PapaCambridge

Cambridge AS & A Level

CHEMISTRY

Paper 2

Topical Past Paper Questions

+ Answer Scheme

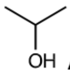
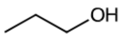
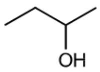
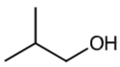
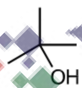
2015 - 2021

PapaCambridge

Appendix A

Answers

1. 9701_s17_ms_21 Q: 1

(a)	The mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecules	1
	Relative / compared to $\frac{1}{12}$ (the mass) of <u>an atom</u> of carbon–12 OR on a scale in which a carbon–12 atom / isotope has a mass of (exactly) 12 (units)	1
(b)(i)	**3**	1
(b)(ii)	**8**	1
(b)(iii)	$C_3H_8O + 4½O_2 \rightarrow 3CO_2 + 4H_2O$	1
(b)(iv)	 **AND** propan–2–ol / 2–propanol	1
	 **AND** propan–1–ol / 1–propanol	1
	Alternative answers (any two):  **AND** butan–1–ol / 1–butanol  **AND** butan–2–ol / 2–butanol  **AND** (2–)methylpropan–1–ol / (2–)methyl–1–propanol  **AND** (2–)methylpropan–2–ol / (2–)methyl–2–propanol	
(b)(v)	correct conversions of data to SI/consistent units p = 100 000 ; V = 20×10^{-6} ; T = 393	1
	calculation of *n* (= *pV*/*RT*) from M1 values $n = \frac{100 \times 10^3 \times 20 \times 10^{-6}}{8.31 \times 393}$	1
	calculation of mass *m* (= *n* × *Mr*) **AND** answer correct to **3sf** $m = 6.12 \times 10^{-4} \times 60 = 0.0367$ (g) Alternative answer for using $C_4H_{10}O$: $m = 6.12 \times 10^{-4} \times 74 = 0.0453$ (g)	1
	Total:	**10**

2. 9701_m16_ms_22 Q: 2

(a) (i)	$\frac{27.30}{1000} \times 0.020 = \mathbf{5.46 \times 10^{-4}}$ (mol)	[1]
(ii)	**(i)** $\times$ 6 = $\mathbf{3.28 \times 10^{-3}}$ (mol)	[1]
(iii)	**(ii)** $\times \frac{250}{25.00}$ = $\mathbf{3.28 \times 10^{-2}}$ (mol)	[1]
(iv)	M_r of $FeCO_3$ = 55.8 + 12.0 + 3(16.0) = **115.8** **(iii)** × $M_r(FeCO_3)$ = **3.79** g	[1] [1]
(v)	$\frac{\text{(iv)}}{5.00} \times 100\%$ = **75.9%**	[1]
(b) (i)	$2Fe^{3+} + Sn^{2+} \rightarrow 2Fe^{2+} + Sn^{4+}$ species balancing	 [1] [1]
(ii)	$\mathbf{SnCl_2(aq)} + \mathbf{2}HgCl_2(aq) \rightarrow SnCl_4\mathbf{(aq)} + Hg_2Cl_2\mathbf{(s)}$ $SnCl_2$ AND 2 state symbols	 [1] [1]

3. 9701_w16_ms_21 Q: 1

(a)	6×10^{-3} (mol)	1	1
(b)	$NaOH + HCl \rightarrow NaCl + H_2O$	1	1
(c)	6×10^{-3} (mol)	1	1
(d)	4×10^{-3} (mol)	1	1
(e)	4×10^{-3} (mol)	1	1
(f)	1×10^{-3} (mol)	1	1
(g)	170	1	1
(h)	28(.0) Si/silicon	1 1	2
	Total:		9

4. 9701_w16_ms_22 Q: 1

(a)	0.04 **OR** 4×10^{-2}	1
(b)(i)	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$	1
(b)(ii)	0.00075 **OR** 7.5×10^{-4}	1
(b)(iii)	0.0015 **OR** 1.5×10^{-3}	1
(b)(iv)	0.015 **OR** 1.5×10^{-2}	1
(b)(v)	0.025 **OR** 2.5×10^{-2}	1
(b)(vi)	0.0125 **OR** 1.25×10^{-2} **OR** 0.013 **OR** 1.3×10^{-2}	1
(b)(vii)	40 Ca / calcium	1 1
	Total:	9

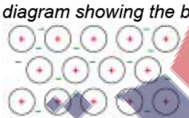
5. 9701_s17_ms_22 Q: 1

(a)

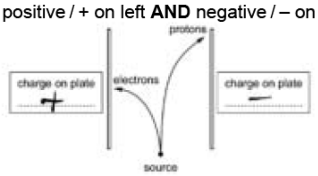
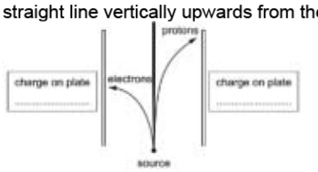
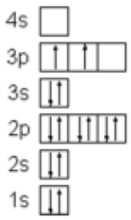
atomic number	nucleon number	number of electrons	number of protons	number of neutrons	symbol		
	6		3	3		1	2
					$^{58}_{26}Fe^{3+}$	1	

Question	Answer		Marks
(b)(i)	EITHER mass of an atom / isotope relative / compared to 1/12 (the mass) of (an atom of) C-12 OR on a scale in which a C-12 (atom / isotope) has (a mass of exactly) 12 (units) OR mass of one mol (of atoms) of an isotope relative / compared to 1/12 (the mass) of 1 mol of C-12 OR on a scale in which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g	 1 1	2
(b)(ii)	$\frac{(10.0129 \times 19.78) + (80.22x)}{100} = 10.8$		1
	x = 10.9941		1
		Total:	6

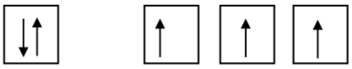
6. 9701_s20_ms_23 Q: 2

Question	Answer	Marks
(a)	**EITHER** **M1** mass of an atom / isotope **M2** relative / compared to 1/12 (the mass) of (an atom of) C-12 OR on a scale in which a C-12 (atom / isotope) has (a mass of exactly) 12 (units) **OR** **M1** mass of one mol (of atoms) of an isotope **M2** relative / compared to 1/12 (the mass) of 1 mol of C-12 OR in which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g	2
(b)	% abundance of ^{63}Cu = 72.5% % abundance of ^{65}Cu = 27.5% **M1** *correct algebraic expression AND correct calculation of x for one isotope* % ab of ^{63}Cu = x (x/100 × 63) + ((1- x)/100 × 65) = 63.55 so x =72.5 OR % ab of ^{65}Cu = x (1- x)/100 × 63) + x/100 × 65) = 63.55 so x = *27.5* **M2** *calculation of abundance of other isotope by 100- x*	2
(c)(i)	metallic	1
(c)(ii)	*diagram showing the bonding in a sample of copper*  **M1** diagram shows regular arrangement of spheres labelled as positively charged ions / +2 or +1 / cations **M2** diagram shows surrounded by electrons and clearly labelled as 'delocalised electrons'	3
(c)(iii)	$(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$ **OR** $(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^{10}$	1
(d)(i)	**M1** *calculate the number mol $S_2O_3^{\ 2-}$ added* 20/1000 x 0.10 = 2×10^{-3} = 0.002 (mol $S_2O_3^{\ 2-}$) **M2** *calculate number mol $CuSO_4$ in 250cm^3* (1mol $S_2O_3^{\ 2-}$: 1 mol $CuSO_4$) = 0.002 mol $CuSO_4$ in 25cm^3 so 0.02 mol $CuSO_4$ in 250cm^3	2
(d)(ii)	**M1** amount of $CuSO_4$ in 10.68 g of $CuSO_4{\cdot}xH_2O$: 7.98 / (159.6) = <u>0.05</u> (mol) **M2** amount of H_2O in 10.68 g of $CuSO_4{\cdot}xH_2O$: (10.68 – 7.98) / 18 = 2.7 / 18 =) <u>0.15</u> (mol) **M3** value of **x**: (mol H_2O ÷ mol $CuSO_4$ =) 3	3

7. 9701_w20_ms_22 Q: 1

<table>
<tr><td>(a)(i)</td><td>positive / + on left AND negative / – on right

</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>straight line vertically upwards from the source

</td><td>1</td></tr>
<tr><td>(b)(i)</td><td><table><tr><td>type of orbital</td><td>s</td><td>p</td><td>d</td></tr><tr><td>number of orbitals</td><td>4</td><td>9</td><td>5</td></tr></table></td><td>3</td></tr>
<tr><td>(b)(ii)</td><td>
</td><td>2</td></tr>
<tr><td>(b)(iii)</td><td>5</td><td>1</td></tr>
<tr><td>(b)(iv)</td><td>Award one mark for each correct bullet point – max 3 marks
• nuclear charge increases
• extra electron(s) in inner shell / n=3 /d-subshell / d- orbital
• increased shielding (of 4s electrons by electrons in n=3 / 3rd shell / 3d)
• (overall) similar nuclear attraction (for outer electron)</td><td>3</td></tr>
<tr><td>(c)</td><td>answer in terms of subatomic particles in the nucleus
same (number of) protons
AND
different (number of) neutrons</td><td>1</td></tr>
</table>

8. 9701_s19_ms_23 Q: 1

(a)(i)	All have the same nucleon number OR same sum / **total** number of protons + neutrons	**1**
(a)(ii)	(different) number of protons, neutrons **and** electrons	**1**
(b)	**M1** x / 100 □ 32 + (100–x / 100 □ 34) = 32.09 **M2** (32x + 3400 – 34x) = 3209 so x = 95.5 **M3** S^{32} 95.5% **AND** S^{34} 4.5%	**3**
(c)(i)	1s	**1**
(c)(ii)		**1**
(c)(iii)	**M1** 3p **M2** It is less attracted to the nucleus (so takes less energy to lose) OR It is the highest energy orbital (which is occupied) / it is in the highest energy orbital	**2**
(d)(i)	 3s 3p	**1**
(d)(ii)	**M1** (in S, the electron is removed from the) 2 electrons in (3)**p** orbital OR a pair of electrons in (3)**p** (orbital / sub-shell) **M2** (paired electrons) repel	**2**

9. 9701_s16_ms_21 Q: 1

(a)	(table below)	[1] [1] [1] [1]

name of element	nucleon no.	atomic no.	no. of protons	no. of neutrons	no. of electrons	overall charge
lithium	6	3	3	3	2	+1
oxygen	17	8	8	9	10	–2
iron	54	26	26	28	24	+2
chlorine	35	17	17	18	17	0

(b)	line straight on labelled 'neutrons' line (curving) up labelled 'protons' proton line clearly shows less (overall) deflection than electron curve	[1] [1] [1]
(c) (i)	Group 16 / 6 / VI AND Big (owtte) increase / big difference / big gap / big jump / jump in increase / jump in difference after 6th IE	[1]
(ii)	increases (across period) due to increasing attraction (of nucleus for electrons) due to increasing nuclear charge / atomic / proton number AND constant/similar shielding / same (outer / number of) shell / energy level	[1] [1]
(iii)	electron (pair) repulsion (**Y** has a) pair of electrons in a (3)p orbital / a (3)p orbital is full ORA	[1] [1]
(iv)	$(1s^2)2s^22p^63s^23p^5$	[1]
(d) (i)	0.56(%)	[1]
(ii)	$\frac{(A\times0.56)+(86\times9.86)+(87\times7.00)+(88\times82.58)}{100}=87.71$ A = 84	[1] [1]

10. 9701_s16_ms_22 Q: 1

(a)

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge	
boron	10	5	5	5	5	0	[1]
nitrogen	15	7	7	8	10	–3	[1]
lead	208	82	82	126	80	+2	[1]
lithium	6	3	3	3	2	+1	[1]

(b) (i)	Group 17 / VII / 7 AND big (owtte) increase / big difference / big gap / big jump / jump in increase / jump in difference after 7th IE	[1]
(ii)	increases across period due to increasing attraction (of nucleus for electrons)	[1]
	due to increasing nuclear charge / atomic / proton number AND constant / similar shielding / same (outer) shell / energy level	[1]
(iii)	$1s^2 2s^2 2p^6 3s^2 3p^4$	[1]
(c) (i)	(100 – 99.76 – 0.04=) 0.2	[1]
(ii)	$\frac{0.2x + (99.76 \times 16) + (0.04 \times 17)}{100} = 16.0044$	[1]
	x = 18	[1]

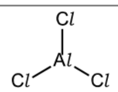
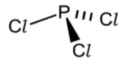
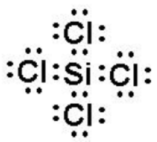
11. 9701_S15_ms_21 Q: 1

(a)		

sub-atomic particle	relative mass	relative charge	
neutron	**1**	0	[1]
electron	1/1836	**–1**	[1]
proton	**1**	**+1**	[1]

(b) (i)	RAM = mean / average mass of the isotope<u>s</u> / an atom(s) relative to 1/12 the mass of an atom of ^{12}C / on a scale where an atom of ^{12}C is (exactly) 12 (units) isotope = atoms with the same number of protons / atomic number / proton number with different mass numbers / numbers of neutrons / nucleon number	[1] [1] [1]
(ii)	$\frac{(0.89\times74)+(9.37\times76)+(7.63\times77)+(23.77\times78)+(49.61\times80)+(8.73\times82)}{100}$ = 79.04 (2 d.p.) **AND** Se	[1] [1]
(c) (i)	**Te** **C*l*** $\frac{47.4}{128}$ $\frac{52.6}{35.5}$ $\frac{0.370}{0.370}$ $\frac{1.48}{0.370}$ 1 4 so EF = $TeCl_4$ Empirical Formula Mass = 270 so MF = $TeCl_4$	[1] [1] [1]
(c) (ii)	Covalent **AND** simple / molecular low melting point / reaction with water	[1] [1]
(iii)	$TeCl_4 + 3H_2O \rightarrow H_2TeO_3 + 4HCl$ **OR** $TeCl_4 + 2H_2O \rightarrow TeO_2 + 4HCl$	[1]
(d) (i)	Yellow / orange flame White fumes / solid Yellow / green gas disappears	[1] [1] [1]
(ii)	NaC*l* giant / lattice **AND** ionic $SiCl_4$ simple / molecular **AND** covalent For NaC*l* large difference in electronegativity (of sodium / Na and chlorine / C*l* / Cl_2) (indicates electron transfer/ions) For $SiCl_4$ smaller difference (indicates sharing/covalency) with (weak) van der Waals' / IM forces (between molecules) ora	[1] [1] [1] [1]

12. 9701_w17_ms_22 Q: 1

(a)	 trigonal planar 120° ;  (trigonal) pyramid(al) 100–107° 3 marking points for each box: diagram, name and shape. for each box: all three correct = 2 marks two correct = 1 mark	4
(b)(i)	$SiCl_4$ simple / molecular **AND** Van der Waals' / id-id forces / London / dispersion forces / IMFs	1
	NaCl ionic **OR** giant	1
	bonding (in NaCl) stronger (than forces in $SiCl_4$) owtte	1
(b)(ii)	$SiCl_4$ has more electrons ORA	1
	stronger Van der Waals' / id-id forces / London / dispersion forces / IMFs	1
(b)(iii)		1

13. 9701_s17_ms_21 Q: 2

(a)		

substance	type of bonding	type of lattice structure	
copper	metallic	giant/metallic	1
ice	covalent OR hydrogen(-bonding) / H(–bonding)	hydrogen-bonded / simple / molecular	1
silicon(IV) oxide	covalent	giant (molecular) / macromolecular	1
iodine	covalent	simple / molecular	1
sodium chloride	ionic	giant / ionic	1

(b)(i)	hydrogen bonding	1
(b)(ii)	H-bond between O and H of different molecules	1
	minimum **three** partial charges (in a row) over **two** H_2O molecules, i.e.: either $^{\delta-}$O—H$^{\delta+}$ - - - - $^{\delta-}$O or H$^{\delta+}$ - - - - $^{\delta-}$O—H$^{\delta+}$	1
	lone pair of electrons on O of H-bond, in line with H-bond	1
(c)(i)	X = liquid AND Z = solid	1
	Y = liquid and solid OR 'liquid / solid' OR 'liquid OR solid'	1
(c)(ii)	(kinetic) energy reducing	1
	motion slowing *owtte*	1
(c)(iii)	energy given out / released forming bonds / forming bonds exothermic	1
	compensates for / counteracts heat loss / cooling *owtte*	1
	Total:	**15**

14. 9701_s16_ms_23 Q: 1

(a) (i)	$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$	[1]
(ii)	$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$	[1]
(iii)	$(0.025 \times 32.0/1000=)\ 8 \times 10^{-4}$	[1]
(iv)	$(8 \times 10^{-4} \times 6 =)\ 4.8 \times 10^{-3}$	[1]
(v)	$(4.8 \times 10^{-3} \times 250/25.0=)\ 4.8 \times 10^{-2}$	[1]
(vi)	$(4.8 \times 10^{-2} \times 55.8=)$ 2.68 / 2.678	[1]
(vii)	(2.68/3.35=) 80%	[1]
(b) (i)	covalent small(er) difference in electronegativity between Fe and C*l* (than between A*l* and C*l*)	[1] [1]
(ii)	$FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6]^{3+}\ 3Cl^-$ OR $FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6OH]^{2+} + H^+ + 3Cl^-$	[1]

15. 9701_S15_ms_23 Q: 1

(a)	$(1s^2)2s^22p^6$	[1]
(b) (i)	The amount of energy required/energy change when one electron is removed from each atom in one mol of gaseous atoms	[1] [1] [1]
(ii)	Greater nuclear charge/number of protons Same shielding/number of shells/energy level	[1] [1]
(c) (i)	mean/average mass of the isotopes/an atom(s) relative to 1/12 of the mass of an atom of ^{12}C/on a scale where an atom of ^{12}C is (exactly) 12	[1] [1]
(ii)	$20.2 = \frac{(20\times 90.48)+(21\times 0.27)+(9.25y)}{100}$ $\frac{2020-1815.27}{9.25} = 22.133$ y = 22	[1] [1]
(d) (i)	$pV = \frac{mRT}{M_r}$ $M_r = \frac{mRT}{pV} = \frac{0.275\times 8.31\times 298}{100\times 10^3\times 200\times 10^{-6}}$ M_r = 34.05/34.1	 [1] [1]
(ii)	(Let % Ne = x so % Ar = 100-x) $\frac{20.2x+39.9(100-x)}{100} = 34.05$ % Ne = 29.7	 [1]
(e) (i)	Van der Waal's/London/dispersion Uneven electron distribution/temporary dipole Induced dipole-dipole attraction	[1] [1] [1]
(ii)	more electrons more polarisable/greater attraction/stronger IMFs	[1] [1]

16. 9701_w15_ms_22 Q: 1

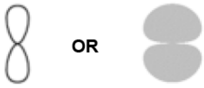
(a)	<table><tr><th>name of isotope</th><th>type of particle</th><th>charge</th><th>symbol</th><th>electron configuration</th></tr><tr><td>carbon-13</td><td>atom</td><td>0</td><td>$^{13}_{6}C$</td><td>$1s^2 2s^2 2p^2$</td></tr><tr><td>chloride(-37)</td><td>anion</td><td>1−</td><td>Cl</td><td>$1s^2 2s^2 2p^6 3s^2 3p^6$</td></tr><tr><td>sulfur-34</td><td>atom</td><td>0</td><td>$^{34}_{16}S$</td><td>$1s^2 2s^2 2p^6 3s^2 3p^4$</td></tr><tr><td>iron-54</td><td>cation</td><td>2+</td><td>$^{54}_{26}Fe^{(2+)}$</td><td>$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$</td></tr></table>	[5]
(b) (i)	ability / tendency / power of an atom / nucleus to attract / pull electron(s) in a covalent bond / shared pair of electrons / bonding pair of electrons	[1] [1]
(ii)	Covalent overlap of orbitals OR shared pair(s) (of electrons) OR metallic positive ions / cations surrounded by delocalised electrons	[1] [1] [1] [1]
(iii)	Ionic/electrovalent (electrostatic) Attraction between oppositely charged / +ve and –ve ions	[1] [1]
(c) (i)	similar strength / amount / number of intermolecular forces / induced dipole / van der Waals' / VdW / London forces / LDF / dispersion forces therefore similar energy needed	[1] [1]
(ii)	M1 HCl polar / has a dipole AND F_2 non-polar / has no dipole OR (permanent) dipole (-dipole) attractions / forces between HCl (molecules) AND induced dipole (-induced dipole) attractions / forces / LDFs between F_2 (molecules) M2 more energy needed for HCl than F_2 OR pd-pd forces stronger than id-id forces OR IMFs / VdWs in HCl stronger than in F_2	[1] [1]
(iii)	Hydrogen bonding (between methanol molecules) Stronger than IMFs / van der Waals' in other three / is the strongest intermolecular force	[1] [1]

17. 9701_s21_ms_21 Q: 2

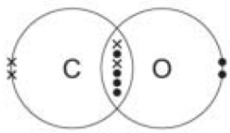
Question	Answer	Marks
(a)(i)	**M1** both make triple (covalent) bond / 3 shared pairs of electrons	1
	M2 one bond in CO is coordinate / dative covalent / formed by donating a pair of electrons from O (to C)	1
(a)(ii)	<table><tr><td></td><td>N_2</td><td>CO</td></tr><tr><td>number of electrons per molecule</td><td>14</td><td>14</td></tr><tr><td>type of van der Waals'</td><td>temporary / instantaneous dipole–induced dipole</td><td>permanent dipoles–(permanent) dipoles (and temporary / induced / instantaneous dipoles)</td></tr></table>	2
(b)	CO / it is a polar molecule / it has a (permanent) dipole (but N_2 is non-polar)	1
(c)(i)	high temperature AND low pressure	1
(c)(ii)	**M1** CO is polar / has a permanent dipole OR N_2 is non-polar	1
	M2 IMF in CO are (more) significant / larger OR IMF in N_2 are smaller / less significant	1
	Alternative answer **M1** (Size of) N_2 smaller than CO OR volume of N_2 molecules / particles smaller	
	Alternative answer **M2** volume of N_2 molecules / particles is more negligible ORA	

Question	Answer	Marks
(d)	**M1** correct conversion to consistent units P = 101 000 V = 100 / 1 000 000 = (1×10^{-4}) T = 293	1
	M2 use of all values from M1 in correct relationship, n = PV / RT	1
	M3 calculation = 4.15×10^{-3} mol	1

18. 9701_s19_ms_21 Q: 3

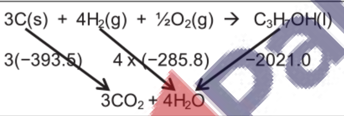
(a)	$Ar^{+}(g) \rightarrow Ar^{2+}(g) + e^{(-)}$ **OR** $Ar^{+}(g) - e^{(-)} \rightarrow Ar^{2+}(g)$	1
(b)	at x = 8, within range 13000–20000	1
	at x = 9, within range 35000–45000	1
(c)		1
(d)(i)	**M1** *correct conversions of data to SI/consistent units* p = 404 000; $V = 20 \times 10^{-6}$; T = 298	1
	M2 *calculation of n (= pV/RT) from* ***M1*** *values* $n = \dfrac{404000 \times 20 \times 10^{-6}}{8.31 \times 298} = 3.263 \times 10^{-3}$ mol of Cl_2	1
	M3 *finding the mass of* Cl_2 $= 3.263 \times 10^{-3} \times 71.0 = 0.23$ (g)	1
(d)(ii)	**Method 1** **M1** $= 3.263 \times 10^{-3} \times 2$ **Method 2** **M1** $= \dfrac{0.23}{71.0} \times 2$ **OR** 6.53×10^{-3}	1
	Method 1: **M2** $= 6.02 \times 10^{23} \times$ **M1** $= 3.93 \times 10^{21}$ atoms of Cl **Method 2**: **M2** $= 6.02 \times 10^{23} \times$ **M1** $= 3.90 \times 10^{21}$ atoms of Cl	1
(d)(iii)	**M1** size / volume of **molecule / particle** becomes significant / non-negligible **OR** IMFs become significant / non-negligible	1
	M2 IMFs becomes significant / non-negligible / collisions are not elastic	1

19. 9701_s21_ms_22 Q: 2

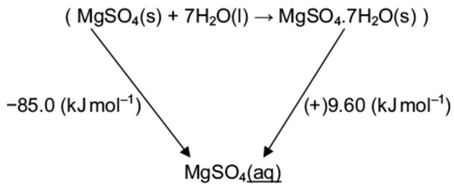
Question	Answer	Marks
(a)(i)	Li^{+} AND S^{2-}	1
(a)(ii)	**M1** giant	1
	M2 (many) strong force(s) of attraction between oppositely charged ions OR (many) strong ionic bond(s)	1
(b)(i)	(covalent) bond with both electrons are provided from the same / one species OR shared pair (of electrons) are provided from the same species / one atom *owtte*	1
(b)(ii)	3 bonding pairs between C and O, 4 •'s AND 2×'s 1 lone pair on C, ××, AND 1 lone pair on O, ••. 	2

Question	Answer	Mark
(c)(i)	*Any two assumptions about the behaviour of particles in an ideal gas from* • (particles / molecules have mass but) negligible size / volume (compared to total volume of gas / container) • no / negligible forces / interactions (between particles / molecules) • collisions are elastic	2
(c)(ii)	**M1** IMF become larger / more significant	1
	M2 volume of <u>molecules / particles</u> becomes significant / no longer negligible	1
(c)(iii)	N_2(g): instantaneous dipole–induced dipole ✓ CO(g): instantaneous dipole–induced dipole (and) permanent dipole–permanent dipole ✓	2
(c)(iv)	O is more electronegative than C	1

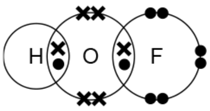
20. 9701_w16_ms_21 Q: 2

(a)(i)	Enthalpy / energy / heat change when one mole of a substance Burns / combusts / reacts in excess oxygen OR Completely burns / combusts / reacts in oxygen under standard conditions	1 1 1	3
(a)(ii)	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	1	1
(b)(i)	6813.4 / 6813 / 6810 / 6800 (J)	1	1
(b)(ii)	–1362.68 / –1362.7 / –1363 / –1360 / –1400 (kJ)	1	1
(b)(iii)	Any 2 from: heat / energy losses (to air and/or to the container/surroundings) incomplete combustion (volatile) ethanol evaporated ethanol is impure not all energy is lost as heat	 1 1	2
(c)(i)		 1+1 1	3
(c)(ii)	$\Delta H_f + (-2021.0) = 3(-393.5) + 4(-285.8)$ $\Delta H_f = -302.7$ (kJ mol^{-1})	1 1	2
	Total:		13

21. 9701_w15_ms_22 Q: 2

(a)		<u>M1 Heat</u> (energy) change (**or** $H_{prod} - H_{react}$) measured at constant pressure OR enthalpy change when the amount/moles of reactants as shown in a (reaction) <u>equation</u> react together to give products	[1]
		M2 measured at standard conditions	[1]
(b)	**(i)**	q = 2125.53	[1]
	(ii)	amount = 0.025(0)	[1]
	(iii)	–85.(0)	[1]
	(iv)		[1]
	(v)	$\Delta H + 9.6 = -85.0$ $\Delta H = -85.0 - 9.6 = -94.6$ (kJ mol^{-1})	[1]

22. 9701_m19_ms_22 Q: 2

(a)(i)	**M1** ① mass of a molecule OR ② (weighted) average / mean mass of the molecules OR ③ mass of one mole of molecules **M2** ① / ② compared to $\frac{1}{12}$ (the mass) of an atom of carbon-12 OR on a scale in which a carbon-12 atom / isotope has a mass of (exactly) 12 (units) ③ relative / compared to $\frac{1}{12}$ (the mass) of 1 mole of carbon-12 OR on a scale in which 1 mole of carbon-12 (atoms / isotope) has a mass of (exactly) 12 g	2
(a)(ii)	**M1** identification of the IMF between F_2 molecules and between HCl molecules HCl has (permanent) dipoles and / or induced dipoles F_2 has induced dipoles **M2** comparison of strength of IMF's in F_2 and HCl Intermolecular forces in HCl are stronger than F_2	2
(a)(iii)	strong (electrostatic) forces of attraction between (oppositely charged) ions	1
(a)(iv)	$CaCO_3(s) + 2HF(aq) \rightarrow CaF_2(aq) + CO_2(g) + H_2O(l)$ **M1** species and balancing **M2** state symbols	2
(b)(i)	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$	1
(b)(ii)	**M1** purple gas / vapour disappears **M2** iodine is not a strong enough oxidising agent ORA	2
(b)(iii)	**M1** silver nitrate / $AgNO_3$ **M2** yellow	2
(b)(iv)	(aqueous) ammonia / $NH_3(aq)$ / ammonium hydroxide / $NH_4OH(aq)$	1
(c)(i)	 **M1** bonding pairs correct **M2** rest of molecule, incl. lone pairs.	2
(c)(ii)	$F_2 + H_2O \rightarrow HF + HOF$	1
(c)(iii)	**M1** labelled reactants **AND** products lower on right **M2** labelled enthalpy change with correct arrow	2
(c)(iv)	$\overset{\delta+}{H}$—$\overset{\delta-}{F}$:⋯⋯⋯$\overset{\delta+}{H}$—$\overset{\delta-}{F}$ **M1** H-bond labelled / shown as distinct from H—F bond **M2** correct sequence of three correct dipoles **M3** lone pair on F in line with H-bond	3
(d)(i)	$pV = nRT \;\therefore\; n = \frac{pV}{RT} = \frac{101\,325 \times 0.001}{8.31 \times 273} = 0.0447$ mol $\therefore M_r = \frac{m}{n} = \frac{4.13}{0.0447} = 92.4$ or 92.5 **M1** Use of $T = 273$ K, $V = 0.001$ m^3 and $p = 101325$ Pa **M2** correct use of $pV = nRT$ using values from M1 **M3** correct calculation of M_r using 4.13 ÷ moles from M2	3
(d)(ii)	ClF_3	1

23. 9701_s20_ms_21 Q: 2

(a)(i)	$2CuSO_4(aq) + 4KI(aq) \rightarrow 2CuI(s) + (1)I_2(aq) + 2K_2SO_4(aq)$ **M1** correct balancing **M2** correct state symbols	**2**
(a)(ii)	Oxidation state of copper in $CuSO_4$ (+)2 AND Oxidation state of copper in CuI (+)1	**1**
(a)(iii)	**M1** redox	**1**
	M2 iodide ions – lost electron(s) AND copper ions – gained electron(s)	**1**
(b)	Mass of 0.0982mol $CuSO_4$ in 17.43g $CuSO_4$.**y**H_2O — **M1** *calculate M_r $CuSO_4$ using Ar from data booklet* 63.5 + 32.1 + 64.0 = 159.6 **M2** *use Mr to calculate mass of $CuSO_4$* (0.0982 × M1) =15.67272g number of water in 17.43g of $CuSO_4$ **y**H_2O — **M3** *calculate the mass amount of water in sample AND use this value to calculate the amount of water present* (17.43-15.67)/18 = 0.097778 mol value of **y** — **M4** *use the ratio of M2: 0.0982 to find y* (mol H_2O ÷ mol $CuSO_4$) = 1	**4**

24. 9701_s19_ms_23 Q: 2

(a)(i)	held in regular / uniform arrangement	**1**
(a)(ii)	**M1** covalent (bonds) AND (temporary) induced dipoles **M2** (temporary) induced dipoles	**2**
(b)(i)	2	**1**
(b)(ii)	iodine (atom / s) donates a pair of electrons (to the A*l*-I covalent bond / s).	**1**
(c)(i)	$2H_2SO_4 + 14HI \rightarrow 7I_2 + 8H_2O + H_2S + S$ **M1** correct species **M2** correctly balanced equation	**2**
(c)(ii)	*explain with ref to ox no's why the reaction in **(c)(i)** is a redox reaction* **M1** I (oxidation number increases) from –1 to 0 = oxidation / reducing agent **M2** S (oxidation number decreases) from (+) 6 to 0 **OR** –2 = reduction / oxidising agent	**2**

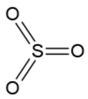
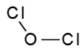
25. 9701_s16_ms_22 Q: 3

(a)	$Cr_2O_7^{2-} + 8H^+ + 3H_2C_2O_4 \rightarrow 2Cr^{3+} + 6CO_2 + 7H_2O$ M1 = species M2 = balancing	 [1] [1]
(b) (i)	$(0.02 \times 32.0/1000 =)\ 6.40 \times 10^{-4}$	[1]
(ii)	$(6.4 \times 10^{-4} \times 3 =)\ 1.92 \times 10^{-3}$	[1]
(iii)	$(0.242 / 1.92 \times 10^{-3} =)$ 126(.0)	[1]
(iv)	(126 – 90 = 36; 36 / 18 = 2 hence) *x* = 2	[1]

26. 9701_s21_ms_23 Q: 2

Question	Answer	Marks
(a)	**M1** H-bond between an O and an H in OH groups in water and methanol molecules	1
	M2 minimum three partial charges (in sequence) over one water and one methanol molecule, *i.e.*:	1
	M3 either $^{\delta-}$O—H$^{\delta+}$- - - - $^{\delta-}$O or H$^{\delta+}$- - - - $^{\delta-}$O—H$^{\delta+}$ lone pair of electrons on O of H-bond, in line with H-bond	1
(b)(i)	**M1** (methanol) gas (particles / molecules) in equilibrium with liquid	1
	M2 (methanol) gas (particles) exert a pressure (on the walls of a container / on the surface of the liquid)	1
(b)(ii)	(liquid) particles (at the surface) have enough energy (to overcome attractive forces / evaporate / to become a vapour)	1
(b)(iii)	**M1** (liquid) H_2O molecules are held by stronger **hydrogen bonding** **OR** it takes more energy to break the **hydrogen bonds** between water molecules (in the liquid state) **OR** each water molecule forms two **hydrogen bonds** (whereas methanol can (only) form one per molecule	1
	M2 fewer H_2O liquid molecules (able to) escape / become gaseous **ora**	1
(c)(i)	**M1** rates of forward and reverse / backward reactions are equal	1
	M2 closed / sealed system / container OR no change in measurable properties / no change in macroscopic properties	1
(c)(ii)	**M1** mol fraction = 0.97 / (0.030 + 0.060 + 0.97) = 0.97 / 1.06 = (0.9151)	1
	M2 M1 × $1.0 \times 10^7 = 9.2 \times 10^6$ (Pa) ✓✓	1
(c)(iii)	*expression for* K_p **M1** $K_p = p(CH_3OH) / p(CO) \times p(H_2)^2$	1
	M2 units = Pa^{-2}	1

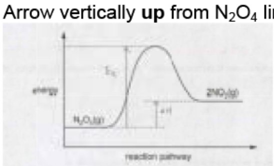
27. 9701_s18_ms_23 Q: 1

(a)	  trigonal planar non-linear/bent/V-shaped/angular	4
(b)(i)	stronger attraction for O^{2-} / stronger ionic bonding / more energy needed to overcome ionic bonding / separate ions	1
	charge density of magnesium (ion) is greater (than sodium ion) ***ora***	1
(b)(ii)	Either: M1 SiO_2 has a giant (covalent) structure / giant molecular M2 Covalent bonds (much) stronger than VdW / id-id / IMFs in SO_3 OR M1 SO_3 has a (simple) molecular structure / (simple) molecule. M2 VdW / id-id / IMFs M2 IMF's are (much) weaker than covalent bonds (broken in SiO_2) OR M1 Covalent bonds are broken in SiO_2 AND VdW / id-id / IMFs in SO_3 M2 Covalent bonds are stronger (than VdW / id-id / IMFs)	2
(c)(i)	molecules / particles / reacting species are closer together	1
	so frequency of collisions increases	1
	few(er) moles on right	1
	so (equilibrium) reaction shifts right / towards products / (as pressure increases to oppose the change)	1
(c)(ii)	Decreasing reactant concentrations (at different time intervals / as reaction progresses)	1
	So rate decreases OR change in concentration ÷ time taken decreases	1
(c)(iii)	(line becomes horizontal when) forward and reverse rates equal / equilibrium established	1
(c)(iv)	2:1 ratio in equation / SO_2 used up more quickly (than O_2) / 2 × SO_2 react for every 1 × O_2	1
(d)(i)	$K_c = \dfrac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$	1
(d)(ii)	SO_2 = 0.02 (mol)	1
	O_2 = 1.01 (mol)	1
(d)(iii)	$K_c = \dfrac{(1.98/40)^2}{(0.02/40)^2\,(1.01/40)}$ M1 = 3.88 / 3.882 × 10^5 M2 Units = $dm^3\,mol^{-1}$ / $mol^{-1}\,dm^3$ M3	3

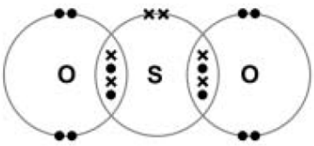
28. 9701_w17_ms_22 Q: 2

(a)	−444	1
(b)(i)	(higher rate / rate increases) due to higher frequency of successful collisions	1
	more molecules / particles with $E \geqslant E_a$	1
(b)(ii)	(percentage decomposition of PCl_5) increases	1
	(forward) reaction is endothermic	1
(c)	rates of forward and reverse / backward reactions are equal	1
	closed / sealed system/container	1
(d)(i)	n_{TOTAL} = 1.20 + 0.80 + 0.80 OR 2.80 (mol) **OR** mole fraction = 1.20 / 2.80 OR 0.429	1
	$pPCl_5$ = $1 \times 10^5 \times (1.20 / 2.80)$ = 4.29×10^4 (Pa)	1
(d)(ii)	$K_p = \dfrac{pPCl_3 \times pCl_2}{pPCl_5}$	1
(d)(iii)	1.91×10^4	1
	Pa	1

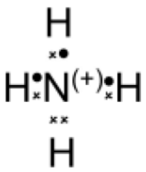
29. 9701_w16_ms_22 Q: 2

(a)	Arrow vertically **up** from N_2O_4 line to $2NO_2$ line labelled enthalpy change / ΔH Arrow vertically **up** from N_2O_4 line to dashed line from peak labelled activation energy / E_a 	1 1
(b)(i)	$M_r = \dfrac{m \times R \times T}{p \times V} \quad \left(= \dfrac{4.606 \times 8.31 \times 323}{1.68 \times 10^5 \times 1 \times 10^{-3}} \right)$ = 73.6	1 1
(b)(ii)	2n	1
(b)(iii)	0.05 – n + 2n **OR** 0.05 + n	1
(b)(iv)	$\dfrac{2n}{(0.05 + n)}$	1
(b)(v)	N_2O_4 = 0.0375 NO_2 = 0.0250	1 1
(b)(vi)	$K_p = \dfrac{pNO_2^2}{pN_2O_4}$	1
(b)(vii)	$(0.4 \times 1.68 \times 10^5)^2 / (0.6 \times 1.68 \times 10^5)$ **OR** $0.4^2 \times 1.68 \times 10^5 / 0.6$ 44800 **OR** 44.8 Pa **OR** kPa	1 1 1
	Total:	13

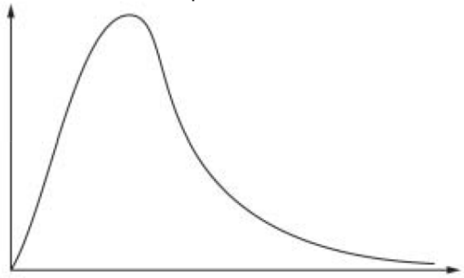
30. 9701_s18_ms_21 Q: 1

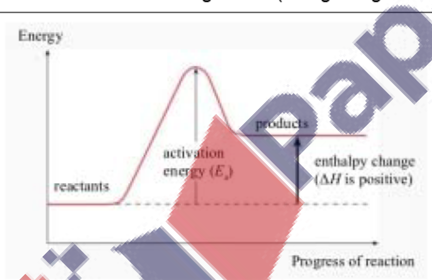
(a)(i)	(It is a substance that) speeds up a reaction	1
	(by creating an alternative pathway / mechanism with) lower E_a	1
(a)(ii)	(a heterogeneous catalyst is in a) different state / phase (to the reactants)	1
(b)	−196 + 6S=O = (4 × 534) + 496	1
	S=O = 2828 / 6 = 471(.3)	1
(c)	**1 = B**	1
	2 = A	1
	3 = D	1
(d)(i)	Increases rate **AND** explanation re collisions	1
	By increasing number / proportion of / more molecules / particles / species with $E \geqslant E_a$	1
	(So) increases frequency of successful collisions / more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
(d)(ii)	(Increasing T) decreases yield (of SO_3)	1
	(Forward) reaction is exothermic (or reverse argument)	1
	So increasing T shifts (equilibrium) reaction to left / towards reactants / in endothermic direction (to oppose the change in T)	1
(e)	$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$	1
(f)(i)		1
(f)(ii)	fully ionises/dissociates	1
	(Brønsted-Lowry acid is a) proton / H^+ donor	1
(f)(iii)	$H_2SO_4(l)/(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$	
	species and balancing	1
	correct state symbols on left hand side; all products aqueous	1

31. 9701_s18_ms_22 Q: 2

(a)	*option 1:* the mass of (all the atoms/ions in) a formula (unit) / molecule OR the (weighted) average / (weighted) mean mass of (all the atoms / ions in) the formula (unit) / molecule [1] relative / compared to 1 / 12 (the mass of an atom) of carbon–12 OR on a scale in which a carbon–12 (atom / isotope) has a (mass) of (exactly) 12 (units) [1] *option 2:* mass of one mol of a compound / formula (unit) / molecule [1] relative / compared to 1 / 12 (the mass) of 1 mol of C-12 OR in which one mol C-12 (atom / isotope) is (a mass of exactly) 12 g [1]	2
(b)(i)		
	4 shared pairs only (any symbols) (in NH_4)	1
	3 × dot-and-cross bonds AND 1 × 2 crosses (in NH_4)	1
(b)(ii)	tetrahedral	1
	109–109.5° (inclusive)	1
c(i)	*in any order explain meaning of:* *weak* partially ionises / incompletely dissociates (into ions) *Bronsted-Lowry acid* is a proton donor / H^+ (ion) donor / hydrogen ion donor	2
c(ii)	$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq \text{ or } g) + H_3O^+(aq)$	
	all correct species and balancing	1
	correct state symbols	1
(d)(i)	$MnO_4^- + \mathbf{5}Fe^{2+} + \mathbf{8}H^+ \rightarrow Mn^{2+} + \mathbf{5}Fe^{3+} + \mathbf{4}H_2O$	1
(d)(ii)	(Fe^{2+} is a) reducing agent / reductant provides/donates electron(s) / loses electron(s) / increases its oxidation number / (Fe^{2+}) becomes Fe^{3+}	2
(d)(iii)	4×10^{-4} / 0.0004	1
(d)(iv)	2×10^{-3} / 0.002	1
(d)(v)	392	1
(d)(vi)	6	1

32. 9701_m21_ms_22 Q: 1

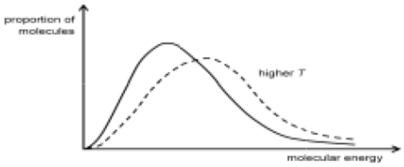
Question	Answer	Marks
(a)(i)	*vertical axis*: number of particles  *horizontal axis:* (kinetic / particle) energy **M1:** shape of curve correct **M2:** labelled axes	**2**
(a)(ii)	Labelled line (**T2**) with lower peak to right of original	**1**
(b)(i)	Any two from: • no VdW forces present / no forces of attraction between particles • (ideal gas) particles have no / negligible volume (compared to container) • collisions between (ideal gas) particles / walls of container are perfectly elastic • (ideal gas) particles behave as rigid spheres	**2**
(b)(ii)	**M1:** moles of krypton = 2.00 ÷ 83.8 (= 0.0239 mol) **M2:** conversion of value into consistent units for $pV = nRT$ **M3:** $p = \frac{M1 \times 8.31 \times 393}{5.00 \times 10^{-3}}$ = 15600 Pa	**3**

Question	Answer	Marks
(b)(iii)	**M1:** low pressure **AND** high temperature **M2:** Either of: • volume of particles is negligible (compared to volume of container) • VdW forces are insignificant (owing to high kinetic energy of particles)	**2**
(c)(i)	 **M1:** end higher than start **AND** 'hill' for E_a **M2:** E_a **AND** ΔH labelled	**2**
(c)(ii)	• rate increases • (increase in temperature means) more particles have energy ⩾ activation energy • frequency of successful collisions increases	**2**

33. 9701_s17_ms_22 Q: 3

(a)	(+) 103	1
(b)(i)	general shape of the curve and peak are displaced to right of original and starts at origin	1
	the peak is lower and curve crosses once only finishing **above** original	1
(b)(ii)	rate increases AND correct explanation in terms of 'more collisions'	1
	at higher T area above *Ea* is greater / more molecules with $E \geqslant Ea$	1
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
(b)(iii)	increases (%) decomposition (of HBr)	1
	(increasing T) shifts equilibrium to the right / in the forward direction / endothermic direction / towards H_2 + Br_2	1
	to oppose the change or oppose the increase in temperature OR to absorb (additional) energy / heat OR to decrease the temperature	1
(b)(iv)	H-I bond strength less than H-Br OR less energy needed to break H-I *ora*	1
	I (atom) is big(ger) (than Br) OR I (atom) has more shielding (than Br) *ora*	1
	Br (atom) has greater (%) orbital / outer shell overlap OR attraction (of nucleus in iodine) for shared (pair of) electrons is weak(er) OR attraction (of nucleus in iodine) for bonding pair (or electrons) is weak(er) *ora*	1
(c)(i)	H_2 = 0.015 (mol)	1
	HC*l* = 0.27 (mol)	1
(c)(ii)	HC*l* = 9/10 AND xH_2 = 1/20 AND Cl_2 = 1/20 OR HC*l* = 0.9(0) AND H_2 = 0.05 AND Cl_2 = 0.05	1
(d)(i)	$(K_p =) \dfrac{pH_2 \times pCl_2}{pHCl^2}$	1
(d)(ii)	equal number of moles (of gas) on either side (of equation) / (total) pressure cancels	1
(d)(iii)	4.649×10^{-3}	1
	Total:	**18**

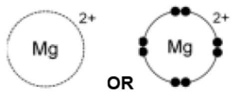
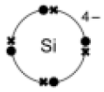
34. 9701_w17_ms_21 Q: 1

(a)(i)	energy needed / required to break a mole of (covalent) bonds	1
	(All) in the gaseous state	1
(a)(ii)	–92 = {944 + 3(436)} – 6E(N–H)	1
	E(N–H) = (+)390.7 / 390.67 / 391	1
(b)(i)	general shape of the curve and peak are displaced to right of original line and starts at origin	1
	the peak is lower and curve crosses once only finishing **above** original line	1
		
(b)(ii)	rate increases AND explanation in terms of collisions	1
	(at higher T) area above E_a is greater OR (at higher T) more molecules with $E \geqslant E_a$	1
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
(b)(iii)	reduces yield (of ammonia).	1
	(increasing *T*) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants / in endothermic direction	1
	to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature	1
(c)(i)	N_2 = 0.850 (mol)	1
	H_2 = 2.55 (mol)	1
(c)(ii)	n_{TOTAL} = 3.7 mol	1
	mol fraction of NH_3 = 0.3 / 3.7	1
	$pNH_3 = 2 \times 10^7 \times (0.3 / 3.7) = 1.62 \times 10^6$	1
(d)(i)	$K_p = \dfrac{pNH_3^{\,2}}{pN_2 \times pH_2^{\,3}}$	1
(d)(ii)	$K_p = 1.(00) \times 10^{-16}$	1
	Pa^{-2}	1
(d)(iii)	(yield of ammonia) increases	1
	(value of K_p) stays the same	1

35. 9701_S15_ms_21 Q: 2

(a) (i)	Straight line drawn horizontally from same intercept	[1]
(ii)	T_1 because it shows greatest deviation/furthest from ideal	[1]
(iii)	reducing T (reduces KE of particles) so intermolecular forces of attraction become more significant	[1]
(iv)	greatest deviation is at high pressure increasing pressure decreases volume so volume of particles becomes more significant ora	[1] [1]
(b)	Mass of air = 100 × 0.00118 = 0.118 g Mass of flask = 47.930 – 0.118 = **47.812** g Mass of **Y** = 47.989 – 47.812 = **0.177** g $pV = nRT = \frac{m}{M_r} RT$ $M_r = \frac{mRT}{pV} = \frac{0.177 \times 8.31 \times 299}{1 \times 10^5 \times 100 \times 10^{-6}}$ = **44.0** (43.979 to 2 or more sf)	 [1] [1] [1] [1]
(c) (i)	strong <u>triple</u> bond	[1]
(ii)	high temperature (needed for reaction between N_2 and O_2)	[1]
(iii)	$2NO + 2CO \rightarrow N_2 + 2CO_2$ **OR** $2NO + C \rightarrow N_2 + CO_2$	[1]
(iv)	$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$	[1]
(v)	$NO + ½O_2 \rightarrow NO_2$ $NO_2 + SO_2 \rightarrow NO + SO_3$ **OR** $NO_2 + SO_2 + H_2O \rightarrow NO + H2SO_4$	[1] [1]

36. 9701_s19_ms_21 Q: 2

(a)	**M1** *magnesium* +2 charge on **two** Mg AND both with 0 or 8 electrons 	1
	M2 *silicide* -4 charge on one Si and 8 electrons 	1
(b)	$Mg_2Si(s) + 4H_2O(l) \rightarrow 2Mg(OH)_2(aq) + SiH_4(g)$ **M1** correct balancing and formulae	1
	M2 state symbols	1
(c)	**M1** simple (covalent) / molecular / molecules	1
	M2 **weak** IMF / (temporary) induced dipole (forces)	1
(d)(i)	$C^{\delta-}$–$H^{\delta+}$	1
	$Si^{\delta+}$–$H^{\delta-}$	1
(d)(ii)	**M1** tetrahedral (molecule)	1
	M2 (so individual bond) dipoles / partial charges cancel	1
(e)	**M1** Si—H bond is (much) weaker than C—H bond	1
	M2 low activation energy *ORA*	1
(f)(i)	**M1** sodium silicate / Na_2SiO_3	1
	M2 water / H_2O	1
(f)(ii)	acid(ic)	1

37. 9701_m18_ms_22 Q: 1

(a)(i)	☐ energy required / energy change ☐ when one electron is removed ☐ from each atom in one mole of ☐ gaseous atoms	**max 3**
(a)(ii)	*for element* ***B*** (outer electron is removed) from a higher energy level more shielding less attraction to nucleus	**3**
(b)	line on graph decreases **P—T** increasing nuclear charge **AND** electrons in same shell greater attraction between nucleus (and electrons)	**3**

38. 9701_w16_ms_22 Q: 3

(a)(i)	Increasing nuclear attraction Increasing nuclear charge / number of protons **AND** constant / similar shielding / same shell	1 1
(a)(ii)	From 12 / Mg to 13 / A*l*: (Outer) electron in '13' / A*l* in (3)p (whereas outer electron in '12' / Mg in (3)s) (3p =) higher energy level / more shielded From 15 / P to 16 / S electron repulsion ('16' / S has a) pair of electrons in a (3)p orbital / a (3)p orbital is full ORA	 1 1 1 1
(a)(iii)	(decreasing IE down Group 0) due to decreasing nuclear attraction increasing shielding / increasing number of shells / energy levels / increasing distance of (outer) electrons (from nucleus)	1 1
(b)(i)	Increasing strength of / more energy needed to break (metallic) bonding / increasing strength of attraction between (cat)ion / nucleus and delocalised / free / sea of / cloud of electrons Increasing number of delocalised electrons / decreasing (cat)ion size / increasing charge / charge density of (cat)ion	1 1
(b)(ii)	Attraction for electrons too strong to fully delocalise all 3 in A*l* **OR** difference in size between 12/Mg^{2+} and 13/Al^{3+} is less than difference in size between 11/Na^{+} and 12/Mg^{2+} **OR** magnitude of increase in charge is less from 2+ to 3+ than from 1+ to 2+	1
(b)(iii)	Increase (15 / P to 16 / S) then decrease (to 17 / C*l* and 18 / Ar) **OR** general decrease (from 15 / P to 18 / Ar) with an increase from 15 / P to 16 / S **OR** $S_{(8)}$>$P_{(4)}$>$Cl_{(2)}$>Ar (melting point depends on strength of) VdW / IMFs The greater the number of electrons in the molecule (atom for Ar) the greater the strength of VdW / IMFs **OR** the greater the melting point ora	1 1 1
(b)(iv)	Giant covalent (structure) / many (strong) covalent bonds (need breaking)	1
	Total:	**15**

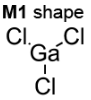
39. 9701_S15_ms_22 Q: 1

(a)	<table><tr><td>name of particle</td><td>relative mass</td><td>relative charge</td></tr><tr><td>**proton**</td><td>**1**</td><td>+1</td></tr><tr><td>**electron**</td><td>1/1836</td><td>**–1**</td></tr><tr><td>**neutron**</td><td>**1**</td><td>**0**</td></tr></table>	[1] [1] [1]
(b) (i)	Mass of an atom(s) relative to 1/12th (the mass) of (an atom of) carbon-12 **OR** relative to carbon-12 which is (exactly) 12	[1] [1]
(ii)	% of third isotope = 10 $\frac{(24\times79)+(26\times11.0)+10x}{100}=24.3$ 10x = 248 x = 24.8 (3s.f.)	[1] [1] [1]
(c) (i)	anode $2Cl^- \rightarrow Cl_2 + 2e^-$ cathode $Mg^{2+} + 2e^- \rightarrow Mg$	[1] [1]
(ii)	Mg O H C*l* $\frac{31.65}{24.3}$ $\frac{20.84}{16}$ $\frac{1.31}{1}$ $\frac{46.2}{35.5}$ 1.30 1.30 1.31 1.30 = 1:1:1:1 MgOHC*l*	[1] [1]
(d) (i)	Na_2O basic/alkaline; Al_2O_3 amphoteric/acidic and basic; SO_3 acidic Na_2O (giant) ionic **AND** SO_3 (simple/molecular) covalent	[1] [1]
(ii)	$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$ $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ $Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaAl(OH)_4(H_2O)_2$ **OR** $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ **OR** $Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ **OR** $Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$ **OR** $Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ **OR** $Al_2O_3 + 2OH^- \rightarrow 2AlO_2^- + H_2O$ $SO_3 + NaOH \rightarrow NaHSO_4$ **OR** $SO_3 + 2NaOH \rightarrow Na_2SO_4 + H_2O$	[1] [1] [1] [1]

40. 9701_s20_ms_21 Q: 1

(a)(i)	(different) number of neutrons.	**1**
(a)(ii)	the relative abundance / % abundance of (each) the isotopes.	**1**
(b)(i)	**M1** *attractions between atoms within a gallium trichloride molecule* covalent (bonds) **M2** *attractions between gallium trichloride molecules* temporary induced dipoles	**2**
(b)(ii)	coordinate / dative (covalent)	**1**
(c)(i)	$4Ga + 3O_2 \rightarrow 2Ga_2O_3$ **M1** correct formula of Ga_2O_3 **M2** correctly balanced equation based on $Ga + O_2$ and formula of gallium oxide in M1	**2**
(c)(ii)	amphoteric	**1**

41. 9701_s20_ms_22 Q: 1

<table>
<tr><td>(a)</td><td>EITHER
M1 (weighted) average/mean mass of the isotope(s)/an atom(s)
M2 relative to 1/12 of the mass (of an atom) of ^{12}C (where an atom of ^{12}C is exactly12).
OR
M1 mass of one mol of atoms
M2 relative / compared to 1/12 (the mass) of 1 mol of C-12 OR
in which one mol C-12 (atom) has a mass of (exactly) 12 g</td><td>2</td></tr>
<tr><td>(b)</td><td>M1 60.11/100 x 69 + 39.89/100x71
M2 69.80</td><td>2</td></tr>
<tr><td>(c)</td><td><table><tr><td>isotope</td><td>nucleon number</td><td>total number of electrons in lowest energy level</td><td>type of orbital contains the electron in the highest energy level</td></tr><tr><td>^{71}Ga</td><td>M1 71</td><td>M2 2</td><td>M3 p (-orbital)</td></tr></table></td><td>3</td></tr>
<tr><td>(d)</td><td>M1 shape

M2 bond angle 120(°)</td><td>2</td></tr>
<tr><td>(e)(i)</td><td>$Ga_2O_3 + 6HCl \rightarrow 2GaCl_3 + 3H_2O$</td><td>1</td></tr>
<tr><td>(e)(ii)</td><td>M1 Identity of correct gallium containing product
$NaGa(OH)_4$ OR $NaGaO_2$

M2 correctly balanced equation for reaction of Ga_2O_3 with NaOH(aq)
EITHER
$Ga_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaGa(OH)_4$
OR
$Ga_2O_3 + 2NaOH \rightarrow 2NaGaO_2 + H_2O$</td><td>2</td></tr>
</table>

42. 9701_w19_ms_21 Q: 2

<table>
<tr><td>(a)</td><td>

<table>
<tr><th>Na_2O</th><th>MgO</th><th>Al_2O_3</th><th>SiO_2</th><th>SO_3</th></tr>
<tr><td>ionic</td><td>ionic</td><td>ionic</td><td>covalent</td><td>covalent</td></tr>
<tr><td>giant</td><td>giant</td><td>giant</td><td>giant / macro-molecular</td><td>simple / molecular</td></tr>
</table>

Award one mark for each correct row.</td><td>2</td></tr>
<tr><td>(b)(i)</td><td>M1 SiO_2 has a network of strong bonds / SiO_2 has many strong bonds

M2 SO_3 has weak intermolecular forces
OR
weak VdW forces (between molecules)

M3 high(er) / more energy required to break bonds than overcome forces (between molecules)</td><td>3</td></tr>
<tr><td>(b)(ii)</td><td>M1: reacts with both acid and base / alkali

M2: use any equation with Al_2O_3 and an acid, e.g. $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

M3: use any equation with Al_2O_3 and a base / alkali, e.g. $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$</td><td>3</td></tr>
<tr><td>(b)(iii)</td><td>solid dissolves / disappears
OR
gets warm / hot</td><td>1</td></tr>
<tr><td>(c)(i)</td><td>octahedral</td><td>1</td></tr>
<tr><td>(c)(ii)</td><td>M1: use of the correct expression in terms of specific bond energies.
($514 - xE_{Se—O} = -346$)

M2: use of correct stoichiometry AND correct processing of expression given in M1. Provided the values 514 and 346 are used.
($514 - 2E_{Se—O} = -346$)

= (+)430 (kJ mol^{-1})</td><td>2</td></tr>
<tr><td>(c)(iii)</td><td>$SeO_2 + 2NaOH \rightarrow Na_2SeO_3 + H_2O$</td><td>1</td></tr>
</table>

43. 9701_w19_ms_22 Q: 2

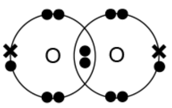
<table>
<tr><td>(a)</td><td>

<table>
<tr><th>Na_2O</th><th>Al_2O_3</th><th>SiO_2</th><th>P_4O_{10} / P_4O_6 / P_2O_3 / P_2O_5</th><th>SO_3</th></tr>
<tr><td>basic</td><td>amphoteric</td><td>acidic</td><td>acidic</td><td>acidic</td></tr>
</table>

M1: all formulae correct

M2: all acid / base behaviour correctly stated</td><td>2</td></tr>
<tr><td>(b)(i)</td><td>reacts with both acid and base</td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>$OH^- + H^+ \rightarrow H_2O$</td><td>1</td></tr>
<tr><td>(b)(iii)</td><td>reaction with strontium / reaction 1 will effervesce / fizz / bubble
OR
no fizzes / bubbles / effervescence with SrO</td><td>1</td></tr>
<tr><td>(b)(iv)</td><td>increases</td><td>1</td></tr>
<tr><td>(c)(i)</td><td>M1: correct conversion of quantities
V = 5(.00) □ 10^{-4} (m^3)
T = 293 (K)
p = 5.37(0) □ 10^3 (Pa)

M2: calculation to find n using n = PV / RT
(n) = 1.1 □ 10^{-3} (mol)</td><td>2</td></tr>
<tr><td>(c)(ii)</td><td>(i) □ 78 = 0.0860 g</td><td>1</td></tr>
<tr><td>(c)(iii)</td><td>



M1: bonding pair between the two O

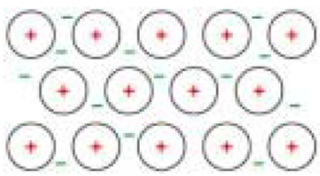
M2: total of 14 electrons distributed equally between the two O</td><td>2</td></tr>
</table>

44. 9701_s18_ms_21 Q: 3

(a)(i)	increasing attraction between nucleus and (outer) electrons	**1**
	increasing nuclear charge with similar shielding / (electrons in) same (outer) shell	**1**
(a)(ii)	(ions of Na to Si have) lost outer shell / outer electrons OR atoms have one more shell than (corresponding) ions OR effective nuclear charge is greater for the ion	**1**
(a)(iii)	(P to C*l* form ions by) gaining electrons (to the same outer shell / p sub-shell)	**1**
	Increased repulsion between electrons in same / outer shell / p sub-shell	**1**
(b)(i)	(outer) electron removed from 3p subshell / orbital	**1**
	(3p) higher in energy / more shielded / further from the nucleus	**1**
(b)(ii)	(outer) electron for S is paired in a p orbital / S has a full p orbital	**1**
	causing (spin / electron) pair repulsion (which reduces attraction)	**1**
(c)(i)	oxidation numbers / states of elements (Na-Si) increase from +1 to +4 / by 1 every time	**1**
	increasing number of valence electrons / $NaCl$, $MgCl_2$, $AlCl_3$, $SiCl_4$ / number of chlorines matches group number	**1**
	chlorine oxidation number / state –1 in all / stays the same	**1**
(c)(ii)	$NaCl \rightarrow Na^+ + Cl^-$	**1**
	$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	**1**
(c)(iii)	see table below	**2**

	structure	bonding
sodium chloride	giant / ionic	ionic
silicon(IV) chloride	simple / molecular	covalent

45. 9701_m17_ms_22 Q: 1

(a)(i)	max O.N. | +1 | (+)2 | (+)3 | (+)5 | (+)6 | +7	**1**
(a)(ii)	(from Na to C*l*) nuclear charge increases	**1**
	electrons are in the same shell / have same shielding	**1**
	greater / stronger attraction (of electrons to nucleus)	**1**
(a)(iii)	Mg^{2+} **AND** S^{2-}	**1**
	ion of Mg / Mg^{2+} has one fewer shell (than ion of S / S^{2-})	**1**
(b)(i)	$P_4 + 5O_2 \rightarrow P_4O_{10} / 2P_2O_5$	**1**
(b)(ii)	any 2 from: • yellow / green colour (of chlorine gas) disappears • white flame • white solid • solid melts	**2**
(b)(iii)	phosphoric(V) acid	**1**
(c)(i)	 diagram showing regular arrangement of (positive) ions 1 surrounded by / sea of (delocalised) electrons 1	**2**
(c)(ii)	any 2 from: • high melting / boiling / sublimation point • electrical / thermal insulator • hard / rigid • retains strength at high temperature / pressure	**2**
(c)(iii)	**M1** % abundance of fourth isotope = 100 – (0.185 + 0.251 + 88.450) = 11.114	**1**
	M2 $\frac{(0.185 \times 135.907) + (0.251 \times 137.906) + (88.450 \times 139.905) + (11.114 \times RIM)}{100}$ = 140.116 ∴ (140.116 × 100) – 12434.35 = 1577.246 = 11.114 × RIM	**1**
	M3 $RIM = \frac{1577.246}{11.114} = 141.915$	**1**

46. 9701_w17_ms_21 Q: 2

(a)(i)	due to increasing nuclear attraction (for electrons)	1
	due to increasing nuclear charge / atomic / proton number AND similar shielding / same (outer/number of) shell / energy level	1
(a)(ii)	Cross shown on first vertical line from the y-axis (Group 0 / Ne) is clearly higher than all shown	1
	Cross shown on second vertical line from the y-axis (Group 1 / Na) lower than all shown	1
(a)(iii)	A*l* (the outer / valence) electron (which is lost) is in (3)p sub-shell (Mg is in (3)s subshell) OR A*l* (the outer / valence) electron (which is lost) is in higher energy sub-shell ora	1
	(electron to be removed) is more shielded / experiences greater screening effect ora	1
	S has a pair of electrons in (a) (3)p <u>orbital</u> / (a 3)p <u>orbital</u> is full **ora**	1
	electron pair repulsion	1
(b)(i)	(**L**=) $MgCl_2$ / magnesium chloride	1
	Any two from (giant) ionic (with strong attractions) $Mg^{2+}(aq)$ / $Mg(H_2O)_6^{2+}(aq)$ is neutral / undergoes (partial) hydrolysis $Mg(OH)_2$ is the white precipitate / solid / insoluble / partially soluble $MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$	2
(b)(ii)	(**M**=) $SiCl_4$ / silicon chloride	1
	Any two from (simple) molecular / simple covalent hydrolysis possible due to available d orbitals forms HC*l* (aq) / hydrochloric acid / solution and / or HC*l* gas / fumes white solid is (hydrated) SiO_2 $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	2

47. 9701_w15_ms_21 Q: 1

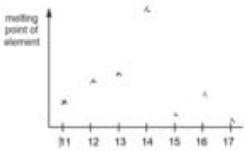
(a)	regular arrangement / lattice of cations / positive ions surrounded by delocalised electrons	[1] [1]
(b) (i)	electrical conductor corrosion resistant low density ductile owtte	[1] [1]
(ii)	Giant / lattice	[1]
(iii)	(electrical) insulator	[1]
(c) (i)	Simple covalent / covalent molecule Weak intermolecular forces / VdW forces OR little energy needed to break down / overcome intermolecular / VdW forces	[1] [1]
(ii)	Al Cl $\frac{20.3}{27}$ $\frac{79.7}{35.5}$ $\frac{0.752}{0.752}$ $\frac{2.25}{0.752}$ 1 3 $AlCl_3$	[1] [1]
(iii)	$pV = \frac{m}{M_r}RT$ $M_r = \frac{mRT}{pV}$ $= \frac{1.36 \times 8.31 \times 473}{100 \times 10^3 \times 200 \times 10^{-6}}$ $= 267$ **OR** $pV = nRT$ $n = \frac{pV}{RT}$ $= \frac{100 \times 10^3 \times 200 \times 10^{-6}}{8.31 \times 473}$ $= 5.09 \times 10^{-3}$ $M_r = \frac{1.36}{5.09 \times 10^{-3}} = 267$	[1] [1] [1] [1]
(iv)	Al_2Cl_6	[1]

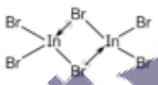
48. 9701_s21_ms_23 Q: 3

Question	Answer	Marks
(a)(i)	<table><tr><td></td><td>state at room temp</td><td>observations on add'n of sample to water</td><td>identity of sample</td></tr><tr><td>**R**</td><td>solid</td><td>alkaline, colourless solution is made but some white solid remains</td><td>**M1** $Ba(OH)_2$ OR barium hydroxide</td></tr><tr><td>**S**</td><td>solid</td><td>white solid disappears, solution is neutral</td><td>**M2** $NaCl$ OR sodium chloride</td></tr><tr><td>**T**</td><td>liquid</td><td>misty fumes, white solid is made in vigorous reaction</td><td>**M3** $SiCl_4$ OR silicon(IV) chloride</td></tr><tr><td>**U**</td><td>solid</td><td>acidic, colourless solution is made in vigorous reaction</td><td>**M4** P_4O_{10} OR phosphorus(V) oxide</td></tr></table>	**4**
(a)(ii)	SiO_2	**1**
(a)(iii)	phosphoric acid / phosphoric(V)acid	**1**
(b)(i)	*any **one** physical property typical of ceramic materials from:* • strong / retain strength (over certain temperatures / conditions) • non-conductors of electricity / electrical insulators • high melting points	**1**
(b)(ii)	SiO_2	**1**

Question	Answer	Marks
(c)	*% of O* **M1** 100 – 79.29 (= 20.71)	**1**
	M2 *express W and O as mol by / 183.8 and / 16 respectively*	**1**
	M3 *divide each by smallest number to give empirical formula* WO_3	**1**

49. 9701_w21_ms_22 Q: 2

Question	Answer	Marks
(a)(i)	M, M, M, C, C, C, C	1
(a)(ii)	All 3 points correct scores two marks Any 2 points scores one mark • *nuclear charge increases OR increasing proton number* e.g. 17 / C*l* has a greater nuclear charge • *describe the similarity in shielding between the two elements* e.g. they have almost the same shielding • *describe the overall effect in terms of greater nuclear attraction for (outer) electrons* e.g. (outer) electrons are attracted more (strongly) to the nucleus	2
(a)(iii)	**M1** describes the difference between 1st IE of elements 15 and 16 (P and S) in terms of either: spin-pair repulsion (in element 16 / S) **OR** electron pair repulsion (in element 16 / S) **M2** describes the location of the electron pair in the (3)p orbital which repel each other	2
(a)(iv)	(+)1, (+)2, (+)3, (+)4, (+)5, (+)6	1
(a)(v)	**M1** (anions have) same number of electrons (but increasing proton number) **M2** increasing proton number / nuclear charge AND increasing attraction of nucleus for (outer) electrons **OR** (outer) electrons attracted more (strongly) to the nucleus AND because of increasing proton number / nuclear charge	2
(b)		2

Question	Answer	Marks
(c)	**M1** density of $_{13}Al$: value within range 2.5–5.0 (g cm^{-3}) **M2** cationic radius of $_{31}Ga$: value within range 0.055–0.075 (nm) **M3** boiling point of $_{49}In$: value within range 1500–2300 (K)	3
(d)(i)	$InCl_3$	1
(d)(ii)	$In_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaIn(OH)_4$	1
(d)(iii)	 **M1** correct connectivity of In_2Br_6 **M2** showing the two correct dative covalent bonds	2

50. 9701_s16_ms_21 Q: 2

(a)	**D** = Ga **G** = Se	[1]
(b) (i)	$D_2O_3 + 6HCl \rightarrow 2DCl_3 + 3H_2O$ M1 = species; M2 = balancing	 [1] [1]
(ii)	$D_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaD(OH)_4(H_2O)_2$ OR $D_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaD(OH)_4$ OR $D_2O_3 + 2NaOH \rightarrow 2NaDO_2 + H_2O$ OR $D_2O_3 + 2OH^- + 7H_2O \rightarrow 2[D(OH)_4(H_2O)_2]^-$ OR $D_2O_3 + 2OH^- + 3H_2O \rightarrow 2[D(OH)_4]^-$ OR $D_2O_3 + 2OH^- \rightarrow 2DO_2^- + H2O$ M1 = species; M2 = balancing	 [1] [1]
(c)	giant ionic / ionic lattice	[1]
(d)	$GO_2 + H_2O \rightarrow H_2GO_3$	[1]

51. 9701_w20_ms_21 Q: 1

(a)	$Mg(g) \rightarrow Mg^+(g) + e^{(-)}$	**1**
(b)	**M1:** distance between nucleus and **outer e⁻** increases **OR outer electron** removed from higher energy shell	**3**
	M2: increased **shielding**	
	M3: decreased **nuclear** attraction	
(c)	**M1**: **greater nuclear attraction**	**2**
	M2: (2nd / 2s) electron being removed from **smaller** (ion)	

52. 9701_w20_ms_22 Q: 2

(a)	more acidic / less basic (from Na to S across period)	**1**
(b)	**M1:** increases (from Na to S / across period)	**2**
	M2: increasing (number of) **valence** electrons **OR** (number of) electrons in **outer** (electron) shell increases	
(c)	reaction — **name** of product; sodium oxide with water — sodium hydroxide; phosphorus(V) oxide with water — phosphoric(V) acid	**2**
(d)	**M1:** *identification of forces broken during melting of phosphorus(V) oxide* intermolecular forces in phosphorus(V) oxide (are broken)	**3**
	M2: *identification of force broken during melting of magnesium oxide* electrostatic forces of attraction between (many oppositely charged) **ions** in magnesium oxide	
	M3: *statement linking difference in strength of appropriate forces described in M1& M2 to explain difference in melting point* (only) **intermolecular forces** weaker than forces (of attraction) between ions / ionic bonds	
(e)(i)	$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$	**1**
(e)(ii)	$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$	**1**
(f)	**M1:** giant	**2**
	M2: covalent **AND** tetrahedral / four Si—O bonds	
(g)(i)	$Na_2O + SiO_2 \rightarrow Na_2SiO_3$	**1**
(g)(ii)	$Na_2CO_3 \rightarrow Na_2O + CO_2$	**1**

Table for 52(c):

reaction	**name** of product
sodium oxide with water	sodium hydroxide
phosphorus(V) oxide with water	phosphoric(V) acid

53. 9701_s19_ms_21 Q: 1

(a)(i)	**M1** (one) fewer (inner) shell of electrons / less shielding (effect) *ORA*	1
	M2 smaller distance of the **outer** electrons (from the nucleus) / stronger nuclear attraction to the (outer) electrons *ORA*	1
(a)(ii)	$Sr(s) + 2H_2O(l) \rightarrow Sr(OH)_2(aq) + H_2(g)$ **M1** species AND balancing	1
	M2 state symbols	1
(a)(iii)	**M1** strontium AND forms a more soluble hydroxide	1
	M2 strontium hydroxide is a stronger base / produces more OH^- / it dissociates more	1
(a)(iv)	(white) **solid** dissolves / effervescence	1
(b)(i)	Similarities (any two from the following list) (both have) +2 ion / (+2) same oxidation state / same stoichiometry of oxide / carbonates decompose (on heating)	2
	Difference (X) forms coloured compounds/oxides/ carbonates **OR** Group 2 elements form white compounds/oxides/carbonates	1
(b)(ii)	XO	1
(b)(iii)	$XCO_3 \rightarrow XO + CO_2$	1

54. 9701_s19_ms_23 Q: 3

(a)	white light / flame **AND** (produces a) white / grey solid / ash / powder / smoke	1
(b)(i)	$MgO + 2HCl \rightarrow MgCl_2 + H_2O$	1
(b)(ii)	neutralisation	1
(c)	**M1** giant (structure / lattice) **M2** (so) lots of energy needed to break the bonds OR strong bonds	2
(d)(i)	$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$	1
(d)(ii)	(thermal) decomposition	1

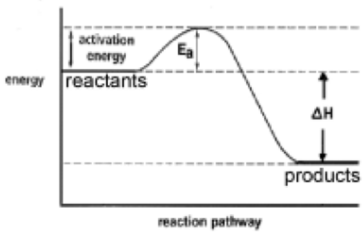
55. 9701_s18_ms_22 Q: 1

(a)(i)	$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$	1
(a)(ii)	the product / $Mg(OH)_2$ sparingly soluble / slightly soluble / less soluble (than NaOH)	1
(b)(i)	*any two from:* • (from Mg to Ba) larger (atomic) radius / more shells / more shielding • electron(s) are less tightly held (by nucleus) / less attracted (to nucleus) • ionisation energy / ies decrease(s) / electron(s) lost (more) easily (down the group) • lower activation energy (for the reactions down the group)	2
(b)(ii)	white light / white flame	1
	white smoke / white solid	1
	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$	1
(b)(iii)	$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$	1
(b)(iv)	*any two from:* • increasing (cation) size / (cat)ionic radius increases / increasing size of atoms • overall charge on (cation) is constant / (+)2 / decreasing charge density of (+2 charged cation) • number of delocalised / outer / valence electrons (per atom) remains the same / 2 • increased shielding	2
	decreasing (strength of) attraction between (cat)ion / nucleus / nuclear charge **AND** delocalised electron(s)	1

56. 9701_m16_ms_22 Q: 1

(a) (i)	greater attractive force OR greater force between nucleus and (outer) electrons proton number / atomic number / nuclear charge increases across period AND electrons occupy same shell / shielding roughly constant	[1] [1]
(ii)	sulfur's electron removed from full (3p) orbital OR sulfur has two electrons in the same orbital electron–electron repulsion (reduces energy required)	[1] [1]
(iii)	sodium has mobile / free electrons / electrons free (to move throughout the structure) phosphorus is simple / covalent / molecular	[1] [1]
(iv)	magnesium has two free / delocalised / outer / valence electrons per atom OR more free / delocalised / outer electrons than sodium	[1]
(b) (i)	**A** = $Mg(NO_3)_2$ **B** = H_2 **C** = NO_2 OR O_2 **D** = O_2 OR NO_2	[1] [1] [1] [1]
(ii)	any Group I carbonate OR ammonium carbonate	[1]

57. 9701_s16_ms_21 Q: 3

(a) (i)	bubbles / effervescence / fizzing	[1]
	calcium gets smaller / disappears	[1]
	water turns cloudy / milky	[1]
	calcium sinks	[1]
(ii)	$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$	[1]
(iii)	faster bubbling / disappearance of Ba OR no / less precipitate forms (owtte)	[1]
(b) (i)		
	M1 – general layout with products below reactants AND both labelled	[1]
	M2 – E_a and ΔH / energy change / released labelled with vertical lines	[1]
(ii)	activation energy is high	[1]
	so few/no particles with $E \geqslant E_a$	[1]
(iii)	high melting / boiling point	[1]
	strong forces (of attraction / between oppositely charged ions) / strong (ionic) bonding	[1]
(iv)	MgO is basic / reacts with acid	[1]
(c) (i)	increases (down the group)	[1]
(ii)	$MgCO_3 \rightarrow MgO + CO_2$	[1]
(iii)	$2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$	[1]

58. 9701_s20_ms_23 Q: 1

(a)(i)	**M1** green flame / white flame (with green tinge) **M2** white solid formed	**2**
(a)(ii)	$2Ba(s) + O_2(g) \rightarrow 2BaO(s)$	**1**
(b)(i)	**M1** heat (followed by) add water **M2** $CaCO_3 \rightarrow CaO + CO_2$ **M3** $CaO + H_2O \rightarrow Ca(OH)_2$	**3**
(b)(ii)	thermal decomposition.	**1**
(b)(iii)	neutralise acid soil / reduce the acidity in soil / increase the pH in soil	**1**
(c)(i)	$4Ga + 3O_2 \rightarrow 2Ga_2O_3$	**1**
(c)(ii)	(+)3	**1**
(c)(ii)	reagent and conditions — Formula of gallium containing product **M1** gallium oxide+ hot HCl(aq) — **M1** $GaCl_3$ **M2** gallium oxide+hot concentrated NaOH(aq) — **M2** $NaGa(OH)_4$ OR $NaGaO_2$	**2**

59. 9701_s17_ms_21 Q: 3

(a)(i)	**A**	**1**
(a)(ii)	**H**	**1**
(a)(iii)	**G**	**1**
(a)(iv)	**B**	**1**
(a)(v)	**F**	**1**
(b)(i)	(strong) heating	**1**
	(to provide / overcome) high activation energy	**1**
(b)(ii)	white flame / white light / white smoke / white solid	**1**
(b)(iii)	$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$	**2**
(c)(i)	$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	**1**
(c)(ii)	$CaCO_3 \rightarrow CaO + CO_2$	**1**
	$CaO + H_2O \rightarrow Ca(OH)_2$	**1**
(d)(i)	reduce acidity in soil / increase pH of soil	**1**
	(both) basic / base(s)	**1**
(d)(ii)	$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ OR $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$	**1**
	Total:	**16**

60. 9701_w16_ms_21 Q: 3

(a)(i)	(Atoms/ ions become larger as) the number of (electron) shells increases (down the group) Increased distance of (outer) electrons (from the nucleus) OR Increased shielding results in weaker (nuclear) attraction / pull	1 1	**2**
(a)(ii)	top line / dotted line is atomic radii / bottom line / line with crosses is ionic radii (as atoms bigger than ions) Atom has one more shell (than corresponding ion) (ora) OR Atom loses two electrons / outer (shell) electrons / valency electrons (ora) OR Atom loses electrons and so (nuclear) attraction is stronger OR Nuclear charge in ion is greater than the electron(ic) charge (ora) OR Effective nuclear charge in ion is greater (ora)	1 1	**2**
(b)(i)	Nitrate / Nitrate(V) / NO_3^-	1	**1**
(b)(ii)	Ba / barium OR Sr / Strontium $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$ OR $Sr^{2+} + SO_4^{2-} \rightarrow SrSO_4$	 1	**1**
(b)(iii)	$Ba(NO_3)_2$ OR $Sr(NO_3)_2$ $2Ba(NO_3)_2 \rightarrow 2BaO + 4NO_2 + O_2$ OR $2Sr(NO_3)_2 \rightarrow 2SrO + 4NO_2 + O_2$	1 1	**2**
(c)(i)	$H^+ + OH^- \rightarrow H_2O$ OR $Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O$ $2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$ OR $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ OR $H^+ + CO_3^{2-} \rightarrow HCO_3^-$ OR $CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$	1 1	**2**
(c)(ii)	Calcium carbonate is insoluble / less soluble (ora) Calcium carbonate is less likely to be / won't get washed away (ora) OR Calcium carbonate lasts longer (ora) OR Calcium carbonate is less reactive / reacts more slowly (ora)	1 1	**2**
(d)	$Mg(OH)_2$ MgO	1 1	**2**
	Total:		**14**

61. 9701_S15_ms_23 Q: 2

(a) (i)	Reactivity increases down the group **OR** reference to observations that indicate trend Outer electrons lost more easily down group Due to increased distance/shielding of outer electrons from nucleus	[1] [1] [1]
(ii)	$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$	[1]
(iii)	Magnesium hydroxide sparingly soluble/insoluble	[1]
(iv)	$Mg + H_2O \rightarrow MgO + H_2$	[1]
(b) (i)	$MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$	[1]
(ii)	(thermal stability) increases down the group	[1]
(iii)	$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	[1]
(iv)	N from (+)5 to (+)3 O from –2 to 0 N is reduced **and** O is oxidised	[1] [1] [1]
(c)	(Very) strong electrostatic attraction/ionic bond High charge (density) of cation and anion/Mg^{2+} and O^{2-}	[1] [1]
(d) (i)	$CaCO_3 \rightarrow CaO + CO_2$ $CaO + H_2O \rightarrow Ca(OH)_2$	[1] [1]
(ii)	$2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$	[1]
(iii)	$1 \times 10^{-4} \times 8000 = 0.8\,mol\ H^+$ $\frac{0.8}{2} \times 100.1 = \text{mass } CaCO_3 = 40\,g$	[1] [1]

62. 9701_m17_ms_22 Q: 2

<table>
<tr><td>(a)(i)</td><td>bond in which the centres of positive and negative charges do not coincide
OR electron distribution is asymmetric / unequal
OR two (bonded) atoms are partially charged</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>HF has the strongest (permanent) dipole–dipole / van der Waals' (forces) / HF has hydrogen bonding</td><td>1</td></tr>
<tr><td></td><td>requires more energy to overcome (than weaker (permanent) dipole–dipole / van der Waals' forces between other hydrogen halides)</td><td>1</td></tr>
<tr><td>(a)(iii)</td><td>thermal stability of the hydrogen halides decreases down group (17)</td><td>1</td></tr>
<tr><td></td><td>larger (halogen) atoms / atomic radius (down group) / increased shielding</td><td>1</td></tr>
<tr><td></td><td>bond energies decrease / less energy required to break H–X</td><td>1</td></tr>
<tr><td>(b)(i)</td><td>M1
base is Cl^- AND conjugate acid is HCl
OR
base is HSO_4^- AND conjugate acid is H_2SO_4</td><td>1</td></tr>
<tr><td></td><td>M2
Cl^- / HSO_4^- / base is a proton acceptor
OR
HCl / H_2SO_4 / (conjugate) acid has one more H^+</td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>H_2SO_4 is (too strong) an oxidising agent</td><td>1</td></tr>
<tr><td></td><td>I_2 would be formed instead</td><td>1</td></tr>
<tr><td>(c)(i)</td><td>$\Delta_rH = \Delta_rH\{products\} - \Delta_rH\{reactants\} = 2 \times (-242) - 4 \times (-92)$</td><td>1</td></tr>
<tr><td></td><td>= –116 (sign AND answer)</td><td>1</td></tr>
<tr><td>(c)(ii)</td><td>heterogeneous (catalyst)</td><td>1</td></tr>
<tr><td></td><td>provides an alternative reaction pathway of lower activation energy</td><td>1</td></tr>
<tr><td>(c)(iii)</td><td>reaction is exothermic</td><td>1</td></tr>
<tr><td></td><td>(increased temperature) shifts equilibrium to the left AND decreases yield of products (Cl_2 and / or H_2O) / less product formed</td><td>1</td></tr>
<tr><td>(c)(iv)</td><td>
<table>
<tr><td></td><td>HCl</td><td>O_2</td><td>Cl_2</td><td>H_2O</td></tr>
<tr><td>initial number of moles</td><td>1.60</td><td>0.500</td><td>0</td><td>0</td></tr>
<tr><td>M1 eqm number of moles</td><td>1.60 – 2 × 0.600 = 0.400</td><td>0.500 – ½ × 0.600 = 0.200</td><td>0.600</td><td>0.600</td></tr>
<tr><td>M2 mole fraction</td><td></td><td></td><td>$\frac{0.600}{1.80}$</td><td></td></tr>
<tr><td>M3 partial pressure</td><td></td><td></td><td>$\frac{0.600}{1.80} \times p_{tot} = 5.00 \times 10^4$</td><td></td></tr>
</table>
</td><td>3</td></tr>
<tr><td>(c)(v)</td><td>$K_p = \frac{(3.6 \times 10^4)^2 \times (3.6 \times 10^4)^2}{(4.8 \times 10^4)^4 \times 3.0 \times 10^4} = 1.05 \times 10^{-5}$</td><td>1</td></tr>
<tr><td></td><td>units = Pa^{-1}</td><td>1</td></tr>
<tr><td>(c)(vi)</td><td>K_p would not change</td><td>1</td></tr>
</table>

63. 9701_w17_ms_22 Q: 3

(a)	(IE) decreases / lower because increasing **distance** of outer electron(s) from nucleus **OR** increasing distance of outer / valence shell from nucleus **OR** increased **shielding** / screening (from inner shells)	1
	reduces nuclear **attraction** (for electrons)	1
(b)(i)	(Melting point) increases / higher because (molecules have an) increasing (number of) electrons	1
	increasing strength / number / amount of IMFs / Van der Waals' / id–id / London / dispersion (forces)	1
(b)(ii)	increased metallic / (cat)ionic radius / size OR decreasing (cat)ion charge-density	1
	decreased attraction (of ions) for delocalised / outer electrons	1
(c)(i)	reaction 1: HNO_3 or nitric((V)) acid	1
	reaction 2: water / H_2O	1
(c)(ii)	barium oxide	1
	$2Ba + O_2 \rightarrow 2BaO$	1
(c)(iii)	NO_2 / nitrogen dioxide / nitrogen(IV) oxide **AND** O_2 / oxygen	1
	(red / yellow-)brown gas **OR** gas given off that relights glowing splint	1
(c)(iv)	white ppt / solid / suspension	1
	of $BaSO_4$ / barium sulfate **OR** $Mg(OH)_2$ / magnesium hydroxide	1
	$BaSO_4$ is insoluble **OR** $Mg(OH)_2$ is insoluble / partially / slightly / sparingly soluble	1

64. 9701_s19_ms_22 Q: 2

(a)	*trend in volatility down the group* decrease (in volatility)	1
	identification of specific IMF increasing increasing (strength of) induced dipole (id) (interactions between molecules)	1
	explanation in terms of electrons increasing number of electrons	1
(b)(i)	*Conditions for reaction with Cl_2 at room temperature* ultra-violet / uv	1
(b)(ii)	$I_2(g / s) + H_2(g) \rightleftharpoons 2HI(g)$ **M1** correctly balanced equation	1
	M2 correct state symbols AND use of equilibrium sign	1
(c)(i)	proton / H^+ donor	1
(c)(ii)	acid HCl AND conjugate base Cl^-	1
(c)(iii)	co-ordinate / dative (covalent)	1
(c)(iv)	(triangular / trigonal) pyramid(al)	1
	$107^{(0)}$	1

65. 9701_s16_ms_22 Q: 2

(a)	(i)	enthalpy / energy / heat change when one mole of gaseous atoms is produced from the element in its standard state under standard conditions	[1] [1] [1]
	(ii)	fluorine and chlorine are gases / bromine liquid and iodine solid OR as ΔH_{at} for bromine / iodine also includes changes of state	[1]
	(iii)	($\frac{1}{2}Cl_2 + \frac{1}{2}I_2 \rightarrow ICl$) $\Delta H_f = (\frac{1}{2}E(Cl_2) + \frac{1}{2}E(I_2)) - E(ICl)$ OR $E(ICl) = (151/2) + (242/2) + 24$ E(ICl) = (+) 220.5 / 221	[1] [1]
(b)	(i)	stronger / more / greater id–id / London / dispersion forces due to increasing numbers of electrons	[1] [1]
	(ii)	(intermolecular forces in HF are) hydrogen bonds (which are) stronger (than vdW) / more energy needed to separate molecules OR HF much more polar / F much more electronegative Intermolecular forces in HF stronger (than in HCl, HBr, HI)	[1] [1] [1] [1]
(c)	(i)	**P** = iodine / I_2 /I; **Q** = chlorine / Cl_2 / Cl	[1]
	(ii)	weaker H–**P** than H–**Q** bond ORA / easier /less energy to break H–**P** than H–**Q** ORA due to greater distance / shielding of nucleus from bond pair ORA	[1] [1]
	(iii)	2H**P** (or 2HI) → (or ⇌) H_2 + $\mathbf{P}_2$ (or I_2)	[1]
	(iv)	$Ag^+(aq) + \mathbf{Q}^-(aq)$ (or Cl^-) → Ag**Q**(s) (or AgCl(s)) Ag**Q**(s) / AgCl(s) + $2NH_3(aq) \rightarrow Ag(NH_3)_2^+(aq)$ + $\mathbf{Q}^-(aq)$ / $Cl^-(aq)$	[1] [1]
(d)	(i)	no of Cl increases by one each time / matches group number due to increasing number of valence/outer(most/shell) electrons / oxidation number / valency (of Mg, Al , Si)	[1] [1]
	(ii)	$MgCl_2 (+aq) \rightarrow Mg^{2+} + 2Cl^-$ $AlCl_3 + 6H_2O \rightarrow Al(H_2O)_6^{3+} + 3Cl^-$ / $Al(H_2O)_5(OH)^{2+} + H^+ + 3Cl^-$ $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4H^+ + 4Cl^-$	[1] [1] [1]

66. 9701_s21_ms_21 Q: 3

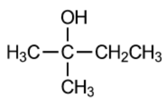
Question	Answer	Marks
(a)(i)	$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ OR $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$	1
(a)(ii)	displacement / acid-base (reaction)	1
(b)(i)	hydrogen iodide / HI	1
(b)(ii)	dark grey solid I_2 / iodine	1
	other product S / sulfur OR H_2S / hydrogen sulfide OR H_2O / water / steam	1
(c)	**M1** iodide ions are strong(er) reducing agents (than chloride ions) ORA	1
	M2 HI / iodide is oxidised OR HCl / chloride is not oxidised	1
(d)	$2Br^- + 2H^+ + H_2SO_4 \rightarrow Br_2 + 2H_2O + SO_2$	1

67. 9701_s21_ms_22 Q: 1

Question	Answer	Mark
(a)	**M1** cream	1
	M2 AgBr	1
(b)	(1)MBr_2 + 2$AgNO_3$ → 2AgBr + **M**$(NO_3)_2$	1
(c)	**M1** *calculate Mr of **M**Br_2 using 8.415 × 10^{-4} mol **M**Br_2 in 0.250 g* M_r = ……. = 297(.1)………	1
	M2 *calculate the atomic mass of **M** using M_r calculated in M1* 297.1 – (2 × 79.9) = 137(.4)	1
	M3 *identify group 2 element from A_r in M2* Ba / barium	1
(d)(i)	(solution / mixture / liquid) turns (colourless to) orange or brown	1
(d)(ii)	displacement	1
(e)	**M1** *reagent:* concentrated sulfuric acid	1
	M2 *observation:* brown vapour / gas (forms)	1
(f)(i)	*explain **how the action of heat** is used to identify the 3 samples* **M1** nitrate AND carbonate lose mass / less than 1 g	1
	M2 nitrate produces brown (NO_2) fumes	1
	M3 MgO no reaction / MgO no change	1
(f)(ii)	*electronic configuration of Mg^{2+}* ($1s^2$) $2s^22p^6$	1

Question	Answer	Mark
(g)	*One similarity* **M1** solid(s) disappear(s)	1
	One difference **M2** $MgCO_3$ fizzes (due to CO_2) OR no fizzing with $Mg(OH)_2$	1

68. 9701_m20_ms_22 Q: 2

(a)	darker / stronger / deeper down the group	1
(b)(i)	weaker oxidising agents / (relative reactivity as oxidising agents) decreases **down the group**	1
(b)(ii)	**M1** (structure =) simple / molecular, because it has a low melting / boiling point **M2** (bonding =) covalent, because it is hydrolysed	2
(c)(i)	**M1** cream ppt / solid **M2** (ppt / solid) partially dissolves in (aqueous) ammonia	2
(c)(ii)	**M1** *Acid behaviour of H_2SO_4* H_2SO_4 acts as an acid with Cl^- OR acid / base reaction with Cl^- **M2** *Oxidising behaviour of H_2SO_4* H_2SO_4 acts as an oxidising agent with I^- OR H_2SO_4 does not oxidise Cl^- **M3** *Products formed* (for iodide reaction) I_2 / S / SO_2 / H_2S is formed OR (for chloride reaction) (only) HCl is formed OR *Comparison of oxidising strength* H_2SO_4 not strong enough to / cannot oxidise Cl^- (to Cl_2) OR I^- more powerful reducing agent than Cl^-	3
(d)(i)	**M1** increases (down the group) because of increasing VdW **M2** because of increasing number of electrons	2
(d)(ii)	**M1** less stable (down the group) / decreases **M2** lower H–Hal bond enthalpy / energy	2
(e)(i)	in the same phase / state	1
(e)(ii)	$C_2H_5CH(OH)C_2H_5 + HCl \rightarrow C_2H_5CH(Cl)C_2H_5 + H_2O$	1
(e)(iii)		1
(e)(iv)	substitution	1

69. 9701_s17_ms_23 Q: 2

(a)(i)	<table><tr><td>halogen</td><td>colour</td><td>state</td></tr><tr><td>chlorine</td><td>yellow / green</td><td>gas</td></tr><tr><td>bromine</td><td>red / brown / orange</td><td>liquid</td></tr><tr><td>iodine</td><td>grey / black</td><td>solid</td></tr></table>	2
(a)(ii)	increasing number of electrons	1
	(gives) increasing strength of van der Waals' / id-id forces / London / dispersion forces	1
(b)	oxidising power decreases down the group. *ora*	1
	ability to accept electrons decreases (down the group) *ora*	1
	because (outer shell experiences) more shielding OR increased distance from nucleus (to outer shell) (outweighs the increasing nuclear charge down the group) *ora*	1
(c)(i)	solid sodium chloride: steamy / misty / white fumes	1
	solid sodium iodide: purple fumes	1
(c)(ii)	(conc sulfuric) not powerful enough oxidising agent (to oxidise chloride) OR chloride not powerful enough reducing agent (to reduce sulfuric acid)	1
	iodide reduces sulfuric acid OR iodide / I^- is oxidised OR sulfuric acid oxidises iodide	1
(c)(iii)	$2NaBr + 2H_2SO_4 \rightarrow Br_2 + SO_2 + Na_2SO_4 + 2H_2O$ OR $NaBr + H_2SO_4 \rightarrow NaHSO_4 + HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$ OR $2NaBr + H_2SO_4 \rightarrow Na_2SO_4 + 2HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$	2
(d)(i)	AgI (and AgC*l* solid) / silver ions reacting with iodide ions	1
(d)(ii)	AgC*l* (precipitate) dissolves (in ammonia) owtte	1
	Total:	**15**

70. 9701_s21_ms_23 Q: 1

Question	Answer	Marks
(a)(i)	increases	1
(a)(ii)	chlorine gas bromine liquid iodine solid	1
(b)	**M1** observation with $Cl_2(aq)$ (colourless / pale green to) orange / brown	1
	M2 observation with $I_2(aq)$ no visible change	1
	M3 explanation chlorine is a stronger oxidising agent (than bromine) AND iodine is a weaker oxidising agent	1
(c)	$Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$	1
(d)(i)	proton / H^+ acceptor	1
(d)(ii)	$ClO^- + H_2O \rightarrow HClO + OH^-$	1
(e)	**M1** *Use volume O_2 to express / find no mol O_2 produced* 24 / 24 000 mol O_2 produced = 1×10^{-3} (mol)	1
	M2 *Use 1:1 ratio to deduce no mol NaClO in 1000 cm^3 sample* M1 × 1000 / 5 = 0.2 (mol dm^{-3})	1
	M3 *Use amount of NaClO and its molecular mass (74.5) to find the mass of NaClO added* 24 / 24 000 × 1000 / 5 × 74.5 = 14.9 (g dm^{-3})	1
(f)	**M1** products contain Cl^- AND Cl_2	1
	M2 correct balanced equation $ClO^- + 2HCl \rightarrow Cl^- + H_2O + Cl_2$	1

71. 9701_s18_ms_23 Q: 3

(a)(i)	(volatility) decreases	1
(a)(ii)	increasing numbers / more of electrons (in molecules)	1
	increased strength of id-id / VdW / IMFs	1
(b)	$Cl_2 + 2NaI \rightarrow 2NaCl + I_2$	1
(c)(i)	<table><tr><td></td><td>NaI(aq) + AgNO₃(aq)</td><td>NaCl(aq) + AgNO₃(aq)</td></tr><tr><td>colour of ppt</td><td>yellow</td><td>white</td></tr><tr><td>name of ppt</td><td>silver iodide</td><td>silver chloride</td></tr><tr><td>effect of addition of aqueous ammonia to the precipitate</td><td>No (visible) change</td><td>dissolves / soluble</td></tr></table>	3
(c)(ii)	$Ag^+(aq) + I^-(aq) \rightarrow AgI(s)$	1
(d)	M1 sulfuric acid acts as an acid with NaCl (and NaBr) OR $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ OR $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$	1
	sulfuric acid acts as an oxidising agent with NaI / I OR NaI is a reducing agent	1
	I^- more powerful reducing agent than Cl^- OR sulfuric acid can oxidise I^- but not Cl^- OR sulfuric acid is a stronger oxidising agent than iodide ions OR sulfuric acid is not as strong an oxidising agent than chloride ions	1
(e)(i)	(Species that) gains electrons / electron acceptor	1
(e)(ii)	$Cl_2 + H_2O \rightarrow HCl + HClO$	1
(e)(iii)	$3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$	1
	0 to –1 (+)5 AND chlorine has been oxidised and reduced.	1

72. 9701_s19_ms_22 Q: 3

(a)(i)	$SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq/g)$ (state symbols required)	1
(a)(ii)	hydrolysis	1
(a)(iii)	$NaCl$ – ionic	1
	$SiCl_4$ – covalent	1
(a)(iv)	**M1** statement correctly comparing the **difference** in electronegativity between Si and C*l* AND Na and C*l* OR Na is less electronegative that Si *ORA*	1
	M2 NaC*l* transfer of electrons	1
	M3 $SiCl_4$ shared (pair of) electrons	1
(b)(i)	Chlorine containing species: Cl_2, HC*l*, HOC*l*; Oxidation number of chlorine: 0, –1, (+)1 Award 2 marks for 3 correct oxidation numbers Award 1 Mark for 2 correct oxidation numbers	2
(b)(ii)	disproportionation	1
(b)(iii)	kills micro-organisms	1
(c)	$2NaOH + HCl + HClO \rightarrow NaCl + NaClO + 2H_2O$ **M1** Identifies the product NaC*l*O **M2** Correctly balances the equation OR The overall equation may be seen as: $NaOH + HCl \rightarrow NaCl + H_2O$ **AND** $NaOH + HClO \rightarrow NaClO + H_2O$	2

Chlorine containing species	Cl_2	HC*l*	HOC*l*
Oxidation number of chlorine	0	–1	(+)1

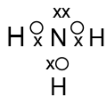
73. 9701_s20_ms_21 Q: 3

(a)	**M1** (enthalpy / energy change) when one mole of a compound/substance is formed **M2** from its elements in their standard states	2
(b)	**M1** *<u>use</u> of correct stoichiometry in calculation* 3xΔH_f NO_2 1x-ΔH_f H_2O 2xΔH_f HNO_3 1xΔH_f NO **M2** *correct signs associated with the appropriate* ΔH_f values/terms *used for the calculation of* $\Delta H_{reaction}$ **M3** $\Delta H_{reaction} = -(102 - 286) + (-346 + 91.1) = -70.9\ kJ\ mol^{-1}$	3
(c)	**M1** nitrogen has a triple bond **M2 EITHER** high energy is needed to break the bond **OR** at normal temperatures there is not enough energy to break the bond / to overcome the activation energy	2
(d)	lightning	1
(e)(i)	**M1** *define homogeneous* (homogeneous catalyst is) in the same phase / state as the reactants **M2 and M3** *Define catalyst* *All 3 points scores 2 marks. Any 2 points scores 1 mark* increase the rate **AND** lowers the activation energy **AND** without being chemically altered at the end of the reaction / are regenerated at the end of the reaction	
(e)(ii)	**M1** $NO_2 + SO_2 \rightarrow NO + SO_3$ **M2** $NO + ½O_2 \rightarrow NO_2$	2

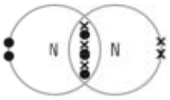
74. 9701_s20_ms_21 Q: 4

<table>
<tr><td>(a)</td><td>Accepts a proton / H^+ (ion)</td><td>1</td></tr>
<tr><td>(b)</td><td>Two reasons why product mixture is added to soil – allow in any order
M1 Acts as a fertiliser / adds nutrients (for plants)
M2 Neutralise acid soils / increases the pH of acid soil</td><td>2</td></tr>
<tr><td>(c)</td><td><table><tr><td></td><td>name of shape</td><td>bond angle / °</td></tr><tr><td>CO_2</td><td>Linear</td><td>180</td></tr><tr><td>NH_3</td><td>Pyramid(al)</td><td>107</td></tr><tr><td>H_2O</td><td>non-linear / V / bent</td><td>104.5</td></tr></table>All 6 correct – 3 marks
4 or 5 correct – 2 marks
2 or 3 correct – 1 mark</td><td>3</td></tr>
</table>

75. 9701_s20_ms_22 Q: 2

(a)	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$	1
(b)		1
(c)(i)	$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$ (+)4 (+)5 (+)2 3 correct oxidation numbers – 2 marks 2 correct oxidation numbers – 1 mark	2
(c)(ii)	*relates the term disproportionation to the reaction described* **M1** nitrogen /N (in nitrogen dioxide) is both gaining electrons and losing electrons during the reaction **M2** *refer to relevant transfer of electrons when NO_2 reacts to form HNO_3 and NO* NO_2 to HNO_3 involves loss of electron(s) **AND** NO_2 to NO involves gain of electron(s)	
(d)	**M1** *state the effect of NO gas on contact with moist air* NO reacts with water **OR** NO reacts with oxygen and water. **M2** *consequence of M1 in terms of atmospheric pollution* causing acid rain **OR** photochemical smog / ground level ozone OR destroy ozone layer	2
(e)	**M1** *number of mol in sample of NH_4NO_3* 40t NH_4NO_3 = 500 000 mol ammonium nitrate **M2** *ratio of mol NO_2: NH_4NO_3* 3/2 mol NO_2 :1 mol NH_4NO_3 **M3** *volume of no mol NO_2 at rtp using 1 mol = 24dm^3* 18 000 000 dm^3 of NO_2	3
(f)	fertiliser	1

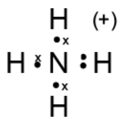
76. 9701_w18_ms_21 Q: 2

(a)(i)	1 mark for each bullet, max 2 • triple bond • non-polar / no dipole • needs a lot of energy to break / strong	**2**
(a)(ii)	 6 e^- between atoms **AND** two electrons on each N atom	**1**
(b)(i)	(lightning) provides the (high) activation energy	**1**
(b)(ii)	**M1** $NO + ½O_2 \rightarrow NO_2$ **M2** $2NO_2 + H_2O + ½O_2 \rightarrow 2HNO_3$	**2**
(c)	**M1** fertiliser / nitrates dissolve in (river / ground water) **OR** fertiliser / nitrates are washed / leached out / flows into (river/groundwater) **M2** algal bloom / promote algal growth / explosion of plant growth **AND** sunlight is blocked out (preventing photosynthesis) / plants can no longer carry out photosynthesis (and die) **AND** bacteria break down or decay **dead** organisms / plants / algae **M3** drop in oxygen (concentration)	**3**
(d)(i)	to increase / raise pH	**1**
(d)(ii)	**M1** ammonia / NH_3 **M2** displaces NH_3	**2**
(d)(iii)	**M1** effervescence / fizzing / bubbling **M2** solid disappears	**2**
(d)(iv)	$2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$	**1**

77. 9701_s17_ms_22 Q: 2

(a)	strong triple bond	**1**
	non-polar / no dipole	**1**
(b)(i)	Any 2 points covered correctly scores 2 marks Any 1 point covered correctly scores 1 mark • nitrogen (and oxygen) from the air / atmosphere (react): • high temperature (of internal combustion engine) / (engine) produces enough OR a lot of heat (energy) : • (so) breaks (strong) bond(s) in nitrogen (and oxygen) :	**2**
(b)(ii)	reduction / decomposition of NO_x using a catalyst / catalytic convertor	**1**
	$2NO_2 + 4CO \rightarrow 4CO_2 + N_2$ OR $2NO + 2CO \rightarrow 2CO_2 + N_2$	**1**
(b)(iii)	(acts as a homogeneous) catalyst OR oxidising agent	**1**
	$SO_2 + NO_2 \rightarrow SO_3 + NO$	**1**
	$NO + ½O_2 \rightarrow NO_2$ OR $SO_3 + H_2O \rightarrow H_2SO_4$	**1**
(b)(iv)	$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ OR $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$	**1**
(c)	fertiliser / nitrates dissolve in (river water) OR fertiliser / nitrates are washed / leached out / flows into (river water)	**1**
	algal bloom / promote algal growth / explosion of plant growth **AND** EITHER sunlight is blocked out (preventing photosynthesis) / plants can no longer carry out photosynthesis (and die) OR bacteria break down or decay dead organisms / plants / algae	**1**
	drop in oxygen (concentration)	**1**
	Total:	**13**

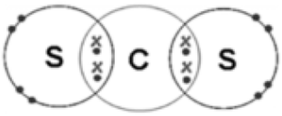
78. 9701_s16_ms_23 Q: 2

(a)	$NH_3 + HNO_3 \rightarrow NH_4NO_3$	[1]
(b) (i)	line from origin AND below left-hand end of original with peak to right of and lower than original crosses original once AND above right-hand end of original AND above energy axis	[1] [1]
(ii)	(curves show) more molecules with $E > E_a$ (at higher T) so greater frequency of successful (owtte) collisions / more successful (owtte) collisions per unit time	[1] [1]
(iii)	catalysed E_a shown to left of original on horizontal axis so more molecules with $E > E_a$ (in presence of catalyst)	[1] [1]
(iv)	production of ammonia is <u>exothermic</u> / (forward) reaction <u>exothermic</u> position of eqm would move to left / reverse / reduce yield (at higher T)	[1] [1]
(c)	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$ N changes from –3 to +2 (so oxidation) O changes from 0 to –2 (so reduction)	[1] [1] [1]
(d) (i)		[1+1]
(ii)	shape = tetrahedral angle = 109°–109.5°	[1] [1]
(e)	eutrophication / algal bloom / stimulates growth of algae (bacteria) use up oxygen when decomposing the plants / algae block light for plants so less oxygen produced aquatic life / fish die (due to lack of oxygen)	[1] [1] [1] [1]

79. 9701_w15_ms_21 Q: 2

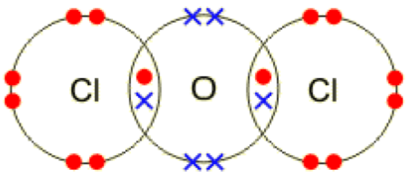
(a) (i)	The enthalpy change when one mole of a compound is formed from its element(s)	[1] [1]
(ii)	$S(s) + 1\frac{1}{2}O_2(g) \rightarrow SO_3(l)$	[1]
(b) (i)	$944 + (3 \times 436) = 2252$ $6 \times 390 = 2340$ $2252 - 2340 = -88$ (kJ mol^{-1})	[1] [1] [1]
(ii)	Fe catalyst 200 atm 400–500 (°)C	[1] [1] [1]
(iii)	High T increases rate AND Low T improves yield owtte Chosen temp is a compromise High P favours / increases (both rate and) yield owtte pressure chosen limited by cost (of compression and 'thick walls')	[1] [1] [1] [1]
(c) (i)	$2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$	[1]
(ii)	NH_3 identified as base AND H_3PO_4 identified as acid base accepts protons AND acid donates protons	[1] [1]
(d) (i)	nitrates / fertilisers wash into rivers eutrophication / algal bloom / promote algal growth bacteria use up oxygen in decay process	[1] [1] [1]
(ii)	(oxides of nitrogen / NO_x / NOs) cause acid rain $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ OR $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ OR $SO_2 + NO_2 \rightarrow SO_3 + NO$ AND $SO_3 + H_2O \rightarrow H_2SO_4$	[1] [1]

80. 9701_w21_ms_21 Q: 1

Question	Answer	Marks
(a)(i)	easily vaporised / easily evaporates / turns to gas easily	**1**
(a)(ii)	 **M1** bonding pairs **M2** Correct number of remaining outer electrons	**2**
(a)(iii)	180°	**1**
(a)(iv)	**M1** CS_2 has more electrons **M2** So stronger induced dipole (forces) (between molecules)	**2**
(b)(i)	**M1** (enthalpy/energy change when) 1 mole of a compound **M2** *burns/combusts/reacts* *in* ***excess*** *oxygen/O_2* **OR** ***completely*** *burns/* ***completely*** *combusts/****completely*** *reacts* *in oxygen/O_2*	**2**
(b)(ii)	**M1** (–394 **+2** (–297) – (+89.7) **M2** = –1080 (kJ mol^{-1})	**2**
(c)(i)	*weak [acid]* partially dissociates/partially ionises (into H^+ ions/protons)	**1**
(c)(ii)	HS^-	**1**

Question	Answer	Marks
(c)(iii)	**M1** S (increases) oxidation number –2 → 0 so oxidation / or is oxidised **M2** O (decreases) O.N. 0 → –2 so reduction / is reduced	**2**
(d)(i)	**M1** moles of As_2S_3 = 0.198 / 246.1 / 8.05 × 10^{-4} **M2** moles *SO_2* (using moles of As_2S_3 as limiting factor) = 2.41(36) × 10^{-3} moles (6 / 2 × 8.05 × 10^{-4}) Volume *SO_2* = 2.41(36) × 10^{-3} × 24 = 0.0579 dm^3 **M3** Moles *O_2* used in reaction = 8.05 × 10^{-4} × 9 / 2 = 3.62 × 10^{-3} Volume *O_2* used in reaction = 3.62 × 10^{-3} × 24 = 0.0869 dm^3 **M4** Final total volume gas = (0.1 – 0.0869) + 0.0579 = [0.0131 + 0.0579] = <u>0.071</u>(0) dm^3 **M4 ONLY award 4th mark if the final answer rounds to <u>0.071</u>** Answer to minimum of 2 sig figs **MAX 3 for using** ecf from M1 to M2 to M3 and M4 **Award all 4 marks if final answer rounds to 0.071**	**4**
(d)(ii)	acid rain	
(d)(iii)	**M1** SO_2(g) + 2NaOH(aq) → Na_2SO_3(aq) + H_2O(*l*) **AND** correct species and balancing **M2** State symbols	**2**

81. 9701_w20_ms_21 Q: 2

(a)(i)	$P_4 + 5O_2 \rightarrow P_4O_{10}$	1
(a)(ii)	any **two** from: • reacts vigorously • solid disappears / colourless solution forms • hydrolysis • exothermic • acid(ic) (solution) • steamy / misty fumes	2
(a)(iii)	Simple and covalent OR molecular and covalent	1
(b)(i)	**M1:** proton / H^+ donor	2
	M2: partially dissociates (in solution)	
(b)(ii)	$SO_2 + H_2O \rightarrow H_2SO_3$	1
(b)(iii)	(homogeneous) catalyst	1
(c)(i)	**thermal** decomposition	1
(c)(ii)	**M1:** $\Delta H_r = -1434 - (-635 + -297)$	2
	M2: = –502 (kJ mol^{-1})	
(d)(i)		1
(d)(ii)	0 (+)4 –1	1
(d)(iii)	***(at 1000 K and 100 kPa)*** **M1:** (yield) **decreases**	4
	M2: reaction is exothermic **AND** equilibrium moves **left**	
	(at 500 K and 500 kPa) **M3:** (yield) **increases**	
	M4: fewer moles (of gas) on right-hand side **AND** equilibrium moves right	
(e)(i)	**M1:** ionic	2
	M2: ions only able / free to move / free to conduct (when liquid / molten)	
(e)(ii)	**M1:** covalent	2
	M2: hydrolysed (by water)	

82. 9701_s19_ms_23 Q: 4

(a)	**M1** sulfur impurities OR sulfur in fossil fuels **M2** converted into SO_2 by combustion / burning sulfur **OR** heat sulfur with oxygen (from the air)	**2**
(b)(i)	**M1** 1 mol SO_2 → 1 mol H_2SO_4 64.1 g / tonne → 98.1 g / tonne **M2** SO_2 → 98.1 / 64.1 □ 1590 = 2433.369735 tonnes	**2**
(b)(ii)	high (enough) temperature / (a lot of) heat (energy) is produced **AND** to break (strong) triple bond in N_2 / break N≡N **AND** nitrogen (and oxygen) from the air / atmosphere react Award two marks for three correct points Award one mark for two correct points	**2**
(b)(iii)	lightning	**1**
(b)(iv)	**M1** nitrogen dioxide increases the rate **OR** lowers the activation energy **M2** (NO_2) is regenerated by reaction of NO with O_2 (in the air) **OR** NO (formed) reacts with O_2 (in air) to (re)form NO_2	**2**

83. 9701_w19_ms_22 Q: 1

(a)(i)		**1**
(a)(ii)	$Si(g) \rightarrow Si^{+}(g) + e^{-}$	**1**
(a)(iii)	**M1:** similar shielding AND increase in proton number / atomic number / nuclear charge **M2:** increased nuclear attraction	**2**
(a)(iv)	**M1:** 3 **OR** 13 **M2:** large(r) *increase* between third and fourth ionisation energies **OR** large(r) *increase* after third electron removed	**2**
(b)(i)	**M1:** $\frac{[92.2 \times 28] + [\%\,^{29}Si \times 29] + [\%\,^{30}Si \times 30]}{100} = 28.09$ **M2:** (x =) 6.6 **OR** 28.09 = 28.078 + x (where x = abundance of Si-29) **M3:** *7.8 – M2 calculated correctly to one decimal place (or more)* (=) 1.2%	**3**
(b)(ii)	**M1** giant (molecule) **M2** strong covalent bonds (between atoms / particles) **M3** no mobile charged particles / carriers	**3**
(c)(i)	$C_2H_5SH + 4\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O + SO_2$	**1**
(c)(ii)	**M1:** (causes) acid rain OR reacts/dissolves with (rain)water (vapour) to form (sulfuric / sulfurous) acid **M2:** one point from the following list. • lowers pH / increases acidity of rivers / lakes / oceans / water supplies / seas / soil / ground water • kills/harms / damages fish • kills / harms / damages plants / damages coral / aquatic life / plants / crops / trees or deforestation • leaches (toxic) aluminium (ions / salts) from soil (into rivers / lakes) • leaches away soil nutrients / soil unfit for agriculture • damages / weathers / erodes / destroys buildings / statues	**2**
(d)(i)	**M1:** no effect / none **M2:** equal mol(es) (*of gas*) on both sides (of equilibrium / equation) owtte	**2**
(d)(ii)	**M1:** (forward reaction is) endothermic **M2:** Any temperature higher than 300 K	**2**

84. 9701_w18_ms_21 Q: 1

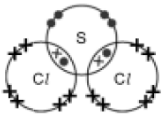
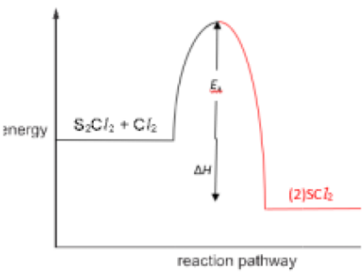
(a)(i)	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 (4s^0)$	1
(a)(ii)	–1	1
(b)	**M1** attraction/hold **M2 positive** ions / cations **AND** delocalised electrons (may be seen in a labelled diagram)	2
(c)(i)	**M1** acid rain **M2** • destroys / damages / weathers / erodes / buildings / statues • kills/harms fish / coral / plants / crops / trees / deforestation • leaches salts / ions (aluminium) from soil (into rivers / lakes) • leaches away soil nutrients • breathing difficulties • lowers pH / increases acidity of soil / rivers / oceans / seas	2
(c)(ii)	balanced equation with $11O_2$ and $8SO_2$ **M1**: O_2 and SO_2 **M2**: 11 and 8	2
(c)(iii)	**M1** *is for process of calculating number of moles of* Fe_2O_3 33.18 ÷ 159.6 (= 0.2079 mol) **M2** *for correct use of stoichiometry and 120.0 with candidate's* ***M1*** **M2** (0.2079) × 4 / 2 × 120.0 = 49.89 (g)	2
(c)(iv)	(0.37/(0.37+49.89)) = 0.74	1

85. 9701_w18_ms_22 Q: 2

(a)		3

Na	Mg	Al	Si	P
metallic	metallic	metallic	covalent	covalent
Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}
$NaCl$	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_5

[1] for each correct row

(b)(i)		1
(b)(ii)	 **M1** profile for exothermic reaction [1] **M2** identification of ΔH and E_a [1]	2
(c)(i)	graph rises to maximum for Si, then falls	1
(c)(ii)	**Max. 3 from:** • increasing strength of metallic bond; Na < Mg < Al OR stronger attraction between delocalised electrons and (positive) ion so melting point of Na < Mg < Al • Si is giant covalent **AND** it has the highest melting point due to breaking / presence of strong (covalent) bonds OR Si requires the most energy because the covalent bonds in Si are stronger than metallic bonds (in Na / Mg / Al) • P and S have weak(er) intermolecular forces / induced dipoles / van der Waals forces (than covalent / metallic bonds) so have low(er) melting points • $S_{(8)}$ has stronger / more intermolecular forces / van der Waals forces / induced dipoles than $P_{(4)}$ so melting point of $S_{(8)}$ is higher	3
(d)	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	1
(e)	**M1** acid rain [1] **M2** any of the following [1] • lowers pH / increases acidity of rivers / lakes / oceans / water supplies / seas / soil / ground water • kills / harms / damages fish / coral / aquatic life / plants / crops / trees or deforestation • leaches (toxic) aluminium (ions / salts) from soil (into rivers/lakes) • leaches away soil nutrients / soil unfit for agriculture • damages / weathers / erodes / destroys buildings / statues • causes breathing difficulties	2
(f)	**M1** process of 'first ionisation energy' involves the loss/removal of an electron [1] **M2** Mg and Al **AND** S and P (in either order) [1] **M3** For Al **3p** (orbital / sub-level / sub-shell) is higher in energy / further from the nucleus / more shielded (than Mg) [1] *ora* **M4** For S the pair of electrons in the (3)**p-orbital** repel [1] *ora*	4

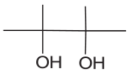
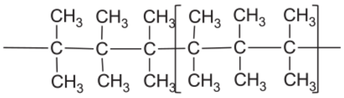
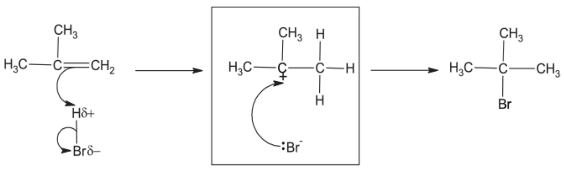
86. 9701_S15_ms_22 Q: 2

(a) (i)	$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$ reagents and formulae balancing	 [1] [1]
(ii)	S (is oxidised) –2 to (+)4 O (is reduced) 0 to –2	[1] [1]
(b) (i)	T = 400 – 600 °C (chosen as a compromise because) High T increases rate ora High T decreases yield / moves eqm left / makes less SO_3 as forward reaction exothermic ora	[1] [1] [1]
(ii)	High pressure increases rate as collision frequency increases ora High pressure moves eqm right / favours forward reaction as more moles on left ora Uneconomic to use high pressures / high yield at low pressure	[1] [1] [1]
(c) (i)	Reaction (too) exothermic / acid spray produced	[1]
(ii)	$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$	[1] [1]
(d)	Preservative owtte antimicrobial / antioxidant / reducing agent	[1] [1]
(e) (i)	$12.35 \times 0.01 / 1000 = 1.235 \times 10^{-4}$	[1]
(ii)	$1.235 \times 10^{-4} \times 1000 / 50 = 2.47 \times 10^{-3}$	[1]
(iii)	$2.47 \times 10^{-3} \times 64.1 = 0.158327$ g = 158 (3 sf only)	[1]

87. 9701_w15_ms_22 Q: 3

(a)	(i)	Na_2O or Na_2O_2; MgO; P_4O_{10} or P_4O_6 ; SO_2	[1] [1]
	(ii)	Na: Yellow / orange / gold flame / white solid / powder / smoke $4Na + O_2 \rightarrow 2Na_2O$ or $2Na + O_2 \rightarrow Na_2O_2$ S: Blue flame / (yellow) solid melts / turns red / amber / white fumes $S + O_2 \rightarrow SO_2$	[1] [1] [1] [1]
(b)	(i)	acidic P and S amphoteric A*l* and basic Na and Mg	[1] [1]
	(ii)	acidic: covalent (bonding) basic: ionic (bonding)	[1] [1]
	(iii)	$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ **OR** $Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$ $Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaAl(OH)_4(H_2O)_2$ **OR** $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ **OR** $Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ **OR** $Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$ **OR** $Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ **OR** $Al_2O_3 + 2OH^- \rightarrow 2AlO_2^- + H_2O$	[1] [1]
(c)		sulfur forms SO_2 / SO_2 + / mixes $H_2O \rightarrow H_2SO_3$ or in words OR SO_2 + / mixes H_2O (→acid) / or in words OR SO_2 + / mixes H_2O + (1/2O_2) →H_2SO_4 / or in words	[1] [1]

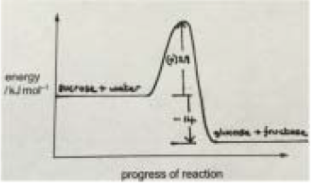
88. 9701_w16_ms_21 Q: 4

(a)(i)	4-methylhex-2-ene	1	**1**
(a)(ii)	(Molecules with the) same structural formula (and same molecular formula) with different arrangement of atoms/groups (in space)	1	**1**
(a)(iii)	4 double-bond / alkene (2) different groups on each double-bonded carbon (one) chiral carbon (centre) / (one) carbon atom has 4 different groups attached / is asymmetric / is chiral	1 1 1 1	**4**
(b)(i)	2,3-dimethylbut-2-ene	1	**1**
(b)(ii)		1	**1**
(b)(iii)	Propanone	1	**1**
(b)(iv)		1	**1**
(c)(i)	(2-)methylprop(-1-)ene	1	**1**
(c)(ii)		4	**4**
(c)(iii)	(tertiary carbocat)ion / (tertiary) intermediate is / C+ with least number of hydrogen atoms bonded to it is more stable (than primary) due to (positive) inductive effect of three/more methyl groups (cf one) / three / more electron releasing methyl groups three / more electron donating methyl groups reducing charge (density) on C+	1 1 1	**3**
	Total:		**18**

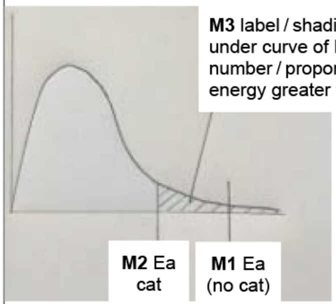
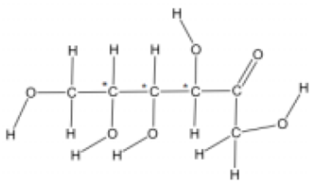
89. 9701_m20_ms_22 Q: 1

(a)(i)	$CaO + H_2O \rightarrow Ca(OH)_2$	1
(a)(ii)	OH^- / hydroxide	1
(b)	**M1** (decreasing melting point down the group because) lower forces of attraction / weaker bonds (between cations and anions / oxide / O^{2-}) **M2** larger cations and constant charge OR decreasing charge density of cation (down group)	2
(c)	high(er) activation energy / heating overcomes activation energy	1
(d)	180(°)	1
(e)(i)	reacts with / behaves as both acid and base	1
(e)(ii)	$BeO + 2OH^- + H_2O \rightarrow Be(OH)_4^{2-}$	1
(f)(i)	**M1** equal rates of forward and backward reactions **M2** closed system **OR** macroscopic properties unchanging	2
(f)(ii)	**M1** Cl_2 O_2 initial x 0 mol equilibrium $0.3x$ $0.35x$ mol **mol fraction** $\mathbf{\frac{6}{13}}$ $\mathbf{\frac{7}{13}}$ **M2** $K_p = \frac{100000 \times \frac{7}{13}}{(100000 \times \frac{6}{13})^2} = 2.53 \times 10^{-5}$ **M3** Pa^{-1}	3
(g)(i)	–1	1
(g)(ii)	**M1** (enthalpy / energy change) when one mole of a compound / substance is formed **M2** from its elements in their standard states	2
(g)(iii)	$-(-602 + -188) + (\Delta H_f[MgO_2] + -286) = -96$ $\Delta H_f[MgO_2] = -600$ (kJ mol^{-1})	2
(g)(iv)	$-(-600) - (+602) = -2$ (kJ mol^{-1})	1

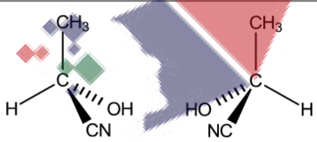
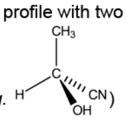
90. 9701_s20_ms_22 Q: 3

(a)	hydrolysis	1
(b)	**M1** both have molecular formula - $C_6H_{12}O_6$ **M2** *idea that in glucose and fructose there are the same number and type of atoms present but the atoms are arranged in a different order ie* one has a carbonyl group at the end of the chain/molecule and the other has a carbonyl group in the middle of the chain/molecule	2
(c)(i)	*value for the activation energy for the reaction **A** (no enzyme) compared to reaction **B** (with enzyme)* value / range of values that are more (+) 29 kJ mol^{-1}	1
(c)(ii)	*value for the enthalpy change for reaction **A** (no enzyme) compared to reaction **B** (with enzyme)* -14 kJ mol^{-1}	1
(c)(iii)	**M1** show the energy of the reactants > products AND label ΔH using the predicted value given in **(ii)** **M2** show activation energy 'hump' AND label using the value given in **(i)** 	2
(d)(i)	**M1** (enthalpy change) when 1 mole of sucrose **M2** burns/combusts/reacts in excess air/oxygen **OR** completely burns/combusts/reacts in air/oxygen	2
(d)(ii)	**M1** *for finding amount of energy released per gram of sucrose using* ΔH /Q = mcΔT OR ΔH = – mcΔT = (-)250x4.18x(40.7-25) = (-)16406.5 J per gram OR(-)16.4065 kJ / g **M2** *for finding amount (mol) sucrose in1g = 1/342 mol* ***M3** = M1 / (M2x1000)* ΔH = - 5610 kJ mol^{-1} (3 sig figs) OR -5611 kJ mol^{-1} (4 sig figs)	3

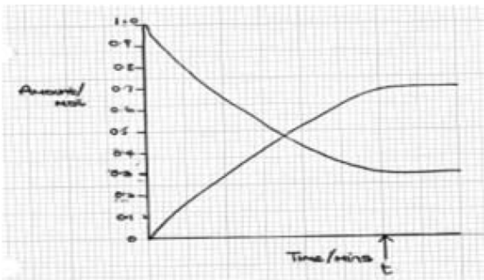
91. 9701_s20_ms_23 Q: 3

(a)(i)	hydrolysis	**1**
(a)(ii)	 **M3** label / shading indicating greater area under curve of Ea(cat) AND state greater number / proportion of sucrose molecules have energy greater than Ea(cat) (so faster rate)	**3**
(b)(i)	an atom which is bonded to four different substituents / groups / atoms	**1**
(b)(ii)	ALL three chiral carbons need to be shown by * 	**1**
(b)(iii)	*empirical formula of fructose* CH_2O	**1**
(c)(i)	**M1** (enthalpy change) when 1 mole of a substance **M2** burns/combusts/reacts in excess air/oxygen **OR** completely burns/combusts/reacts in air/oxygen	**2**
(c)(ii)	$C_{12}H_{22}O_{11}$ + 12 O_2 $\rightarrow$ 12CO_2 + 11H_2O	**1**
(c)(iii)	**M1** ΔH = -5643 – (-2805 + -2810) **M2** = –28 kJ mol^{-1}	**2**

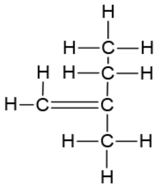
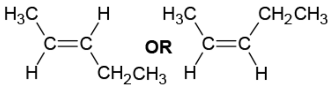
92. 9701_s19_ms_21 Q: 5

(a)	**M1** a lone pair / electron pair donor	**1**
	M2 (:)CN^- / $^-$(:)CN / cyanide ion	**1**
(b)(i)	optical	**1**
(b)(ii)	 **M1** one 3-D structure of **correct** molecule shown.	**1**
	M2 a mirror image of the molecule drawn in **M1** **OR** same profile with two groups swapped (*e.g.* )	**1**
	M3 central chiral C shown as *	**1**
(c)	$CH_3CH(OH)CO_2H$ **OR** $HO_2CCH(OH)CH_3$	**1**

93. 9701_s19_ms_22 Q: 1

(a)(i)	C_4H_{10} / same molecular formula / OR same number of carbon (atoms) and hydrogen (atoms)	1
	different structural formula OR description of different structural formula which does not imply stereoisomerism	1
(a)(ii)	structural / chain	1
(b)	(forward reaction is) exothermic reaction	1
	the proportion of methylpropane / product decreases OR the proportion of butane / reactant increases	1
(c)(i)	*t* shown on graph which corresponds to start of the horizontal part of both curves. 	1
(c)(ii)	concentration of butane = 0.3 mol dm^{-3} AND concentration of methylpropane = 0.7 mol dm^{-3}	1
(c)(iii)	[methylpropane] / [butane] OR $[(CH_3)_2CHCH_3] / [CH_3(CH_2)_2CH_3]$	1
(c)(iv)	**M1** *value for K_c* $K_c = \dfrac{\text{value of methylpropane in } \mathbf{(ii)}}{\text{value of butane in } \mathbf{(ii)}}$ = 0.7 / 0.3 = 2.3 (3)	1
	M2 *units consistent with expression used in* M1 no units / dimensionless / none	1

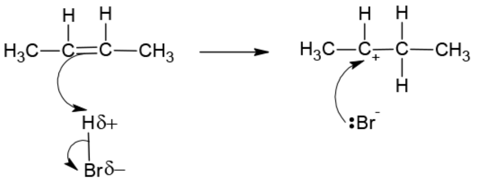
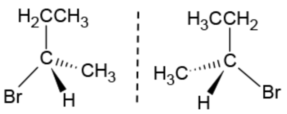
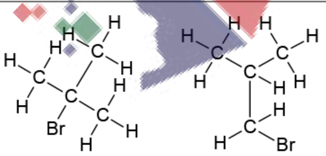
94. 9701_s18_ms_23 Q: 2

(a)(i)	(molecules / isomers with) the same molecular formula / same number of atoms of each element	1
	different structural formulae / different structures	1
(a)(ii)	(Molecules / isomers) with the same (molecular and) structural formula	1
	different arrangement of atoms in space / different spatial arrangement of atoms.	1
(b)(i)	two Hs on one of the C=C carbons / terminal C / C–1	1
	no chiral C / no C with 4 different groups / atoms / chains attached has a super(im)posable mirror image	1
(b)(ii)		1
	2-methylbut-1-ene	1
(b)(iii)	structure 	1
	trans–pent–2–ene or or *E*– cis–pent–2–ene or *Z*–	1

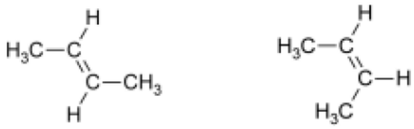
95. 9701_s17_ms_23 Q: 3

(a)(i)	(enthalpy / energy change) when one mole of a compound is formed	1
	from its elements in their standard states / standard conditions	1
(a)(ii)	($\Delta H_r = \sum\Delta H_f$ products – $\Sigma\Delta H_f$ reactants) $-196 = 2\Delta H_f\ SO_3 - (2 \times -296.8)$ $2\Delta H_f\ SO_3 = -196 + (2 \times -296.8) = -789.6$	1
	$\Delta H_f\ SO_3 = -394.8$ (kJ mol^{-1})	1
(b)(i)	Mark to right of original E_a	1
(b)(ii)	2 marks for any two points: • Benefit of using a catalyst in terms of increasing rate or economic benefit i.e. (less heat required) • Creates alternative pathway with lower E_a • More molecules with $E > E_a$	2
(b)(iii)	(rate) increases AND correct explanation in terms of 'more collisions'	1
	more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
	(yield) increases and shifts equilibrium to the right / in the forward direction / towards SO_3 / towards the product / in exothermic direction	1
	to oppose the change or oppose the increase in pressure / fewer molecules on RHS so eqm moves to right (to oppose change)	1
(c)(i)	$SO_2 = 0.01$ (mol) AND $SO_3 = 0.99$ (mol)	1
(c)(ii)	$n_{TOT} = 1.505$	1
	$pO_2 = 1.50 \times 10^5 \times (0.505 / 1.505) = 5.03 \times 10^4$ (Pa)	1
(d)(i)	$(K_p =)\dfrac{pSO_3^{\,2}}{pO_2 \times pSO_2^{\,2}}$	1
(d)(ii)	0.1946737305	1
	Pa^{-1}	1
	Total:	**17**

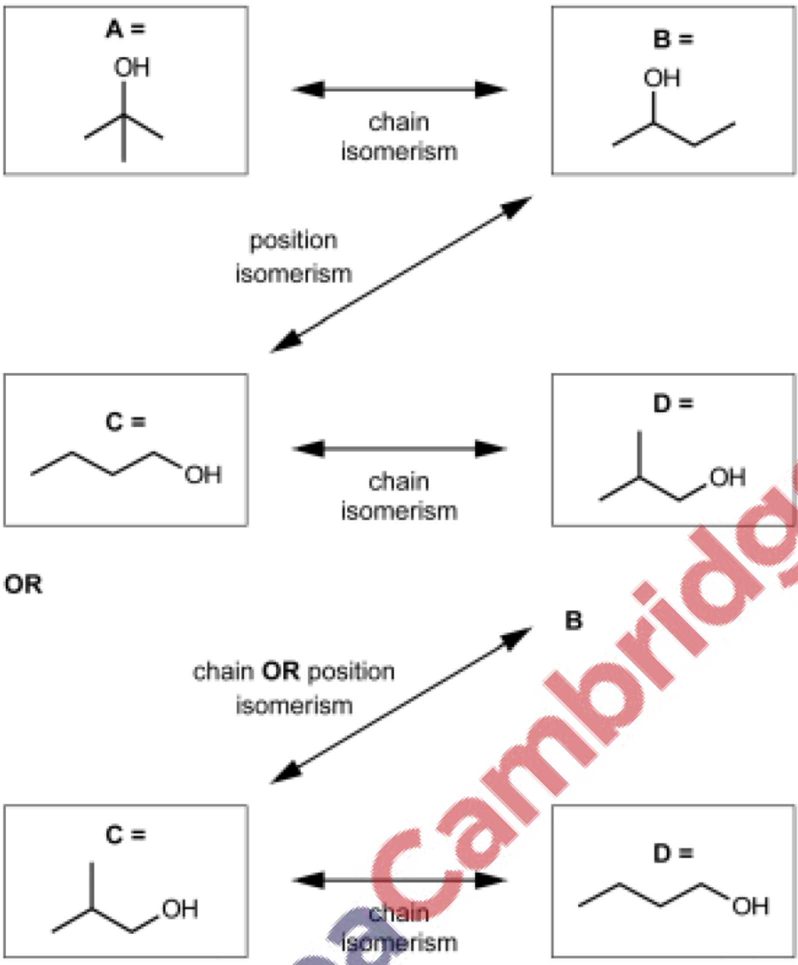
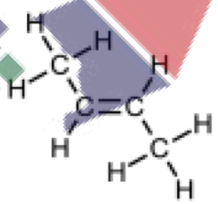
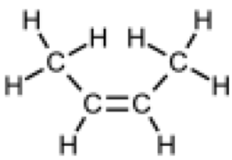
96. 9701_s17_ms_23 Q: 4

(a)	cracking	1
(b)	**In any order** $CH_2{=}CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ / $CH_2CHC_2H_5$ AND $CH_3CH{=}CHCH_3$ / $CH_3CHCHCH_3$ AND $(CH_3)_2C{=}CH_2$ / $(CH_3)_2CCH_2$	1
(c)(i)	(different) molecules with the same (molecular and) structural formula	1
	(due to) different arrangement in space caused by C=C / double bond	1
(c)(ii)	 arrow from the C=C double bond drawn to the H	1
	dipole on H–Br in correct orientation AND arrow from the H-Br bond to the $Br^{\delta-}$	1
	correct carbocation from the structure with C=C drawn	1
	Br^- with lone pair, negative charge AND arrow from lone pair to the positively charged carbon atom of intermediate	1
(d)(i)	a (tetrahedral) atom with four different groups / atoms / substituents attached OR a carbon (atom) with four different groups / atoms / substituents attached	1
(d)(ii)	but–1–ene	1
(d)(iii)	 One 3D structure of 2–bromobutane which must have 2 bonds shown the same and two different, i.e. **three** bond types altogether, e.g. two solid lines, one wedge and one dash. If two bonds are drawn in the plane of the paper, i.e. single solid lines, they must **not** be at 180 degrees to each other.	1
	Second structure either mirror of first OR all bonds drawn the same with position of two groups swapped.	1
(d)(iv)	intermediate / (secondary carbo) cation from **X** is more stable ora OR charge density of C^+ (of the intermediate of **X**) is reduced	1
	(due to) electron-releasing character / (positive) inductive effect of alkyl groups / / due to electron releasing alkyl group	1
(e)(i)	(2–)methylpropene / (2–)methylprop–1–ene	1
(e)(ii)		2
	Total:	**17**

97. 9701_s16_ms_21 Q: 4

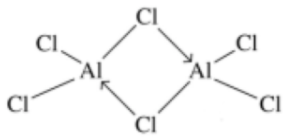
(a)	CH_2=$CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ AND CH_3CH=$CHCH_3$ / $CH_3CHCHCH_3$	[1]
(b)	CH_2=$CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ AND $(CH_3)_2C$=CH_2 / (CH3)$_2$CCH$_2$	[1]
(c)	 *trans*-but-2-ene (or *E*) *cis*-but-2-ene (or *Z*)	[1] [1]
(d)	**B** is CH_2=$CHCH_2CH_3$ OR CH_3CH=$CHCH_3$ OR $(CH_3)_2C$=CH_2 distinguished by addition of bromine brown/red/orange/yellow to colourless/decolourises with **B** (but not **A**)	[1] [1] [1]

98. 9701_S15_ms_21 Q: 4

(a)		[1] [1] [1] [1] [1] [1] [1]
(b) (i)	but-1-ene / 1-butene but-2-ene / 2-butene	[1] [1]
(ii)	but-2-ene **AND** two different groups on each carbon (of C=C) double bond means no free rotation	[1] [1]
(iii)	 and  (either way round)	[1+1]

99. 9701_m21_ms_22 Q: 2

Question	Answer	Marks
2(a)	kills bacteria/microbes/micro-organisms	1
2(b)(i)	$Cl(g) - e^- \rightarrow Cl^+(g)$	1

Question	Answer	Marks
(b)(ii)	**M1:** increasing proton number but similar shielding **M2:** greater attraction of nucleus (for outer / valence electrons)	2
(c)(i)	**M1:** (thermal stability) decreases (down group) **M2:** (H—X) bond energy / strength decreases	2
(c)(ii)	(+)6, (+)4, –2	1
(c)(iii)	halides are better / stronger / more able reducing agents / are more easily oxidised **down group**	1
(d)(i)	when a species is both oxidised and reduced	1
(d)(ii)	$Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$	1
(e)(i)	 **M1:** 2 × coordinate bonds in the right place **M2:** all other bonds	2
(e)(ii)	**M1:** • ($AlCl_3$ / solid) disappears • misty / steamy fumes • temperature increases **M2:** hydrolysis	2
(f)(i)	simple / molecular **AND** covalent	1

Question	Answer	Marks
(f)(ii)	**M1:** 11.54 ÷ 143.4 = 0.0805 **M2:** so ratio **Z**:Cl is 1:4 / n = 4	2
(g)(i)	(free-)radical substitution	1
(g)(ii)	ultraviolet (UV) light / sunlight	1
(g)(iii)	$(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^5$	1
(g)(iv)	$Cl^{\bullet}$ **AND** CH_2Cl_2	1
(g)(v)	termination	1
(g)(vi)	$CHCl_3$ **OR** $(CH_2Cl)_2$	1

100. 9701_w19_ms_21 Q: 1

(a)(ii)	It oxidises chlorine from –1 to 0	1
(a)(ii)	effervescence / fizzing / bubbling **OR** green gas formed **OR** solid dissolves / disappears / soluble	1
(b)	**M1:** decreases (down the group) **M2:** increasing induced dipoles **M3:** greater number of electrons	3
(c)(i)	**M1:** Cl_2 + 2NaOH → NaCl + NaClO + H_2O **M2: chlorine** is oxidised and reduced	2
(c)(ii)	$NaClO_3$ / sodium chlorate(V)	1
(d)	**M1:** chloric(I) acid / hypochlorous acid / HClO **M2:** kills bacteria / micro-organisms / microbes	2
(e)(i)	ultra-violet (light) / sunlight	1
(e)(ii)	C_2H_6 + Cl_2 → C_2H_5Cl + HCl	1

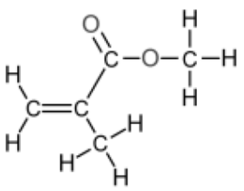
101. 9701_w19_ms_21 Q: 3

(a)(i)	cracking	1
(a)(ii)	enthalpy change of combustion / ΔH_c is high / large energy release (per mole / per unit mass) **OR** combust / burn easily	1
(a)(iii)	C_4H_8 + $4O_2$ → 4CO + $4H_2O$	1
(a)(iv)	**M1**: infrared spectroscopy **M2:** Compare / measure (characteristic) wavelengths	2
(b)(i)	$C_4H_4S(l)$ + $6O_2(g)$ → $4CO_2(g)$ + $2H_2O(l)$ + $SO_2(g)$ • correct species • balancing • state symbols Award one mark for two correct bullet points, award two marks for all three correct.	2
(b)(ii)	**M1** (enthalpy change when) 1 mol of a substance **M2** EITHER burns / combusts / reacts in excess air / oxygen OR completely burns / combusts / reacts in air / oxygen	2
(b)(iii)	**M1** m = 200 and ΔT = 37.5–18.5 **M2** $Q = mc\Delta T$ = 200 × 4.18 × (37.5 – 18.5) = 15 884 (J)	2
(b)(iv)	**M1** mol of thiophene used = 0.63 / 84.1 OR 7.49(1 082 045) × 10^{-3} **M2** calculation ÷ 1000 AND negative sign $\Delta H_c = \frac{-\textbf{(iii)}}{\textbf{1000}} \div n = \frac{-\textbf{(iii)}}{\textbf{21000}} \div (0.63 / 84.1)$ = –2120 (–2120.39) (kJ mol^{-1})	2

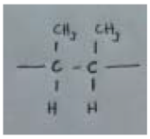
102. 9701_m18_ms_22 Q: 2

(a)(i)	simple molecular regular arrangement (of C_{60} molecules)	**2**
(a)(ii)	C_{60} has (weak) intermolecular / VdW / London / dispersion / id–id forces (and covalent bonds) diamond has covalent bonds (diamond's) bonds are strong<u>er</u> more energy required / lots of energy to break (covalent bonds in diamond)	**4**
(b)(i)	(a molecule / compound that is made up of) carbon and hydrogen (atoms) only	**1**
(b)(ii)	add bromine (water) / $Br_2(aq)$ (brown to) colourless / decolourised	**2**
(c)(i)	addition	**1**
(c)(ii)	(n_{C60} = 0.144 / 720 =) 2×10^{-4}	**1**
(c)(iii)	$pV = nRT$ ∴ $\Delta n = (p_1 - p_2)V / RT$ $\Delta n = (1.00 \times 10^5 - 2.21 \times 10^4).100 \times 10^{-6} / 8.31 \times 293$ = 0.00320	**2**
(c)(iv)	(C_{60}:H_2 =) 2.00×10^{-4} : 0.00320 or 1:16 <u>C_{60}</u>H_{32}	**2**
(d)(i)	giant (molecular) (each Si has four) covalent (bonds)	**2**
(d)(ii)	$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$	**1**
(d)(iii)	$Mg_2Si(s) + 4HCl(aq) \rightarrow SiH_4(g) + 2MgCl_2(aq)$ species **AND** balancing state symbols	**2**
(d)(iv)	tetrahedral	**1**
(d)(v)	$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$	**1**

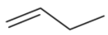
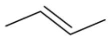
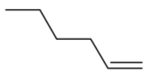
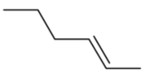
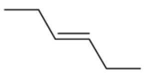
103. 9701_s18_ms_21 Q: 2

(a)	Different (hydrocarbon) molecules have different numbers of electrons	**1**
	so different strengths / numbers / amount of VdW / IMFs / id-id	**1**
(b)	Produces more useful / more valuable / higher demand substances / alkanes / alkenes	**1**
(c)(i)	$C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$	**1**
(c)(ii)	addition polymerisation	**1**
(c)(iii)	*two from* save space in landfill avoid litter prevent eyesore non-biodegradable conserves non-renewable resources harmful incineration products harmful to wildlife	**2**
(c)(iv)		
	correct monomer	**1**
	fully displayed	**1**

104. 9701_s18_ms_22 Q: 3

(a)(i)	combustion	1
(a)(ii)	$C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$	
	correct species	1
	correct balancing	1
(b)(i)	cracking	1
(b)(ii)	$-CH(CH_3)CH(CH_3)-$ OR 	
	even number of C's in correct backbone with 'end bonds' AND no C=C	1
	CH_3 and H on each of two C drawn for 1 repeat unit only AND all the carbons must be tetravalent	1
(b)(iii)	addition	1
c(i)	catalytic converter / catalyst	1
c(ii)	$2CO + NO_2 \rightarrow 2CO_2 + ½N_2$	1
c(iii)	(photochemical) smog / fog / haze OR global dimming	1
(d)(i)	*any 2 from:* lowers pH / increases acidity of rivers / lakes / oceans / seas / soil kills/harms fish OR harms / kills coral / plants / crops / trees leaches (toxic) aluminium (ions / salts) from soil (into rivers / lakes) leaches away soil nutrients damages / weathers / erodes buildings / statues	2
(d)(ii)	$NO_2 + SO_2 \rightarrow NO + SO_3$	1
	$SO_3 + H_2O \rightarrow H_2SO_4$	1
(d)(iii)	(it is) regenerated / not used up / undergoes temporary chemical change / recovered unchanged	1
	$NO + ½O_2 \rightarrow NO_2$	1

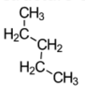
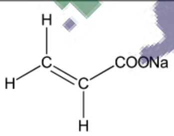
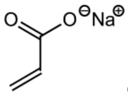
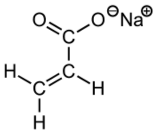
105. 9701_s17_ms_23 Q: 1

(a)	(molecules / isomers with) the same molecular formula / same number of atoms of each element	1
	different structural / displayed formulae / different arrangement of bonds	1
(b)(i)	4	1
(b)(ii)	6	1
(b)(iii)	molecular = C_4H_8	1
	empirical = CH_2 using alternative supplied data molecular = C_6H_{12} empirical = CH_2	1
(b)(iv)		1
	 alternative using supplied data: any two   	1
(b)(v)	correct conversions of data to SI / consistent units P = 100 000; V = 25×10^{-6}; T = 310	1
	calculation of *n* (= *pV* / *RT*) $n = \frac{100 \times 10^3 \times 25 \times 10^{-6}}{8.31 \times 310}$	1
	calculation of mass *m* (= $n \times M_r$) AND answer correct to **3sf** $m = 9.705 \times 10^{-4} \times 56 = 0.0543$ (g)	1
	Alternative answer for using C_6H_{12}: $m = 9.705 \times 10^{-4} \times 84 = 0.0815$ (g)	
	Total:	**11**

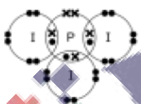
106. 9701_w15_ms_21 Q: 3

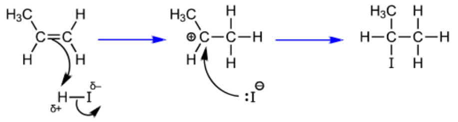
(a) (i)	structural isomers: (different molecules with) same molecular formula but different structural formulae chiral: has a carbon / C attached to 4 different groups / atoms / chains OR has no plane / line of symmetry / has non-superimposable mirror images	[1] [1]
(ii)	$CH_3CH_2CH(CH_3)CH_2CH_2CH_3$ 3-methylhexane $CH_3CH(CH_3)CH(CH_3)CH_2CH_3$ / $(CH_3)_2CHCH(CH_3)CH_2CH_3$ 2,3-dimethylpentane	[1] [1] [1] [1]
(b) (i)	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$	[1]
(ii)	$C_7H_{16} + 4O_2 \rightarrow 7C + 8H_2O$	[1]
(iii)	global dimming / PAN / smog / global warming	[1]
(c) (i)	(Free) Radical Substitution	[1]
(ii)	$Cl_2 \rightarrow 2Cl\bullet$ OR $Cl_2 \rightarrow Cl\bullet + Cl\bullet$ $C_7H_{16} + Cl\bullet \rightarrow \bullet C_7H_{15} + HCl$ $\bullet C_7H_{15} + Cl_2 \rightarrow C_7H_{15}Cl + Cl\bullet$ $\bullet C_7H_{15} + Cl\bullet \rightarrow C_7H_{15}Cl$ OR $\bullet C_7H_{15} + \bullet C_7H_{15} \rightarrow C_{14}H_{30}$ Initiation; Propagation; Termination (used correctly)	[1] [1] [1] [1] [1]

107. 9701_s21_ms_21 Q: 5

Question	Answer	Marks
(a)(i)	(compounds / molecules) containing only / entirely carbon and hydrogen (atoms)	**1**
(a)(ii)	crude oil	**1**
(b)(i)	(thermal) cracking	**1**
(b)(ii)	*structure of* ***W***  OR $CH_3(CH_2)_3CH_3$ OR 	**1**
(c)(i)	CO_2H / carboxylic acid	**1**
(c)(ii)	**M1** (add) $Br_2(aq)$ / bromine water	**1**
	M2 (solution) turns (from brown / orange / red to) colourless / decolorises OR brown / orange / red fades	**1**
(d)	 OR $CH_2CH(CO_2^{(-)}Na^{(+)})$ OR $CH_2{=}CH(COO^{(-)}Na^{(+)})$ OR  OR  , etc.	**1**
(e)(i)	carbon dioxide / CO_2	**1**
(e)(ii)	CO / hydrocarbons **AND** toxic / poisonous / harmful to health / (catalyses formation of) photochemical smog	**1**

108. 9701_w21_ms_22 Q: 1

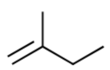
Question	Answer	Marks
(a)(i)	**M1** (HI / I / iodine / hydrogen iodide has a) greater number of electrons **M2** greater induced dipoles (between molecules)	2
(a)(ii)	**M1** bar at HF shows any boiling point above HI on graph **M2** *explanation of difference in boiling point of a sample of HF in terms of strength* (sum of) hydrogen bonds (and induced dipoles in HF) are **stronger** than (sum of) induced dipoles (and permanent dipoles in HC*l* / HBr / HI)	2
(b)	(enthalpy / energy change) when one mole of a compound is formed from its elements in their standard states	2
(c)(i)	$K_p = \frac{p\mathrm{HI}^2}{p\mathrm{H}_2\ p\,\mathrm{I}_2}$	1
(c)(ii)	28.76 **OR** 28.8 **OR** 29	1
(c)(iii)	**EITHER** **option 1** which assumes $\Delta H_{reaction}$ *is (still) endothermic (using the value shown in (b)).* **M1** (K_p) decreases **AND** endothermic / $\Delta H_{(f)}$ = + / positive **M2** reaction favours formation of reactants / hydrogen and iodine OR (product) yield / partial pressure of HI decreases / equilibrium shifts to the left **OR** **option 2** which realises that $\Delta H_{reaction}$ *is in fact exothermic (using bond energy data in Data Booklet)* **M1** (K_p) increases **AND** exothermic / $\Delta H_{(f)}$ = + / negative **M2** reaction favours formation of products / hydrogen iodide yield increases / partial pressure of HI increases / equilibrium shifts to the right	2
(d)(i)	$4HI + O_2 \rightarrow 2I_2 + 2H_2O$	1
(d)(ii)	**M1** I / iodine (increases) oxidation number –1 → 0 so oxidation / is oxidised **OR** HI / is oxidised as I (increases) oxidation number –1 → 0 **M2** O (decreases) oxidation number 0 → –2 so reduction / is reduced	2
(e)	**M1** pressure increases **M2** (pressure goes up as) number of moles/molecules increases in ratio 3 (gas) reactants to 5 (gas) products **OR** pressure is (directly) proportional to number of moles/molecules	2
(f)(i)	 **M1** correct bonding pairs **M2** correct number of remaining outer electrons on each atom	2
(f)(ii)	hydrolysis	1
(f)(iii)	proton donor / H^+ donor fully dissociates / fully ionises	2
(f)(iv)	$H_2PO_3^-$	1
(g)(i)	**M1** 2-iodopropane – formed from a (more) stable (secondary) (carbo)cation/intermediate **M2** (because of) greater (positive) inductive effect / (+)I of two alkyl groups **OR** (because of positive) inductive effect / (+)I of more R / more methyl / more alkyl groups	2

Question	Answer	Marks
(g)(ii)	 **M1** curly arrow from = of C=C to H **AND** curly arrow from bond of H—I to I **M2** curly arrow from lone pair of I^- to $C^{(+)}$ of their intermediate **M3** correct carbocation **AND** product for 2-iodopropane	3

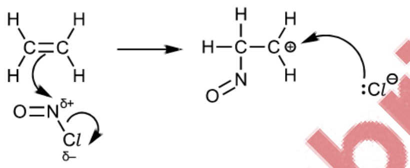
109. 9701_s20_ms_23 Q: 4

(a)	**M1** (no reaction) not enough energy **M2** bromine (free) radicals are not produced OR homolytic fission of bromine does not occur.	2
(b)(i)	free-radical substitution	1
(b)(ii)	C_6H_{14} + (·)Br → (·)C_6H_{13} + HBr	1
(b)(iii)	(·)C_6H_{13} + Br_2 → $C_6H_{13}Br$ + (·)Br	1
(b)(iv)	(·)C_6H_{13} + (·)Br → $C_6H_{13}Br$	1
(c)(i)	$CH_3(CH_2)_3CH{=}CH_2$	1
(c)(ii)	cold **AND** acidified **AND** dilute 2 marks for 3 correct conditions 1 mark for 2 correct conditions	2
(d)(i)	addition **OR** reduction	1
(d)(ii)	**M1** only sigma / σ (bonds) in hexane / alkanes **M2** **B** has sigma σ (bonds) and a / one pi / π (bond)	2

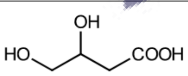
110. 9701_w20_ms_21 Q: 4

(a)(i)	**M1:** (Volatility) decreases (down the group) **M2:** more electrons so greater intermolecular forces / intermolecular attractions **OR** more electrons so greater VdW **between molecules**	2
(a)(ii)	(HI has the) lowest bond enthalpy	1
(a)(iii)	**M1:** HF has permanent dipole(-dipole forces) **AND** HI has ((only)) instantaneous dipole / induced dipole (forces) / permanent dipole(-dipole forces) **M2:** IMF's in HI are **weaker** (than IMF's in HF)	2
(a)(iv)	$3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$	1
(b)(i)	HI(g) / PI_3 / P and I_2	1
(b)(ii)	Electrophilic addition	1
(c)(i)	2(-)iodo(-)2(-)methylbutane	1
(c)(ii)	Nucleophilic substitution / S_N	1
(c)(iii)		1
(c)(iv)	(**L** has) two identical / two methyl groups attached to one end / one carbon of the C=C / double bond	1
(c)(v)	ethanoic acid / CH_3COOH	1
(c)(vi)	CH_3COCH_3 + **3**I_2 + **4**OH^- → (**1**)CH_3COO^-+ **3**H_2O + **3**I^- + **CHI_3** **M1:** correctly balanced **M2:** CHI_3 product	2
(c)(vii)	yellow ppt / yellow solid	1

111. 9701_m19_ms_22 Q: 1

(a)	strong triple bond / strong N≡N OR high activation energy / E_a OR non-polar	1
(b)(i)	$3Mg + N_2 \rightarrow Mg_3N_2$	1
(b)(ii)	solid disappears	1
(c)(i)	(it is used to make) fertilisers	1
(c)(ii)	**M1** CaO displaces NH_3 (from its salt / NH_4^+) **M2** CaO is a stronger base / more basic (than NH_3)	2
(d)(i)	NO: (+)2 / (+)II; NO_2: (+)4 / (+)IV	1
(d)(ii)	**M1** $\frac{1}{2}N_2 + O_2 \rightarrow NO_2$ **M2** $Mg(NO_3)_2 \rightarrow MgO + 2NO_2 + \frac{1}{2}O_2$	2
(d)(iii)	**M1** +82 (= $E_{O=O} - 2E_{N\rightarrow O}$) = (+)496 – 2 × $E_{N\rightarrow O}$ **M2** $E_{N\rightarrow O}$ = ½ × (496–82) = ½ × 414 = 207 (kJ mol^{-1})	2
(e)	 **M1** curly arrow from C=C to $N^{\delta+}$ **AND** curly arrow from N—C*l* to $Cl^{\delta-}$ **M2** intermediate **AND** curly arrow from lone pair on Cl^- to C(+)	2

112. 9701_m19_ms_22 Q: 4

(a)	3-chloroprop-1-ene	1
(b)(i)	ultra-violet (light) / sun(light)	1
(b)(ii)	$CH_2{=}CHCH_3 + Cl\bullet \rightarrow CH_2{=}CHCH_2\bullet + HCl$ OR $C_3H_6 + Cl\bullet \rightarrow C_3H_5\bullet + HCl$	1
(b)(iii)	free-radical (substitution) reactions are uncontrolled OR further chlorination / substitution occurs	1
(b)(iv)	$SOCl_2$ OR PCl_5 OR PCl_3 OR c(oncentrated) HC*l*	1
(c)(i)	cold, dilute acidified $KMnO_4$ / potassium manganate(VII)	1
(c)(ii)	**M1** catalyst **M2** ethanoic acid / CH_3CO_2H	2
(c)(iii)	nucleophilic substitution / S_N2	1
(c)(iv)	 **M1** hydrolysed nitrile on straight-chain 4C backbone **M2** 3,4-diol	2
(d)	**M1** major product formed from more stable intermediate / carbocation OR (intermediate has) 2°carbocation which is (more) stable **M2** (positive) inductive effect / (+)I of alkyl groups (on the intermediate)	2

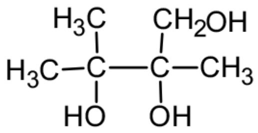
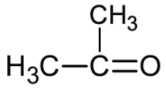
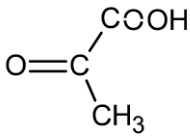
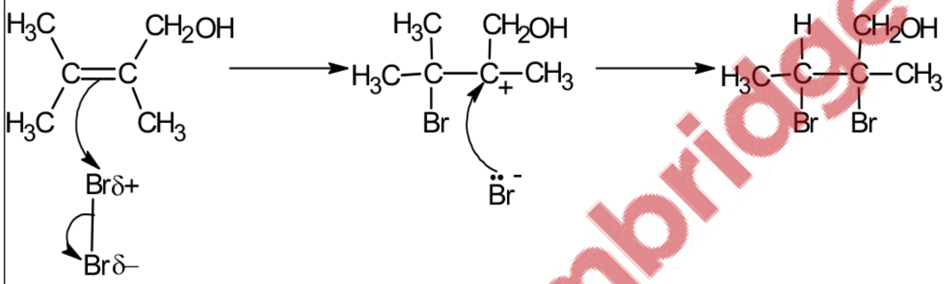
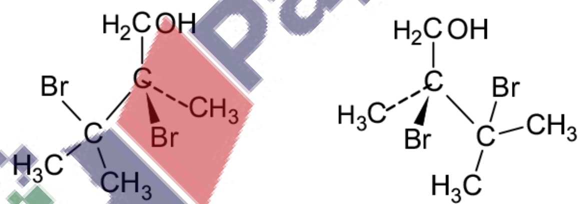
113. 9701_s19_ms_22 Q: 4

(a)	name of source crude oil / petroleum			1
	outline of separation of hydrocarbons (separation of molecules according to) different boiling points			1
(b)(i)	cracking			1
(b)(ii)	$2C_7H_{16} \rightarrow C_4H_{10} + C_6H_{14} + 2C_2H_4$			1
(c)		*method 1*	*method 2*	
	M1	1 / 28 (= 0.035714)	1 : 88 / 28 (= 3.14286)	1
	M2	2 × M1 (= 1 / 14 = 0.07143)	M1 / 44 (= 0.071429)	1
	M3	M2 × 24 = 1.7 dm^3	M2 × 24 = 1.7 dm^3	1
(d)(i)	unpaired electron(s)			1
(d)(ii)	homolytic (fission)			1
	one electron goes to each chlorine / atom OR pair of electrons is shared out (equally between the two atoms)			*1*
(d)(iii)	propagation			1
(d)(iv)	CH_4 + (•)C*l* → (•)CH_3 + HC*l* **OR** CH_4 + (•)C*l* → HC*l* + CH_3(•)			1
(d)(v)	***M1** identify bond types in alkanes and alkenes* bonds in alkanes are (all) sigma / σ AND alkenes have (C = C made of) sigma AND pi / σ AND π			1
	***M2** electrons in π (of the C = C) are responsible for the reaction* electrophiles are attracted to / attack to electrons in **pi / π** OR electrophiles react with **pi / π**			1

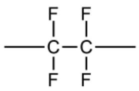
114. 9701_S15_ms_22 Q: 3

(a) (i)	Bond breaking = Cl-Cl = 242 C-H = 410 = 652 kJ Bond forming = C-Cl = 340 H-Cl = 431 = 771 kJ Enthalpy change = 652 – 771 = –119	[1] [1] [1]
(ii)	UV / High T / sunlight	[1]
(iii)	Initiation Cl_2 → 2Cl• Propagation C_2H_6 + Cl• → •C_2H_5 + HCl •C_2H_5 + Cl_2 → C_2H_5Cl + Cl• Termination •C_2H_5 + •C_2H_5 → C_4H_{10} All three names correctly assigned	[1] [1] [1] [1] [1]
(b) (i)	ethene	[1]
(ii)	KOH / NaOH ethanolic **AND** heat / reflux	[1] [1]
(iii)	H_2 **AND** Pt or Ni (catalyst)	[1]

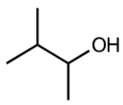
115. 9701_S15_ms_23 Q: 4

(a) (i)		[1]
(ii)	 	[1] [1]
(b) (i)	 M1 = 2 curly arrows M2 = intermediate ion M3 = Br with –ve charge, lone pair and curly arrow to C+	[1] [1] [1]
(ii)	dipole is <u>induced</u> by proximity to C=C	[1]
(iii)	Optical	[1]
(iv)		[1+1]

116. 9701_w18_ms_21 Q: 3

(a)(i)	**M1** gas / vapour (particles / molecules) in **equilibrium** (with liquid / solid) **M2** greater proportion of gas (particles) than liquid (particles) (in comparison to a liquid of lower vapour pressure)	**2**
(a)(ii)	–17.(0) (kJ mol^{-1}) ✓✓✓ **M1** $\Delta H_r = x(–482.2) + y(–92.3) – v(–103.2) – w(–273.3)$ where x y v and w are integers $\geqslant 1$ (ignore stoichiometry) **M2** use of correct stoichiometry where $x = 1$ $y = 2$ $v = 1$ and $w = 2$	**3**
(a)(iii)	**M1** in a different phase / state from reactants **M2** a substance that speeds up a (chemical) reaction **M3** catalyst is regenerated / not used up / undergoes temporary chemical change / recovered unchanged	**3**
(b)(i)	**Human activity** creates / additional / more/increase / thicker layer in greenhouse gas(es) / $CHClF_2$ **OR** **Human activity** has an impact on climate change / temperature at earth's surface / temperature of sea	**1**
(b)(ii)	**M1** traps (more)heat **M2** (in the atmosphere leading to) greater global warming or wtte	**2**
(b)(iii)	ozone depletion / thinning	**1**
(c)(i)	addition	**1**
(c)(ii)		**1**
(c)(iii)	molecule unreactive / inert	**1**
(c)(iv)	non-biodegradable creates toxic / harmful gases / HF / CO_2 / CO **if burnt**	**2**

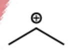
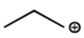
117. 9701_m16_ms_22 Q: 4

(a) (i)	$\underline{C_4H_{10}}$	[1]
(ii)	$\underline{C_4H_9}$	[1]
(iii)		[1]
(b)	$C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$	[1]
(c)	sulfur dioxide would be produced on combustion (which contributes to) acid rain	[1] [1]
(d)	M1 = **H** has more / greater / stronger van der Waals' / intermolecular forces than **G** / ora M2 = (because) **H** has more electrons (than **G**) M3 = **J** has hydrogen bonding (between molecules) M4 = strong(er) / great(er) forces require AND high / more energy to overcome	[1] [1] [1] [1]
(e)	NaOH(aq)	[1]

118. 9701_s16_ms_23 Q: 3

(a)	**(i)**	vaporise / boil / turn to gas	[1]
	(ii)	increasing molecular size / no of carbon atoms per molecule / length of carbon chain	[1]
	(iii)	increasing b.pt / decreasing volatility increasing viscosity increasing density increasing depth of colour decreasing flammability / decreasing 'cleanliness' of flame owtte	[1] [1]
(b)	**(i)**	$C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$	[1]
	(ii)	ethene use = <u>making</u> polythene / plastic / polymers feature of ethene = double bond / unsaturated octane / alkane use = fuel / petrol feature of octane / alkane = flammability / releases energy when burned / combusted	[1] [1] [1] [1]
(c)	**(i)**	(produced by) reaction of (atmospheric) oxygen and nitrogen due to high temperature / engine provides energy / combustion provides energy	[1] [1]
	(ii)	$2NO + 2CO \rightarrow N_2 + 2CO_2$ / $NO + CO \rightarrow \frac{1}{2}N_2 + CO_2$	[1]
	(iii)	$NO + \frac{1}{2}O_2 \rightarrow NO_2$ $NO_2 + SO_2 \rightarrow SO_3 + NO$ $SO_3 + H_2O \rightarrow H_2SO_4$ / $2H^+ + SO_4^{2-}$ / $H^+ + HSO_4^-$	[1] [1] [1]
	(iv)	lowers pH of rivers / lakes / kills fish leaches (toxic) aluminium from soil (into rivers / lakes) leaches away soil nutrients damage to buildings / statues / trees / plants / crops ocean acidification / damage to coral	[1] [1] [1] [1] [1]

119. 9701_s21_ms_21 Q: 6

Question	Answer	Marks
(a)	addition	**1**
(b)	**M1** *catalyst* = sulfuric acid / phosphoric(V) acid	**1**
	M2 *conditions of reaction* = steam / heat (and pressure)	**1**
(c)	<table><tr><td></td><td>σ</td><td>π</td></tr><tr><td>C_3H_6</td><td>8</td><td>1</td></tr><tr><td>C_3H_8O</td><td>11</td><td>0</td></tr></table>	**2**
(d)(i)	**M1** more stable = $CH_3C^+(H)(CH_3)$ 	**1**
	M2 less stable = $CH_3CH_2C^+(H_2)$ / 	**1**
	M3 greater (positive) inductive effect of two alkyl groups OR greater electron donation of two alkyl groups owtte	**1**
(d)(ii)	propan-2-ol	**1**
(e)(i)	elimination	**1**
(e)(ii)	**M1** NaOH / KOH	**1**
	M2 ethanolic solution / ethanol / alcohol + heat	**1**

120. 9701_w21_ms_21 Q: 2

Question	Answer	Marks
(a)(i)	hydrogen / H_2	1
(a)(ii)	$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + ½O_2$	1
(a)(iii)	(thermal stability) increases	1
(a)(iv)	$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$	1
(b)	reduces acidity of soil	1
(c)(i)	Mixing / overlap / combination of one / an s and one / a p orbital	1
(c)(ii)	*Sketch a diagram to show HOW two sp hybrid orbitals can form a SIGMA bond* **M1**  **M2** 	2
(d)(i)	**M1** moles of NH_3 = $1.50 \times 10^6 \times 10^6 \div 17 = 8.82 \times 10^{10}$ **M2** mass of $CaCN_2$ = $\frac{½ \times M1 \times 80.1}{10^6} = 3.53 \times 10^6$	2
(d)(ii)	CH_3CH_2CN ; $CH_3CH_2CO_2H$ $CH_3C(OH)(CN)CH_3$	3

121. 9701_s20_ms_22 Q: 4

(a)(i)	Bromine / Br	1
(a)(ii)	$Ag^+(aq) + X^-(aq) \rightarrow AgX(s)$ OR $Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$	1
(a)(iii)	**M1** *reagent* Add (aqueous) ammonia **M2** *expected result* **EITHER** (Dilute ammonia) – partial amount precipitate dissolves OR not much precipitate dissolves **OR** add concentrated ammonia – precipitate dissolves	2
(b)(i)	$CH_3CH_2CH_2CH_2CH_2Br$	1
(b)(i)	**M1** primary/ 1° (carbo)cation formed is not very stable **M2 EITHER** (as) only one alkyl group exerting an inductive effect **OR** only one alkyl group so the charge is (more) localised on the C+	2
(c)(i)	elimination	1
(c)(ii)	$C_4H_9Cl + NaOH \rightarrow C_4H_8 + NaCl + H_2O$	1
(c)(iii)	 ONLY	1
(c)(iv)	**M1** 2-chloro(-2-)methylpropane **M2** 1-chloro(-2-)methylpropane ALLOW in any order	2

122. 9701_s19_ms_23 Q: 5

(a)(i)	pentanenitrile	1
(a)(ii)	a lone pair / electron pair donor	1
(a)(iii)	(:)CN^- / $^-$(:)CN / cyanide ion	1
(a)(iv)	Br (atom) is replaced (with / by CN / nitrile)	1
(b)	**M1** *reagent* Ammonia **M2** *conditions* heat with under pressure / heat in a sealed tube	2
(c)(i)	**M1** Increasing reactivity from C*l* → Br → I **M2** Due to decreasing strength of C-X bond (from C-C*l* to C-Br to C-I) OR Less energy needed to break C-X (from C-C*l* to C-Br to C-I)	2
(c)(ii)	**M1** tertiary / 3° halogenoalkane **M2** (carbo)cation / intermediate is stable **M3** due to (3) electron releasing/donating methyl groups / + I groups (attached to central C) OR (positive) inductive effect of the (three) methyl groups /	3
(c)(iii)	*Any* **formula / name** for *any* **primary** halogenoalkane i.e. 1-chlorobutane / 1-bromobutane / 1-iodobutane	1

123. 9701_s19_ms_23 Q: 6

(a)(i)	Orange / brown **to** colourless / decolourises	1
(a)(ii)	any non-ambiguous structures of:	
	X $(CH_3)_2C = CH_2$ / $(CH_3)_2CCH_2$	1
	Y $CH_3CH_2CH = CH_2$ / $C_2H_5CHCH_2$	1
	Z $CH_3CH = CHCH_3$ / $CH_3CHCHCH_3$	1
(a)(iii)	C_4H_8	1
(b)(ii)	V = primary / 1° alcohol	1
	W = tertiary / 3° alcohol	1
(b)(ii)	$CH_3(CH_2)_2CH_2OH$ + Na → $CH_3(CH_2)_2CH_2ONa$ + ½ H_2	1
(b)(iii)	**M1** Reagent — H^+ / $Cr_2O_7{}^{2-}$ **M2** Observations for V — orange to green **M3** Observations for W — no change / remains orange	3

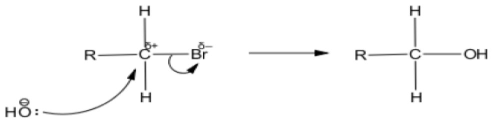
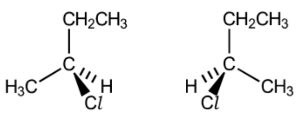
124. 9701_s18_ms_23 Q: 4

(a)(i)	2-bromobutane	1
(a)(ii)	ketone	1
(b)	$(CH_3)_3CBr$; $(CH_3)_2CHCH_2Br$; $CH_2BrCH_2CH_2CH_3$ 3 correct = 2 marks 2 correct = 1 mark	2
(c)(i)	S = substitution N = nucleophilic	1
(c)(ii)	 M1 = dipole and curly arrow M2 = intermediate carbocation IGNORE CH_2CH_3 shown as C_2H_5 M3 = OH^- with lone pair and curly arrow from lone pair to the 'C'	3
(d)	• C_4H_9Cl slower (than C_4H_9Br) • C_4H_9I faster (than C_4H_9Br) • C–Cl bond stronger than C–Br OR C–Cl 340 C–Br 280 • C–I bond weaker then C–Br OR C–Br 280 C–I 240 1 mark for each point, max 3	3
(e)	ethanolic (instead of aqueous)	1
	hotter/higher temperature (heat under) reflux	1

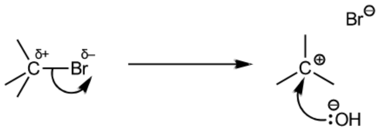
125. 9701_w17_ms_21 Q: 3

(a) — 6

reaction	reagent(s) and conditions	reaction type(s)
1	aqueous / aq / dilute NaOH / KOH OR water	substitution OR hydrolysis
2	alcoholic / ethanolic NaOH / KOH	elimination
3	NaCN / KCN in ethanol / alcohol	substitution
4	aqueous /dilute H_2SO_4 / H^+(aq)	hydrolysis OR substitution OR addition-elimination
5	acidified / H^+ (with) $K_2Cr_2O_7$ / $Cr_2O_7^{2-}$ (and distil) NOT reflux	oxidation OR elimination
6	acidified / H^+ $K_2C_{r2}O_7$ / Cr_2O_7 $^{2-}$ Fehling's / Tollens' / Benedict's (reagent)	oxidation

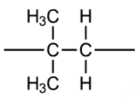
(b)	 M1 lone pair on O of $^-$OH AND curly arrow from lone pair to C(—Br) M2 correct dipole on $C^{\delta+}$—$Br^{\delta-}$ AND curly arrow from bond to Br	2
(c)(i)	(different molecules) with same molecular formula / same numbers of atoms of (each type) of element	1
	different structural formulae / displayed formulae	1
	chain / skeletal functional group position(al) / regioisomerism two types correct = 1 mark, all three correct = 2 marks	2
(c)(ii)	S_N / nucleophilic substitution	1
	($(CH_3)_3CBr$ / tertiary halogenoalkane) forms a stable (carbo)cation / stable intermediate (as charge density on cation is reduced) OR (in) 1-bromobutane / primary halogenoalkane there is no (stable) (carbo)cation / intermediate formed	1
	(because) there are (3 /more) alkyl / methyl groups AND (+) I / (greater) inductive effect OR (because) there is only one / fewer alkyl / methyl group(s) (compared to reaction with 2-bromo-2-methyl propane / tertiary halogenoalkane) AND limited (+) I / (less) inductive effect	1
(d)(i)	(different molecules) with the same (molecular and) structural formula /	1
	with different arrangements of atoms in space / spatial arrangement of atoms	1
(d)(ii)	mirror images are super(im)posable / no chiral carbon / no chiral centre / it is achiral	1
	(one) C of double bond has identical groups / H (atoms) (attached) OR (one) end of double bond has identical groups / 2 H (atoms) (attached)	1
(d)(iii)	**X** = 2-chlorobutane	1
	Y = 1-chlorobutane	1
(d)(iv)	optical (isomerism)	1
(d)(v)	one acceptable 3D structure of 2-chlorobutane	1
	the 2nd optical isomer EITHER drawn as a mirror image of the first OR the same bond pattern is shown but two of the groups swap positions. 	1

126. 9701_w17_ms_22 Q: 4

<table>
<tr><td>(a)</td><td>
<table>
<tr><td>1</td><td>concentrated H_2SO_4 / H_3PO_4 AND NaBr
OR (red) P / Br_2
OR HBr</td><td>substitution</td></tr>
<tr><td>2</td><td>aqueous / dilute NaOH / KOH</td><td>hydrolysis
OR substitution</td></tr>
<tr><td>3</td><td>concentrated H_2SO_4 / H_3PO_4
OR Al_2O_3 / P_4O_{10} / pumice / porous pot / SiO_2</td><td>dehydration</td></tr>
<tr><td>4</td><td>(ethanolic) HBr</td><td>addition</td></tr>
</table>
4 marks for column 1 (one per row) 1 mark for col 2</td><td>5</td></tr>
<tr><td>(b)</td><td>

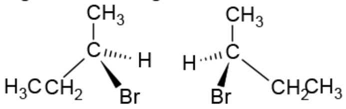
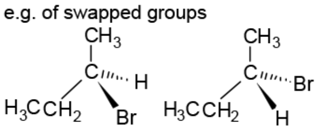
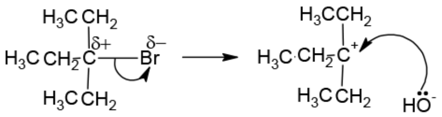
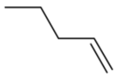
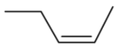
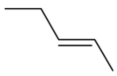
M1
correct dipole on $^{\delta+}C—Br^{\delta-}$ AND curly arrow from C—Br bond to Br

M2 correct intermediate with + charge

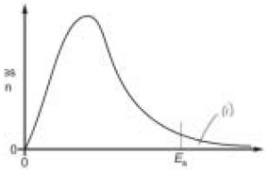
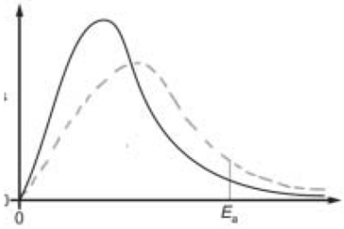
M3 curly arrow from lone pair on $:\overset{\ominus}{O}H$ to C^+ of carbocation</td><td>3</td></tr>
<tr><td>(c)(i)</td><td>(different molecules) same molecular formula / same numbers of atoms of each (type of) element</td><td>1</td></tr>
<tr><td></td><td>different structural formulae / displayed formulae</td><td>1</td></tr>
<tr><td></td><td>chain / skeletal
functional group
position(al) / regioisomerism
two types correct = 1 mark, all three correct = 2 marks</td><td>2</td></tr>
<tr><td>(c)(ii)</td><td>S_N / nucleophilic substitution</td><td>1</td></tr>
<tr><td></td><td>no (stable) (carbo)cation / intermediate is formed</td><td>1</td></tr>
<tr><td></td><td>only one alkyl group / fewer alkyl / methyl groups (compared to reaction 2) AND limited (+)I / inductive effect / less electron donating (effect)</td><td>1</td></tr>
<tr><td>(d)(i)</td><td>mirror images are super(im)posable
OR not chiral / no chirality / no chiral/asymmetric carbon/centre / achiral</td><td>1</td></tr>
<tr><td></td><td>one or both C/end of double bond has identical groups / 2 methyl groups / 2 H (atoms)</td><td>1</td></tr>
<tr><td>(d)(ii)</td><td>addition</td><td>1</td></tr>
<tr><td></td><td>

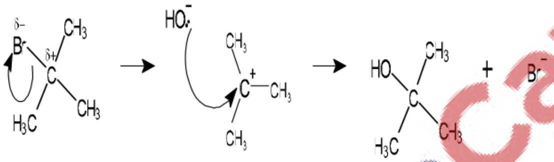
marking points:
• correct number of tetravalent carbon atoms in backbone, with extension bonds
• correct groups on backbone carbon atoms and only one repeat unit</td><td>2</td></tr>
<tr><td>(d)(iii)</td><td>not/non- biodegradable / harmful combustion products</td><td>1</td></tr>
<tr><td>(e)</td><td>2-bromo-2-methylpropane</td><td>1</td></tr>
<tr><td></td><td>1-bromo-2-methylpropane</td><td>1</td></tr>
</table>

127. 9701_w16_ms_22 Q: 4

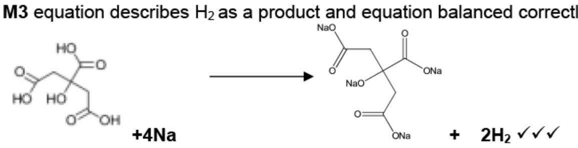
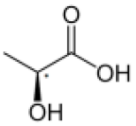
(a)(i)	2–bromobutane	1
(a)(ii)	e.g. of mirror images  e.g. of swapped groups 	1+1
(a)(iii)	$CH_3CH_2CH_2CH_2Br$ $(CH_3)_2CHCH_2Br$ $(CH_3)_3CBr$	1 1 1
(b)(i)	3-bromo-3-ethylpentane	1
(b)(ii)	 M1 = dipole and curly arrow from bond to (or just beyond) Br M2 = correct carbocation M3 = OH^- with curly arrow from lone pair <u>on O</u> to C(+)	 1 1 1
(b)(iii)	S_N1 / nucleophilic substitution	1
(c)(i)	Sodium / potassium hydroxide Ethanol / alcohol **AND** heat	1 1
(c)(ii)	elimination	1
(c)(iii)	  	1 1 1
	Total:	17

128. 9701_s21_ms_22 Q: 3

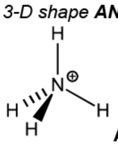
Question	Answer	Mark
(a)	change in amount of substance with time	1
(b)(i)	label **area** under the original curve to the right of E_a. 	1
(b)(ii)	**M1** *curve starts at the origin but peak lies to the right of original.*	1
	M2 *peak at higher temperature is lower than the original AND graph crosses the original once only – beyond the peak of original* 	1
(b)(iii)	no change / none	1

Question	Answer	Mark
(c)(i)	 **M1** correct dipole on haloalkane AND arrow from bond to Br or just beyond	1
	M2 correct intermediate	1
	M3 arrow from lone pair on O of OH^- / ^-OH to central C of their intermediate shown in M2 OR arrow from lone pair on O of OH^- / ^-OH to central C of 2-bromo 2-methylpropane if S_N2 mechanism shown	1
(c)(ii)	nucleophilic substitution	1
(d)	**M1** more time (because the rate is lower)	1
	M2 C-C*l* (bond) is stronger (than C-Br)	1

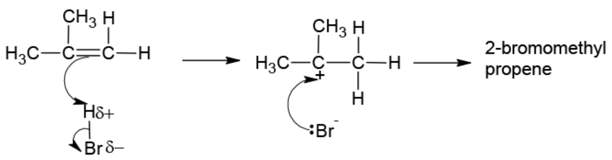
129. 9701_s21_ms_23 Q: 5

Question	Answer	Marks
(a)	**M1**all 3 COOH form COONa / CO_2Na / COO^-Na^+	1
	M2 the OH group forms CONa / CO^-Na^+	1
	M3 equation describes H_2 as a product and equation balanced correctly  OR $C(CH_2COOH)_2(COOH)(OH) + 4Na \rightarrow C(CH_2COONa)_2(COONa)(ONa) + 2H_2$ ✓✓✓	1
(b)(i)	**M1** *skeletal formula of 2-hydroxypropanoic acid / similar chiral isomer that meet the criteria in table* 	1
	M2 chiral carbon marked with *	1
(b)(ii)	**M1** citric acid has a tertiary alcohol group so is not oxidised	1
	M2 **X** has a secondary alcohol group which is oxidised (to a ketone)	1
(c)	**M1** chiral centre / non superimposable mirror image / has a C **attached** to 4 different groups	1
	M2 C=C where each C is attached to (two) different groups	1
(d)	(molecules / isomers with) the same molecular formula / same number of atoms of each element AND different structural formulae / different structures	1

130. 9701_w19_ms_22 Q: 3

(a)(i)	green gas fades **OR** white solid / white powder / white smoke / white fumes	**1**
(a)(ii)	hydrolysis	**1**
(a)(iii)	□ P goes from 0 to (+)5 / (+)V □ P is oxidised □ N goes from (+)5 / (+)V to (+)4 / (+)IV □ N is reduced Award one mark for two correct bullet points, award two marks for all four correct.	**2**
(b)(i)	accepts a proton / H^+ **OR** donates a (lone) pair of e^-	**1**
(b)(ii)	*3-D shape **AND** bond angle*  **AND** $109\frac{1}{2}$ (°)	**1**
(b)(iii)	fertilisers	**1**
(c)(i)	$C_2H_5OH + PCl_5 \rightarrow C_2H_5Cl + POCl_3 + HCl$	**1**
(c)(ii)	substitution	**1**
(c)(iii)	EITHER **M1:** HI / I^- is a strong(er) reducing agent (than HCl / Cl^-) **M2:** HI / I^- is oxidised (to iodine but the chloride is not) **OR** **M1:** H_2SO_4 is a (strong enough) oxidising agent (to react with HI / I^- here) **M2:** HI / I^- forms iodine **OR** **M1:** phosphoric acid is a weak / not an oxidising agent **M2:** (so) does not react with iodide (where M2 is dependent on M1 here)	**2**
(c)(iv)	**M1:** C_2H_5I reacts fastest AND C_2H_5Cl reacts slowest **OR** $C_2H_5Cl < C_2H_5Br < C_2H_5I$ **M2:** C—I bond is the weak(est) AND C—Cl bond strong(est)	**2**

131. 9701_s18_ms_21 Q: 4

(a)(i)	Iodoform / triiodomethane	**1**
(a)(ii)	butan-2-ol	**1**
(b)	$CH_3CH_2CH_2CH_2OH$ $(CH_3)_3COH$ $(CH_3)_2CHCH_2OH$	**2**
(c)(i)	oxidation / redox	**1**
(c)(ii)	acidified / H^+ **AND** potassium / sodium dichromate((VI)) or formulae	**1**
(c)(iii)	*In any order:*	
	but-1-ene	**1**
	but-2-ene	**1**
	cis / *Z*- AND *trans* / *E*-	**1**
(d)(i)		
	curly arrow from C=C to H	**1**
	correct dipole on HBr and curly arrow from bond of HBr to Br	**1**
	tertiary intermediate cation	**1**
	Br^- with curly arrow from lone pair	**1**
(d)(ii)	(carbo)cation / tertiary ion / tertiary intermediate (more) stable (than primary)	**1**
	due to electron-releasing / (positive) inductive effect of more alkyl / methyl groups	**1**

132. 9701_w15_ms_21 Q: 4

(a) (i)	$CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$ or $CH_3CH_2OH + PCl_5 \rightarrow CH_3CH_2Cl + HCl + POCl_3$ or $CH_3CH_2OH + SOCl_2 \rightarrow CH_3CH_2Cl + HCl + SO_2$	[1+1]
(ii)	NaOH / KOH warm / heat / reflux AND aqueous	[1] [1]
(b) (i)	CH_2=CH_2 / ethane / C_2H_4 / CH_2CH_2	[1]
(ii)	White ppt / solid / suspension	[1]
(iii)	$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$	[1]
(c) (i)	CH_3CHO / ethanal	[1]
(ii)	CH_3CH_2OH higher bpt than CH_3CHO ora due to hydrogen bonding in ethanol / stronger IMFs prevents further oxidation owtte	[1] [1] [1]

133. 9701_s21_ms_23 Q: 4

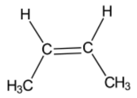
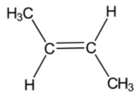
<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>(a)(i)</td><td>1,3-dichloropropan(-2-)one</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>carbonyl / ketone</td><td>1</td></tr>
<tr><td>(a)(iii)</td><td>$NaBH_4$ OR $LiAlH_4$</td><td>1</td></tr>
<tr><td>(b)</td><td>
<table>
<tr><td>reagent</td><td>observation with Q</td><td>observation with R</td></tr>
<tr><td>2,4-DNPH</td><td>M1 red / orange / yellow AND precipitate / solid / crystals</td><td>M2 red / orange / yellow AND precipitate / solid / crystals</td></tr>
<tr><td>$Na_2CO_3(aq)$</td><td>M3 no visible change</td><td>M4 fizz / effervescence</td></tr>
</table>
</td><td>4</td></tr>
<tr><td>(c)</td><td>
<table>
<tr><td>step</td><td>reagent and conditions</td><td>type of rxn</td></tr>
<tr><td>1</td><td>M1 HCN and (trace) KCN / NaCN</td><td>M3 Addition</td></tr>
<tr><td>2</td><td>dilute sulfuric acid</td><td>Hydrolysis</td></tr>
<tr><td>3</td><td>M2 KCN/NaCN in ethanol / alcohol</td><td>M4 Substitution</td></tr>
<tr><td>4</td><td>dilute sulfuric acid</td><td>Hydrolysis</td></tr>
</table>
M5 type of reaction for step 2 AND step 4
</td><td>5</td></tr>
</table>

134. 9701_m21_ms_22 Q: 4

Question	Answer	Marks
(a)	**M1:** x = 108–110° **M2:** y = 118–122°	**2**
(b)	**M1:** red / orange / yellow ppt / solid **M2:** silver mirror **OR** silver / grey / black / brown ppt / solid	**2**
(c)(i)	oxidising agent	**1**
(c)(ii)	**M1:** (excess dichromate and) heat under reflux **M2:** to allow full oxidation (of alcohol and aldehyde groups)	**2**
(d)(i)	$CH_2OHCHO + 2[H] \rightarrow (CH_2OH)_2$	**1**
(d)(ii)	$NaBH_4$ / $LiAlH_4$	**1**
(d)(iii)	ethene	**1**

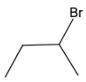
135. 9701_s21_ms_22 Q: 4

Question	Answer	Mark
(a)(i)	(see table below)	4

	structural formula	name
A	$CH_3CH_2CH{=}CH_2$	but-1-ene OR 1-butene
B		cis / Z but-2-ene OR cis / Z 2-butene
C		trans / E but-2-ene OR trans / E 2-butene
D	$CH_2{=}C(CH_3)_2$	(2) methyl prop(-1-)ene

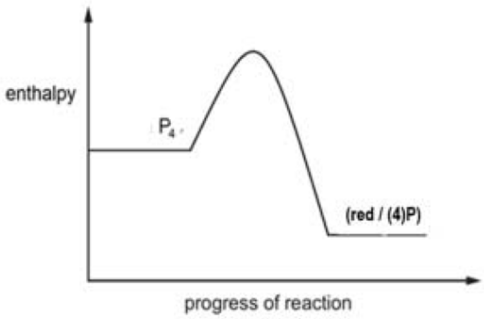
M1 correct identification of but-1-ene (for **A**)
M2 correct identification of but-2-ene for **B** and **C**
M3 identification of cis / trans (Z / E) for **B** and **C** (in correct order)
M4 correct name of **D**

Question	Answer	Mark
(a)(ii)	(molecules with the) same structural formula (and same molecular formula) with different arrangement of atoms / groups in space	1
(b)(i)	**A**	1

Question	Answer	Mark
(b)(ii)	**M1**  skeletal formula only	1
	M2 *explanation in terms of increased / greater stability of intermediate / carbocation* intermediate / (secondary) carbocation / $CH_3C^+(H)(CH_2CH_3)$ is (more) stable	1
	M3 *reason for increased stability of intermediate in terms of greater number of alkyl groups showing largest inductive (electron releasing) effect* greater (positive) inductive effect due to two alkyl groups OR greater electron donation of two alkyl groups	1
(c)	dehydrating agent / cause dehydration	1
(d)(i)	oxidation	1
(d)(ii)	(see table below)	1

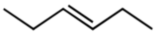
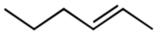
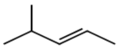
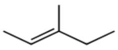
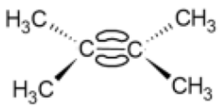
functional group	present in **Z**
aldehyde	✓
ketone	
carboxylic acid	

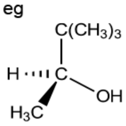
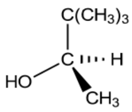
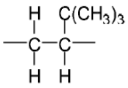
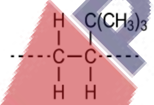
136. 9701_w21_ms_21 Q: 3

Question	Answer	Marks
(a)(i)	**M1** simple molecular **M2** giant molecular **M3** weak IMFs (overcome) in P_4 **AND** strong (covalent) bonds (broken) in P	3
(a)(ii)		1
(b)(i)	(+)5/V	1
(b)(ii)	$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$ $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	2
(c)(i)	$C_{18}H_{15}P$	1
(c)(ii)	stage 1 = reduction stage 2 = substitution	2

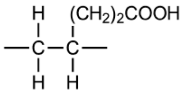
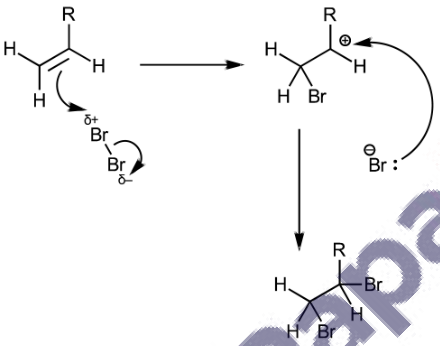
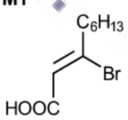
Question	Answer		Marks
(c)(iii)	**G** = $C_2H_5CH_2OH$	**H** = $C_2H_5CH{=}CHC_2H_5$	2
(d)	$CH_3CH_2CO_2H$	CH_3COCH_3	2

137. 9701_w21_ms_22 Q: 3

Question	Answer	Marks
(a)	(2,3-)dimethylbut-2-ene	1
(b)	 OR  OR  OR 	1
(c)(i)		1
(c)(ii)	sp^2	1
(d)(i)	cold dilute acidified potassium manganate(VII)	1
(d)(ii)	**M1** (2,4-DNPH will produce a) red / orange / yellow precipitate **M2** **V** has a carbonyl group	2
(d)(iii)	**M1** C—O in range 1040–1300 (cm^{-1}) **M2** C=O in range 1670–1740 (cm^{-1})	2
(e)(i)	yellow precipitate	1
(e)(ii)	Iodine / I_2	1
(e)(iii)	$C_6H_{12}O$ + 2[H] → $C_6H_{14}O$	1

Question	Answer	Marks
(e)(iv)	Draw two optical isomers of X. eg  OR  **M1** *One correct 3-dimensional representation of X* **M2** *3-d structure which represents the enantiomer of their X*	1 1
(e)(v)	heat **AND** concentrated H_2SO_4 / concentrated H_3PO_4 / concentrated sulfuric [(VI)] acid / concentrated phosphoric[(V)] acid	1
(e)(vi)	 OR 	1
(e)(vii)	high activation energy	1

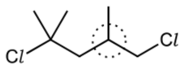
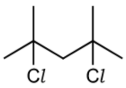
138. 9701_m20_ms_22 Q: 3

(a)(i)	**M1** acidified / H^+ $Cr_2O_7^{2-}$ / (potassium / sodium) dichromate OR manganate(VII) / MnO_4^- / $KMnO_4$ **M2** (heat under) reflux	2
(a)(ii)	nucleophilic addition	1
(a)(iii)	yellow / orange / red ppt / solid	1
(a)(iv)	it does not have four different (groups of) atoms attached to (central) carbon OR it does not have a chiral carbon / centre OR it has two identical / COOH groups attached to (central) carbon OR mirror image is super(im)posable	1
(a)(v)	**M1** hydrolysis **M2** esterification / condensation	2
(b)(i)	**M1** no. of mol $O_2 = \frac{1.00\times10^5\times1.06\times10^{-3}}{(8.31\times850)}$ **M2** no. of mol of nitroglycerine = $4\times0.0150 = 0.0600$ (mol) **M3** mass of nitroglycerine = $0.0600\times227 = 13.6(2)$ (g)	3
(b)(ii)	$1.06\times29 = 30.7(4)$ dm^3	1
(c)(i)	$C_5H_8O_2$	1
(c)(ii)		1
(c)(iii)	 **M1** curly arrow from C=C double bond to Br **M2** correct dipole in Br_2 **AND** curly arrow from Br—Br to $Br^{\delta-}$ **M3** correct intermediate **AND** curly arrow from lone pair on Br^- to C^+ **M4** correct product	4
(d)(i)	**M1**  **M2** (two) different groups on each C atom in the C=C / end of the C=C double bond **M3** no / restricted rotation about C=C	3
(d)(ii)	H_2 / hydrogen	1
(d)(iii)	**M1 / M2** *absorptions seen in both spectra (any two):* (same) both show an absorption at 1680–1730 (cm^{-1}) because of C=O (same) both show an absorption at 1040–1300 (cm^{-1}) because of C–O (same) both show an absorption at 2500–3000 (cm^{-1}) because of RCO_2–H / O–H in RCO_2H / carboxyl(ic acid) **M3** *absorption only seen in spectrum of* **T**: (different) **T** shows an absorption at 1500–1680 (cm^{-1}) because of C=C (different) **T** shows an absorption at 3000–3100 (cm^{-1}) because of (C=)C–H	3

139. 9701_s20_ms_21 Q: 5

(a)(i)	C*l*	1
(a)(ii)	HC*l* **AND** H_2O	1
(a)(iii)	**M1** CO_3^{2-} **M2** propanoic acid – effervesce. (Propan-1-ol – no reaction)	2
(b)(i)	ultraviolet light / uv	1
(b)(ii)	homolytic fission (of chlorine (gas) / Cl_2)	1
(c)(i)	carbonyl / aldehyde / ketone	1
(c)(ii)	tertiary halogenoalkane	1
(d)(i)	*Two structures representing the intermediate* **M1** $C_2H_5C^+HCH_3$ **M2** $CH_3CH_2CH_2C^+H_2$	2
(d)(ii)	*Identify the most stable intermediate* **M1** $C_2H_5C^+HCH_3$ *explanation* **M2** (more / 2 alkyl groups attached so) it has the greater inductive / electron donating effect	2

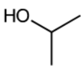
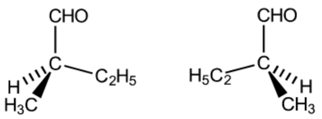
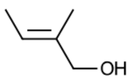
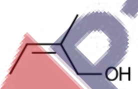
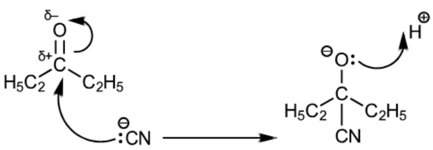
140. 9701_w20_ms_22 Q: 3

(a)(i)	$P_4 + 10Cl_2 \rightarrow 4PCl_5$	1
(a)(ii)	simple / molecular AND covalent	1
(b)(i)	steamy / misty fumes	1
(b)(ii)	$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$	1
(b)(iii)	0 to 4	1
(c)(i)	$LiAlH_4$ OR lithium tetrahydridoaluminate((III))	1
(c)(ii)	**M1:** molecule with a non super-(im)posable mirror image	2
	M2: 	
(c)(iii)		1
(d)(i)	**M1:** (trigonal) pyramidal	2
	M2: 107	
(d)(ii)	**M1:** proton / H^+ donor	2
	M2: partially dissociates (in solution)	
(d)(iii)	**method 1** **M1:** *show the number of mol gas produced from 0.241 g NCl_3* *[$M_r(NCl_3)$ = 120.5 1 mol NCl_3 produces 2 mol gas]* $n = 2 \times 0.241 / 120.5$ OR $n = 0.0040$ (mol gas produced.)	4
	M2: *correct conversion of T to Kelvin, V to m^3 and correct value of R*	
	M3: *use of equation P = nRT / V with M2 values for n, R, T and V to find pressure of mol gas produced* increase in $p = nRT / V = \frac{0.0040 \times 8.31 \times 293}{250 \times 10^{-6}}$ $= 3.90 \times 10^4$	
	M4: *$= 1.00 \times 10^5$ + M3 (Pa)* total pressure $= 1.00 \times 10^5 + 3.90 \times 10^4$ $= 1.39 \times 10^5$ (Pa)	
	method 2 **M1:** *calculate the produced from 0.241 g NCl_3* 0.003 (mol) Cl_2 **AND** 0.001 (mol) N_2	
	M2: *conversion of T to Kelvin, V to m^3 and correct value of R in all PV/RT equations used* **M3:** *use of equation PV / RT= n for both calculations or a combined equation with M2 values for R,T and V to find partial pressure for each of the gases* $ppCl_2 = 29217.96$ AND $ppN_2 = 9739.32$	
	M4: *Use P_{total} = pp unreacted gas + $ppCl_2$ + ppN_2* $1 \times 10^5 + 2.92 \times 10^4 + 9.74 \times 10^3 = 138\,940$	

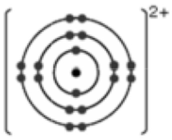
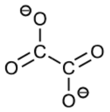
141. 9701_s19_ms_21 Q: 4

(a)	3-chloroprop-1-ene	1
(b)	*a* = 109(.5)°	1
	b = 120°	1
(c)(i)	$C_3H_7ClO_2$	1
(c)(ii)	oxidation	1
(c)(iii)	<table><tr><td></td><td>alcohol group present in Z</td></tr><tr><td>primary</td><td>✓</td></tr><tr><td>secondary</td><td>✓</td></tr><tr><td>tertiary</td><td></td></tr></table>	1
(d)(i)	A and B	1
(d)(ii)	<table><tr><td></td><td>Compound(s)</td><td>Observation</td></tr><tr><td>Reaction with Tollens' reagent</td><td>B ✓</td><td>**silver** mirror OR grey / black / brown / silver precipitate ✓</td></tr></table>	2
	<table><tr><td></td><td>Compound(s)</td><td>Observation</td></tr><tr><td>Reaction with alkaline aq. iodine</td><td>A ✓ and C ✓</td><td>(Pale) yellow precipitate /solid ✓</td></tr></table>	3
	<table><tr><td></td><td>Compound(s)</td><td>Observation</td></tr><tr><td>Reaction with sodium metal</td><td>C ✓ and D✓</td><td>Effervescence / sodium/solid disappears ✓</td></tr></table>	3

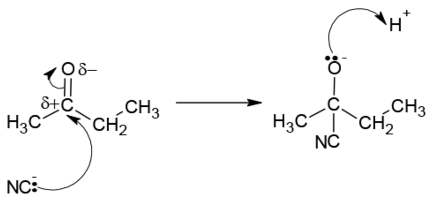
142. 9701_w19_ms_21 Q: 4

<table>
<tr><td>(a)(i)</td><td>(2,2–)dimethylpropanal</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>sp^2</td><td>1</td></tr>
<tr><td>(b)(i)</td><td>acidified potassium dichromate[(VI)] AND heat under reflux</td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>M1: A has H-bonding (between molecules)
M2: B only has dipole–dipole / VdW forces (between molecules)
M3: H-bonding is stronger / requires more energy to overcome</td><td>3</td></tr>
<tr><td>(b)(iii)</td><td>$(CH_3)_3CCHO + 2[H] \rightarrow (CH_3)_3CCH_2OH$</td><td>1</td></tr>
<tr><td>(b)(iv)</td><td>M1:  / $CH_3CH(OH)CH_3$
M2: H_2SO_4 / sulfuric acid</td><td>2</td></tr>
<tr><td>(c)(i)</td><td>• orange / red / yellow precipitate
• orange / red / yellow precipitate</td><td>1</td></tr>
<tr><td>(c)(ii)</td><td>Aldehyde</td><td>1</td></tr>
<tr><td>(c)(iii)</td><td>has a carbon / atom attached / bonded to four different atoms / groups / groups of atoms / chains</td><td>1</td></tr>
<tr><td>(c)(iv)</td><td>
M1: Correct 3D representation
M2: Correct 3D representation of drawn enantiomer</td><td>2</td></tr>
<tr><td>(c)(v)</td><td><table><tr><td>principal absorptions in the infra-red spectrum</td><td>bond responsible</td></tr><tr><td>3200–3600 cm^{-1}</td><td>RO-H / O-H</td></tr><tr><td>1630 cm^{-1}</td><td>C=C</td></tr><tr><td>1050 cm^{-1}</td><td>C—O</td></tr></table></td><td>1</td></tr>
<tr><td>(c)(vi)</td><td> OR 
M1: skeletal alkene group AND C5 structure
M2: one alcohol group
M3: branched chain AND capable of geometrical isomerism</td><td>3</td></tr>
<tr><td>(c)(vii)</td><td>M1: Correct structure of X and correct dipole on C=O
M2: curly arrow from C=O bond to O AND intermediate with CN attached and –ve charge on the O
M3: curly arrow from lone pair on CN^- to C(=O) in X
AND
curly arrow from lone pair in the intermediate to H^+
</td><td>3</td></tr>
<tr><td>(c)(viii)</td><td>catalyst</td><td>1</td></tr>
</table>

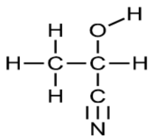
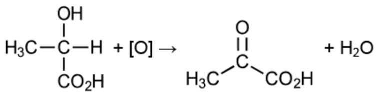
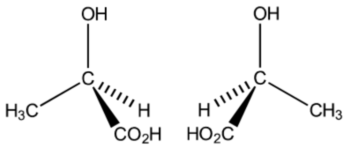
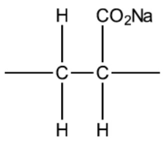
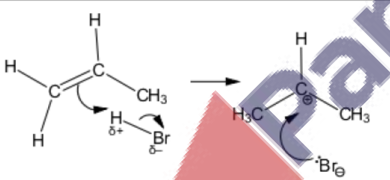
143. 9701_m18_ms_22 Q: 3

(a)(i)	$Ca + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2$	1
(a)(ii)	$CaSO_4$ does not react (with sulfuric acid) coating / crust / protective layer / $CaSO_4$ prevents reaction (of sulfuric acid) with calcium	2
(b)(i)	 dot-and-cross diagram **AND** 2+	1
(b)(ii)	 displayed structure of ethanedioate two – charges on carboxylates **OR** 2– charge overall	2
(c)(i)	bleach	1
(c)(ii)	$Cl_2 + 2OH^- \rightarrow Cl^- + ClO^- + H_2O$	1
(c)(iii)	–1 **AND** (+)5	1
(c)(iv)	gains **AND** loses electrons	1
(d)(i)	carbon dioxide **AND** water	1
(d)(ii)	reaction | reagent(s) and condition(s) 1 | HCN ✓ NaCN ✓ 3 | □ $K_2Cr_2O_7$ □ H_2SO_4 / acid / H^+ □ (heat under) reflux	4
(d)(iii)	hydrolysis	1
(d)(iv)	reducing agent	1
(d)(v)	has a carbon / C / atom attached to four different groups / atoms / chains **OR** has no plane / line of symmetry / has non-superimposable images	1

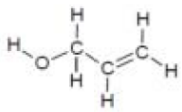
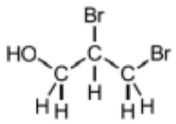
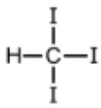
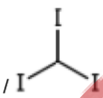
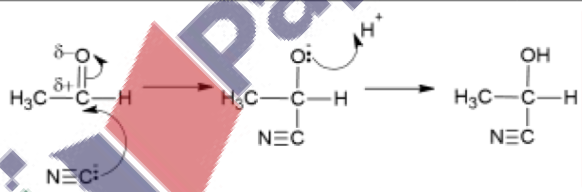
144. 9701_s18_ms_22 Q: 4

(a)(i)	iodoform / tri-iodomethane	1
(a)(ii)	butanone	1
(b)	$CH_3CH_2CH_2CHO$	1
	$(CH_3)_2CHCHO$	1
(c)(i)	reduction	1
(c)(ii)	$NaBH_4$ / sodium borohydride OR $LiAlH_4$ / lithium aluminium hydride	1
(d)(i)		
	lone pair on C of CN^- and curly arrow to C of C=O	1
	correct dipole on C=O and curly arrow from = to O	1
	correct intermediate anion	1
	curly arrow from lone pair on O to H^+	1
(d)(ii)	optical	1
(d)(iii)	(X has a) chiral centre / asymmetric carbon atom OR (X has a) C atom attached to four different groups / atoms / chains	1
	non-super(im)posable mirror images	1
(e)(i)	*M1 is for the process of taking the % of each element and dividing by its relative atomic mass.* C $\frac{51.3}{12}$ H $\frac{9.40}{1}$ N $\frac{12.0}{14}$ O $\frac{27.3}{16}$ OR 4.28 9.40 0.857 1.71 *M2 is for dividing the smallest %/A_r into each of the remaining values to produce the correct ratio.* $\frac{4.28}{0.857}$ $\frac{9.40}{0.857}$ $\frac{0.857}{0.857}$ $\frac{1.71}{0.857}$ OR 4.9942 : 10.9685 : 1 : 1.9953	2
(e)(ii)	$C_5H_{11}NO_2$ **AND** because the EFM = RFM	1

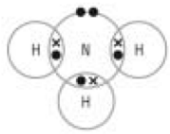
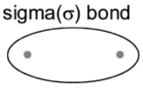
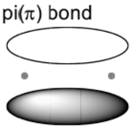
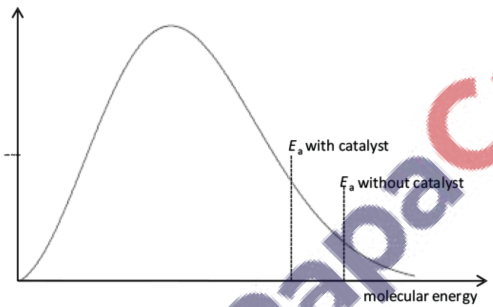
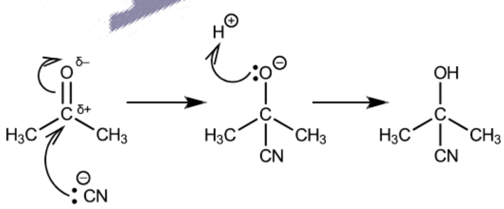
145. 9701_w18_ms_22 Q: 4

(a)(i)		1
(a)(ii)	dehydration	1
(a)(iii)		1
(a)(iv)	$Na_2Cr_2O_7$ / $K_2Cr_2O_7$ **AND** (dilute) H_2SO_4 / $H^+(aq)$ / acidified	1
(b)(i)	(Molecules that are) non-super(im)posable mirror images	1
(b)(ii)	 **M1** correct 3-d drawing of one isomer of Q [1] **M2** correct pair of 3-d structures of the optical isomers of Q [1]	2
(c)	 OR $-CH_2CH(CO_2Na)-$	3
(d)(i)	**M1** I experiences a (greater positive) inductive effect due to more alkyl groups OR I contains more electron donating alkyl groups (than II) [1] **M2** which stabilises the charge / reduces the charge (on the ion/intermediate) OR spreads the charge across the ion / molecule / intermediate [1]	2
(d)(ii)	 **M1** curly arrow from double bond to H of H—Br [1] **M2** curly arrow from H—Br bond to Br **AND** correct dipole on H—Br [1] **M3** curly arrow from lone pair on Br^- to C^+ [1]	3
(d)(iii)	nucleophilic substitution	1
(e)(i)	$CH_3COCO_2H + 6[H] \rightarrow CH_3CHOHCH_2OH + H_2O$ **M1** correct organic product $CH_3CHOHCH_2OH$ [1] **M2** [H] present as reactant with H_2O as product and balancing [1]	2
(e)(ii)	$1s^2\ 2s^2\ 2p^6\ (3s^0)$	1
(e)(iii)	Ions/elements have more shells / energy levels (as the group is descended)	1

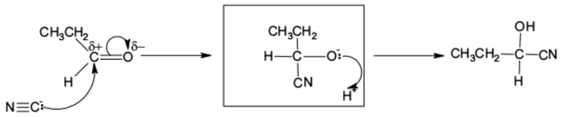
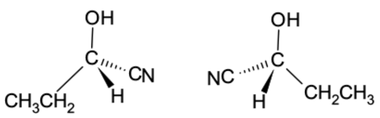
146. 9701_s17_ms_21 Q: 4

(a)(i)	(molecules / isomers with) the same molecular formula / same number of atoms of each element	1
	different structural / displayed formulae / arrangement of bonds	1
(a)(ii)	sp^2 overlap of (2)s with two (2)p (atomic) orbitals	1
	sp^3 overlap of (2)s with all three (2)p (atomic) orbitals	1
(a)(iii)	sp^2 = 116° – 124°	1
	sp^3 = 106° – 112°	1
(b)(i)		1
(b)(ii)	(electrophilic) addition	1
	bromine decolourises / turns colourless / fades (from orange / brown)	1
(b)(iii)	$HOCH_2CHBrCH_2Br$ OR 	1
(b)(iv)	CO_2 / carbon dioxide	1
(c)(i)	**P** = propanal	1
	Q = propanone	1
(c)(ii)	tr(i)iodomethane / CHI_3 /  / 	1
(d)(i)	(molecules / isomers with) the same (molecular and) structural formula	1
	Any two of: chiral centre / C attached to four different groups / atoms non-super(im)posable mirror images different spatial / 3D arrangement of atoms (owtte) different rotation of plane-polarised light	1
(d)(ii)		
	curly arrow from lone pair on :C≡N to $C^{(\delta+)}$	1
	correct dipole on carbonyl $^{\delta+}C=O^{\delta-}$ AND curly arrow from bond to $O^{(\delta-)}$	1
	correct intermediate, including $C–O^-$ AND curly arrow from lone pair to H^+	1
	Total:	**19**

147. 9701_m16_ms_22 Q: 3

(a) (i)	 three bonding pairs lone pair AND octet shape = (trigonal) pyramidal	[1] [1] [1]
(ii)	sigma(σ) bond  OR  pi(π) bond 	[1] [1]
(b) (i)	forward and backward reactions occurring <u>at same rate</u> OR <u>the rate of</u> forward and backward reactions are equal	[1]
(ii)	M1 = decreased yield of products / less products formed / ora M2 = <u>left</u>-hand side has fewer moles of gas OR equilibrium shifts to the <u>left</u>	[1] [1]
(c)	 M1 = correct Boltzmann curve M2, M3 any 2 from: • line for **both** E_a values or statement in text that catalyst lowers E_a • (catalyst) increases proportion/number of molecules/particles with energy ⩾ activation energy • so more frequent successful collisions	[1] [1] [1]
(d) (i)	nucleophilic addition	[1]
(ii)	 correct dipole on carbonyl curly arrow from lone pair on CN^- AND from C=O to O correct intermediate curly arrow from lone pair on O^- to H^+ correct product	[1] [1] [1] [1] [1]

148. 9701_s16_ms_22 Q: 5

(a) (i)	acidified / H^+ AND potassium / sodium dichromate	[1]
(ii)	distillation (rather than reflux) (ensures aldehyde escapes) to avoid further oxidation / to avoid forming acid / as reflux causes further oxidation	[1] [1]
(b)	reaction 3 – (conc) H_2SO_4 / (conc) H_3PO_4 or Al_2O_3 / pumice / porcelain / porous pot / ceramic AND heat reaction 4 – KBr / NaBr with (conc) H_2SO_4 or (red)P and Br_2 / PBr_3 AND heat	[1] [1]
(c) (i)	 M1 = lone pair on C of CN^- AND curly arrow from lone pair to carbonyl carbon M2 = dipole on C=O AND curly arrow to O from = M3 = intermediate with negative charge M4 = lone pair and curly arrow to H^+	[1] [1] [1] [1]
(ii)		[1+1]
(iii)	attack / attach from either side / above or below / from two directions because the carbonyl / molecule is planar / trigonal / flat / because of the shape of the molecule OR product is chiral / has a chiral carbon / has a carbon attached to four different groups / has a chiral centre / is asymmetric (equal) chance of forming either (of the two optical isomers) / mechanism doesn't distinguish between the two (optical isomers) / able to form either / chance of forming / able to form 50:50 OR because the carbonyl / molecule is planar / trigonal / flat OR because of the shape of the molecule (equal) chance of forming either (of the two optical isomers) / mechanism doesn't distinguish between the two (optical isomers) / able to form either / chance of forming / able to form 50:50	[1] [1]

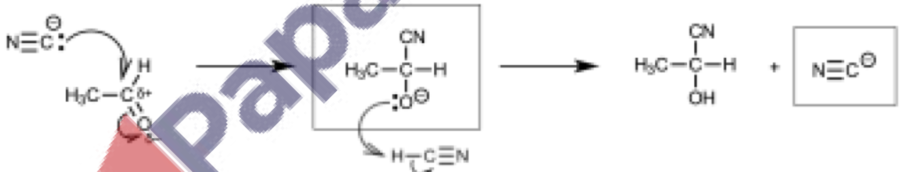
149. 9701_w16_ms_21 Q: 5

(a)		1	1
(b)	H^+ / $Cr_2O_7^{2-}$ (heat under) reflux	1 1	2
(c)	H^+ / $Cr_2O_7^{2-}$ (heat and) distil	1 1	2
(d)	(1-)propyl propanoate	1	1
	Total:		**6**

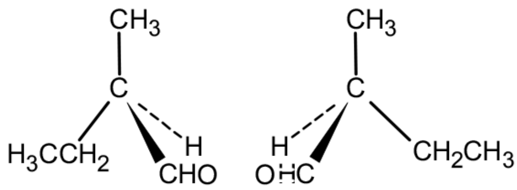
150. 9701_w16_ms_22 Q: 5

(a)(i)	$Cl\bullet$ and $\bullet CH_3$	1
(a)(ii)	Cl^- and $^+CH_3/CH_3^+$	1
(b)(i)	Oxidation **OR** reduction	1
(b)(ii)	Condensation	1
(b)(iii)	Reduction **OR** oxidation **OR** addition	1
(b)(iv)	Addition	1
	Total:	**6**

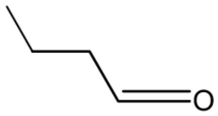
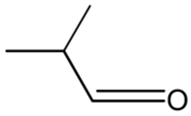
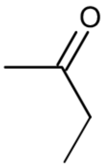
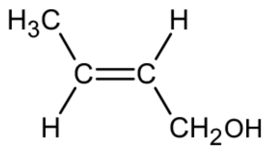
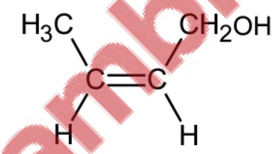
151. 9701_S15_ms_21 Q: 3

(a)	Bond breaking = C=O = 740 C–H = 410 = 1150 kJ	[1]
	Bond forming = C–C = 350 C–O = 360 O–H = 460 = 1170 kJ	[1]
	Enthalpy change = 1150 – 1170 = **–20** kJ mol^{-1}	[1]
(b) (i)	Stereoisomerism = (molecules with the same molecular formula and) same structural formula but different spatial arrangements of atoms	[1]
	Chiral centre = atom with four different atoms/groups attached	[1]
(ii)	(Planar) carbonyl so (equal chance of nucleophile) attacking either side	[1]
(c) (i)		
	M1 = lone pair **AND** curly arrow from lone pair to carbonyl C	[1]
	M2 = partial charges on C=O **AND** curly arrow from bond (=) to O$^{\delta-}$	[1]
	M3 = structure of intermediate including charge	[1]
	M4 = lone pair **AND** two correct curly arrows (from lone pair to H **AND** from H—C to C)	[1]
	M5 = CN$^-$	[1]
(ii)	(CN$^-$ regenerated so) catalyst	[1]

152. 9701_S15_ms_22 Q: 4

(a) (i)	**A** = $CH_3CH_2CH_2CH_2CHO$	[1]
	B = $CH_3CH_2CH(CH_3)CHO$	[1]
	C = $(CH_3)_2CHCH_2CHO$	[1]
	D = $(CH_3)_3CCHO$	[1]
(ii)		[1+1]
(b) (i)	Fehling's / Benedict's **OR** Tollens' **OR** dichromate **OR** manganate	[1]
	Warm / heat	[1]
	Fehling's / Benedict's =(Brick)-red ppt Tollens' = silver / mirror **OR** grey/black precipitate Dichromate = orange to green Manganate = purple to colourless } with the aldehyde / A-D	[1]
(ii)	(2,4-)DNP(H) / Brady's reagent	[1]
	Orange / yellow / red-orange / yellow-orange ppt	[1]

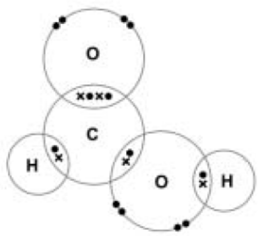
153. 9701_S15_ms_23 Q: 3

(a) (i)	**A/B** =   **C** = 	[1] [1] [1]
(ii)	Chain	[1]
(iii)	Silver mirror/ppt/solid (black/grey)	[1]
(b) (i)	**D**: $CH_2{=}C(CH_3)CH_2OH$ **E**:  trans **OR** *E* **E**:  cis **OR** *Z* **F**: $H_2C{=}CHCH_2CH_2OH$	[1] [1+1] [1] [1]
(ii)	Hydrogen	[1]
(c) (i)	$C_3H_6O + [O] \rightarrow C_3H_6O_2$	[1]
(ii)	$C_3H_6O + 2[H] \rightarrow C_3H_8O$	[1]

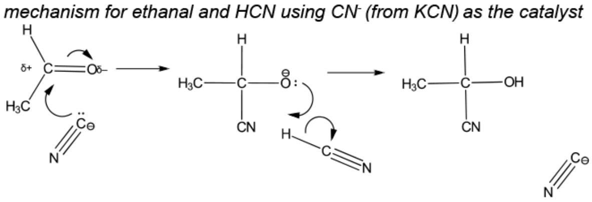
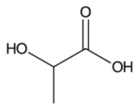
154. 9701_s21_ms_21 Q: 1

Question	Answer	Marks
(a)(i)	**option 1** **M1** the mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecule(s)	1
	option 1 and **M2** relative / compared to 1 / 12 (the mass) of **an atom** of carbon–12	1
	OR on a scale in which a carbon–12 atom / isotope has a mass of (exactly) 12 (units) **option 2** **M1** mass of one mol of molecules	
	option 2 **M2** relative / compared to 1 / 12 (the mass) of 1 mol of C-12 OR which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g	
(a)(ii)	CO_2H	1
(a)(iii)	$0.18/90 \times 2 \times 6.02 \times 10^{23} = 2.408 \times 10^{21}$ (atoms) OR $\mathbf{2.4(1) \times 10^{21}}$ (atoms) **M1** no mole ethanedioic acid 0.18 / 90 = 0.0020	1
	M2 no mole ethanedioic acid × 2 0.0020 × 2 = 0.0040	1
	M3 no mole ethanedioic acid × 6.02×10^{23} 2.4×10^{21}	1
(b)(i)	$CaC_2O_4(s) \rightarrow CaO(s) + CO_2(g) + CO(g)$ **M1** correct formulae	1
	M2 balancing equation AND state symbols.	1
(b)(ii)	(thermal) decomposition OR disproportionation	1
(b)(iii)	calcium carbonate / $CaCO_3$	1

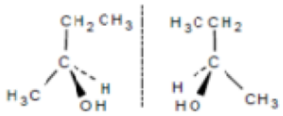
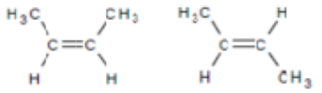
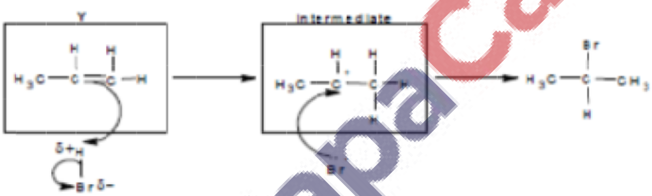
155. 9701_s21_ms_21 Q: 4

Question	Answer	Marks
(a)	Br / bromine as the oxidation number of Br decreases / goes from 0 → –1 OR bromine as it causes oxidation number of C (in methanoic acid) to increase / go from (+)2 → (+)4	1
(b)	(solution) turns (from brown / orange / red to) colourless / decolorises OR brown / orange / red fades	1
(c)(i)	rate = total change in concentration of Br_2 divided by time taken *calculation dependent on graph* *$(100 \times 10^{-5} - 12 \times 10^{-5}) / 600$* **M1** average rate of reaction 1.47×10^{-6}	1
	M2 units mol dm^{-3} s^{-1}	1
(c)(ii)	graph shown on same axes has steeper initial gradient AND reaches the same final $[Br_2]$	1
(c)(iii)	**M1** (at increased temp the average kinetic) energy of particles / species / molecules increases.	1
	M2 (many) more/greater proportion of particles with energy ⩾ E_a	1
(d)	 **M1** correct bonding electrons	1
	M2 correct number of non-bonding electrons around each oxygen	1

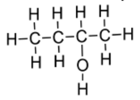
156. 9701_s20_ms_22 Q: 5

<table>
<tr><td>(a)</td><td>
<table>
<tr><td>Rxn.</td><td>name of mechanism</td><td>Name of reagents and conditions</td></tr>
<tr><td>1</td><td>M1 electrophilic addition</td><td>M2 steam AND
concentrated phosphoric acid (catalyst)</td></tr>
<tr><td>2</td><td></td><td>M3 & M4 Two marks for name of reagent and both conditions.
One mark for name of reagent and one conditions
acidified potassium dichromate ((VI))
condition 1 warm
condition 2 distil NOT reflux</td></tr>
<tr><td>6</td><td>M5 nucleophilic substitution</td><td>M6
ammonia (alcoholic) AND
heat in a sealed tube / heat under pressure</td></tr>
</table>
</td><td>6</td></tr>
<tr><td>(b)(i)</td><td>mechanism for ethanal and HCN using CN^- (from KCN) as the catalyst

M1arrow from lone pair of electrons on $:CN^-$ to C of C=O
M2 correct dipole on $C^{\delta+}=O^{\delta-}$ AND arrow from the double bond to or beyond the O of C=O
M3 arrow from lone pair of electrons on O of intermediate to H of HCN AND arrow from H-C bond to C of H-C≡N</td><td>3</td></tr>
<tr><td>(b)(ii)</td><td>ALLOW in any order
M1 nitrile
M2 (secondary) alcohol</td><td>2</td></tr>
<tr><td>(b)(iii)</td><td>
ALLOW any unambiguous structure</td><td>1</td></tr>
</table>

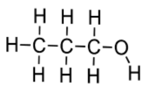
157. 9701_w15_ms_22 Q: 4

(a) (i)	Nucleophilic Substitution	[1]
(ii)	Has a chiral centre / carbon OR has a <u>carbon / C</u> attached to 4 different groups / atoms / chains OR has no plane / line of symmetry	[1]
(iii)		[1+1]
(iv)	Elimination	[1]
(v)	 *cis*-but-2-ene *trans*-but-2-ene	[1] [1]
(vi)	But-1-ene 2 Hs on one of the double-bonded Cs OR does not have 2 different groups on both atoms / each atom in C=C	[1] [1]
(b) (i)	ammonia / NH_3	[1]
(ii)	propanoyl chloride / C_2H_5COCl	[1]
(iii)	$CH_3CH(NHCOC_2H_5)CH_3$	[1]
(iv)	Reduction $LiAlH_4$ / $NaBH_4$ / H_2 and Ni / tin and concentrated HCl	[1] [1]
(v)	aluminium oxide	[1]
(vi)	 M1 = correct structure of **Y** and curly arrow from double bond to H M2 = dipole and curly arrow from H-Br bond to Br M3 = correct intermediate M4 = Br^- with lone pair and curly arrow from lone pair to C(+)	[1] [1] [1] [1]
(vii)	electrophilic addition	[1]
(viii)	secondary carbocation more stable than primary due to electron releasing character / (positive) inductive effect of alkyl groups	[1] [1]

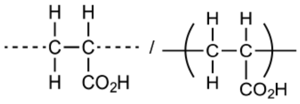
158. 9701_s20_ms_23 Q: 5

(a)(i)	dehydration	**1**
(a)(ii)	**M1** correct identification of butan-2-ol **M2** correct displayed formula including correct connectivity of C–O–H 	**2**
(a)(iii)	isomer / name: C – cis but-2-ene D – trans but-2-ene E – but -1-ene 2 marks for 3 correct names 1 mark for 2 correct names	**2**
(b)(i)	Functional group: F – **M1** Ester / RCOOR(') / $RCO_2R^{(')}$ G – **M2** Carboxyl / carboxylic acid / RCOOH H – **M3** Alcohol / hydroxy / R-OH	**3**
(b)(ii)	triiodomethane	**1**
(b)(iii)	**M1 G** = HCOOH / HCO_2H **M2 H** = C_2H_5OH	**2**

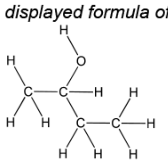
159. 9701_s19_ms_22 Q: 5

(a)(i)	(n–)propyl ethanoate	**1**
(a)(ii)	NaOH / sodium hydroxide	**1**
a(iii)		**1**
(a)(iv)	perfume / solvent	**1**
(b)(i)	**M1** *divide by A_r* C: 54.5 / 12 H: 9.1 / 1 O: 36.4 / 16	**1**
	M2 *divide by smallest number* 4.54 / 2.275 (= 2 OR 1.99) 9.1 / 2.275(=4) 2.275 / 2.275 (=1)	**1**
	M3 *empirical formula based on correctly rounded values of M2* C_2H_4O	**1**
(b)(ii)	(relative) molecular mass / M_r	**1**
(c)(i)	$C_3H_6O_2$	**1**
(c)(ii)	X and Z – no reaction / no (visible) change	**1**
	Y – effervesces	**1**
(d)	$2HCO_2H + Na_2CO_3 \rightarrow 2HCO_2Na + CO_2 + H_2O$	**1**

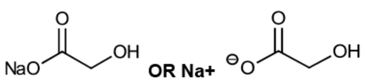
160. 9701_m21_ms_22 Q: 3

Question	Answer	Marks
(d)(i)	addition polymerisation	**1**
(d)(ii)		**1**
(d)(iii)	propan-1-amine / 1-aminopropane	**1**
(d)(iv)	alcoholic / ethanolic solution **AND** high pressure / heat in a sealed container	**1**

161. 9701_s21_ms_22 Q: 5

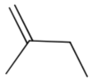
Question	Answer	Mark
(a)	*displayed formula of butan-2-ol structure with O—H shown* 	**1**
(b)(i)	2-bromobutane	**1**
(b)(ii)	substitution	**1**
(b)(iii)	*reagent* **M1** NaCN or KCN	**1**
	conditions **M2** ethanolic AND heat (under reflux)	**1**
(b)(iv)	(1)C_4H_9CN + (1)H^+ + 2H_2O → (1)$C_4H_9CO_2H$ + (1)NH_4^+ ✓✓ *correct organic product showing carboxylic acid functional group* **M1** $C_4H_9CO_2H$ / C_4H_9COOH	**1**
	M2 balanced equation with a $C_5H_{10}O_2$ or equivalent structure as product	**1**
(b)(v)	2200–2250 (cm^{-1} due to) C≡N / triple bond between C and N.	**1**

162. 9701_w21_ms_21 Q: 4

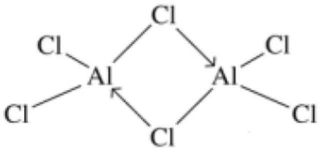
Question	Answer	Marks
(a)(i)	potassium/sodium dichromate [(VI)] / $K_2Cr_2O_7$ / $Na_2Cr_2O_7$ acidified **AND** (heat) under reflux	**2**
(a)(ii)	$C_2H_5OH + 2[O] \rightarrow CH_3CO_2H + H_2O$	**1**
(a)(iii)	substitution	**1**
(a)(iv)	in the same phase / in same state	**1**
(b)	**M1** ester **M2** 1100 cm^{-1} linked to C—O **AND** 1720 cm^{-1} linked to C=O **M3** No COOH / carboxylic acid and No OH / alcohol in D (but present in C) **OR** COOH / carboxylic acid and OH / alcohol reacted /lost (in C to form D)	**3**
(c)(i)		**1**
(c)(ii)	Not a strong (enough) reducing agent	**1**

Question	Answer	Marks
(c)(iii)	*Construct an equation* $(CH_2OH)_2 + SOCl_2 \rightarrow (CH_2Cl)_2 + SO_2 + H_2O$	1
(d)	Forms hydrogen bonds **with water**	1

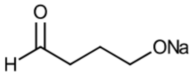
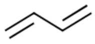
163. 9701_s20_ms_21 Q: 6

(a)		1
(b)(i)	hot **AND** concentrated	1
(b)(ii)	oxidation	1
(c)	*Structural formula of **X**:* HCO_2H OR HCOOH	1
(d)	**M1** *reagent* (2,4–) DNPH / (2,4)-dinitrophenylhydrazine **M2** *observation* yellow / orange / red precipitate	2
(e)	*Predict **two** differences, with reasons, between spectra of **Y**, $CH_3CH_2COCH_3$ and 2-methylbut-1-ene (shown)* *first difference* **M1** absence of peak/ absorption at 3100 (cm^{-1}) as no longer any =C–H present (in **Y**) *second difference* **M2** peak at 1650 (cm^{-1}) moves to the left to any value / range of values between 1670 and 1740) due to disappearance of C=C (in **Y**) and appearance of C=O (in **Y**) OR absence of peak at 1650 (cm^{-1}) as no longer any C=C present (in **Y**) AND appearance of peak (in **Y**) at (any value / range of values) between 1670-1740(cm^{-1}) due to C=O	2
(f)(i)	$CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$	1
(f)(ii)	propan-1-ol ALLOW propan-2-ol as error carried forward from **6f(i)**	1
(g)(i)	*Molecular formula of **W*** $C_3H_6O_2$	1
(g)(ii)	*Possible structure of **W*** CH_3COOCH_3 **OR** $HCOOCH_2CH_3$	1

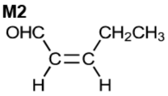
164. 9701_w20_ms_21 Q: 3

(a)(i)	**M1:** *correct representation of Al_2Cl_6, dot and cross or line diagram*  **M2: TWO** correct co-ordinate bonds identified	**2**
(a)(ii)	120	**1**
(a)(iii)	Li^+ is $1s^2$ H^- is $1s^2$	**1**
(a)(iv)	(Lattice of) cations / positive ions surrounded by **delocalised** electrons'	**1**
(b)	$Al(OH)_3$ / aluminium hydroxide	**1**
(c)(i)	**M1:** potassium dichromate[(VI)] **M2:** acid(ified) AND (heat under) **reflux**	**2**
(c)(ii)	**(M1:** *correct identity of* ***R*** *and statement re: reaction 3 ONLY ketone reduced*) **R** (is 2-hydroxybutanoic acid) **AND** as (only) C=O / ketone reduced **(M2:** *correct explanation re: strength of reducing agents*) $NaBH_4$ cannot reduce the COOH / **carboxylic acid** **OR** $LiAlH_4$ can reduce the COOH / **carboxylic acid**	**2**
(c)(iii)	 **M1:** Presence of :CN (if bonding shown, must be unambiguous triple bond) **M2:** curly arrow from :CN lone pair to carbonyl carbon **M3:** correct dipole **AND** curly arrow from double bond to oxygen **M4:** correct intermediate drawn	**4**
(c)(iv)	$C_2H_5CH(OH)CN$ + **HCl + $2H_2O$** → $C_2H_5CH(OH)COOH$ + **NH_4Cl**	**1**
(c)(v)	Any two of three absorption references: • absorption 2200–2250 (cm^{-1}) shows presence of C≡N • lack of absorption at 1680–1730 (cm^{-1}) shows lack of C=O • lack of absorption at 2500–3000 (cm^{-1}) shows lack of RCO_2–H / O–H in RCO_2H	**2**

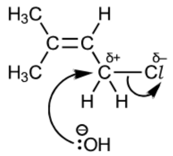
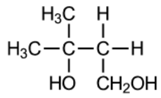
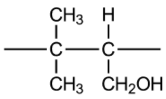
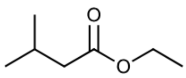
165. 9701_w20_ms_22 Q: 4

<table>
<tr><td>(a)(i)</td><td>oxidation</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>M1: potassium dichromate[(VI)]
M2: acid(ified) AND (heat under) reflux</td><td>2</td></tr>
<tr><td>(a)(iii)</td><td>structure of H

OR $CHO(CH_2)_2CH_2O^- Na^+$</td><td>1</td></tr>
<tr><td>(a)(iv)</td><td>(formation of) silver mirror / ppt</td><td>1</td></tr>
<tr><td>(a)(v)</td><td>esterification</td><td>1</td></tr>
<tr><td>(b)(i)</td><td>positional (isomerism) / regioisomerism</td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>M1: add aqueous alkaline iodine
M2: G no change AND J yellow ppt</td><td>2</td></tr>
<tr><td>(b)(iii)</td><td>reducing agent</td><td>1</td></tr>
<tr><td>(b)(iv)</td><td>(1,3-)butadiene OR buta(-1,3-)diene OR </td><td>1</td></tr>
<tr><td>(c)</td><td><table>
<tr><th>reagent</th><th>result with P</th><th>result with Q</th></tr>
<tr><td>Br_2(aq)</td><td>no change / stays orange</td><td>no change / stays orange</td></tr>
<tr><td>2,4-DNPH</td><td>no change</td><td>orange ppt</td></tr>
<tr><td>Na_2CO_3</td><td>effervescence</td><td>no change</td></tr>
</table>
Award one mark for every two correct observations.</td><td>3</td></tr>
<tr><td>(d)(i)</td><td>X is C=O AND Z is C—O</td><td>1</td></tr>
<tr><td>(d)(ii)</td><td>hexanoic acid</td><td>1</td></tr>
<tr><td>(d)(iii)</td><td>$C_{12}H_{20}O_2$</td><td>1</td></tr>
</table>

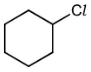
166. 9701_m19_ms_22 Q: 3

<table>
<tr><td>(a)</td><td><table>
<tr><th></th><th>P</th><th>Q</th><th>R</th></tr>
<tr><td>Na(s)</td><td>effervescence</td><td>no reaction</td><td>no reaction</td></tr>
<tr><td>2,4-DNPH</td><td>no reaction</td><td>orange ppt</td><td>orange ppt</td></tr>
<tr><td>acidified $K_2Cr_2O_7$(aq)</td><td>no reaction</td><td>no reaction</td><td>(turns) green</td></tr>
</table></td><td>3</td></tr>
<tr><td>(b)</td><td>$C_5H_{10}O + 2[H] \rightarrow C_5H_{12}O$</td><td>1</td></tr>
<tr><td>(c)</td><td>M1 geometric(al)
M2
</td><td>2</td></tr>
<tr><td>(d)</td><td>M1 compound P
M2 (absorption at) 2250 cm^{-1} AND C≡N (stretch)
M3 (absorption at) 3100–3700 cm^{-1} AND O—H (stretch)</td><td>3</td></tr>
</table>

167. 9701_w19_ms_22 Q: 4

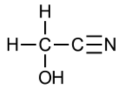
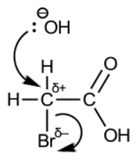
(a)	 **M1:** curly arrow from lone pair on O of OH^- to C of C—C*l* **M2:** correct dipole on C—C*l* **AND** curly arrow from C—C*l* bond to $Cl^{\delta-}$	2
(b)(i)		1
(b)(ii)	$(CH_3)_2CHCH(OH)CH_2OH$	1
(b)(iii)	optical (isomerism)	1
(b)(iv)	$C_5H_{12}O_2 + 3[O] \rightarrow C_5H_8O_3 + 2H_2O$	1
(c)(i)	Add bromine water / $Br_2(aq)$ **AND** turns (from orange / brown to) colourless	1
(c)(ii)		1
(d)(i)	3-methylbutan-1-ol	1
(d)(ii)	heterogeneous	1
(d)(iii)	**M1:** skeletal formula of Q  ONLY **M2:** **one** commercial use of Q (ethyl isovalerate / ethyl 3methylbutyrate) solvents / perfumes / flavourings	2
(e)(i)	1500–1680 (cm^{-1}) **AND** C=C	1
(e)(ii)	potassium cyanide / KCN / sodium cyanide / NaCN	1
(e)(iii)	(acidic) hydrolysis	1
(e)(iv)	**M1:** recognise this reaction involves less stable intermediate 1° (carbo)cation (intermediate) is less stable (than 3°) **M2:** explain difference in reactivity in terms of positive inductive effect – comparative answer lower (positive) inductive effect / lower (+)I **OR** inductive effect of **less** alkyl groups	2

168. 9701_m18_ms_22 Q: 4

(a)(i)	ultraviolet / UV light	1
(a)(ii)	initiation HC*l* propagation 	4
(b)	elimination	1
(c)(i)	acidified **AND** $KMnO_4$ hot **AND** <u>c</u>(oncentrated)	2
(c)(ii)	cyclohexene would have absorption at 1500–1680 (cm^{-1}) because of C=C (and adipic acid would not) cyclohexene would have absorption at 3000–3100 (cm^{-1}) because of =C—H/C—H in alkene (and adipic acid would not) adipic acid would have absorption at 2500–3000 (cm^{-1}) because of O—H/CO_2—H (and cyclohexene would not) adipic acid would have absorption at 1040–1300 (cm^{-1}) because of C—O (and cyclohexene would not) adipic acid would have absorption at 1640–1750 (cm^{-1}) because of C=O (and cyclohexene would not)	**max 3**

169. 9701_w18_ms_21 Q: 4

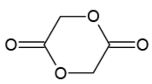
<table>
<tr><td>(a)</td><td>
<table>
<tr><th>reagent</th><th>observation with glycolic acid</th><th>does a reaction occur? ✓ / ×</th><th>functional group</th></tr>
<tr><td>$Na_2CO_3(aq)$</td><td>effervescence / fizzing / bubbling</td><td>✓</td><td>COOH / carboxylic acid</td></tr>
<tr><td>2,4–DNPH</td><td>no visible reaction owtte</td><td>×</td><td>(no group required)</td></tr>
<tr><td>acidified $Cr_2O_7^{2-}$</td><td>orange to green</td><td>✓</td><td>–OH / alcohol</td></tr>
</table>
1 mark for each in column 2 (obs)

1 mark for COOH and OH</td><td>4</td></tr>
<tr><td>(b)(i)</td><td></td><td>1</td></tr>
<tr><td>(b)(ii)</td><td>hydrochloric / sulfuric / nitric / phosphoric acid</td><td>1</td></tr>
<tr><td>(b)(iii)</td><td>free-radical substitution</td><td>1</td></tr>
<tr><td>(b)(iv)</td><td>UV (light) / sunlight</td><td>1</td></tr>
<tr><td>(b)(v)</td><td>

M1 lone pair on ^-OH AND curly arrow from lone pair to C of C—Br

M2 correct dipole on C—Br AND curly arrow from bond to Br</td><td>2</td></tr>
<tr><td>(c)(i)</td><td>reducing agent / reductant</td><td>1</td></tr>
<tr><td>(c)(ii)</td><td>$C_2H_2O_3 + 2[H] \rightarrow C_2H_4O_3$
M1 for correct molecular formulae $C_2H_2O_3$ and $C_2H_4O_3$
M2 for balancing</td><td>2</td></tr>
<tr><td>(d)(i)</td><td>EITHER
Glycolic acid would have:
M1 2500–3000 due to RCO_2-H
M2 range within 3200–3650 due to RO–H

OR

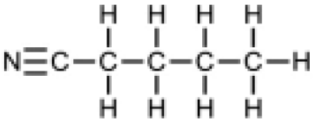
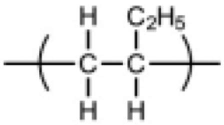
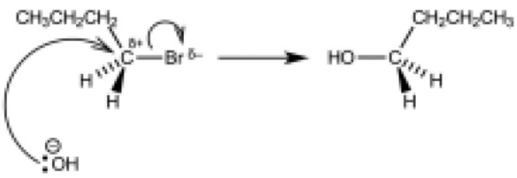
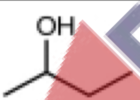
Spectrum Y would NOT have:
M1 2500–3000 due to RCO_2-H
M2 range within 3200–3650 due to RO–H</td><td>2</td></tr>
<tr><td>(d)(ii)</td><td>

M1 ANY ester group AND valid $C_4H_4O_4$ molecule
M2 correct cyclic structure</td><td>2</td></tr>
</table>

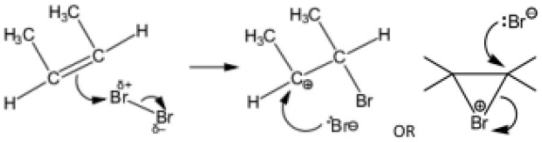
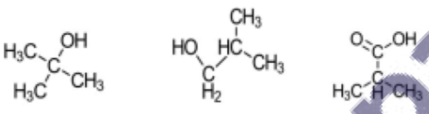
170. 9701_w18_ms_22 Q: 3

(a)	ΔH_r = (–692.9)+3(–61.8)- (–182.1) –3(–204.6) = –82.4 (kJ mol^{-1}) **M1** ΔH_r = *x*(–692.9) + *y*(–61.8) –*v*(–182.1) –*w*(–204.6) where *x y v* and *w* are integers ⩾1 [1] **M2** use of correct stoichiometry where *x* =1 *y* =3 *v* =1 and *w*=3 [1] **M3** –82.4 [1]	3
(b)(i)	1 mark for each bullet, max 3 • particles / molecules have (mass but) negligible size / volume (compared to total volume of gas / container) • no / negligible forces / interactions between particles / molecules • collision between particles / molecules are elastic • gas obeys (all) basic gas laws	3
(b)(ii)	**M1** particles / molecules are (so) close [1] **M2** particle / molecule size becomes significant [1] OR <u>repulsive</u> forces between particle / molecules become significant	2
(c)(i)	$CHCl_3 + ½O_2 \rightarrow COCl_2 + HCl$	1
(c)(ii)	**M1 X** marked on peak at 1670–1740 cm^{-1} [1] **M2** $CHCl_3$ has no C=O [1]	2
(c)(iii)	(It / $CHCl_3$ has a) peak at 2850–2950 (cm^{-1}) OR carbonyl dichloride spectrum has no peak 2850–2950 (cm^{-1})	1

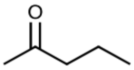
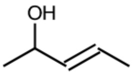
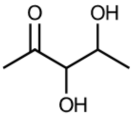
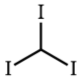
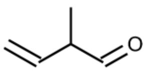
171. 9701_m17_ms_22 Q: 3

(a)(i)		**1**
(a)(ii)	reaction **1** = HC*l*(aq)	**1**
	reaction **2** = (conc.) NaOH / KOH **AND** ethanol	**1**
(a)(iii)	 C–C backbone with dangling bonds rest of structure	**2** 1 1
(b)	 lone pair on O **AND** curly arrow from O to C of C–Br dipole on C–Br **AND** curly arrow from C–Br to Br product (butan-1-ol)	**3** 1 1 1
(c)(i)	(electrophilic) addition	**1**
(c)(ii)	**S** has CH_3CHOH **OR** methyl / CH_3 group next to CHOH	**1**
(c)(iii)	positive inductive effect of more alkyl groups / more alkyl groups donate electron density	**1**
	secondary carbocation / secondary intermediate is more stable (than primary)	**1**
(c)(iv)	**S** = 	**1**
	T = 	**1**
	U = 	**1**
(c)(v)	$CH_3CHOHCH_2CH_3$ + [O] → $CH_3COCH_2CH_3$ + H_2O	**1**
(d)(i)	methyl pentanoate	**1**
(d)(ii)	(compound **V** is) spectrum X	**1**
	spectra X and Z show a C=O (stretch) at 1730 (cm^{-1})	**1**
	spectra Y and Z show O–H (stretches) above 2500 (cm^{-1})	**1**
	V has a C=O (bond) and no O–H (bond)	**1**

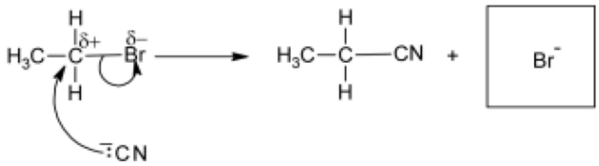
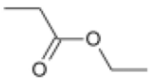
172. 9701_s17_ms_22 Q: 4

(a)(i)	(**A** =) 	**1**
(a)(ii)	(**A** / straight chain) has strong(er) (temporary dipole-) induced dipole (attractions) *ora*	**1**
	(because **A** / straight chain has) bigger (surface) area / more (points of) contact (in unbranched isomer) *ora* OR (so) more energy required to break the intermolecular forces *ora*	**1**
(a)(iii)	$CH_3CHCHCH_3$ OR $CH_3CH{=}CHCH_3$	**1**
(a)(iv)	No rotation / restricted / limited rotation of C=C / (carbon) double bond	**1**
	One (of the two) methyl groups / one (of the two) H (atoms) is on each C (of C=C)	**1**
(a)(v)	 arrow from the C=C double bond drawn to the bromine	**1**
	dipole on Br_2 in correct orientation AND arrow from the Br-Br bond to the $Br^{\delta-}$	**1**
	correct carbocation / bromonium ion from the structure with C=C drawn	**1**
	Br^- with lone pair, negative charge AND arrow from lone pair to the carbon atom of intermediate OR using both arrows shown (in alternative diagram)	**1**
(a)(vi)	electrons in pi bond induce it (the dipole) OR (high) electron density in pi bond / double bond / C=C repels electrons (away from nearest Br) OR polarised by (high) electron density in pi bond / double bond / C=C	**1**
(b)(i)	**C** = (2-)methylpropan-2-ol / $(CH_3)_3COH$ / any unambiguous structure	**1**
	D = (2-)methylpropan-1-ol / $(CH_3)_2CHCH_2OH$ / any unambiguous structure	**1**
	E = (2-)methylpropanoic acid /$(CH_3)_2CHCO_2H$ / any unambiguous structure  **C** **D** **E**	**1**
(b)(ii)	$2C_4H_8O_2 + Na_2CO_3 \rightarrow 2C_4H_7O_2Na + H_2O + CO_2$	**1**
(c)(i)	triiodomethane	**1**
(c)(ii)	**F** = $CH_3CH_2CH_2COCH_3$	**1**
	G = $C_2H_5CH(CH_3)CHO$	**1**
(c)(iii)	a (tetrahedral) atom with four different groups / atoms / substituents attached OR a carbon (atom) with four different groups / atoms / substituents attached	**1**
(d)(i)	**H** C=O (group / bond) AND O–H (group / bond)	**1**
	I C=O (group / bond) AND C–H (group / bond)	**1**
(d)(ii)	**H** = ethanoic acid	**1**
	I = methyl methanoate	**1**
	Total:	**23**

173. 9701_m16_ms_22 Q: 5

(a) (i)	Q  R  S  T 	[1] [1] [1] [1]
(ii)	pent-3-en(e)-2-one OR 3-penten-2-one	[1]
(iii)	red / orange / yellow precipitate / solid	[1]
(b)	*This question was discounted.* M1 = decolourises bromine / 1500–1600 cm^{-1} = alkene M2 = absorption at 1700 cm^{-1} is C=O AND (very) broad absorption at 2500–3000 cm^{-1} is O—H = carboxylic acid M3 = no cis-trans so terminal alkene OR chiral so contains a carbon atom with 4 different groups attached M4 = **U** is 	[1] [1] [1] [1]

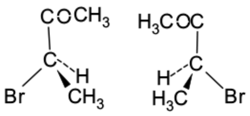
174. 9701_s16_ms_21 Q: 5

(a)		
	M1 = lone pair on C of CN− AND curly arrow from lone pair to C of C—Br	[1]
	M2 = correct dipole on C—Br, curly arrow from C—Br bond to Br AND Br^-	[1]
(b) (i)	reduction	[1]
(ii)	disappearance of peak / dip / trough / absorption at 1680–1730	[1]
	due to (loss of) C=O	[1]
	OR	
	peak at 3200–3650	[1]
	due to (alcohol) O—H (formation)	[1]
(c) (i)	sodium/potassium hydroxide aqueous	[1] [1]
(ii)	ethanol	[1]
(d) (i)	(conc) H^+ / (conc) acid / (conc)H_2SO_4 / (conc)H_3PO_4	[1]
(ii)		[1]
(iii)	ethyl propanoate	[1]
(e) (i)	**V** = $CH_3CH_2CHCHCH_2CH_3$ / $CH_3CH_2CH{=}CHCH_2CH_3$ **T** = $CH_3CH_2CH(OH)CH(OH)CH_2CH_3$	[1] [1]
(ii)	**V** = geometric(al) / *cis-trans* / *E–Z* **T** = optical	[1] [1]

175. 9701_s16_ms_22 Q: 4

(a)	$CH_3CH_2CH_2COOH$	[1]
	$(CH_3)_2CHCOOH$ / $CH_3CH(CH_3)COOH$	[1]
(b) (i)	Two from 1. $CH_3CH_2COOCH_3$ 2. $CH_3COOCH_2CH_3$ 3. $HCOOCH_2CH_2CH_3$	[1] [1]
(ii)	correct acid + alcohol for either ester 1. methanol + propanoic acid 2. ethanol + ethanoic acid 3. propan-1-ol + methanoic acid	[1]
	(conc)H_2SO_4 / (conc)H_3PO_4 AND heat / warm / reflux	[1]
(c)	Peak at 1710–1750 (for ester) due to C(=)O Peak at 1500–1680 (for **X**) due to C(=)C / alkene Peak at 3200–3650 (for **X**) due to (alcohol) O(–)H	[1] [1] [1]

176. 9701_s16_ms_23 Q: 4

(a)	3-hydroxybutan(-2-)one	[1]
(b)	H_2 / $Cr_2O_7^{2-}$ or names heat / reflux / warm	[1] [1]
(c) (i)	absorption at 1670–1740 C (=) O absorption at 2850–3000 C (-) H absorption at 3200–3650 O (-) H	[1] [1] [1]
(ii)	no absorption at 3200–3650 O-H disappears / no O-H bond in diacetyl	[1] [1]
(d) (i)	$CH_3COCH(=)CH_2$	[1]
(ii)	one of the double-bonded C atoms / first C has 2H atoms attached **ora** so no cis-trans / *E-Z* / geometric(al) isomerism possible OR no chiral C so mirror images superimposable / molecule not asymmetric	[1] [1]
(iii)	asymmetric / chiral C atom / carbon with four different groups / atoms attached	[1]
(iv)		[1+1]

177. 9701_w18_ms_22 Q: 1

<table>
<tr><td>(a)</td><td>
<table>
<tr><td>particle</td><td>relative mass</td><td>relative charge</td><td>location</td><td>total number in an atom of ^{197}Au</td></tr>
<tr><td>electron</td><td>0.0005</td><td>–1</td><td>shell(s) [1]</td><td>79</td></tr>
<tr><td>neutron</td><td>1.(001) [1]</td><td>0 [1]</td><td>nucleus</td><td>118 [1]</td></tr>
</table>
</td><td>4</td></tr>
<tr><td>(b)</td><td>metallic</td><td>1</td></tr>
<tr><td>(c)(i)</td><td>M1 (atoms of the same element) with the same proton / atomic number [1]

M2 (but) different number of neutrons/mass number [1]</td><td>2</td></tr>
<tr><td>(c)(ii)</td><td>same number of electrons/electronic structure</td><td>1</td></tr>
<tr><td>(d)(i)</td><td>(100 – 56.36 – 25.14) = 18.5(0)</td><td>1</td></tr>
<tr><td>(d)(ii)</td><td>M1 correct use of ^{63}Cu and ^{65}Cu and their % abundance [1]

M2 ÷ (56.36 + 25.14) AND answer correct to two decimal places [1]</td><td>2</td></tr>
</table>