International Baccalaureate®
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Chemistry

Higher and standard level

Specimen papers 1, 2 and 3

For first examinations in 2016

CONTENTS

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CHEMISTRY
HIGHER LEVEL
PAPER 1

SPECIMEN PAPER

1 hour

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- The periodic table is provided for reference on page 2 of this examination paper.
- The maximum mark for this examination paper is *[40 marks]*.

The Periodic Table

Atomic number
Element
Relative atomic mass

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.90
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (270)	108 **Hs** (269)	109 **Mt** (278)	110 **Ds** (281)	111 **Rg** (281)	112 **Cn** (285)	113 **Unt** (286)	114 **Uug** (289)	115 **Uup** (288)	116 **Uuh** (293)	117 **Uus** (294)	118 **Uuo** (294)

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

1. Which changes of state are endothermic processes?

I. Condensing
II. Melting
III. Subliming

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

2. What is the sum of the coefficients when the equation for the combustion of ammonia is balanced using the smallest possible whole numbers?

$$\_\_\_ NH_3(g) + \_\_\_ O_2(g) \rightarrow \_\_\_ N_2(g) + \_\_\_ H_2O(g)$$

A. 6

B. 12

C. 14

D. 15

3. 5.00 g of calcium carbonate, when heated, produced 2.40 g of calcium oxide. Which is the correct expression for the percentage yield of calcium oxide? ($M_r(CaCO_3) = 100$; $M_r(CaO) = 56$.)

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

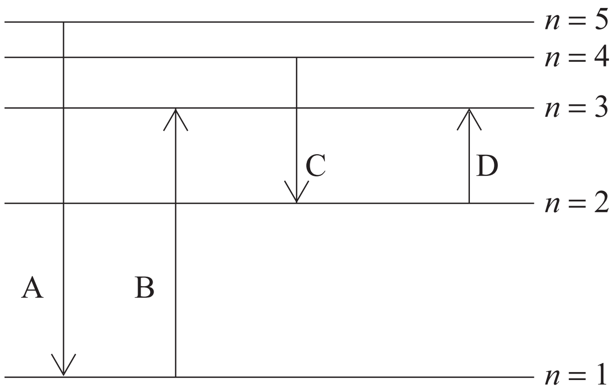
A. $\dfrac{56 \times 5.00 \times 100}{2.40}$

B. $\dfrac{2.40 \times 100 \times 100}{56 \times 5.00}$

C. $\dfrac{56 \times 5.00 \times 100}{2.40 \times 100}$

D. $\dfrac{2.40 \times 100}{56 \times 5.00}$

4. Which electronic transition would absorb the radiation of the shortest wavelength?



5. Which is the electron configuration of the ion Fe^{2+}?

A. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

B. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$

C. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^4\ 4s^2$

D. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$

6. Which element is in group 2?

	1st ionization energy / kJ mol^{-1}	**2nd ionization energy / kJ mol^{-1}**	**3rd ionization energy / kJ mol^{-1}**	**4th ionization energy / kJ mol^{-1}**
A.	1402	2856	4578	7475
B.	590	1145	4912	6474
C.	403	2632	3900	5080
D.	578	1817	2745	11578

7. Which element is in the f-block of the periodic table?

A. Be

B. Ce

C. Ge

D. Re

8. Which property increases down group 1 of the periodic table?

A. Melting point

B. First ionization energy

C. Atomic radius

D. Electronegativity

9. What is the overall charge on the complex ion formed by iron(II) and six cyanide ions, CN^-?

A. 4+

B. 4–

C. 8–

D. 8+

10. Which statement about transition metal complex ions is correct?

A. The difference in energy of the d orbitals is independent of the oxidation state of the metal.

B. The colour of the complex is caused by light emitted when an electron falls back from a higher to a lower energy level.

C. The colour of the complex is the colour of the light absorbed when an electron moves from a lower to a higher energy level.

D. The difference in energy of the d orbitals depends on the nature of the ligand.

11. Which is the best description of ionic bonding?

A. Electrostatic attraction between oppositely charged ions

B. Electrostatic attraction between positive ions and electrons

C. Electrostatic attraction of nuclei towards shared electrons in the bond between the nuclei

D. Electrostatic attraction between nuclei

12. Which intermolecular forces are covered by the term van der Waals'?

I. London dispersion forces

II. Dipole-induced dipole forces

III. Dipole-dipole forces

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

13. Which bond is the **least** polar?

A. C=O in CO_2

B. C–H in CH_4

C. C–Cl in CCl_4

D. N–H in CH_3NH_2

14. Which pair of compounds contains 9 sigma, σ, and 2 pi, π, bonds in each molecule?

A. CH_3CO_2H and $CH_3CH(OH)CH_3$

B. CH_3COCH_3 and $CH_3COOCH_2CH_3$

C. $CHCCH_2CH_3$ and $CH_2CHCHCH_2$

D. CH_3COH and CH_3CH_2OH

15. Which molecule contains an atom with sp^2 hybridization?

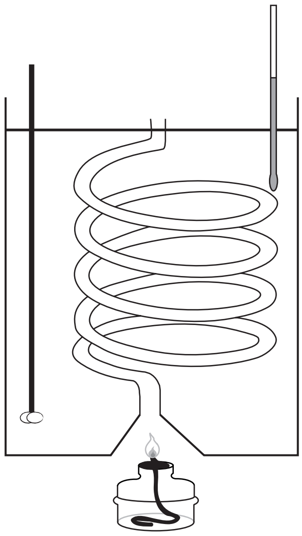
A. $CH_3CH_2CH_2NH_2$

B. $CH_3CH_2CH_2CN$

C. $CH_3CH_2CH_2CH_2Cl$

D. $CH_3CH_2CHCHCH_3$

16. When 0.46 g of ethanol is burned under a water-filled calorimeter, the temperature of 500 g of water is raised by 3.0 K. (Molar mass of ethanol = 46 g mol^{-1}; specific heat capacity of water = 4.18 J g^{-1} K^{-1}; $q = mc\Delta T$.)



What is the expression for the enthalpy of combustion, ΔH_c, in kJ mol^{-1}?

A. $-\dfrac{500 \times 4.18 \times 3.0 \times 46}{0.46}$

B. $-\dfrac{500 \times 4.18 \times (273 + 3.0) \times 46}{0.46 \times 1000}$

C. $-\dfrac{500 \times 4.18 \times 3.0 \times 46}{0.46 \times 1000}$

D. $-\dfrac{0.46 \times 1000}{500 \times 4.18 \times 3.0 \times 46}$

17. Given the following information, what is the standard enthalpy of formation, $\Delta H^{\ominus}{}_{f}$, of methane?

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = E \text{ kJ}$$
$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H = F \text{ kJ}$$
$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \qquad \Delta H = G \text{ kJ}$$

A. E + F + G

B. E + F – G

C. E + 2F + G

D. E + 2F – G

18. Which combination has the most endothermic lattice enthalpy?

	Radius of positive ion / nm	Radius of negative ion / nm	Charge on positive ion	Charge on negative ion
A.	0.100	0.185	2+	2–
B.	0.102	0.180	1+	1–
C.	0.149	0.180	1+	1–
D.	0.100	0.140	2+	2–

19. In which reaction is the value of ΔS positive?

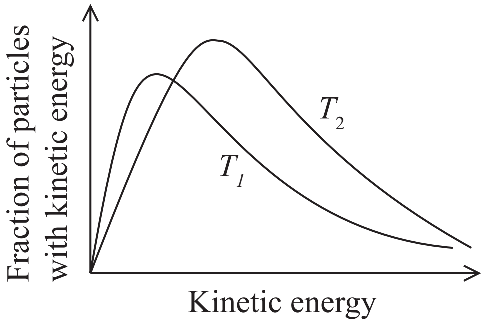
A. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

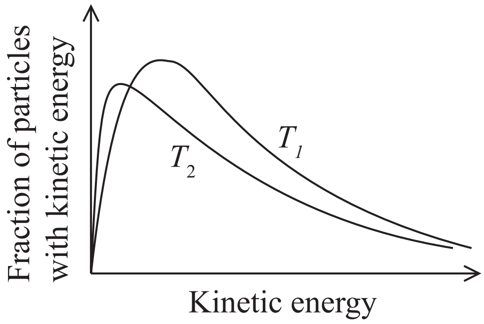
B. $H_2O(g) \rightarrow H_2O(s)$

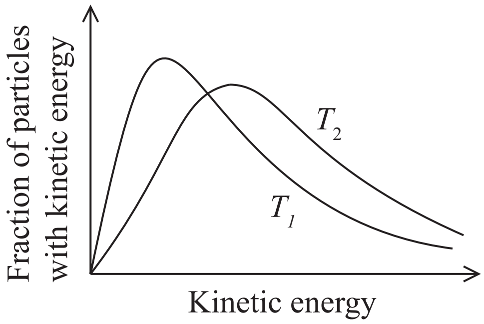
C. $2KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

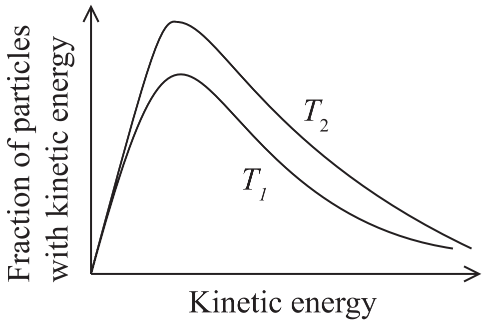
D. $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$

20. Which graph shows the Maxwell-Boltzmann energy distribution of a same amount of a gas at two temperatures, where T_2 is greater than T_1?

A.


B.


C.


D.


21. Which changes increase the rate of this reaction, other conditions remaining constant?

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

I. Using larger lumps of calcium carbonate

II. Increasing the temperature of the reaction mixture

III. Increasing the concentration of hydrochloric acid

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

22. The rate information below was obtained for the following reaction at a constant temperature.

$$H_2O_2(aq) + 2H^+(aq) + 2I^-(aq) \rightarrow 2H_2O(l) + I_2(aq)$$

Initial $[H_2O_2(aq)]$ / mol dm^{-3}	**Initial $[H^+(aq)]$ / mol dm^{-3}**	**Initial $[I^-(aq)]$ / mol dm^{-3}**	**Initial rate of reaction / mol dm^{-3} s^{-1}**
0.005	0.05	0.015	1.31×10^{-6}
0.01	0.05	0.015	2.63×10^{-6}
0.01	0.05	0.03	5.25×10^{-6}
0.01	0.1	0.03	5.25×10^{-6}

What is the overall order of the reaction?

A. 0

B. 1

C. 2

D. 3

23. Which reaction is **most** likely to be spontaneous?

	Enthalpy change	**Entropy**
A.	exothermic	entropy decreases
B.	exothermic	entropy increases
C.	endothermic	entropy decreases
D.	endothermic	entropy increases

24. Which conditions give the greatest equilibrium yield of methanal, $H_2CO(g)$?

$$CO(g) + H_2(g) \rightleftharpoons H_2CO(g) \qquad \Delta H = -1.8\,kJ$$

	Pressure	Temperature
A.	high	low
B.	high	high
C.	low	high
D.	low	low

25. Which combination of temperature and equilibrium constant is most typical of a reaction going to completion? (Refer to the equation $\Delta G = -RT \ln K$.)

	Temperature	Equilibrium constant
A.	high	> 1
B.	high	< 1
C.	low	> 1
D.	low	< 1

26. Which of the following is **not** amphiprotic?

A. H_2O

B. HPO_4^{2-}

C. $H_2PO_4^{-}$

D. H_3O^{+}

27. The pH of a solution changes from 3 to 5. What happens to the concentration of hydrogen ions?

A. It increases by a factor of 2.

B. It increases by a factor of 100.

C. It decreases by a factor of 2.

D. It decreases by a factor of 100.

28. Which statement is correct about a Lewis base?

A. It is an electron pair donor and can act as a nucleophile.

B. It is an electron pair acceptor and can act as a nucleophile.

C. It is an electron pair donor and can act as an electrophile.

D. It is an electron pair acceptor and can act as an electrophile.

29. Which mixture forms a buffer solution with a pH < 7?

A. $50\,cm^3$ $0.10\,mol\,dm^{-3}$ $NH_4Cl(aq)$ + $50\,cm^3$ $0.10\,mol\,dm^{-3}$ $NH_3(aq)$

B. $50\,cm^3$ $0.10\,mol\,dm^{-3}$ $HCl(aq)$ + $100\,cm^3$ $0.10\,mol\,dm^{-3}$ $NH_3(aq)$

C. $50\,cm^3$ $0.10\,mol\,dm^{-3}$ $NaOH(aq)$ + $100\,cm^3$ $0.10\,mol\,dm^{-3}$ $CH_3COOH(aq)$

D. $50\,cm^3$ $0.10\,mol\,dm^{-3}$ $H_2SO_4(aq)$ + $100\,cm^3$ $0.10\,mol\,dm^{-3}$ $NH_3(aq)$

30. The equations below represent reactions involved in the Winkler method for determining the concentration of dissolved oxygen in water:

$$2Mn(OH)_2(s) + O_2(aq) \rightarrow 2MnO(OH)_2(s)$$
$$MnO(OH)_2(s) + 2H_2SO_4(aq) \rightarrow Mn(SO_4)_2(s) + 3H_2O(l)$$
$$Mn(SO_4)_2(s) + 2I^-(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2SO_4^{2-}(aq)$$
$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

What is the amount, in mol, of thiosulfate ions, $S_2O_3^{2-}(aq)$, needed to react with the iodine, $I_2(aq)$, formed by 1.00 mol of dissolved oxygen?

A. 2.00

B. 3.00

C. 4.00

D. 6.00

31. What are the products when molten sodium chloride is electrolysed?

	Cathode	Anode
A.	hydrogen	chlorine
B.	sodium	chloride
C.	sodium	chlorine
D.	chlorine	sodium

32. $E^{\ominus}$ values for some half-equations are given below.

$$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s) \qquad E^{\ominus} = -1.18\,V$$
$$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s) \qquad E^{\ominus} = -0.45\,V$$
$$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s) \qquad E^{\ominus} = -0.13\,V$$

Which reaction is spontaneous under standard conditions?

A. $Fe^{2+}(aq) + Mn(s) \rightarrow Fe(s) + Mn^{2+}(aq)$

B. $Mn^{2+}(aq) + Pb(s) \rightarrow Mn(s) + Pb^{2+}(aq)$

C. $Fe^{2+}(aq) + Pb(s) \rightarrow Fe(s) + Pb^{2+}(aq)$

D. $Mn^{2+}(aq) + Fe(s) \rightarrow Mn(s) + Fe^{2+}(aq)$

33. $50.0\,cm^3$ of $0.50\,mol\,dm^{-3}$ aqueous copper(II) sulfate, $CuSO_4(aq)$, is electrolysed using a current of 0.50 A for 30 minutes. What mass of copper, in g, is deposited on the cathode?
(M(Cu) = $64\,g\,mol^{-1}$; Faraday's constant (F) = $96500\,C\,mol^{-1}$.)

A. $\dfrac{50.0 \times 0.50 \times 64}{1000}$

B. $\dfrac{0.50 \times 30 \times 64}{96500 \times 2}$

C. $\dfrac{0.50 \times 30 \times 60 \times 64}{96500 \times 2}$

D. $\dfrac{50.0 \times 0.50 \times 64}{1000 \times 2}$

34. Which is propyl propanoate?

A. $CH_3CH_2CH_2OOCCH_2CH_3$

B. $CH_3CH_2CH_2COOCH_2CH_3$

C. $CH_3CH_2CH_2COCH_2CH_3$

D. $CH_3CH_2CH_2OCH_2CH_2CH_3$

35. Which could form an addition polymer?

A. $H_2NCH_2CHCHCH_2NH_2$

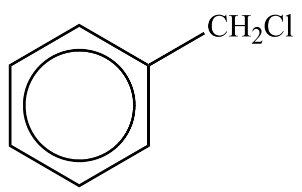
B. $H_2N(CH_2)_6CO_2H$

C. $HO(CH_2)_2CO_2H$

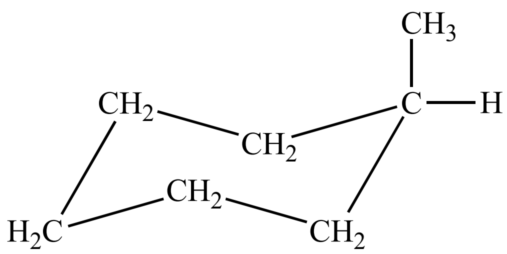
D. $H_2N(CH_2)_6NH_2$

36. Which benzene derivative can be formed from methylbenzene by electrophilic substitution?

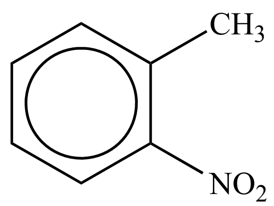
A.



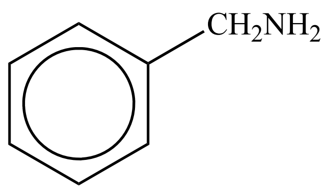
B.



C.



D.



37. Which compound has two enantiomeric forms?

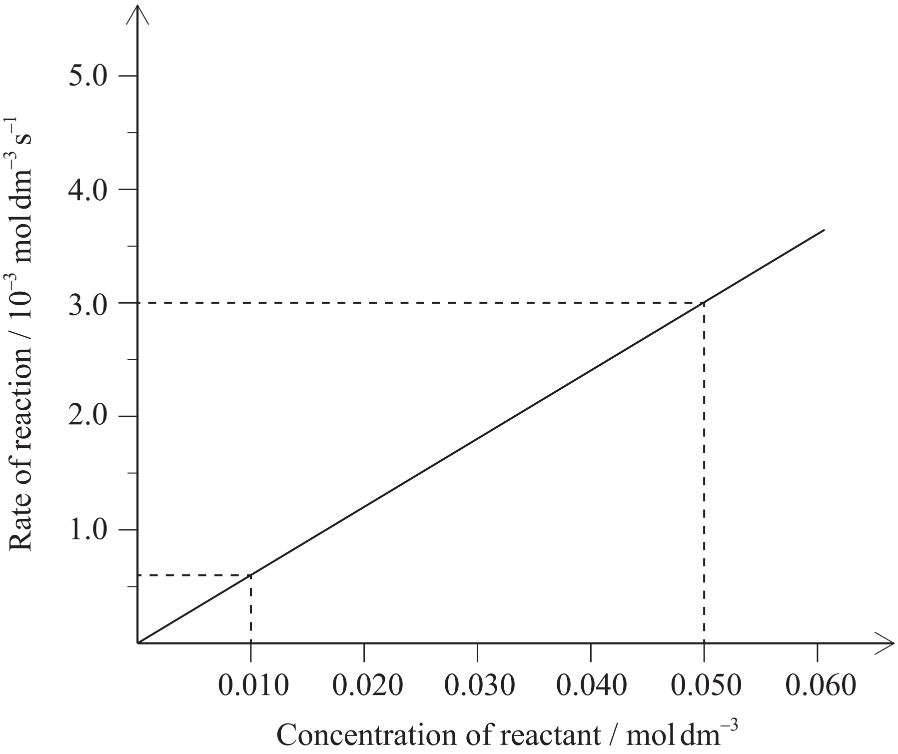
A. $CH_3CH_2CBr_2CH_3$

B. $CH_3CH_2CHBrCH_3$

C. $CH_3(CH_2)_2CH_2Br$

D. $CH_3CH_2CHBrCH_2CH_3$

38. Which combination in the table correctly states the value and units of the gradient?



	Value	Units
A.	$\dfrac{3.0\times10^{-3}-0.6\times10^{-3}}{0.050-0.010}$	s^{-1}
B.	$\dfrac{3.0\times10^{-3}-0.6\times10^{-3}}{0.050-0.010}$	s
C.	$\dfrac{0.050-0.010}{3.0\times10^{-3}-0.6\times10^{-3}}$	s^{-1}
D.	$\dfrac{0.050-0.010}{3.0\times10^{-3}-0.6\times10^{-3}}$	s

39. Which technique involves the absorption of radiation by bonds between atoms?

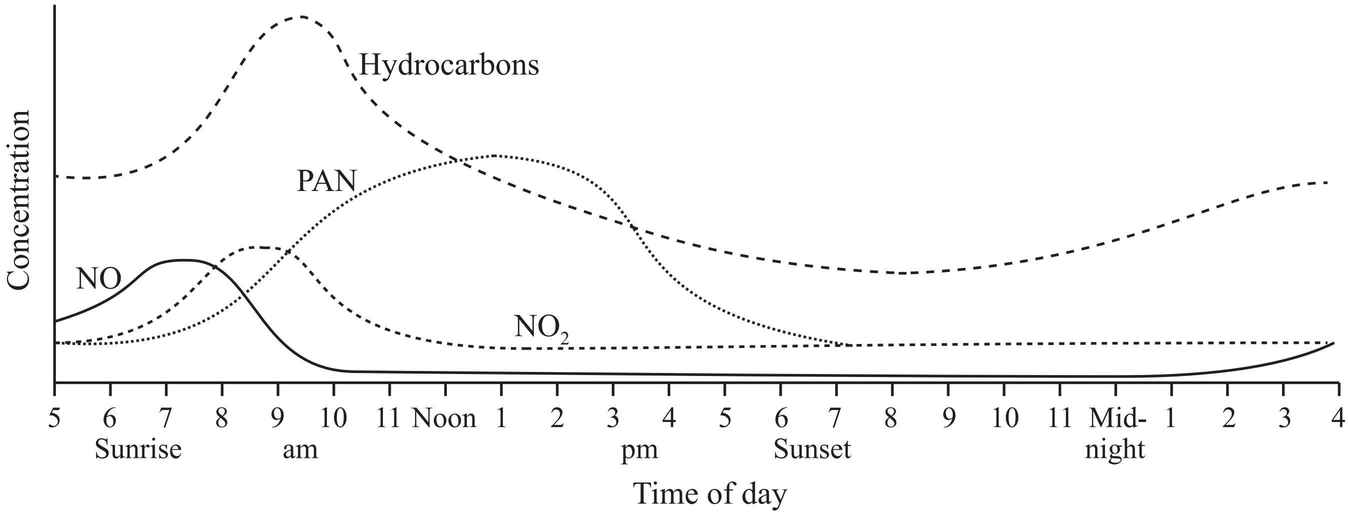
A. ^{1}H NMR

B. Infrared spectroscopy

C. X-ray crystallography

D. Mass spectrometry

40. The graph shows the concentration of some pollutants in a city over a 24-hour period.



Which of the following could **not** be inferred from the graph?

A. Hydrocarbons cause less harm to health than PAN.

B. An increase in hydrocarbons is caused by the morning rush hour.

C. PAN concentration increases as the intensity of sunlight increases.

D. NO_2 production follows the production of NO.

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MARKSCHEME

SPECIMEN PAPER

CHEMISTRY

Higher Level

Paper 1

2 pages

1.	C	16.	C	31.	C	46.	–
2.	D	17.	D	32.	A	47.	–
3.	B	18.	D	33.	C	48.	–
4.	B	19.	A	34.	A	49.	–
5.	A	20.	C	35.	A	50.	–
6.	B	21.	C	36.	C	51.	–
7.	B	22.	C	37.	B	52.	–
8.	C	23.	B	38.	A	53.	–
9.	B	24.	A	39.	B	54.	–
10.	D	25.	A	40.	A	55.	–
11.	A	26.	D	41.	–	56.	–
12.	D	27.	D	42.	–	57.	–
13.	B	28.	A	43.	–	58.	–
14.	C	29.	C	44.	–	59.	–
15.	D	30.	C	45.	–	60.	–

International Baccalaureate®
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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

SPECIMEN PAPER

Examination code

2 hours 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the *Chemistry data booklet* is required for this paper.
- The maximum mark for this examination paper is *[95 marks]*.

29 pages

*Answer **all** questions. Write your answers in the boxes provided.*

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

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

Experimental procedure:

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

$$ClO^-(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow Cl^-(aq) + I_2(aq) + H_2O(l)$$

- The iodine formed was titrated with 0.100 mol dm^{-3} sodium thiosulfate solution, $Na_2S_2O_3(aq)$, using starch indicator.

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

The following data were recorded for the titration:

	First titre	**Second titre**	**Third titre**
Final burette reading of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	23.95	46.00	22.15
Initial burette reading of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	0.00	23.95	0.00

(i) Calculate the volume, in cm^3, of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ required to react with the iodine to reach the end point. *[1]*

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(ii) Calculate the amount, in mol, of $Na_2S_2O_3(aq)$ that reacts with the iodine. *[1]*

. . . .
. . . .

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

. . . .
. . . .
. . . .

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

. . . .
. . . .

(This question continues on the following page)

(Question 1 continued)

(b) Some of the group 17 elements, the halogens, show variable valency.

(i) Deduce the oxidation states of chlorine and iodine in the following species. *[1]*

NaClO:

. . . .

I_2:

. . . .

(ii) Deduce, with a reason, the oxidizing agent in the reaction of hypochlorite ions with iodide ions in part (a). *[1]*

. . . .

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. . . .

(iii) From a health and safety perspective, suggest why it is not a good idea to use hydrochloric acid when acidifying the bleach. *[1]*

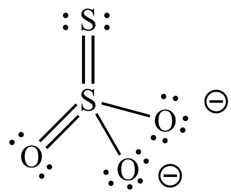
. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(iv) The thiosulfate ion, $S_2O_3^{2-}$, is an interesting example of oxidation states. The sulfur atoms can be considered to have an oxidation state of +6 on one atom and –2 on the other atom. Discuss this statement in terms of your understanding of oxidation state. *[2]*



Lewis (electron dot) structure of thiosulfate

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(This question continues on the following page)

(Question 1 continued)

(c) The various changes that have been made to the definitions of oxidation and reduction show how scientists often broaden similarities to general principles.

Combustion is also a redox type of reaction.

With reference to the combustion reaction of methane, explore **two** different definitions of oxidation, choosing one which is valid and one which may be considered not valid. *[2]*

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

Valid:

. . . .

. . . .

. . . .

Not valid:

. . . .

. . . .

. . . .

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

. . . .

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

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

A mechanism proposed for its formation is:

$$HO\bullet(g) + SO_2(g) \rightarrow HOSO_2(g)$$
$$HOSO_2(g) + O_2(g) \rightarrow HOO\bullet(g) + SO_3(g)$$
$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

(a) State what the symbol (•) represents in the species shown in this mechanism. *[1]*

. . . .
. . . .

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

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -198\,\text{kJ}$$

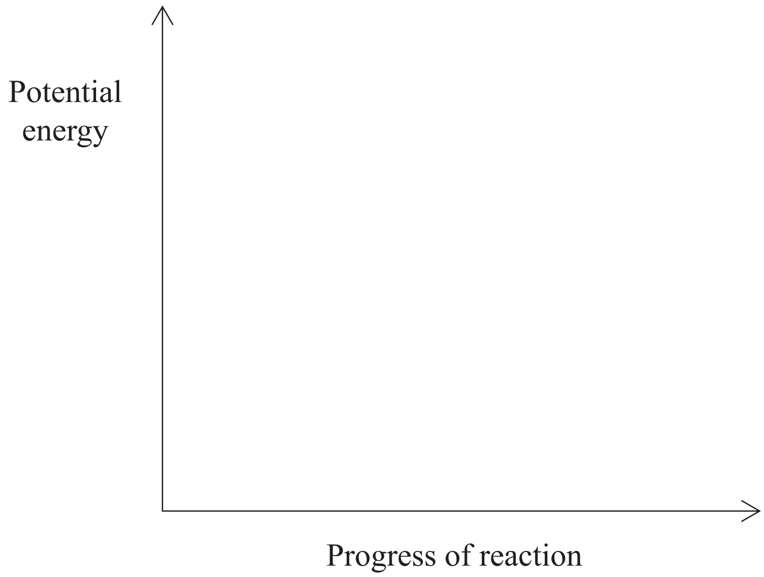
Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below. *[3]*

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

(This question continues on the following page)

(Question 2 continued)

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



(d) Other compounds present in acid rain are formed from nitrogen dioxide, NO_2. Formulate an equation for the reaction of nitrogen dioxide with water. *[1]*

. . . .

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

. . . .

. . . .

. . . .

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

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

. . . .

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

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

. . . .

. . . .

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

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(This question continues on the following page)

(Question 3 continued)

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

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

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4. 1-iodoethane reacts with sodium hydroxide.

(a) Explain the mechanism of this reaction, using curly arrows to represent the movement of electron pairs and showing any stereochemical features of the reaction mechanism. *[4]*

(b) State the rate expression for this reaction and identify the molecularity of the rate-determining step (RDS). *[2]*

Rate expression:

. . . .

Molecularity of RDS:

. . . .

(This question continues on the following page)

(Question 4 continued)

(c) Suggest why polar, aprotic solvents are more suitable for S_N2 reactions whereas polar, protic solvents favour S_N1 reactions. *[2]*

S_N2:

. . . .

. . . .

. . . .

. . . .

S_N1:

. . . .

. . . .

. . . .

. . . .

(d) Deduce, with a reason, if water or DMF (N,N-Dimethylformamide, $HCON(CH_3)_2$) is a better solvent for this reaction. *[1]*

. . . .

. . . .

(e) Describe what you understand by the term *frequency (pre-exponential) factor, A*. *[1]*

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. . . .

(This question continues on the following page)

(Question 4 continued)

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

Calculate the rate constant, k, of the reaction at 25 °C, indicating the units of k, and giving a reason for your choice. *[2]*

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

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

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. . . .

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

$$H_2(g) + C_2H_4(g) \rightarrow C_2H_6(g)$$

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

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

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

	Lewis (electron dot) structure
Ozone	
Sulfur hexafluoride	

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

	Electron domain geometry	**Molecular geometry**
Ozone	. . . .	. . . .
Sulfur hexafluoride	. . . .	. . . .

(This question continues on the following page)

(Question 6 continued)

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

. . . .

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

Ozone:

. . . .

Sulfur hexafluoride:

. . . .

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

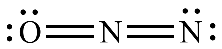
(This question continues on the following page)

(Question 6 continued)

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

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

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

	Lewis (electron dot) structure	**FC of O on LHS**	**FC of central N**	**FC of N on RHS**
A				
B				
C				

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

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

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(This question continues on the following page)

Turn over

(Question 6 continued)

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

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

. . . .

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

$O_3(g)$
$\Delta H_f^{\ominus} = +142.3\,kJ\,mol^{-1}$

. . . .

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

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(This question continues on the following page)

(Question 6 continued)

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

$O_2(g)$	$O_3(g)$
$S^{\ominus} = +205.0\,J\,K^{-1}\,mol^{-1}$	$S^{\ominus} = +237.6\,J\,K^{-1}\,mol^{-1}$

. . . .

. . . .

. . . .

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

. . . .

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. . . .

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

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(This question continues on the following page)

(Question 6 continued)

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

I $O_2 \xrightarrow{hv} 2O\bullet$

II $O_2 + O\bullet \rightarrow O_3$

III $O_3 \xrightarrow{hv} O_2 + O\bullet$

Explain by reference to the bonding in O_2 and O_3, which of the reactions, I or III, needs more energy. *[3]*

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(ii) Using dichlorodifluoromethane, CCl_2F_2, as an example, outline the reactions in which ozone depletion occurs in the upper atmosphere. Formulate an equation for each step in this process and explain the initial step by reference to the bonds in CCl_2F_2. *[5]*

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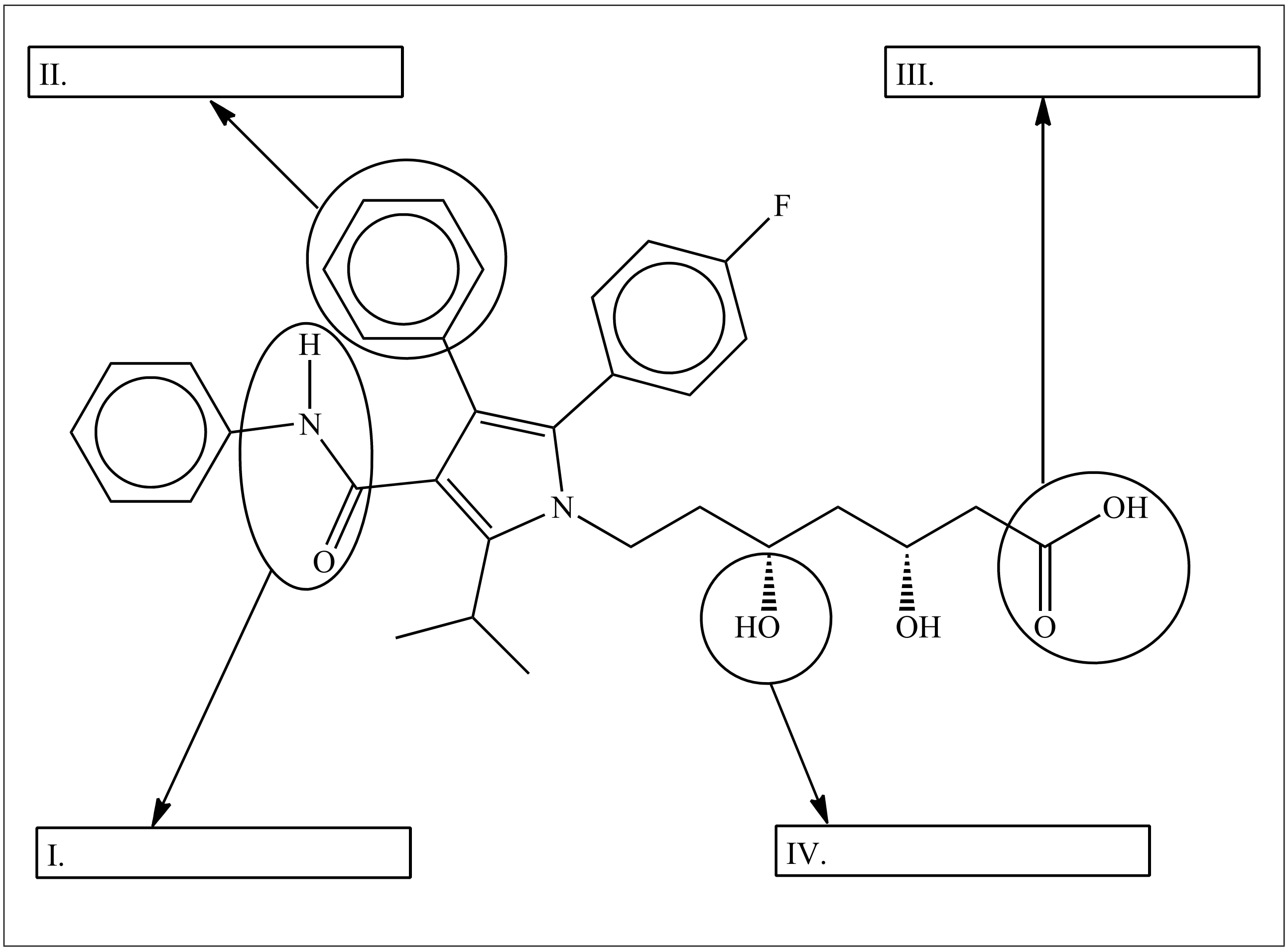
7. The biopharmaceutical industry is now a global contributor to the world economy.

(a) Atorvastatin, a drug used to lower cholesterol, recently gained attention from the global media.

Atorvastatin has the structure shown below.



Identify the **four** functional groups, I, II, III and IV. *[2]*

(This question continues on the following page)

(Question 7 continued)

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

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

Element	**Percentage**
C	73.99
H	6.55
N	9.09
O	Remainder

Calculate the empirical formula of bute, showing your working. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

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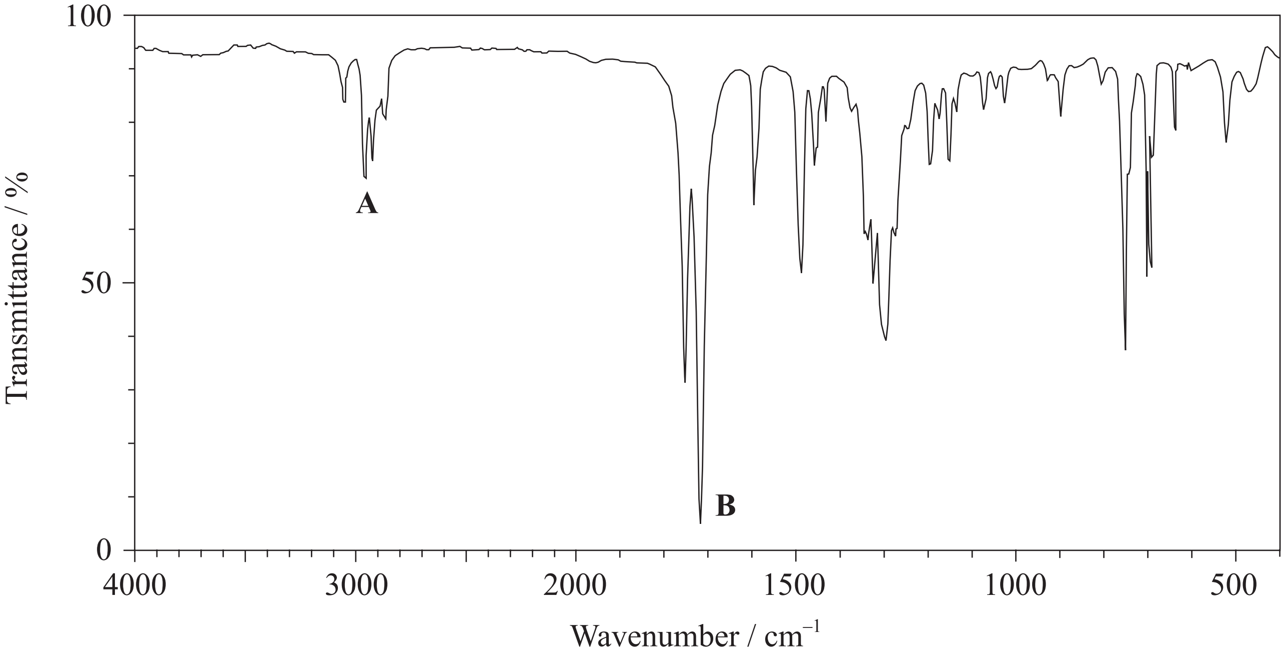
(This question continues on the following page)

(Question 7 continued)

(iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute. *[1]*

. . . .
. . . .
. . . .

(iv) The infrared (IR) spectrum of bute is shown below.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Using information from section 26 of the data booklet, identify the bonds corresponding to **A** and **B**. *[1]*

A: . . . .

B: . . . .

(This question continues on the following page)

(Question 7 continued)

(v) Based on analysis of the IR spectrum, predict, with an explanation, one bond containing oxygen and one bond containing nitrogen that could **not** be present in the structure. *[2]*

Bond containing oxygen not present in structure:

. . . .

Bond containing nitrogen not present in structure:

. . . .

Explanation:

. . . .

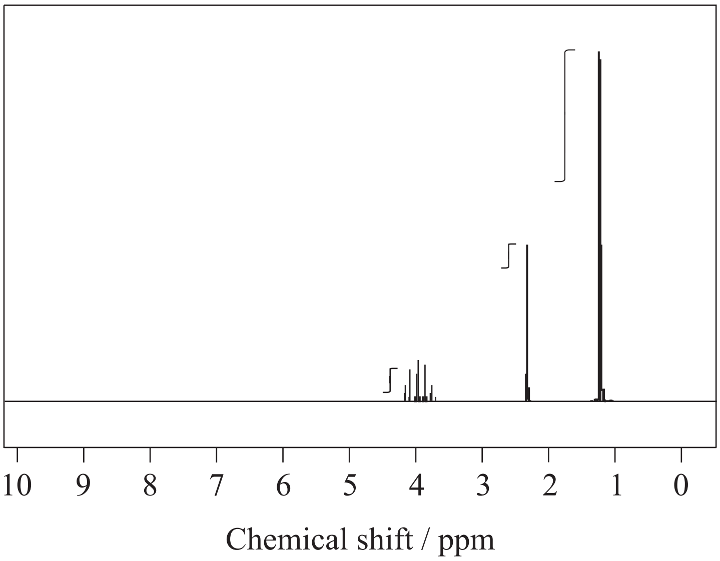
. . . .

. . . .

(This question continues on the following page)

(Question 7 continued)

(c) An alcohol, **X**, of molecular formula C_3H_8O, used as a disinfectant in hospitals, has the following ^{1}H NMR spectrum:



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the ^{1}H NMR spectrum of **X** have chemical shift values centred at δ = 4.0, 2.3 and 1.2 ppm.

(i) From the integration trace, estimate the ratio of hydrogen atoms in different chemical environments. *[1]*

. . . .

. . . .

(ii) Deduce the full structural formula of **X**. *[1]*

(This question continues on the following page)

(Question 7 continued)

(iii) **Y** is an isomer of **X** containing a different functional group. State the condensed structural formula of **Y**. *[1]*

. . . .
. . . .

(iv) Compare and contrast the expected mass spectra of **X** and **Y** using section 28 of the data booklet. *[2]*

One similarity:

. . . .
. . . .
. . . .

One difference:

. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 7 continued)

(v) Both **X** and **Y** are soluble in water. Deduce whether or not both **X** and **Y** show hydrogen bonding with water molecules, representing any hydrogen bonding present by means of a diagram. *[2]*

. . . .

. . . .

(This question continues on the following page)

(Question 7 continued)

(d) The two isomers of $[Pt(NH_3)_2Cl_2]$ are crystalline. One of the isomers is widely used as a drug in the treatment of cancer.

(i) Draw both isomers of the complex. *[1]*

(ii) Explain the polarity of each isomer, using a diagram for each isomer to support your answer. *[2]*

. . . .

. . . .

(iii) State a suitable method (other than looking at dipole moments) to distinguish between the two isomers. *[1]*

. . . .

(This question continues on the following page)

(Question 7 continued)

(iv) Compare and contrast the bonding types formed by nitrogen in $[Pt(NH_3)_2Cl_2]$. *[2]*

Similarity:

. . . .

. . . .

Difference:

. . . .

. . . .

(v) Deduce all of the intermolecular forces between molecules of ammonia. *[2]*

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Subject Details: Chemistry HL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions. Maximum total = **[95 marks]**.

1. Each row in the “Question” column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the “Total” column.

3. Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by “**max**” written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.

5. An alternative wording is indicated in the “Answers” column by a slash (/). Either wording can be accepted.

6. An alternative answer is indicated in the “Answers” column by “***OR***” on the line between the alternatives. Either answer can be accepted.

7. Words in angled brackets ‹ › in the “Answers” column are not necessary to gain the mark.

8. Words that are <u>underlined</u> are essential for the mark.

9. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.

10. If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the “Notes” column.

11. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. "ECF acceptable" will be displayed in the "Notes" column.

13. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

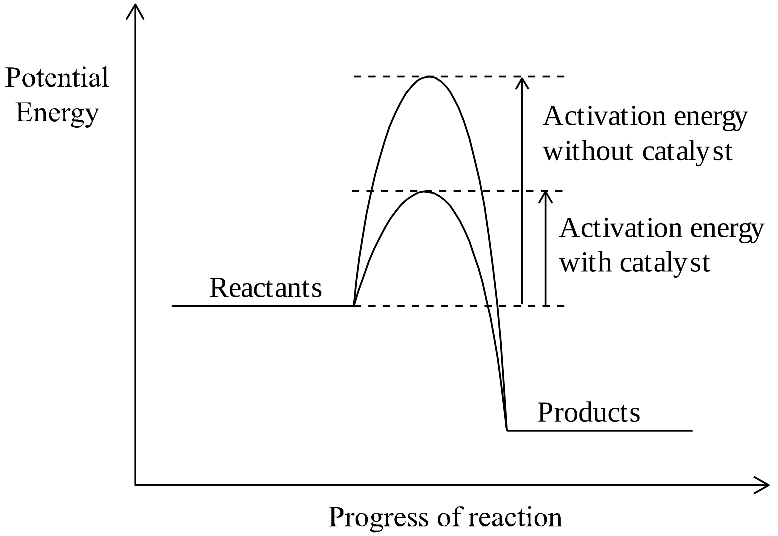
14. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the "Notes" column, similarly, if the formula is specifically asked for, unless directed otherwise in the "Notes" column do not award a mark for a correct name.

15. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the "Notes" column.

16. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

Question			Answers	Notes	Total
1.	**a**	**i**	$\langle (22.05 + 22.15)(0.5) = \rangle 22.10 \langle \text{cm}^3 \rangle$ ✓		**1**
	a	**ii**	$\left\langle \frac{22.10 \times 0.100}{1000} = \right\rangle 2.21 \times 10^{-3}$ / $0.00221 \langle \text{mol} \rangle$ ✓		**1**
	a	**iii**	$\left\langle \frac{0.5 \times 2.21 \times 10^{-3} \times 1000}{25.00} = \right\rangle 4.42 \times 10^{-2}$ / $0.0442 \langle \text{mol dm}^{-3} \rangle$ ✓		**1**
	a	**iv**	$\langle 4.42 \times 10^{-2} \times 10 = \rangle 4.42 \times 10^{-1}$ / $0.442 \langle \text{mol dm}^{-3} \rangle$ ✓		**1**
	b	**i**	*NaClO*: +1 ‹for chlorine› **and** *I_2*: 0 ‹for iodine› ✓		**1**
	b	**ii**	ClO^- since chlorine reduced/gains electrons ***OR*** ClO^- since oxidation state of chlorine changes from +1 to –1/decreases ***OR*** ClO^- since it loses oxygen / causes iodide to be oxidized ✓		**1**
	b	**iii**	produces chlorine ‹gas›/Cl_2 ‹on reaction with ClO^-› which is toxic ✓	*OWTTE*	**1**
	b	**iv**	oxidation states are not real ***OR*** oxidation states are just used for electron book-keeping purposes ✓ average oxidation state of sulfur calculated to be +2 ✓ but the two sulfurs are bonded differently/in different environments in thiosulfate so have different oxidation states ✓	*OWTTE*	**2 max**

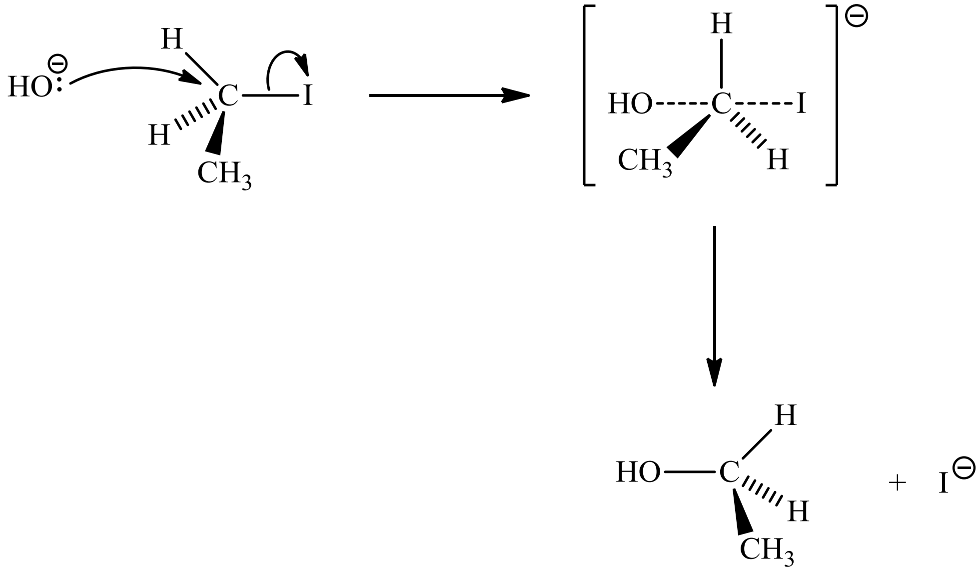
Question			Answers	Notes	Total
	c		*Valid:* addition of oxygen signifies an oxidation reaction so C is oxidized ***OR*** loss of hydrogen signifies an oxidation reaction so C is oxidized ***OR*** oxidation state of C changes from –4 to +4/increases ✓ *Not valid:* loss of electrons might suggest formation of ionic product but not valid since CO_2 is covalent ***OR*** loss of electrons might suggest formation of ionic product but not valid since reaction only involves neutral molecules ✓	*OWTTE*	**2**
	d	**i**	$[Ne]3s^2 3p^4$ ✓	*Electrons must be given as superscript.*	**1**
	d	**ii**	$\underset{1s^2}{\boxed{\uparrow\downarrow}}\quad \underset{2s^2}{\boxed{\uparrow\downarrow}}\quad \underset{2p^6}{\boxed{\uparrow\downarrow}\boxed{\uparrow\downarrow}\boxed{\uparrow\downarrow}}\quad \underset{3s^2}{\boxed{\uparrow\downarrow}}\quad \underset{3p^4}{\boxed{\uparrow\downarrow}\boxed{\uparrow\ }\boxed{\uparrow\ }}$ ✓		**1**

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Notes</th><th>Total</th></tr>
<tr><td>2.</td><td>a</td><td></td><td>radical / unpaired electron ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>b</td><td></td><td>
<table>
<tr><th>Change</th><th>Shift</th><th>Reason</th></tr>
<tr><td>Increase in temperature</td><td>LHS</td><td>since ‹forward› exothermic reaction/ $\Delta H < 0$ ✓</td></tr>
<tr><td>Increase in pressure</td><td>RHS</td><td>since fewer ‹gaseous› molecules on RHS ✓</td></tr>
<tr><td>Addition of a catalyst to the mixture</td><td>No change</td><td>since affects rate of forward and reverse reactions equally ✓</td></tr>
</table>
</td><td></td><td>3</td></tr>
<tr><td></td><td>c</td><td></td><td>

correct positions of reactants and products ✓
correct profile with labels showing activation energy with and without a catalyst ✓</td><td></td><td>2</td></tr>
</table>

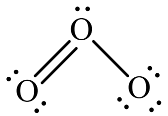
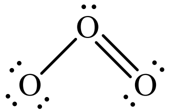
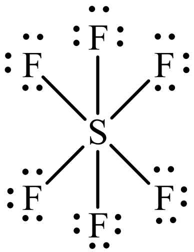
Question			Answers	Notes	Total
	d		$2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$ ✓	*Ignore state symbols.*	**1**
	e		ionic radius of nitrogen is $146\,pm/146\times10^{-12}$ m which is greater than atomic radius which is $71\,pm/71\times10^{-12}$ m due to increased repulsion between electrons ✓	*Values must be given to score mark.*	**1**

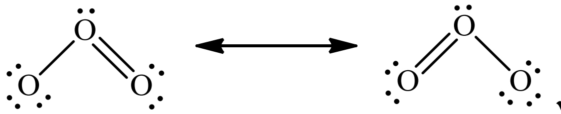
3.	**a**		$HCOO^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + HCOOH(aq)$ ✓	*Equilibrium sign must be given for mark.*	**1**
	b		$K_a = 1.8\times10^{-4}$ ✓		**1**
	c		$K_b = \left\langle \frac{K_w}{K_a} = \frac{1.0\times10^{-14}}{1.8\times10^{-4}} = \right\rangle 5.6\times10^{-11}$ ✓		**1**
	d		$K_b = \frac{x^2}{0.12} = 5.6\times10^{-11}$ ✓ $[OH^-(aq)] = 2.6\times10^{-6} \langle mol\,dm^{-3}\rangle$ ✓ *Assumption:* $0.12 - x \sim 0.12$ ✓	*Award **[2]** for correct final answer of $[OH^-(aq)]$.* *Accept any other reasonable assumption.*	**3**
	e		$pOH = \langle -\log(2.6\times10^{-6}) = \rangle 5.59$ ✓ $pH = \langle 14.00 - 5.59 = \rangle 8.41$ ✓	*Award **[2]** for correct final answer.*	**2**

Question			Answers	Notes	Total
4.	**a**		 curly arrow going from lone pair/negative charge on O in HO^- to C ✓	*Do not allow curly arrow originating on H in HO^-*	**4**
			curly arrow showing I leaving ✓	*Accept curly arrow going from bond between C and I to I in 1-iodoethane or in the transition state.* *Do not allow arrow originating from C to C–I bond.*	
			representation of transition state showing negative charge, square brackets and partial bonds at 180° to each other ✓	*Do not award M3 if OH---C bond is represented.*	
			formation of organic product CH_3CH_2OH **and** I^- ✓	*Inversion of configuration must be shown to score M4.*	
	b		*Rate expression:* $\text{rate} = k[OH^-][CH_3CH_2I]$ ✓ *Molecularity of RDS:* bimolecular ✓		**2**

Question			Answers	Notes	Total
	c		*S_N2:* polar, protic solvents decrease nucleophilic reactivity due to hydrogen bonding ***OR*** polar, protic solvents have a cage of solvent molecules surrounding anionic nucleophile resulting in increased stabilization ‹so are slower› ***OR*** polar, aprotic solvents have no hydrogen bonding so S_N2 reactions are favoured since nucleophiles do not solvate effectively so have an enhanced/pronounced effect on nucleophilicity of anionic nucleophiles ‹so are faster› ✓ *S_N1:* polar, protic solvents favour S_N1 reactions since the carbocation ‹intermediate› is solvated by ion-dipole interactions by the polar solvent ✓		**2**
	d		DMF since aprotic solvent so favours S_N2 ✓		**1**
	e		*A* is indicative of frequency of collisions **and** probability that collisions have proper orientations ✓		**1**
	f		$k = \left\langle \exp\left[\frac{(-87.0\times1000)}{(8.31\times298)} + \ln(2.10\times10^{11})\right] = \right\rangle 1.2\times10^{-4}$ ✓ S_N2 implies second-order so $mol^{-1}\ dm^3\ s^{-1}$ ✓		**2**

Question			Answers	Notes	Total
5.	**a**		<u>only</u> water/H_2O produced ‹so non-polluting› ✓		**1**
	b		*Bond breaking*: $(1)(\text{H–H}) + (4)(\text{C–H}) + (1)(\text{C=C})$ ***OR*** $(1)(436) + (4)(414) + (1)(614) = 2706$ ‹kJ mol^{-1}› ✓ *Bond formation*: $(6)(\text{C–H}) + (1)(\text{C–C})$ ***OR*** $(6)(414) + (1)(346) = 2830$ ‹kJ mol^{-1}› ✓ ‹$+2706 - 2830$› $= -124$ ‹kJ mol^{-1}› ✓	*Award **[2 max]** for +124 ‹kJ mol^{-1}›.* *Award **[3]** for correct final answer.*	**3**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>6.</td><td>a</td><td>i</td><td>
<table>
<tr><th></th><th>Lewis (electron dot) structure</th></tr>
<tr><td>Ozone</td><td> /  ✓</td></tr>
<tr><td>Sulfur hexafluoride</td><td> ✓</td></tr>
</table>
</td><td>Lines, x's or dots may be used to represent electron pairs.
Charges may be included in Lewis structures of ozone but are not required.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>ii</td><td>
<table>
<tr><th></th><th>Electron domain geometry</th><th>Molecular geometry</th></tr>
<tr><td>Ozone</td><td>trigonal/triangular planar</td><td>v-shaped/bent/angular ✓</td></tr>
<tr><td>Sulfur hexafluoride</td><td>octahedral/square bipyramidal</td><td>octahedral/square bipyramidal ✓</td></tr>
</table>
</td><td>Award [1 max] for either both electron domain geometries correct OR for either both molecular geometries correct.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>iii</td><td>sulfur hexafluoride/SF_6 ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>a</td><td>iv</td><td>Ozone: Accept any angle greater than 115° but less than 120°
and
Sulfur hexafluoride: 90° (and 180°) ✓</td><td>Experimental value of bond angle in O_3 is 117°.</td><td>1</td></tr>
</table>

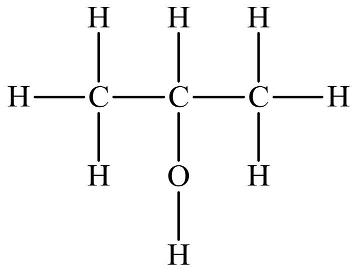
<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>6.</td><td>a</td><td>v</td><td> ✓</td><td>Double-headed arrow not necessary for mark.
Lines, x’s or dots may be used to represent electron pairs.</td><td>1</td></tr>
<tr><td></td><td>b</td><td>i</td><td>
<table>
<tr><th></th><th>Lewis (electron dot) structure</th><th>FC of O on LHS</th><th>FC of central N</th><th>FC of N on RHS</th></tr>
<tr><td>A</td><td>$:\ddot{O}{=}N{=}\ddot{N}:$</td><td>0</td><td>+1</td><td>–1</td></tr>
<tr><td>B</td><td>$:\underset{\cdot\cdot}{\ddot{O}}-N\equiv N:$</td><td>–1</td><td>+1</td><td>0</td></tr>
<tr><td>C</td><td>$:O\equiv N-\underset{\cdot\cdot}{\ddot{N}}:$</td><td>+1</td><td>+1</td><td>–2</td></tr>
</table>
</td><td>Award [2] for all nine FCs correct, [1] for six to eight FCs correct.</td><td>2</td></tr>
<tr><td></td><td>b</td><td>ii</td><td>smallest FC difference for A or B, so either is preferred ✓

however B is preferred as oxygen is more electronegative than nitrogen, even though FC per se ignores electronegativity ✓</td><td>Reason required for M1.

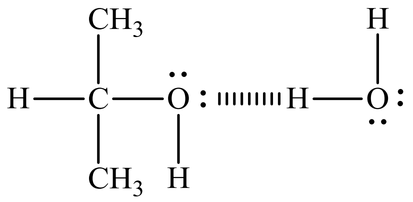
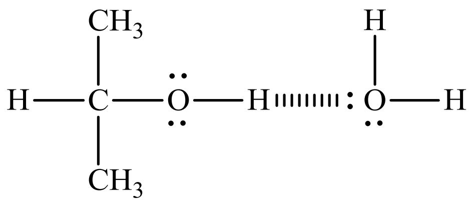
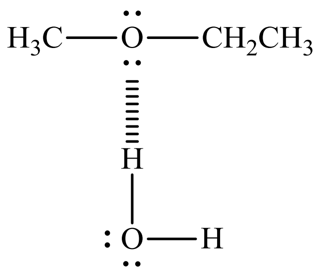
OWTTE</td><td>2</td></tr>
<tr><td></td><td>c</td><td>i</td><td>$CH_4(g)+5O_2(g)\rightarrow CO_2(g)+2H_2O(g)+2O_3(g)$ ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>c</td><td>ii</td><td>$\Delta H^{\ominus} = \langle[(-393.5)+(2)(-241.8)+(2)(+142.3)]-[(-74.0)]=\rangle -660.8 \langle \text{kJ mol}^{-1}\rangle$ ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>c</td><td>iii</td><td>standard enthalpy change of formation/ $\Delta H_f^{\ominus}$ of an element ‹in most stable form› is always zero ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>c</td><td>iv</td><td>$\Delta S^{\ominus} = \langle[(+213.8)+(2)(+188.8)+(2)(+237.6)]-[(+186)+(5)(+205.0)]=\rangle$
$-144.4 \langle \text{J K}^{-1}\text{ mol}^{-1}\rangle$ ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>c</td><td>v</td><td>$\Delta G^{\ominus} = \left\langle \Delta H^{\ominus} - T\Delta S^{\ominus} = (-660.8)-(298)\left(\frac{-144.4}{1000}\right)= \right\rangle -617.8 \langle \text{kJ mol}^{-1}\rangle$ ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>c</td><td>vi</td><td>spontaneous since negative $\Delta G^{\ominus}$ ✓</td><td></td><td>1</td></tr>
</table>

Question			Answers	Notes	Total
6.	**d**	**i**	O_2 has a double bond ✓ O_3 has intermediate bonds between double and single bonds ***OR*** O_3 has a bond order of 1½ ✓ bond in O_2 is stronger therefore **I** needs more energy ✓	*Do not award mark for **I** on its own with no justification.*	**3**
	d	**ii**	C–Cl ‹bond› breaks since weakest bond ✓ $CCl_2F_2 \xrightarrow{\langle hv \rangle} \bullet CClF_2 + Cl\bullet$ ✓ $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$ ✓ $ClO\bullet + O\bullet \rightarrow O_2 + Cl\bullet$ ✓ $ClO\bullet + O_3 \rightarrow Cl\bullet + 2O_2$ ✓	*Allow representation of radicals without • as long as consistent throughout.*	**5**

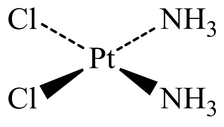
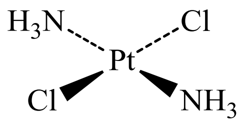
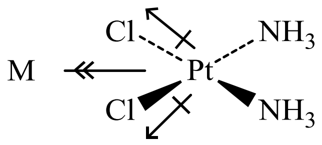
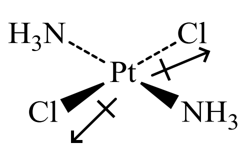
Question			Answers	Notes	Total
7.	**a**		*I:* carboxamide ✓ *II:* phenyl ✓ *III:* carboxyl / carboxy ✓ *IV:* hydroxyl ✓	*Award **[2]** for all four correct, **[1]** for two or three correct.* *Do not allow benzene.* *Do not allow carboxylic/alkanoic acid.* *Do not allow alcohol or hydroxide.*	**2 max**
	b	**i**	$n_C : \left\langle \frac{73.99}{12.01} \right\rangle = 6.161\,(\text{mol})$ **and** $n_H : \left\langle \frac{6.55}{1.01} \right\rangle = 6.49\,(\text{mol})$ **and** $n_N : \left\langle \frac{9.09}{14.01} \right\rangle = 0.649\,(\text{mol})$ **and** $n_O : \left\langle \frac{10.37}{16.00} \right\rangle = 0.6481\,(\text{mol})$ ✓ $n_C : n_H : n_N : n_O = 9.5 : 10 : 1 : 1$ ✓ *Empirical formula*: $C_{19}H_{20}N_2O_2$ ✓	*Award **[2 max]** for correct final answer without working.*	**3**
	b	**ii**	$C_{19}H_{20}N_2O_2$ ✓		**1**
	b	**iii**	$\langle (0.5)(40-20-2) = \rangle 9$ ✓		**1**
	b	**iv**	*A:* C–H **and** *B:* C=O ✓		**1**
	b	**v**	O–H **and** N–H ✓ frequencies/stretches due to O–H and N–H occur above 3200 ‹cm^{-1}› which are not present in IR of *bute* ✓		**2**
	c	**i**	1:1:6 ✓		**1**

Question			**Answers**	**Notes**	**Total**
7.	**c**	**ii**			**1**
	c	**iii**	$CH_3OCH_2CH_3$		**1**
	c	**iv**	*Similarity:* both have fragment corresponding to $(M_r - 15)^+$ / $m/z = 45$ *Difference:* **X** has fragment corresponding to $(M_r - 17)^+$ / $m/z = 43$ ***OR*** **X** has fragment corresponding to $(M_r - 43)^+$ / $m/z = 17$ ***OR*** **Y** has fragment corresponding to $(M_r - 31)^+$ / $m/z = 29$ ***OR*** **Y** has fragment corresponding to $(M_r - 29)^+$ / $m/z = 31$	*Allow "both have same molecular ion peak/M^+ / both have m/z = 60". However in practice the molecular ion peak is of low abundance and difficult to observe for propan-2-ol.*	**2**

(Question 7 continued)

Question			Answers	Notes	Total
	c	**v**	both **X** and **Y** will exhibit hydrogen bonding with water molecules ✓ diagrams showing hydrogen bonding ✓ X:  **OR**  Y: 		**2**

(Question 7 continued)

Question			Answers	Notes	Total
7.	**d**	**i**	 Cisplatin **and**  Transplatin ✓	*Names of complexes are not required.* *Complexes may be drawn without tapered bonds.*	**1**
	d	**ii**	 Cisplatin **and**  M = 0 ✓ Transplatin *Cis:* polar **and** *trans:* non-polar ✓		**2**
	d	**iii**	X-ray crystallography ✓	*Accept NMR spectroscopy.*	**1**
	d	**iv**	*Similarity:* both involve shared pair of electrons / both are covalent ✓ *Difference:* *Pt–N:* pair of electrons comes from nitrogen / coordinate bond **and** *N–H:* one electron comes from each bonded atom ✓		**2**
	d	**v**	London / dispersion / instantaneous induced dipole-induced dipole ✓ dipole-dipole ✓ hydrogen bonding ✓	*Award **[2]** for all three correct, **[1]** for any two correct.*	**2 max**

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CHEMISTRY
HIGHER LEVEL
PAPER 3

Candidate session number

SPECIMEN PAPER

Examination code

1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer all of the questions from one of the options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the *Chemistry data booklet* is required for this paper.
- The maximum mark for this examination paper is *[45 marks]*.

Option	**Questions**
Option A — Materials	3 – 7
Option B — Biochemistry	8 – 12
Option C — Energy	13 – 16
Option D — Medicinal chemistry	17 – 21

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. Compounds used to generate cooling in refrigerators and air-conditioning systems are known as refrigerants. A refrigerant undergoes a reversible change of state involving vaporization and condensation. The search for suitable refrigerants has occupied chemists for approximately 200 years.

Previously, the most popular refrigerants were chlorofluorocarbons (CFCs), but these have been replaced first by hydrochlorofluorocarbons (HCFCs) and more recently by hydrofluorocarbons (HFCs).

Some data on examples of these three classes of refrigerants are shown below.

Class	**Compound**	**ODP**[1]	**GWP**[2] **over 100 years**	ΔH_{vap}[3] **/ kJ mol**$^{-1}$	**Atmospheric lifetime / years**
CFC	CCl_3F	1.0	4000	24.8	45
CFC	CCl_2F_2	1.0	8500	20.0	102
HCFC	$CHCl_2CF_3$	0.02	90	26.0	1
HCFC	$CHClF_2$	0.05	1810	20.2	12
HFC	CH_2FCF_3	0	1100	–	–
HFC	CHF_2CF_3	0	3500	30.0	32

1 ODP: The ozone depletion potential (ODP) is a relative measure of the amount of degradation to the ozone layer caused by the compound. It is compared with the same mass of CCl_3F, which has an ODP of 1.0.

2 GWP: The global warming potential (GWP) is a relative measure of the total contribution of the compound to global warming over the specified time period. It is compared with the same mass of CO_2, which has a GWP of 1.0.

3 ΔH_{vap}: Defined as the energy required to change one mole of the compound from a liquid to a gas.

(a) (i) Explain why the values for ODP and GWP have no units. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(ii) By making reference to the chemical formulas and ODP values of the compounds, comment on the hypothesis that chlorine is responsible for ozone depletion. *[1]*

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(b) Use data from the table to interpret the relationship between the atmospheric lifetime of a gas and its GWP. *[2]*

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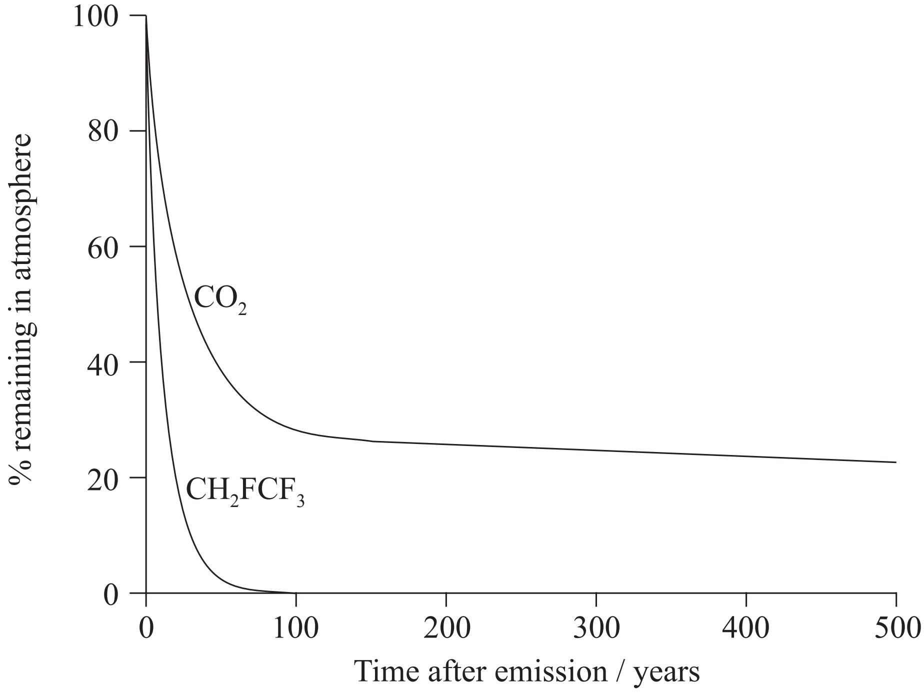
(This question continues on the following page)

(Question 1 continued)

(c) The graph shows the change in levels with time of equal masses of CO_2 and CH_2FCF_3 introduced into the atmosphere.



(i) Apply IUPAC rules to state the name of CH_2FCF_3. *[1]*

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(ii) The $\Delta H_{\text{vaporization}}$ for CH_2FCF_3 is $217\,\text{kJ}\,\text{kg}^{-1}$. Calculate the value of the enthalpy change for the condensation of one mole of CH_2FCF_3. *[2]*

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(This question continues on the following page)

(Question 1 continued)

(iii) With reference to the graph on page 4, comment on the atmospheric lifetime of CO_2 relative to CH_2FCF_3, and on the likely influence of this on climate change. *[2]*

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2. Thomas wants to determine the empirical formula of red-brown copper oxide. The method he chooses is to convert a known amount of copper(II) sulfate into this oxide. The steps of his procedure are:

- Make $100\,cm^3$ of a $1\,mol\,dm^{-3}$ solution using hydrated copper(II) sulfate crystals.
- React a known volume of this solution with alkaline glucose in order to convert it to red-brown copper oxide.
- Separate the precipitated oxide and find its mass.

(a) Thomas calculates that he needs $0.1 \times [1 \times 63.55 + 1 \times 32.07 + 4 \times 16.00] = 15.962 \pm 0.001\,g$ of the copper(II) sulfate to make the solution. Outline the major error in his calculation. *[1]*

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(b) He now adds $100 \pm 1\,cm^3$ of water from a measuring/graduated cylinder and dissolves the copper(II) sulfate crystals. A friend tells him that for making standard solutions it is better to use a volumetric flask rather than adding water from a measuring cylinder. Suggest **two** reasons why a volumetric flask is better. *[2]*

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(c) Thomas now heats $25\,cm^3$ of the solution with excess alkaline glucose to convert it to a suspension of red-brown copper oxide. Describe how he can obtain the pure, dry solid product. *[2]*

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(This question continues on the following page)

(Question 2 continued)

(d) Using the same chemical reactions, suggest how Thomas' method to determine the mass of red-brown copper oxide that could be obtained from a known mass of copper(II) sulfate crystals might be simplified to produce more precise results. *[1]*

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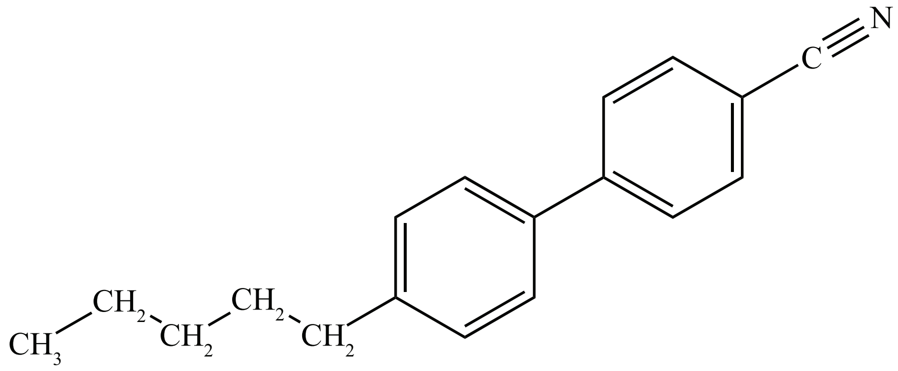
SECTION B

*Answer **all** of the questions from **one** of the options.*

Option A — Materials

3. (a) The molecule shown below is frequently used in liquid-crystal displays (LCDs).



Identify a physical characteristic of this molecule that allows it to exist in a liquid-crystal state. *[1]*

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(b) (i) Describe the chemical vapour deposition (CVD) method for the production of carbon nanotubes. *[2]*

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(ii) Many modern catalysts use carbon nanotubes as a support for the active material. State the major advantage of using carbon nanotubes. *[1]*

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(Option A continues on the following page)

(Option A continued)

4. Different metal oxides are widely used in the production of ceramic materials and their function is closely linked to the type of bonding present in the compound.

(a) Both magnesium oxide and cobalt(II) oxide are incorporated into ceramics. Use section 8 of the data booklet to calculate values to complete the table below. *[2]*

Compound	**Magnesium oxide**	**Cobalt(II) oxide**
Electronegativity difference	. . . .	. . . .
Average electronegativity	. . . .	. . . .

(b) Predict the bond type and percentage covalent character of each oxide, using section 29 of the data booklet. *[2]*

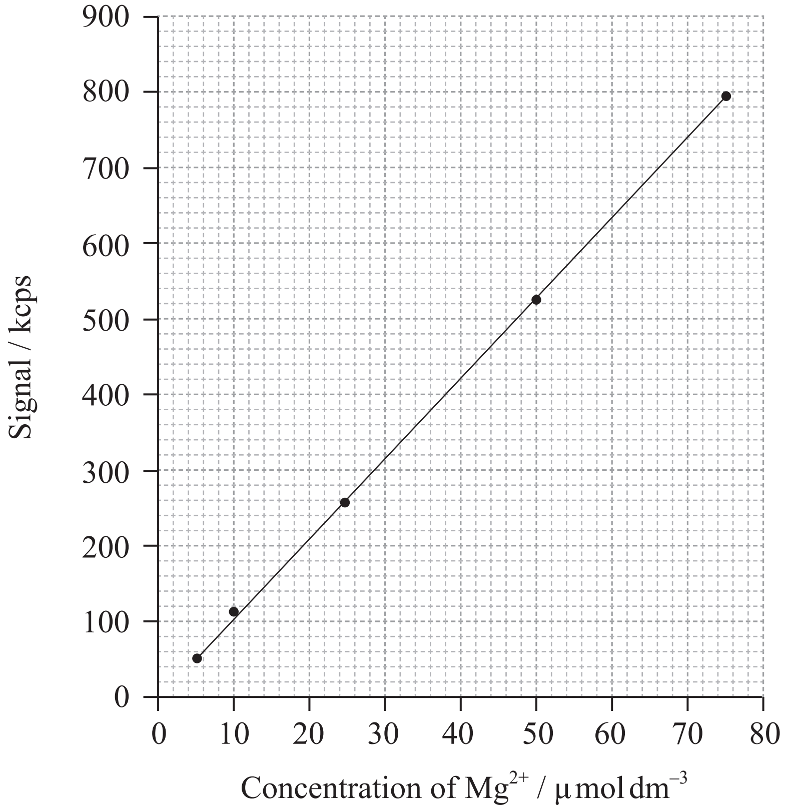
Compound	**Magnesium oxide**	**Cobalt(II) oxide**
Bond type	. . . .	. . . .
% covalent character	. . . .	. . . .

(Option A continues on the following page)

(Option A continued)

5. Magnesium is an essential component of chlorophyll and traces of it can be found in various fluids from plants. Its concentration may be estimated using inductively coupled plasma optical emission spectroscopy (ICP-OES).

(a) An ICP-OES calibration curve for magnesium is shown in the graph below.



(i) Determine the mass of magnesium ions present in $250\,cm^3$ of a solution with a concentration of $10\,\mu mol\,dm^{-3}$. *[2]*

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(Option A continues on the following page)

(Option A, question 5 continued)

(ii) Two solutions gave count rates of 627 kcps and 12 kcps respectively. Justify which solution could be more satisfactorily analysed using this calibration graph. *[1]*

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(b) Magnesium ion concentrations could also be determined by precipitation as magnesium hydroxide. The solubility product of magnesium hydroxide is 1.20×10^{-11} at 298 K. A saturated solution of magnesium hydroxide is formed, at 298 K, in a solution with a hydroxide ion concentration of 2.00 mol dm^{-3}. Calculate the magnesium ion concentration. *[3]*

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(Option A continues on the following page)

(Option A continued)

6. Plastics, such as PVC and melamine, are widely used in modern society.

(a) PVC is thermoplastic, whereas melamine is thermosetting. State one other way in which scientists have tried to classify plastics, and outline why the classification you have chosen is useful. *[2]*

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(b) It was almost a century after the discovery of PVC before Waldo Semon turned it into a useful plastic by adding plasticizers. State and explain the effect plasticizers have on the properties of PVC. *[2]*

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(c) Justify why, in terms of atom economy, the polymerization of PVC could be considered "green chemistry". *[1]*

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(Option A continues on the following page)

(Option A, question 6 continued)

(d) In spite of the conclusion in part (c), many consider that PVC is harmful to the environment. Identify **one** specific toxic chemical released by the combustion of PVC. *[1]*

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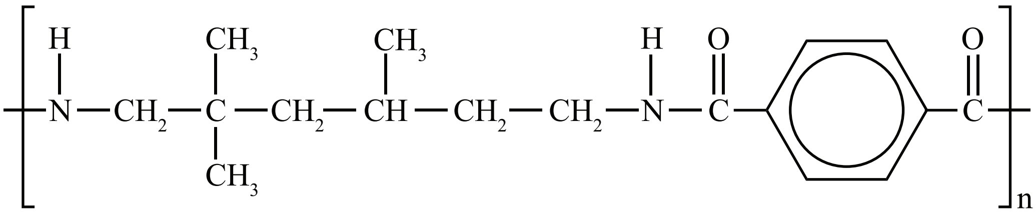
(e) The formula below shows the repeating unit of a polymer marketed as Trogamid®.



Deduce both the class of polymer to which this belongs **and** the structural formulas of the monomers used to produce it. *[2]*

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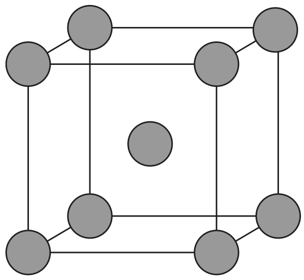
(Option A continues on the following page)

(Option A continued)

7. Superconductors are now widely used in devices such as MRI scanners and MagLev trains. Many superconductors involve the use of niobium.

(a) Niobium is most commonly found in a crystalline form with the unit cell shown below.



Classify the crystal structure, the coordination number of the atoms and the number of atoms to which the unit cell is equivalent. *[3]*

Crystal structure:

. . . .

Coordination number:

. . . .

Number of atoms:

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(b) X-ray diffraction shows that the length of the side of the unit cell is 0.314 nm. Use this, along with data from part (a), to determine the density, in $kg\,m^{-3}$, of niobium. *[3]*

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(Option A continues on the following page)

(Option A, question 7 continued)

(c) According to Bardeen-Cooper-Schrieffer (BCS) theory, Cooper pairs account for Type 1 superconductivity. Describe how Cooper pairs are formed and the role of the positive ion lattice in this. *[2]*

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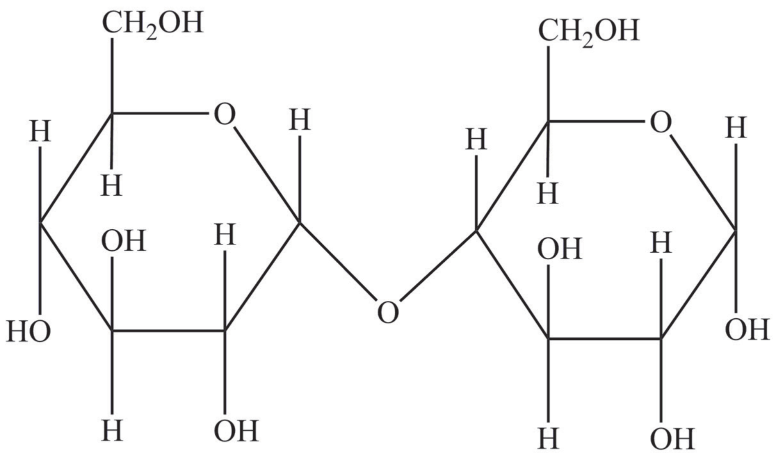
End of Option A

Option B — Biochemistry

8. The diagram below shows the structure of a disaccharide called maltose.



(a) Identify on the diagram one primary alcohol group by marking I on the oxygen, **and** one secondary alcohol group by marking II on the oxygen. *[1]*

(b) (i) Formulate an equation, using molecular formulas, to show the conversion of this molecule into its monomers. *[1]*

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(ii) Identify the type of metabolic process shown in part (b)(i). *[1]*

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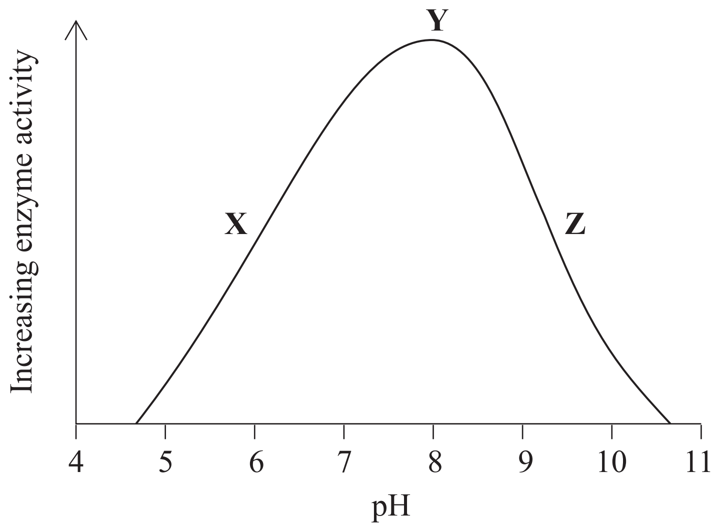
(Option B continues on the following page)

(Option B, question 8 continued)

(c) The reaction in part (b) is catalysed by the enzyme maltase. Experiments were carried out to investigate the rate of breakdown of maltose in the presence of maltase over a range of pH values from 4 to 11. The results are shown below.



Describe how the activity of the enzyme changes with pH, including in your answer specific reference to how the pH is affecting the enzyme at **X**, **Y** and **Z**. *[3]*

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(Option B continues on the following page)

(Option B, question 8 continued)

(d) The experiments described in part (c) use a range of buffer solutions. A student needed to make $1.00\,dm^3$ of pH 5.00 buffer solution starting with $0.10\,mol\,dm^{-3}$ butanoic acid solution and solid sodium butanoate. The molar mass of sodium butanoate is $110.01\,g\,mol^{-1}$.

Use information from sections 1 and 21 of the data booklet to determine how much of each component the student should mix together. Assume no volume change occurs on mixing. Show all your working. *[3]*

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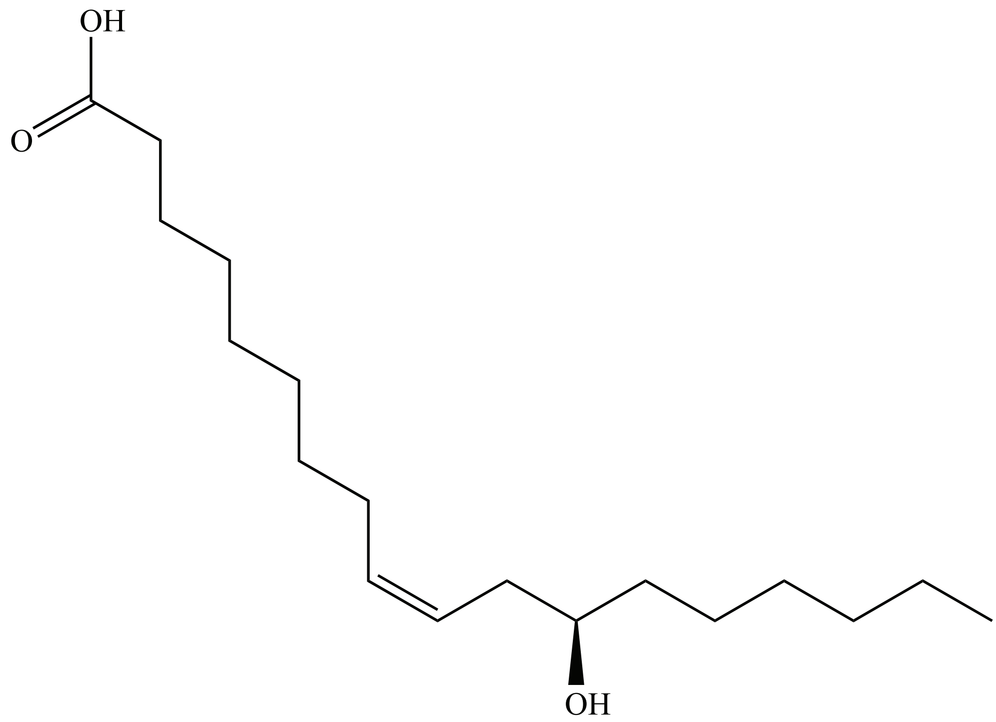
(Option B continues on the following page)

(Option B continued)

9. The castor plant is grown as a crop for its oil. Castor oil is mostly a triglyceride of the relatively rare fatty acid ricinoleic acid, whose structure is given below.



(a) State the molecular formula of ricinoleic acid. *[1]*

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(b) (i) Compare and contrast the structure of ricinoleic acid with stearic acid, whose structure is given in section 34 of the data booklet. *[3]*

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(Option B continues on the following page)

(Option B, question 9 continued)

(ii) State and explain how you would expect ricinoleic acid triglyceride to differ from stearic acid triglyceride in its tendency to undergo oxidative rancidity. *[2]*

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(c) Deduce the number of possible stereoisomers of ricinoleic acid. *[1]*

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(d) The castor seed contains ricin, a toxic protein which is fatal in small doses. During the oil extraction process, the toxin is inactivated by heating.

(i) Outline why ricin loses its toxic effects on being heated. *[1]*

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(ii) Examine why many countries no longer harvest the castor plant but rely instead on imports of castor oil from other countries. *[2]*

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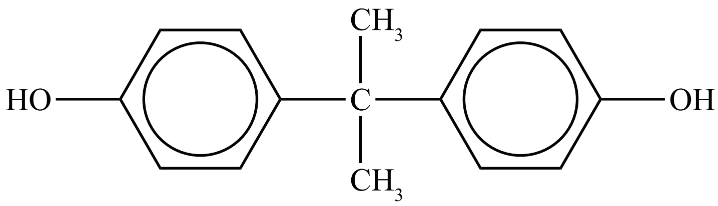
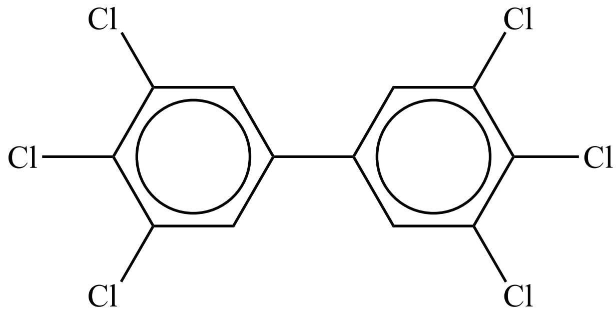
(Option B continues on the following page)

(Option B continued)

10. The figure below shows two examples of molecules known as xenoestrogens, a type of xenobiotic. They have effects on living organisms similar to those of the female hormone estrogen. These compounds are found in the environment and can be taken up by living organisms, where they may be stored in certain tissues.





(a) State what is meant by the term xenobiotic. *[1]*

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(b) With reference to their structures, outline why these xenobiotics are stored easily in animal fat. *[1]*

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(Option B continues on the following page)

(Option B, question 10 continued)

(c) One way to decrease the concentration of a xenobiotic in the environment is to develop a specific molecule, a "host", that can bind to it. The binding between the host and the xenobiotic forms a supramolecule.

State **three** types of association that may occur within the supramolecule between the host and the xenobiotic. *[1]*

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11. DNA is the molecule that carries genetic information in nearly all cells. Two months before Watson and Crick published their paper describing the double helical nature of DNA in 1953, Linus Pauling published a suggested structure for DNA based on a triple helix. Pauling's model, which was soon proved to be incorrect, had the phosphate groups facing into the core of the helix and the nitrogenous bases facing out.

(a) Suggest why Pauling's model would not have been a stable structure for DNA. *[2]*

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(b) DNA has the unusual property of being able to replicate. State the type and position of the bonds that break at the start of the replication process. *[1]*

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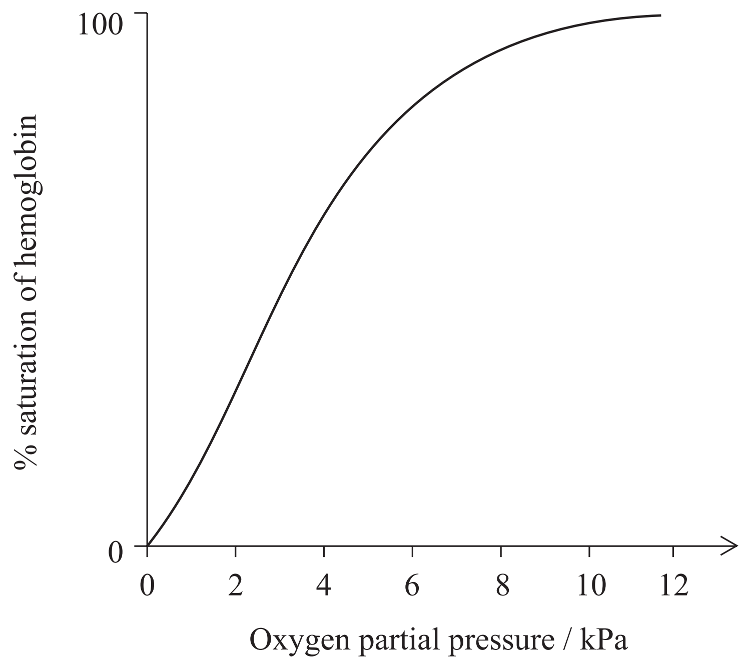
(Option B continues on the following page)

(Option B continued)

12. Hemoglobin is a protein with a quaternary structure. The graph below shows the relationship between the percentage saturation of hemoglobin with oxygen and the oxygen partial pressure, which is a measure of its concentration.



(a) Describe why the curve rises steeply in the range of approximately 2 – 6 kPa *[2]*

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(b) (i) Annotate the graph above to show how the oxygen binding curve for hemoglobin changes in the presence of an increased concentration of carbon dioxide. *[1]*

(Option B continues on the following page)

(Option B, question 12 continued)

(ii) Explain how the change you have drawn in part (b)(i) affects the oxygen saturation of the blood when it is close to cells that are actively respiring. *[2]*

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End of Option B

Option C — Energy

13. Plants convert solar energy into chemical energy. It would therefore be very convenient to use plant products, such as vegetable oils, directly as fuels for internal combustion engines.

(a) Visible light from the Sun is absorbed by chlorophyll. The structure of chlorophyll is given in section 35 of the data booklet. Identify the characteristic of the bonding in chlorophyll that enables it to absorb light in the visible region of the spectrum. *[1]*

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(b) (i) Identify the major problem involved in using vegetable oils directly as a fuel in a conventional internal combustion engine. *[1]*

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(ii) Transesterification of the oil overcomes this problem. State the reagents required for this process. *[1]*

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(Option C continues on the following page)

(Option C, question 13 continued)

(c) Plant products can also be converted to ethanol, which can be mixed with alkanes, such as octane, to produce a fuel. The table below gives some properties of these compounds.

Compound	**Molar mass / $g\,mol^{-1}$**	**Density / $g\,dm^{-3}$**	**ΔH_c / $kJ\,mol^{-1}$**	**Equation for combustion**
Ethanol	46.08	789	–1367	$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$
Octane	114.26	703	–5470	$C_8H_{18}(l) + 12\frac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$

(i) The energy density of ethanol is $23\,400\,kJ\,dm^{-3}$. Use data from the table above to determine the energy density of octane. *[1]*

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(ii) Use these results to outline why octane is the better fuel in vehicles. *[1]*

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(Option C continues on the following page)

(Option C, question 13 continued)

(iii) Use data from the table on page 26 to demonstrate that ethanol and octane give rise to similar carbon footprints. *[1]*

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(iv) Outline why, even though they have similar carbon footprints, using ethanol has less impact on levels of atmospheric carbon dioxide. *[1]*

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(Option C continues on the following page)

(Option C continued)

14. Nuclear power is an energy source that does not involve fossil fuels. Current nuclear technology is dependent on fission reactions.

(a) Commercial nuclear power technology developed very rapidly between 1940 and 1970. Outline why this occurred. *[1]*

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(b) The equation for a typical nuclear fission reaction is:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n}\,(\rightarrow {}^{236}_{92}\mathrm{U}) \rightarrow {}^{90}_{38}\mathrm{Sr} + {}^{136}_{54}\mathrm{Xe} + 10\,{}^{1}_{0}\mathrm{n}$$

The masses of the particles involved in this fission reaction are shown below.

Mass of neutron	=	1.00867 amu
Mass of U-235 nucleus	=	234.99333 amu
Mass of Xe-136 nucleus	=	135.90722 amu
Mass of Sr-90 nucleus	=	89.90774 amu

Using these data and information from sections 1 and 2 of the data booklet, determine the energy released when one uranium nucleus undergoes fission. *[3]*

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(Option C continues on the following page)

(Option C, question 14 continued)

(c) The half-life of strontium-90 is 28.8 years. Using information from section 1 of the data booklet, calculate the number of years required for its radioactivity to fall to 10 % of its initial value. *[2]*

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(d) Nuclear fuels require the enrichment of natural uranium. Explain how this process is carried out, including the underlying physical principle. *[3]*

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(Option C continues on the following page)

(Option C continued)

15. Energy production presents many threats to the environment. One issue that has caused much controversy over recent years is the emission of greenhouse gases, which most scientists believe is a major cause of global warming.

(a) Explain the molecular changes that must occur in order for a molecule to absorb infrared light. *[2]*

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(b) (i) Carbon dioxide and water vapour are the most abundant greenhouse gases. Identify **one** other greenhouse gas and a natural source of this compound. *[1]*

Greenhouse gas:

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Natural source:

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(ii) Even though water vapour is the more potent greenhouse gas, there is greater concern about the impact of carbon dioxide. Suggest why this is the case. *[1]*

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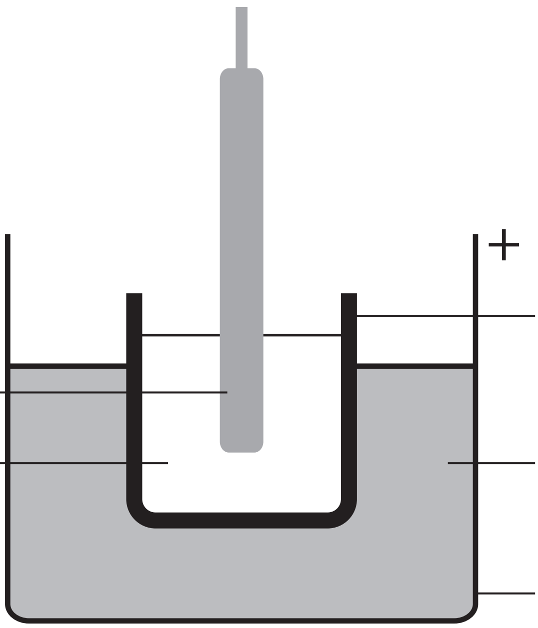
(Option C continues on the following page)

(Option C continued)

16. Providing electricity in remote locations, or in portable devices, is very important.

(a) One of the earliest devices used was the Daniell cell, illustrated below.



The porous cup allows the movement of ions between the two solutions, while preventing physical mixing. The standard potential of the cell, $E^{\ominus}_{cell}$, is 1.10 V.

(i) If the copper and the zinc electrodes are connected using a good electrical conductor, identify the process that initially limits the current. *[1]*

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(Option C continues on the following page)

(Option C, question 16 continued)

(ii) Outline, giving a reason, which solution should have its concentration increased in order to increase the cell potential. *[1]*

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(iii) In one remote location copper(II) sulfate was in short supply so the concentration of its solution had to be decreased to 0.1 $mol\,dm^{-3}$. Calculate the resulting cell potential, using information from sections 1 and 2 of the data booklet. *[2]*

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(iv) Suggest another effect that this decrease in the concentration of copper(II) sulfate will have on the cell as a source of electrical energy. *[1]*

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(Option C continues on the following page)

(Option C, question 16 continued)

(b) A modern solution to the provision of power for remote places is the dye-sensitized solar cell (DSSC). A Grätzel DSSC contains an organic dye molecule on the surface of a titanium dioxide, TiO_2, semiconductor that is in contact with an electrolyte containing iodide ions, I^-.

Explain its operation, including the importance of nanotechnology in its construction and its advantage over silicon-based photovoltaic devices. *[5]*

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End of Option C

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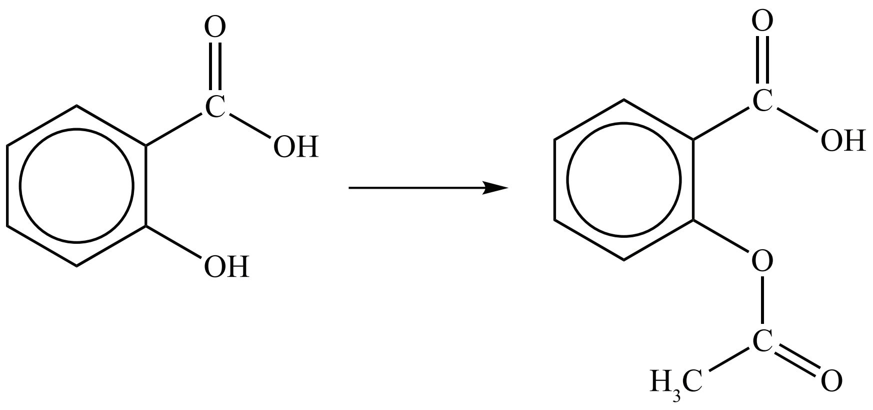
Option D — Medicinal chemistry

17. Salicylic acid has been used to relieve pain and reduce fevers for centuries, although it can be irritating to the stomach. In the 1800s it was discovered that converting it into acetylsalicylic acid reduces the stomach irritation while still allowing it to be effective.



Salicylic acid Acetylsalicylic acid (aspirin)

(a) Identify the type of reaction used to convert salicylic acid to acetylsalicylic acid. *[1]*

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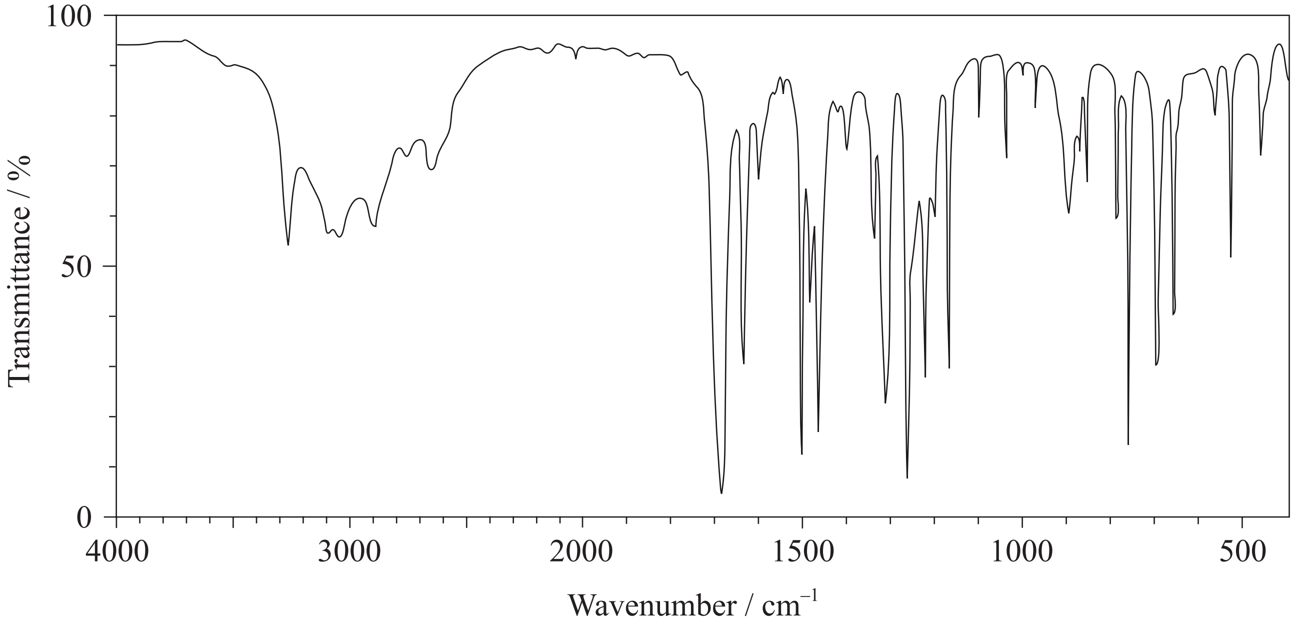
(Option D continues on the following page)

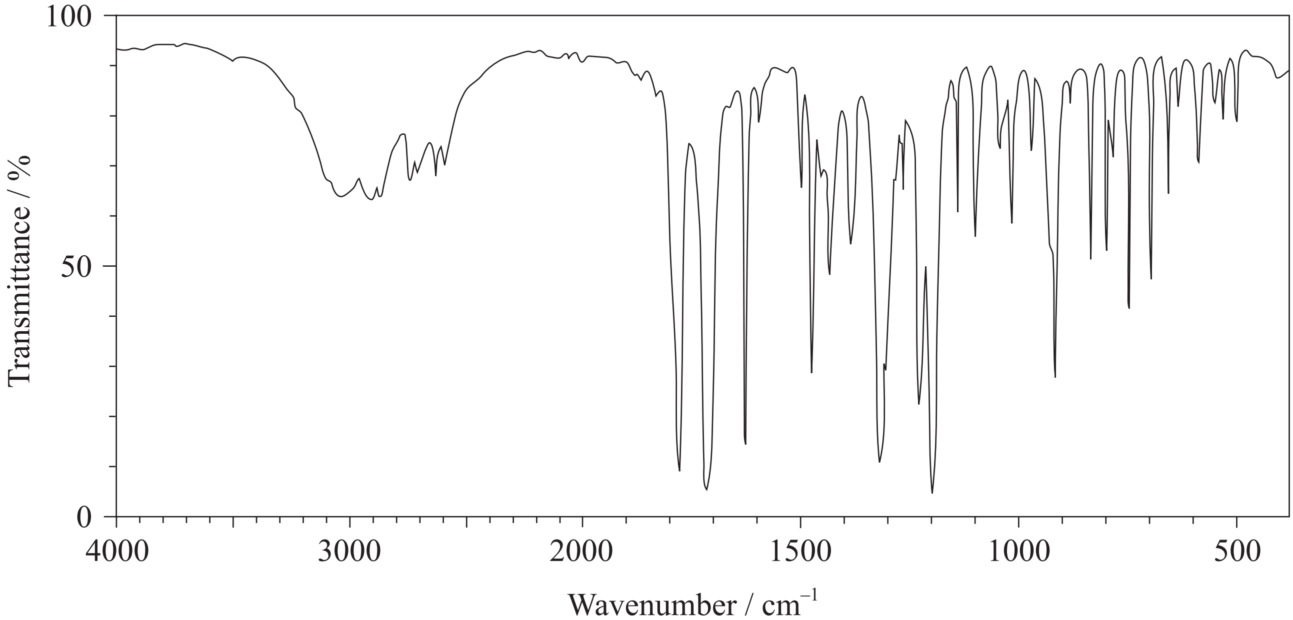
(Option D, question 17 continued)

(b) The infrared (IR) spectra for salicylic acid and acetylsalicylic acid are shown below.

Salicylic acid



Acetylsalicylic acid



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

(Option D continues on the following page)

(Option D, question 17 continued)

Using information from section 26 of the data booklet, compare and contrast the two spectra with respect to the bonds present. *[3]*

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(c) A modified version of aspirin is sometimes made by reacting it with a strong base, such as sodium hydroxide. Explain why this process can increase the bioavailability of the drug. *[3]*

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(Option D continues on the following page)

(Option D continued)

18. Recent advances in research into the viruses that cause flu have led to the production of two antiviral drugs, oseltamivir (Tamiflu®) and zanamivir (Relenza®).

(a) Outline why viruses are generally more difficult to target with drugs than bacteria. *[1]*

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(b) By reference to their molecular structures given in section 37 of the data booklet, state the formulas of **three** functional groups that are present in both oseltamivir and zanamivir and the formulas of **two** functional groups that are present in zanamivir only. *[3]*

Present in both:

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. . . .
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Present in zanamivir only:

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(c) Comment on how the widespread use of these drugs may lead to the spread of drug-resistant viruses. *[2]*

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(Option D continues on the following page)

(Option D continued)

19. Antacids help to neutralize excess hydrochloric acid produced by the stomach. The neutralizing power of an antacid can be defined as the amount in moles of hydrochloric acid that can be neutralized per gram of antacid.

(a) Formulate an equation to show the action of the antacid magnesium hydroxide. *[1]*

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(b) An antacid tablet with a mass of 0.200 g was added to 25.00 cm^3 of 0.125 $mol\,dm^{-3}$ hydrochloric acid. After the reaction was complete, the excess acid required 5.00 cm^3 of 0.200 $mol\,dm^{-3}$ sodium hydroxide to be neutralized. Determine the neutralizing power of the tablet. *[3]*

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(Option D continues on the following page)

(Option D continued)

20. Radiotherapy is widely used as part of the treatment for many types of cancer. It uses ionizing radiation to control or kill cancerous cells.

A promising development in this field is targeted alpha therapy, which uses alpha-emitting radionuclides specifically directed at the biological target.

(a) Explain **two** characteristics of alpha particles that enable them to be particularly effective in cancer treatments. *[2]*

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(b) (i) Other forms of radiotherapy use radionuclides that are beta emitters. Yttrium-90, ^{90}Y, is commonly used and undergoes beta decay with a half-life of 64 hours.

Formulate the nuclear equation for the decay of ^{90}Y. *[2]*

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(ii) Use information from section 1 of the data booklet to calculate how much of a 65.7 g sample of ^{90}Y would remain after 264 hours. *[2]*

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(Option D continues on the following page)

(Option D continued)

21. Taxol® is a chemotherapeutic drug used for the treatment of several types of cancer.

(a) Describe the original source and the environmental impact of obtaining Taxol® from this source. *[2]*

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(b) Outline a current "green chemistry" approach for isolating Taxol®, and why this is less harmful to the environment. *[2]*

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(c) The structure of Taxol® is shown in section 37 of the data booklet. It has been described as a "very chiral molecule". Explain the meaning of this statement and why processes to synthesize Taxol® chemically are complex and crucial to control. *[3]*

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End of Option D

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MARKSCHEME

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Paper 3

23 pages

Subject Details: Chemistry HL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions in Section A **[15 marks]** and all questions from **ONE** option in Section B **[30 marks]**.
Maximum total = **[45 marks]**.

1. Each row in the “Question” column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the “Total” column.

3. Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by “**max**” written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.

5. An alternative wording is indicated in the “Answers” column by a slash (/). Either wording can be accepted.

6. An alternative answer is indicated in the “Answers” column by “***OR***” on the line between the alternatives. Either answer can be accepted.

7. Words in angled brackets **‹ ›** in the “Answers” column are not necessary to gain the mark.

8. Words that are <u>underlined</u> are essential for the mark.

9. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.

10. If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the “Notes” column.

11. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. "ECF acceptable" will be displayed in the "Notes" column.

13. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

14. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the "Notes" column, similarly, if the formula is specifically asked for, unless directed otherwise in the "Notes" column do not award a mark for a correct name.

15. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the "Notes" column.

16. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

SECTION A

Question			Answers	Notes	Total
1.	**a**	**i**	relative values ***OR*** compared with a standard ***OR*** not absolute measure ✓		**1**
	a	**ii**	high ODP for compounds with high Cl ***OR*** low ODP for compounds with less Cl ***OR*** zero ODP for compounds with no Cl ✓		**1**
	b		increasing atmospheric lifetime correlates with increasing GWP ✓ total contribution to global warming depends on length of time in atmosphere ***OR*** GWP depends on efficiency as greenhouse gas and atmospheric lifetime ✓	*Accept alternate answers based on sound scientific reasoning.*	**2**
	c	**i**	1,1,1,2-tetrafluoroethane ✓	*Allow without commas or dashes.*	**1**
	c	**ii**	$M\,(CH_2FCF_3) = (12.01 \times 2) + (1.01 \times 2) + (19.00 \times 4) = 102.04 \langle g\,mol^{-1} \rangle$ ✓ $\Delta H\,(\text{condensation } CH_2FCF_3) = -[0.217 \langle kJ\,g^{-1} \rangle \times 102.04 \langle g\,mol^{-1} \rangle] = -22.1 \langle kJ\,mol^{-1} \rangle$ ✓	*Award **[1 max]** for* $\Delta H = 22.1\,kJ$	**2**
	c	**iii**	atmospheric lifetime CO_2 much longer than CH_2FCF_3 ***OR*** after 100 years approx 30 % CO_2 still present whereas CH_2FCF_3 removed ✓ CO_2 from current emissions will continue to effect climate change/global warming far into the future ✓	*OWTTE*	**2**

Question			Answers	Notes	Total
2.	**a**		forgot to take account of water of crystallisation ***OR*** should have used 24.972 g ✓	*OWTTE*	**1**
	b		less uncertainty in the volume ***OR*** more precise ✓ takes into account volume change on dissolving ***OR*** concentration is for a given volume of solution not volume of solvent ✓		**2**
	c		filter ***OR*** centrifuge ✓ rinse (the solid) with water ✓ heat in an oven ***OR*** rinse with propanone/ethanol/volatile organic solvent and leave to evaporate ✓	*Award **[2]** for all 3, **[1]** for any 2.*	**2**
	d		taking a known mass of the solid to react directly with glucose ***OR*** not making the standard solution ✓	*OWTTE* *Accept any other valid answer based on sound scientific reasoning.*	**1**

SECTION B

Option A — Materials

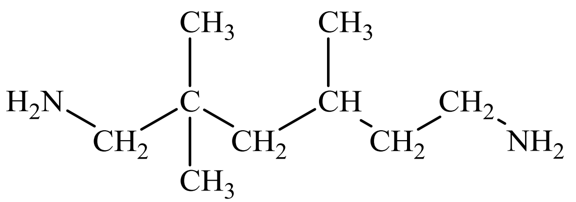
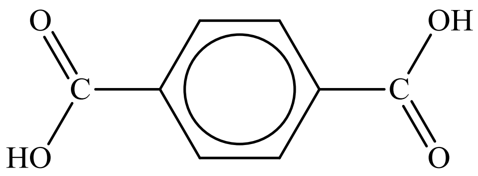
<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>3.</td><td>a</td><td></td><td>rigid
OR
rod-shaped/long thin molecule ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>b</td><td>i</td><td>mixture of carbon containing compound and inert dilutant in gas/vapour phase ✓

passed over a heated metal catalyst ✓</td><td></td><td>2</td></tr>
<tr><td></td><td>b</td><td>ii</td><td>(very) large surface area ✓</td><td></td><td>1</td></tr>
</table>

<table>
<tr><td>4.</td><td>a</td><td></td><td><table><tr><th>Compound</th><th>Magnesium oxide</th><th>Cobalt(II) oxide</th><th></th></tr><tr><td>Electronegativity difference</td><td>2.1</td><td>1.5</td><td>✓</td></tr><tr><td>Average electronegativity</td><td>2.35</td><td>2.65</td><td>✓</td></tr></table></td><td>Award [1] per correct row or column.</td><td>2</td></tr>
<tr><td></td><td>b</td><td></td><td><table><tr><th>Compound</th><th>Magnesium oxide</th><th>Cobalt(II) oxide</th><th></th></tr><tr><td>Bond type</td><td>Ionic</td><td>Polar covalent</td><td>✓</td></tr><tr><td>% covalent character</td><td>30 – 35</td><td>53 – 58</td><td>✓</td></tr></table></td><td>Award [1] per correct row or column.</td><td>2</td></tr>
</table>

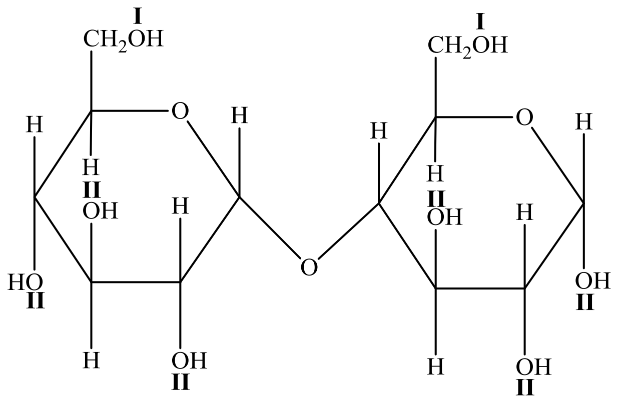
Question			Answers	Notes	Total
5.	**a**	**i**	mass of solid too small to weigh accurately ✓ successive dilution of solution ***OR*** dilution of concentrated solution ✓	*OWTTE*	**2**
	a	**ii**	627 kcps **and** it lies inside of the calibrated region ***OR*** 627 kcps **and** 12 kcps lies outside of calibrated region ✓	*Accept other correct suggestions, for example "Low values such as 12 kcps would have very high uncertainty".*	**1**
	b		$K_{sp} = [Mg^{2+}][OH^-]^2$ ✓ $[Mg^{2+}] = \frac{1}{4} \times 1.20 \times 10^{-11}$ ✓ $[Mg^{2+}] = 3.00 \times 10^{-12} \langle mol\,dm^{-3} \rangle$ ✓		**3**

Question			Answers	Notes	Total
6.	**a**		resin identification codes ✓ ensures uniformity for recycling ✓ ***OR*** addition/condensation ✓ classification into similar reaction types ✓ ***OR*** flexible ✓ direct towards appropriate uses ✓ ***OR*** brittle ✓ direct towards appropriate uses ✓	*OWTTE* *Accept "predict possible monomers". OWTTE* *Accept any other valid scientific classification with a justifiable scientific reason for* ***[2]****.*	**2**
	b		softens the polymer ✓ separates the polymer chains ***OR*** reduces intermolecular forces ✓		**2**
	c		all of the reagents end up in useful product ***OR*** atom economy is 100% ***OR*** there is no chemical waste ✓	*OWTTE*	**1**
	d		hydrogen chloride/HCl ***OR*** dioxin ✓		**1**

Question			Answers	Notes	Total
	e		polyamide ***OR*** condensation ✓  / $H_2NCH_2C(CH_3)_2CH_2CH(CH_3)CH_2CH_2NH_2$ **and**  / $HOOCC_6H_4COOH$	*Accept H_2N written as NH_2.* *Accept the acyl chloride.*	**2**

Question			Answers	Notes	Total
7.	**a**		bcc / body-centred cubic ✓ 8 ✓ 2 ✓		**3**
	b		mass of Nb in unit cell $= \langle \frac{2\times 92.91\times 10^{-3}}{6.02\times 10^{23}} = \rangle 3.087\times 10^{-25}$ ‹kg› ✓ volume of unit cell $= \langle (3.14\times 10^{-10})^3 = \rangle 3.096\times 10^{-29} \langle \text{m}^3 \rangle$ ✓ density $= \langle \frac{3.087\times 10^{-25}}{3.096\times 10^{-29}} \rangle = 9970 \langle \text{kg m}^{-3} \rangle$ ✓	*Award **[3]** for correct final answer.*	**3**
	c		‹at low temperatures› the positive ions in the lattice are attracted to a passing electron, distorting the lattice slightly ✓ a second electron with <u>opposite spin</u> is attracted to this ‹slightly positively charged› deformation ‹and a coupling of the two electrons occurs› ✓		**2**

Option B — Biochemistry

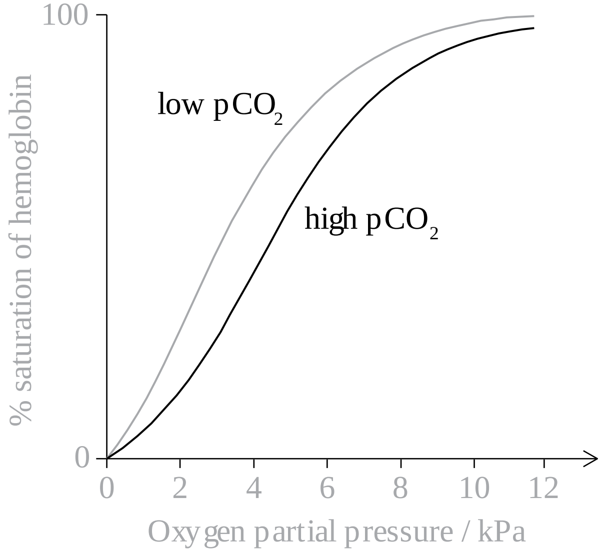
Question			Answers	Notes	Total
8.	**a**		 ✓	*Award mark for a correctly placed **I** **and** a correctly placed **II**.* *Allow **II** placed on hemiacetal.*	**1**
	b	**i**	$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$ ✓		**1**
	b	**ii**	catabolism ✓	*Accept hydrolysis.*	**1**
	c		at X (low pH) enzyme/protein protonated / positively charged / cationic (so unable to bind effectively) ✓ at Y (optimum pH) enzyme maximally able to bind to substrate/maltose ✓ at Z (high pH) enzyme/protein deprotonated / negatively charged / anionic (so unable to bind effectively) ✓	*Award **[1 max]** for reference to denaturation/change in shape of active site without explanation in terms of changes in ionization.*	**3**

Question			Answers	Notes	Total
8.	**d**		‹$\mathrm{pH} = \mathrm{p}K_a + \log\left\{\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}\right\}$, butanoic acid $\mathrm{p}K_a = 4.83$› $5.00 - 4.83 = \log\left(\frac{[\text{butanoate ion}]}{0.10}\right)$ **OR** $10^{0.17} = \frac{[\text{butanoate ion}]}{0.10} = 1.479$ ✓ $[\text{butanoate ion}] = 0.1479$ ‹$\mathrm{mol\,dm^{-3}}$› ✓ if $1.00\,\mathrm{dm^3}$, $0.10\,\mathrm{mol\,dm^{-3}}$ butanoic acid $1.00\,\mathrm{dm^3}$ of $0.1479\,\mathrm{mol\,dm^{-3}}$ solution: $0.1479\,\mathrm{mol} \times 110.01\,\mathrm{g\,mol^{-1}} = 16.27\,\mathrm{g}$ sodium butanoate ✓	*Accept alternate valid methods.*	**3**

Question			Answers	Notes	Total
9.	a		$C_{18}H_{34}O_3$ ✓		1
	b	i	both have 18 carbon atoms ✓ both have COOH/carboxylic acid group ***OR*** both are fatty acids ✓ ricinoleic acid has a <u>carbon-carbon</u> double bond/C=C/‹mono›unsaturated whereas stearic acid has all single C–C bonds/saturated ✓ ricinoleic acid has an OH/hydroxyl group ‹in the chain› whereas stearic acid does not ✓	*Do not accept just acids in M2* *Any 3 for **[3 max]**.*	**3 max**
	b	ii	ricinoleic acid more likely to undergo oxidative rancidity (than stearic acid) ✓ <u>carbon-carbon</u> double bond/C=C can be oxidised ✓		2
	c		4 ✓		1
	d	i	‹heating causes› denaturation ***OR*** ‹heating causes› loss of conformation ***OR*** ‹heating causes› change of shape ***OR*** ‹heating causes› inability to bind substrates ✓	*Do not accept inactivated.*	1
	d	ii	castor seeds contain toxins/ricin ***OR*** ingesting raw seeds can be fatal ✓ different health/safety standards in different countries ***OR*** richer countries exploit workers in less-developed/poorer countries ✓	*Accept alternate valid answers, such as economic considerations.*	2

Question			Answers	Notes	Total
10.	**a**		substance/chemical/compound found in organism not normally present ***OR*** compound foreign to living organism ✓	*Accept artificially synthesised/man-made compound in the environment/biosphere.*	**1**
	b		non-polar ***OR*** lipophilic ***OR*** structure based on phenyl/hydrocarbon ***OR*** hydrophobic interactions ***OR*** similar (non)polarity to fat ✓		**1**
	c		ionic bonds ✓ hydrogen bonds ✓ van der Waals' forces ✓ hydrophobic interactions ✓	*Award **[1]** for any 3 correct answers.* *Accept alternate valid answers other than covalent bonding*	**1 max**

11.	**a**		phosphate groups negatively charged/anionic so repulsion when close together/stacked ***OR*** negative charged/hydrophilic phosphate groups associate with aqueous exterior/surface ✓ nitrogenous bases hydrophobic/non-polar will not easily associate with aqueous exterior/surface ***OR*** non-polar groups form hydrophobic/non-polar internal environment ✓	*OWTTE* *OWTTE*	**2**
	b		hydrogen bonds between paired/complementary bases ✓	*Allow hydrogen bonds between A & T and C & G.*	**1**

Question			Answers	Notes	Total
12.	**a**		binding to the first polypeptide causes a conformational/3D change in shape ✓ facilitates the binding to the other polypeptides ***OR*** cooperative binding ✓		**2**
	b	**i**	 curve of same shape to the right of given graph ✓		**1**
	b	**ii**	respiration releases CO_2 ***OR*** high concentration of CO_2 near actively respiring cells ✓ percentage saturation of hemoglobin is lower as CO_2 increases ***OR*** hemoglobin lower affinity/binds less to oxygen at higher CO_2 ***OR*** oxyhemoglobin dissociates more easily/releases O_2 at higher CO_2 ✓		**2**

Option C — Energy

Question			Answers	Notes	Total
13.	**a**		<u>extended</u> system of delocalized ‹pi-›bonding/electrons ***OR*** <u>extensive</u> conjugation ✓		**1**
	b	**i**	viscosity too high ✓		**1**
	b	**ii**	alcohol **and** (strong) acid ***OR*** base ✓		**1**
	c	**i**	$\langle \frac{703\times 5470}{114.26} = \rangle 33700 \langle \text{kJ dm}^{-3} \rangle$ ✓		**1**
	c	**ii**	more energy from a given volume of fuel ✓	*Accept greater energy density.*	**1**
	c	**iii**	ethanol: $\frac{1367}{2} = 683.5\,\text{kJ mol}^{-1}$ **and** octane: $\frac{5470}{8} = 683.8\,\text{kJ mol}^{-1}$ ***OR*** mass of CO_2 produced in the release of 1000 kJ ethanol: $\frac{2\times 44.01\times 1000}{1367} = 64.4\,\text{g}$ **and** octane: $\frac{8\times 44.01\times 1000}{1367} = 64.4\,\text{g}$ ✓	*Accept other methods that show the amount carbon dioxide produced for the same heat energy output is the same for both fuels.*	**1**
	c	**iv**	ethanol is a biofuel/produced from plant material ***OR*** growing plants absorbs carbon dioxide ✓		**1**

Question			Answers	Notes	Total
14.	**a**		nuclear power benefitted from the race to develop nuclear weapons ✓	*OWTTE* *Accept other valid explanations.*	**1**
	b		$\Delta m = \langle 234.99333 - 135.90722 - 89.907738 - [9 \times 1.00867] = \rangle\, 0.100342 \langle \text{amu} \rangle$ ✓ $= \langle 0.100342 \times 1.66 \times 10^{-27} \langle \text{kg} \rangle = \rangle 1.67 \times 10^{-28} \langle \text{kg} \rangle$ ✓ $E = \langle mc^2 = 1.67 \times 10^{-28} \times (3 \times 10^8)^2 = \rangle 1.50 \times 10^{-11} \langle \text{J} \rangle$ ✓	*Award* ***[3]*** *for correct final answer.*	**3**
	c		$\lambda = \langle \frac{\ln 2}{t_{½}} = \frac{\ln 2}{28.8} = \rangle\, 0.0241$ ✓ $t = \langle -\frac{1}{\lambda} \ln \frac{N}{N_0} = -\frac{\ln 0.1}{0.0241} = \rangle\, 95.7\ \langle \text{years} \rangle$ ✓ ***OR*** $0.5^n = x$ $n = \langle \frac{\log x}{\log 0.5} = \frac{\log 0.1}{0.301} = \rangle 3.32$ ✓ time $= 28.3 \times 3.32 = 95.7\ \langle \text{years} \rangle$ ✓	*Award* ***[2]*** *for correct final answer.*	**2**
	d		conversion to UF_6 ✓ different isotopes have different rates of diffusion ✓ gases diffuse at rate proportional to $(M_r)^{-½}$ ✓ diffusion produced by ultracentifuges ✓		**3 max**

Question			Answers	Notes	Total
15.	**a**		stretching ***OR*** bending ✓ causing a change in polarity/dipole moment ✓		**2**
	b	**i**	methane **and** anaerobic decomposition of organic matter ***OR*** digestion in animals ✓	*Accept other examples of greenhouse gases with correct <u>natural</u> sources.*	**1**
	b	**ii**	major sources of water vapour are natural rather than anthropogenic/due to humans ***OR*** levels of water vapour have remained almost constant whereas those of CO_2 have increased significantly in recent times ✓		**1**

16.	**a**	**i**	movement/diffusion of ions between the two solutions/through the porous cup ✓		**1**
	a	**ii**	$CuSO_4$/copper(II) sulfate **and** displaces equilibrium towards Cu/copper ***OR*** $CuSO_4$/copper(II) sulfate **and** makes Cu/copper half cell more positive ✓		**1**
	a	**iii**	$E = 1.10 - \left(\frac{298R}{2F}\right)\ln\frac{[Zn^{2+}]}{[Cu^{2+}]} = 1.10 - \left(\frac{298 \times 8.31}{2 \times 96500}\right)\ln\frac{1}{0.1} = 1.10 - 0.0295$ ✓ $E = 1.07 \langle \mathrm{V} \rangle$ ✓	*Award* ***[2]*** *for correct final answer.*	**2**
	a	**iv**	run out of power much more rapidly ***OR*** would not last as long ***OR*** would not be able to produce as much electricity ✓		**1**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td></td><td>b</td><td></td><td>Operation:
light energy excites dye molecules ✓

(excited) dye molecules inject electrons into TiO_2 layer
OR
$dye \rightarrow dye^{+} + e^{-}$ ✓

oxidized dye molecules oxidize/convert I^{-} to I_3^{-}
OR
$2\,dye^{+} + 3I^{-} \rightarrow I_3^{-} + 2dye$
OR
$dye^{+} + e^{-} \rightarrow dye$ and $3I^{-} \rightarrow I_3^{-} + 2e^{-}$ ✓

electrons flow through external circuit back to counter electrode ✓

electrons reduce/convert I_3^{-} ions to I^{-} (at the counter electrode)
OR
$I_3^{-} + 2e^{-} \rightarrow 3I^{-}$ ✓

Advantage:
dye sensitised cells can use light of lower energy/lower frequency/longer wavelength than silicon cells ✓

Importance of nanotechnology:
nanoparticles ensure a large surface area ✓</td><td>Any three for [3 max] for its operation.</td><td>5 max</td></tr>
</table>

Option D — Medicinal chemistry

Question			Answers	Notes	Total
17.	**a**		esterification ***OR*** condensation ✓		**1**
	b		*Difference*: only spectrum for salicylic acid has ‹strong broad› peak from 3200–3600 cm^{-1} for OH ‹in alcohol/phenol› ✓ *Similarities*: both have ‹strong› peaks from 1050–1410 cm^{-1} for C–O ‹in alcohol/phenol› ✓ both have ‹strong› peaks from1700–1750 cm^{-1} for C=O ‹in carboxylic acid› ✓ both have ‹broad› peaks from 2500–3000 cm^{-1} for OH ‹in carboxylic acid› ✓ both have peaks from 2850–3090 cm^{-1} for C–H ✓	*Accept "acetylsalicylic acid has two peaks in the 1700–1800 cm^{-1} range due to 2 different C=O".* *Award **[2 max]** for two of the following similarities.*	**3 max**
	c		reaction with NaOH produces ‹ionic› salt ***OR*** $C_6H_4(OH)(COOH) + NaOH \rightarrow C_6H_4(OH)(COONa) + H_2O$ ✓ increases ‹aqueous› solubility ‹for transport/uptake› ✓ higher proportion of drug/dosage reaches target region/cells ✓		**3**

Question			Answers	Notes	Total
18.	**a**		lack cell structure ***OR*** exist within host cell ***OR*** mutate easily and frequently ✓		**1**
	b		*Present in both*: NH_2 ✓ CONH ✓ C=C ✓ COC ✓ *Present in zanamivir only*: COOH **and** OH ✓	*For similarities, award **[2 max]** for any three correct, **[1 max]** for two correct, **[0]** for one correct.* *Accept C=N*	**3 max**
	c		exposure of viruses to the drug favours resistant strains ✓ resistant strains difficult to treat ***OR*** drugs should be used only when required ‹not as prophylactic› ✓	*OWTTE*	**2**

Question			Answers	Notes	Total
19.	a		$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$ ✓		1
	b		n(HCl added) $= \langle 0.02500 \times 0.125 = \rangle\ 0.00313 \langle mol \rangle$ ✓ n(HCl unreacted with tablet) $= n(NaOH) = 0.00500 \times 0.200 = 0.00100 \langle$mol HCl excess$\rangle$ n(HCl reacted with antacid) $= \langle 0.00313 - 0.00100 = \rangle\ 0.00213 \langle mol \rangle$ ✓ neutralizing power $\langle mol\ g^{-1} \rangle = \langle \frac{0.00213}{0.200} = \rangle\ 0.011 \langle$mol HCl neutralized per g antacid$\rangle$ ✓		3

20.	a		very high ionizing density **and** so a high probability of killing cells along their track ✓ short range **and** so minimise unwanted irradiation of normal tissue surrounding the targeted cancer cells ✓	*OWTTE*	2
	b	i	${}^{90}_{39}Y \rightarrow {}^{90}_{40}Zr + {}^{0}_{-1}e / {}^{0}_{-1}\beta$ ✓✓	*Award **[1]** for correctly balanced mass and proton numbers.* *Award **[1]** for identification of Zr.*	2
	b	ii	$N_t = (65.7)(0.5)^{264/64}$ ✓ $N_t = 3.77 \langle g \rangle$ ✓ ***OR*** number of half-lives $(n) = \frac{264}{64} = 4.125$ ✓ proportion remaining $= (0.5)^n = 0.0573$ so $m = 3.77\,g$ ✓		2

Question			Answers	Notes	Total
21.	a		obtained from the bark of ‹Pacific› yew tree ✓ harvesting bark kills the tree ***OR*** trees/habitat became endangered ✓		**2**
	b		obtained from needles of Pacific yew tree ***OR*** obtained from fungus ***OR*** fermentation process ✓ avoids production of waste/hazardous by-products ***OR*** (fermentation) avoids use of solvents/reagents ***OR*** resources used renewable ✓		**2**

21.	c		many/11 chiral carbon centres ✓ large number enantiomers/stereoisomers exist ✓ different enantiomers have different effects in the body ***OR*** some enantiomers may be physiologically harmful ✓ synthetic routes use chiral auxiliaries to control enantiomer produced ✓ low yields from multi-stage processes ✓		**3 max**

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CHEMISTRY
STANDARD LEVEL
PAPER 1

SPECIMEN PAPER

45 minutes

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- The periodic table is provided for reference on page 2 of this examination paper.
- The maximum mark for this examination paper is *[30 marks]*.

The Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01				Atomic number **Element** Relative atomic mass													2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.90
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (270)	108 **Hs** (269)	109 **Mt** (278)	110 **Ds** (281)	111 **Rg** (281)	112 **Cn** (285)	113 **Unt** (286)	114 **Uug** (289)	115 **Uup** (288)	116 **Uuh** (293)	117 **Uus** (294)	118 **Uuo** (294)

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

1. What is the total number of atoms in 0.50 mol of 1,4-diaminobenzene, $H_2NC_6H_4NH_2$?
(Avogadro's constant (L or N_A) = 6.0×10^{23} mol^{-1}.)

A. 16.0×10^{23}

B. 48.0×10^{23}

C. 96.0×10^{23}

D. 192.0×10^{23}

2. What is the sum of the coefficients when the equation for the combustion of ammonia is balanced using the smallest possible whole numbers?

$$\_\_\_\ NH_3(g) + \_\_\_\ O_2(g) \rightarrow \_\_\_\ N_2(g) + \_\_\_\ H_2O(g)$$

A. 6

B. 12

C. 14

D. 15

3. Which changes of state are endothermic processes?

I. Condensing
II. Melting
III. Subliming

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

4. 5.00 g of calcium carbonate, when heated, produced 2.40 g of calcium oxide. Which is the correct expression for the percentage yield of calcium oxide? ($M_r(CaCO_3) = 100$; $M_r(CaO) = 56$.)

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

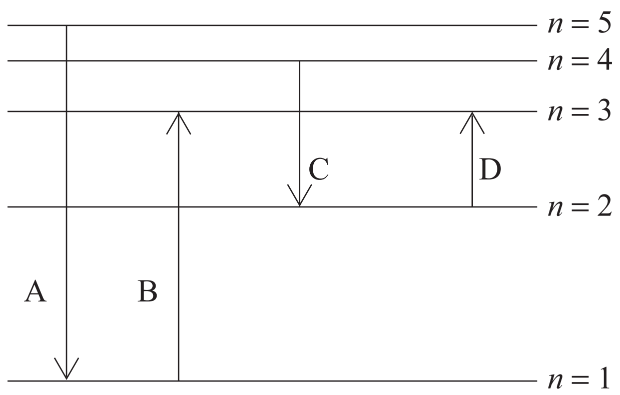
A. $\frac{56 \times 5.00 \times 100}{2.40}$

B. $\frac{2.40 \times 100 \times 100}{56 \times 5.00}$

C. $\frac{56 \times 5.00 \times 100}{2.40 \times 100}$

D. $\frac{2.40 \times 100}{56 \times 5.00}$

5. Which electronic transition would absorb the radiation of the shortest wavelength?



6. What are the numbers of protons, neutrons and electrons in the ion $^{238}_{92}X^{2+}$?

	Protons	Neutrons	Electrons
A.	146	92	144
B.	92	146	90
C.	92	146	94
D.	92	238	90

7. Which element is in the f-block of the periodic table?

A. Be

B. Ce

C. Ge

D. Re

8. Which property increases down group 1 of the periodic table?

A. Melting point

B. First ionization energy

C. Atomic radius

D. Electronegativity

9. Which is the best description of ionic bonding?

A. Electrostatic attraction between oppositely charged ions

B. Electrostatic attraction between positive ions and electrons

C. Electrostatic attraction of nuclei towards shared electrons in the bond between the nuclei

D. Electrostatic attraction between nuclei

10. Which has bonds with the greatest covalent character?

A. $SrCl_2$

B. $SiCl_4$

C. $SnCl_2$

D. Sn

11. Which bond is the **least** polar?

A. C=O in CO_2

B. C–H in CH_4

C. C–Cl in CCl_4

D. N–H in CH_3NH_2

12. Which substance has a high melting point and does not conduct electricity in any state?

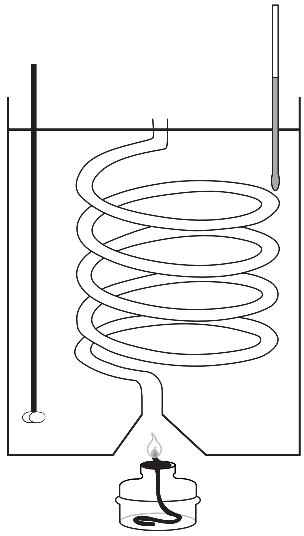
A. $PbBr_2$

B. Fe

C. NaCl

D. SiO_2

13. When 0.46 g of ethanol is burned under a water-filled calorimeter, the temperature of 500 g of water is raised by 3.0 K. (Molar mass of ethanol = 46 g mol^{-1}; specific heat capacity of water = 4.18 J g^{-1} K^{-1}; $q = mc\Delta T$.)



What is the expression for the enthalpy of combustion, ΔH_c, in kJ mol^{-1}?

A. $-\dfrac{500 \times 4.18 \times 3.0 \times 46}{0.46}$

B. $-\dfrac{500 \times 4.18 \times (273 + 3.0) \times 46}{0.46 \times 1000}$

C. $-\dfrac{500 \times 4.18 \times 3.0 \times 46}{0.46 \times 1000}$

D. $-\dfrac{0.46 \times 1000}{500 \times 4.18 \times 3.0 \times 46}$

14. Which reaction represents the average bond enthalpy of the C–H bond?

A. $\frac{1}{4}CH_4(g) \rightarrow \frac{1}{4}C(g) + \frac{1}{2}H_2(g)$

B. $\frac{1}{4}CH_4(g) \rightarrow \frac{1}{4}CH_2(g) + \frac{1}{4}H_2(g)$

C. $\frac{1}{4}CH_4(g) \rightarrow \frac{1}{4}C(g) + H(g)$

D. $\frac{1}{4}CH_4(g) \rightarrow \frac{1}{4}C(s) + H(g)$

15. Given the following information, what is the standard enthalpy of formation, $\Delta H^{\ominus}_{f}$, of methane?

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = \text{E kJ}$$
$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H = \text{F kJ}$$
$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \qquad \Delta H = \text{G kJ}$$

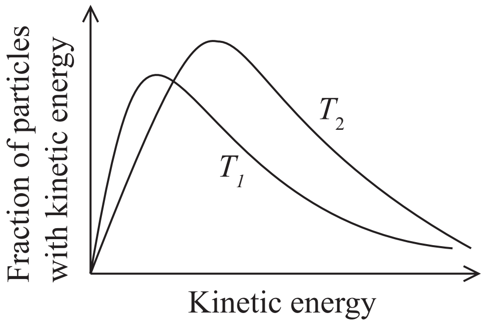
A. E + F + G

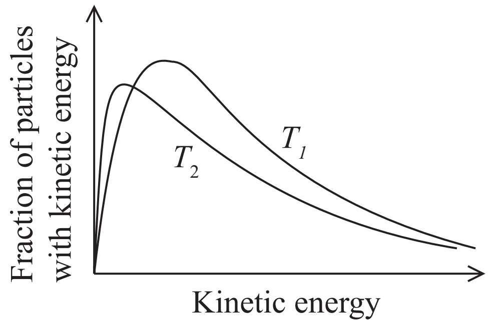
B. E + F – G

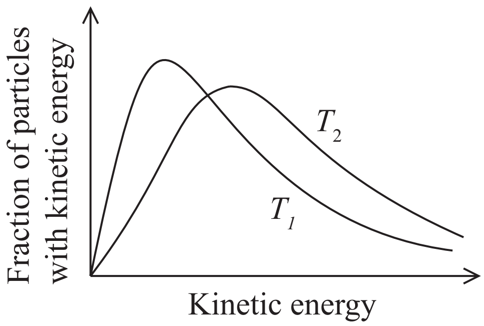
C. E + 2F + G

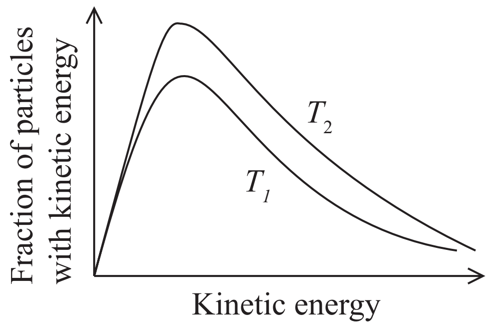
D. E + 2F – G

16. Which graph shows the Maxwell-Boltzmann energy distribution of a same amount of a gas at two temperatures, where T_2 is greater than T_1?

A.


B.


C.


D.


17. Which changes increase the rate of this reaction, other conditions remaining constant?

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

I. Using larger lumps of calcium carbonate

II. Increasing the temperature of the reaction mixture

III. Increasing the concentration of hydrochloric acid

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

18. Which conditions give the greatest equilibrium yield of methanal, $H_2CO(g)$?

$$CO(g) + H_2(g) \rightleftharpoons H_2CO(g) \qquad \Delta H = -1.8\,kJ$$

	Pressure	**Temperature**
A.	high	low
B.	high	high
C.	low	high
D.	low	low

19. Which of the following is **not** amphiprotic?

A. H_2O

B. HPO_4^{2-}

C. $H_2PO_4^-$

D. H_3O^+

20. Which compound will react with dilute hydrochloric acid, $HCl(aq)$, to give off a gas?

A. $Cu_2O(s)$

B. $Cu(OH)_2(s)$

C. $CuCO_3(s)$

D. $CuO(s)$

21. The equations below represent reactions involved in the Winkler method for determining the concentration of dissolved oxygen in water:

$$2Mn(OH)_2(s) + O_2(aq) \rightarrow 2MnO(OH)_2(s)$$
$$MnO(OH)_2(s) + 2H_2SO_4(aq) \rightarrow Mn(SO_4)_2(s) + 3H_2O(l)$$
$$Mn(SO_4)_2(s) + 2I^-(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2SO_4^{2-}(aq)$$
$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

What is the amount, in mol, of thiosulfate ions, $S_2O_3^{2-}(aq)$, needed to react with the iodine, $I_2(aq)$, formed by 1.00 mol of dissolved oxygen?

A. 2.00

B. 3.00

C. 4.00

D. 6.00

22. What are the products when molten sodium chloride is electrolysed?

	Cathode	Anode
A.	hydrogen	chlorine
B.	sodium	chloride
C.	sodium	chlorine
D.	chlorine	sodium

23. Which is propyl propanoate?

A. $CH_3CH_2CH_2OOCCH_2CH_3$

B. $CH_3CH_2CH_2COOCH_2CH_3$

C. $CH_3CH_2CH_2COCH_2CH_3$

D. $CH_3CH_2CH_2OCH_2CH_2CH_3$

24. Which are consecutive members of a homologous series?

A. CH_4, CH_3Cl, CH_2Cl_2

B. HCOOH, CH_3COOH, C_2H_5COOH

C. C_2H_2, C_2H_4, C_2H_6

D. HCOOH, HCHO, CH_3OH

25. Which could form an addition polymer?

A. $H_2NCH_2CHCHCH_2NH_2$

B. $H_2N(CH_2)_6CO_2H$

C. $HO(CH_2)_2CO_2H$

D. $H_2N(CH_2)_6NH_2$

26. A compound decolorizes bromine water in the dark. Which statement is correct?

A. It contains C=C and is an alkene.

B. It contains C–C and is an alkene.

C. It contains C=C and is an alkane.

D. It contains C–C and is an alkane.

27. How can a systematic error be minimized?

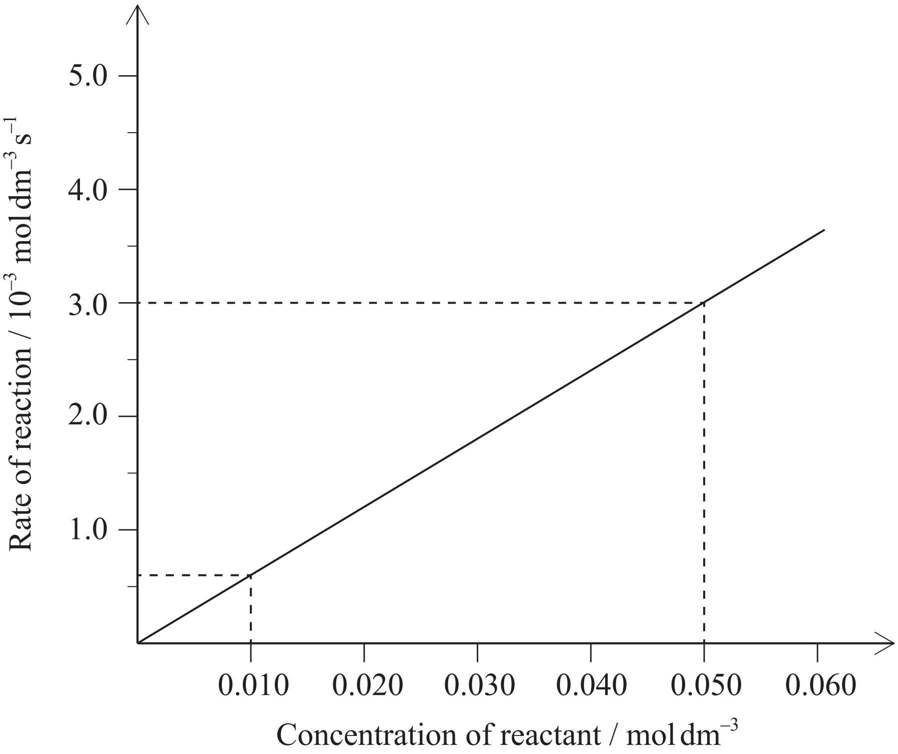
A. By taking the reading many times

B. By repeating the experiment many times

C. By using a more accurate measuring device

D. By evaluating and modifying the method

28. Which combination in the table correctly states the value and units of the gradient?



	Value	Units
A.	$\dfrac{3.0\times10^{-3}-0.6\times10^{-3}}{0.050-0.010}$	s^{-1}
B.	$\dfrac{3.0\times10^{-3}-0.6\times10^{-3}}{0.050-0.010}$	s
C.	$\dfrac{0.050-0.010}{3.0\times10^{-3}-0.6\times10^{-3}}$	s^{-1}
D.	$\dfrac{0.050-0.010}{3.0\times10^{-3}-0.6\times10^{-3}}$	s

29. Which part of the electromagnetic spectrum is used by ^{1}H NMR spectroscopy?

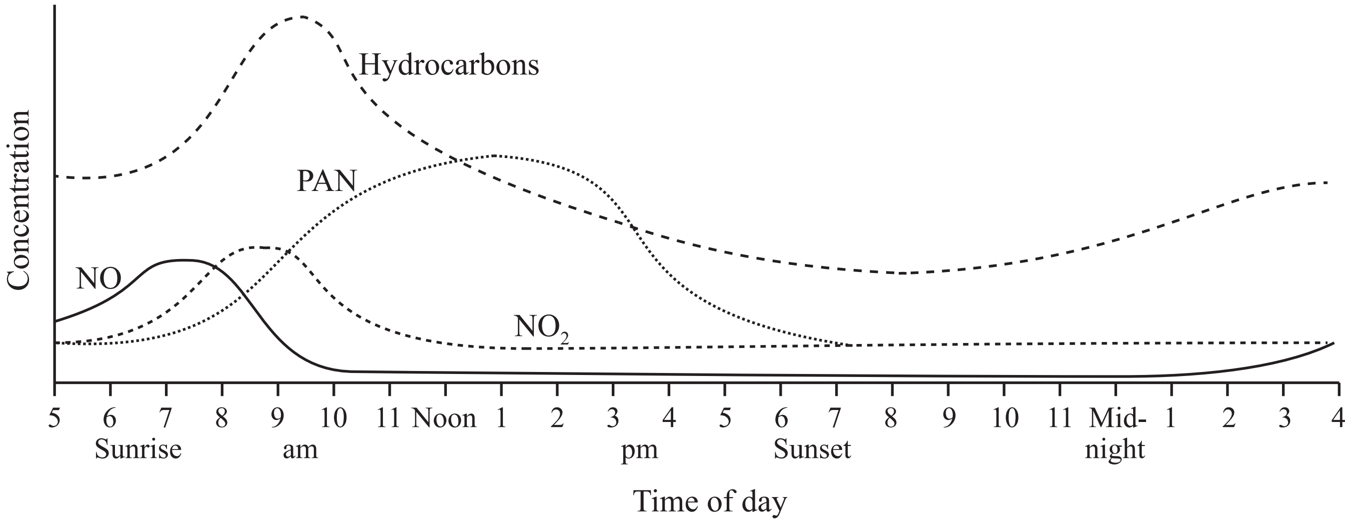
A. γ rays

B. X-rays

C. Microwaves

D. Radio waves

30. The graph shows the concentration of some pollutants in a city over a 24-hour period.



Which of the following could **not** be inferred from the graph?

A. Hydrocarbons cause less harm to health than PAN.

B. An increase in hydrocarbons is caused by the morning rush hour.

C. PAN concentration increases as the intensity of sunlight increases.

D. NO_2 production follows the production of NO.

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MARKSCHEME

SPECIMEN PAPER

CHEMISTRY

Standard Level

Paper 1

2 pages

1.	B	16.	C	31.	–	46.	–
2.	D	17.	C	32.	–	47.	–
3.	C	18.	A	33.	–	48.	–
4.	B	19.	D	34.	–	49.	–
5.	B	20.	C	35.	–	50.	–
6.	B	21.	C	36.	–	51.	–
7.	B	22.	C	37.	–	52.	–
8.	C	23.	A	38.	–	53.	–
9.	A	24.	B	39.	–	54.	–
10.	B	25.	A	40.	–	55.	–
11.	B	26.	A	41.	–	56.	–
12.	D	27.	D	42.	–	57.	–
13.	C	28.	A	43.	–	58.	–
14.	C	29.	D	44.	–	59.	–
15.	D	30.	A	45.	–	60.	–

SPEC/4/CHEMI/SP2/ENG/TZ0/XX

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CHEMISTRY
STANDARD LEVEL
PAPER 2

Candidate session number

SPECIMEN PAPER

Examination code

1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the *Chemistry data booklet* is required for this paper.
- The maximum mark for this examination paper is *[50 marks]*.

19 pages

*Answer **all** questions. Write your answers in the boxes provided.*

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

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

Experimental procedure:

- The bleach solution was first diluted by adding $25.00\,cm^3$ of the bleach to a $250\,cm^3$ volumetric flask. The solution was filled to the graduation mark with deionized water.

- $25.00\,cm^3$ of this solution was then reacted with excess iodide in acid.

$$ClO^-(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow Cl^-(aq) + I_2(aq) + H_2O(l)$$

- The iodine formed was titrated with $0.100\,mol\,dm^{-3}$ sodium thiosulfate solution, $Na_2S_2O_3(aq)$, using starch indicator.

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

The following data were recorded for the titration:

	First titre	**Second titre**	**Third titre**
Final burette reading of $0.100\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	23.95	46.00	22.15
Initial burette reading of $0.100\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	0.00	23.95	0.00

(i) Calculate the volume, in cm^3, of $0.100\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ required to react with the iodine to reach the end point. *[1]*

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(ii) Calculate the amount, in mol, of $Na_2S_2O_3(aq)$ that reacts with the iodine. *[1]*

. . . .

. . . .

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

. . . .

. . . .

. . . .

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

. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(b) Some of the group 17 elements, the halogens, show variable valency.

(i) Deduce the oxidation states of chlorine and iodine in the following species. *[1]*

NaClO:

. . . .

I_2:

. . . .

(ii) Deduce, with a reason, the oxidizing agent in the reaction of hypochlorite ions with iodide ions in part (a). *[1]*

. . . .

. . . .

. . . .

(iii) From a health and safety perspective, suggest why it is not a good idea to use hydrochloric acid when acidifying the bleach. *[1]*

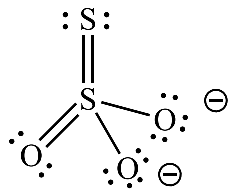
. . . .

. . . .

(This question continues on the following page)

(Question 1 continued)

(iv) The thiosulfate ion, $S_2O_3^{2-}$, is an interesting example of oxidation states. The sulfur atoms can be considered to have an oxidation state of +6 on one atom and –2 on the other atom. Discuss this statement in terms of your understanding of oxidation state. *[2]*



Lewis (electron dot) structure of thiosulfate

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 1 continued)

(c) The various changes that have been made to the definitions of oxidation and reduction show how scientists often broaden similarities to general principles.

Combustion is also a redox type of reaction.

With reference to the combustion reaction of methane, explore **two** different definitions of oxidation, choosing one which is valid and one which may be considered not valid.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$ *[2]*

Valid:

. . . .

. . . .

. . . .

Not valid:

. . . .

. . . .

. . . .

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

. . . .

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

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

A mechanism proposed for its formation is:

$$HO\bullet(g) + SO_2(g) \rightarrow HOSO_2(g)$$
$$HOSO_2(g) + O_2(g) \rightarrow HOO\bullet(g) + SO_3(g)$$
$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

(a) (i) State what the symbol (•) represents in the species shown in this mechanism. *[1]*

. . . .

. . . .

(ii) Draw one valid Lewis (electron dot) structure for each molecule below. *[2]*

Molecule	**Lewis (electron dot) structure**
SO_2	
H_2O	

(This question continues on the following page)

(Question 2 continued)

(iii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule. *[2]*

	Electron domain geometry	**Molecular geometry**
SO_2	. . . .	. . . .
H_2O	. . . .	. . . .

(iv) Deduce the bond angles in SO_2 and H_2O. *[1]*

SO_2:

. . . .

H_2O:

. . . .

(This question continues on the following page)

(Question 2 continued)

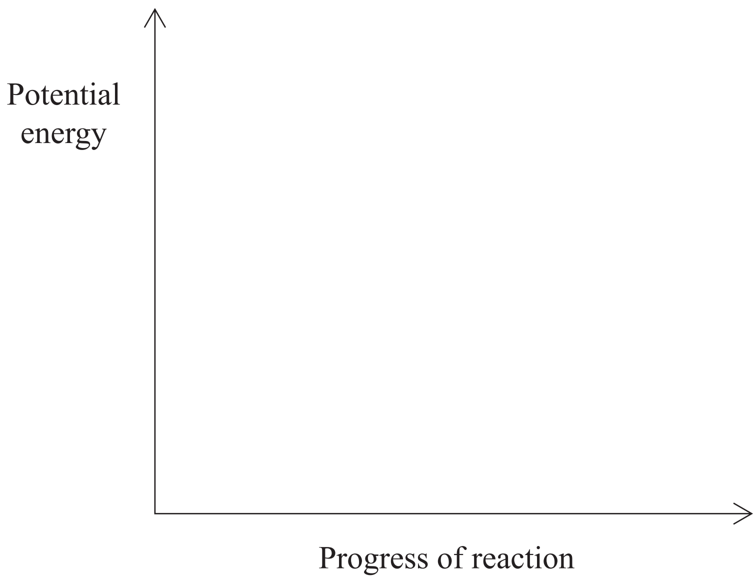
(v) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -198\,kJ$$

Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below. *[3]*

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

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



(This question continues on the following page)

(Question 2 continued)

(vii) Sulfuric acid, H_2SO_4, can be described as a Brønsted–Lowry acid. State what you understand by this description. *[1]*

. . . .

(viii) The hydrogen sulfate anion, HSO_4^-, is amphiprotic, so can act as an acid or a base. In the reaction of HSO_4^- with the hydronium cation, H_3O^+, identify the two species acting as bases.

$$HSO_4^-(aq) + H_3O^+(aq) \rightleftharpoons H_2SO_4(aq) + H_2O(l)$$ *[1]*

. . . .

(ix) Other compounds present in acid rain are formed from nitrogen dioxide, NO_2. Formulate an equation for the reaction of nitrogen dioxide with water. *[1]*

. . . .

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

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

. . . .

. . . .

(b) Hydrogen can be produced from the reaction of coke with steam:

$$C(s) + 2H_2O(g) \rightarrow 2H_2(g) + CO_2(g)$$

Using information from section 12 of the data booklet, calculate the change in enthalpy, ΔH, in $kJ\,mol^{-1}$, for this reaction. *[2]*

. . . .

. . . .

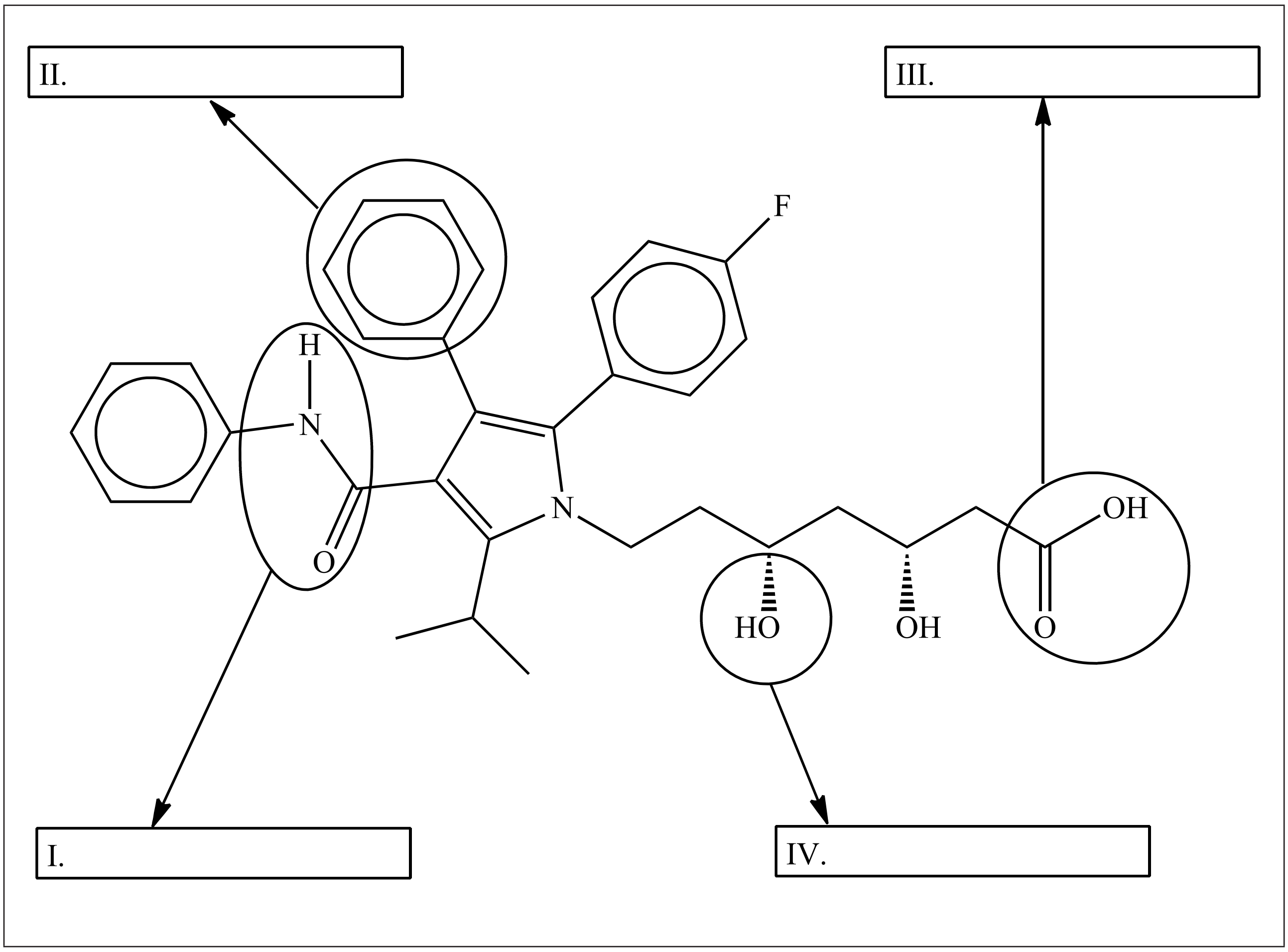
. . . .

. . . .

4. The biopharmaceutical industry is now a global contributor to the world economy.

(a) Atorvastatin, a drug used to lower cholesterol, recently gained attention from the global media.

Atorvastatin has the structure shown below.



Identify the **four** functional groups, I, II, III and IV. *[2]*

(This question continues on the following page)

(Question 4 continued)

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

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

Element	**Percentage**
C	73.99
H	6.55
N	9.09
O	Remainder

Calculate the empirical formula of bute, showing your working. *[3]*

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

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

. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 4 continued)

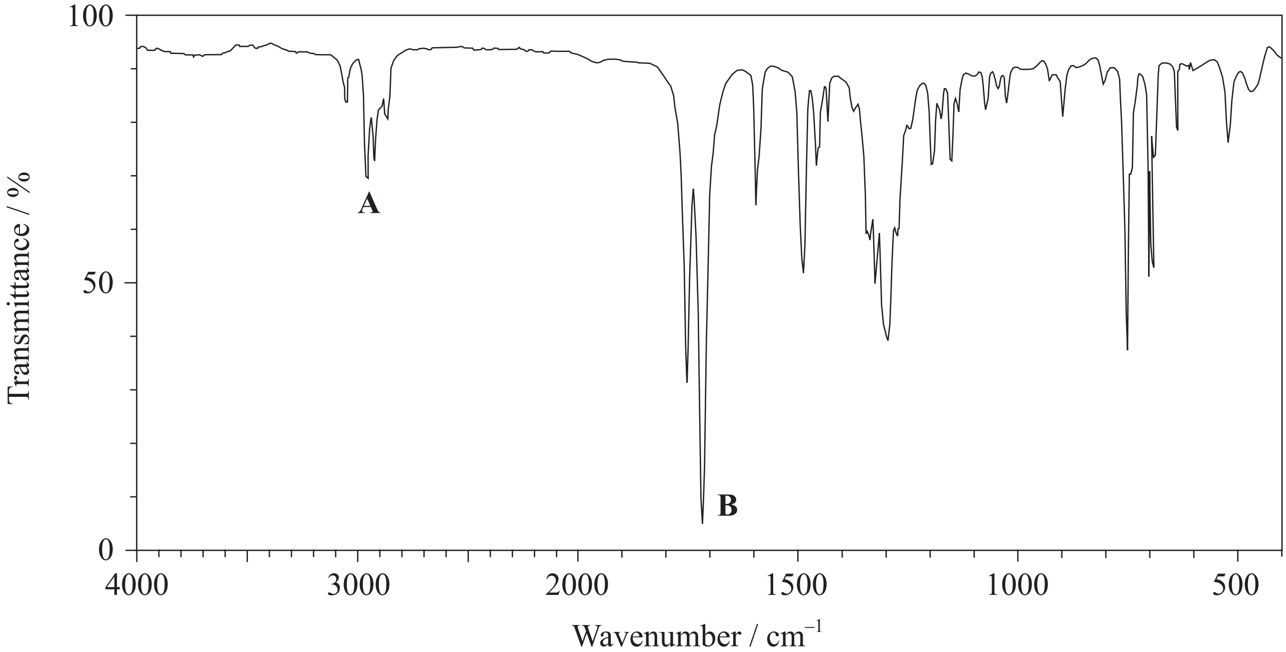
(iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute. *[1]*

. . . .

. . . .

. . . .

(iv) The infrared (IR) spectrum of bute is shown below.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Using information from section 26 of the data booklet, identify the bonds corresponding to **A** and **B**. *[1]*

A: . . . .

B: . . . .

(This question continues on the following page)

(Question 4 continued)

(v) Based on analysis of the IR spectrum, predict, with an explanation, one bond containing oxygen and one bond containing nitrogen that could **not** be present in the structure. *[2]*

Bond containing oxygen not present in structure:

. . . .

Bond containing nitrogen not present in structure:

. . . .

Explanation:

. . . .

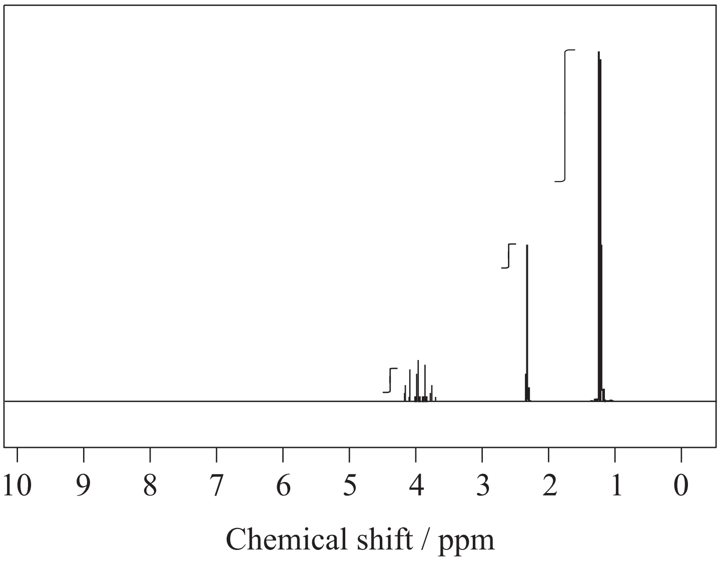
. . . .

. . . .

(This question continues on the following page)

(Question 4 continued)

(c) An alcohol, **X**, of molecular formula C_3H_8O, used as a disinfectant in hospitals, has the following ^1H NMR spectrum.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the ^1H NMR spectrum of **X** have chemical shift values centred at $\delta = 4.0$, 2.3 and 1.2 ppm.

(i) From the integration trace, estimate the ratio of hydrogen atoms in different chemical environments. *[1]*

. . . .

. . . .

(ii) Deduce the full structural formula of **X**. *[1]*

(This question continues on the following page)

(Question 4 continued)

(iii) **Y** is an isomer of **X** containing a different functional group. State the condensed structural formula of **Y**. *[1]*

. . . .
. . . .

(iv) Compare and contrast the expected mass spectra of **X** and **Y** using section 28 of the data booklet. *[2]*

One similarity:

. . . .
. . . .
. . . .

One difference:

. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 4 continued)

(v) Both **X** and **Y** are soluble in water. Deduce whether or not both **X** and **Y** show hydrogen bonding with water molecules, representing any hydrogen bonding present by means of a diagram. *[2]*

. . . .

. . . .

(vi) **X** reacts with acidified potassium dichromate(VI) solution to form **Q** and with ethanoic acid to form **W**. Deduce the condensed structural formula of **Q** and **W**. *[2]*

Q:

. . . .

W:

. . . .

(This question continues on the following page)

(Question 4 continued)

(vii) Apply IUPAC rules to state the name of compound **Q**. *[1]*

. . . .

Please **do not** write on this page.

Answers written on this page
will not be marked.

SPEC/4/CHEMI/SP2/ENG/TZ0/XX/M

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MARKSCHEME

SPECIMEN

CHEMISTRY

Standard Level

Paper 2

10 pages

Subject Details: Chemistry SL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions. Maximum total = **[50 marks]**.

1. Each row in the "Question" column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the "Total" column.

3. Each marking point in the "Answers" column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by "**max**" written after the mark in the "Total" column. The related rubric, if necessary, will be outlined in the "Notes" column.

5. An alternative wording is indicated in the "Answers" column by a slash (/). Either wording can be accepted.

6. An alternative answer is indicated in the "Answers" column by "***OR***" on the line between the alternatives. Either answer can be accepted.

7. Words in angled brackets **‹ ›** in the "Answers" column are not necessary to gain the mark.

8. Words that are underlined are essential for the mark.

9. The order of marking points does not have to be as in the "Answers" column, unless stated otherwise in the "Notes" column.

10. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the "Answers" column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the "Notes" column.

11. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. “ECF acceptable” will be displayed in the “Notes” column.

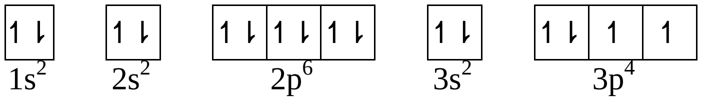
13. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the “Notes” column.

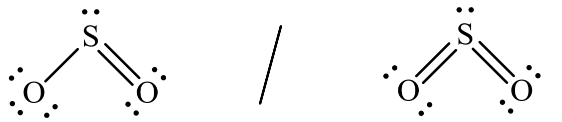
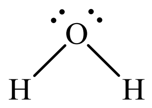
14. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the “Notes” column, similarly, if the formula is specifically asked for, unless directed otherwise in the “Notes” column do not award a mark for a correct name.

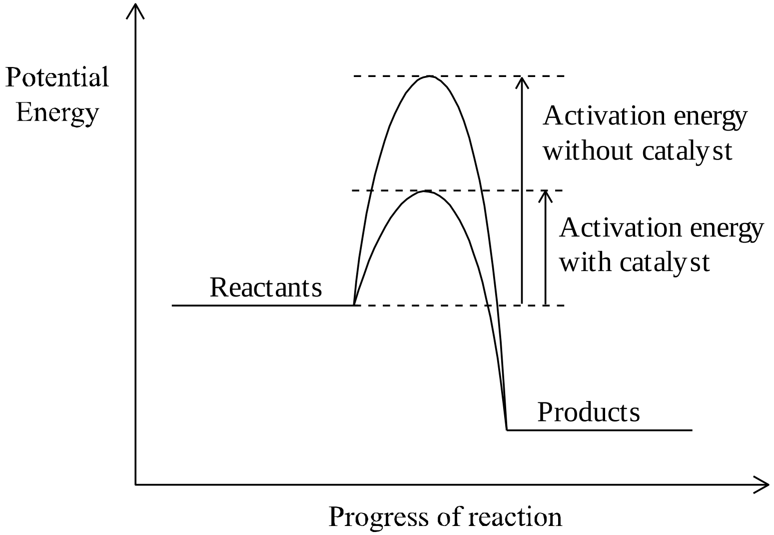
15. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the “Notes” column.

16. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the “Notes” column.

Question			Answers	Notes	Total
1.	**a**	**i**	$\langle (22.05+22.15)(0.5) = \rangle 22.10 \langle \text{cm}^3 \rangle$ ✓		**1**
	a	**ii**	$\left\langle \frac{22.10\times 0.100}{1000} = \right\rangle 2.21\times 10^{-3}\ /\ 0.00221 \langle \text{mol} \rangle$ ✓		**1**
	a	**iii**	$\left\langle \frac{0.5\times 2.21\times 10^{-3}\times 1000}{25.00} = \right\rangle 4.42\times 10^{-2}\ /\ 0.0442 \langle \text{mol dm}^{-3} \rangle$ ✓		**1**
	a	**iv**	$\langle 4.42\times 10^{-2}\times 10 = \rangle 4.42\times 10^{-1}\ /\ 0.442 \langle \text{mol dm}^{-3} \rangle$ ✓		**1**
	b	**i**	*NaClO*: +1 ‹for chlorine› **and** I_2: 0 ‹for iodine› ✓		**1**
	b	**ii**	ClO^- since chlorine reduced/gains electrons ***OR*** ClO^- since oxidation state of chlorine changes from +1 to –1/decreases ***OR*** ClO^- since it loses oxygen / causes iodide to be oxidized ✓		**1**
	b	**iii**	produces chlorine ‹gas›/Cl_2 ‹on reaction with ClO^-› which is toxic ✓	*OWTTE*	**1**
	b	**iv**	oxidation states are not real ***OR*** oxidation states are just used for electron book-keeping purposes ✓ average oxidation state of sulfur calculated to be +2 ✓ but the two sulfurs are bonded differently/in different environments in thiosulfate so have different oxidation states ✓	*OWTTE*	**2 max**

Question			**Answers**	**Notes**	**Total**
	c		*Valid:* addition of oxygen signifies an oxidation reaction so C is oxidized ***OR*** loss of hydrogen signifies an oxidation reaction so C is oxidized ***OR*** oxidation state of C changes from –4 to +4/increases ✓ *Not valid:* loss of electrons might suggest formation of ionic product but not valid since CO_2 is covalent ***OR*** loss of electrons might suggest formation of ionic product but not valid since reaction only involves neutral molecules ✓	*OWTTE*	**2**
	d	**i**	$[Ne]3s^2 3p^4$ ✓	*Electrons must be given as superscript.*	**1**
	d	**ii**	 ✓		**1**

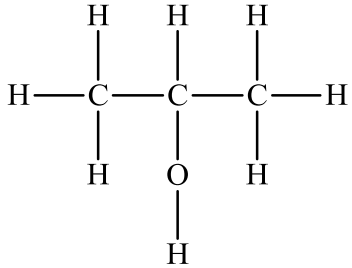
<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>2.</td><td>a</td><td>i</td><td>radical / unpaired electron ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>a</td><td>ii</td><td><table><tr><th>Molecule</th><th>Lewis (electron dot) structure</th></tr><tr><td>SO_2</td><td> ✓</td></tr><tr><td>H_2O</td><td> ✓</td></tr></table></td><td>Lines, x’s or dots may be used to represent electron pairs.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>iii</td><td><table><tr><th></th><th>Electron domain geometry</th><th>Molecular geometry</th></tr><tr><td>SO_2</td><td>trigonal/triangular planar</td><td>bent/v-shaped/angular✓</td></tr><tr><td>H_2O</td><td>tetrahedral</td><td>bent/v-shaped/angular✓</td></tr></table></td><td>Award [1 max] for either both electron domain geometries correct OR for either both molecular geometries correct.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>iv</td><td>SO_2: Accept any angle in the range greater than 115° but less than 120°.
and
H_2O: 104.5° ✓</td><td>Experimental value is 119°</td><td>1</td></tr>
</table>

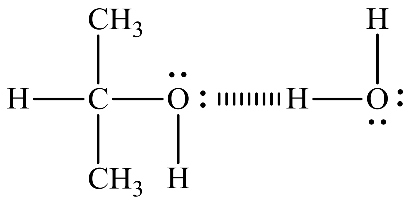
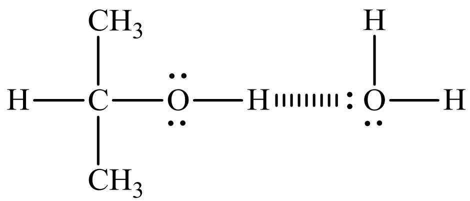
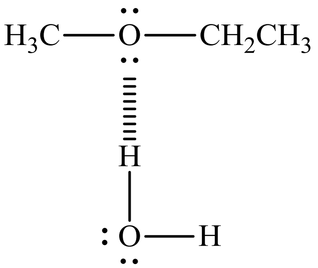
<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>2</td><td>a</td><td>v</td><td>
<table>
<tr><th>Change</th><th>Shift</th><th>Reason</th></tr>
<tr><td>Increase in temperature</td><td>LHS</td><td>since ‹forward› exothermic reaction/ $\Delta H < 0$ ✓</td></tr>
<tr><td>Increase in pressure</td><td>RHS</td><td>since fewer ‹gaseous› molecules on RHS ✓</td></tr>
<tr><td>Addition of a catalyst to the mixture</td><td>No change</td><td>since affects rate of forward and reverse reactions equally ✓</td></tr>
</table>
</td><td></td><td>3</td></tr>
<tr><td></td><td>a</td><td>vi</td><td>


correct positions of reactants and products ✓
correct profile with labels showing activation energy with and without a catalyst ✓
</td><td></td><td>2</td></tr>
<tr><td></td><td>a</td><td>vii</td><td>proton/H^+ donor ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>a</td><td>viii</td><td>$HSO_4^-(aq)$ and $H_2O(l)$ ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>a</td><td>ix</td><td>$2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$ ✓</td><td>Ignore state symbols.</td><td>1</td></tr>
</table>

Question			Answers	Notes	Total
3.	**a**		only water/H_2O produced ‹so non-polluting› ✓		**1**
	b		$\Delta H = [(-393.5)] - [(2)(-241.8)]$ ✓ +90.1‹kJ› ✓	*Award **[2]** for correct final answer.*	**2**

4.	**a**		*I:* carboxamide ✓ *II:* phenyl ✓ *III:* carboxyl / carboxy ✓ *IV:* hydroxyl ✓	*Award **[2]** for all four correct, **[1]** for two or three correct.* *Do not allow benzene.* *Do not allow carboxylic/alkanoic acid.* *Do not allow alcohol or hydroxide.*	**2 max**
	b	**i**	$n_C : \left\langle \frac{73.99}{12.01} \right\rangle = 6.161\,(\text{mol})$ **and** $n_H : \left\langle \frac{6.55}{1.01} \right\rangle = 6.49\,(\text{mol})$ **and** $n_N : \left\langle \frac{9.09}{14.01} \right\rangle = 0.649\,(\text{mol})$ **and** $n_O : \left\langle \frac{10.37}{16.00} \right\rangle = 0.6481\,(\text{mol})$ ✓ $n_C : n_H : n_N : n_O = 9.5 : 10 : 1 : 1$ ✓ *Empirical formula*: $C_{19}H_{20}N_2O_2$ ✓	*Award **[2 max]** for correct final answer without working.*	**3**
	b	**ii**	$C_{19}H_{20}N_2O_2$ ✓		**1**
	b	**iii**	$\langle (0.5)(40-20-2) = \rangle 9$ ✓		**1**
	b	**iv**	*A:* C–H **and** *B:* C=O		**1**
	b	**v**	O–H **and** N–H ✓ frequencies/stretches due to O–H and N–H occur above 3200 ‹cm^{-1}› which are not present in IR of *bute* ✓		**2**
	c	**i**	1:1:6 ✓		**1**

Question			Answers	Notes	Total
	c	**ii**	 ✓		**1**
	c	**iii**	$CH_3OCH_2CH_3$ ✓		**1**
	c	**iv**	*Similarity:* both have fragment corresponding to $(M_r - 15)^+$ / both have $m/z = 45$ ✓ *Difference:* **X** has fragment corresponding to $(M_r - 17)^+$ / **X** has $m/z = 43$ ***OR*** **X** has fragment corresponding to $(M_r - 43)^+$ / **X** has $m/z = 17$ ***OR*** **Y** has fragment corresponding to $(M_r - 31)^+$ / **Y** has $m/z = 29$ ***OR*** **Y** has fragment corresponding to $(M_r - 29)^+$ / **Y** has $m/z = 31$ ✓	*Allow "both have same molecular ion peak/M^+ / both have m/z = 60". However in practice the molecular ion peak is of low abundance and difficult to observe for propan-2-ol.*	**2**

Question			Answers	Notes	Total
4.	**c**	**v**	both **X** and **Y** will exhibit hydrogen bonding with water molecules ✓ diagrams showing hydrogen bonding ✓ X:  **OR**  Y: 		**2**
	c	**vi**	*I:* CH_3COCH_3 ✓ *II:* $CH_3COOCH(CH_3)_2$ ✓		**2**
	c	**vii**	propanone ✓		**1**

SPEC/4/CHEMI/SP3/ENG/TZ0/XX

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CHEMISTRY
STANDARD LEVEL
PAPER 3

Candidate session number

SPECIMEN PAPER

Examination code

1 hour

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer all of the questions from one of the options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the *Chemistry data booklet* is required for this paper.
- The maximum mark for this examination paper is *[35 marks]*.

Option	**Questions**
Option A — Materials	3 – 6
Option B — Biochemistry	7 – 9
Option C — Energy	10 – 12
Option D — Medicinal chemistry	13 – 15

34 pages

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. Compounds used to generate cooling in refrigerators and air-conditioning systems are known as refrigerants. A refrigerant undergoes a reversible change of state involving vaporization and condensation. The search for suitable refrigerants has occupied chemists for approximately 200 years.

Previously, the most popular refrigerants were chlorofluorocarbons (CFCs), but these have been replaced, first by hydrochlorofluorocarbons (HCFCs) and more recently by hydrofluorocarbons (HFCs).

Some data on examples of these three classes of refrigerants are shown below.

Class	Compound	ODP[1]	GWP[2] over 100 years	ΔH_{vap}[3] / kJ mol^{-1}	Atmospheric lifetime / years
CFC	CCl_3F	1.0	4000	24.8	45
CFC	CCl_2F_2	1.0	8500	20.0	102
HCFC	$CHCl_2CF_3$	0.02	90	26.0	1
HCFC	$CHClF_2$	0.05	1810	20.2	12
HFC	CH_2FCF_3	0	1100	–	–
HFC	CHF_2CF_3	0	3500	30.0	32

1 ODP: The ozone depletion potential (ODP) is a relative measure of the amount of degradation to the ozone layer caused by the compound. It is compared with the same mass of CCl_3F, which has an ODP of 1.0.

2 GWP: The global warming potential (GWP) is a relative measure of the total contribution of the compound to global warming over the specified time period. It is compared with the same mass of CO_2, which has a GWP of 1.0.

3 ΔH_{vap}: Defined as the energy required to change one mole of the compound from a liquid to a gas.

(a) (i) Explain why the values for ODP and GWP have no units. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(ii) By making reference to the chemical formulas and ODP values of the compounds, comment on the hypothesis that chlorine is responsible for ozone depletion. *[1]*

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(b) Use data from the table to interpret the relationship between the atmospheric lifetime of a gas and its GWP. *[2]*

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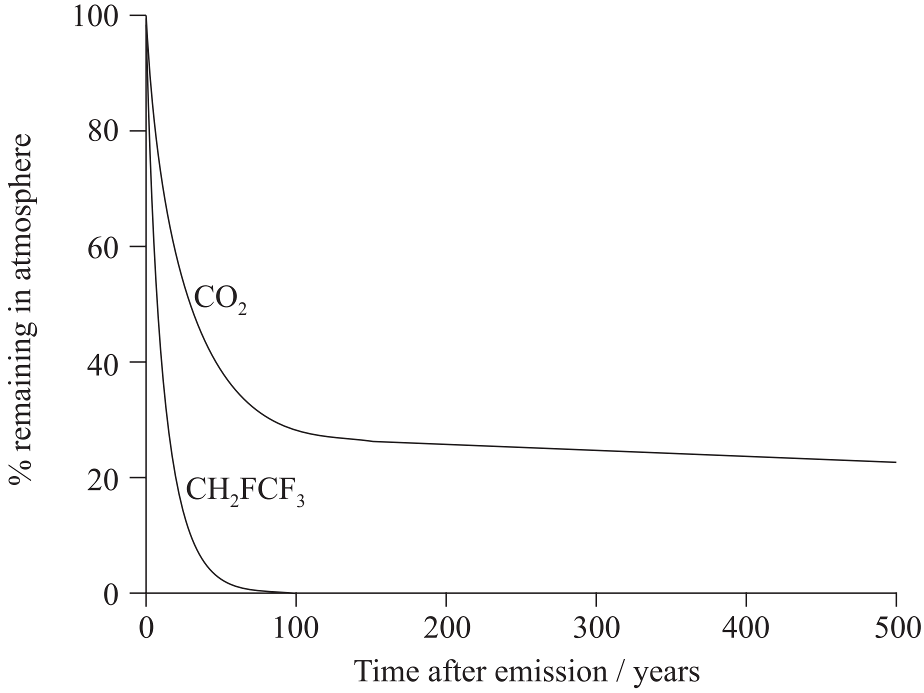
(This question continues on the following page)

(Question 1 continued)

(c) The graph shows the change in levels with time of equal masses of CO_2 and CH_2FCF_3 introduced into the atmosphere.



(i) Apply IUPAC rules to state the name of CH_2FCF_3. *[1]*

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(ii) The $\Delta H_{vaporization}$ for CH_2FCF_3 is $217\,kJ\,kg^{-1}$. Calculate the value of the enthalpy change for the condensation of one mole of CH_2FCF_3. *[2]*

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(This question continues on the following page)

(Question 1 continued)

(iii) With reference to the graph on page 4, comment on the atmospheric lifetime of CO_2 relative to CH_2FCF_3, and on the likely influence of this on climate change. *[2]*

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2. Thomas wants to determine the empirical formula of red-brown copper oxide. The method he chooses is to convert a known amount of copper(II) sulfate into this oxide. The steps of his procedure are:

- Make $100\,cm^3$ of a $1\,mol\,dm^{-3}$ solution using hydrated copper(II) sulfate crystals.
- React a known volume of this solution with alkaline glucose in order to convert it to red-brown copper oxide.
- Separate the precipitated oxide and find its mass.

(a) Thomas calculates that he needs $0.1 \times [1 \times 63.55 + 1 \times 32.07 + 4 \times 16.00] = 15.962 \pm 0.001$ g of the copper(II) sulfate to make the solution. Outline the major error in his calculation. *[1]*

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(b) He now adds $100 \pm 1\,cm^3$ of water from a measuring/graduated cylinder and dissolves the copper(II) sulfate crystals. A friend tells him that for making standard solutions it is better to use a volumetric flask rather than adding water from a measuring cylinder. Suggest **two** reasons why a volumetric flask is better. *[2]*

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(c) Thomas now heats $25\,cm^3$ of the solution with excess alkaline glucose to convert it to a suspension of red-brown copper oxide. Describe how he can obtain the pure, dry solid product. *[2]*

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(This question continues on the following page)

(Question 2 continued)

(d) Using the same chemical reactions, suggest how Thomas' method to determine the mass of red-brown copper oxide that could be obtained from a known mass of copper(II) sulfate crystals might be simplified to produce more precise results. *[1]*

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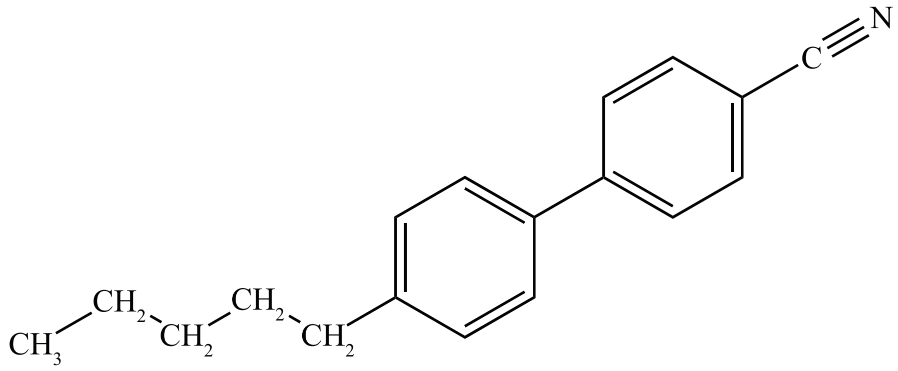
SECTION B

*Answer **all** of the questions from **one** of the options.*

Option A — Materials

3. (a) The molecule shown below is frequently used in liquid-crystal displays (LCDs).



Identify a physical characteristic of this molecule that allows it to exist in a liquid-crystal state. *[1]*

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(b) (i) Describe the chemical vapour deposition (CVD) method for the production of carbon nanotubes. *[2]*

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(ii) Many modern catalysts use carbon nanotubes as a support for the active material. State the major advantage of using carbon nanotubes. *[1]*

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(Option A continues on the following page)

(Option A continued)

4. Different metal oxides are widely used in the production of ceramic materials and their function is closely linked to the type of bonding present in the compound.

(a) Both magnesium oxide and cobalt(II) oxide are incorporated into ceramics. Use section 8 of the data booklet to calculate values to complete the table below. *[2]*

Compound	**Magnesium oxide**	**Cobalt(II) oxide**
Electronegativity difference	. . . .	. . . .
Average electronegativity	. . . .	. . . .

(b) Predict the bond type and percentage covalent character of each oxide, using section 29 of the data booklet. *[2]*

Compound	**Magnesium oxide**	**Cobalt(II) oxide**
Bond type	. . . .	. . . .
% covalent character	. . . .	. . . .

(Option A continues on the following page)

(Option A continued)

5. Magnesium is an essential component of chlorophyll and traces of it can be found in various fluids from plants. Its concentration may be estimated using inductively coupled plasma optical emission spectroscopy (ICP-OES).

(a) Outline what the specific plasma state involved in ICP spectroscopy comprises. *[1]*

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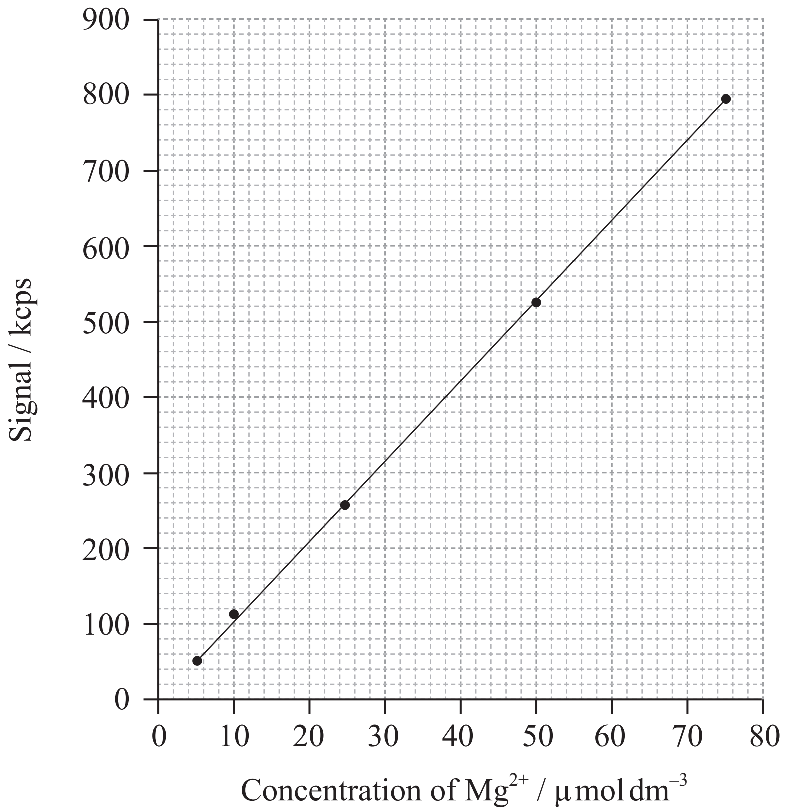
(b) An ICP-OES calibration curve for magnesium is shown in the graph below.



(Option A continues on the following page)

(Option A, question 5 continued)

(i) Determine the mass of magnesium ions present in $250\,cm^3$ of a solution with a concentration of $10\,\mu mol\,dm^{-3}$. *[2]*

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(ii) Taking into account your answer to part (b)(i), discuss how the solutions for this calibration curve could be produced. *[2]*

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(iii) Two solutions gave count rates of 627 kcps and 12 kcps respectively. Justify which solution could be more satisfactorily analysed using this calibration graph. *[1]*

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(Option A continues on the following page)

(Option A continued)

6. Plastics, such as PVC and melamine, are widely used in modern society.

(a) PVC is thermoplastic, whereas melamine is thermosetting. State one other way in which scientists have tried to classify plastics, and outline why the classification you have chosen is useful. *[2]*

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(b) It was almost a century after the discovery of PVC before Waldo Semon turned it into a useful plastic by adding plasticizers. State and explain the effect plasticizers have on the properties of PVC. *[2]*

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(c) Justify why, in terms of atom economy, the polymerization of PVC could be considered "green chemistry". *[1]*

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(Option A continues on the following page)

(Option A, question 6 continued)

(d) In spite of the conclusion in part (c), many consider that PVC is harmful to the environment. Identify **one** specific toxic chemical released by the combustion of PVC. *[1]*

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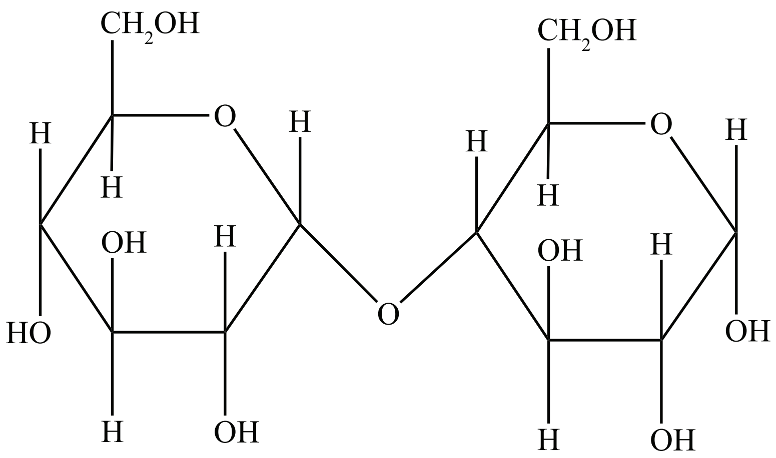
End of Option A

Option B — Biochemistry

7. The diagram below shows the structure of a disaccharide called maltose.



(a) Identify on the diagram one primary alcohol group by marking I on the oxygen, **and** one secondary alcohol group by marking II on the oxygen. *[1]*

(b) (i) Formulate an equation, using molecular formulas, to show the conversion of this molecule into its monomers. *[1]*

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(ii) Identify the type of metabolic process shown in part (b)(i). *[1]*

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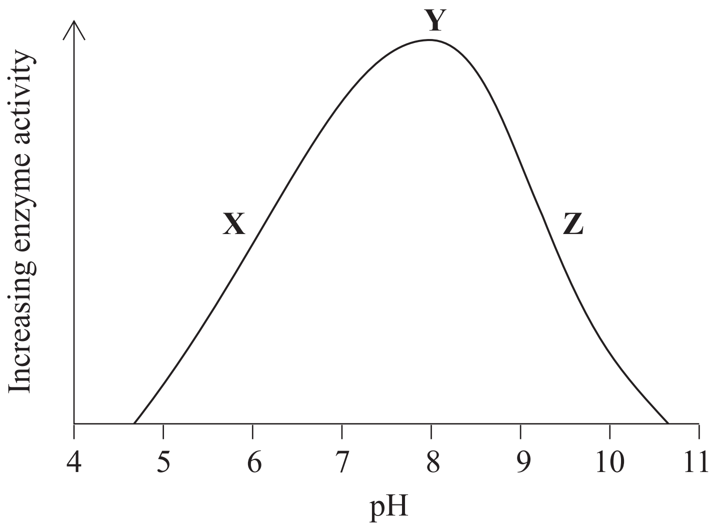
(Option B continues on the following page)

(Option B, question 7 continued)

(c) The reaction in part (b) is catalysed by the enzyme maltase. Experiments were carried out to investigate the rate of breakdown of maltose in the presence of maltase over a range of pH values from 4 to 11. The results are shown below.



Describe how the activity of the enzyme changes with pH, including in your answer specific reference to how the pH is affecting the enzyme at **X**, **Y** and **Z**. *[3]*

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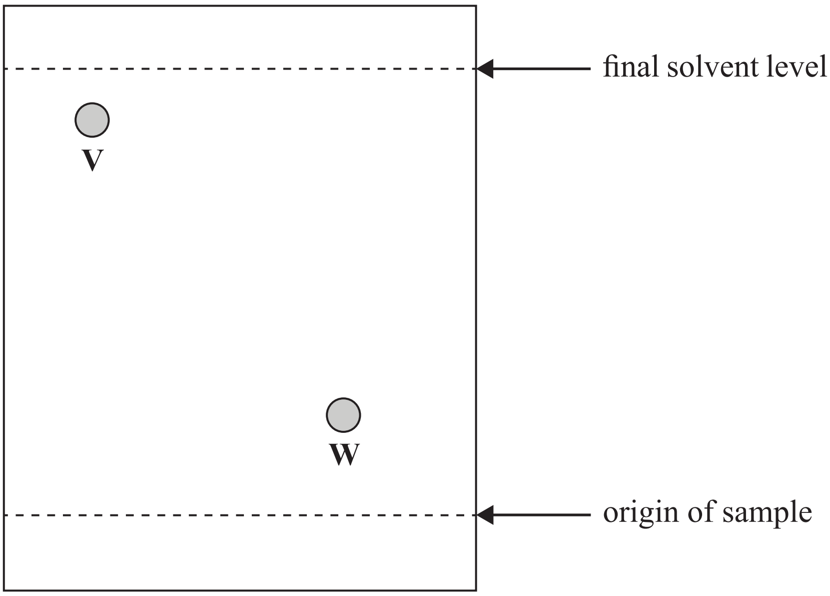
(Option B continues on the following page)

(Option B, question 7 continued)

(d) A separate experiment was done to determine the amino acid composition of maltase. A sample of the enzyme was hydrolysed into a mixture of its component amino acids. Paper chromatography and a locating agent were then used to try to identify the amino acids present in the mixture. The diagram below shows part of the chromatogram in which the positions of two amino acids, **V** and **W**, can be seen.



Amino acid	R_f
Lysine	0.14
Glutamine	0.26
Proline	0.41
Methionine	0.56
Leucine	0.73

Use the chromatogram and the data table to deduce the identity of **V** and **W** if possible. *[2]*

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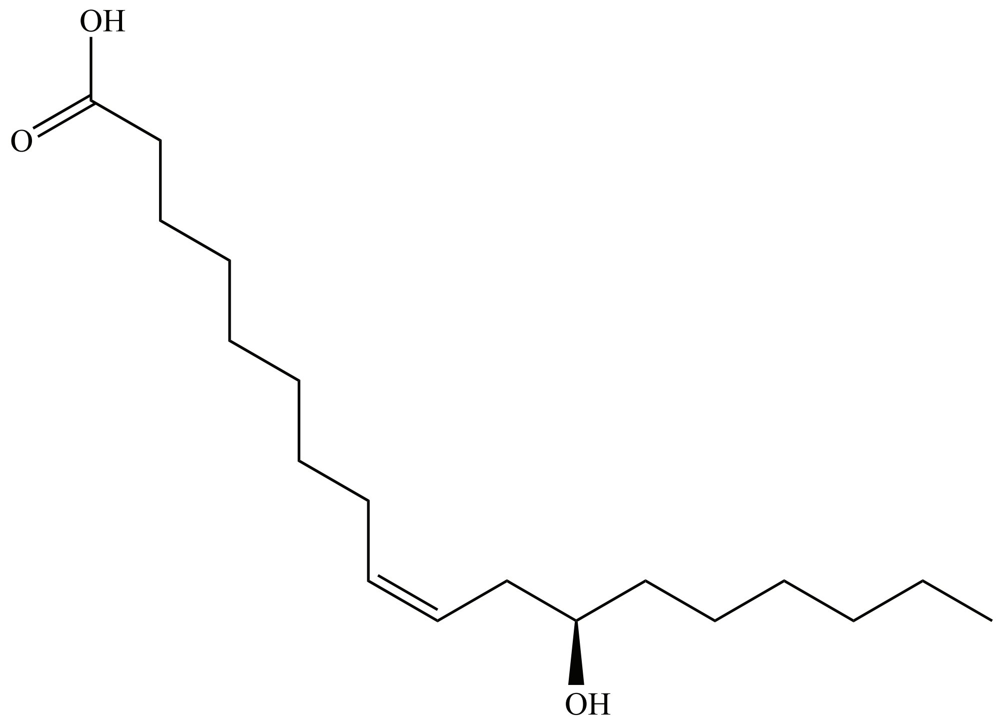
(Option B continues on the following page)

(Option B continued)

8. The castor plant is grown as a crop for its oil. Castor oil is mostly a triglyceride of the relatively rare fatty acid ricinoleic acid, whose structure is given below.



(a) State the molecular formula of ricinoleic acid. *[1]*

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(b) (i) Compare and contrast the structure of ricinoleic acid with stearic acid, whose structure is given in section 34 of the data booklet. *[3]*

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(Option B continues on the following page)

(Option B, question 8 continued)

(ii) State and explain how you would expect ricinoleic acid triglyceride to differ from stearic acid triglyceride in its tendency to undergo oxidative rancidity. *[2]*

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(c) The castor seed contains ricin, a toxic protein which is fatal in small doses. During the oil extraction process, the toxin is inactivated by heating.

(i) Outline why ricin loses its toxic effects on being heated. *[1]*

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(ii) Examine why many countries no longer harvest the castor plant but rely instead on imports of castor oil from other countries. *[2]*

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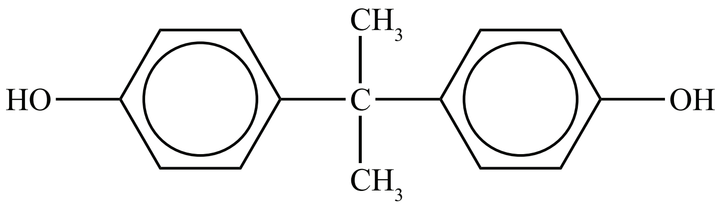
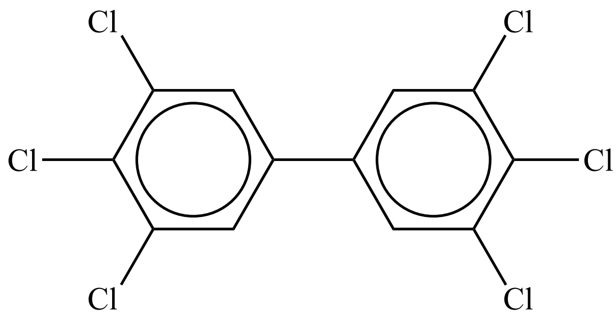
(Option B continues on the following page)

(Option B continued)

9. The figure below shows two examples of molecules known as xenoestrogens, a type of xenobiotic. They have effects on living organisms similar to those of the female hormone estrogen. These compounds are found in the environment and can be taken up by living organisms, where they may be stored in certain tissues.





(a) State what is meant by the term xenobiotic. *[1]*

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(b) With reference to their structures, outline why these xenobiotics are stored easily in animal fat. *[1]*

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(Option B continues on the following page)

(Option B, question 9 continued)

(c) One way to decrease the concentration of a xenobiotic in the environment is to develop a specific molecule, a "host", that can bind to it. The binding between the host and the xenobiotic forms a supramolecule.

State **three** types of association that may occur within the supramolecule between the host and the xenobiotic. *[1]*

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End of Option B

Please **do not** write on this page.

Answers written on this page will not be marked.

Option C — Energy

10. Plants convert solar energy into chemical energy. It would therefore be very convenient to use plant products, such as vegetable oils, directly as fuels for internal combustion engines.

(a) (i) Identify the major problem involved in using vegetable oils directly as a fuel in a conventional internal combustion engine. *[1]*

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(ii) Transesterification of the oil overcomes this problem. State the reagents required for this process. *[1]*

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(b) Plant products can also be converted to ethanol, which can be mixed with alkanes, such as octane, to produce a fuel. The table below gives some properties of these compounds.

Compound	**Molar mass / $g\,mol^{-1}$**	**Density / $g\,dm^{-3}$**	**ΔH_c / $kJ\,mol^{-1}$**	**Equation for combustion**
Ethanol	46.08	789	–1367	$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$
Octane	114.26	703	–5470	$C_8H_{18}(l) + 12\frac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$

(i) State the name of the process by which ethanol can be produced from sugars. *[1]*

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(Option C continues on the following page)

(Option C, question 10 continued)

(ii) The energy density of ethanol is 23 400 kJ dm^{-3}. Use data from the table to determine the energy density of octane. *[1]*

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(iii) Use these results to outline why octane is the better fuel in vehicles. *[1]*

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(iv) Use data from the table to demonstrate that ethanol and octane give rise to similar carbon footprints. *[1]*

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(v) Outline why, even though they have similar carbon footprints, using ethanol has less impact on levels of atmospheric carbon dioxide. *[1]*

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(Option C continues on the following page)

(Option C continued)

11. Nuclear power is an energy source that does not involve fossil fuels. Current nuclear technology is dependent on fission reactions.

(a) Commercial nuclear power technology developed very rapidly between 1940 and 1970. Outline why this occurred. *[1]*

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(b) The equation for a typical nuclear fission reaction is:

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} (\rightarrow ^{236}_{92}\text{U}) \rightarrow ^{90}_{38}\text{Sr} + ^{136}_{54}\text{Xe} + 10\,^{1}_{0}\text{n}$$

The masses of the particles involved in this fission reaction are shown below.

Mass of neutron	=	1.00867 amu
Mass of U-235 nucleus	=	234.99333 amu
Mass of Xe-136 nucleus	=	135.90722 amu
Mass of Sr-90 nucleus	=	89.90774 amu

Using these data and information from sections 1 and 2 of the data booklet, determine the energy released when one uranium nucleus undergoes fission. *[3]*

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(Option C continues on the following page)

(Option C, question 11 continued)

(c) The half-lives of components of spent nuclear fuels range from a few years to more than 10,000 years. This means that while the radioactivity of nuclear waste initially decreases rapidly, some radioactivity remains for a very long time. Outline the storage of spent nuclear fuels in both the short and long term. *[2]*

Short term:

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Long term:

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(Option C continues on the following page)

(Option C continued)

12. Energy production presents many threats to the environment. One issue that has caused much controversy over recent years is the emission of greenhouse gases, which most scientists believe is a major cause of global warming.

(a) Explain how greenhouse gases affect the temperature of the Earth's surface. *[3]*

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(b) Explain the molecular changes that must occur in order for a molecule to absorb infrared light. *[2]*

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(Option C continues on the following page)

(Option C, question 12 continued)

(c) (i) Carbon dioxide and water vapour are the most abundant greenhouse gases. Identify **one** other greenhouse gas and a natural source of this compound. *[1]*

Greenhouse gas:

. . . .

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Natural source:

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(ii) Even though water vapour is the more potent greenhouse gas, there is greater concern about the impact of carbon dioxide. Suggest why this is the case. *[1]*

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End of Option C

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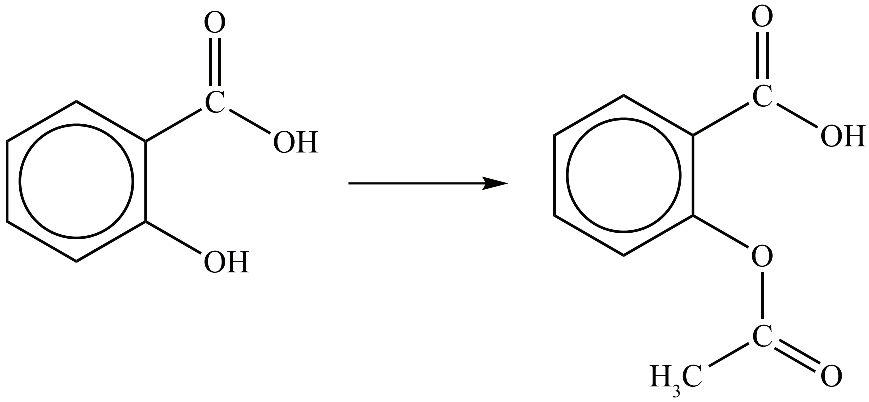
will not be marked.

Option D — Medicinal chemistry

13. Salicylic acid has been used to relieve pain and reduce fevers for centuries, although it can be irritating to the stomach. In the 1800s it was discovered that converting it into acetylsalicylic acid reduces the stomach irritation while still allowing it to be effective.



Salicylic acid Acetylsalicylic acid (aspirin)

(a) Identify the type of reaction used to convert salicylic acid to acetylsalicylic acid. *[1]*

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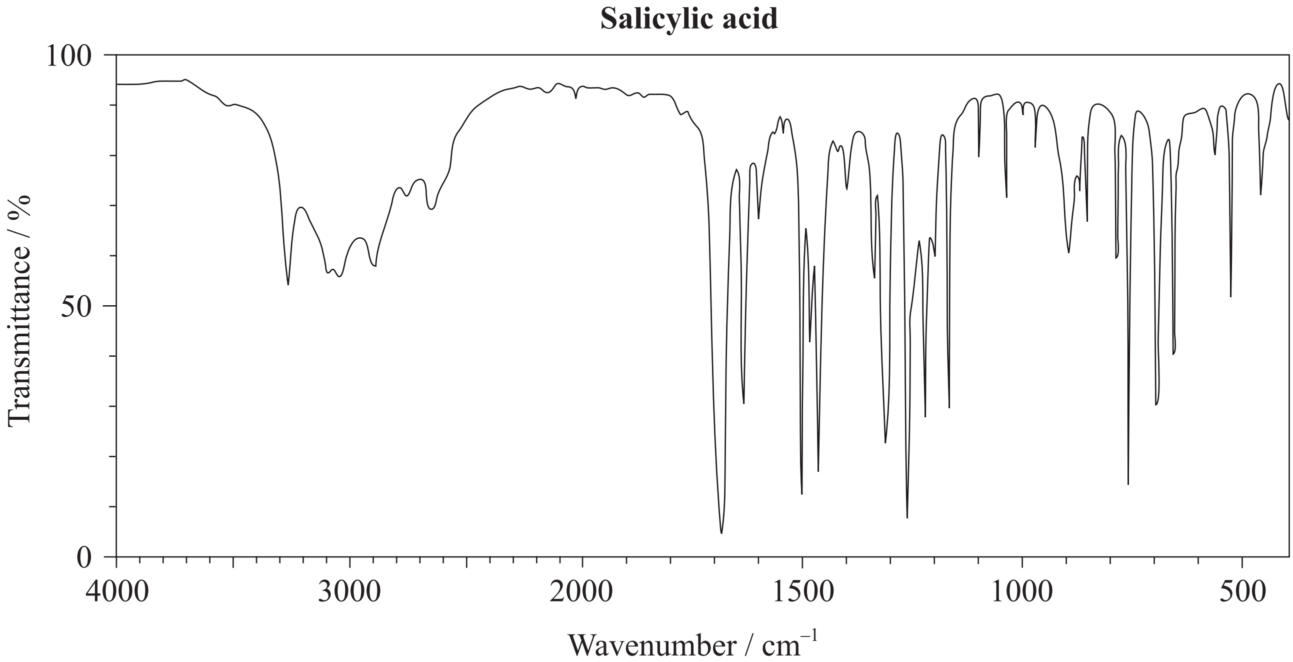
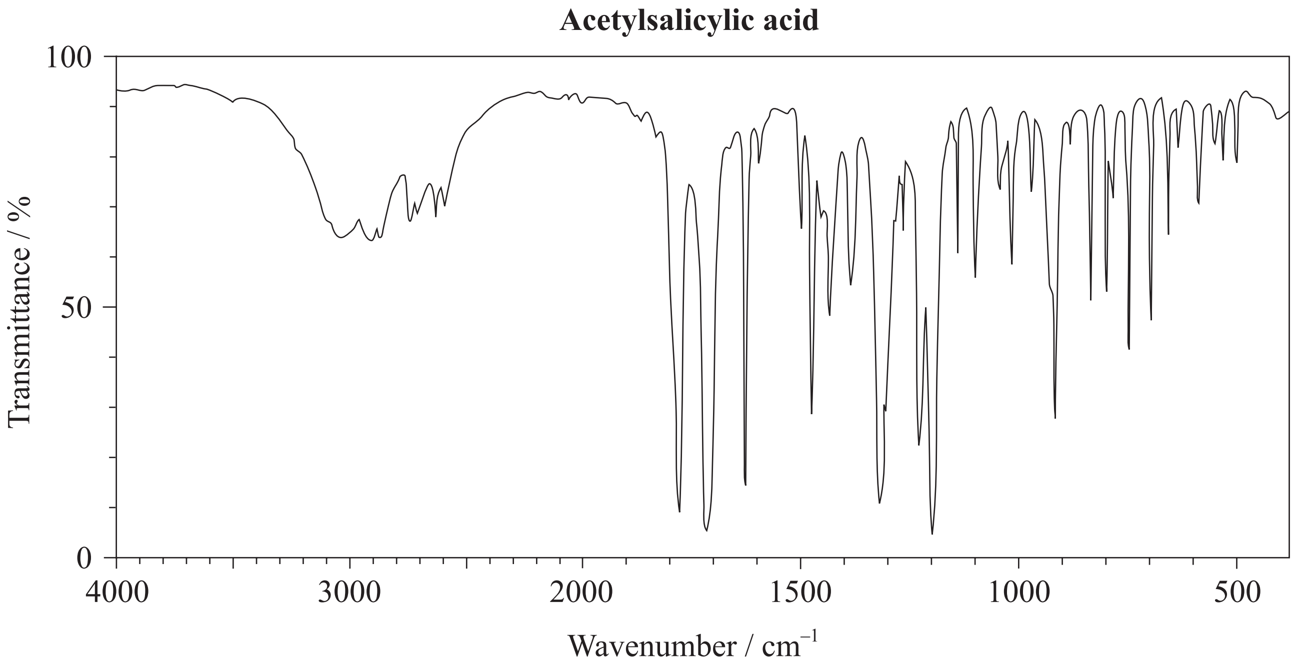
(Option D continues on the following page)

(Option D, question 13 continued)

(b) The infrared (IR) spectra for salicylic acid and acetylsalicylic acid are shown below.





[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

(Option D continues on the following page)

(Option D, question 13 continued)

Using information from section 26 of the data booklet, compare and contrast the two spectra with respect to the bonds present. *[3]*

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(c) A modified version of aspirin is sometimes made by reacting it with a strong base, such as sodium hydroxide. Explain why this process can increase the bioavailability of the drug. *[3]*

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(Option D continues on the following page)

(Option D continued)

14. Recent advances in research into the viruses that cause flu have led to the production of two antiviral drugs, oseltamivir (Tamiflu®) and zanamivir (Relenza®).

(a) Outline why viruses are generally more difficult to target with drugs than bacteria. *[1]*

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. . . .

(b) By reference to their molecular structures given in section 37 of the data booklet, state the formulas of **three** functional groups that are present in both oseltamivir and zanamivir and the formulas of **two** functional groups that are present in zanamivir only. *[3]*

Present in both:

. . . .

. . . .

. . . .

Present in zanamivir only:

. . . .

. . . .

(c) Comment on how the widespread use of these drugs may lead to the spread of drug-resistant viruses. *[2]*

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(Option D continues on the following page)

(Option D, question 14 continued)

(d) Outline the general processes that should be followed to promote "green chemistry" in the manufacture of drugs such as oseltamivir and zanamivir. *[3]*

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(Option D continues on the following page)

(Option D continued)

15. Antacids help to neutralize excess hydrochloric acid produced by the stomach. The neutralizing power of an antacid can be defined as the amount in moles of hydrochloric acid that can be neutralized per gram of antacid.

(a) Formulate an equation to show the action of the antacid magnesium hydroxide. *[1]*

. . . .

. . . .

(b) An antacid tablet with a mass of 0.200 g was added to 25.00 cm^3 of 0.125 mol dm^{-3} hydrochloric acid. After the reaction was complete, the excess acid required 5.00 cm^3 of 0.200 mol dm^{-3} sodium hydroxide to be neutralized. Determine the neutralizing power of the tablet. *[3]*

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End of Option D

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will not be marked.

SPEC/4/CHEMI/SP3/ENG/TZ0/XX/M

MARKSCHEME

SPECIMEN

CHEMISTRY

Standard Level

Paper 3

17 pages

Subject Details: Chemistry SL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions in Section A **[15 marks]** and all questions from **ONE** option in Section B **[20 marks]**.
Maximum total = **[35 marks]**.

1. Each row in the “Question” column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the “Total” column.

3. Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by “**max”** written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.

5. An alternative wording is indicated in the “Answers” column by a slash (/). Either wording can be accepted.

6. An alternative answer is indicated in the “Answers” column by ‘***OR***’ on the line between the alternatives. Either answer can be accepted.

7. Words in angled brackets **‹ ›** in the “Answers” column are not necessary to gain the mark.

8. Words that are <u>underlined</u> are essential for the mark.

9. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.

10. If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the “Notes” column.

11. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. "ECF acceptable" will be displayed in the "Notes" column.

13. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

14. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the "Notes" column, similarly, if the formula is specifically asked for, unless directed otherwise in the "Notes" column do not award a mark for a correct name.

15. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the "Notes" column.

16. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

SECTION A

Question			Answers	Notes	Total
1.	**a**	**i**	relative values ***OR*** compared with a standard ***OR*** not absolute measure ✓		**1**
	a	**ii**	high ODP for compounds with high Cl ***OR*** low ODP for compounds with less Cl ***OR*** zero ODP for compounds with no Cl ✓		**1**
	b		increasing atmospheric lifetime correlates with increasing GWP ✓ total contribution to global warming depends on length of time in atmosphere ***OR*** GWP depends on efficiency as greenhouse gas and atmospheric lifetime ✓	*Accept alternate answers based on sound scientific reasoning.*	**2**
	c	**i**	1,1,1,2-tetrafluoroethane ✓	*Allow without commas or dashes.*	**1**
	c	**ii**	$M\,(CH_2FCF_3) = (12.01 \times 2) + (1.01 \times 2) + (19.00 \times 4) = 102.04 \langle g\,mol^{-1} \rangle$ ✓ $\Delta H\,(\text{condensation } CH_2FCF_3) = -[0.217 \langle kJ\,g^{-1} \rangle \times 102.04 \langle g\,mol^{-1} \rangle] = -22.1 \langle kJ\,mol^{-1} \rangle$ ✓	*Award **[1 max]** for $\Delta H = 22.1\,kJ$*	**2**
	c	**iii**	atmospheric lifetime CO_2 much longer than CH_2FCF_3 ***OR*** after 100 years approx 30 % CO_2 still present whereas CH_2FCF_3 removed ✓ CO_2 from current emissions will continue to effect climate change/global warming far into the future ✓	*OWTTE*	**2**

Question			Answers	Notes	Total
2.	**a**		forgot to take account of water of crystallisation ***OR*** should have used 24.972 g ✓	*OWTTE*	**1**
	b		less uncertainty in the volume ***OR*** more precise ✓ takes into account volume change on dissolving ***OR*** concentration is for a given volume of solution not volume of solvent ✓		**2**
	c		filter ***OR*** centrifuge ✓ rinse (the solid) with water ✓ heat in an oven ***OR*** rinse with propanone/ethanol/volatile organic solvent and leave to evaporate ✓	*Award* ***[2]*** *for all 3,* ***[1]*** *for any 2.*	**2**
	d		taking a known mass of the solid to react directly with glucose ***OR*** not making the standard solution ✓	*OWTTE* *Accept any other valid answer based on sound scientific reasoning.*	**1**

SECTION B

Option A — Materials

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>3.</td><td>a</td><td></td><td>rigid
OR
rod-shaped/long thin molecule ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>b</td><td>i</td><td>mixture of carbon containing compound and inert dilutant in gas/vapour phase ✓

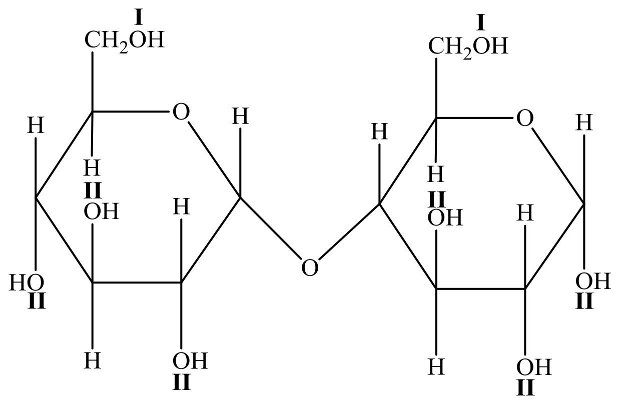
passed over a heated metal catalyst ✓</td><td></td><td>2</td></tr>
<tr><td></td><td>b</td><td>ii</td><td>(very) large surface area ✓</td><td></td><td>1</td></tr>
</table>

<table>
<tr><td>4.</td><td>a</td><td></td><td>
<table>
<tr><th>Compound</th><th>Magnesium oxide</th><th>Cobalt(II) oxide</th><th></th></tr>
<tr><td>Electronegativity difference</td><td>2.1</td><td>1.5</td><td>✓</td></tr>
<tr><td>Average electronegativity</td><td>2.35</td><td>2.65</td><td>✓</td></tr>
</table>
</td><td>Award [1] per correct row or column.</td><td>2</td></tr>
<tr><td></td><td>b</td><td></td><td>
<table>
<tr><th>Compound</th><th>Magnesium oxide</th><th>Cobalt(II) oxide</th><th></th></tr>
<tr><td>Bond type</td><td>Ionic</td><td>Polar covalent</td><td>✓</td></tr>
<tr><td>% covalent character</td><td>30 – 35</td><td>53 – 58</td><td>✓</td></tr>
</table>
</td><td>Award [1] per correct row or column.</td><td>2</td></tr>
</table>

Question			Answers	Notes	Total
5.	**a**		positive argon ions and (free) electrons ✓		**1**
	b	**i**	mol $Mg^{2+} = \langle 0.25 \times 10 \times 10^{-6} = \rangle\ 2.5 \times 10^{-6}\ \langle \text{mol} \rangle$ ✓ mass $Mg^{2+} = \langle 24.31 \times 2.5 \times 10^{-6} = \rangle\ 6.08 \times 10^{-5}$ g ✓		**2**
	b	**ii**	mass of solid too small to weigh accurately ✓ successive dilution of solution ***OR*** dilution of concentrated solution ✓	*OWTTE*	**2**
	b	**iii**	627 kcps **and** it lies inside of the calibrated region ***OR*** 627 kcps **and** 12 kcps lies outside of calibrated region ✓	*Accept other correct suggestions, for example "low values such as 12 kcps would have very high uncertainty".*	**1**

Question			Answers	Notes	Total
6.	**a**		resin identification codes ✓ ensures uniformity for recycling ✓ ***OR*** addition/condensation ✓ classification into similar reaction types ✓ ***OR*** flexible ✓ direct towards appropriate uses ✓ ***OR*** brittle ✓ direct towards appropriate uses ✓	*OWTTE* *Accept "predict possible monomers". OWTTE* *Accept any other valid scientific classification with a justifiable scientific reason for* ***[2]****.*	**2**
	b		softens the polymer ✓ separates the polymer chains ***OR*** reduces intermolecular forces ✓		**2**
	c		all of the reagents end up in useful product ***OR*** atom economy is 100% ***OR*** there is no chemical waste ✓		**1**
	d		hydrogen chloride/HCl ***OR*** dioxin ✓		**1**

Option B — Biochemistry

Question			Answers	Notes	Total
7.	**a**		 ✓	*Award mark for a correctly placed **I** **and** a correctly placed **II**.* *Allow **II** placed on hemiacetal.*	**1**
	b	**i**	$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$ ✓		**1**
	b	**ii**	catabolism ✓	*Accept hydrolysis.*	**1**
	c		at X (low pH) enzyme/protein protonated/positively charged/cationic (so unable to bind effectively) ✓ at Y (optimum pH) enzyme maximally able to bind to substrate/maltose ✓ at Z (high pH) enzyme/protein deprotonated/negatively charged/anionic (so unable to bind effectively) ✓	*Award **[1 max]** for reference to denaturation/change in shape of active site without explanation in terms of changes in ionization.*	**3**
	d		R_f value $V = \frac{5.4}{5.9} = 0.91$ **and** R_f value $W = \frac{1.5}{5.9} = 0.25$ ✓ so W is glutamine (V cannot be identified) ✓		**2**

Question			Answers	Notes	Total
8.	a		$C_{18}H_{34}O_3$ ✓		**1**
	b	i	both have 18 carbon atoms ✓ both have COOH/carboxylic acid group ***OR*** both are fatty acids ✓ ricinoleic acid has a <u>carbon-carbon</u> double bond/C=C/‹mono›unsaturated whereas stearic acid has all single C–C bonds/saturated ✓ ricinoleic acid has an OH/hydroxyl group ‹in the chain› whereas stearic acid does not ✓	*Do not accept just acids in M2* *Any 3 for **[3 max]**.*	**3 max**
	b	ii	ricinoleic acid more likely to undergo oxidative rancidity ‹than stearic acid› ✓ <u>carbon-carbon</u> double bond/C=C can be oxidised ✓	*OWTTE*	**2**
	c	i	‹heating causes› denaturation ***OR*** ‹heating causes› loss of conformation ***OR*** ‹heating causes› change of shape ***OR*** ‹heating causes› inability to bind substrates ✓	*Do not accept inactivated.*	**1**
	c	ii	castor seeds contain toxins/ricin ***OR*** ingesting raw seeds can be fatal ✓ different health/safety standards in different countries ***OR*** richer countries exploit workers in less-developed/poorer countries ✓	*Accept alternate valid answers, such as economic considerations.*	**2**

Question			Answers	Notes	Total
9.	**a**		substance/chemical/compound found in organism not normally present ***OR*** compound foreign to living organism ✓	*Accept artificially synthesised/man-made compound in the environment/biosphere.*	**1**
	b		non-polar ***OR*** lipophilic ***OR*** structure based on phenyl/hydrocarbon ***OR*** hydrophobic interactions ***OR*** similar (non)polarity to fat ✓		**1**
	c		ionic bonds ✓ hydrogen bonds ✓ van der Waals' forces ✓ hydrophobic interactions ✓	*Award* ***[1]*** *for any 3 correct answers.* *Accept alternate valid answers other than covalent bonding.*	**1 max**

Option C — Energy

Question			Answers	Notes	Total
10.	**a**	**i**	viscosity too high ✓		**1**
	a	**ii**	alcohol **and** (strong) acid ***OR*** base ✓	*Accept any specific alcohol (eg ethanol).*	**1**
	b	**i**	fermentation ✓		**1**
	b	**ii**	$\left\langle \frac{703 \times 5470}{114.26} = \right\rangle 33700 \left\langle \mathrm{kJ\,dm^{-3}} \right\rangle$ ✓		**1**
	b	**iii**	more energy from a given volume of fuel ✓	*Accept greater energy density.*	**1**
	b	**iv**	ethanol: $\frac{1367}{2} = 683.5\,\mathrm{kJ\,mol^{-1}}$ **and** octane: $\frac{5470}{8} = 683.8\,\mathrm{kJ\,mol^{-1}}$ ***OR*** mass of CO_2 produced in the release of 1000 kJ ethanol: $\frac{2 \times 44.01 \times 1000}{1367} = 64.4\,\mathrm{g}$ **and** octane: $\frac{8 \times 44.01 \times 1000}{1367} = 64.4\,\mathrm{g}$ ✓	*Accept other methods that show the amount carbon dioxide produced for the same heat energy output is the same for both fuels.*	**1**
	b	**v**	ethanol is a biofuel/produced from plant material ***OR*** growing plants absorbs carbon dioxide ✓		**1**

Question			Answers	Notes	Total
11.	**a**		nuclear power benefitted from the race to develop nuclear weapons ✓	*OWTTE* *Accept other valid explanations.*	**1**
	b		$\Delta m = \langle 234.99333 - 135.90722 - 89.907738 - [9 \times 1.00867] = \rangle\ 0.100342 \langle \text{amu} \rangle$ ✓ $= \langle 0.100342 \times 1.66 \times 10^{-27} \langle \text{kg} \rangle = \rangle 1.67 \times 10^{-28} \langle \text{kg} \rangle$ ✓ $E = \langle mc^2 = 1.67 \times 10^{-28} \times (3 \times 10^8)^2 = \rangle\ 1.50 \times 10^{-11} \langle \text{J} \rangle$ ✓	*Award **[3]** for correct final answer.*	**3**
	c		*Short term:* in cooling ponds ✓ *Long term:* vitrification ***OR*** underground in stable geological formations ✓		**2**

Question			Answers	Notes	Total
12.	a		incoming solar radiation is short wavelength ***OR*** incoming solar radiation is high frequency ***OR*** incoming solar radiation is high energy radiation ***OR*** incoming solar radiation is (UV radiation) ✓ radiation emitted (by the Earth's surface) is long wavelength ***OR*** radiation emitted (by the Earth's surface) is low frequency ***OR*** radiation emitted (by the Earth's surface) is low energy ***OR*** radiation emitted (by the Earth's surface) is IR radiation ✓ this energy is absorbed in the bonds of greenhouse gases ***OR*** the molecules vibrate when IR radiation is absorbed ✓ this energy is then re-radiated ‹some of it towards the surface of the Earth› ✓		**3 max**
	b		stretching ***OR*** bending ✓ causing a change in polarity/dipole moment ✓		**2**
	c	i	methane **and** anaerobic decomposition of organic matter ***OR*** digestion in animals ✓	*Accept other examples of greenhouse gases with correct <u>natural</u> sources.*	**1**
	c	ii	major sources of water vapour are natural rather than anthropogenic/due to humans ***OR*** levels of water vapour have remained almost constant whereas those of CO_2 have increased significantly in recent times ✓		**1**

Option D — Medicinal chemistry

Question			Answers	Notes	Total
13.	**a**		esterification ***OR*** condensation ✓		**1**
	b		*Difference*: only spectrum for salicylic acid has ‹strong broad› peak from 3200–3600 cm^{-1} for OH ‹in alcohol/phenol› ✓ *Similarities*: both have ‹strong› peaks from 1050–1410 cm^{-1} for C–O ‹in alcohol/phenol› ✓ both have ‹strong› peaks from1700–1750 cm^{-1} for C=O ‹in carboxylic acid› ✓ both have ‹broad› peaks from 2500–3000 cm^{-1} for OH ‹in carboxylic acid› ✓ both have peaks from 2850–3090 cm^{-1} for C–H ✓	*Accept "acetylsalicylic acid has two peaks in the 1700–1800 cm^{-1} range due to 2 different C=O".* *Award **[2 max]** for two of the following similarities.*	**3 max**
	c		reaction with NaOH produces ‹ionic› salt ***OR*** $C_6H_4(OH)(COOH) + NaOH \rightarrow C_6H_4(OH)(COONa) + H_2O$ ✓ increases ‹aqueous› solubility ‹for transport/uptake› ✓ higher proportion of drug/dosage reaches target region/cells ✓		**3**

Question			Answers	Notes	Total
14.	**a**		lack cell structure ***OR*** exist within host cell ***OR*** mutate easily and frequently ✓		**1**
	b		*Present in both*: NH_2 ✓ CONH ✓ C=C ✓ COC ✓ *Present in zanamivir only*: COOH **and** OH ✓	*For similarities award **[2 max]** for any three correct, **[1 max]** for two correct, **[0]** for one correct.* *Accept C=N.*	**3 max**
	c		exposure of viruses to the drug favours resistant strains ✓ resistant strains difficult to treat ***OR*** drugs should be used only when required ‹not as prophylactic› ✓	*OWTTE*	**2**

(Question 14 continued)

Question			Answers	Notes	Total
	d		design chemicals to be less hazardous to health and environment ✓ use solvents/reagents that are less hazardous to the environment ✓ design ‹synthetic› processes that use less energy/materials ***OR*** design ‹synthetic› processes with high atom economy ✓ use renewable resources ***OR*** reuse/recycle materials ✓ treat waste to make less hazardous ✓ proper disposal of hazardous waste ✓		**3 max**

15.	**a**		$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$ ✓		**1**
	b		n(HCl added) $=$ ‹$0.02500 \times 0.125 =$› 0.00313 ‹mol› ✓ n(HCl unreacted with tablet) $= n$(NaOH) $= 0.00500 \times 0.200 = 0.00100$ ‹mol HCl excess› n(HCl reacted with antacid) $=$ ‹$0.00313 - 0.00100 =$› 0.00213 ‹mol› ✓ neutralizing power ‹mol g^{-1}› $=$ ‹$\frac{0.00213}{0.200} =$› 0.011 ‹mol HCl neutralized per g antacid› ✓		**3**