociated» ✓		1
2.	b	iii	10^{-10} «mol dm^{-3}» ✓		1

2.	c		*Mole percentage H_2S:* volume of H_2S = «550 – 525 = » 25 «cm^3» ✓ mol % H_2S = « $\frac{25\ cm^3}{550\ cm^3} \times 100$ = » 4.5 «%» ✓ *Assumption:* «both» gases behave as ideal gases ✓	*Award [2] for correct final answer of 4.5* *Accept "volume of gas α mol of gas".* *Accept "reaction goes to completion".* *Accept "nitrogen is insoluble/does not react with NaOH/only H2S reacts with NaOH".*	3

Q# 95/ Chem 8 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	e	iii	sulfur dioxide/SO_2 causes acid rain ✓	*Accept sulfur dioxide/SO_2/dust causes respiratory problems* *Do not accept just "causes respiratory problems" or "causes acid rain".*	1

Q# 96/ Chem 8 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	a		$CH_3COOH\,(aq) + KOH\,(aq) \rightarrow CH_3COOK\,(aq) + H_2O\,(l)$ ✓	*Accept the ionic equation.*	1
5.	b	i	B: CH_3COOH ***AND*** CH_3COO^- ✓ C: CH_3COO^- ✓	*Accept names.* *Accept CH_3COOK for CH_3COO^-*	2
5.	b	ii	phenolphthalein ✓	*Accept "phenol red" or "bromothymol blue".*	1
5.	b	iii	B ***AND*** the region where small additions «of the base/KOH » result in little or no change in pH ***OR*** B ***AND*** the flattest region of the curve «at intermediate pH/before equivalence point » ***OR*** B ***AND*** half the volume needed to reach equivalence point ***OR*** B ***AND*** similar amounts of weak acid/CH_3COOH/ethanoic acid ***AND*** conjugate base/CH_3COO^-/ethanoate ✓		1
5.	c		$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$	*Accept H^+ instead of H_3O^+.*	1
5.	d		«$K_a = 10^{-4.76} = 1.7 \times 10^{-5}$» «$K_w = K_a \cdot K_b = 1.0 \times 10^{-14} = 1.7 \times 10^{-5} \times K_b$» «$K_b$ =» 5.8×10^{-10} ✓	*Accept answers between 5.7–5.9 × 10^{-10}.*	1
5.	e		«n(KOH) = 0.02075 dm^3 × 1.00 mol dm^{-3} =» 0.0208 «mol» ✓ «n(KOH) = n(CH_3COOH)» «[CH_3COOH] = $\frac{0.0208\text{ mol}}{0.02500\text{ dm}^3}$ =» 0.830 «mol dm^{-3}» ✓	*Award [2] for correct final answer.*	2

Q# 97/ Chem 8 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	c	i	partially dissociates/ionizes «in water» ✓		1
1.	c	ii	ClO^- ✓		1
1.	c	iii	«$[H^+] = 10^{-3.61}$ =» 2.5×10^{-4} «mol dm^{-3}» ✓		1

Q# 98/ Chem 9 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5	b	i	«contains» mobile/free moving ions ✓	*Accept has ions that can carry an «electric» current/charge.*	1
5	b	ii	*Electrode:* cathode ***AND*** *Polarity:* negative ✓		1
5	b	iii	$2\,Cl^- \rightarrow Cl_2 + 2\,e^-$ ✓	*Accept $Cl^- \rightarrow \frac{1}{2}\,Cl_2 + e^-$.* *Accept e for e^-.* *Do not apply ECF.*	1
5	b	iv	amount of electrons «$\frac{1.00\times10^6\text{ coulomb}}{9.65\times10^4\text{ coulomb mol}^{-1}}$» = 10.4 mol ✓ mass «= $\frac{1}{2}$ × 10.4 mol × 9.01 g mol^{-1}»= 46.9 «g» ✓	*Accept answers in the range 46.5 to 47.0.* *Award [1 max] for 93.37, as M1 met, even if amount of electrons not stated.*	2

5	f	i	E° «= -0.83 – (-1.85)» = +1.02 «V» ✓		1
5	f	ii	spontaneous ***AND*** E° positive/>0 ✓	*Accept spontaneous **AND** ΔG negative.*	1

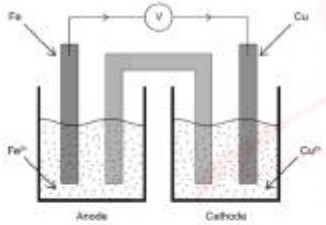
Q# 99/ Chem 9 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2	g		+2 ✓	*Do not accept 2 or 2+.*	1

Q# 100/ Chem 9 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	(a)		+6/VI ✓	*Do not accept 6/6+.*	1
4.	(b)	(i)	Zinc more reactive/ <<better>> reducing agent/ <<more>> easily oxidized/loses electrons <<more>> easily. ✓	*Accept "zinc higher in the activity «series»".* *Accept "zinc has a negative electrode potential/Cu has a positive electrode potential".*	1
4.	(b)	(ii)	Anode (negative electrode): $Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^-$ ✓ Cathode (positive electrode): $Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$ ✓	*Award **[1 max]** for equilibria.* *Award **[1 max]** for equations at the wrong electrodes.* *State symbols not required for mark.*	2
4.	(c)	(i)	«$E^\ominus_{cell}$ = +0.34-(-0.76) = +» 1.10 «V» ✓	*Accept ECF from 4 (b) (ii).*	1
4.	(c)	(ii)	«$\Delta G^\ominus = -nFE^\ominus$ =» -2 x 9.65 x 10^4 x 1.10 ✓ - 212.3 «kJ mol^{-1}» ✓ Alternate: «$\Delta G^\ominus$ =» -2 x 9.65 x 10^4 x 1.05 ✓ -202.7 «kJ mol^{-1}» ✓	*Award **[2]** for the correct final answer.*	2

Q# 101/ Chem 9 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	(f)	(i)	 all 4 species correctly labelled ✓ arrow showing electron flow from anode to cathode in the external circuit ✓	*Accept any soluble salt of copper(II) for Cu^{2+} and any soluble salt of iron(II) for Fe^{2+}.* *Do not apply ECF for M2.*	2
3.	(f)	(ii)	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$ ✓	*Accept equilibrium arrow.* *Do not award ECF for $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$.*	1
3.	(f)	(iii)	«keep» each half-cell/electrolyte «electrically» neutral ✓	*Accept balance charges/ions.* *Accept allow ion flow «between cells».*	1

3.	(f)	(iv)	NO_3^- to anode/Fe/left ✓ K^+ «and Fe^{2+}» to cathode/Cu/right ✓	*Accept other specific anions in addition to nitrate for M1.* *Award [1 max] for "anions/negative ions to anode **AND** cations/positive ions to cathode".*	2
3.	(f)	(v)	«$E^\ominus$ = + 0.34 V – (– 0.45 V) = +» 0.79 «V» ✓		1
3.	(f)	(vi)	«$\Delta G^\ominus = -nF\,E^\ominus$ = – 2 mol x (9.65 x10^4 C mol^{-1}) x (0.79 V) x =» –152 «kJ» ✓	*Accept answers in the range 150 – 153.*	1

Q# 102/ Chem 9 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	(e)		*Anode:* $H_2O(l) \rightarrow 1/2O_2(g) + 2H^+(aq) + 2e^-$ ✓ *Cathode:* $H^+(aq) + e^- \rightarrow 1/2H_2(g)$ ✓	*Do not accept other equations.*	2

Q# 103/ Chem 9 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

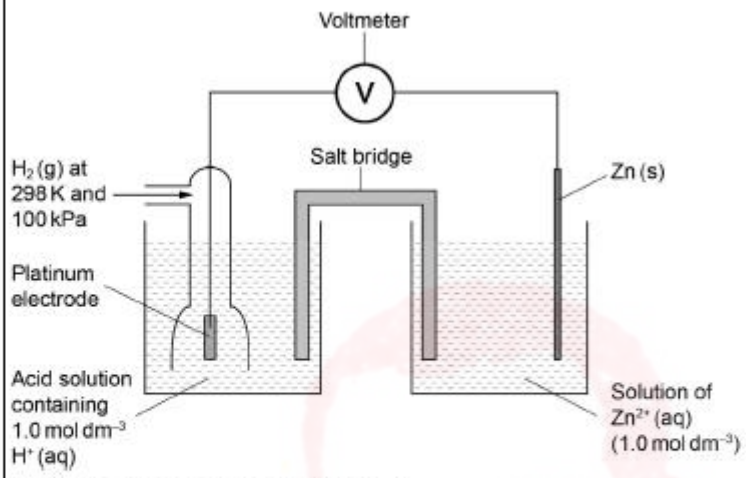
2.	a		**Alternative 1** put Mg in Zn^{2+} (aq) ✓ Zn/«black» layer forms «on surface of Mg» ✓ **Alternative 2** place both metals in acid ✓ bubbles evolve more rapidly from Mg *OR* Mg dissolves faster ✓ **Alternative 3** construct a cell with Mg and Zn electrodes ✓ bulb lights up *OR* shows (+) voltage *OR* size/mass of Mg(s) decreases <<over time>> *OR* size/mass of Zn increases <<over time>> ✓	*Award [1 max] for "no reaction when Zn placed in Mg^{2+}(aq)".* *Accept "electrons flow from Mg to Zn".* *Accept Mg is negative electrode/anode* *OR* *Zn is positive electrode/cathode* *Accept other correct methods.*	2
2.	b	i	Cell potential: «(–0.45 V – (–2.37 V)» = «+»1.92 «V»✓		1
2.	b	ii	«$\Delta G^\circ = -nFE^\circ$» n = 2 *OR* ΔG° = «-»2×96500×1.92 / «-»370,560 «J» ✓ -371 «kJ» ✓	*For n = 1, award [1] for –185 «kJ».* *Award [1 max] for (+)371 «kJ».*	2
2.	b	iii	$2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$ ✓	*Accept equation with equilibrium arrows.*	1

Q# 104/ Chem 9 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	d	iii	Mg_3N_2: -3 *AND* NH_3: -3 ✓	*Do not Accept 3 or 3-.*	1

1.	d	iv	*Acid–base:* yes ***AND*** N^{3-} accepts H^+/donates electron pair«s» ***OR*** yes ***AND*** H_2O loses H^+ «to form OH^-»/accepts electron pair«s» ✓ *Redox:* no ***AND*** no oxidation states change ✓	*Accept "yes **AND** proton transfer takes place"* *Accept reference to the oxidation state of specific elements not changing. Accept "not redox as no electrons gained/lost".* *Award [1 max] for Acid–base: yes AND Redox: no, if no other mark is awarded."*	2

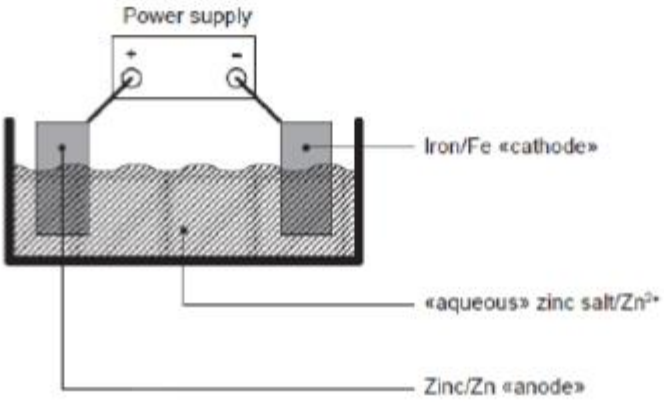
Q# 105/ Chem 9 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q8. www.SmashingScience.org :o)

8.			 H_2 (g) entering at «298 K and» 100 kPa ✓ platinum electrode on left ✓ voltmeter connecting electrodes ***AND*** salt bridge connecting electrolytes ✓ 1 mol dm^{-3} H^+ on the left ***AND*** 1 mol dm^{-3} Zn^{2+} on the right ✓	*Voltmeter and salt bridge need to be drawn but not necessarily annotated for **M3.*** *Concentrations, but not state symbols, required for **M4.***	4

Q# 106/ Chem 9 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6	a		«amount of» oxygen used to decompose the organic matter in water ✓		1
6.	b		$\left(\frac{0.0001\text{ g}}{0.1240\text{ g}} \times 100\,\% \right) \Rightarrow 0.08$ «%» ***OR*** $\left(\frac{0.4\text{ cm}^3}{1000.0\text{ cm}^3} \times 100\,\% \right) \Rightarrow 0.04$ «%» ✓ «0.08 % + 0.04 % => 0.12/0.1 «%» ✓	*Award **[2]** for correct final answer.* *Accept fractional uncertainties for **M1**, i.e., 0.0008 **OR** 0.0004.*	2
6.	c	i	$\left(\frac{37.50\text{ cm}^3}{1000} \times 5.000 \times 10^{-4}\text{ mol dm}^{-3} \right) \Rightarrow 1.875 \times 10^{-5}$ «mol» ✓		1
6.	c	ii	1:4 ✓	*Accept "4 mol $S_2O_3^{2-}$:1 mol O_2", but not just 4:1.*	1
6.	c	iii	$\left(1.875 \times 10^{-5}\text{ mol} \times \frac{1}{4} \right) \Rightarrow 4.688 \times 10^{-6}$ «mol» ✓ $\left(\frac{4.688 \times 10^{-6}\text{ mol}}{\frac{25.00\text{ cm}^3}{1000}} \right) \Rightarrow 1.875 \times 10^{-4}$ «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.*	2
6.	c	iv	MnO_2 (s) + 2e$^-$ + 4H^+ (aq) → Mn^{2+} (aq) + 2H_2O (l) ✓		1
6.	c	v	rate of reaction of oxygen with impurities depends on temperature ***OR*** rate at which bacteria/organisms grow/respire depends on temperature ✓		1

Q# 107/ Chem 9 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	d		*Equation:* $2Fe^{3+}(aq) + Fe(s) \rightarrow 3Fe^{2+}(aq)$ ✓ *Cell potential:* «+0.77 V − (−0.45 V) = +»1.22 «V» ✓	*Do not accept reverse reaction or equilibrium arrow.* *Do not accept negative value for M2.*	2
3.	e		 left electrode/anode labelled zinc/Zn *AND* right electrode/cathode labelled iron/Fe ✓ electrolyte labelled as «aqueous» zinc salt/Zn^{2+} ✓	*Accept an inert conductor for the anode.* *Accept specific zinc salts such as $ZnSO_4$.*	2

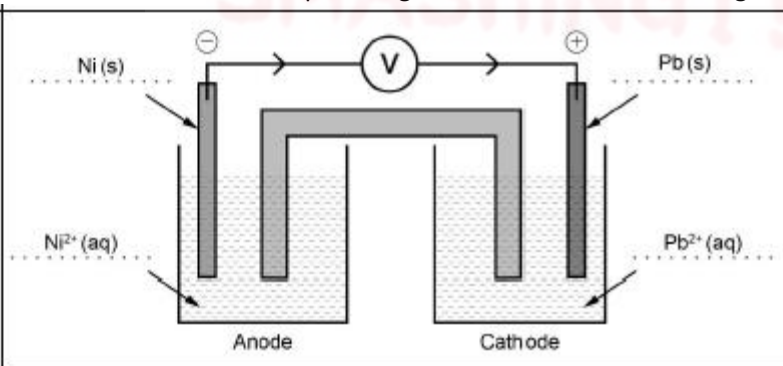
Q# 142/ Chem 9 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	e	i	$4FeS(s) + 7O_2(g) \rightarrow 2Fe_2O_3(s) + 4SO_2(g)$ ✓	*Accept any correct ratio.*	1
1.	e	ii	+6 *OR* −2 to +4 ✓	*Accept "6/VI".* *Accept "–II, 4/+4/IV".* Do not accept 2- to 4+.	1

Q# 108/ Chem 9 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	c		cathode/negative «electrode» *AND* Cu^{2+} reduced «at that electrode» ✓	*Accept cathode/negative «electrode» AND copper forms «at that electrode».*	1

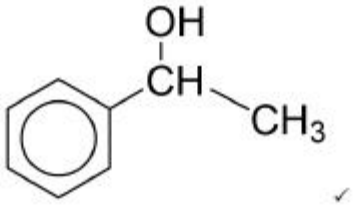
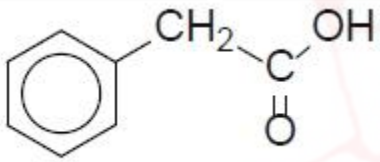
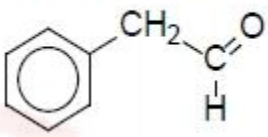
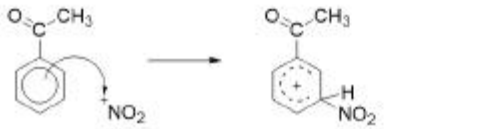
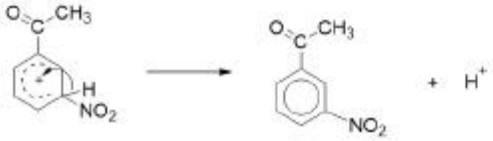
Q# 109/ Chem 9 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	d	i			1
4.	d	ii	«−0.13 V − (−0.26 V) = +» 0.13 «V» ✓		1
4.	d	iii	$\text{«}\Delta G^{\ominus} = -nFE^{\ominus} = -2 \times 96\,500 \times \frac{0.13}{1000} \text{=»} -25$ «kJ» ✓		1
4.	d	iv	Bi/Cu/Ag/Pd/Hg/Pt/Au ✓	*Accept Sb OR As.*	1

Q# 110/ Chem 9 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	b	v	MnO_2: +4 ✓ $MnCl_2$: +2 ✓		2
1.	b	vi	oxidizing agent ***AND*** oxidation state of Mn changes from +4 to +2/decreases ✓		1

Q# 111/ Chem 10 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6	a	i	 ✓	*Accept C_6H_5- instead of benzene ring.*	1
6	a	ii	it contains a chiral carbon atom ✓	*Accept it contains an asymmetric carbon / carbon with 4 different groups attached.* *Accept its mirror image is non-superimposable.*	1
6	a	iii	acidified/H^+ ***AND*** potassium dichromate(VI)/$K_2Cr_2O_7/Cr_2O_7^{2-}$ ***OR*** potassium permanganate(VII)/$KMnO_4/MnO_4^-$ ✓		1
6	a	iv	 /phenylethanoic acid ✓ addition of water «in first step» produces primary alcohol «as a minor product» ✓	*Accept phenylethanal /*  *for M1.* *Accept anti-Markovnikov addition «of water» / water can add in opposite direction for M2.*	2
6	b	i	NO_2^+ / $^+NO_2$ ✓	*Do not accept equation for the equilibrium, as electrophile not identified.*	1
6	b	ii	  curly arrow going from delocalized electrons in benzene to $^+NO_2$ ✓ representation of carbocation with correct formula and positive charge on ring ✓ curly arrow going from C-H bond to benzene ring cation ✓ formation of organic product ***AND*** H^+/HSO_4^- accepting the H^+ ✓	*Do not penalize if NO_2^+ is written.* *Award [3 max] for substitution at other positions on the benzene ring.* *Allow mechanism with corresponding Kekulé structures.* *Accept curly arrow going to either an atom or the charge on $^+NO_2$ for M1.* *For M2 accept different variations of indicating delocalized electrons in ring.*	4

Q# 112/ Chem 10 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3	a		*Reagent:* methanol ✓ *Catalyst:* «concentrated» sulfuric acid ✓	*Do not accept formula for M1.* *For M2 accept H_2SO_4/phosphoric acid/H_3PO_4/hydrochloric acid/HCl, but do not accept nitric acid.*	2
3	d		esters ✓		1

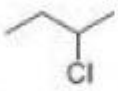
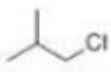
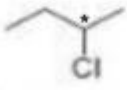
Q# 113/ Chem 10 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

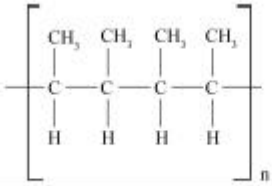
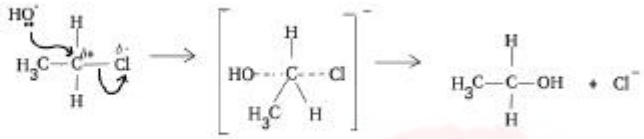
2	a		it removes CO_2 «from the atmosphere» ✓ CO_2 is a «major» contributor to climate change / global warming *OR* CO_2 is a greenhouse gas ✓	*Accept reduces CO_2 emissions for M1.* *Award [1] for reactants are cheap/readily available.* *Award [1] for atom economy is 100%.* *Award [1] for methanoic acid can be used to manufacture other useful products.* *Award [1] for reference to depletion of fossil fuels as a source of organic chemicals.*	2

Q# 114/ Chem 10 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

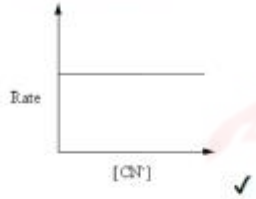
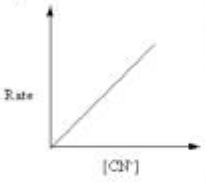
1	a		*Award [1] for two of the following:* same functional group/family same general formula «successive members» differ by a common structural unit/CH_2 ✓	*Accept "different chain lengths" for "differ by a common structural unit".*	1
1	c	i	«strongest intermolecular forces in» methanoic acid are hydrogen/H-bonds ***AND*** ethanal dipole-dipole forces ✓ hydrogen/H-bonds stronger «than dipole-dipole forces so methanoic acid has higher boiling point» ✓	*Do not award marks for answers based on difference in polarity or molar mass.* *Do not accept van der Waals' forces for dipole-dipole forces.*	2
1	c	ii	«both can» form hydrogen bonds with water «molecules» ✓		1
1	c	iii	*Relative electrical conductivity:* ethanal < methanoic acid < hydrochloric acid ✓ conductivity depends on concentration/amount of ions *OR* solutions contain increasing concentrations/amounts of ions «in this order» ✓ hydrochloric acid is a strong acid/fully dissociated ***AND*** methanoic acid is a weak acid/partially dissociated ***AND*** ethanal is not acidic/minimally dissociated/undissociated ✓	*M2 should be awarded if implied through addressing extent of dissociation/ionization in the compounds.* *Accept equations with appropriate arrows for M3.*	3
1	d	iv	the double/pi/π bond «in the methanoate ion» is delocalized *OR* resonance occurs ✓ shorter than the single bond ***AND*** longer than the double bond «in methanoic acid» / intermediate between single and double bond ✓	*Accept drawing showing delocalization of the bond or resonance structures for M1.*	2

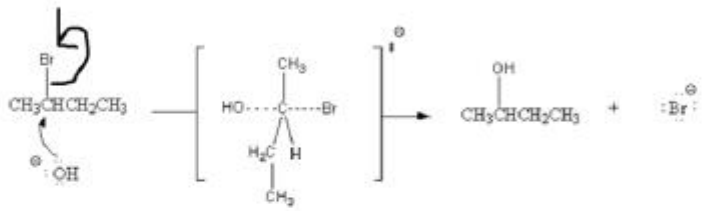
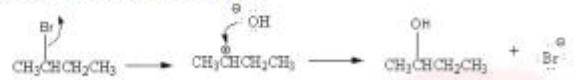
Q# 115/ Chem 10 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	(a)	(i)	compounds of the same family ***AND*** general formula *OR* compounds of the same family ***AND*** differ by a common structural unit/CH_2 ✓	*Accept contains the same functional group for same family.*	1
3.	(a)	(ii)	 2-chlorobutane ✓  1-chloro-2-methylpropane ✓	*Accept 1-chloromethylpropane for M2, but not* 2-methyl-1-choloropropane.	2
3.	(a)	(iii)	 ✓		1

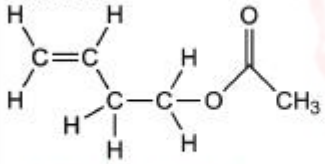
3.	(a)	(iv)	 ✓	*Allow any orientation of methyl groups.* *Ignore square brackets and "n".* Continuation lines must be shown.	1
3.	(b)		Step 1: $KOH_{(aq)}/NaOH_{(aq)}/OH^{-1}{}_{(aq)}$ ✓ Step 2: $KMnO_4$ *OR* acidified/H^+ ***AND*** $K_2Cr_2O_7$ ✓	*Do not accept H_2O for $KOH_{(aq)}/NaOH_{(aq)}/OH^{-1}{}_{(aq)}$ for M1.* *Accept potassium permanganate/MnO_4^- /dichromate/$Cr_2O_7^{2-}$ for M2.* *Accept H_2SO_4 as acid.* *Do not allow any other acid.*	2
3.	(c)	(i)	Nucleophilic ***AND*** substitution. ✓	*Allow S_N2.* *Do not allow S_N1.* *Do not allow hydrolysis.*	1
3.	(c)	(ii)	 curly arrow going from lone pair/negative charge on O in ^-OH to C ✓ curly arrow showing Cl leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓ correct products ✓	*Accept OH^- with or without the lone pair.* *Do not allow curly arrows originating on H in OH^-.* *Accept curly arrows in the transition state.* *Do not penalize if HO and Cl are not at 180°.* *Do not award M3 if OH–C bond is represented.* *If the answer in 3 (c) (i) is correct Award [3 max] for S_N1 mechanism.* if answer in 3 (c) (i) is S_N1, award **[4]** for S_N1 mechanism.	4
3.	(c)	(iii)	ethyl ethanoate/$CH_3CH_2OOCCH_3$ ***AND*** water/H_2O. ✓	*Accept structural/skeletal formulae.*	1

Q# 116/ Chem 10 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

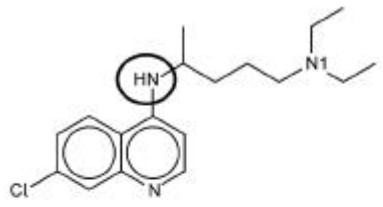
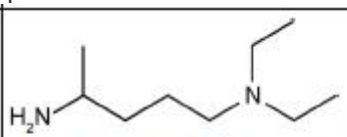
6.	(a)		*S_N1 mechanism:*  ✓ *S_N2 mechanism:*  ✓		2
6.	(b)		S_N2 ***AND*** S_N2 «mechanism» occurs with inversion of configuration *OR* S_N2 ***AND*** S_N1 «mechanism» would create a racemic mixture ✓	*Accept appropriate diagrams.*	1
6.	(c)		polarimeter ✓		1
6.	(d)		aprotic ***AND*** polar ✓		1

6.	(e)		slower ***AND*** C-Cl bond is stronger «than C-Br» ***OR*** slower ***AND*** Br/Br^- is a better leaving group ✓		1
6.	(f)		 arrow from – charge/lone pair to carbon attached to Br ✓ arrow from C-Br bond to Br ✓ transition state representing the partially formed and partially broken bonds ✓ *If S_N1 was selected in 6 (b):*  arrow from C-Br bond to Br ✓ carbocation intermediate ✓ arrow from – charge/lone pair to carbocation ✓		3

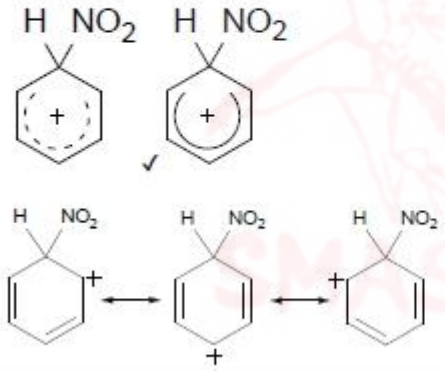
Q# 117/ Chem 10 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q4. www.SmashingScience.org :o)

4.	(a)	(i)	*Structure:*  ester functional group ✓ rest of structure ✓ *Empirical Formula:* C_3H_5O ✓	*Accept condensed/skeletal formula.*	3
4.	(a)	(ii)	dilute adds «excess» water ***OR*** water is a product ✓ shift left ***AND*** decreases yield ✓		2
4.	(a)	(iii)	A has hydrogen bonding/bonds «and dipole-dipole and London/dispersion forces» ***AND*** B has dipole-dipole «and London/dispersion forces» ***OR*** A has hydrogen bonding/bonds ***AND*** B does not ✓ intermolecular forces are weaker in B ***OR*** hydrogen bonding/bonds stronger «than dipole-dipole» ✓		2
4.	(b)		brown/orange/red/yellow to colourless ✓	*Do not accept clear for colourless.*	1

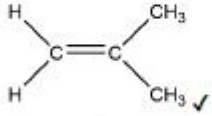
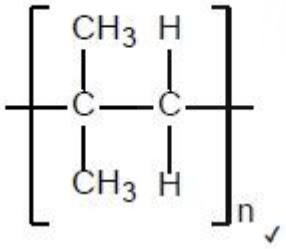
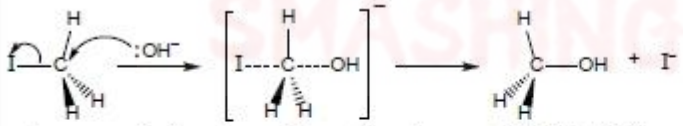
Q# 118/ Chem 10 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	(a)		 ✓		1
2.	(b)		nine/9 ✓		1
2.	(c)		seven/7 ✓		1
2.	(d)		«bond in ring is» shorter ***AND*** more electrons are shared ***OR*** «bond in ring is» shorter ***AND*** partial double/multiple bonding/bond order 1.5 ✓		1
2.	(e)	(i)	 primary amine/-NH_2 ✓ rest of structure ✓	*Do not penalize using "N1".*	2

Q# 119/ Chem 10 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	b	i	$HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + H_3O^+ + 2HSO_4^-$ ✓	*Accept "$HNO_3 + H_2SO_4 \rightleftharpoons NO_2^+ + H_2O + HSO_4^-$".* *Accept "$HNO_3 + H_2SO_4 \rightleftharpoons H_2NO_3^+ + HSO_4^-$" **AND** "$H_2NO_3^+ \rightleftharpoons NO_2^+ + H_2O$".* *Accept single arrows instead of equilibrium signs.*	1
6.	b	ii		*Accept any of the five structures.* *Do not accept structures missing the positive charge.*	1 max
6.	b	iii	*Number of signals:* three/3 ✓ *Relative areas:* 2 : 2 : 1 ✓		2

Q# 120/ Chem 10 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

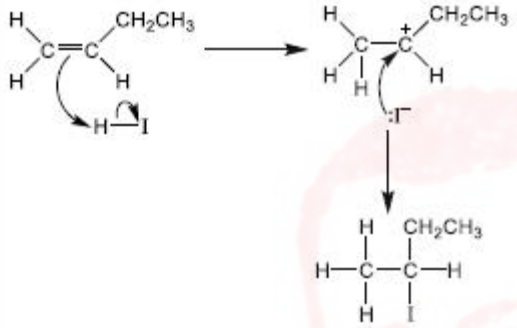
5.	a	i	2-methylpropan-2-ol /2-methyl-2-propanol ✓	*Accept methylpropan-2-ol/* methyl-2-propanol. *Do not accept 2-methylpropanol.*	1
5.	a	ii	dipole-dipole ✓	*Do not accept van der Waals' forces.*	1
5.	a	iii	*σ*: 9 ***AND*** *π*: 1 ✓		1
5.	a	iv	sp^2 ✓		1
5.	a	v	butan-2-ol/$CH_3CH(OH)C_2H_5$ ✓		1
5.	b	i	 ✓		1
5.	b	ii	carbocation formed from $(CH_3)_3COH$ is more stable / $(CH_3)_3C^+$ is more stable than $(CH_3)_2CHCH_2^+$ ✓ «because carbocation has» greater number of alkyl groups/lower charge on the atom/higher e^- density *OR* «greater number of alkyl groups» are more electron releasing *OR* «greater number of alkyl groups creates» greater inductive/+I effect ✓	*Do not award any marks for simply quoting Markovnikov's rule.*	2
5.	b	iii	 ✓	*Do not penalize missing brackets or n.* *Do not award mark if continuation bonds are not shown.*	1
5.	c		no change «in colour/appearance/solution» ✓		1
5.	d	i	«nucleophilic» substitution *OR* SN2 ✓	*Accept "hydrolysis".* *Accept SN1*	1
5.	d	iii	 curly arrow going from lone pair/negative charge on O in ^-OH to C ✓ curly arrow showing I leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓	*Accept OH^- with or without the lone pair.* *Do not allow curly arrows originating on H, rather than the -, in OH^-.* *Accept curly arrows in the transition state.* *Do not penalize if HO and I are not at 180°.* *Do not award M3 if OH–C bond is represented.* *Award **[2 max]** if SN1 mechanism shown.*	3

Q# 121/ Chem 10 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7.	a		«$q = mc\Delta T = 20.0\,g \times 4.18\,J\,g^{-1}\,°C^{-1} \times 57.3\,°C$ =» 4790 «J» ✓ «$\Delta H_c = -\frac{4790\ J}{\frac{1000}{8.75\times10^{-4}\ mol}}$ =» −5470 «kJ mol^{-1}» ✓	*Award **[2]** for correct final answer.* *Accept answers in the range –5470 to -5480 «kJ mol^{-1}».* *Accept correct answer in any units, e.g. – 5.47 «MJ mol^{-1}» or 5.47 x 10^6 «J mol^{-1}».*	2

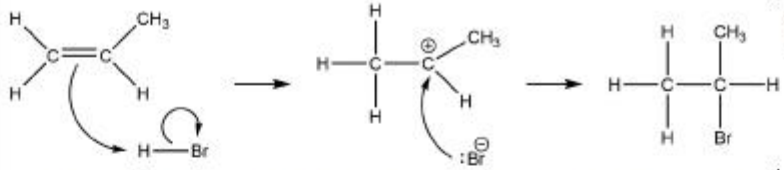
7.	b		$Cl\cdot + C_2H_6 \rightarrow \cdot C_2H_5 + HCl$ ✓ $\cdot C_2H_5 + Cl_2 \rightarrow Cl\cdot + C_2H_5Cl$ ✓ $\cdot C_2H_5 + Cl\cdot \rightarrow C_2H_5Cl$ ***OR*** $Cl\cdot + Cl\cdot \rightarrow Cl_2$ ***OR*** $\cdot C_2H_5 + \cdot C_2H_5 \rightarrow C_4H_{10}$ ✓	*Do not penalize incorrectly placed radical sign, eg $C_2H_5\cdot$.*	3

Q# 122/ Chem 10 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q10. www.SmashingScience.org :o)

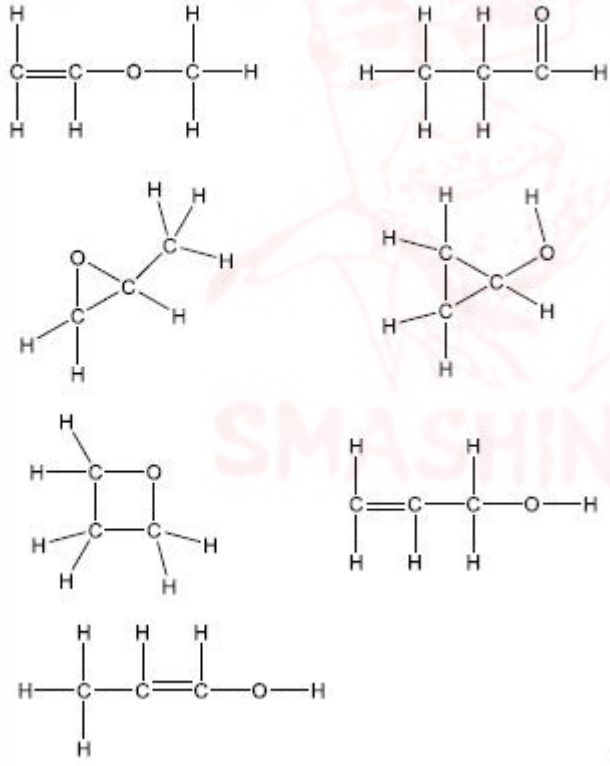
10.	b	i	no ***AND*** 2 groups on a carbon «in the double bond» are the same/hydrogen «atoms» ***OR*** no ***AND*** molecule produced by rearranging atoms bonded on a carbon «in the double bond» is the same as the original ✓		1
10.	b	ii	«electrophilic» addition ✓	*Do not allow nucleophilic addition.*	1
10.	b	iii	 curly arrow going from C=C to H of HI ***AND*** curly arrow showing I leaving ✓ representation of carbocation ✓ curly arrow going from lone pair/negative charge on I^- to C^+ ✓ 2-iodobutane formed ✓	*Penalize incorrect bond, e.g. -CH-H_3C or –CH_3C once only.*	4
10.	b	iv	yes ***AND*** has a carbon attached to four different groups ***OR*** yes ***AND*** it contains a chiral carbon ✓	*Accept yes **AND** mirror image of molecule different to original/non-superimposable on original.*	1
10.	d		S_N2 ***AND*** rate depends on both OH^- and 2-chloropentane ✓	*Accept E2 **AND** rate depends on both OH^- and 2-chloropentane.*	1
10.	e		delocalized electrons/pi bonds «around the ring» ***OR*** molecule has a region of high electron density/negative charge ✓ electrophiles are attracted/positively charged ***AND*** nucleophiles repelled/negatively charged✓	*Do not accept just "nucleophiles less attracted" for **M2**.* *Accept "benzene **AND** nucleophiles are both electron rich" for "repels nucleophiles".*	2

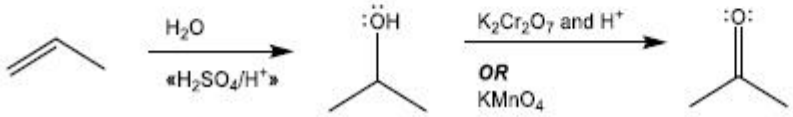
Q# 123/ Chem 10 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	a	i	alkene ✓		1
5.	a	ii	C_3H_6 ✓	*Accept structural formula.*	1
5.	c		carbon monoxide/CO ***AND*** carbon/C/soot ✓		1
5.	d		«addition» polymerization ✓		1

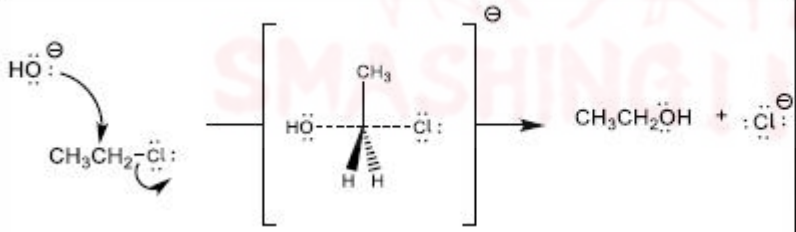
5.	e	i	 curly arrow going from C=C to H of HBr ***AND*** curly arrow showing Br leaving ✓ representation of carbocation ✓ curly arrow going from lone pair/negative charge on Br^- to C^+ ✓	*Award **[2 max]** for mechanism producing 1-brompropane.*	3
5.	e	ii	«2-bromopropane involves» formation of more stable «secondary» carbocation/carbonium ion/intermediate *OR* 1-bromopropane involves formation of less stable «primary» carbocation/ carbonium ion/intermediate ✓ «increased» positive inductive/electron-releasing effect of extra –R group/–CH_3/methyl «increases stability of secondary carbocation» ✓	*Award [1] for "more stable due to positive inductive effect".* *Do not award marks for quoting Markovnikov's rule without any explanation.*	2
5.	e	iii	sodium hydroxide/NaOH/potassium hydroxide/KOH ✓	*Accept «aqueous» hydroxide ions/OH^-*	1
5.	e	iv	*Name of carbonyl compound:* propanone ✓ *Type of reaction:* reduction ✓	*Accept other valid alternatives, such as "2-propyl ethanoate" for M1 and "hydrolysis" for M2.*	2

Q# 124/ Chem 10 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	e		*Accept any two C_3H_6O isomers except for propanone and propen-2-ol:*  ✓✓	*Penalize missing hydrogens in displayed structural formulas once only.*	2

2.	f	i	B *AND* K_c is greater than 1/large ✓		1
2.	f	ii	«$\Delta G^\ominus = -RT\ln K = 0.00831\ kJ\ mol^{-1}\ K^{-1}\ (298\ K)\ (\ln 1.0 \times 10^8) =$» –46 «kJ mol^{-1}» ✓		1
2.	g	i	 H_2O/water «and H^+» ✓ $CH_3CH(OH)CH_3$/propan-2-ol ✓ $K_2Cr_2O_7$/«potassium» dichromate(VI) *AND* H^+ *OR* $KMnO_4$/ «acidified potassium» manganate(VII) ✓	*Accept H_3O^+.*	3
2.	g	ii	primary carbocation «intermediate forms» *OR* minor product «of the water addition would be» propan-1-ol *OR* anti-Markovnikov addition of water ✓ primary alcohol/propan-1-ol oxidizes to an aldehyde/propanal ✓		2

Q# 125/ Chem 10 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	d	i	«free radical» substitution/S_R ✓	*Do not accept electrophilic or nucleophilic substitution.*	1
1.	d	ii	chloroethane *AND* C–Cl bond is weaker/324 kJ mol^{-1} than C–H bond/414 kJ mol^{-1} *OR* chloroethane *AND* contains a polar bond ✓	*Accept "chloroethane **AND** polar".*	1
1.	d	iii	 curly arrow going from lone pair/negative charge on O in ^-OH to C ✓ curly arrow showing Cl leaving ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓	*Accept OH^- with or without the lone pair.* *Do not accept curly arrows originating on H in OH^-.* *Accept curly arrows in the transition state.* *Do not penalize if HO and Cl are not at 180°.* *Do not award M3 if OH–C bond is represented.*	3

Q# 126/ Chem 11 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5	a	i	X-ray crystallography/diffraction ✓		1

Q# 127/ Chem 11 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3	c	i	*Similarity:* «absorption at» 1700-1750 «cm^{-1}» *OR* absorption by the carbonyl/C=O bond *OR* «absorption at» 2850-3090 «cm^{-1}» *OR* absorption by carbon-hydrogen/C- H bond ✓ *Difference:* methanoic acid «has absorption at» 2500-3000 «cm^{-1} which is absent for methyl methanoate» *OR* methanoic acid has absorption by the hydroxyl/O-H bond «which is absent for methyl methanoate» ✓	*Do not accept the bond without the wavenumber or reference to the spectrum (e.g. absorption, peak, trough).* *Do not accept absorption of C-O bond at 1050-1410 cm^{-1} for M1 as it is outside range.* *Do not accept hydroxide instead of hydroxyl for M2.* *Do not accept 3200-3600 cm^{-1} for M2 as O-H is in carboxylic acid.*	2
3	c	ii	methyl methanoate ***AND*** the ratio «of areas under peaks» is 1:3 ✓	*Accept methyl methanoate **AND** methanoic acid would have a 1:1 ratio.* *Do not accept answers in terms of chemical shift.*	1

Q# 128/ Chem 11 IB Chem/2023/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2	c	ii	*ALTERNATIVE 1* sum of absolute uncertainties «= 0.804 + 0.436 + 0.414 + 0.358 + 0.463 =» 2.475 «$kJ\ mol^{-1}$» ✓ percentage uncertainty «= $100 \times \frac{2.475}{5}$ = 49.5% = » 50 «%» ✓ *ALTERNATIVE 2* sum of absolute uncertainties «= 3(0.804) + 0.436 + 0.414 + 0.358 + 0.463 =» 4.083 «$kJ\ mol^{-1}$» ✓ percentage uncertainty «= $100 \times \frac{4.083}{5}$ = 81.7%» = 80 «%» ✓	*Award [2] for correct final answer.*	2

Q# 129/ Chem 11 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q7. www.SmashingScience.org :o)

7.	(a)	(i)	<table><tr><td>Name</td><td>Number of signals</td></tr><tr><td>Ethyl methanoate</td><td>3</td></tr><tr><td>Methyl ethanoate</td><td>*AND* 2</td></tr></table> ✓		1
7.	(a)	(ii)	same types of bonds «present in both molecules» *OR* same wavenumbers absorbed ✓		1

Q# 130/ Chem 11 IB Chem/2023/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	(a)	(i)	«$\Delta H°rxn = \sum \Delta H°f$ (Products) − $\sum \Delta H°f$ (Reactants) =» -395.8 - (-296.8)» = –99.0«kJ mol^{-1}» ✓		1
6.	(b)	(i)	«$q = -mc\Delta T$ = 50.00g x 4.18J $K^{-1}g^{-1}$ x (35.0-20.0)°C =» -3140.0 «J» ✓ «(3140/0.1)/1000 =» -31.4 «kJ mol^{-1}» ✓	*Award [1 max] for +31.4 kJ mol^{-1}* *Award [2] for correct final answer.*	2
6.	(b)	(ii)	Source of systematic error: heat loss «to the surroundings» ✓ Improvement: insulate reaction apparatus/put a lid on the beaker *OR* use a bomb/calibrated calorimeter *OR* use of windbreak around the dish/apparatus ✓		2
6.	(b)	(iii)	«1.0/15.0 x 100 =» 6.7«%» ✓ *OR* $\frac{\sqrt{0.5^2+0.5^2}}{15.0} \times 100\% \approx 5\%$	*Do not allow 6.6%* *Accept "5%" if the formula $\sqrt{\Sigma(\Delta A)^2}$ is used.*	1

6.	(b)	(iv)	more precise/more divisions per degree «on the thermometer» *OR* more precise balance *OR* larger quantities of sulfur/water *OR* larger temperature change ✓	*Do not accept more repetitions.*	1
6.	(b)	(v)	« -297 kJ mol^{-1} - -31.4kJ mol^{-1}/-297 kJ mol^{-1}x 100 =» 89.4 «%» ✓ alternate: « -297 kJ mol^{-1} - -50.0 kJ mol^{-1}/-297 kJ mol^{-1}x 100 =» 83.2 «%» ✓		1

Q# 131/ Chem 11 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	(g)	(i)	*Number of signals:* 4 ✓ *Ratio of areas:* 3:1:2:3 ✓	*Accept ratio of areas in any order.*	2
6.	(g)	(ii)	*Splitting pattern of the signal of the hydrogen atoms in circle A:* doublet ✓ *Splitting pattern of the signal of the hydrogen atoms in circle B:* triplet ✓		2

Q# 132/ Chem 11 IB Chem/2022/w/TZ0/Paper 2/Higher Level/Q3. www.SmashingScience.org :o)

3.	(b)		$\frac{(63 \times 69) + (65 \times 31)}{100}$ *OR* $65x + (1-x)63 = 63.62$ ***AND*** $x = 0.31 / 31$«%» ***AND*** $1 - x = 0.69 / 69$«%» ✓		1

Q# 133/ Chem 11 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q6. www.SmashingScience.org :o)

6.	a	iv	X-ray crystallography ✓		1

Q# 134/ Chem 11 IB Chem/2022/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	b	ii	mass of product « = 56.941 g – 47.372 g» = 9.569 «g» ✓ $\langle\langle 100 \times \frac{2 \times 0.001\text{g}}{9.569\text{g}} = 0.0209 \rangle\rangle$ = 0.02 «%» ✓	*Award [2] for correct final answer* *Accept 0.021%.*	2

Q# 135/ Chem 11 IB Chem/2021/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	c		**Spectrum** / **Identity** / **Reason** A / Propan-1-ol / absence of carbonyl/C=O «absorption»/ no peak in 1700 - 1750 «cm^{-1}» range ***OR*** presence of hydroxyl/O-H in alcohols «absorption»/peak in 3200 – 3600 «cm^{-1}» range ✓ B / Propanoic acid / **ALTERNATIVE 1:** carbonyl/C=O ***AND*** hydroxyl/O-H «in carboxylic acids absorptions» ***OR*** «strong» peaks in 2500 – 3000 «cm^{-1}» ***AND*** 1700 – 1750 «cm^{-1}» ranges ✓ **ALTERNATIVE 2:** O-H in carboxylic acids «absorption» ***AND*** 2500 – 3000 «cm^{-1}» range ✓ **ALTERNATIVE 3:** strong/broad «peak» ***AND*** 2500 – 3000 «cm^{-1}» range ✓	*Award **[1 max]** for correctly identifying all 3 compounds without valid reasons given.* *Accept specific values of wavenumbers within each range.*	3

			C | Propanal | presence of carbonyl/C=O «absorption»/ peak in 1700 – 1750 «cm^{-1}» range ***AND*** absence of hydroxyl/O-H «in carboxylic acids absorption»/ no «broad» peak in 2500 – 3000 «cm^{-1}» range ✓		
1.	d		**Compound** | **Number of signals** | **Splitting pattern of $-CH_3$** *propanone* | 1 | singlet *propanal* | 3 | triplet		2
1.	e		CH_3O^+	*Accept any structure i.e. "CH_2OH^+".*	1

Q# 136/ Chem 11 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

5.	b	i	hydrogen atoms/protons in same chemical environment ✓	*Accept "all H atoms/protons are equivalent".* *Accept "symmetrical"*	1
5.	b	ii	4.5 to 6.0 «ppm» ✓	*Accept a single value within this range.*	1

Q# 137/ Chem 11 IB Chem/2021/s/TZ1/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	d	ii	X-ray crystallography ✓		1

Q# 138/ Chem 11 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q5. www.SmashingScience.org :o)

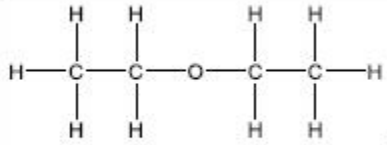
5.	f	i	systematic «error» ✓		1
5.	f	ii	$[CH_3COOH]$ would be higher ✓ actual [KOH] is lower «than the value in calculation» *OR* larger volume of KOH «solution» needed to neutralize the acid ✓	*Accept KOH partially neutralised by CO_2 from air.*	2

Q# 139/ Chem 11 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q2. www.SmashingScience.org :o)

2.	d		B ***AND*** C=O absorption/1750 «cm^{-1}» *OR* B ***AND*** absence of O–H /3200–3600 «cm^{-1} absorption» ✓	*Accept any value between 1700–1750 cm^{-1}.*	1

Q# 140/ Chem 11 IB Chem/2020/w/TZ0/Paper 2/Higher Level/Q1. www.SmashingScience.org :o)

1.	a	iv	«two major» isotopes «of atomic mass 35 and 37» ✓		1
1.	a	v	«diatomic» molecule composed of «two» chlorine-37 atoms ✓ chlorine-37 is the least abundant «isotope» *OR* low probability of two ^{37}Cl «isotopes» occurring in a molecule ✓		2

1.	d	iv	 / $CH_3CH_2OCH_2CH_3$ ✓	*Accept $(CH_3CH_2)_2O$.*	1
1.	d	v	2 «signals» ✓ 0.9–1.0 ***AND*** triplet ✓ 3.3–3.7 ***AND*** quartet ✓	*Accept any values in the ranges.* *Award [1] for two correct chemical shifts or two correct splitting patterns.*	3