FOR THE IB DIPLOMA PROGRAMME

THIRD EDITION

Chemistry

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Practice Exam-style Questions

Boost

HODDER EDUCATION
AN HACHETTE UK COMPANY

Contents

S1.1 Introduction to the particulate nature of matter

Paper 1

1 Which equation represents sublimation?

A $2Al\,(s) + 3Cl_2\,(g) \rightarrow 2AlCl_3\,(s)$

B $C_{10}H_{16}O\,(s) \rightarrow C_{10}H_{16}O\,(g)$

C $CO_2\,(g) \rightarrow CO_2\,(s)$

D $MgCO_3\,(s) + 2HCl\,(aq) \rightarrow MgCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$

2 Which statements about mixtures are correct?

I The components may be elements or compounds.

II All mixtures are homogeneous.

III The components can be separated by physical means.

A I and II only

B I and III only

C II and III only

D I, II and III

3 Which change of state is exothermic?

A $I_2\,(s) \rightarrow I_2\,(g)$

B $NH_3\,(l) \rightarrow NH_3\,(g)$

C $H_2O\,(g) \rightarrow H_2O\,(l)$

D $Cu\,(s) \rightarrow Cu\,(l)$

4 Which statement about sodium oxide is true?

A It is a homogenous mixture.

B It melts overs a range of temperature.

C It has a fixed composition by mass.

D It can be separated into sodium and oxygen by physical means.

5 A new substance was discovered and a series of experiments were carried out on it. Which observation suggests that the substance cannot be an element?

A Electrolysis of the molten substance gave two products.

B It reacted and dissolved in water to give a colourless solution and a gas.

C It has fixed melting and boiling points (under standard conditions).

D When heated in oxygen it can form two oxides.

6 Which physical processes could be used to separate decane ($C_{10}H_{22}$) and water. The two liquids are immiscible and have different boiling points.

1 distillation

2 filtration

3 sublimation

4 use of a separating funnel

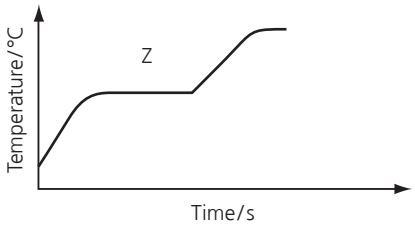
A 1, 2, 3 and 4

B 1, 2 and 3 only

C 1 and 2 only

D 1 and 4 only

7 A colourless solid crystalline sample was heated from a temperature of 25 °C (standard conditions) until it completely melted to form a colourless liquid. As the temperature starts to rise again the state change is complete.



State which of the following statements best explains the shape of the graph at region Z.

A There was no further heating.

B The particles do not have any kinetic and potential energy.

C A chemical reaction has taken place as the solid was melted.

D Heat energy is used to separate the solid particles from their fixed positions in the lattice.

8 Benzenecarboxylic acid is widely used in the food industry as a food preservative. The melting and boiling points of benzenecarboxylic acid are given below.

melting point of 122 °C boiling point of 249 °C

Which of the following will occur to the molecules of benzenecarboxylic acid when it is cooled from 260 °C to 100 °C?

	Distance between molecules	Kinetic energy of particles
A	decreases	decreases
B	increases	decreases
C	increases	increases
D	decreases	increases

9 Which of the following is **not** true about the Kelvin scale of temperature?

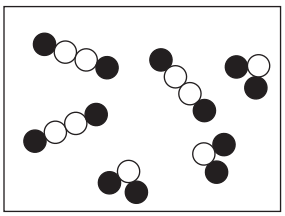
A The values on the absolute scale are directly proportional to the average kinetic energy of the particles.

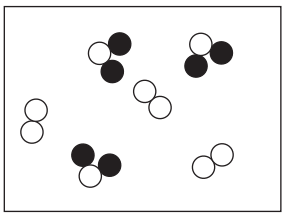
B To convert a temperature on the Celsius scale to the absolute scale, subtract 273.15 from the Celsius temperature.

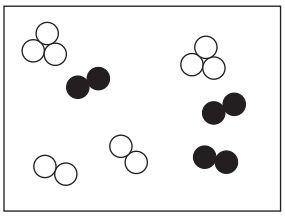
C A kelvin has the same size as Celsius degree.

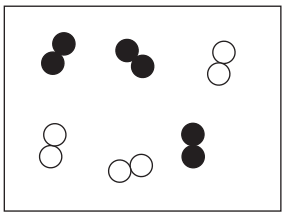
D Absolute zero corresponds to the absence of molecular movement.

10 The black and white balls represent atoms of different elements.

A 

C 

B 

D 

Which diagram shows a mixture of only compounds?

11 Which statement most clearly indicates that diamond and graphite are forms of pure elemental carbon?

A Both are crystalline solids.

B Complete combustion of equal masses of both solids at high temperature produces equal masses of carbon dioxide.

C Graphite is an electrical conductor, but diamond is an electrical insulator.

D Under high pressure graphite can be partially converted to diamond.

12 It is suspected that a coloured juice contains a low concentration of a poisonous green dye with a boiling point of 75 °C in addition to two harmless yellow and green dyes with boiling points of 72 °C and 75 °C.

Which is the most suitable separation technique by which the green dye may be detected?

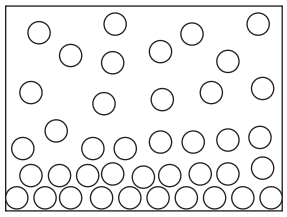
A recrystallization

B fractional distillation

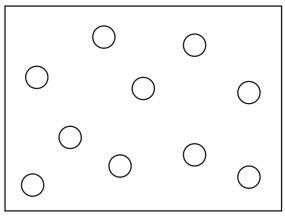
C paper chromatography

D evaporation

13 The diagrams below show the arrangement of particles in a substance at the same pressure and at temperatures −90 °C and −70 °C.



−90 °C



−70 °C

Which of the following could be the property of the substance?

	Melting point / °C	Boiling point / °C
A	−100	−75
B	−110	−65
C	−66	−32
D	−80	−60

14 Which statement about the kinetic molecular theory is not true?

A It explains why ionic salts have different solubilities in water.

B It explains the changes of state, boiling and freezing.

C It explains the difference in physical properties of solids, liquids and gases.

D It explains the diffusion of gases in air.

15 Which of the following best explains why iodine slowly sublimes under standard conditions?

A The iodine molecules at the surface reacts with oxygen.

B The iodine is heated and decomposes to form a gaseous product.

C Solid iodine is unstable.

D Iodine molecules at the surface gain sufficient kinetic energy to escape as gas.

16 Which one of the following correctly describes the properties of a molecular liquid?

A Hard to compress; has a fixed shape and a fixed volume.

B Hard to compress; has no fixed shape but has a fixed volume.

C Easy to compress; has no fixed shape but a fixed volume.

D Easy to compress; has a fixed shape, but no fixed volume.

Paper 2

1 Substances **W**, **X**, **Y** and **Z** have the physical properties shown below:

Substance	Melting point / °C	Boiling point / °C	Solubility in water
W	−114	78	soluble
X	−6	300	insoluble
Y	801	1413	soluble
Z	Sublimes at 340 °C		soluble

When these substances are mixed, physical methods of separating them may include:

filtration	sublimation	simple distillation
fractional distillation	chromatography	separating funnel
crystallization	evaporation to dryness	

State the best method(s) from the above list by which each of the following mixtures may be separated under standard conditions (25 °C), assuming that the components do not dissolve in each other. You may use a method once, more than once or not at all.

a a mixture of W and X [1]

b a mixture of X and Y [1]

c a mixture of Y and Z [1]

d a mixture of W, X and water [1]

2 A mixture of magnesium and sulfur powders burns with a bright white flame when ignited and forms a white solid. The mixture is known as "flash powder".

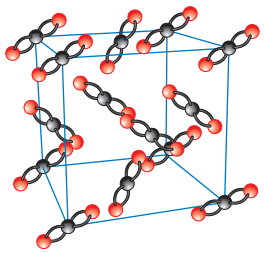
a Magnesium and sulfur are elements. Outline the meaning of the term element. [2]

b State one observation to show that a chemical reaction had taken place. [1]

The white solid is the compound magnesium sulfide.

c State three differences between the white solid and the mixture of magnesium and sulfur. [3]

3 Solid carbon dioxide, CO_2 (s), is known as dry ice and has the structure shown below. Under standard conditions (298.15 K and 100 kPa) it will undergo sublimation.



a Write a symbol equation to show the sublimation of solid carbon dioxide and explain why it is a physical change and not a chemical reaction. [2]

b State the type of particle present in the structure and explain why it can be deduced that dry ice is a crystalline solid. [2]

c Explain, in terms of bonding, why carbon dioxide exists as a gas at −78 °C and 100 kPa. [1]

The solid can be made by allowing liquid carbon dioxide, at 298 K and 4053 kPa to evaporate rapidly (by reducing the pressure to 100 kPa).

d Convert −78 °C to kelvin and 298 K to Celsius. Give both answers to the nearest integer. [2]

e State and explain whether the change CO_2 (l) → CO_2 (g) is exothermic or endothermic. [2]

f Suggest why the rapid expansion of liquid CO_2 produces some solid CO_2. [3]

g Explain why the gaseous carbon dioxide produced by the reaction occupies a significantly greater volume than the liquid carbon dioxide it was formed from. [2]

h State two physical differences between liquid and gaseous carbon dioxide. [2]

i Carbon dioxide gas reacts with calcium hydroxide solution to form solid calcium carbonate and water. Add state symbols to the equation below.

$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$ [1]

S1.2 The nuclear atom

Paper 1

1 How many electrons does the ion $^{209}_{84}Po^{2+}$ contain?

A 127

B 123

C 86

D 82

2 What is the same for both nuclides $^{64}_{29}Cu$ and $^{65}_{30}Zn$?

A nucleon (mass) number

B number of electrons

C number of neutrons

D atomic (proton) number

3 Skin cancer can be treated using the radioactive phosphide ion, $^{32}_{15}P^{3-}$. What is the composition of the nuclide?

A 15 protons, 17 neutrons, 18 electrons

B 15 protons, 17 neutrons, 32 electrons

C 32 protons, 17 neutrons, 15 electrons

D 17 protons, 15 neutrons, 17 electrons

4 For which of the following pairs of species are the chemical properties most similar?

A $^{1}_{1}H$ and $^{1}_{1}H^{+}$

B $^{14}_{6}C$ and $^{1}_{1}H^{+}$

C $^{23}_{11}Na$ and $^{39}_{19}K$

D $^{7}_{3}Li^{+}$ and $^{4}_{2}He$

5 How many neutrons are there in the stable nuclide $^{17}O^{2-}$?

A 9

B 11

C 15

D 19

6 The electron arrangement of potassium is 2.8.8.1. How many occupied main electron energy levels are there in an atom of potassium?

A 3

B 4

C 18

D 19

7 Information is given about four different atoms:

atom	neutrons	protons
A	22	18
B	20	16
C	18	20
D	20	18

Which two atoms are isotopes?

A A and C

B A and D

C B and D

D B and C

8 Which species has three more 3 neutrons than electrons?

A $^{11}_{5}B^{3+}$

B $^{14}_{7}N^{3-}$

C $^{42}_{20}Ca^{+}$

D $^{23}_{11}Na^{+}$

(Questions 9-12 HL only)

9 Which factors control the path of gaseous ions during deflection in a mass spectrometer?

A only the mass of the ion

B only the charge on the ion

C both the charge and mass of the ion

D neither the charge nor the mass of the ion.

10 A naturally occurring sample of bismuth contains the following isotopes.

Nuclide	Relative abundance
^{208}Bi	10.45
^{209}Bi	87.45
^{211}Bi	2.10

What is its relative atomic mass?

A 211.94

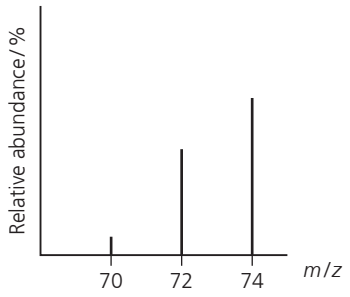
B 210.94

C 209.94

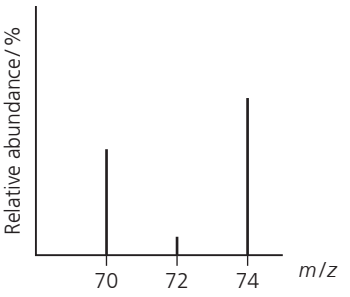
D 208.94

11 Chlorine has two isotopes, ^{35}Cl and ^{37}Cl, in the ratio of 3 atoms of ^{35}Cl to 1 atom of ^{37}Cl. Thus, diatomic molecules formed by chlorine have three possible relative isotopic masses, 70, 72 and 74. Which of the following shows the correct relative abundance of the molecules formed by chlorine?

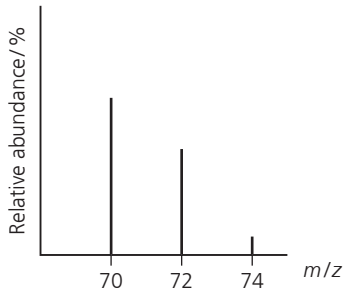
A



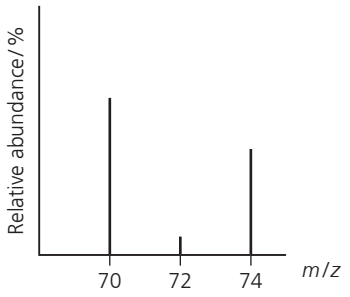
B



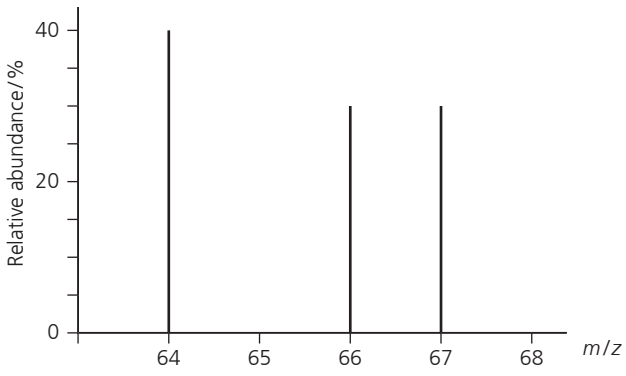
C



D



12 The mass spectrum of a sample of atoms in an element is shown below.



Which value is closest to the relative atomic mass of the element?

A 64.2

B 66.0

C 65.5

D 65.0

Paper 2

1 The element vanadium has two isotopes, $^{50}_{23}V$ and $^{51}_{23}V$, and a relative atomic mass of 50.94.

a Define the term isotope. [1]

b Vanadium-49 is an unstable radioisotope of vanadium. State the number of protons, electrons and neutrons in an atom of $^{49}_{23}V^{3+}$. [1]

c State and explain which is the less abundant isotope. [1]

d State the name and the mass number of the isotope relative to which **all** atomic masses are measured. [1]

e State a physical property that is different for isotopes of a gaseous element. [1]

2 Semi-heavy water, HDO, contains one atom of protium (^1H) and one atom of deuterium (^2H).

a Calculate the relative atomic mass of a sample of hydrogen to 5 decimal places using the data below. [1]

Isotope	Abundance
^1H	99.985
^2H	0.015

b State the number and type of subatomic particles in a deuterium atom and the location of each type. [3]

c State one physical property that is likely to be different for semi-heavy water compared to normal water (H_2O). [1]

Heavy water, D_2O, and heavy hydrogen, D_2, can be used to prepare a range of deuterated compounds.

d Formulate balanced equations to represent the formation of the following compounds, starting with D_2 or D_2O.

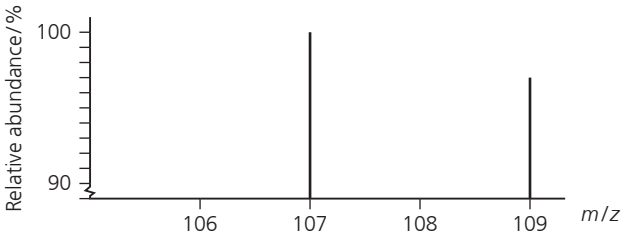
i ND_3 [1]

ii KOD [1]

e Calculate the total number of nucleons in one molecule of $^{14}ND_3$. [1]

(Question 3 HL only)

3 The following diagram shows the mass spectrum for the element silver.



a State the name of the instrument used to measure the relative abundances of isotopes. [1]

b Define the term relative atomic mass. [2]

c Calculate the relative atomic mass of silver (to the nearest integer). [2]

d Define the term atomic number of an element. [1]

e Write down the nuclide notation for the most abundant isotope of silver. [1]

f State why the isotopes of silver have identical chemical properties. [1]

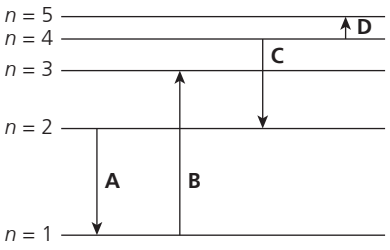
An atom has half as many protons as an atom of ^{28}Si and also has six fewer neutrons than an atom of ^{28}Si.

g State the nuclide symbol, including the mass number and the atomic number, of this atom. [2]

S1.3 Electron configuration

Paper 1

1 Which electron transition absorbs electromagnetic radiation with the longest wavelength?



2 Which statement correctly describes the atomic emission spectrum of gaseous helium atoms?

A It is a continuous spectrum converging at low frequency.

B It is a continuous spectrum converging at high frequency.

C It is a line spectrum converging at low frequency.

D It is a line spectrum converging at high frequency.

3 Which statements correctly describe the emission spectrum of gaseous hydrogen atoms at low pressure?

I Sharp coloured lines form when electrons transition from a higher energy level to a lower energy level.

II It is a continuous spectrum that has a convergence limit at high frequency.

III The electronic transitions from $n = 5$ to $n = 2$ will result in a line in the visible light spectrum of the electromagnetic radiation.

A I and II only

B I and III only

C II and III only

D I, II and III

4 What is the total number of electrons in all the s orbitals found in Cu^+ (g)?

A 6

B 5

C 1

D 3

5 What is the condensed electron configuration of the manganese ion, Mn^+ (g)?

A [Ar] $3d^4\ s^1$

B [Ar] $3d^4\ 4s^2$

C [Ar] $3d^5\ 4s^1$

D [Ar] 3d

6 Which electron transition in the hydrogen atom emission spectrum emits radiation with the shortest wavelength?

A $n = 2 \rightarrow n = 1$

B $n = 3 \rightarrow n = 2$

C $n = 4 \rightarrow n = 3$

D $n = 3 \rightarrow n = 1$

7 An element is in period 4 and group 16 of the periodic table. How many electrons are present in the highest occupied main energy level of atom of this element?

A 4

B 6

C 16

D 20

8 What is the total number of electrons in the s orbitals of a Bi^{5+} (g) ion?

A 2

B 6

C 10

D 12

9 Which one of the following ions or atoms has the ground state electron configuration $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$?

A Co^{2+}

B Mn

C Fe^{3+}

D Cr^{2+}

10 What is the condensed electron configuration of the telluride ion, Te^{2-}?

A [Kr] $5s^2\ 4d^{10}\ 5p^2$

B [Kr] $5s^2\ 5d^{10}\ 5p^6$

C [Kr] $5s^2\ 4d^{10}\ 5p^6$

D [Ar] $5s^2\ 4d^{10}\ 5p^4$

11 Which species on losing an electron would have a half-filled set of p orbitals?

A C^-

B N

C N^-

D O^+

12 Which one of the following sequences correctly represents the filling order of electron levels and sublevels according to the Aufbau principle?

A 1s → 2s → 3s → 4s → 2p → 3p → 4p

B 1s → 2s → 2p → 3s → 4s → 3d → 4p

C 1s → 2s → 2p → 3s → 3p → 4s → 2d

D 1s → 2s → 2p → 3s → 3p → 4s → 3d

13 How many unpaired electrons does a gaseous nickel atom have in its ground state?

A 4

B 3

C 2

D 0

14 What is the condensed electron configuration of the iron(III) ion, Fe^{3+} (g)?

A [Ar] $3d^5$

B [Ar] $3d^4\ 4s^1$

C [Ar] $3d^6$

D [Ar] $3d^6\ 4s^2$

(Questions 15–20 HL only)

15 The first five successive ionization energies of an atom of an element are given in the table below.

	Ionization energy/ kJ mol^{-1}
1st	805
2nd	2435
3rd	3680
4th	25040
5th	32840

Which group is the element most likely to belong to?

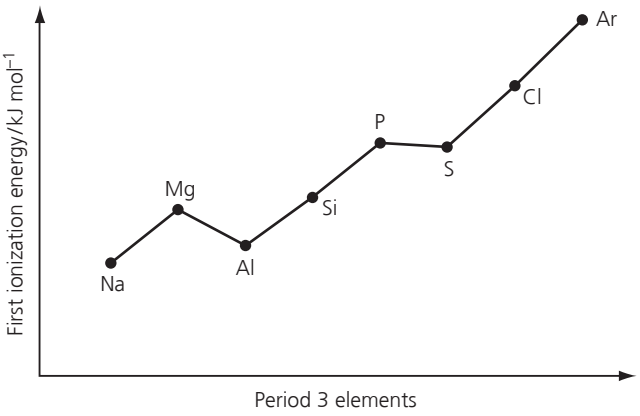
A 1

B 2

C 13

D 14

16 Which statement explains one of the small decreases observed in first ionization energy across period 3?



A The nuclear charge of the aluminium atom is greater than an atom of magnesium.

B A new sublevel is being filled at sulfur.

C The 3p orbital being filled in aluminium is at a lower energy than the 3s orbital in magnesium.

D There is electron–electron repulsion for the spin pair in the sulfur atom.

17 The first seven successive ionization energies (in kJ mol^{-1}) of an atom of an element are given below:

1025 1955 2730 4582 6025 12305 15400

Which of the following statements about the element is definitely correct?

A It is a metal.

B It forms an acidic oxide.

C It has a valence shell electronic configuration of $ns^2\ np^3$.

D It forms an ionic compound with sodium in a 1:1 mole ratio.

18 Which one of the following represents the third ionization energy of bismuth (Bi)?

A $Bi^+(g) \rightarrow Bi^{3+}(g) + e^-$

B $Bi^{2+}(g) \rightarrow Bi^{3+}(g) + e^-$

C $Bi(g) \rightarrow Bi^+(g) + e^-$

D $Bi(g) + 3e^- \rightarrow Bi^{3-}(g)$

19 In which of the following series are the atoms arranged in order of increasing first ionization energy?

A Be, Mg, Ca

B O, F, Ne

C Be, B, C

D Ne, O, F

20 A gallium atom has the electronic configuration [Ar] $3d^{10}\ 4s^2\ 4p^1$ where [Ar] represents the configuration of argon. In which order are the electrons lost in forming the Ga^{4+} (g) ion?

	1st	2nd	3rd	4th
A	4s	4s	4p	3d
B	3d	4s	4s	4p
C	4p	3d	4s	3p
D	4p	4s	4s	3d

Paper 2

1 The emission spectrum of gaseous hydrogen atoms is shown in the diagram below.

a Draw two separate arrows on the diagram to show increasing frequency and decreasing wavelength of electromagnetic radiation. [2]

b State an electron transition that corresponds to lines in the visible spectrum. [1]

c State two deductions about the energy levels of the hydrogen atom from the emission spectrum. [2]

The frequencies of two lines in the emission spectrum of hydrogen are given in the table below.

Higher level	Lower level	Frequency/ Hz
5	3	2.34×10^{14}
6	3	2.74×10^{14}

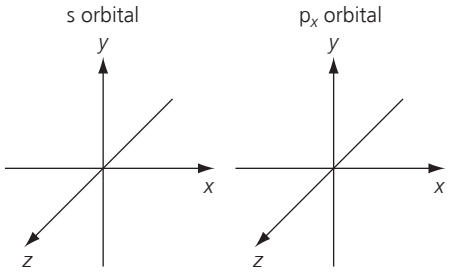
d Calculate the energy difference between energy levels 5 and 6 in a hydrogen atom. [3]

2 **a** State the full and condensed electron configurations of a nitrogen atom. [2]

b Sketch the orbital diagram of the valence shell of a nitrogen atom (ground state) on the energy axis provided. Use boxes to represent atom orbitals and arrows to represent electrons. [1]

c **(HL only)** Compare and explain the difference between the first ionization energies of nitrogen and oxygen atoms. [2]

d Nitrogen and oxygen atoms contain s and p orbitals. Draw the shape of an s orbital and a p_x orbital on the axes below. [2]



(Questions 2c-5 HL only)

3 The following table shows the first four successive ionization energies in $kJ\,mol^{-1}$ of atoms of the first four elements from group 2 in the periodic table.

Element	1st ionization energy	2nd ionization energy	3rd ionization energy	4th ionization energy
magnesium	737	1450	7733	10543
calcium	590	1145	4912	6491
strontium	549	1064	4137	5430
barium	503	965	3458	4530

a State the meaning of the term second ionization of energy of barium and state the relevant equation with state symbols. [3]

b Describe and explain the trend in second ionization energy of the group 2 elements. [3]

c State the element whose atoms would require the most energy to convert one mole of gaseous atoms into dispositive gaseous ions. [1]

4 The graphs below show the variation in first ionization energy of the atoms of some chemical elements. Figure S1 refers to the chemical elements C–G and Figure S2 refers to atoms of chemical elements in the same group as element C.

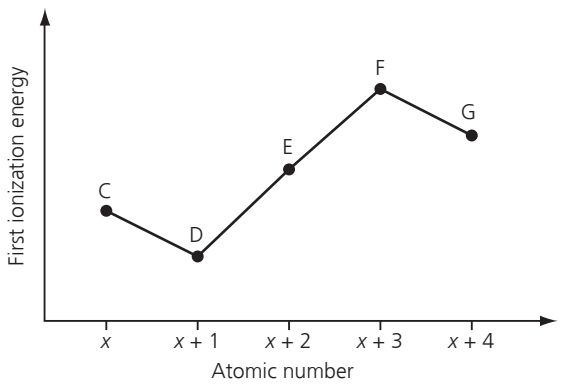


Figure S1

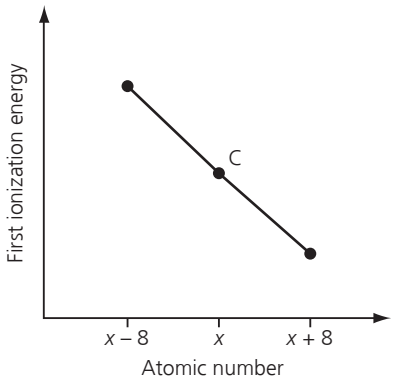


Figure S2

a Define the term first ionization energy of an element. [2]

b Element C, with atomic number *x*, is in group 2 of the periodic table. Justify this using all the information from Figure S1. [4]

c Explain the trend in the first ionization energy as shown in Figure S2. [3]

d State which period element C is in and explain your reasoning. [3]

e Explain why the first ionization energy of element G is lower than that of element F. [2]

5 Values of first ionization energy for the elements are in Table 9 in the IB *Chemistry data booklet*.

a Define the term *first ionization energy* and write an equation to illustrate it, using magnesium as an example. [3]

b Explain why the first ionization energy of aluminium is lower than that of magnesium. [2]

c Explain why the third ionization energy of magnesium is much higher than its first ionization energy. [2]

d Use the Aufbau principle to deduce the full electron configuration of cobalt. Identify the sublevel from which an electron is removed when the first ionization energy of cobalt is measured. [2]

Higher Level Paper 2, Time Zone 2, May 08, Q3

S1.4 Counting particles by mass: the mole

Paper 1

1 Which compound has the least percentage by mass of nitrogen atoms?

A N_2H_4

B NH_3

C N_2O_4

D $NaNO_3$

2 What is the sum of the integer coefficients when the equation is balanced?

___ C_6H_{14} (g) + ___ O_2 (g) → ___ CO (g) + ___ H_2O (l)

A 39

B 30

C 41

D 54

3 How many oxygen atoms are there in 0.500 mol of hydrated iron(II) ammonium sulfate, $(NH_4)_2Fe(SO_4)_2.6H_2O$ (s)?

(Avogadro's constant = 6.02×10^{23} mol^{-1}).

A $8 \times 6.02 \times 10^{23}$

B $0.500 \times 8 \times 6.02 \times 10^{23}$

C $14 \times 6.02 \times 10^{23}$

D $0.500 \times 14 \times 6.02 \times 10^{23}$

4 Calculate the approximate mass (in grams) of one molecule of C_{80}.

(Take the Avogadro constant to be 6×10^{23} mol^{-1}).

A 960 g

B 1.6×10^{-21} g

C 1.33×10^{-22} g

D 6×10^{-23} g

5 1 dm^3 of a gaseous sample of fluorine molecules contains x atoms. How many atoms are there in 1 dm^3 of xenon gas under the same experimental conditions?

A $\frac{x}{4}$

B $\frac{x}{2}$

C x

D $2x$

6 Which one of the following is Avogadro's constant?

A molecules in one mole of chlorine molecules in the solid state

B ions in one mole of lithium fluoride formula units

C atoms in one mole of gaseous oxygen molecules

D electrons in one mole of helium atoms

7 Carbon disulfide is oxidized upon combustion as follows:

$CS_2(g) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$

400 cm^3 of carbon disulfide vapour is ignited with 900 cm^3 of oxygen. What is the final volume of gas remaining after burning?

(Assume all gas volumes are measured at the same temperature and pressure and that CS_2 and O_2 react in a 1 : 3 ratio by volume so all the oxygen is consumed and there is excess CS_2).

A 400 cm^3

B 600 cm^3

C 800 cm^3

D 1000 cm^3

8 150 cm^3 of water is added to a solution of 100 cm^3 of 0.50 mol dm^{-3} caesium nitrate.

What is the concentration of caesium nitrate, in mol dm^{-3}, in the new diluted solution?

A 0.20

B 0.15

C 0.10

D 0.05

9 How many moles of calcium hydroxide are produced with 5.0 mol of ammonia?

Ca_3N_2 (s) + $6H_2O$ (l) → $3Ca(OH)_2$ (aq) + $2NH_3$ (aq)

A 2.5

B 3.3

C 7.5

D 15.0

10 Which volume, in cm^3, of 0.20 mol dm^{-3} KOH (aq) is needed to neutralize 0.050 mol of H_2S (g)?

H_2S (g) + 2KOH (aq) → K_2S (aq) + $2H_2O$ (l)

A 500

B 200

C 0.50

D 0.25

11 The complete combustion of 150 cm^3 of a gaseous hydrocarbon X produces 600 cm^3 of carbon dioxide and 750 cm^3 of water vapour. What is the molecular formula of X?

(All volumes are measured at the same temperature and pressure).

A C_6H_{10}

B C_4H_{10}

C C_4H_8

D C_4H_6

12 14 g of nitrogen gas is completely oxidized to one of its oxides.

If the mass of the oxide is 54 g, what is its empirical formula?

A NO

B N_2O

C N_2O_3

D N_2O_5

13 Group 2 ionic hydrides react with water as follows:

$CaH_2\,(s) + 2H_2O\,(l) \rightarrow Ca(OH)_2\,(aq) + 2H_2\,(g)$

In an experiment, a certain mass of calcium hydride was dissolved in excess water. The resulting solution required 200.0 cm^3 of a 2.00 mol dm^{-3} HCl solution for complete neutralization. What was the mass of calcium hydride?

A 4.21 g

B 5.71 g

C 7.41 g

D 8.42 g

14 What amount of oxygen, O_2, (in moles) contains 1.8×10^{23} molecules?

A 0.030

B 0.30

C 3.0

D 30.0

15 Which compound has the empirical formula with the lowest mass?

A C_2H_6

B C_4H_{10}

C C_6H_6

D C_5H_{10}

16 Which of the following contains the greatest number of molecules?

A 10 g of CH_3F

B 10 g of CH_2F_2

C 10 g of CF_4

D 10 g of CHF_3

17 Which one the following quantities has units?

A relative atomic mass

B relative formula mass

C mass number

D molar mass

18 What is the total number of ions present in the formula, $KAl(SO_4)_2.12H_2O$?

A 4

B 2

C 12

D 24

19 In order to dilute 40.0 cm^3 of 0.600 mol dm^{-3} HCl(aq) to 0.100 mol dm^{-3}, what volume of water must be added?

A 60 cm^3

B 200 cm^3

C 160 cm^3

D 240 cm^3

20 What is the concentration of nitrate ions in 0.500 cm^3 of 0.60 mol dm^{-3} $Fe(NO_3)_3$ solution?

A 0.60 mol dm^{-3}

C 1.20 mol dm^{-3}

B 0.90 mol dm^{-3}

D 1.80 mol dm^{-3}

Paper 2

1 **a** State what is meant by the term empirical formula. [1]

b A chromium compound contains 28.4% of sodium and 32.1% of chromium by mass, the remainder being oxygen.

c Calculate the empirical formula of this compound. [3]

2 3.00 g ± 0.02 g of iodine, I_2, reacts stoichiometrically with 0.70 g ± 0.02 g of tin to form an orange solid with the chemical formula SnI_x.

a Calculate the amount, in moles, of iodine atoms. [1]

b Calculate the amount, in moles, of tin atoms. [1]

c Determine the value of *x* (to the nearest integer). [1]

d Assuming the molar masses are constants, calculate the absolute uncertainty of *x*. [2]

e Tin forms another iodide with the formula SnI_2. Calculate the percentage by mass of tin (to the nearest integer) in this compound. [1]

3 When a 0.100 g sample of a nitrogen-containing fertilizer was boiled with excess KOH (aq), the following reaction took place:

NH_2CONH_2 (aq) + 2KOH (aq) → $2NH_3$ (g) + K_2CO_3 (aq)

The ammonia gas formed was absorbed in water and the resulting solution titrated with hydrochloric acid. 15.00 cm^3 of 0.200 mol dm^{-3} HCl were required for neutralization.

NH_3 (g) + HCl (aq) → NH_4Cl (aq)

Determine the mass of nitrogen in this sample of fertilizer. [4]

4 Outline the steps to prepare 0.100 mol dm^{-3} and 0.0100 mol dm^{-3} aqueous solutions of calcium chloride from a stock solution of concentration 1.00 mol dm^{-3}. State clearly the apparatus used with capacities and random uncertainties. [3]

5 100 cm^3 of ethene, C_2H_4, is burned in 300 cm^3 of oxygen, producing carbon dioxide and liquid water.

a State Avogadro's law. [1]

b Write the equation with state symbols for the complete combustion of ethene. [1]

c Calculate the volume of carbon dioxide produced. [1]

S1.5 Ideal gases

Paper 1

1 Why do gases deviate from the ideal gas law at high pressure?

A Molecules have finite volumes.

B Intermolecular forces increases the actual gas volume from the ideal gas volume.

C Collisions between molecules occur more frequently as pressure increases.

D Increasing pressure increases the temperature of the gas.

2 Which factors affect the molar volume of an ideal gas?

I Pressure

II Temperature

III Type of gas particles

A I and II only

B I and III only

C II and III only

D I, II and III

3 What is the final volume of gas when the pressure on 1000 cm^3 of gas is changed from 400 kPa to 200 kPa at constant temperature?

A 500 cm^3

B 1000 cm^3

C 8000 cm^3

D 2000 cm^3

4 The volume of a sample of gas measured at 27 °C is 10.0 dm^3. What is the temperature when the volume is reduced to 8.0 dm^3 at the same pressure?

A −33.0 °C

B −102 °C

C 102 °C

D 33.0 °C

5 For a sample of gas in a balloon the pressure and the absolute temperature (in kelvin) are both reduced by 50%. How will the final volume of the gas compare with its initial volume?

A the same

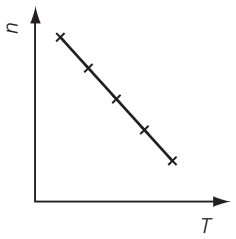
B half as large

C twice as large

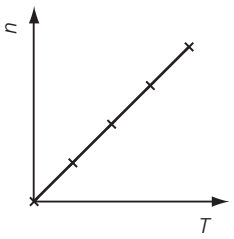
D one quarter as large

6 What is the graphical relationship between n and T in the ideal gas equation, $PV = nRT$, if all other variables remain constant?

A



B



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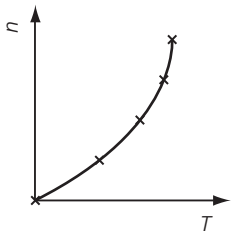
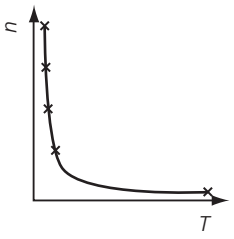


D



7 What is the pressure, in Pa, inside a 200 dm^3 cylinder containing 40 kg of $H_2(g)$ at 300 °C?

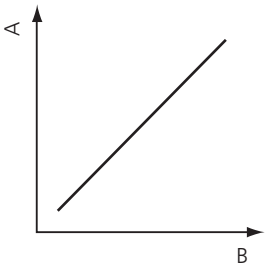
A $\dfrac{4 \times 10^4 \times 8.31 \times 300}{200 \times 10^{-3}}$

B $\dfrac{2 \times 10^4 \times 8.31 \times 573}{200}$

C $\dfrac{40 \times 8.31 \times 300}{200 \times 10^{-3}}$

D $\dfrac{2 \times 10^4 \times 8.31 \times 573}{200 \times 10^{-3}}$

8 Which of the following represents the variables A and B?



	A	B
A	molar mass / g mol^{-1}	volume / dm^3
B	amount of gas / mol	temperature / K
C	volume / dm^3	temperature / K
D	pressure / Pa	volume / dm^3

9 Under what conditions would one mole of SF_6 (g) occupy the smallest volume?

A 273 K and 1.01×10^6 Pa

B 273 K and 2.02×10^6 Pa

C 546 K and 1.01×10^6 Pa

D 546 K and 2.02×10^6 Pa

10 A sample of ideal gas composed of molecules in a sealed container of fixed volume is heated from 25 to 150 °C. Which one of the following properties will remain constant?

A pressure of the gas

B average velocity of the gas molecule

C average kinetic energy of the molecules

D density of the gas

11 According to the kinetic molecular theory, the pressure of an ideal gas in a container is due to which of the following?

I collisions between molecules

II collisions between molecules and walls

A I only

B II only

C Both I and II

D Neither I nor II

12 Which of the following statements about an ideal gas is *not* true.

A An increase in the temperature of the gas will increase the pressure of the gas at a constant volume.

B An increase in the temperature of the gas will increase the volume of the gas at a constant pressure.

C An increase in the volume of the gas will decrease the temperature at a constant pressure.

D An increase in the volume of the gas will decrease the pressure at a constant temperature.

13 Which gas is likely to deviate most from ideal gas behaviour?

A HF

B He

C CH_4

D N_2

14 At 27 °C and 51 kPa the density of a gaseous hydrocarbon is 0.91 g dm^{-3}. Identify the likely formula of the hydrocarbon.

A C_3H_6

B C_2H_6

C C_2H_4

D C_6H_6

15 A 4.00 dm^3 sample of gas exerts a pressure of 73 kPa at 60 °C. Which mathematical expression determines its pressure at 3.00 dm^3 and 30 °C?

A $\frac{73 \times 4.00 \times 30}{3.00 \times 60}$

B $\frac{73 \times 3.00 \times 30}{4.00 \times 60}$

C $\frac{73 \times 3.00 \times 333}{4.00 \times 3.03}$

D $\frac{73 \times 4.00 \times 303}{3.00 \times 333}$

16 When compared at the same pressure and temperature, which one of the following physical properties has the same value for H_2, and for D_2? [D = $^2_1$H and H = $^1_1$H]?

A average molecular speed

B relative molecular mass

C collision rate between molecules

D average kinetic energy of molecules

17 1000 cm^3 of hydrogen gas (hydrogen molecules, H_2) contains *Z* molecules at room temperature and pressure. What will be the number of atoms in 500 cm^3 of radon gas (radon atoms) at the same temperature and pressure? (Assume both gases behave ideally.)

A *Z*

B 2*Z*

C *Z* / 2

D *Z* / 4

18 A 350 cm^3 sample of helium gas is collected at 22.0 °C and 99.3 kPa. What volume would this gas occupy at STP?

A 322 cm^3

B 450 cm^3

C 477 cm^3

D 220 cm^3

19 What is the ratio of the average kinetic energy of oxygen molecules, O_2, to the average kinetic energy of methane molecules, CH_4, in sample of gas both maintained at a temperature of 200 °C?

A 1 : 4

B 4 : 1

C 1 : 2

D 1 : 1

20 A sample of an ideal gas occupies a volume V_1 at a pressure P_1 and an absolute temperature T_1. What would be the absolute temperature of the gas, T_2, if both its pressure and volume are doubled?

A $T_2 = T_1$

B $T_2 = ½T_1$

C $T_2 = 2T_1$

D $T_2 = 4T_1$

Paper 2

1 A balloon, which can hold a maximum of 1000 cm^3 of nitrogen before bursting, contains 955 cm^3 of nitrogen at 5 °C.

a Determine whether the balloon will burst if the temperature is increased to 30 °C. [3]

b Use the kinetic theory to explain what happens to the molecules of nitrogen inside the balloon as the temperature is increased to 30 °C. [2]

2 Oxygen is regenerated from carbon dioxide in a closed system, such as submarines and rocket capsules by the chemical reaction:

$4NaO_2\,(s) + 2CO_2\,(g) \rightarrow 2Na_2CO_3\,(s) + 3O_2\,(g)$

4.60 m^3 of carbon dioxide, at 30.0 °C and 100 kPa are produced each day in a large submarine.

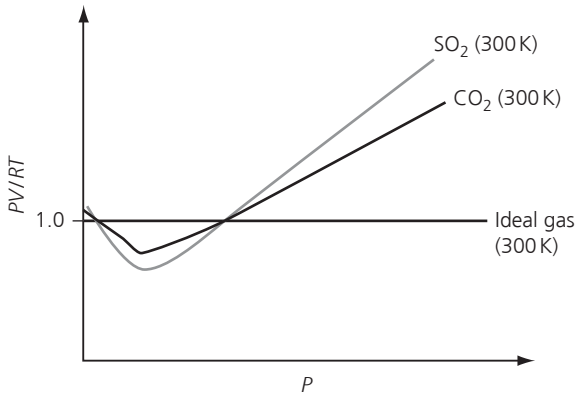
a Calculate the minimum daily mass (in grams) of sodium superoxide, NaO_2, which is used to convert carbon dioxide into oxygen. [4]

b Suggest an advantage of this process. [1]

3 **a** State two assumptions that are made about the behaviour of an ideal gas. [2]

b State and explain under which conditions real gases deviate the most from ideal behaviour. [6]

Plots of PV/RT against p for one mole of an ideal gas, one mole of SO_2 at 300 K and one mole of CO_2 at 300 K are shown below.

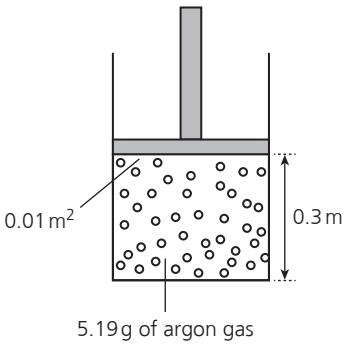


c Explain the difference in behaviour between carbon dioxide and sulfur dioxide at 300 K. [2]

d Explain what happens when the sulfur dioxide gas is cooled down to 100 K.

Sketch the new curve on the graph. [2]

4 The diagram below shows a well-insulated gas cylinder containing 5.19 g of argon gas. The area of the piston is 0.01 m^2.



a Given that the temperature of the argon gas is 20 °C, calculate the pressure of the argon gas in the cylinder (assuming that the piston does not move). [2]

b Calculate the distance moved by the piston if the temperature of the argon gas is increased to 50 °C. Assume that the pressure remains unchanged. [2]

5 A (0.425 ± 0.002) g sample of gaseous aluminium chloride occupies a volume of (52.0 ± 0.3) cm^3 at (398.5 ± 0.5) K and exerts a pressure of (101000 ± 1000) Pa.

Calculate the relative molecular mass of aluminium chloride and its absolute uncertainty, expressing both values to the appropriate number of significant figures. Comment on the value obtained. [3]

S2.1 The ionic model

Paper 1

1 Which compound contains ionic bonds?

A magnesium fluoride, MgF_2

B dichloromethane, CH_2Cl_2

C fluoroethanoic acid, CH_2FCOOH

D silicon tetrachloride, $SiCl_4$

2 A group 1 element, X, bonds with a group 17 element, Y. What is the most likely formula and type of bonding in this compound?

A X_2Y ionic

B XY ionic

C XY_7 covalent

D XY covalent

3 What is the formula for the ionic compound formed when barium reacts with nitrogen?

A BaN

B Ba_2N

C Ba_3N_2

D Ba_2N_3

4 A hard crystalline substance with a high melting point is an electrical insulator as a solid but a good conductor when melted. What type of substance is it likely to be?

A covalent network solid

B molecular covalent

C metallic

D ionic

5 Which one of the following elements is most likely to form ionic bonds with sulfur?

A chlorine

B oxygen

C silicon

D caesium

6 Which one of the following substances is most likely to exist as a solid under standard conditions?

A BaF_2

B BCl_3

C $SiCl_4$

D HCl

7 A mineral has the formula $Mg_3Si_4O_{10}(OH)_2$. Based on the formula of the mineral, deduce the correct chemical formula of the compound formed between the calcium ion and the anion of Si_4O_{10}.

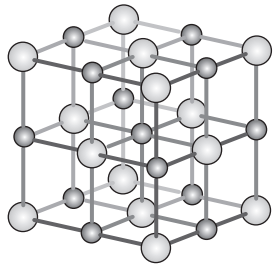
A $Ca_2Si_4O_{10}$

B $Ca_2(Si_4O_{10})_3$

C $Ca_3Si_4O_{10}$

D $Ca_3(Si_4O_{10})_2$

8 The diagram shows the arrangement of the ions in an ionic crystal.



Key

positive ion

negative ion

Which compound cannot have this lattice?

A magnesium oxide

B calcium chloride

C iron(II) sulfate

D lithium chloride

9 Which statement is true for most ionic compounds?

A They are formed from elements of similar electronegativity.

B They conduct electricity in the solid state.

C They are coloured and volatile.

D They have relatively high melting and boiling points.

10 How does a rubidium atom form a stable ion present in all its compounds?

A The atom gains a proton to form a cation.

B The atom loses a proton to form an anion.

C The atom loses its valence electron to form a cation.

D The atom gains an electron to form an anion.

11 The formula for samarium(III) chloride is $SmCl_3$. What is the formula for samarium(III) sulfate(VI)?

A $Sm_2(SO_4)_3$
B $Sm(SO_4)_3$
C $Sm_3(SO_4)_2$
D Sm_2SO_4

12 Which element forms more than one stable cation?

A Ca
B Mn
C Zn
D Al

13 Which statement best describes the lattice structure of solid sodium chloride?

A Each sodium cation is surrounded by only one chloride anion.
B Each chloride anion is surrounded by two sodium cations.
C Each chloride anion is surrounded by four sodium cations.
D Each sodium cation is surrounded by six chloride anions.

14 Which pair of atoms of the elements shows the greatest difference in electronegativity?

A Li and I
B Na and S
C Ca and O
D Cs and F

15 Which of the following ionic compounds is expected to have the most positive value of lattice enthalpy?

A NaF
B NaBr
C LiI
D LiF

16 Which is the best description of ionic bonding?

A electrostatic attraction between cations and electrons
B electrostatic attraction between cations and anions
C electrostatic attraction of nuclei toward shared electrons in the bond between the nuclei
D electrostatic attraction between nuclei of ions

17 Which compound has the largest value of lattice enthalpy?

A Al_2O_3
B MgS
C NaF
D MgO

18 Which of these properties is shown by all ionic compounds in the solid state?

A high volatility
B very poor electrical conductivity below the melting point
C low boiling point
D high solubility in water

19 Element X is in group 2, and element Y in group 17, of the periodic table. Which cations and anions will be present in the compound formed when atoms of X and Y react together?

A X^+ and Y^-
B X^{2+} and Y^-
C X^{2-} and Y^+
D X^+ and Y^{2-}

20 Which statement is a correct description of electron loss in this redox reaction?

$2Al + 3Se \rightarrow Al_2Se_3$

A Each aluminium atom loses two valence electrons.
B Each aluminium atom loses three valence electrons.
C Each selenium atom loses two valence electrons.
D Each selenium atom loses three valence electrons.

Paper 2

1 Silver reacts with fluorine to form silver fluoride, AgF. Silver fluoride has a high melting point and has a simple cubic structure similar to that of sodium chloride.

a Explain why the formula, AgF, is an empirical formula. [1]
b State the equation showing the synthesis of silver fluoride from its elements [1]
c State the type of reaction involved. [1]
d State and describe the type of bonding involved in silver fluoride. [2]
e State four properties typical of compounds with this type of bonding. [1]
f Draw a diagram to show how the particles are arranged in a silver fluoride lattice and show the charges on the particles [2]

Silver fluoride is insoluble in organic solvents, but lithium bromide shows significant solubility in organic solvents.

g Suggest a reason for this behaviour of lithium bromide. [3]

2 Caesium fluoride is an ionic compound.

a Explain the following physical properties in terms of its structure:

i volatility

ii electrical conductivity

iii solubility. [6]

b Define the term lattice enthalpy and write an equation showing it for caesium fluoride. [2]

3 Magnesium sulfate is used as an electrolyte to treat brain injury patients in hospitals. Magnesium sulfate contains both covalent bonds and ionic bonding.

a State the formulas of the ions present and the nature of the force operating between the oppositely charged ions. [2]

b State which atoms are covalently bonded. [1]

c A metal atom has the electron configuration of $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$. Identify the element and predict the charge on the cation. [2]

d Deduce the formula of its sulfate which finds use as a blood coagulant. [1]

4 Magnesium chloride melts at 718 °C and aluminium chloride melts at 192 °C.

a Explain, in terms of structure and bonding, the significant difference in melting points. [2]

b State and explain the conditions under which magnesium chloride will act as an electrical conductor. [3]

5 Halogens react readily with lead to form lead halides. The melting points of some of the lead halides are given in the table below.

Compound	Melting point /°C
PbF_2	824
$PbCl_2$	501
$PbBr_4$	373
$PbCl_4$	−15

a Explain, in terms of structure and bonding, why the melting points of the lead(II) halides decrease from lead(II) fluoride to lead(II) bromide. [2]

b Explain why $PbCl_4$ is a covalent compound and account for its low melting point. [2]

S2.2 The covalent model

Paper 1

1 Which one of the following is correct for carbon suboxide, O=C=C=C=O?

	C=O bond	C_3O_2 molecule
A	polar	non-polar
B	non-polar	polar
C	polar	polar
D	non-polar	non-polar

2 Which compound contains both ionic and covalent bonds?

A CH_3CH_2CHO

B $CH_3CH_2NH_2$

C $CoCl_2$

D K_2CuCl_4

3 What type of bonding or intermolecular force is not present in $NH_3.BF_3$ (s)?

A hydrogen bonds

B coordination bonds

C London (dispersion) forces

D ionic bonds

4 Based on electronegativity values, which bond is the most polar?

A B–C

B C–O

C O–F

D N–O

5 Which molecule is non-polar?

A H_2CO

B SO_3

C $NFCl_2$

D $CHCl_3$

6 Which one of the following pairs of molecules has identical shapes for both species?

A CCl_4, SF_4

B XeF_2, CO_2

C BCl_3, PF_3

D PF_5, IF_5

7 What is the main interaction between liquid decane ($C_{10}H_{22}$) molecules?

A covalent bonding

B dipole–dipole forces

C London (dispersion) forces

D hydrogen bonding

8 Which of the following describes an observation that cannot be explained by hydrogen bonding?

A Ice has a lower density than water at 0 °C.

B Hydrazine (N_2H_4) is more soluble in water than in ammonia.

C CH_3F has a lower boiling point than methanol CH_3OH.

D The boiling point of alcohols increases with increasing number of carbon atoms.

9 Which of the following compounds are arranged in decreasing order of their solubility in water?

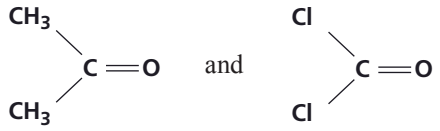
A $CH_3CH_2CO_2Na$, $CH_3CH_2CH_2OH$, $CH_3CH_2CH_2Cl$

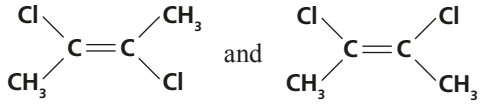
B $CH_3CH_2CO_2Na$, $CH_3CH_2CH_2Cl$, $CH_3CH_2CH_2OH$

C $CH_3CH_2CH_2OH$, $CH_3CH_2CO_2Na$, $CH_3CH_2CH_2Cl$

D $CH_3CH_2CH_2Cl$, $CH_3CH_2CH_2OH$, $CH_3CH_2CO_2Na$

10 In which one of the following pairs does the first molecule have a larger dipole than the second?

A 

B 

C HCl and HF

D SO_3 and SO_2

(Questions 11–20 HL only)

11 Which substance does not contain delocalized electrons?

A graphene

B carbon-60, C_{60}

C methylbenzene, $C_6H_5–CH_3$

D ethene, C_2H_4

12 Which species have resonance structures?

I the azide ion, N_3^-

II the carbon dioxide molecule, CO_2

III the methylbenzene molecule, $C_6H_5–CH_3$

A I and II only

B I and III only

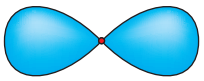
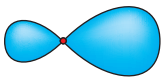
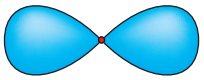
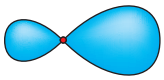
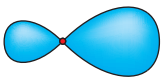
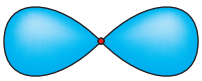
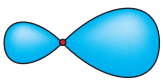
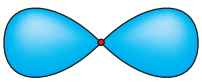
C II and III only

D I, II and III

13 Which of the following information about the specified central atom is correct?

	Atom	Number of electron domains around one central atom	Molecular geometry	Hybridization
A	C in C_2FCl	2	linear	sp
B	C in C_2H_6	4	square planar	sp^3
C	P in PH_3	3	trigonal pyramidal	sp^3
D	O in H_2O	4	Bent / V-shaped	sp^2

14 Which diagram shows the correct shape and relative energies of a p orbital and a sp^3 hybrid orbital of a nitrogen atom?

	p orbital	sp^3 hybrid orbital	Energy level from p to sp^3
A			increase
B			decrease
C			increase
D			decrease

15 What is the hybridization state of carbon in ethyne (C_2H_2), graphite and diamond?

A sp, sp^2, sp^3

B sp, sp^3, sp^2

C sp^3, sp^2, sp

D sp, sp^3, sp^3

16 Which of the following species does not contain an sp^3 hybridized oxygen atom?

A H_2O_2

B H_3O^+

C H_2O

D CH_3CHO

17 Which of the following molecules does not have a **π** bond?

A CO_2

B CO

C H_2O_2

D SO_3

18 What is the number of **σ** and **π** bonds in $(NC)_2C=C(CN)_2$?

A 5, 4

B 6, 6

C 9, 4

D 9, 9

19 Which one of the following contains the largest number of lone pairs on the central atom?

A ClO_3^-

B XeF_4

C I_3^-

D SF_4

20 What is the formal charge of boron in the borohydride ion, BH_4^-?

A −1

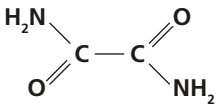
B 0

C +1

D −4

Paper 2

1 The structural formula of ethanediamide is shown below.



a Predict the electron domain and molecular geometries at the nitrogen and carbon atoms, applying VSEPR theory. [4]

b State the hybridization of the carbon atoms. [1]

c State the number of sigma bonds, pi bonds and lone pairs in a molecule of ethanediamide. [3]

d Suggest why ethanediamide is a solid and ammonia is a gas under standard conditions. [2]

e Explain why ethanediamide is relatively soluble in water. [1]

2 The melting and boiling points of the noble gases are tabulated below.

Noble gas	*helium*	*neon*	*argon*	*krypton*	*xenon*	*radon*
Boiling point / °C	–269	–246	–186	–152	–107	–62
Melting point / °C	–272	–249	–189	–157	–112	–71

Two selected noble gases can be compared to hydrocarbons and perfluorocarbons (which contain only carbon and fluorine atoms) of similar molar masses, as shown in the table below.

Molar mass analogues of noble gases / g mol^{-1}	Boiling point/° C	Difference between noble gas and organic boiling point
Kr (83.3)	−152	
CF_4 (88.0)	−129	
C_6H_{14} (86.2)	69	
Xe (131.1)	−107	
C_2F_6 (138.0)	−79	
C_9H_{20} (128.3)	151	

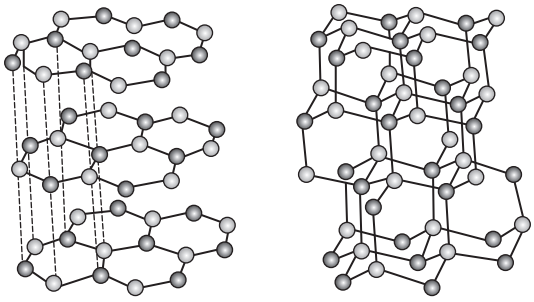
a State the trend in the boiling and melting points of the noble gases down the group. [1]

b Explain this general trend in boiling points for the noble gases in terms of the type of structure and intermolecular forces. [2]

c Calculate the differences in boiling points between the noble gas and the organic molecules in the table above. Evaluate which organic substance behaves most like the noble gas. [2]

d Suggest why the perfluorocarbons have lower boiling points than hydrocarbons. [3]

3 Boron nitride is found to exist in two possible forms, hexagonal boron nitride and cubic boron nitride as shown.



hexagonal boron nitride cubic boron nitride

boron atom nitrogen atom

Carbon can also be found in two different forms (allotropes).

a Name the allotropes of carbon which have a similar structure to hexagonal boron nitride and cubic boron nitride. [2]

b Based on the structures shown, explain the difference in **one** physical property of hexagonal and cubic boron nitride other than electrical conductivity. [3]

c Explain the difference in electrical conductivity between graphene and carbon-60. [2]

4 Explain why the solubility of trichloromethane ($CHCl_3$) in water is ten times greater than that of carbon tetrachloride (CCl_4) in water at the same temperature. [3]

5 Silanes (see table below) are the silicon analogues of alkanes and follow a similar general formula. They only have Si–H and Si–Si single bonds. Silanes can be used to prepare pure silicon.

	silane SiH_4	disilane Si_2H_6	trisilane Si_3H_8	tetrasilane Si_4H_{10}
Melting point / °C	–185	–133	–117	–90
Boiling point / °C	–112	–14	53	108

a State the general formula of the silanes and predict the molecular formula of hexasilane. [2]

b State the general trend in the boiling and melting points of the silanes across the table from left to right. [1]

c State the name of one silane from the table which is a liquid under standard conditions. [1]

d Explain this general trend in boiling points for the silanes in terms of the type of structure and intermolecular forces. [3]

e Write an equation to show the combustion of silane. [1]

f State the molecular shape of silane, SiH_4, and state the bond angle. [2]

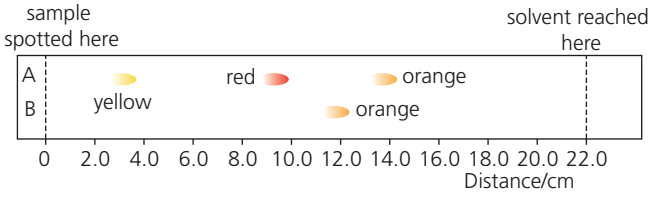
g Explain why the Si–H bond is longer than the C–H bond. [2]

h Using the data booklet compare the polarity of the bonds in a molecule of methane with those in silane and explain the difference. [2]

i Describe the structure of silicon and state one physical property of silicon. [2]

6 a Outline the basic principle of **all** chromatographic techniques. [2]

b Paper chromatograms formed by two orange food colourings, A and B, are shown below.



i State which of these food colourings is a mixture of dyes. [1]

ii State which of these food colourings is a pure substance. [1]

iii Explain whether the same dye is present in each of the food colourings. [2]

The R_f value is the ratio of the distance moved by the solute/distance moved by solvent.

iv Calculate the R_F value of the substance responsible for the red spot in the chromatogram of A. [1]

c The results of a thin-layer chromatography separation on silica gel are shown below.

Compound	Distance travelled / cm
Compound 1	1.6
Compound 2	9.2
Compound 3 (solvent)	12.6

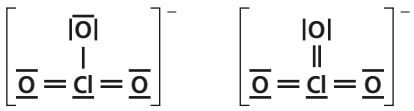
i Calculate the R_F values of the compounds 1 and 2 and comment on their values. [3]

ii State one advantage of thin-layer chromatography over paper chromatography. [1]

(Questions 7–9 HL only)

7 Benzene is an aromatic hydrocarbon. State two empirical pieces of evidence that support a π electron delocalized structure of benzene. [2]

8 Two possible Lewis structures of the chlorate(VI) ion, ClO_3^- ion are shown below.



A B

a Outline the principles of the valence shell electron-pair repulsion (VSEPR) theory. [3]

b Using VSEPR theory, state the electron domain geometry, molecular shape and the O–Cl–O bond angle in structure II. [3]

c Using formal charge, state and explain which is likely to be the Lewis structure of the ClO_3^- ion. [3]

9 a Draw a labelled diagram of sp^3 orbitals. [1]

b Describe the bonding of sp^3 carbon in terms of orbital overlap in propanone, $(CH_3)_2C{=}O$. [2]

S2.3 The metallic model

Paper 1

1 Which one of the following does not contain any delocalized electrons?

A poly(propene)

B methyl benzene

C graphene

D sodium

2 What particles are responsible for the high electrical conductivity of metals when a potential difference is applied?

A delocalized cations

B delocalized valence electrons

C delocalized metal atoms

D delocalized anions

3 Which is a correct description of a simple model of metallic bonding?

A Cations are attracted to anions.

B Anions are attracted to cations.

C Cations are attracted to delocalized electrons.

D Anions attracted to delocalized electrons.

4 Which statement best describes the attraction present in metallic bonding?

A the attraction between metal nuclei and valence electrons

B the attraction between cations and valence electrons

C the attraction between cations and anions

D the attraction between protons and valence electrons

5 The melting and boiling points of an element are 1550 °C and 3000 °C, respectively. It is an excellent conductor of electricity in the solid and molten states.

What type of bonding is present in the element?

A ionic

B polar covalent

C coordination bonding

D metallic

6 Why does silver wire conduct electricity when a potential difference (voltage) is applied?

A Valence electrons in the lattice move.

B Silver(I) ions move to the negative electrode.

C The atoms of silver become ionized.

D The crystal lattice breaks down.

7 Which particles are responsible for the conduction of electricity in liquid mercury?

A cations

B anions

C electrons

D protons

8 Which combination results in the strongest metallic bonding?

	Charge on cations	Ionic radius
A	larger	smaller
B	smaller	larger
C	larger	larger
D	smaller	smaller

9 Which metal has the strongest metallic bonding?

A Li

B K

C Rb

D Cs

10 The melting point of calcium, 839 °C, is much higher than the melting point of sodium, 98 °C.

Which statement is most relevant in explaining this difference?

A The calcium atom has a larger radius than the sodium atom.

B The calcium atom has a higher molar mass than the sodium atom.

C The calcium ion has a higher charge than the sodium ion.

D The calcium ion has more electrons than the sodium ion.

11 Which substance does not have delocalized electrons?

A graphene

B graphite

C silicon

D scandium

12 Which one of the factors will favour formation of a cation from a metal atom?

A high charge on the metal cation

B high value of ionization energy

C large atomic radius

D small atomic radius

13 Why are alloys usually stronger than the pure metals from which they are made?

A They have stronger bonds between the molecules they contain.

B They combine the properties of the metals from which they are made.

C They have atoms of different sizes in their structures.

D They are made using electrolysis.

14 Which is the correct description of the lattice in the alloy brass, composed of copper and zinc?

A delocalized cations and anions in fixed positions

B delocalized anions and cations in fixed positions

C cations in fixed positions and delocalized valence electrons

D molecules in fixed positions and delocalized valence electrons

15 In which of the following substances does metallic bonding predominate?

A graphene

B brass

C silicon

D boron

16 Which statements are correct for metals?

I They are good thermal conductors because they have free-moving cations.

II They often consist of a close packed lattice of cations with delocalized valence electrons.

III They are malleable and ductile because the layers of cations can slide across each other and still remain bonded.

A I and II only

B I and III only

C II and III only

D I, II and III

Paper 2

1 a Describe metallic bonding. [4]

b Explain why metals generally have high melting points, conduct electricity in both solid and liquid states and are good conductors of heat. [7]

2 Describe the variation in melting points and electrical conductivities of the elements in period 3 (sodium to argon), and explain these variations in terms of their structures and bonding. [6]

3 Strontium metal is used in the manufacture of alloys.

a Describe the bonding in a group 2 metal. [2]

b Explain why barium and strontium readily form an alloy. [2]

c Explain why strontium has a higher melting point than barium. [2]

(Questions 3d–4 HL only)

d State and explain one difference in physical property between chromium (d-block metal) and strontium (a main group metal). [2]

4 The table below shows part of the central block of the periodic table which displays transition metals found in periods 4, 5 and 6. The proton numbers and melting points of each of the metals are shown.

Period	Melting points of transition metals / °C							
4	$_{22}$Ti 1668	$_{23}$V 1910	$_{24}$Cr 1907	$_{25}$Mn 1244	$_{26}$Fe 1535	$_{27}$Co 1495	$_{28}$Ni 1453	$_{29}$Cu 1083
5	$_{40}$Zr 1852	$_{41}$Nb 2468	$_{42}$Mo 2617	$_{43}$Tc 2152	$_{44}$Ru 2034	$_{45}$Rh 1966	$_{46}$Pd 1552	$_{47}$Ag 962
6	$_{72}$Hf 2227	$_{73}$Ta 3017	$_{74}$W 3422	$_{75}$Re 3180	$_{76}$Os 3033	$_{77}$Ir 2446	$_{78}$Pt 1772	$_{79}$Au 1064

a Plot an appropriate graph to display the data. [3]

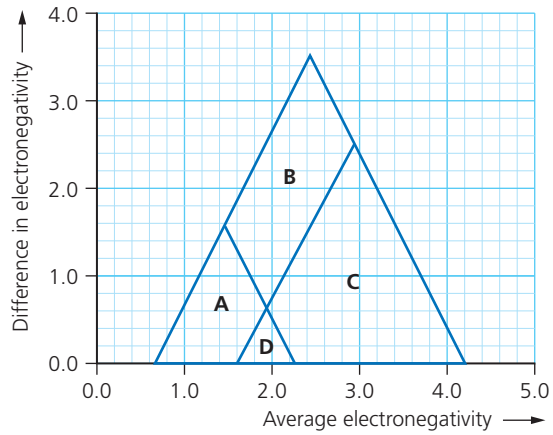
b Use the information above to describe the trends in the melting points of transition metals down the groups and across the periods. [3]

c Evaluate the hypothesis that more unpaired electrons present in an atom tends to increase the bonding strength of a metal in the solid state. [2]

S2.4 From models to materials

Paper 1

1 The electronegativity of antimony is 2.0 and that of chlorine is 3.2. In which region of the bonding triangle diagram would $SbCl_5$ be found?



2 Two elements that have very similar electronegativity values chemically combine. The compound they form is plotted on a bonding triangle diagram.

Which statement about the compound must be correct?

A The compound has a low conductivity compared to a metal.

B The covalent character is high.

C The ionic character is high.

D The metallic character is low.

3 Which is the correct composition of the alloy stainless steel?

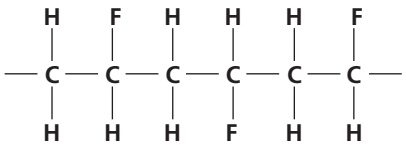
A iron, carbon and silver

B iron, carbon and lead

C iron, carbon and chromium

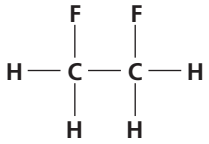
D iron and carbon only

4 The diagram shows three repeat units in the structure of an addition polymer.

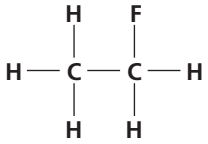


Which alkene monomer is used to make this polymer?

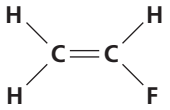
A



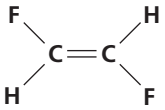
B



C



D



5 Which row in the table describes the formation of a polymer?

	monomer	polymer
A	ethane	poly(ethane)
B	ethene	poly(ethene)
C	ethane	poly(ethene)
D	ethene	poly(ethane)

6 Which statement about polymers is correct?

A All addition polymers are biodegradable.

B All condensation polymers can be hydrolysed to release amino acids.

C The formation of all addition polymers produces only one product.

D All condensation polymers are naturally occurring.

7 In which row are the monomer and polymer chain correctly matched?

	Monomer	Polymer
A	$CH_3CH{=}CHCH_3$	$-CH(CH_3)-CH(CH_3)-CH(CH_3)-CH(CH_3)-$
B	$CH_2{=}CHF$	$-CHC-CHF-CHF-CHF-$
C	$CH_3CH{=}CH_2$	$-CH_3-CH-CH_2-CH_3-CH-CH_2-$
D	$CH_2{=}CHCH_2CH_3$	$-CH_2-CH_2-CH_2-CH(CH_2CH_3)-$

(Questions 8–11 HL only)

8 Nylon-6,6 is a condensation polymer synthesized from hexanedioic acid and 1,6-diamino hexane. What type of linkage is present?

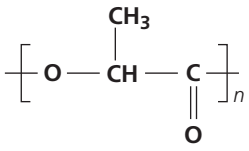
A carboxyl

B amine

C ester

D amide

9 State the name of the linkage present in polylactic acid whose repeating unit is shown below.

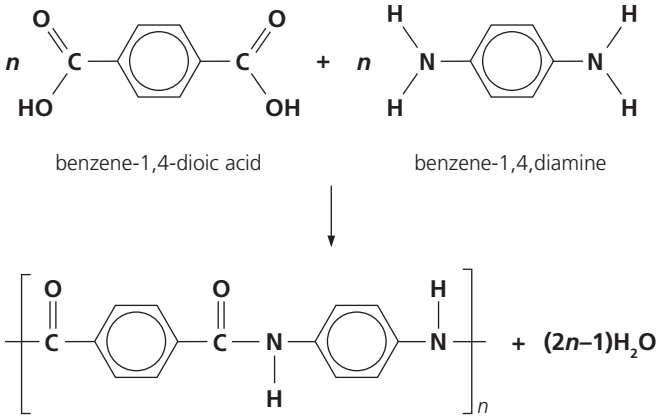


A ester
B amide
C peptide
D carbonyl

10 Which two molecules have the same linkages bonding the monomers together?

A nylon and maltose
B nylon and protein
C Terylene and maltose
D Terylene and protein

11 The equation below shows the synthesis of Kevlar.



Which row describes Kevlar?

	Type of polymerization	Type of polymer
A	condensation polymerization	polyester
B	condensation polymerization	polyamide
C	addition polymerization	polyester
D	addition polymerization	polyamide

Paper 2

1 a Define the term electronegativity. [2]

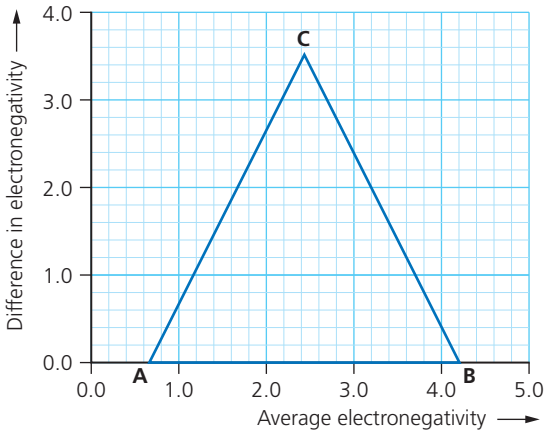
b Explain why elements with low electronegativities can conduct electricity. [2]

c i Explain in terms of electronegativity why ionic bonding results from the transfer of one or more electrons from one atom to another. [1]

ii Explain in terms of electronegativities and ionization energy why this transfer takes place. [1]

2 The following substances are all hard materials used in body armour: AlN, B_4C, SiC, Si_3N_4, and WC.

a Plot labelled points for each compound on the bonding triangle diagram and deduce the type of bonding they are predicted to exhibit. [5]



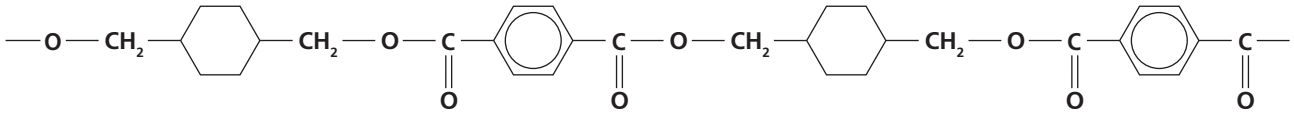
b Compare the degree of metallic bonding in silicon carbide, SiC, with silicon nitride, Si_3N_4. [1]

c Suggest one limitation of using the bonding triangle diagram to predict bonding type. [1]

3 Describe how, in general, alloying improves the usefulness of metals and how strength is increased in terms of structure. Use diagrams in your answers. No specific alloys need to be mentioned. [6]

(Questions 4–5 HL only)

4 Kodel is a polymer used in fabrics and its structure shown below

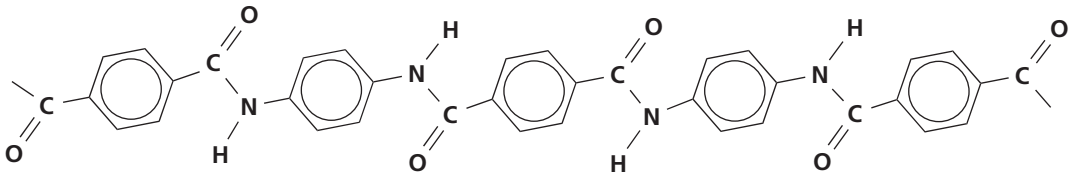


a Draw the two monomers used to synthesize Kodel. [2]

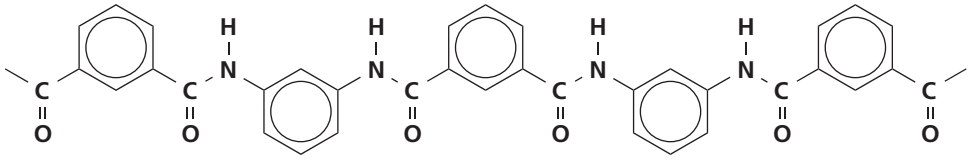
b Explain why this type of polymer is known as a condensation polymer. [1]

c Identify the linkage in the polymer. [1]

5 The polymer Kevlar is used to make bulletproof vests and cords to reinforce the walls of car tyres. Part of the structure of a Kevlar molecule and that of a related condensation polymer molecule called Nomex are shown below.



Kevlar



Nomex

a Kevlar and Nomex are aromatic polyamides. Explain why these molecules can be described as aromatic. [1]

b Draw the structural formulas of the two monomers from which Kevlar is made. [2]

c Draw the structural formulas of the two monomers from which Nomex is made. [2]

d One reason why Kevlar is so strong is because of the close packing of the polymer molecules. State the type of bonds that operate between adjacent polymer chains. [1]

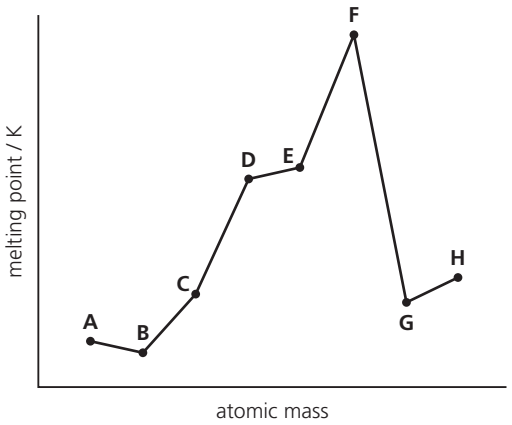
e Nomex has a lower tensile strength than Kevlar. Suggest a reason why. [2]

f Kevlar is insoluble in most solvents but dissolves in concentrated sulfuric acid. Suggest how this happens. [2]

S3.1 The periodic table: classification of elements

Paper 1

1 Which statement is correct?



A Element D forms an acidic oxide.

B Element E does not conduct electricity.

C Element H forms molecular covalent oxides with oxidation states of +4 and +6 respectively.

D Element C is a gas which is chemically inert at room temperature.

2 Which of the following properties would increase from the atoms sodium to chlorine across period 3?

I electronegativity

II nuclear charge

III atomic radius

A I and II only

B I and III only

C II and III only

D I, II and III

3 Which properties of the group 17 elements from fluorine to bromine decrease down the group?

A electronegativity and ionic radius

B boiling point and ionic radius

C oxidizing strength and electronegativity

D oxidizing strength and melting point

4 Which metal is in the f-block of the periodic table?

A Sr

B Sm

C Pb

D Tc

5 What are the oxidation states of the individual elements in a molecule of phosphoric(V) acid, H_3PO_4?

	hydrogen	phosphorus	oxygen
A	+3	+5	–8
B	+3	+1	–4
C	+1	+5	–2
D	+1	+3	–2

6 Which compound has iron in a different oxidation state from the others?

A $Fe(OH)_3$

B Fe_2O_3

C $Fe_2(SO_4)_3$

D FeO_3

7 In which reaction does chromium undergo a change in oxidation state?

A $Cr_2O_3 + 6HCl \rightarrow 2CrCl_3 + 3H_2O$

B $Cr_2(SO_4)_3 + 6NaOH \rightarrow 2Cr(OH)_3 + 3Na_2SO_4$

C $2Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + Na_2SO_4 + H_2O$

D $Na_2Cr_2O_7 + 4H_2SO_4 + 6HCl \rightarrow Cr_2(SO_4)_3 + Na_2SO_4 + 7H_2O + 3Cl_2$

8 Which oxides produce a solution with a pH of less than 7 when added to water?

I SiO_2

II SO_3

III P_4O_6

A I and II only

B I and III only

C II and III only

D I, II and III

9 Which of the following electron configurations could represent a transition metal atom?

A $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3\ 4s^2$

B $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$

C $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^3$

D $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

10 Which one of the following ion or atom has the electron configuration

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$?

A Mn

B Co^{2+}

C Fe^{3+}

D Cr^{2+}

11 In which one of the following does the underlined element exhibit an oxidation state that is different from the others?

A $\underline{Mn}_2O_7$

B $\underline{Cl}O_4^-$

C $H_5\underline{I}O_6$

D $\underline{Cl}O_2$

12 Which compound is **not** a product of the reaction between an oxide of a period 3 element and water?

A NaOH

B $Al(OH)_3$

C H_2SO_3

D H_3PO_4

13 Which element in period 3 is not correctly described?

	element	bonding	structure
A	chlorine	covalent	simple molecular
B	sulfur	covalent	simple molecular
C	silicon	covalent	simple molecular
D	sodium	metallic	giant metallic

14 What is the oxidation state of iron in the compound potassium ferrate(VI), K_2FeO_4?

A +6

B −6

C 6−

D 6+

15 Tellerium is an element in the same group as sulfur. Which of the following would be the correct formula for telluric(VI) acid?

A H_2Te

B H_2TeO_2

C H_2TeO_4

D H_2TeO_3

16 An element M of mass number 40 has the electron configuration

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

Which statement regarding this element is not correct?

A It belongs to Group 2 of the periodic table.

B The nucleus of the atom has 20 neutrons.

C It belongs to period 4 of the periodic table.

D The formula of its oxide is MO_2.

17 What are the oxidation states of chlorine in the oxyacids HOCl, $HClO_3$ and $HClO_4$?

A −1, +5 and +7

B −1, −5 and +7

C +1, +3 and +4

D +1, +5 and +7

18 The ionic compound $YBa_2Cu_3O_7$ is a superconductor. In this compound, the oxidation state of yttrium (an f-block metal) is +3, barium is +2 and oxygen is –2.

What could be the oxidation states of the three copper species?

A +3, +3, +3

B +2, +2, +3

C +1, +2, +3

D 0, +2, +3

19 Applying IUPAC rules, what is the name of CeO_2?

A cerium(I) oxide

B cerium (II) oxide

C cerium (III) oxide

D cerium (IV) oxide

20 Which of the following gases does not result in acid rain?

A SO_3

B CO_2

C NO

D NO_2

21 How do the following properties change down group 18 of the periodic table?

	Ionization energy	Ionic radius
A	increases	increases
B	increases	decreases
C	decreases	increases
D	decreases	decreases

22 What happens when an aqueous solution of chlorine is added to an aqueous solution of caesium iodide?

A No reaction occurs because chlorine is less electronegative than iodine.

B Chlorine molecules are oxidized to chloride ions.

C Iodide ions are oxidized to iodine molecules.

D A purple precipitate of iodine is formed.

23 Which one of the following series represents the correct size order for the various iodine species (in the gas phase)?

A $I < I^- < I^+$

B $I < I^+ < I^-$

C $I^+ < I < I^-$

D $I^- < I < I^+$

(Questions 24–30 HL only)

24 The thiocyanate ion is a conjugate base of thiocyanic acid, HSCN. What is the value of x in the chemical formula of the iron(III) complex ion, $[Fe(H_2O)_5SCN]^x$?

A 3+ **B** 2+ **C** 2− **D** 1−

25 Which one of the following complex ions would be expected to be colourless?

A $[Sc(H_2O)_6]^{3+}$

B $[Cr(H_2O)_5Br]^{2+}$

C $[Fe(CN)_6]^{3-}$

D $[CuI_4]^{2-}$

26 Which is an essential feature of a ligand?

A a negative charge

B an odd number of electrons

C the presence of two or more covalently bonded atoms

D the presence of an available non-bonding (lone) pair of electrons

27 Which combination is correct for the complex ion in the coordination compound $[Co(NH_3)_4(H_2O)Br]Cl$?

	Oxidation state of cobalt	Shape of the complex ion	Overall charge of the complex ion
A	+2	octahedral	+2
B	+3	square planar	–1
C	+2	octahedral	+1
D	+2	tetrahedral	+1

28 Potassium manganate(VII) is purple in colour. In which region of the visible spectrum does it mainly absorb?

A red

B purple

C blue

D green

29 When attracted by a strong magnet, some species are able to exhibit paramagnetism. Such species contain unpaired electrons which are able to spin in a way which aligns parallel to the magnetic field.

Which of the following species in the ground state is able to exhibit paramagnetism?

1 O

2 Al^+

3 Ti^{2+}

4 Cu^+

A 1 and 3 only

B 2 and 4 only

C 2, 3 and 4 only

D 1, 3 and 4 only

30 Which statements are correct for the complex ion $[Cu(CN)_2]^-$?

I The oxidation state of copper in the complex ion is +1.

II The coordination number of the copper ion is 2.

III Cyanide ions are behaving as ligands.

A I and II only

B I and III only

C II and III only

D I, II and III

Paper 2

1 Describe and explain the variation in the size (radius) of simple ions formed by the elements across period 3 from sodium (Na^+) to chloride (Cl^-). [6]

2 Physicists are trying to synthesize the element with atomic number 119, provisional symbol Z.

a State the ground state electron configuration for Z, showing only the valence shell electrons. [1]

b State whether Z would be a metal or a non-metal. Explain your answer in terms of electron configuration. [2]

c State whether on the basis of periodic trends why Z is expected to have the largest atomic radius in its group. Explain in terms of electronic structure. [2]

d State and explain how the melting point of Z would compare to the other elements in its group in the periodic table. [3]

e State the most likely oxidation state of Z in its compounds. [1]

f State whether the oxide of Z would be expected to be acidic, basic or amphoteric. [1]

3 Oxygen gas reacts with various period 3 elements.

Element X forms a white oxide that is soluble in cold water. Its chloride dissolves in water to give a neutral solution.

Element Y forms an oxide which has a trigonal planar geometry around the central atom.

1 mole of the oxide of element X is added to an aqueous solution containing the same amount of the oxide of element Y to form a neutral solution.

Given that X and Y are period 3 elements, identify element X and the oxide of element Y. State an equation to show the formation of the neutral solution. [3]

4 Magnesium oxide and silicon dioxide are used as refractory materials inside furnaces due to their high melting points. If a sample of one of the oxides was provided as a white powder, describe two chemical reactions that can be carried out to determine the identity of the unknown oxide sample. State the chemical equations for the two reactions. [3]

(Questions 5–6 HL only)

5 The following shows a series of reactions involving titanium compounds.

concentrated HC*l*

$$TiCl_4 \xrightarrow{\text{I}} [TiCl_6]^{2-} \text{ colourless solution} \xrightarrow{\text{II}} [Ti(H_2O)_6]^{3+} \text{ violet solution} \xrightarrow{\text{III}} [TiCl_6]^{3-} \text{ orange solution}$$

a Suggest the type of reaction for II and III. [2]

b Explain why a solution of $[TiCl_6]^{2-}$ is colourless but $[TiCl_6]^{3-}$ is orange. [2]

The formula relating energy gap between d orbitals, ΔE and wavelength, λ is given as $\Delta E = hc / \lambda$ where h is the Planck's constant and c is the speed of light.

c Use Table 14 in the data booklet to deduce the colours absorbed by $[Ti(H_2O)_6]^{3+}$ and $[TiCl_6]^{3-}$ and therefore identify which complex ion has the larger energy gap between the d orbitals. [2]

d Explain why titanium shows variable oxidation states. [2]

6 Answer the following questions about the complex $[RhCl_6]^{3-}$, where Rh is the transition element rhodium [Kr] $4d^8\ 4s^1$.

a Define the term *transition element*. [1]

b Deduce the oxidation state of rhodium in the complex ion. [1]

c Deduce the electron configuration of the metal cation. [1]

d Deduce the number of unpaired electrons present in the complex ion. [1]

e State the shape of the complex and show the arrangement of electrons. [2]

S3.2 Functional groups: classification of compounds

Paper 1

1 Which compound can exist as a pair of enantiomers (optical isomers)?

A CH_3CHFCH_3

B $CH_2FCHFCH_3$

C $CH_2FCHFCH_2F$

D $CHF_2CHFCHF_2$

2 In which homologous series of compound, in its general formula, is the ratio of hydrogen atoms to carbon atoms the highest?

A alcohols

B aldehydes

C carboxylic acids

D halogenoalkanes

3 Which one of the following organic compounds does not exist?

A an ester which is a structural isomer of a carboxylic acid, $C_3H_6O_2$

B a carboxylic acid which is a structural isomer of an ester, $C_2H_4O_2$

C an aldehyde which is a structural isomer of a ketone, C_3H_6O

D a ketone which is a structural isomer of an aldehyde, C_2H_4O

4 Which compound is a member of the same homologous series as 1-iodobutane?

A 1-iodohexane

B 1-chlorobutane

C 1-iodobut-1-ene

D 1,1-diodobutane

5 Which three compounds form part of a homologous series?

A C_2H_2, C_2H_4, C_2H_6

B CH_3OH, C_3H_7OH, $CH_3(CH_2)_5–OH$

C $CH_3(CH_2)_4OH$, $CH_3(CH_2)_2CH(OH)CH_3$, $CH_3CH(CH_3)(CH_2)_2OH$

D C_2H_5CHO, CH_3COCH_3, $CH_3(CH_2)_2OH$

6 What is the IUPAC name for $CH_3(CH_2)_4CHO$?

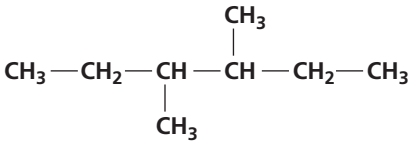
A hexan-1-ol

B 2-hexanone

C hexanal

D hexanoic acid

7 What is the name of this compound using the IUPAC rules?



A 2-ethyl-3-methylpentane

B 2,3-diethylbutane

C 3-methyl-4-ethylpentane

D 3,4-dimethylhexane

8 What is the general formula of alkenes?

A C_nH_{2n-2}

B C_nH_{2n}

C C_nH_{2n+2}

D C_nH_{2n+1}

9 Which one of the following is a ketone?

A $CH_3CH(OH)CH_2CH_2CH_3$

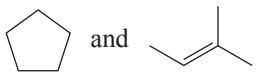
B $CH_3CH_2COCH_3$

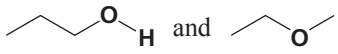
C $CH_3CH_2O(CH_2)_3CH_3$

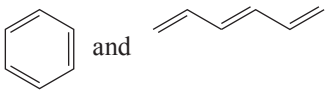
D $CH_3CH_2CH_2CHO$

10 In which pair are the compounds **not** structural isomers?

A. 

B. 

C. 

D. 

11 What is the number of structural isomers of C_4H_9I?

A 4

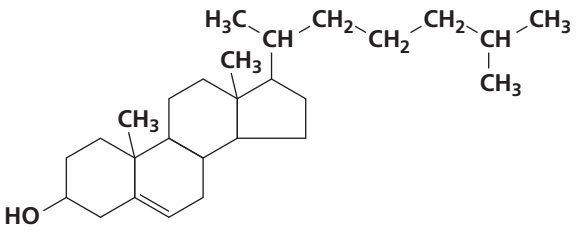
B 5

C 7

D 8

(Questions 12–22 HL only)

12 How many chiral centres are present in the cholesterol molecule?



A 9

B 8

C 7

D 6

13 How many signals (peaks) would be present in the ^{1}H NMR spectrum of $C(CH_3)_4$?

A 1

B 3

C 4

D 12

14 Which of the following compounds exhibit three signals (peaks) with an integration trace ratio of 3 :3 :2 in their low resolution ^{1}H NMR spectrum?

I $CH_3CH_2OCH_3$

II $CH_3CH(OH)CH_3$

III $CH_3CH_2COOCH_3$

A I and II only

B I and III only

C II and III only

D I, II and III

15 Which types of stereoisomers are shown by 2,4-dimethylhex-2-ene?

A enantiomers only

B *cis* and *trans* isomers

C *cis* and *trans* isomers and enantiomers

D neither *cis* and *trans* isomers nor enantiomers

16 What can be deduced from the infrared (IR) spectrum of an organic molecule?

A Number of hydrogen atoms

B Bonds and functional groups present

C Molar mass

D Number of hydrogen chemical environments

17 What is the ratio of areas under each signal in the ^{1}H NMR spectrum of 2-methylbutane?

A 6 :1 :5

B 1 :3 :3 :5

C 3 :3 :3 :1 :2

D 6 :1 :2 :3

18 An unknown compound X contains only carbon and hydrogen atoms. Its ^{1}H NMR spectrum shows a singlet signal only. Which compounds can X be?

I benzene

II 2,2-dimethylpropane

III ethene

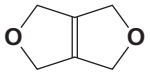
A I and II only

B I and III only

C II and III only

D I, II and III

19 How many signals (peaks) are observed in the ^{1}H NMR spectrum?



A 6

B 4

C 1

D 2

20 Given equimolar concentrations, which substance would produce the largest integral trace (strongest signal)?

A $Si(CH_3)_4$

B C_7H_{16}

C C_6H_6

D $(CH_3)_3CH$

21 Which molecule can show optical activity?

A CHBrCHF

B $CH_3CH_2CHFCH_2CH_3$

C $(CH_3)_2CBrF$

D $CH_3CH_2CH(CH_3)F$

22 Which compound exists as two *cis–trans* isomers?

A $CF_2=CF_2$

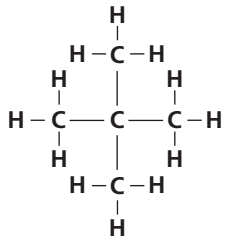
B $CH_2=CHF$

C CHF_2CH_2F

D CHF=CHF

Paper 2

1 The table gives the structure and boiling points of three organic compounds.

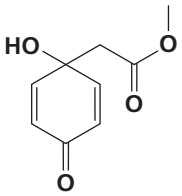
Name	Structure	Boiling point / °C
pentane	$CH_3CH_2CH_2CH_2CH_3$	36
2,2-dimethylpropane		10
propane	$CH_3CH_2CH_3$	−42

a Explain why the boiling point of pentane is higher than that of propane. [2]

b Explain why the boiling point of pentane is higher than 2,2-dimethylpropane. [2]

c State the type of isomerism exhibited by pentane and 2,2-dimethylpropane. [2]

2 Jacaranone is a natural plant product, which is used in cancer treatments. Its structure is given below as a skeletal formula.



a Deduce its molecular formula. [1]

b State the names of four functional groups present in the molecule. [2]

c State and explain what class of alcohols the molecule belongs to. [2]

(Questions 3–7 HL only)

3 ^{1}H NMR and IR spectroscopy both involve the absorption of electromagnetic radiation.

a Identify the regions of the electromagnetic spectrum used in ^{1}H NMR spectroscopy. [1]

b State which of the two techniques listed involves higher frequency radiation. [1]

c Explain why IR spectroscopy cannot be used to distinguish between propan-1-ol and propan-2-ol for wavenumbers outside the fingerprint region. [1]

d Describe how the ^{1}H NMR spectra of propan-1-ol and propan-2-ol will be different. [2]

4 ^{1}H NMR spectroscopy can be used to obtain information about the structure of molecules. The ^{1}H NMR spectrum of a compound with the formula $C_4H_8O_2$ exhibits three major peaks. The chemical shifts, areas and splitting patterns of the peaks are given below.

Chemical shift / ppm	Peak area	Splitting pattern
0.9	3	triplet
2.0	2	quartet
4.1	3	singlet

a State the information that can be obtained from the number of signals (peaks) and splitting pattern. [2]

b Use chemical shifts from the data booklet and the information given above, to deduce the structure of the compound. Explain your answer. [3]

5 There are four structural isomers that are alcohols with the formula C_4H_9OH.

a Explain why the infrared spectra of all four alcohols show very similar absorptions around 3350 cm^{-1} and 2900 cm^{-1}. [2]

b Describe how these alcohols can be distinguished using their infrared spectra. [1]

c Explain why the mass spectra of all four alcohols show a peak at $m/z = 74$. [1]

d Suggest the formulas of the fragments formed from C_4H_9OH with the following m/z values:

i $m/z = 57$

ii $m/z = 45$ [2]

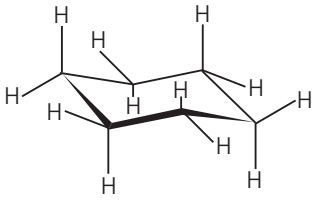
e The numbers of signals (peaks), and the areas under them, in the ^{1}H NMR spectra of these alcohols can be used to identify them.

i Explain why the ^{1}H NMR spectrum of $(CH_3)_2CHCH_2OH$ has four signals (peaks). Predict the ratio of the areas under the peaks. [2]

ii Deduce the structure of the alcohol whose ^{1}H NMR spectrum has two signals (peaks) with areas in the ratio 9:1. [1]

6 Deduce and draw the high-resolution ^{1}H NMR spectrum of propan-1-ol and explain why two triplets at different chemical shifts are observed in this spectrum. [5]

7 Cycloalkanes are saturated hydrocarbons. The diagram below shows the structure and shape of cyclohexane, C_6H_{12}.



The table below summarizes the shapes, interior angles and bond angles for the first four cycloalkanes.

Interior angles of regular polygons		
polygon	***no. of vertices, n***	***interior angle / °***
triangle	3	60
square	4	90
pentagon	5	108
hexagon	6	120

Bond angle deformation of cycloalkanes		
compound	***no. of C, n***	***bond angle / °***
cyclopropane	3	60
cyclobutane	4	90
cyclopentane	5	108
cyclohexane	6	109.5

a State the meaning of the terms:

i homologous series [2]

ii hydrocarbon [1]

iii saturated [1]

b Deduce the general formula for cycloalkanes. [1]

Some of the cycloalkanes show ring strain. This is a measure of the deviation of a bond angle from its normal tetrahedral value (109.5 °); the greater the deviation the higher the value of ring strain and the more unstable the molecule.

Number of carbon atoms (n) in cycloalkane	Ring strain / kJ mol^{-1}
3	115
4	109
5	27
6	0
7	27
8	42
9	54
10	50
15	6

c Plot a graph of ring strain against number of $-CH_2-$ groups. [2]

d With reference to the graph, describe how ring strain is affected by the number of $-CH_2-$ groups in the cycloalkanes. [3]

e Identify the most stable and least stable of the C_3 to C_{15} cycloalkanes. [2]

f State what is unusual about the bond angle in cyclohexane. Suggest a reason to account for this observation. [2]

R1.1 Measuring enthalpy changes

Paper 1

1 Which of the following must have a negative value for a reaction to be exothermic?

A enthalpy change

B entropy change

C equilibrium constant

D standard cell potential

2 Which of the following reactions would you expect to have the most exothermic enthalpy change?

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

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

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

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

3 A temperature change of 6.4 °C is measured when adding 5.0 cm^3 of 1.0 mol dm^{-3} hydrochloric acid to 5.0 cm^3 of 1.0 mol dm^{-3} potassium hydroxide. Both solutions had the same initial temperature. For the resulting mixture assume the density is 1.0 g cm^{-3} and the specific heat capacity is 4.18 J g^{-1} K^{-1}.

What is the change in enthalpy of the reaction in kJ mol^{-1}?

A $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005}$

B $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 2}$

C $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 1000}$

D $\Delta H^{\ominus} = -\dfrac{10 \times 4.18 \times 6.4}{1.0 \times 0.005 \times 2 \times 1000}$

4 When equal masses of X and Y absorb the same amount of heat energy, their temperatures rise by 5 °C and 10 °C respectively. Which is correct?

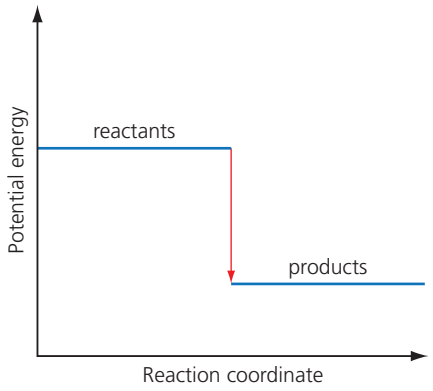
A The specific heat capacity of X is twice that of Y.

B The specific heat capacity of X is half that of Y.

C The specific heat capacity of X is one fifth that of Y.

D The specific heat capacity of X is the same as Y.

5 The potential energy profile of a reaction is shown.



What can be determined about stability and energy change from the potential energy profile shown?

	More stable	Reaction
A	reactants	exothermic
B	reactants	endothermic
C	products	exothermic
D	products	endothermic

6 A sample of an ideal gas is cooled by 20 K. Which of the following is always true?

A The gas has increased its volume at constant pressure.

B The particles have less average kinetic energy.

C The gas has condensed into a liquid.

D The pressure of the gas has increased at constant volume.

7 The table shows the specific heat capacities of four metals.

Metal	Specific heat capacity (J g^{-1} K^{-1})
copper	0.385
magnesium	1.02
mercury	0.138
lead	0.129

If 100 kJ of heat energy is absorbed by 10.0 g samples of each of the metals above, which are all at 25 °C, which metal will have the lowest temperature?

A copper

B magnesium

C mercury

D lead

8 Consider the following reaction.

$H_2O\,(g) \rightarrow H_2\,(g) + \frac{1}{2}O_2\,(g) \qquad \Delta H^{\ominus} = x\,kJ\,mol^{-1}$

What is the enthalpy change of:

$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(g)$

A $\Delta H^{\ominus} = -x\,kJ\,mol^{-1}$

B $\Delta H^{\ominus} = 2x\,kJ\,mol^{-1}$

C $\Delta H^{\ominus} = -\frac{1}{2}x\,kJ\,mol^{-1}$

D $\Delta H^{\ominus} = -2x\,kJ\,mol^{-1}$

9 Which change of state is exothermic?

A $CO_2(s) \rightarrow CO_2(g)$

B $H_2O(l) \rightarrow H_2O(g)$

C $NH_3(g) \rightarrow NH_3(l)$

D $Fe(s) \rightarrow Fe(l)$

10 When 25.0 cm^3 0.100 $mol\,dm^{-3}$ NaOH (aq) is mixed with 25.0 cm^3 0.100 $mol\,dm^{-3}$ HCl (aq) at the same temperature, a temperature rise, ΔT, is recorded. What is the expression, in $kJ\,mol^{-1}$, for the enthalpy of neutralization? (Assume the density of the mixture = 1.00 $g\,cm^{-3}$ and its specific heat capacity = 4.18 $kJ\,kg^{-1}\,K^{-1}$.)

A $-\frac{25.0 \times 4.18 \times \Delta T}{50.0 \times 0.100}$

B $-\frac{25.0 \times 4.18 \times \Delta T}{25.0 \times 0.100}$

C $-\frac{50.0 \times 4.18 \times \Delta T}{50.0 \times 0.100}$

D $-\frac{50.0 \times 4.18 \times \Delta T}{25.0 \times 0.100}$

11 Which statement is correct for this reaction?

$Fe_2O_3\,(s) + 3CO\,(g) \rightarrow 2Fe\,(s) + 3CO_2\,(g) \quad \Delta H^{\ominus} = -26.6\,kJ$

A 13.3 kJ are released for every mole of Fe produced.

B 26.6 kJ are absorbed for every mole of Fe produced.

C 53.2 kJ are released for every mole of Fe produced.

D 26.6 kJ are released for every mole of Fe produced.

12 Which expression gives the mass, in g, of ethanol required to produce 683.5 kJ of heat upon complete combustion? (molar mass for ethanol = 46.0 $g\,mol^{-1}$)

$C_2H_5OH\,(l) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(l) \quad \Delta H^{\ominus} = -1367\,kJ\,mol^{-1}$

A $\frac{683.5}{1367 \times 46.0}$

B $\frac{1367}{683.5 \times 46.0}$

C $\frac{683.5 \times 46.0}{1367}$

D $\frac{1367 \times 46.0}{683.5}$

13 Which of the following is true for all endothermic reactions?

A The reaction has a negative enthalpy change.

B The reaction occurs slowly.

C There is a transfer of energy from the surroundings to the system.

D The surroundings will increase in temperature.

14 Which of the following is not implied by the $\ominus$ symbol?

A reacting 1 mole of a compound

B gas pressure of 1 bar or 10^5 pascal

C the most stable allotrope under standard conditions

D concentration of 1.0 $mol\,dm^{-3}$ (for solutions).

15 400 J of energy is transferred to two 1 kg blocks of different metals. One block of metal is made from copper and the other aluminium. The specific heat capacities of copper and aluminium are different. Which of the following statements is true?

A The blocks will increase in temperature by the same amount.

B The blocks will decrease in temperature by the same amount.

C The block with the highest specific heat capacity will have the largest temperature increase.

D The block with the lowest specific heat capacity will have the largest temperature increase.

16 Consider the following reaction.

$2C_2H_4\,(g) + 2H_2O\,(g) \rightarrow 2C_2H_5OH\,(g) = y\,kJ\,mol^{-1}$

What will the enthalpy change of this reaction be?

$C_2H_5OH\,(g) \rightarrow C_2H_4\,(g) + H_2O\,(g) \qquad = ?\ kJ\,mol^{-1}$

A $+\frac{1}{2}y$ **B** $-\frac{1}{2}y$ **C** $-y$ **D** $+y$

Paper 2

1 a Explain what is meant by the term *standard enthalpy of reaction*. [3]

b Describe an experiment to determine the enthalpy change of the reaction between dilute hydrochloric acid and aqueous sodium hydroxide. Show how the value of would be calculated from the data obtained. [9]

2 In aqueous solution, lithium hydroxide and hydrochloric acid react as follows.

$LiOH\,(aq) + HCl\,(aq) \rightarrow LiCl\,(aq) + H_2O\,(l)$

The data below is from an experiment to determine the standard enthalpy change of this reaction.

$50.0\,cm^3$ of a $0.500\,mol\,dm^{-3}$ solution of LiOH was mixed rapidly in a glass beaker with $50.0\,cm^3$ of a $0.500\,mol\,dm^{-3}$ solution of HCl.

Initial temperature of each solution = 20.6 °C

Final temperature of the mixture = 24.1 °C

a State, with a reason, whether the reaction is exothermic or endothermic. [1]

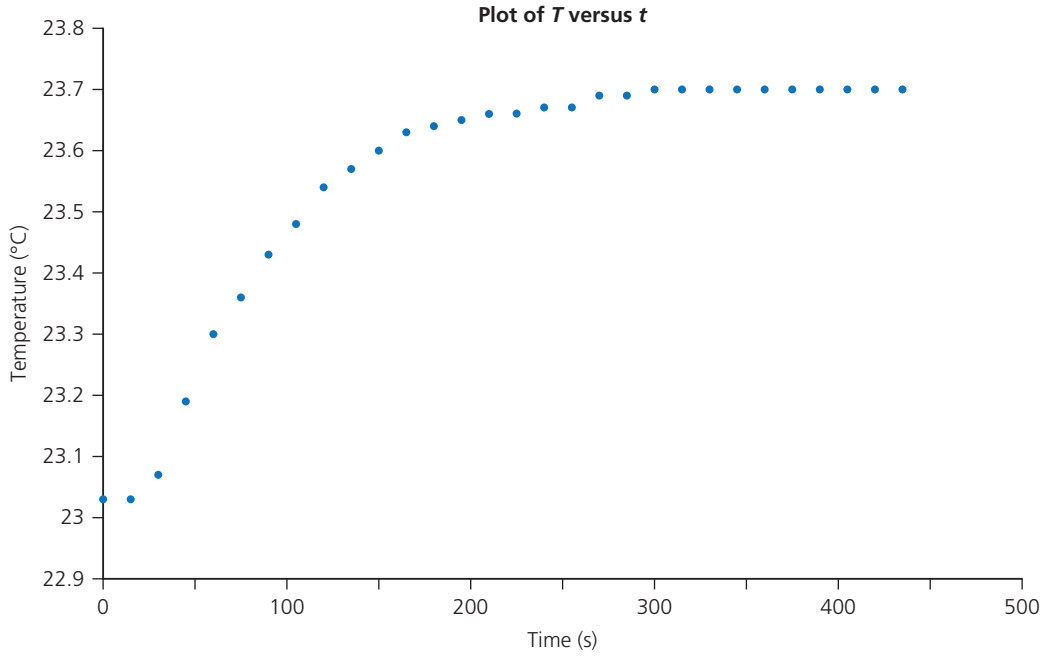
b Explain why the solutions were mixed rapidly. [1]

c Calculate the enthalpy change of this reaction in $kJ\,mol^{-1}$. Assume that the specific heat capacity of the solution is the same as that of water. [4]

d Identify the major source of error in the experimental procedure described above. Explain how it could be minimized. [2]

e The experiment was repeated but with an HCl concentration of $0.520\,mol\,dm^{-3}$ instead of $0.500\,mol\,dm^{-3}$. State and explain what the temperature change would be. [2]

3 The data below is from an experiment used to measure the enthalpy change for the combustion of sucrose (common table sugar), $C_{12}H_{22}O_{11}$ (s). The time–temperature data was taken from a data-logging software program.



Mass of sample of sucrose, $m = 0.4835\,g$

Heat capacity of the system, $C_{system} = 10.114\,kJ\,K^{-1}$

a Calculate ΔT for the water surrounding the chamber in the calorimeter. [1]

b Determine the amount, in moles, of sucrose. [1]

c **i)** Calculate the enthalpy change for the combustion of 1 mole of sucrose. [2]

ii) The literature value for the combustion of sucrose is $-5.6 \times 10^3\,kJ\,mol^{-1}$. Calculate the percentage error in your calculated value. [1]

d A hypothesis is suggested that TNT, 2-methyl-1,3,5-trinitrobenzene, is a powerful explosive because it has:

- a large enthalpy of combustion
- a high reaction rate
- a large volume of gas generated upon combustion.

Use you answer in part (c)(i) and the following data to evaluate this hypothesis. [3]

Equation for combustion	Relative rate of combustion	Enthalpy of combustion / kJ mol^{-1}
$C_{12}H_{22}O_{11}$ (s) + $12O_2$ (g) → $12CO_2$ (g) + $11H_2O$ (g)	low	−5600
$2C_7H_5N_3O_6$ (s) → $7CO_2$(g) + 7C (s) + $5H_2O$ (g) + $3N_2$ (g)	high	−3406

Higher Level Paper 2, IB Specimen Paper 2009, Section A, Q1

R1.2 Energy cycles in reactions

Paper 1

1 Which change of state is exothermic?

A $CO_2\,(s) \rightarrow CO_2\,(g)$

B $H_2O\,(l) \rightarrow H_2O\,(g)$

C $NH_3\,(g) \rightarrow NH_3\,(l)$

D $Fe(s) \rightarrow Fe(l)$

2 The C=C bond has a bond length of 134 pm and an average bond enthalpy of 614 kJ mol^{-1}. Which values would be most likely for the C–C bond?

	Bond length / pm	Average bond enthalpy / kJ mol^{-1}
A	154	346
B	154	780
C	116	346
D	116	780

3 Which equation represents the average bond enthalpy of the C–H bond in CH_4?

A $CH_4\,(g) \rightarrow CH_3\,(g) + H\,(g)$

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

C $CH_4\,(g) \rightarrow CH_3\,(g) + \frac{1}{2}H_2\,(g)$

D $CH_4\,(g) \rightarrow C\,(g) + 4H\,(g)$

4 Which statement is correct for this reaction

$Fe_2O_3\,(s) + 3CO\,(g) \rightarrow 2Fe\,(s) + 3CO_2\,(g) \quad \Delta H = -26.6\,kJ$

A 53.2 kJ are released for every mole of Fe produced.

B 26.6 kJ are absorbed for every mole of Fe produced.

C 13.3 kJ are released for every mole of Fe produced.

D 26.6 kJ are released for every mole of Fe produced.

5 The enthalpy changes for two reactions are:

$Br_2\,(l) + F_2\,(g) \rightarrow 2BrF\,(g) \qquad \Delta H = m\,kJ$

$Br_2\,(l) + 3F_2\,(g) \rightarrow 2BrF_3\,(g) \qquad \Delta H = n\,kJ$

What is the enthalpy change for the following reaction?

$BrF_3\,(g) \rightarrow BrF\,(g) + F_2\,(g)$

A $m - n$

B $-m + n$

C $\frac{1}{2}(-m + n)$

D $\frac{1}{2}(m - n)$

6 What is the enthalpy change, in kJ mol^{-1}, of the following reaction?

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

Bond	Bond enthalpy / kJ mol^{-1}
N≡N	945
H–H	436
N–H	391

A $(6 \times 391) - [(3 \times 436) + 945]$

B $(3 \times 391) - (436 + 945)$

C $-[(3 \times 436) + 945] + (3 \times 391)$

D $-(6 \times 391) + [(3 \times 436) + 945]$

7 Which expression gives the enthalpy change, ΔH, for the thermal decomposition of calcium carbonate?

$CaCO_3\,(s) + 2HCl \rightarrow CaCl_2\,(aq) + H_2O\,(l) + CO_2\,(g) \quad \Delta H_1$

$CaO\,(s) + 2HCl \rightarrow CaCl_2\,(aq) + H_2O\,(l) \quad \Delta H_2$

A $\Delta H = \Delta H_1 - \Delta H_2$

B $\Delta H = 2\Delta H_1 - \Delta H_2$

C $\Delta H = \Delta H_1 - 2\Delta H_2$

D $\Delta H = \Delta H_1 + \Delta H_2$

8 In which order does the oxygen–oxygen bond enthalpy increase?

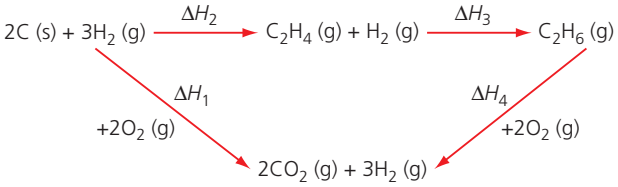
A $H_2O_2 < O_2 < O_3$

B $H_2O_2 < O_3 < O_2$

C $O_2 < O_3 < H_2O_2$

D $O_3 < H_2O_2 < O_2$

9 Which combination will give you the enthalpy change for the hydrogenation of ethene to ethane, ΔH_3?



A $\Delta H_2 + \Delta H_1 - \Delta H_4$

B $\Delta H_2 - \Delta H_4 + \Delta H_1$

C $-\Delta H_2 + \Delta H_1 - \Delta H_4$

D $-\Delta H_2 - \Delta H_1 + \Delta H_4$

(Questions 10–17 HL only)

10 Hydrazine reacts with oxygen.

$N_2H_4\,(l) + O_2\,(g) \rightarrow N_2\,(g) + 2H_2O\,(l)$ $\quad \Delta H^{\ominus} = -623\,kJ\,mol^{-1}$

What is the standard enthalpy of formation of N_2H_4 (l) in $kJ\,mol^{-1}$? The standard enthalpy of formation of H_2O (l) is −286 kJ.

A −623 – 286

B −623 + 572

C −572 + 623

D −286 + 623

11 What is the enthalpy of combustion of urea, $(NH_2)_2CO$, in $kJ\,mol^{-1}$?

$CO(NH_2)_2\,(s) + \frac{3}{2}O_2\,(g) \rightarrow CO_2\,(g) + N_2\,(g) + 2H_2O\,(l)$

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
CO_2 (g)	−394
$CO(NH_2)_2$ (s)	−333
H_2O (l)	−286

A (−333) − (−394) −2 × (−286)

B $(-394) + 2 \times (-286) - \frac{3}{2} \times (-333)]$

C (−394) + 2 × (−286) + (−333)

D (−394) + 2 × (−286) − (−333)

12 What is the enthalpy change of the reaction?

$C_6H_{14}\,(l) \rightarrow C_2H_4\,(g) + C_4H_{10}\,(g)$

	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
C_6H_{14} (l)	−4163
C_2H_4 (g)	−1411
C_4H_{10} (g)	−2878

A + 1411 + 2878 + 4163

B + 1411 − 2878 – 4163

C + 1411 + 2878 – 4163

D − 1411 − 2878 + 4163

13 Consider the following equations:

$2Al\,(s) + \frac{3}{2}O_2\,(g) \rightarrow Al_2O_3\,(s) \quad \Delta H^{\ominus} = -1670\,kJ\,mol^{-1}$

$Mn\,(s) + O_2\,(g) \rightarrow MnO_2\,(s) \quad \Delta H^{\ominus} = -520\,kJ\,mol^{-1}$

What is the standard enthalpy change, in $kJ\,mol^{-1}$, of the reaction below?

$4Al\,(s) + 3MnO_2\,(s) \rightarrow 2Al_2O_3\,(s) + 3Mn\,(s)$

A −1670 + 520

B $(\frac{3}{2} \times -1670) + (3 \times 520)$

C (2 × −1670) + (3 × −520)

D (2 × −1670) – (3 × −520)

14 Which equation shows the enthalpy of formation, $\Delta H_f^{\ominus}$, of ethanol?

A $2C\,(s) + 3H_2\,(g) + \frac{1}{2}O_2\,(g) \rightarrow C_2H_5OH\,(g)$

B $4C\,(s) + 6H_2\,(g) + O_2\,(g) \rightarrow 2C_2H_5OH\,(g)$

C $2C\,(s) + 3H_2\,(g) + \frac{1}{2}O_2\,(g) \rightarrow C_2H_5OH\,(l)$

D $4C\,(s) + 6H_2\,(g) + O_2\,(g) \rightarrow 2C_2H_5OH\,(l)$

15 Which ionic compound has the largest value of lattice enthalpy?

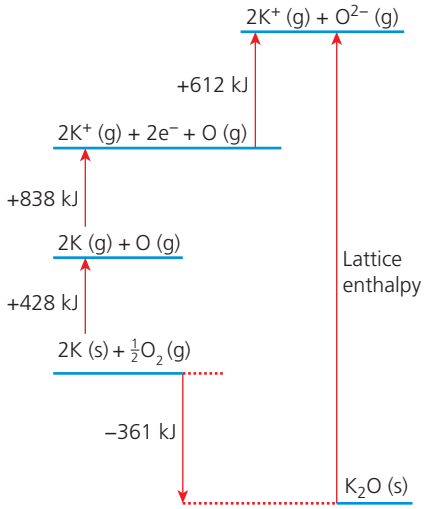
A MgS

B MgO

C $CaBr_2$

D NaF

16 The Born–Haber cycle for potassium oxide is shown below:



Which expression represents the lattice enthalpy in $kJ\,mol^{-1}$?

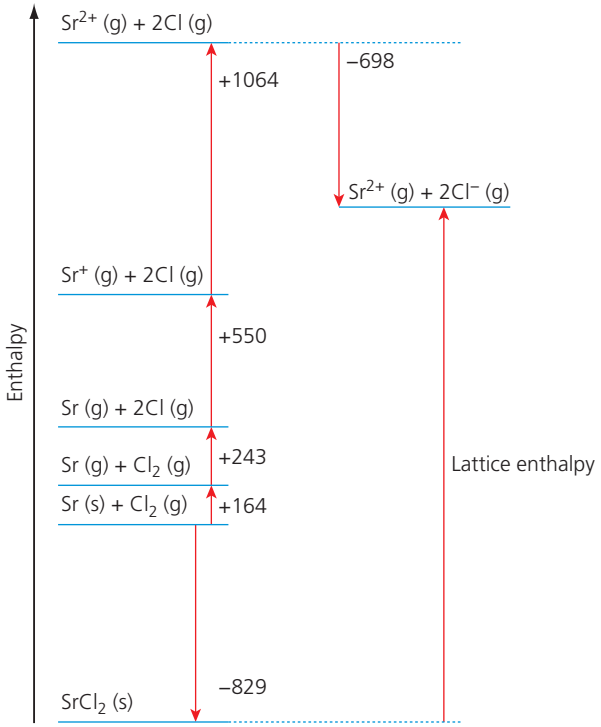
A –361 + 428 + 838 + 612

B –(–361) + 428 + 838 + 612

C –361 + 428 + 838 – 612

D –(–361) + 428 + 838 – 612

17 Which value represents the lattice enthalpy, in kJ mol^{-1}, of strontium chloride, $SrCl_2$?



A –(–829) + 164 + 243 + 550 + 1064 – (–698)

B –829 + 164 + 243 + 550 + 1064 – 698

C – (–829) + 164 + 243 + 550 + 1064 – 698

D –829 + 164 + 243 + 550 + 1064 – (–698)

Paper 2

1 In December 2010, researchers in Sweden announced the synthesis of N,N-dinitronitramide, $N(NO_2)_3$. They speculated that this compound, more commonly called trinitramide, may have significant potential as an environmentally friendly rocket fuel oxidant.

a Methanol reacts with trinitramide to form nitrogen, carbon dioxide and water. Deduce the coefficients required to balance the equation for this reaction.

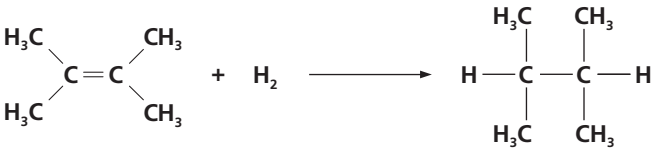
__ $N(NO_2)_3$ (g) + __ CH_3OH (l) → __ N_2 (g) + __ CO_2 (g) + __ H_2O (l) [1]

b Suggest **one** reason why trinitramide might be more environmentally friendly than other rocket fuel oxidants such as ammonium perchlorate (NH_4ClO_4). [1]

c Calculate the enthalpy change, in kJ mol^{-1}, when one mole of trinitramide decomposes to its elements, using bond enthalpies from section 12 of the data booklet. Assume that all the N–O bonds in this molecule have a bond enthalpy of 305 kJ mol^{-1}. [3]

Standard Level Paper 2, Time Zone 0, November 2013, Q4a–c

2 In the gas phase, A reacts with hydrogen to form D.



A D

a Use bond enthalpies given in section 12 of the IB Chemistry data booklet to determine the enthalpy change, in kJ mol^{-1}, of the reaction. State whether the reaction is exothermic or endothermic. [4]

b The standard enthalpy change of combustion of A is −4000 kJ mol^{-1}. Calculate the amount of A, in mol, that would have to be burned to raise the temperature of 1 dm^3 of water from 20 °C to 100 °C. [2]

Standard Level Paper 2, Time Zone 2, May 2014, Q6g(iii–iv)

(Questions 3–4 HL only)

3 Ethanol, C_2H_5OH, has many industrial uses.

a Define the term average bond enthalpy. [1]

b Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in $kJ\,mol^{-1}$, using the values given in section 13 of the *IB Chemistry data booklet*, assuming all reactants and products are gaseous. [4]

c Students can also measure the enthalpy of combustion of ethanol in a laboratory using calorimetry. Suggest the major source of systematic error in these procedures. [1]

d The standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, of propanoic acid is $-1527\,kJ\,mol^{-1}$. Determine the standard enthalpy change of formation of propanoic acid, in $kJ\,mol^{-1}$, using this information and data from section 13 of the *IB Chemistry data booklet*. [4]

Higher Level Paper 2, Time Zone 1, May 2015, Q5b(i–ii), c, f(i)

4 a Two chemistry students wished to determine the enthalpy of hydration of anhydrous magnesium sulfate. They measured the initial and the highest temperature reached when anhydrous magnesium sulfate, $MgSO_4(s)$, was dissolved in water. They presented their results in this table.

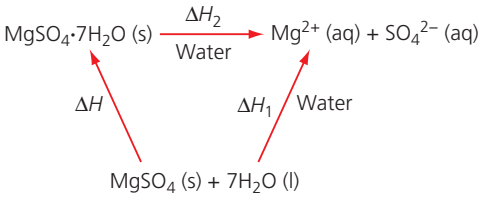
Mass of anhydrous magnesium sulfate / g	**3.01**
volume of water / cm^3	50.0
initial temperature / °C	17.0
highest temperature / °C	26.7

i) Calculate the amount, in mol, of anhydrous magnesium sulfate. [1]

ii) Calculate the enthalpy change, ΔH_1, for anhydrous magnesium sulfate dissolving in water, in $kJ\,mol^{-1}$. State your answer to the correct number of significant figures. [2]

b The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, $MgSO_4 \cdot 7H_2O$ (s), and 50 cm^3 of water. They found the enthalpy change, ΔH_2, to be $+18\,kJ\,mol^{-1}$.

The enthalpy of hydration of solid magnesium sulfate is difficult to determine experimentally, but can be determined using the diagram below.



i Determine the enthalpy change, ΔH, in $kJ\,mol^{-1}$, for the hydration of solid anhydrous magnesium sulfate, $MgSO_4$. [1]

ii The literature value for the enthalpy of hydration of anhydrous magnesium sulfate is $-103\,kJ\,mol^{-1}$. Calculate the percentage difference between the literature value and the value determined from experimental result, giving your answer to **one** decimal place. (If you did not obtain an answer for the experimental value in (c) i), then use a value of $-100\,kJ\,mol^{-1}$ but this is **not** the correct value.) [1]

c Another group of students experimentally determined an enthalpy of hydration of $-95\,kJ\,mol^{-1}$. Outline two reasons which may explain the variation between the experimental and literature values. [2]

Higher Level Paper 2, Time Zone 1, May 2014, Q1a–c

R1.3 Energy from fuels

Paper 1

1 Which of the following is produced during the complete combustion of a hydrocarbon?

A C

B CO_2

C CO

D H_2

2 When 11 g of an organic compound is burnt in an excess of oxygen, 22 g of carbon dioxide and 9.0 g of water are produced as the only products of combustion. What is the empirical formula of the organic compound?

A CH_2O

B CH_2

C C_4H_7O

D C_2H_4O

3 Which of the following compounds is most likely to have some incomplete combustion when burnt in oxygen?

A C_2H_5OH

B CH_3OH

C $C_6H_5CH_3$

D C_3H_8

4 What is the reducing agent in the combustion of glucose ($C_6H_{12}O_6$)?

A O_2

B CO_2

C $C_6H_{12}O_6$

D H_2

5 Which of the following is not a greenhouse gas?

A CH_4

B N_2

C CO_2

D H_2O

6 Which of the following is correct?

	CO_2 absorbs radiation in the	**CO_2 contributes to**	**CO_2 is a product of**
A	UV region	the greenhouse effect	fermentation
B	IR region	acid rain	photosynthesis
C	IR region	the greenhouse effect	photosynthesis
D	IR region	the greenhouse effect	fermentation

7 A balloon is filled with 200 cm^3 of a hydrocarbon mixture. The hydrocarbon mixture consists of 25% ethane and 75% propane. What is the minimum volume of pure oxygen needed for complete combustion?

A 925 cm^3

B 1000 cm^3

C 650 cm^3

D 700 cm^3

8 This question is about two fossil fuels, natural gas and coal. Select the row which shows the correct answers.

	Produces the most CO_2 per gram of fuel burnt	**Releases the most energy per gram of fuel burnt**
A	natural gas	coal
B	natural gas	natural gas
C	coal	natural gas
D	coal	coal

9 Which statement is false?

A Ethanol has a lower specific energy (energy content per gram) than gasoline.

B Ethanol is a biofuel that reduces the demand for gasoline.

C Biofuels are renewable energy sources.

D Biofuels are carbon neutral.

10 The hydrocarbon C_4H_8 was burnt in air. Incomplete combustion occurred. Which equation, A, B, C or D, correctly represents an incomplete combustion reaction?

A $C_4H_8 + 4O \rightarrow 4CO + 4H_2$

B $C_4H_8 + 4O_2 \rightarrow 4CO + 4H_2O$

C $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$

D $C_4H_8 + 8O \rightarrow 4CO_2 + 4H_2$

11 Which statement about diesel and biodiesel is correct?

A Diesel consists of long-chain hydrocarbons; biodiesel contains benzene and its derivatives.

B Diesel has greater viscosity and hence flows more slowly along fuel lines than biodiesel.

C Diesel emits soot (small carbon particles) when burning is incomplete; biodiesel does not produce any harmful emissions when burnt.

D Diesel is produced by distilling crude oil; biodiesel is produced by transesterification of oils in plants.

12 Which of these is not a disadvantage of using a hydrogen–oxygen fuel cell?

A very low efficiency

B fuel storage can be problematic

C needs constant supply of fuel

D expensive metals are needed on the electrodes

Paper 2

1 In recent years, there has been worldwide interest in the extraction of 'shale gas' (mainly methane) as an important energy source.

The table shows the percentage composition of shale gas from one source.

Percentage composition				
CH_4	C_2H_x	C_3H_y	CO_2	N_2
88.0	0.8	0.7	10.4	0.1

In the general chemical formulas above, x and y are variables.

a Draw the structures (cyclic and/or non-cyclic) of four possible compounds with the formula C_3H_y. [2]

b Suggest a chemical method by which carbon dioxide could be removed from shale gas. [1]

The table shows a comparison of the specific energy content of shale gas, fuel oil (burnt in ships and furnaces) and coal.

	Shale gas	Fuel oil	Coal
Specific energy / kJ g^{-1}		42	33
Relative volume of CO_2 formed per kJ released	117	164	208

c i The enthalpy change of combustion of methane is $\Delta_c H^\ominus = -891\,\text{kJ mol}^{-1}$. Calculate the specific energy of methane. [1]

ii State and explain whether the specific energy of untreated shale gas will be lower or higher than that of methane. [1]

d Suggest why shale gas produces the smallest amount of carbon dioxide for ever kiloJoule (kJ) of energy released [1]

2 Ethanol is an example of a biofuel used in place of gasoline.

a State two advantages and two disadvantages associated with the use of ethanol as a biofuel. [4]

The table shows some information about some alcohols and the amount of heat energy released when one mole of each alcohol is completely burnt in oxygen.

Alcohols	Molecular formula	Energy released / kJ mol^{-1}	Density g cm^{-3}
methanol	CH_3OH	726	0.793
ethanol	C_2H_5OH	1367	0.789
propan-1-ol	C_3H_7OH	2021	0.804
butan-1-ol	C_4H_9OH	2676	0.810

b Write a chemical equation for the complete combustion of butan-1-ol. [1]

c Sandro suggests that filling a car's fuel tank with butan-1-ol instead of methanol would mean there is more than 3 times the chemical energy in the tank. Explain why his statement is incorrect. [1]

d Ethanol and gasoline have different physical and chemical properties. When 1.00 dm^3 of petrol is burnt completely in air, 38 000 kJ of energy is released. Using the data from the table, calculate the amount of energy released when 1.00 dm^3 of ethanol is burnt completely in air given that the density of ethanol is 0.780 g cm^{-3}. [3]

3 a Methanol can be used directly as a fuel in fuel cells. State the half equations for the redox reactions occurring at the anode and cathode in a methanol–oxygen fuel cell. [2]

Propan-2-ol is another alcohol which can act as a fuel in a fuel cell. In an analogous process to methanol, propan-2-ol is oxidized to carbon dioxide and hydrogen ions, and the hydrogen ions move through the electrolyte to react with oxygen to produce water.

b Suggest half equations for the reactions occurring at the electrodes in a propan-2-ol fuel cell, and hence deduce the equation for the overall reaction. [3]

c State one advantage a propan-2-ol fuel cell will have over a hydrogen fuel cell. [1]

4 Intercontinental jet airlines use kerosene as fuel. The formula of kerosene may be taken as $C_{14}H_{30}$.

a State the homologous series kerosene belongs to. [1]

The flight path from Singapore to London is approximately 10 700 km. a typical intercontinental jet airliner burns 10.8 kg of kerosene for each kilometre covered.

b i Calculate the mass, in tonnes, of $C_{14}H_{30}$ burnt on a flight from Singapore to London. [1 tonne = 1000 kg] [1]

ii Calculate the mass of carbon dioxide, CO_2, produced during this flight. [2]

R1.4 Entropy and spontaneity (HL)

Paper 1

1 When barium hydroxide and ammonium thiocyanate powders are stirred together with a thermometer, the chemical reaction between them causes the temperature to drop from room temperature to below the freezing point of water.

Which row of the table describes the entropy changes involved?

	ΔS_{system}	$\Delta S_{surroundings}$	ΔS_{total}
A	increase	increase	decrease
B	increase	decrease	increase
C	decrease	increase	increase
D	decrease	decrease	decrease

2 Consider the following reactions in the gas phase:

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

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

$C_2H_6\,(g) + 3½O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(g)$ H

What is the order of increasing standard entropy change, ΔS, for these reactions, with the most negative first?

A F,G,H

B F,H,G

C G,H,F

D H,G,F

3 The overall chemical equation for the electrolysis of dilute sulfuric acid using inert electrodes is shown below.

$2H_2O\,(l) \rightarrow 2H_2\,(g) + O_2\,(g)$

Which row of the table gives the correct sign for each property of the reaction?

	$\Delta H^\ominus$	$\Delta S^\ominus$	$\Delta G^\ominus$
A	−	+	+
B	+	−	−
C	−	−	−
D	+	+	+

4 Which reaction has the greatest increase in entropy?

A $Pb(NO_3)_2\,(aq) + 2KCl\,(aq) \rightarrow PbCl_2\,(s) + 2KNO_3\,(aq)$

B $SrCO_3\,(s) \rightarrow SrO\,(s) + CO_2\,(g)$

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

D $H_2\,(g) + I_2\,(g) \rightarrow 2HI\,(g)$

5 Which row of the table corresponds to a system at equilibrium?

	Entropy	Gibbs energy
A	maximum	maximum
B	maximum	minimum
C	minimum	maximum
D	minimum	minimum

6 Which reaction has the greatest increase in the entropy of the system?

A $HI\,(g) + NH_3\,(g) \rightarrow NH_4I\,(s)$

B $(NH_4)_2Cr_2O_7\,(s) \rightarrow Cr_2O_3\,(s) + N_2\,(g) + 4H_2O\,(g)$

C $H_2O\,(g) \rightarrow H_2O\,(s)$

D $ZnCO_3\,(s) \rightarrow ZnO\,(s) + CO_2\,(g)$

7 What are the signs for the entropy changes associated with vaporization of water?

$H_2O\,(l) \rightarrow H_2O\,(g)$

	ΔSsystem	ΔSsurroundings
A	+	+
B	+	−
C	−	+
D	−	−

8 The complete combustion of propanone, $(CH_3)_2CO\,(l)$, in oxygen is exothermic. Which row of the table correctly describes the reaction?

	ΔH	ΔS	Spontaneous/non-spontaneous
A	negative	positive	spontaneous
B	negative	positive	non-spontaneous
C	positive	negative	spontaneous
D	positive	positive	non-spontaneous

9 What are the signs of $\Delta H^\ominus$ and $\Delta S^\ominus$ for a reaction which is spontaneous at low temperatures and non-spontaneous at very high temperature?

	$\Delta H^\ominus$	$\Delta S^\ominus$
A	+	+
B	+	−
C	−	−
D	−	+

10 Which of the following terms is equivalent to the entropy change of the surroundings?

A $\Delta G^{\ominus}$

B $T\Delta S^{\ominus}$

C $-\dfrac{\Delta H^{\ominus}}{T}$

D $-T\Delta S^{\ominus}$

11 Given that the enthalpy change of vaporisation of water is +40.8 kJ mol^{-1}, what term gives the entropy change when 36.04 g of water boil to form water vapour?

A $\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 398}\,\text{J K}^{-1}$

B $-\dfrac{40.8 \times 36.04}{18.02 \times 373}\,\text{J K}^{-1}$

C $\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 373}\,\text{J K}^{-1}$

D $-\dfrac{40.8 \times 10^3 \times 36.04}{18.02 \times 373}\,\text{J K}^{-1}$

12 In a sealed vessel, ammonium chloride forms an equilibrium with ammonia and hydrogen chloride:

$NH_4Cl\,(s) \rightleftharpoons NH_3\,(g) + HCl\,(g)\quad \Delta G^{\ominus} = +91\,\text{kJ mol}^{-1}$

$\Delta G^{\ominus} = -RT \ln K$

Which of the following statements is correct?

A The equilibrium mixture will contain mainly reactants and the value of $K \ll 1$.

B The equilibrium mixture will contain mainly reactants and the value of $K \gg 1$.

C The equilibrium mixture will contain mainly products and the value of $K \ll 1$.

D The equilibrium mixture will contain mainly products and the value of $K \gg 1$.

13 What is the correct order of decreasing entropy for a pure substance?

A liquid > solid > gas

B solid > gas > liquid

C solid > liquid > gas

D gas > liquid > solid

14 The expression for the standard free energy change of a reaction is given by the Gibbs equation:

$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$

What are the signs for $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ for a reaction that is spontaneous at all temperatures?

	$\Delta H^{\ominus}$	$\Delta S^{\ominus}$
A	–	–
B	+	+
C	–	+
D	+	–

15 Which of the following combination of thermodynamic changes for a forward reaction would result in the most products?

	Entropy	Enthalpy
A	decreasing	decreasing
B	increasing	decreasing
C	increasing	increasing
D	decreasing	increasing

16 Which of the following has the highest entropy?

A H_2O (g) at 150 °C

B H_2O (g) at 100 °C

C H_2O (l) at 100 °C

D H_2O (l) at 4 °C (the temperature of maximum density)

17 For systems at equilibrium, which of the following must always be true?

A $\Delta S = 0$

B $q = 0$

C $\Delta H = 0$

D $\Delta G = 0$

Paper 2

1 Magnesium carbonate decomposes on heating according to the equation shown below. The values of the standard enthalpy change and standard entropy change of the decomposition are provided.

$MgCO_3\,(s) \rightarrow MgO(s) + CO_2\,(g)\quad \Delta H^{\ominus} = +117\,\text{kJ mol}^{-1}$ and $\Delta S^{\ominus} = +175\,\text{J mol}^{-1}\,\text{K}^{-1}$

a Explain why the entropy increases when magnesium carbonate decomposes. [1]

b Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for the decomposition of magnesium carbonate. Hence, comment on the spontaneity of the decomposition of magnesium carbonate under standard conditions. [2]

2 The table lists the standard enthalpy change of formation of four compounds.

Compound	$\Delta H_f^\ominus$ / kJ mol–1
H_2O (l)	−286
HCl (g)	−92
SiO_2 (s)	−910
$SiCl_4$ (l)	−640

a State the meaning of standard enthalpy change of formation of a compound. [2]

b i State the balanced equation, with state symbols, for the reaction between silicon tetrachloride and water to form silicon dioxide and hydrogen chloride gas. [2]

ii Using the data in the table, calculate the standard enthalpy change for the reaction in part b) i). [2]

c State and explain whether the hydrolysis has a positive, negative or zero change in entropy. [2]

d Use the Gibbs equation to explain why the hydrolysis of liquid silicon tetrachloride is always a spontaneous process. [2]

3 Solid mercury(II) sulfide, HgS, can exist in either the red or black form. The $\Delta H^\ominus$ for the conversion from the red to black form is +4.2 kJ mol^{-1}.

HgS (red) → HgS (black); $\Delta H^\ominus$ = +4.2 kJ mol^{-1}

The standard entropy values, $S^\ominus$, for HgS (red) and HgS (black) are +77.8 J K^{-1} mol^{-1} and +88.3 J K^{-1} mol^{-1}, respectively.

a Determine the minimum temperature HgS (red) must be heated to in order to change it to HgS (black). [3]

b Given that the equilibrium constant, K, of the reaction at 298 K is 2.97 × 10^{-13}, calculate the value of $\Delta G^\ominus$ of the reaction under standard conditions. [1]

c Comment on the sign of $\Delta G^\ominus$ with reference to the position of equilibrium of the reaction under standard conditions. [1]

4 Hydrogen can be made from steam according to the following equation:

H_2O (g) + C (s) → H_2 (g) + CO (g)

The Gibbs free energy change of the reaction at two different temperatures are shown:

ΔG_1 = +78 kJ mol^{-1} at 378 K ΔG_2 = −58 kJ mol^{-1} at 1300 K.

a Deduce the correct signs of ΔH and ΔS for this reaction. [2]

b Calculate the values of ΔH and ΔS. You can assume they are independent of temperature. [4]

5 At a pressure of 1.01 × 10^5 Pa and a temperature of 188 K, the liquid and gaseous states of HCl will be in equilibrium:

HCl (l) ⇌ HCl (g); ΔG = 0.0 kJ mol^{-1} and ΔH = +16.8 kJ mol^{-1}

The enthalpy change for the vaporization process, the forward reaction as written, is shown.

a Calculate the entropy change, ΔS, for the vaporization, and explain the significance of its sign. [2]

b Calculate ΔG for this process at a temperature of 298 K, and explain the significance of its sign. [2]

R2.1 How much? : the amount of chemical change

Paper 1

1 0.10 mol of hydrochloric acid is mixed with 0.10 mol of magnesium carbonate.

$2HCl\,(aq) + MgCO_3\,(s) \rightarrow MgCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$

Which is correct?

	Limiting reagent	Maximum yield of CO_2 / mol
A	HCl (aq)	0.10
B	$MgCO_3$ (s)	0.05
C	$MgCO_3$ (s)	0.10
D	HCl (aq)	0.05

2 How many moles of FeS_2 are required to produce 64.07 g of SO_2?

$4FeS_2\,(s) + 11O_2\,(g) \rightarrow 2Fe_2O_3\,(s) + 8SO_2\,(g)$

A 0.50

B 1.0

C 2.0

D 4.0

3 How many grams of potassium azide, KN_3, are needed to produce 68.1 dm^3 of N_2 (g) at STP?

Molar gas volume at STP = 22.7 $dm^3\,mol^{-1}$;
M of KN_3 = 81.13 $g\,mol^{-1}$.

$2KN_3\,(s) \rightarrow 3N_2\,(g) + 2K\,(s)$

A 40.57

B 81.13

C 162.26

D 243.39

4 In which reaction mixture is KOH the limiting reagent?

A 0.20 mol KOH + 0.10 mol H_2SO_4

B 0.10 mol KOH + 0.10 mol H_2SO_4

C 0.10 mol KOH + 0.10 mol CH_3COOH

D 0.20 mol KOH + 0.10 mol HNO_3

5 Which of the following reactions has an atom economy of 100%?

A $HCl\,(aq) + KOH\,(aq) \rightarrow KCl\,(aq) + H_2O\,(l)$

B $K_2O\,(s) + H_2SO_4\,(aq) \rightarrow K_2SO_4\,(aq) + H_2O\,(l)$

C $MgCO_3\,(s) \rightarrow MgO\,(s) + CO_2\,(g)$

D $C_2H_4\,(g) + H_2O\,(g) \rightarrow C_2H_5OH\,(l)$

6 Which reaction produces the smallest atom economy of $CaCl_2$?

A $CaCl_2 \cdot H_2O \rightarrow CaCl_2 + 2H_2O$

B $CaO + 2HCl \rightarrow CaCl_2 + H_2O$

C $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$

D $Ca + 2HCl \rightarrow CaCl_2 + H_2$

7 0.8 dm^3 of nitrogen monoxide is mixed with 0.6 dm^3 of oxygen under standard conditions. The reaction below takes place until one of the reactants is used up.

$2NO(g) + O_2\,(g) \rightarrow 2NO_2\,(g)$

What is the volume of the mixture under standard conditions after the reaction has taken place?

A 0.80 dm^3

B 1.00 dm^3

C 1.40 dm^3

D 1.20 dm^3

8 Calculate the amount of oxygen molecules that are required to react with phosphorus molecules (P_4) to produce 5.497 g of phosphorus(III) oxide, P_4O_6.
[M of P_4O_6 = 219.88 $g\,mol^{-1}$]

$P_4\,(s) + 3O_2\,(g) \rightarrow P_4O_6\,(s)$

A 0.0250 mol

B 0.0500 mol

C 0.0750 mol

D 0.1500 mol

9 1000 cm^3 of ammonia gas combines with 1250 cm^3 of oxygen gas to produce two gaseous compounds with a combined volume of 2500 cm^3, all volumes being measured at STP.

Which of the following equations agrees with these observations?

A $4NH_3 + 7O_2 \rightarrow 4NO_2 + 6H_2O$

B $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

C $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

D $4NH_3 + 5O_2 \rightarrow 2N_2O_2 + 6H_2O$

10 Ethanedioic acid reacts with manganate(VII) ions according to the following ionic equation.

$2MnO_4^-$ (aq) + $5H_2C_2O_4$ (aq) + $6H^+$ (aq) → $10CO_2$ (g) + $2Mn^{2+}$ (aq) + $8H_2O$ (l)

In which mixture is ethanedioic acid the limiting reagent?

	$[MnO_4^-$ (aq)] = 0.200 M	$[H_2C_2O_4$ (aq)] = 0.400 M
A	0.200 dm^3	0.300 dm^3
B	0.200 dm^3	0.500 dm^3
C	0.400 dm^3	0.400 dm^3
D	0.400 dm^3	0.600 dm^3

11 Copper can react with concentrated nitric(V) acid in a redox reaction.

3Cu (s) + _HNO_3 (aq) → _$Cu(NO_3)_2$ (aq) + _H_2O (l) + _NO (g)

What is the coefficient for nitric(V) acid, HNO_3, when the equation is balanced?

A 10

B 4

C 6

D 8

12 What mass of carbon dioxide, CO_2 (g), in grams, is produced when 5.0045 g of calcium carbonate, $CaCO_3$(s), reacts completely with hydrochloric acid, HCI (aq)?

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

A 0.0550

B 2.2005

C 4.4010

D 5.0045

13 How many grams of silver chloride, AgCl, would be precipitated if an excess of silver nirate solution, $AgNO_3$ (aq) were added to 55.00 cm^3 of 0.200 mol dm^{-3} KCl (aq) solution? [Molar mass of silver chloride = 143.32 g mol^{-1}]

$AgNO_3$ (aq) + KCl (aq) → AgCl (s) + KNO_3 (aq)

A 1.58 g

B 1.11 g

C 6.43 g

D 7.80 g

14 10 cm^3 of hydrogen fluoride gas reacts with 5 cm^3 of dinitrogen difluoride gas (N_2F_2) to form 10 cm^3 of a single gas. Which of the following is the most likely equation to describe the reaction?

A HF + N_2F_2 → N_2HF_3

B 2HF + N_2F_2 → $2NHF_2$

C 2HF + N_2F_2 → $N_2H_2F_4$

D HF + $2N_2F_2$ → N_4HF_4

15 What volume of 0.500 M HCl is required to react with 8.432 g of magnesium carbonate according to the following equation:

$MgCO_3$ (s) + 2HCl (aq) → $MgCl_2$ (aq) + H_2O (l) + CO_2 (g)

A 600 cm^3

B 200 cm^3

C 400 cm^3

D 100 cm^3

16 What volume (cm^3) of 0.500 mol dm^{-3} hydrochloric acid solution are needed to titrate completely 25.00 cm^3 of 0.150 mol dm^{-3} barium hydroxide solution?

$Ba(OH)_2$ (aq) + 2HCl (aq) → $BaCl_2$ (aq) + $2H_2O$ (l)

A 12.50 cm^3

B 7.50 cm^3

C 10.00 cm^3

D 15.00 cm^3

17 What is the sum of all the coefficients (integers) when the equation below is balanced?

_$(CH_3)_2NNH_2$ + _N_2O_4 → _N_2 + _CO_2 + _H_2O

A 14

B 12

C 11

D 9

18 Nitrogen(II) oxide, NO, is made from the oxidation of ammonia, NH_3:

$4NH_3 + 5O_2 → 4NO + 6H_2O$

An 8.52 g sample of NH_3 forms 14.75 g of NO. What is the percentage yield of NO?

A 40%

B 60%

C 80%

D 98%

19 Potassium chlorate(VII) is prepared by three consecutive reactions:

Cl_2 (g) + 2KOH (aq) → KCl (aq) + **KClO** (aq) + H_2O (l)

3KClO (aq) → 2KCl (s) + **$KClO_3$** (s)

4**$KClO_3$** (s) → 3$KClO_4$ (s) + KCl (s)

If the overall percentage yield is 50%, what amount (mol) will be produced from 283.60 g of chlorine gas?

A 0.25 mol

B 1.00 mol

C 0.50 mol

D 2.00 mol

20 The thermal decomposition of mercury(II) thiocyanate is known as Pharaoh's Snake experiment. The overall equation is given below.

__ $Hg(SCN)_2$ + __ O_2 → __ HgS + __ C_3N_4 + __ CO_2 + __ SO_2

If the equation is balanced using the smallest integer coefficients, what will be the coefficient of oxygen, O_2?

A 6

B 5

C 4

D 3

21 Which coefficients would balance this equation?

_HCl + _MnO_2 → _$MnCl_2$ + _Cl_2 + _H_2O

	HCl	MnO_2	$MnCl_2$	Cl_2	H_2O
A	2	1	1	1	1
B	3	1	1	1	1
C	4	1	1	1	2
D	4	1	1	2	2

22 Which chemical process is the most sustainable in terms of the atom economy of the organic product?

A CO_2 +3H_2 → CH_3OH + H_2O

B CH_3CH_2Br + KOH → CH_3CH_2OH + KBr

C CH_3H_2OH + NaCl + H_2SO_4 → CH_3CH_2Cl + $NaHSO_4$ + H_2O

D $CH_3(CH_2)_3OH$ → $CH_3CH_2CH{=}CH_2$ + H_2O

Paper 2

1 1.59 g of lithium hydride (LiH) was treated with an excess of water to form lithium hydroxide and hydrogen.

Write appropriate equations and determine:

a The volume at STP of the hydrogen formed.

b The volume of hydrochloric acid containing 72.92 g dm^{-3} required to neutralize the lithum hydroxide solution [7]

2 Copper metal may be produced by the reaction of copper(I) oxide and copper(I) sulfide to form copper and sulfur dioxide.

a Deduce the balanced equation with state symbols. [2]

A mixture of 12.0 kg of copper(I) oxide and 4.00 kg of copper(I) sulfide was heated until no further reaction occurred.

b Determine the limiting reagent in this reaction, showing your working. [3]

c Calculate the maximum mass of copper that could be obtained from these masses of reactants. [2]

3 On combustion carbon disulfide is oxidized as follows:

CS_2 (g) + 3O_2 (g) → CO_2 (g) + 2SO_2 (g)

A 20 cm^3 sample of carbon disulfide vapour is ignited with 100 cm^3 of oxygen. The final volume of gas after burning is treated with an excess of aqueous alkali to react and absorb any acidic oxides.

[All volumes were measured at the same temperature and pressure, conditions under which CS_2 is a gas.]

Determine the percentage of this final volume that dissolves in the alkali. Show your working in the form of a table showing the intial volume, change in volume and final volumes for the two reactants and two products. [5]

4 Phenol, C_6H_5OH, is an important pharmaceutical raw material for pharmaceutical synthesis including aspirin. It is produced industrially by the cumene process which involves the oxidation of benzene and propene.

C_6H_6 + C_3H_6 + O_2 → C_6H_5OH + CH_3COCH_3

Another new method of producing phenol involves the use of solid zeolites as the catalyst. The chemical equation for the process is shown below. This involves the oxidation of benzene by nitrogen(I) oxide.

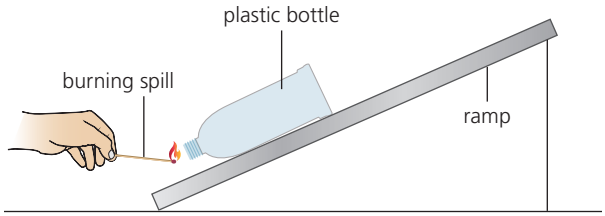
C_6H_6 + N_2O → C_6H_5OH + N_2

a Calculate the atom economy of the two processes. Hence state the process that is more sustainable. [3]

b Other than atom economy, state three other factors that are considered in determining the sustainability and degree of green chemistry present in an industrial chemical process. [3]

5 Hydrogen reacts with oxygen in a highly exothermic reaction. If a burning splint is placed near a mixture of hydrogen and oxygen there is an explosion and liquid water is formed.

A chemistry teacher filled a plastic bottle with different volumes of hydrogen and oxygen gases. The teacher placed the bottle on a sloping ramp and placed a burning splint near the open end of the bottle.



The teacher wanted to find the volumes of hydrogen and oxygen gases that propelled the bottle the greatest distance. The teacher repeated the experiment using the same 1 dm^3 plastic bottle, but changing the volumes of hydrogen and oxygen used. The results are shown in the table.

Volume of hydrogen gas used / cm^3	Volume of oxygen gas used / cm^3	Distance traveled by plastic bottle / m
0	1000	0.00
200	800	3.00
400	600	4.50
600	400	5.75
800	200	4.75
1000	0	0.00

a Write a balanced equation (with state symbols) for this reaction. [1]

b State Avogadro's law as applied to volumes of gases. [1]

c Use it to predict which ratio of hydrogen and oxygen gases in 1 dm^3 would make it move the longest distance. [1]

d Describe the relationship between the volume of hydrogen and distance moved by the plastic bottle. [2]

e Explain why the plastic bottle did not move when it contained 1000 cm^3 of hydrogen. [1]

2 moles of hydrogen reacted with 1 mole of oxygen to form 1 mole of liquid water.

f Deduce the mass ratio in the smallest integers. Show your working. [2]

6 Copper can exist in +1, +2 and +3 oxidation states in its compounds. After heating with a Bunsen burner 24.74 g of an unknown oxide of copper for 3 minutes, 19.76 g of copper remained.

a Calculate the amounts (mol) of copper and oxygen. Use these values to determine the empirical formula of the oxide and state the oxidation state of the copper. [4]

b Suggest why the mass of solid obtained by heating 24.74 g of a copper oxide may be greater than 19.76 g, giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

7 Butyl ethanoate is an ester used as a flavouring. This ester can be synthesized from butan-1-ol by two different processes.

Process 1 is a one-step process that involves a reversible reaction.

$$\underset{CH_3COOH}{CH_3CH_2CH_2CH_2OH} + \rightleftharpoons \underset{H_2O}{CH_3COOCH_2CH_2CH_2CH_3} +$$

6.25 g of butan-1-ol forms 6.57 g of butyl ethanoate.

a Calculate the percentage yield for process 1. [2]

b Calculate the atom economy for process 1. [2]

Process 2 is a two-step process. Thionyl chloride ($SOCl_2$) is a volatile and reactive liquid used as a chlorinating agent which reacts with water to form sulfur dioxide and hydrochloric acid. Ethanoyl chloride (CH_3COCl) hydrolyses with water to form hydrochloric acid and ethanoic acid.

$$CH_3COOH + SOCl_2 \rightarrow CH_3COCl + SO_2 + HCl$$

$$\underset{CH_3COCl}{CH_3CH_2CH_2CH_2OH} + \rightarrow \underset{HCl}{CH_3COOCH_2CH_2CH_2CH_3} +$$

5.450 g of ethanoic acid produces 9.806 g of butyl ethanoate.

c Calculate the overall percentage yield for process 2. [2]

d Calculate the overall atom economy for process 2. [2]

e Explain why process 2 has a high percentage yield but a low atom economy. [2]

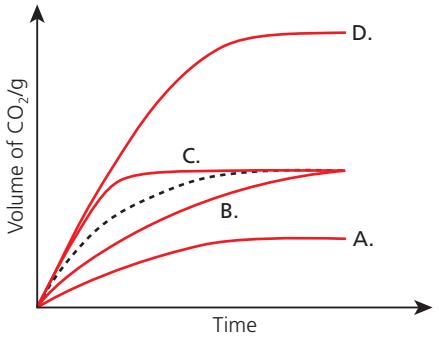
f Suggest two reasons why butyl ethanoate is manufactured by process 1 rather than by process 2. [2]

R2.2 How fast?: the rate of chemical change

Paper 1

1 The dotted line represents the volume of carbon dioxide released when **excess** magnesium carbonate is added to dilute nitric acid.

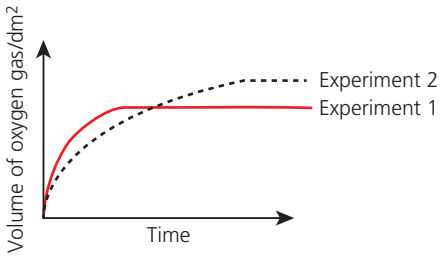
Which graph represents the production of carbon dioxide when excess magnesium carbonate is added to the same volume of nitric acid of double concentration?



2 Experiments were carried out to investigate the rates of the decomposition of 100 cm^3 of 1.00 mol dm^{-3} hydrogen peroxide, catalysed by manganese(IV) oxide.

$2H_2O_2\,(aq) \rightarrow 2H_2O\,(l) + O_2\,(g)$

The volume of oxygen gas collected using a gas syringe was monitored. The results are shown in the diagram.



Which of the following alteration to the experimental conditions in Experiment 1 would produce the curve observed in Experiment 2?

A Decreasing the temperature

B Decreasing the mass of manganese(IV) oxide used

C Diluting the hydrogen peroxide solution with water

D Adding 0.10 mol dm^{-3} hydrogen peroxide

3 Why does a reaction for a sample of gases, at constant temperature, occur slower at lower pressure?

A Collisions are less frequent.

B Collisions are less energetic.

C Lower pressure increases activation energy.

D The reaction is less exothermic at low pressure.

4 Which experimental methods could be used to observe the progress of the following reaction?

$Cr_2O_7^{2-}\,(aq) + 6I^-\,(aq) + 14H^+\,(aq) \rightarrow 2Cr^{3+}\,(aq) + 3I_2\,(aq) + 7H_2O\,(l)$

I Change in colour

II Change in mass

III Change in electrical conductivity

A I and II only

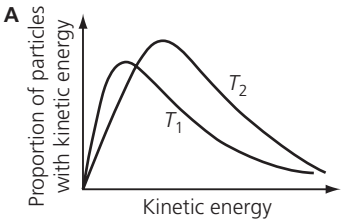
B I and III only

C II and III only

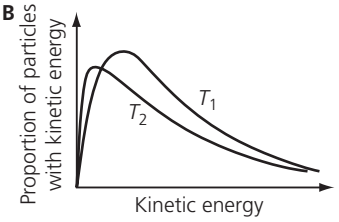
D I, II and III

5 Which of the graphs below shows the Maxwell–Boltzmann distribution of kinetic energies for the same amount of gas molecules (behaving ideally) at two temperatures, where T_2 is greater than T_1?

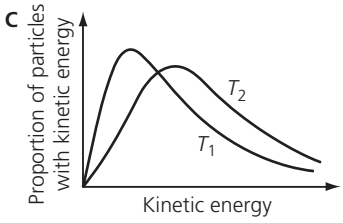
A



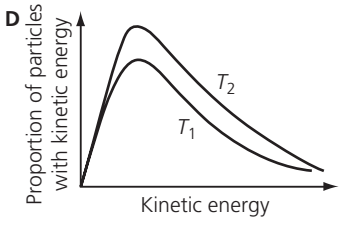
B



C



D



6 Which piece of equipment could not be used in an experiment to measure the rate of this reaction?

CH_3COCH_3 (aq) + Br_2 (aq) → CH_3COCH_2Br (aq) + H^+ (aq) + Br^- (aq)

A a spectrophotometer

B a gas syringe

C an electronic stopwatch

D a pH probe and meter

7 Which change does **not** increase the initial rate of reaction when magnesium carbonate is added to excess hydrochloric?

$MgCO_3$ (s) + 2HCl (aq) → $MgCl_2$ (aq) + H_2O (l) + CO_2 (g)

A an increase in the temperature of the reaction mixture

B a decrease in the size of the magnesium carbonate particles

C an increase in the concentration of hydrochloric acid

D addition of deionized water into the reaction mixture

8 Dilute hydrochloric acid reacts with iron:

$2H^+$ (aq) + Fe (s) → H_2 (g) + Fe^{2+} (aq)

What will increase the rate of this reaction but **not** change the Maxwell–Boltzmann distribution of kinetic energies?

I addition of a suitable catalyst

II an increase in the concentration of hydrochloric acid

III an increase in the temperature of hydrochloric acid

A Only I is correct.

B I and II are correct.

C II and IIII are correct.

D I, II and III are correct.

9 A reversible reaction is catalysed. Which of the following statements about this reaction are correct?

I The catalyst alters the mechanism of the reaction.

II The catalyst reduces the activation energy for both the forward and the backward reaction.

III The catalyst alters the composition of the equilibrium mixture.

A I, II and III

B I and II only

C II and III only

D I only

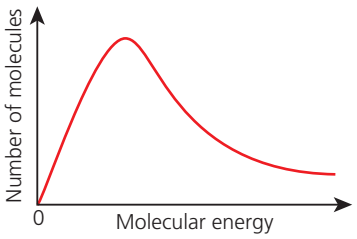
10 A piece of magnesium ribbon was added to 25 cm^3 of dilute hydrochloric acid. The magnesium ribbon was completely reacted and the total volume of hydrogen gas released was measured.

In a second experiment, an identical piece of magnesium ribbon was used. This was added to another 50 cm^3 of the same dilute hydrochloric acid. The total volume of hydrogen gas released was measured.

How will the initial rate of reaction and total volume of hydrogen gas evolved in the second experiment compare to the first experiment?

	Initial rate of reaction	Total volume of hydrogen gas released
A	increase	no change
B	increase	increase
C	no change	increase
D	no change	no change

11 The diagram represents the Boltzmann distribution ofmolecular kinetic energies at a given temperature.



How does the shape of the graph change when the temperature decreases?

A The peak is higher and further to the left.

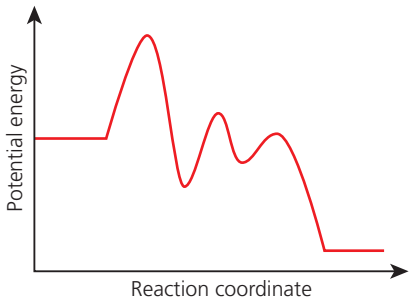
B The peak is higher and further to the right.

C The peak is lower and further to the left.

D The peak is lower and further to the right.

(Questions 12–21 HL only)

12 The energy profile diagram of a reaction is shown in the figure.



Which of the following is true about the reaction?

A The reaction occurs in two elementary steps.

B The reaction absorbs heat from the surroundings.

C The last step of the reaction is the rate-determining step.

D The products are energetically more stable than the reactants.

13 The reaction between X and Y, in aqueous solution, follows the general rate equation:

rate = $k[X]^a[Y]^b$

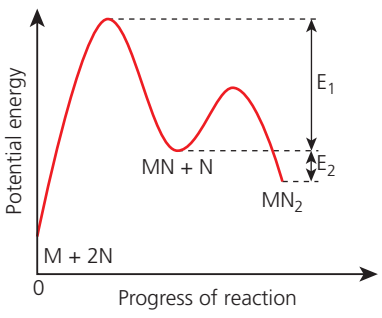
The initial rate of this reaction was measured for different concentrations of X and Y, and the following results were obtained.

[X] / mol dm^{-3}	[Y] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
0.040	2.40	2.63×10^{-3}
0.040	4.80	1.05×10^{-2}
0.040	7.20	2.37×10^{-2}
0.160	2.40	1.05×10^{-2}

What are the values of *a* and *b* for the rate equation?

	a	*b*
A	1	1
B	0	2
C	1	2
D	2	1

14 The energy profile diagram of the reversible reaction between M and N is shown in the figure.



Which of the following statements are correct?

I The activation energy of the reverse reaction is $E_1 + E_2$.

II Rate equation of the reaction is rate = $k[M][N]^2$.

III The equilibrium [MN_2] increases as temperature increases.

A I and II only

B I and III only

C II and III only

D I, II and III

15 For the gas phase reaction:

A (g) + B (g) → C (g)

The experimentally determined rate equation is:

rate = $k[A]^2[B]$

By what factor will the rate change if the concentration of A is tripled and the concentration of B halved?

A 6

B 4.5

C 0.75

D 1.5

16 A reaction proceeds by the following mechanism:

Step 1: A + B ⇌ X fast

Step 2: X + A → P slow

Which rate equation is consistent with this mechanism?

A rate = $k[A]^2[B]$

B rate = $k[A]^2[B][X]$

C rate = $k[X][P]$

D rate = $k[A][B]$

17 Under acidic conditions hydrogen peroxide oxidizes iodide ions to iodine molecules in the following reaction.

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

Kinetic studies of this reaction using different initial concentration of reactants at a constant temperature

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 zero (zeroth) order

B first order

C second order

D third order

18 Which of the following statements of an Arrhenius plot of $\ln k$ against $\frac{1}{T}$ (K^{-1}) is correct?

$\ln k = (\frac{-E_a}{R})(\frac{1}{T}) + \ln A$

A The graph has a positive gradient.

B The activation energy can be calculated from the gradient.

C The y–intercept is the Arrhenius factor, A.

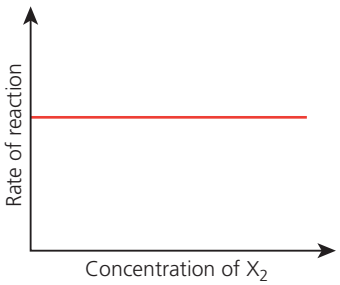
D The gradient becomes steeper when a catalyst is added.

19 The equation of a reaction involving X_2 is:

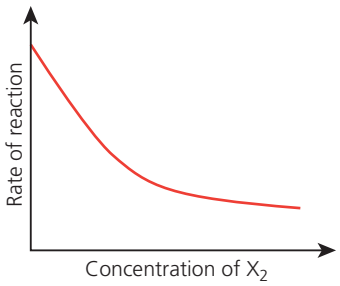
$2X_2 \rightarrow X + X_3$

Which graph shows that the reaction is first order with respect to X_2?

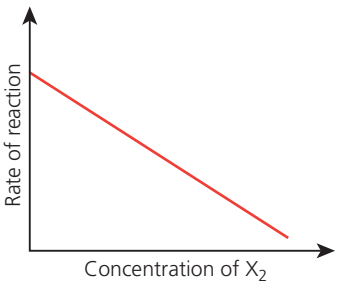
A.



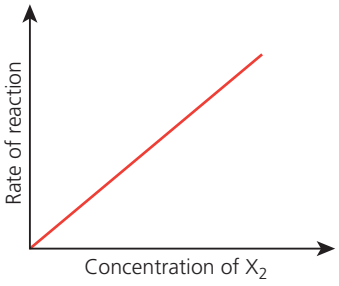
B.



C.



D.



20 Which of the following graphs allows the activation energy of a reaction to be determined from the gradient of its graph (where k is the rate constant and T is the absolute temperature)?

A $\ln k$ versus T

B $\frac{1}{k}$ versus T

C $\ln k$ versus $\frac{1}{T}$

D $\ln k$ versus $\ln T$

21 The following equations show the mechanism proposed for a reaction.

Step 1: $NO_2I\ (g) \rightarrow NO_2\ (g) + I\bullet\ (g)$ slow

Step 2: $NO_2I\ (g) + I\bullet\ (g) \rightarrow NO_2\ (g) + I_2\ (g)$ fast

Which of the following statements is not correct?

A The rate equation is rate = $k[NO_2I]$.

B I• is the catalyst for this reaction.

C When the concentration of NO_2I (g) is doubled, the rate of reaction increases by two times.

D The equation for the overall reaction is:

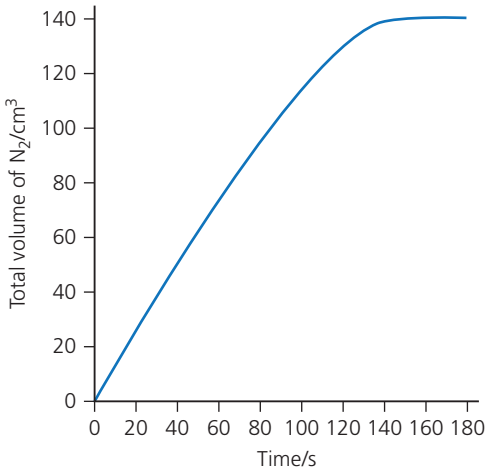
$2NO_2I\ (g) \rightarrow 2NO_2\ (g) + I_2\ (g)$

Paper 2

1 The reaction between ammonium iodide and potassium nitrite in aqueous solution can be represented by the equation:

$NH_4I\,(aq) + KNO_2\,(aq) \rightarrow N_2\,(g) + 2H_2O\,(l) + KI\,(aq)$

The graph below shows the total volume of nitrogen gas produced in a sealed gas syringe at 30 second intervals from a mixture of ammonium iodide and potassium nitrite in aqueous solution at 25 °C.



a i State how the rate of formation of nitrogen changes with time. Explain your answer in terms of collision theory. [2]

ii Explain why the volume of nitrogen eventually remains constant. [1]

b i State and explain how the rate of formation of nitrogen would change if the temperature were increased from 25 °C to 40 °C. [4]

ii State and explain how the rate of formation of nitrogen would change if the same mass of ammonium iodide was used as large lumps instead of as a fine powder. [2]

(Questions 2–4 HL only)

2 Propanone reacts with iodine in the presence of acid according to the equation:

$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$

A student wanted to study the kinetics of the above reaction.

The student prepared a mixture containing:

- 5 cm^3 of propanone of concentration 1.0 mol dm^{-3}
- 10 cm^3 of sulfuric acid of concentration 1.0 mol dm^{-3}
- 10 cm^3 of a solution of iodine of concentration 1.0×10^{-3} mol dm^{-3}
- 75 cm^3 of distilled water.

At five minute intervals, 10.0 cm^3 samples were removed and 10 cm^3 of aqueous sodium hydrogencarbonate was added, followed by a titration against a solution of sodium thiosulfate.

The experiment was repeated using 20 cm^3 of sulfuric acid in the reaction mixture, with 65 cm^3 of water to keep the total volume constant.

The results were obtained are shown in the table.

Time / min		5	10	15	20	25
Titre / cm^3	for 10 cm^3 acid (experiment 1)	18.50	17.00	15.50	14.00	12.50
	for 20 cm^3 acid (experiment 2)	17.00	14.00	11.00	8.00	5.00

a i State the roles of iodine and sulfuric acid in this reaction. [2]

ii Explain why sodium hydrogencarbonate was added prior to the titration. [1]

b The student plotted a line graph of titre volume against time for both experiment 1 and 2 on the same graph. He obtained a straight line with a negative gradient for both graphs. He also found that the gradient for experiment 1 was half of that for experiment 2.

i Using the above information, deduce the order of reaction with respect to iodine and sulfuric acid respectively. [2]

ii State what the magnitude of the gradient represents. [1]

iii If the experiment was repeated at a higher temperature, state how you would expect the magnitude of the gradient to change. [1]

iv The student found that the volume of thiosulfate required was 20.00 cm^3 from extrapolating the graph to the *y*-axis at $t = 0$ min in a 10.0 cm^3 reaction mixture. Calculate the concentration of the sodium thiosulfate solution used in the titration. [2]

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

v Sketch a concentration–time graph for sulfuric acid in this reaction showing the half-life. [2]

vi Using a Maxwell–Boltzmann distribution curve, explain how the rate of reaction will be affected if the reaction is carried out at a higher temperature. [4]

3 Ethyl propanoate is an ester and can be hydrolysed according to the equation:

$C_2H_5OCOCH_2CH_3 + H_2O \rightarrow C_2H_5OH + CH_3CH_2CO_2H$

a The kinetics of the above hydrolysis may be investigated by measuring the concentration of propanoic acid produced. In this investigation, 0.240 moles of the ester was mixed with a suitable catalyst. Sufficient water was then added to raise the total volume to 1 dm^3 and the mixture was kept at a constant temperature of 35 °C.

10 cm^3 samples were withdrawn periodically at hourly intervals and rapidly cooled by the addition of cold water. The resulting solution was then titrated against a solution of standard sodium hydroxide every hour over a period of four hours. The results obtained are shown in the table. were obtained.

Time / h	Concentration of propanoic acid / mol dm^{-3}
0	0.000
1	0.084
2	0.140
3	0.178
4	0.195

i Identify the role of the cold water used prior to the titration and explain why it is necessary. [2]

ii By using a suitable graphical method, determine the half-life of the reaction and hence show that the hydrolysis reaction is first order with respect to the ester. [6]

iii Explain the role of catalyst in the experiment with the help of a Maxwell–Boltzmann distribution curve. [4]

b The ester, ethyl propanoate, can also undergo base hydrolysis and the reaction is monitored using the initial rates method. The initial rate of the hydrolysis reaction between the ester and NaOH(aq) was measured in three separate experiments at a constant temperature. The results obtained are shown in the table.

Experiment	Initial [NaOH] / mol dm^{-3}	Initial [ester] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.020	0.015	2.70×10^{-3}
2	0.030	0.015	4.05×10^{-3}
3	0.060	0.020	*r*

i Use the data to deduce the order of reaction with respect to NaOH. [2]

ii Given that the reaction is first order with respect to the ester, calculate the initial rate of reaction, *r*, for experiment 3. [1]

4 Sodium bisulfite, $NaHSO_3$, reacts with methanal, converting it into a non-toxic compound which can be disposed safely. The overall equation is shown below.

$HSO_3^-(aq) + H_2CO(aq) \rightarrow CH_2(OH)SO_3^-$

The initial rate of this reaction can be studied by the 'clock' method, using phenolphthalein as a suitable indicator. The sudden appearance of the pink colour indicates the time to stop the stopwatch.

A series of experiments was carried out using different concentrations of HSO_3^- and H_2CO. The results obtained are shown in the table.

Experiment number	$[HSO_3^-]$ / mol dm^{-3}	$[H_2CO]$ / mol dm^{-3}	Time for the appearance of the pink colour / s
1	0.040	0.040	60
2	0.040	0.050	48
3	0.050	0.060	40
4	0.040	0.070	34

a State the relationship between the time taken for the pink colour to appear and the initial rate of reaction. [1]

b Calculate the relative rates (1/time) for each of these four experiments and use them to deduce the order of reaction with respect to the two reactants. [4]

c State the rate equation for the reaction and state the units for the rate constant. [2]

Kinetic studies suggest that the mechanism involves the following two elementary steps:

Step 1: Bisulfite ion reacts with water molecule via an acid–base reaction, forming sulfite ions, SO_3^{2-}.

Step 2: The resulting sulfite ions reacts with methanal molecules to produce the non-toxic product, $CH_2(OH)SO_3^-$ and hydroxide ions.

d Formulate balanced equations for these two elementary steps. [2]

R2.3 How far?: the extent of chemical change

Paper 1

1 The smaller the value of an equilibrium constant, K

A the slower the reaction rate

B the more endothermic the reaction

C the lower the concentration of products at equilibrium

D the faster the reactants are converted to products

2 The following equilibrium can be set up in a closed container:

$N_2O_4\,(g) \rightleftharpoons 2NO_2\,(g); \qquad \Delta H^{\ominus} = +57\,kJ\,mol^{-1}$

colourless brown

Which of the following changes would produce a darkening of the colour of the gaseous mixture in the container?

A an increase in temperature

B adding a catalyst

C an increase in pressure

D a decrease in temperature

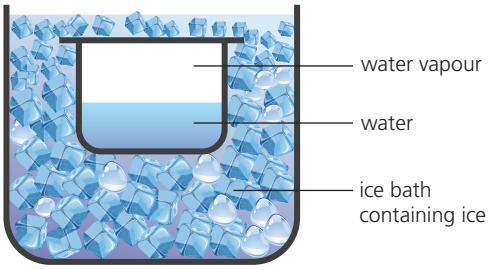
3 When silver bromide, AgBr, is mixed with water, a very small amount of silver bromide will dissolve in water in an equilibrium process.

$AgBr\,(s) \rightleftharpoons Ag^+\,Br^-\,(aq); \qquad K = [Ag^+\,(aq)][Br^-\,(aq)]$

How will the concentration of Ag^+ (aq) and K change when some solid sodium bromide is dissolved into a mixture of silver bromide and water at equilibrium?

	Solubility	Equilibrium constant, K
A	increase	increase
B	increase	no change
C	constant	no change
D	decrease	increase

3 A sealed container at room temperature is half full of water with only water vapour above it. The temperature of the sealed container is slowly decreased in an ice bath. The set-up is left for equilibrium to establish while more ice is continually added. Which statement is correct when the equilibrium of the water and water vapour mixture reached equilibrium at the lower temperature?



A The rate of condensation is the same as the rate of vaporization.

B The number of moles of water will be equal to the number of moles of water vapour in the sealed container.

C The pressure in the sealed container increases.

D The volume of water in the container remains the same throughout the entire process.

4 In the following reaction, the yield of bromine chloride, BrCl, increases with higher temperature:

$Cl_2\,(g) + Br_2\,(g) \rightleftharpoons 2BrCl\,(g)$

Which one of the following statements about the reversible reaction is correct?

A Increasing the pressure will also lead to a higher yield of bromine chloride.

B The forward reaction is exothermic.

C The position of equilibrium shifts to the reactants side when the temperature is decreased.

D The equilibrium constant, K, decreases as the temperature increases.

5 Consider the following reaction:

$2A\,(g) \rightleftharpoons C\,(g); \qquad K = 1.1$

Which statement is correct when the reaction is at equilibrium?

A [A] >> [C]

B [A] > [C]

C [A] = [C]

D [A] < [C]

6 For a gaseous reaction, the equilibrium constant expression is:

$$K = \frac{[O_2]^5[NH_3]^4}{[NO]^4[H_2O]^6}$$

Which equation corresponds to this equilibrium expression?

A $4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_2O$

B $4NO + 6H_2O \rightleftharpoons 4NH_3 + 5O_2$

C $8NH_3 + 10O_2 \rightleftharpoons 8NO + 12H_2O$

D $2NO + 3H_2O \rightleftharpoons 2NH_3 + O_2$

Standard Level Paper 1, Time Zone 1, May 2002, Q21

7 The Haber process is an industrial process for manufacturing ammonia from hydrogen and nitrogen gas. The reaction is:

$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g); \quad \Delta H = -92\,kJ\,mol^{-1}$

Which of the following statement best describes the conditions for the process?

A High temperature and pressure is required for a high yield of ammonia.

B Low temperature and low pressure are required for a high yield of ammonia.

C The temperature employed cannot be too high or the reaction will be too slow.

D The pressure employed during the process cannot be too high due to high costs.

8 Solid iodine and gaseous iodine are at equilibrium inside a sealed container.

$I_2\,(s) \rightleftharpoons I_2\,(g)$

Which change will shift the position of equilibrium to the right?

A increasing the mass of solid iodine

B decreasing the mass of solid iodine

C increasing the volume of the container

D decreasing the temperature of the mixture

9 Which changes will shift the position of equilibrium to the right in the following reaction?

$CH_4\,(g) + H_2S\,(g) \rightleftharpoons CS_2\,(g) + 4H_2\,(g); \quad \Delta H^{\ominus} > 0$

I decreasing the concentration of hydrogen gas

II adding a catalyst

III increasing the volume of the container

A I and II only

B I and III only

C II and III only

D I, II and III

10 Which of the following changes is always true for a chemical reaction that has reached chemical equilibrium?

A The yield of the product(s) is greater than 50%.

B The rate of the forward reaction is greater than the backward reaction.

C The amounts of reactants and products do not change.

D Both forward and backward reactions have stopped.

11 Consider the following equilibrium system:

$2AlCl_3\,(g) \rightleftharpoons Al_2Cl_6\,(g); \quad \Delta H^{\ominus} < 0$

Which of the following statements will cause the position of the above equilibrium to shift to the left?

A decreasing the volume of the vessel

B increasing the temperature

C pumping inert gas into the vessel at constant volume

D pumping $AlCl_3$ gas into the vessel

(Questions 12–15 HL only)

12 An equilibrium can be represented by the following chemical equation.

$A\,(aq) + B\,(aq) \rightleftharpoons 2C\,(aq) + D\,(aq)$

In a certain 1.0 dm^3 mixture, the equilibrium concentration of B is 10.0 mol dm^{-3}.

What will be the new equilibrium concentration of B if 5 moles of pure B is dissolved in the mixture?

A 15.0 mol dm^{-3}

B between 10.0 mol dm^{-3} and 15.0 mol dm^{-3}

C between 5.0 mol dm^{-3} and 10.0 mol dm^{-3}

D 10.0 mol dm^{-3}

13 $H_2\,(g)$ and $I_2\,(g)$ react according to the following equilibrium:

$H_2\,(g) + I_2\,(g) \rightleftharpoons 2HI\,(g)$

When 0.10 mol of $H_2\,(g)$ and 0.10 mol of $I_2\,(g)$ are heated in a sealed vessel at 600 K, 0.06 mol of HI is present at equilibrium.

What is the K value for the reaction at 600 K?

A 0.184

B 1.360

C 0.360

D 0.735

14 At 445 °C, the equilibrium constant (K) for the following reaction is 0.020.

$2HI\ (g) \rightleftharpoons H_2\ (g) + I_2\ (g)$

A mixture of H_2, I_2, and HI in a vessel at 445 °C has the following concentrations: $[HI] = 2.0\,mol\,dm^{-3}$, $[H_2] = 0.50\,mol\,dm^{-3}$ and $[I_2] = 0.10\,mol\,dm^{-3}$.

Which one of the following statements concerning the reaction quotient, Q, is correct for this equilibrium system?

A $Q = K$ and the system is at equilibrium.

B Q is less than K and more H_2 and I_2 will be produced.

C Q is less than K and more HI will be produced.

D Q is greater than K and more H_2 and I_2 will be produced.

15 N_2O_4 dissociates into NO_2 as shown in the equation below.

$N_2O_4\ (g) \rightleftharpoons 2NO_2\ (g)$

The equilibrium constant, K, for this dissociation at 373 K is $0.210\,mol\,dm^{-3}$. Which of the following statements is true?

A ΔG for the forward reaction is negative at 373 K.

B ΔG for the forward reaction is zero at 373 K.

C ΔH for the forward reaction is zero at 373 K.

D ΔH for the forward reaction is positive at 373 K.

Paper 2

1 The table gives information about the percentage yield of ammonia obtained in the Haber process under different conditions.

Pressure / atm	Temperature / °C			
	200	300	400	500
10	50.7	14.7	3.9	1.2
100	81.7	52.5	25.2	10.6
200	89.1	66.7	38.8	18.3
300	89.9	71.1	47.1	24.4
400	94.6	79.7	55.4	31.9
600	95.4	84.2	65.2	42.3

a From the table, identify which combination of temperature and pressure gives the highest yield of ammonia. [2]

b The equation for the main reaction in the Haber process is:

$N_2\ (g) + 3H_2\ (g) \rightleftharpoons 2NH_3\ (g)$; $\Delta H^{\ominus}$ is negative

Use this information to state and explain the effect on the yield of ammonia of increasing

i pressure [2]

ii temperature [2]

c In practice, typical conditions used in the Haber process are a temperature of 500 °C and a pressure of 200 atmospheres. Explain why these conditions are used rather than those that give the highest yield. [2]

d Write the equilibrium constant expression, K, for the production of ammonia. [1]

e **i** Suggest why this reaction is important for humanity. [1]

ii A chemist claims to have developed a new catalyst for the Haber process, which, unlike iron, increases the yield of ammonia. Evaluate the claim made by this chemist. [2]

2 Sulfur trioxide, SO_3, is formed when sulfur dioxide, SO_2, reacts reversibly with oxygen, O_2.

At 500 °C, 0.100 mol of SO_2 was mixed with 0.050 mol of O_2 in a 1 dm^3 vessel. The mixture was allowed to reach dynamic equilibrium and the mixture at equilibrium contained 0.020 mol of SO_3.

a Write an equation with state symbols describing this system. [1]

b (HL only) Calculate the equilibrium concentrations of SO_2 and O_2. Hence calculate the equilibrium constant, K, of the reaction at 500 °C. [4]

3 Methanol is an important alcohol used in fuel mixtures, making methyl esters and oxidation to methanol (formaldehyde) to make urea–formaldehyde resin glues.

Methanol is manufactured industrially from carbon monoxide and hydrogen gas in an enclosed system according to the following reaction.

$CO\ (g) + 2H_2\ (g) \rightleftharpoons CH_3OH\ (g)$; $\Delta H = -90\,kJ\,mol^{-1}$

The reaction is typically subjected to the following industrial conditions.

Pressure	50 MPa
Temperature	250 °C
Catalyst	copper-zinc oxide mixture

a Describe what happens at dynamic equilibrium. [2]

b Suggest the effect of the high pressure and catalyst used under industrial conditions have on the position of equilibrium and the rate of reaction. [4]

c The reaction is performed at a moderately high temperature of 250 °C. Suggest why a low temperature is not used industrially instead. [2]

(Question 4 HL only)

4 Methanol can be formed from carbon monoxide and hydrogen:

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

The reaction was investigated by mixing 3.20 mol of carbon monoxide and 3.20 mol of hydrogen in a 10.0 dm^3 sealed vessel, and equilibrium was established at 120 °C under a pressure of 1.60×10^6 Pa.

a Assuming ideal gas behaviour, determine the total amount of gas in moles, at equilibrium. [1]

b Calculate the amounts (mol) of CO, H_2 and CH_3OH in moles, present at equilibrium. [3]

c Calculate the value (to 3 s.f.) for the equilibrium constant, *K*. [1]

d Calculate the change in Gibbs energy ($kJ\,mol^{-1}$), ΔG, for the formation of methanol from carbon monoxide and hydrogen at 120 °C. [1]

R3.1 Proton transfer reactions

Paper 1

1 10.00 cm^3 of 0.01 mol dm^{-3} nitric acid (HNO_3) is diluted with 90.00 cm^3 of water. What is the pH of the resulting solution?

A 4

B 3

C 2

D 1

2 Solutions of hydrochloric acid (HCl(aq)) and propanoic acid (C_2H_5COOH(aq)) of the same concentration reacted completely with 2.50 g of magnesium carbonate in separate containers. Which statement is correct?

A C_2H_5COOH (aq) reacted slower because it has a lower pH than HCl (aq).

B A smaller volume of CO_2 (g) was produced with C_2H_5COOH (aq) than with HCl (aq).

C A greater volume of CO_2 (g) was produced with C_2H_5COOH (aq) than with HCl (aq).

D The same volume of CO_2 (g) was produced with both C_2H_5COOH (aq) and HCl (aq).

3 Which of the following represents the reaction between zinc powder and a dilute aqueous solution of sulfuric acid?

A $Zn + 2H_2SO_4 \rightarrow 2ZnS + 2H_2O + 3O_2$

B $4Zn + H_2SO_4 \rightarrow 4ZnO + H_2S$

C $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

D $Zn + H_2SO_4 \rightarrow ZnH_2 + SO_2 + O_2$

4 When the following 1.00 mol dm^{-3} aqueous solutions are listed in increasing order of pH (lowest first), what is the correct order?

A $HNO_3 < HCOOH < NH_3 < Ba(OH)_2$

B $NH_3 < Ba(OH)_2 < HCOOH < HNO_3$

C $Ba(OH)_2 < HCOOH < NH_3 < HNO_3$

D $HNO_3 < HCOOH < Ba(OH)_2 < NH_3$

5 The amino acid alanine has the molecular structure $NH_2CH(CH_3)COOH$

Which of the following species represents its conjugate acid?

A $^+NH_3CH(CH_3)COOH$

B $^+NH_3CH(CH_3)COOH_2^+$

C $^+NH_3CH(CH_3)COO^-$

D $NH_2CH(CH_3)COO^-$

6 Which of the following mixtures is **not** an acid / conjugate base pair?

A H_2O/OH^-

B $H_2PO_4^-/HPO_4^{2-}$

C KH/K

D NH_3/NH_2^-

7 Which ions produced by the ionization of phosphoric(V) acid, H_3PO_4, are amphiprotic?

A HPO_4^{2-} and PO_4^{3-}

B $H_2PO_4^-$ and HPO_4^{2-}

C HPO_4^{2-} only

D $H_2PO_4^-$ and PO_4^{3-}

8 Which is a conjugate acid–base pair according to the Brønsted–Lowry theory?

$$CH_2ClCOOH\ (aq) + H_2O\ (l) \rightleftharpoons CH_2ClCOO^-\ (aq) + H_3O^+\ (aq)$$

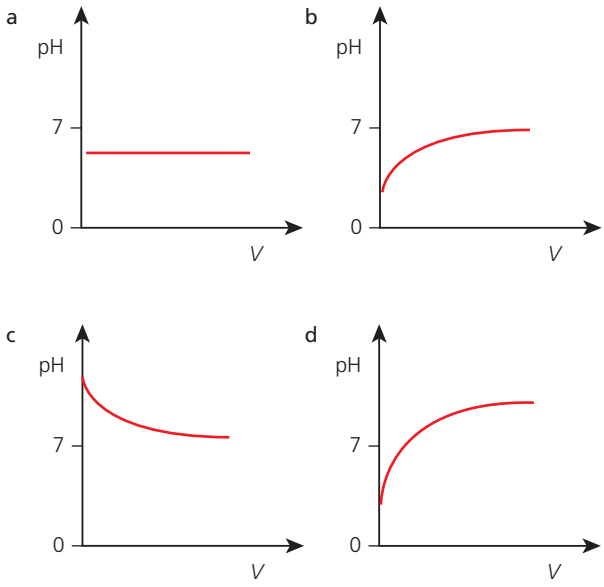
A H_2O / H_3O^+

B H_2O / CH_2ClCOO^-

C CH_2ClCOO^- / H_3O^+

D $CH_2ClCOOH$ / H_2O

9 A sample of benzenecarboxylic acid solution, C_6H_5COOH (aq), is diluted at constant temperature. Which diagram shows how the pH of the acid changes as it is diluted? [*V* is the volume of water added.]



10 Under suitable conditions, NH_4I and $NaNH_2$ react as follows:

$NH_4I + KNH_2 \rightarrow KI + 2NH_3$

Which term best describes the above reaction?

A reduction-oxidation reaction

B displacement reaction

C Brønsted–Lowry acid–base reaction

D substitution reaction

(Questions 11–22 HL only)

11 When the following acids are listed in decreasing order of acid strength (strongest first), what is the correct order?

Acid	K_a
benzoic	6.31×10^{-5}
fluoroethanoic	2.50×10^{-3}
ethanoic	1.74×10^{-5}

A fluoroethanoic > benzoic > ethanoic

B benzoic > ethanoic > fluoroethanoic

C fluoroethanoic > ethanoic > benzoic

D ethanoic > benzoic > fluoroethanoic

12 The strengths of organic acids can be compared using K_a and pK_a values.

Which acid is the strongest?

A	acid A	$pK_a = 6.6$
B	acid B	$pK_a = 2.5$
C	acid C	$K_a = 1 \times 10^{-5}$
D	acid D	$K_a = 1 \times 10^{-3}$

13 Phosphoric(V) acid, H_3PO_4, is a triprotic acid which has three acid dissociation constants. The table below shows the first, second and third acid dissociation constants, K_a, respectively.

Ionization	Equilibrium in aqueous solution	K_a / mol dm^{-3}
first	$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$	7.5×10^{-3}
second	$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HPO_4^{2-}(aq)$	6.2×10^{-8}
third	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq)$	2.2×10^{-13}

Which of the following ranks the conjugate bases in order of increasing basicity?

	Lowest	⟶	Highest
A	PO_4^{3-}	HPO_4^{2-}	$H_2PO_4^-$
B	$H_2PO_4^-$	HPO_4^{2-}	PO_4^{3-}
C	HPO_4^{2-}	PO_4^{3-}	$H_2PO_4^-$
D	HPO_4^{2-}	$H_2PO_4^-$	PO_4^{3-}

14 What is correct for ultra-pure hot water?

	pH	$[H^+(aq)]$ $[OH^-(aq)]$
A	above 7	$[H^+(aq)] = [OH^-(aq)]$
B	below 7	$[H^+(aq)] > [OH^-(aq)]$
C	below 7	$[H^+(aq)] = [OH^-(aq)]$
D	exactly 7	$[H^+(aq)] = [OH^-(aq)]$

15 Stomach juices have a pH of 1.0.

Aspirin is a monoprotic acid represented by HA ($K_a = 10^{-4}$ mol dm^{-3}) which dissociates into ions H^+ and A^-. What are the relative concentrations of H^+, A^- and HA when aspirin from a tablet enters the stomach?

A	$[H^+] > [HA] > [A^-]$	**B**	$[HA] > [H^+] = [A^-]$
C	$[H^+] > [A^-] > [HA]$	**D**	$[H^+] = [A^-] > [HA]$

16 Aqueous solutions of CH_3COOH and HCl of equal concentration (and at the same temperature) are compared. Which statement is not correct?

A The ionization of CH_3COOH is less than HCl.

B HCl reacts with K_2O but CH_3COOH does not.

C The K_a of CH_3COOH is smaller than the K_a of HCl.

D HCl has a greater electrical conductivity than CH_3COOH.

17 What is a possible value of pH at the equivalence point in the titration of a strong acid with a weak base?

A 11

B 8

C 7

D 5

18 Which of the following 1 dm^3 acid solutions will form an acidic buffer when added to 1 dm^3 0.100 mol dm^{-3} NaOH?

A 0.200 mol dm^{-3} HCl

B 0.200 mol dm^{-3} CH_3CO_2H

C 0.050 mol dm^{-3} $(COOH)_2$

D 0.100 mol dm^{-3} H_2SO_4

19 Pepsin in the stomach operates at a maximum rate when in an aqueous solution buffered at acidic condition. Which combination of substances, when dissolved in 10 dm^3 of water, would produce the acidic buffer solution?

A 1 mol of HCl and 1 mol of CH_3COOK

B 2 mol of CH_3COOH and 1 mol of KOH

C 2 mol of NH_3 and 1 mol of HCl

D 1 mol of KOH and 1 mol of NH_4Cl

20 What is the volume of 0.100 mol dm^{-3} NaOH that should be added to 20.0 cm^3 of 0.100 mol dm^{-3} CH_3COOH ($K_a = 1.8 \times 10^{-5}$) to form a buffer of pH 5.5?

A 15.0 cm^3

B 16.0 cm^3

C 17.0 cm^3

D 18.0 cm^3

21 Bromocresol green indicator has a pH range of 3.8–5.5. It is yellow at pH < 3.8 and blue at pH > 5.5. Which statement about bromocresol green is incorrect?

A The indicator is suitable for a strong acid–weak base titration.

B The indicator is yellow in 0.10 mol dm^{-3} of an acid with $K_a = 10^{-5}$ mol dm^{-3}.

C The indicator is green in a solution containing equimolar concentrations of CH_3COOH and CH_3COOK. (pK_b of CH_3COOK = 9.24)

D When an acid in the conical flask is titrated against a base, the indicator changes from yellow to blue at the end-point.

22 Which salt will dissolve in water to give a solution with a pH greater than 7?

A rubidium chloride

B sodium carbonate

C ammonium nitrate

D calcium sulfate

Paper 2

1 **a** Outline the Brønsted–Lowry theory of acids and bases. [2]

b Write a chemical equation, including state symbols, to show why rain water is slightly acidic. [1]

c The carbonate ion is a conjugate base of the hydrogencarbonate ion, HCO_3^-.

Define the term conjugate base. [1]

d Using appropriate chemical equations, show that the hydrogencarbonate ion is amphiprotic and can act as a proton donor and a proton acceptor. [2]

(Questions 2–6 HL only)

2 During exercise, muscle cells convert glucose into lactic acid (2-hydroxypropanoic acid). A sample of blood was taken from an athlete. A sample of lactic acid having a mass of 1.00 g was extracted from a blood sample. It was dissolved in water and titrated with 0.250 mol dm^{-3} calcium hydroxide, $Ca(OH)_2$. It was found that 22.30 cm^3 of $Ca(OH)_2$ was required for neutralization.

a Calculate the molar mass of lactic acid. [3]

A solution of lactic acid with concentration 0.10 mol dm^{-3} has a pH of 2.43.

b Use the data given to calculate the concentration of hydrogen ions and determine value of K_a for lactic acid. [2]

c Explain, using equations, why an aqueous mixture of lactic acid and sodium lactate can act as a buffer solution

i on addition of acid [1]

ii on addition of alkali. [1]

You may represent lactic acid as HA and sodium lactate as Na^+A^-.

A buffer solution best resists pH changes when the concentrations of lactic acid and that of sodium lactate in the buffer are the same.

d Determine the mass of sodium lactate that needs to be added to 500 cm^3 of 0.100 mol dm^{-3} solution of lactic acid to create this buffer solution. [2]

3 When carbon dioxide reacts with water, it forms carbonic acid, H_2CO_3, which ionizes into hydrogencarbonate ions, HCO_3^-, and hydrogen ions, H^+, into the sea, decreasing its pH and causing acidification.

A solution of 0.100 mol dm^{-3} H_2CO_3 has a pH of 3.68. Due to the increasing levels of atmospheric CO_2, the pH of seawater has decreased over 150 years from 8.25 to 8.14.

HCO_3^- and CO_3^{2-} are the essential components of the carbonate buffer system which regulates the pH of seawater.

$$CO_2\,(aq) + CO_3^{2-}\,(aq) + H_2O\,(l) \rightleftharpoons 2HCO_3^-\,(aq)$$

The natural pH of the ocean is determined by the deposition of calcium carbonate in coral reefs against the entry of calcium and carbonate ions into the ocean from weathering of limestone rocks and other minerals on land.

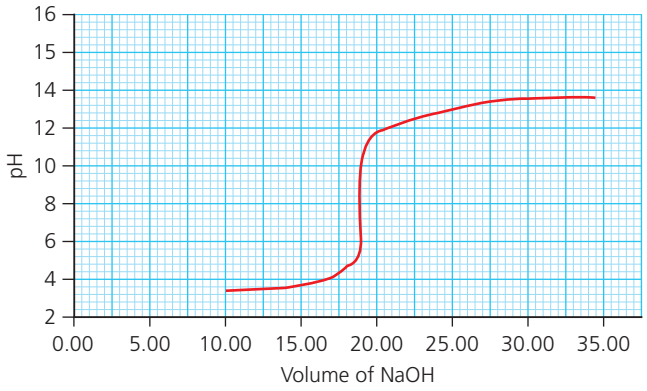
$$Ca^{2+}\,(aq) + CO_3^{2-}\,(aq) \rightleftharpoons CaCO_3\,(s)$$

a Explain, with the aid of appropriate calculations, whether carbonic acid, H_2CO_3, is a strong or weak acid. Assume carbonic acid to be monoprotic in your calculations. [2]

b Calculate the percentage increase in the concentration of H^+ ions in the last 150 years. [2]

c Suggest another environmental problem that can contribute to ocean acidification. [1]

4 A 20.00 cm^3 solution of the weak monoprotic acid (HA), was titrated against a solution of 0.50 mol dm^{-3} of sodium hydroxide in which a few drops of indicator had been added. The pH readings were not recorded until 10.00 cm^3 of sodium hydroxide had been added.



a State the volume of sodium hydroxide needed to exactly neutralize the weak acid and hence calculate the amount of sodium hydroxide, in moles, required for neutralization. [2]

b Write an expression for the dissociation constant, K_a, of the weak acid. [1]

c Calculate a value for the dissociation constant, K_a, of the weak acid if the pH of the solution titrated is 2.10. [4]

d Given the following information about three indicators, state and explain which indicator is the most suitable for determining the end-point of this reaction. [2]

Indicator	pH range of colour change
methyl red	4.4–6.2
cresol red	7.2–8.8
alizarin yellow	10.1–12.0

5 a In the reaction

$2H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + OH^-\ (aq)$

use the Brønsted–Lowry theory to discuss the acidic and/or basic nature of water molecules. [2]

b State the conjugate acid of the hydroxide ion, OH^- [1]

c Define the terms pH and pOH and state the values of pH and pOH of pure water (at 25 °C). [4]

d i Write an expression for the ion product of water, K_w. [1]

ii The value of K_w increases with temperature. Explain with reasoning whether the dissociation of water is endothermic or exothermic. [3]

iii State the effect of an increase in temperature on the ratio $[H^+]\ [OH^-]$. [1]

6 a i A 25.00 cm^3 sample of 0.100 mol dm^{-3} hydrochloric acid is placed in a conical flask, and 0.100 mol dm^{-3} potassium hydroxide is added until a total of 50.00 cm^{-3} has been added.

Sketch a graph of pH against volume of KOH (aq) added, clearly showing the volume of KOH (aq) needed for complete reaction and the pH value at the start, the equivalence point and finish. [4]

ii The experiment in a ii was repeated but with 25.00 cm^3 sample of 0.100 mol dm^{-3} ethanoic acid ($pK_a = 4.76$) in the conical flask instead of the hydrochloric acid.

Calculate the pH at the start of the experiment. State and explain the approximate pH value at the equivalence point. [6]

b i Describe how an indicator, HIn, that is a weak acid functions in aqueous solution. [3]

ii Name a suitable indicator for the reaction between ethanoic acid and potassium hydroxide. Use the information from in the IB *Chemistry data booklet* to explain your choice. [2]

R3.2 Electron transfer reactions

Paper 1

1 What is the coefficient of H^+ (aq) when the following redox equation in aqueous solution is balanced using integers?

$$\_MnO_4^-\,(aq) + \_H_2O_2\,(aq) + \_H^+\,(aq) \rightarrow \_Mn^{2+}\,(aq) + \_O_2\,(g) + \_H_2O\,(l)$$

A 16

B 10

C 8

D 6

2 Consider the following reaction:

$$3H_2Se + 8HFeO_4^- + 6H_2O \rightarrow 8Fe(OH)_3 + 3SeO_4^{2-} + 2OH^-$$

Which statement is correct?

A $HFeO_4^-$ is the oxidizing agent because it undergoes oxidation.

B $HFeO_4^-$ is the oxidizing agent because it undergoes reduction.

C H_2Se is the oxidizing agent because it undergoes reduction.

D H_2Se is the oxidizing agent because it undergoes oxidation

3 In the reaction

$$3I_2\,(aq) + 6CO_3^{2-}\,(aq) + 3H_2O\,(l) \rightarrow 5I^-\,(aq) + IO_3^-\,(aq) + 6HCO_3^-\,(aq)$$

A I_2 is only oxidized.

B I_2 is only reduced.

C I_2 is neither oxidized or reduced.

D I_2 is both oxidized and reduced.

4 Which of the reactions below is **not** a redox reaction?

A $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

B $3OH^- + P_4 + 3H_2O \rightarrow 3H_2PO_2^- + PH_3$

C $H_2S + Au_2SO_4 \rightarrow Au_2S + 2H^+ + SO_4^{2-}$

D $4KO_2 + 2CO_2 \rightarrow 2K_2CO_3 + 3O_2$

5 In which of the following reactions does the greatest change in oxidation state of nitrogen occur?

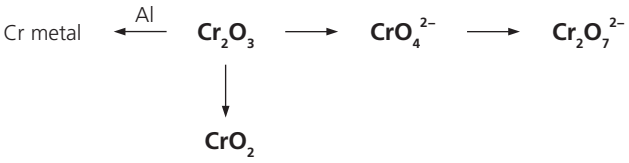
A $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

B $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

C $2NO + O_2 \rightarrow 2NO_2$

D $4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$

6 Chromium(III) oxide, Cr_2O_3, can undergo different reactions to give other chromium-containing species as shown in the diagram below:



Which statement correctly describe these reactions?

A The formation of $Cr_2O_7^{2-}$ from CrO_4^{2-} is a redox reaction.

B Aluminium is acting as an oxidizing agent.

C CrO_3, CrO_4^{2-}, $Cr_2O_7^{2-}$ contains chromium in its highest oxidation state.

D Cr_2O_3 reacts with CrO_3 in a disproportionation reaction to give CrO_2.

7 Consider the following reactions which all occur in solution at room temperature.

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

$$Mg\,(s) + Zn^{2+}\,(aq) \rightarrow Mg^{2+}\,(aq) + Zn\,(s)$$

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

Which is the correct combination of the strongest oxidizing agent and the strongest reducing agent?

	strongest oxidizing agent	strongest reducing agent
A	Zn (s)	Fe^{2+} (aq)
B	Cu^{2+} (aq)	Mg (s)
C	Mg (s)	Cu^{2+} (aq)
D	Cu (s)	Mg^{2+} (aq)

8 Which conditions are used to convert ethanol to ethanal in the presence of an oxidizing agent?

A excess oxidizing agent and reflux

B excess oxidizing agent and distillation

C excess ethanol and reflux

D excess ethanol and distillation

9 Which compounds are susceptible to oxidation with potassium manganate(VII)?

I $CH_3CH_2CH_2CH_2OH$

II $(CH_3)_3CCH_2OH$

III $CH_3CH_2CH(OH)CH_3$

A I and II only

B I and III only

C II and III only

D I, II and III

10 Which alcohol would produce a carboxylic acid when heated with acidified potassium dichromate(VI)?

A propan-2-ol

B butan-1-ol

C 2-methylpropan-2-ol

D pentan-3-ol

11 Which of these functional groups will react with a reducing agent?

I alkoxy

II carboxyl

III carbonyl

A I and II only

B I and III only

C II and III only

D I, II and III

12 All non-cyclic structural isomers of alcohols with molecular formula $C_4H_{10}O$ are reacted with hot acidified $KMnO_4$. How many will decolourize the purple $KMnO_4$?

A 2

B 3

C 4

D 5

13 A voltaic cell is made by connecting zinc and metal W half-cells. The overall equation for the reaction occurring in the cell is shown below.

$Zn\ (s) + W^{2+}\ (aq) \rightarrow W\ (s) + Zn^{2+}\ (aq)$

Which statements are correct when the cell produces electricity?

I The zinc is oxidized.

II The mass of the metal W decreases.

III Electrons move from zinc to metal W in the external circuit.

A I and II

B I and III

C II and III

D I, II and III

14 What happens at the cathode of an electrolytic cell and voltaic cell respectively?

	Electrolytic cell	Voltaic cell
A	oxidation	reduction
B	oxidation	oxidation
C	reduction	reduction
D	reduction	oxidation

15 Which statement is correct about the electrolysis of copper(II) sulfate solution using graphite electrodes?

A A colourless and odourless gas is produced at the negative electrode (cathode).

B The electrolyte does not lose its blue colour.

C The negative electrode (cathode) decreases in mass.

D A colourless and odourless gas is produced at the positive electrode (anode).

16 Starting with the appropriate metal electrode, which one of the following would be produced by the passage of 1 mole of electrons during electrolysis?

A 0.5 mole of Cu^{2+}

B 1.0 mole of Ni^{2+}

C 1.5 mole of Cr^{3+}

D 3.0 mole of Al^{3+}

(Questions 17–28 HL only)

17 Consider the following standard electrode potential values:

$Cu^+ (aq) + e^- \rightleftharpoons Cu (s)$ $E^\ominus = +0.52\,V$

$MnO_4^- (aq) + 8H^+ (aq) + 5e^- \rightleftharpoons Mn^{2+} (aq) + 4H_2O (l)$ $E^\ominus = +1.51\,V$

What is the cell potential for this reaction?

$MnO_4^- (aq) + 8H^+ (aq) + 5Cu(s) \rightarrow Mn^{2+} (aq) + 4H_2O (l) + 5Cu^+ (aq)$

A +2.03

B +0.99

C −0.99

D −2.03

18 Consider the following standard electrode potential values:

$Fe^{3+} (aq) + 2e^- \rightleftharpoons Fe^{2+} (aq)$; $E^\ominus = +0.77\,V$

$Ni^{2+} (aq) + 2e^- \rightleftharpoons Ni (s)$; $E^\ominus = -0.26\,V$

$Fe^{2+} (aq) + 2e^- \rightleftharpoons Fe (s)$; $E^\ominus = -0.45\,V$

$Ca^{2+} (aq) + 2e^- \rightleftharpoons Ca (s)$; $E^\ominus = -2.87\,V$

Which reaction is spontaneous?

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

B $Fe (s) + 2Fe^{3+} (s) \rightarrow 3Fe^{2+} (aq)$

C $3Fe^{2+} (aq) \rightarrow Fe (s) + 2Fe^{3+} (aq)$

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

19 What condition is necessary for the electroplating of gold, Au onto a cleaned steel plate?

A The steel plate must be the positive electrode.

B The gold electrode must be the negative electrode.

C The steel plate must be the negative electrode.

D The electrolyte must contain dilute acid.

20 Which equation represents the reduction process occurring in the hydrogen half-cell?

A $H^+ (aq) + OH^- (aq) \rightarrow H_2O (l)$

B $H_2 (g) \rightarrow 2H^+ (aq) + 2e^-$

C $2H^+ (aq) + 2e^- \rightarrow H_2 (g)$

D $O_2 (g) + 4H^+ (aq) + 4e^- \rightarrow 2H_2O (l)$

21 Which is a feature of the hydrogen half-cell?

A hydrogen gas at 100 kPa

B 1.00 mol dm^{-3} sulfuric acid

C a silver electrode

D a temperature of 273 K

22 Aqueous solutions containing different concentrations of NaCl were electrolysed using inert platinum electrodes. What is the **major** product at the positive electrode in each case?

	0.0001 mol dm^{-3} NaCl(aq)	2.0 mol dm^{-3} NaCl (aq)
A	H_2	H_2
B	H_2	Na
C	O_2	Cl_2
D	Cl_2	O_2

23 Ethanol fuel cells are more practical than hydrogen fuel cells since ethanol is easier to store and transport than hydrogen. Ethanol is converted to carbon dioxide when the fuel cell is operated.

Which statement is correct about ethanol fuel cells?

A Ethanol fuel cells can work indefinitely as long as there is a supply of ethanol and air.

B Electrical energy is converted to chemical (chemical potential) energy.

C Hydrogen ions, $H^+ (aq)$, react with air to produce water at the anode.

D The acid needs to be replenished as hydrogen ions are being used up.

24 The standard electrode potentials of three elements, X, Y and Z, are:

X = +1.09 V

Y = +0.54 V

Z = +1.36 V

A Z will oxidize $X^- (aq)$ and $Y^- (aq)$.

B Y will oxidize $X^- (aq)$ and $Z^- (aq)$.

C X will oxidize $Z^- (aq)$ but not $Y^- (aq)$.

D Y is a stronger oxidizing agent than X.

25 The overall chemical equation for the electrolysis of acidified water using inert platinum electrodes is shown below:

$2H_2O (l) \rightarrow 2H_2 (g) + O_2 (g)$

Which combination of signs for the enthalpy change, entropy change and Gibbs energy change is correct?

	$\Delta H^\ominus$	$\Delta S^\ominus$	$\Delta G^\ominus$
A	+	+	+
B	−	−	−
C	−	+	+
D	+	−	−

26 Using the standard electrode potentials given, calculate the standard cell potential when an I_2, I^- half-cell ($E^\ominus = +0.54\,V$) is connected to a Cl_2/Cl^- half-cell ($E^\ominus = +1.36\,V$).

A +3.80 V

B +1.90 V

C +1.64 V

D +0.82 V

27 A student constructs a voltaic cell using tin and lead electrodes immersed in 1.00 mol dm^{-3} solutions of tin(II) and lead(II) ions.

What is the cell potential for the spontaneous reaction?

The electrode potentials are:

$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$ $\quad E^\ominus = -0.14\,V$

$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$ $\quad E^\ominus = -0.13\,V$

A −0.27 V

B −0.01 V

C +0.01 V

D +0.27 V

28 For which of the reactions below will be the Gibbs energy change $\Delta G^\ominus$ be the most negative?

A $Cu(s) + 2Ag^+(aq) \rightarrow 2Ag(s) + Cu^{2+}(aq)$ $\quad E^\ominus = +0.46\,V$

B $Co(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Co^{2+}(aq)$ $\quad E^\ominus = +0.62\,V$

C $Fe^{2+}(aq) + Cu^{2+}(aq) \rightarrow Fe^{3+}(aq) + Cu^+(aq)$ $\quad E^\ominus = -0.61\,V$

D $H_2(g) + Cr^{2+}(aq) \rightarrow Cr(s) + 2H^+(aq)$ $\quad E^\ominus = -0.74\,V$

Paper 2

1 a Use these equations, which refer to aqueous solutions, to answer the questions that follow:

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

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

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

(Au represents gold, which is below silver in the reactivity series.)

i List the metals above in order of decreasing reactivity. [1]

ii Define oxidation, in electronic terms, using one example from above. [2]

iii Define reduction, in terms of oxidation state, using one example from above. [2]

iv State and explain which is the strongest reducing agent in the examples above. [2]

v State and explain which is the strongest oxidizing agent in the examples above. [2]

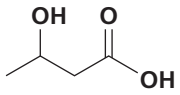
vi Deduce whether gold will react with aqueous magnesium nitrate. [2]

b Sketch a diagram of a cell used to electrolyse a molten salt. Label the essential components. [4]

c Describe how electrode reactions occur in an electrolytic cell and state the products at each electrode when molten copper(II) iodide is electrolysed. [5]

d Describe the two different ways in which electricity is conducted when the cell is in operation. [2]

2 3-hydroxybutanoic acid is a metabolite which the body can use to provide energy when it is low on glucose.



a Name the functional groups present in 3-hydroxybutanoic acid. [2]

b Draw the two stereoisomers of 3-hydroxybutanoic acid. [2]

c Draw the organic product formed when 3-hydroxybutanoic acid is left to react with an excess of a reducing agent and the mixture is quenched with acid. [1]

d i When 3-hydroxybutanoic acid is reacted with potassium manganate(VII) (an oxidizing agent) an unstable compound with a degree of unsaturation of 2 is formed. Suggest the structure of this unstable compound. [1]

ii The unstable compound produced decomposes to form carbon dioxide and one other product with a degree of unsaturation of 1. Identify the product formed in this decomposition reaction. [1]

3 During a titrimetric analysis, 25.00 cm^3 of an aqueous solution containing ethanol required 37.50 cm^3 of 1.50 mol dm^{-3} of acidified potassium dichromate(VI) solution for complete reaction. The density of ethanol is 0.790 g cm^{-3}.

During the reaction, ethanol, CH_3CH_2OH, is oxidized to ethanoic acid, CH_3COOH, while dichromate(VI) ions, $Cr_2O_7^{2-}$, react as shown in the following half–equation.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

a Explain, in terms of change in oxidation state why dichromate(VI) ions undergo reduction. [1]

b Write the half-equation for the oxidation of ethanol, CH_3CH_2OH, to ethanoic acid, CH_3COOH. [1]

c Use the half–equations to construct an ionic equation for the above redox reaction. [1]

d Using the titration results and relevant data calculate the volume of ethanol in 25.00 cm^3 of the alcoholic solution. [4]

e Determine the concentration as a percentage by volume of the alcoholic solution. [2]

4 Propan-2-ol can be used as a fuel in the fuel cell. At the anode propan-2-ol is oxidized to carbon dioxide. The electrons pass around the external circuit to the cathode. The protons formed from the oxidation move through the electrolyte to the cathode, where they react with oxygen to produce water.

a Formulate half-equations for the reactions at the anode and cathode respectively. [2]

b Formulate the equation for the overall reaction. [1]

c The fuel cell has a cell potential (under standard conditions) of 1.56 V. By using suitable data from the data booklet suggest a value for the $E^\ominus$ of the $CO_2/CH_3CH(OH)CH_3$ electrode reaction. [1]

d Suggest a possible advantage of using the propan-2-ol fuel cell compared to a hydrogen fuel cell. [1]

(Questions 5–8 HL only)

5 In copper-plating, orchids are coated with a thin layer of graphite paste before placing them in a bath of aqueous copper(II) sulfate and electroplating with copper as the anode.

a Suggest a reason why orchids are first coated with graphite. [1]

b Deduce the half equations at the cathode and anode. [2]

c To ensure high standards of electroplated orchids, the copper coating must be at least 0.5 mm thick. Given that the total surface area of a typical orchid is 10 cm^2 and the operating current is 20 A, calculate the time required to electroplate an orchid. [Density of copper = 8.96 g cm^{-3}]. [5]

6 An aqueous solution of potassium chloride is electrolysed. State and explain the different gaseous products obtained at the positive electrode (anode) if the concentration of aqueous potassium chloride is increased from 0.50 mol dm^{-3} to 5.00 mol dm^{-3}. [3]

7 Hydrogen peroxide can act as a reducing agent or an oxidizing agent depending on the reacting conditions.

a Define oxidation and reduction in terms of electron loss and gain. [2]

b Distinguish between the terms oxidizing and reducing agent. [2]

The two half-equations involving hydrogen peroxide are shown below:

$$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l); \quad E^\ominus = +1.78\,V$$

$$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq); \quad E^\ominus = +0.68\,V$$

c State and explain if hydrogen peroxide is more likely to be an oxidizing agent or reducing agent under standard conditions. [2]

The chemical equation for the decomposition of aqueous hydrogen peroxide is shown below:

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

d Calculate the $E^\ominus$ value for this reaction and hence explain if this reaction is spontaneous under standard conditions. [2]

8 a i Draw a diagram for the voltaic cell formed by connecting the following standard half-cells:

$$Ni(s) \mid Ni^{2+}(aq) \parallel Mn^{2+}(aq) \mid Mn(s)$$ [3]

ii Describe the key features of the hydrogen half-cell. [3]

b i Write an equation for the reaction in each half-cell, identifying the species which is oxidized and the oxidizing agent. [4]

ii State which electrode is the anode and state the direction of electron flow in the external circuit. [2]

iii For the overall cell, calculate its voltage and state the sign of ΔG. [2]

R3.3 Electron sharing reactions

Paper 1

1 Which statement is correct about the reaction between cyclohexane and chlorine in the gas phase in the presence of ultraviolet light?

A It involves heterolytic fission and chloride ions, Cl^-.

B It involves heterolytic fission and chlorine radicals, Cl•.

C It involves homolytic fission and chlorine radicals, Cl•.

D It involves homolytic fission and chloride ions, Cl^-.

2 Which are characteristic typical of radicals formed during the photochemical reaction between halogens and alkanes?

I It has a lone pair of electrons for coordination bond formation.

II It can be formed by the homolytic fission of a covalent bond.

III It is usually uncharged.

A I and II only

B I and III only

C II and III only

D I, II and III

3 Which species is a radical?

A $\bullet C_2H_5$

B $^+C_2H_5$

C $^-C_2H_5$

D CH_2CH_2

4 Which species reacts most readily with pentane in the gas phase?

A Br_2

B Br•

C Br^-

D Br^+

5 Which equation represents a propagation step in the reaction of chloromethane with bromine?

A $CH_3Cl \rightarrow \bullet CH_2Cl + H\bullet$

B $CH_3Cl + Br\bullet \rightarrow \bullet CH_2Cl + HBr$

C $\bullet CH_2Cl + Br\bullet \rightarrow CH_2ClBr$

D $CH_3Cl + Br\bullet \rightarrow CH_2ClBr + H\bullet$

6 Which of following are possible products when methane and chlorine are mixed and subjected to UV light?

I C_2H_6

II $CHCl_3$

III HCl

A I and II only

B I and III only

C II and III only

D I, II and III

7 Which of the following reactions is a radical substitution reaction?

A $CH_4 + 2Cl_2 \rightarrow CH_2Cl_2 + 2HCl$

B $CH_3CH_2OH \rightarrow CH_2CH_2 + H_2O$

C $CH_2CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$

D $CH_3Cl + NaOH \rightarrow CH_3OH + HCl$

8 Which of the following molecules is a radical?

A BF_3

B CO

C O_3

D NO

9 High–energy irradiation in the stratosphere produces radicals from chlorofluoroalkanes, commonly known as CFCs. The radicals form through homolytic fission of the weakest bonds in the molecules.

Which radical could result from this irradiation of $CHFClCF_2Cl$?

A CHFClC FCl

B $CHClCF_2Cl$

C $CHFCF_2Cl$

D $CFClCF_2Cl$

10 Ethane reacts with chlorine gas in the presence of ultraviolet light to form a mixture of products via free radical substitution. Which statement about this reaction is true?

A Homolytic fission occurs only in the initiation step.

B Bond formation occurs only in the termination step.

C Chloroethane is formed only in the propagation step.

D Small quantities of butane is formed only in the termination step.

11 Which reaction involves homolytic fission?

A $CH_4 + Cl_2$

B $CH_3I + KOH$

C $(C_2H_5)_3CCl + KOH$

D $C_6H_5CH_3 + HNO_3 + H_2SO_4$

Paper 2

1 Methylbenzene, $C_6H_5–CH_3$, reacts with chlorine to form different products depending on the reaction's conditions.

Gaseous methylbenzene and chlorine in the presence of ultraviolet radiation will form chloromethyl benzene, $C_6H_5–CH_2Cl$.

a Give the displayed formula of the product. [1]

b Give equations for the steps which lead to the production of chloromethyl benzene and explain the role of the ultraviolet radiation. [4]

c A small amount of by product with the relative formula mass of 182.3 g mol^{-1} is found. Suggest the molecular formula of this product. [1]

2 Bromine, Br_2, reacts with butane, C_4H_{10}, when exposed to ultraviolet light.

a State the type of reaction that occurs between bromine and butane and give the name of the product formed which does not contain a carbon atom. [2]

Some of the products produced in the mixture have the molecular formula $C_4H_8Br_2$.

b Give a single equation for the formation of $C_4H_8Br_2$ from bromine and butane. [1]

c State the number of structural isomers with the formula C_4H_8Br2 that could have been formed in the reaction between bromine and butane. [1]

One of the structural isomers with the molecular formula C_4H_9Br displays optical isomerism.

d Draw the displayed formula of the radical which leads to the formation of the two optical isomers. [1]

3 Iron(II) salts catalyse the decomposition of aqueous hydrogen peroxide to water and oxygen. The reaction mechanism involves •OH and HOO• free radicals.

$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\bullet + OH^-$

$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO\bullet + H^+$

a Define the term radical. [1]

b Draw the Lewis formula for the HOO• free radical. [1]

c State the type of catalysis that takes place between iron(II) sulfate and hydrogen peroxide and state the property of iron(II) sulfate that allows it to carry out its function as a catalyst in the above decomposition reaction. [2]

R3.4 Electron pair sharing reactions

Paper 1

1 Which compound would decolourize bromine water?

A CH_3CH_3

B $CH_3(CH_2)_4OH$

C $CH_3CHCHCH_3$

D $CH_3COCH_2CH_3$

2 Which terms correctly describe the role an azide ion, N_3^-, plays in the following reaction:

$N_3^- + CH_3CH_2Br \rightarrow CH_3CH_2N_3 + Br^-$

I nucleophile

II Lewis base

III Lewis acid

A I and II only

B I and III only

C I only

D III only

3 Which of these is not able to act as a nucleophile?

A ammonia molecule

B water molecule

C methane molecule

D ethanol molecule

4 Study the reaction scheme below. What could compound X be?

Step 1. $CH_3CH_2I \rightarrow X$ Step 2. $X \rightarrow CH_3COOH$

A CH_3CHO

B CH_3OCH_3

C $H_2C{=}CHI$

D CH_3CH_2OH

5 What type of reactions do alkenes typically take part in?

A electrophilic substitution

B nucleophilic addition

C neutralization

D electrophilic addition

6 What are the species produced by heterolytic fission of bromine molecules?

A 2Br•

B $Br^+ + Br^-$

C $2Br^+$

D $2Br^-$

(Questions 7–21 HL only)

7 Which halogenoalkane would have the fastest rate of reaction with potassium hydroxide?

A $(CH_3)_3CF$

B $(CH_3)_3CCl$

C $(CH_3)_3CBr$

D $(CH_3)_3CI$

8 Which species are **both** Lewis and Bronsted–Lowry bases?

I CH_3COO^-

II OH^-

III $N(CH)_3$

A I and II only

B II and III only

C I and III only

D I, II and III

9 What is the major product of the reaction between HCl and but-2-ene?

A 2-chlorobutane

B 1-chlorobutane

C 2,3-dichlorobutane

D 1,2-dichlorobutane

10 Which type of bond is formed when a Lewis acid reacts with a Lewis base?

A covalent

B hydrogen

C double

D dipole–dipole

11 The reaction of ethene with bromine in the presence of aqueous potassium chloride gives a mixture of products. Which pair of products will be present in the mixture?

A $CH_2Br{-}CH_2Br$ and $CH_2OH{-}CH_2Cl$

B $CH_2Br{-}CH_2Br$ and $CH_2Cl{-}CH_2Br$

C $CH_2Br{-}CH_2Br$ and $CH_2OH{-}CH_2Cl$

D $CH_2Br{-}CH_2Br$ and $CH_2Cl{-}CH_2Cl$

12 In which complex ion does iron have the oxidation state +2?

A $[Fe(H_2O)_6]^{3+}$

B $[Fe(NH_3)_4Cl_2]Cl$

C $[Fe(Cl)_4]^-$

D $[Fe(CO)_4Cl_2]$

13 Which statement about the reaction of a hydroxide ion with the organic reagent is correct?

A 1-bromopentane predominately follows an S_N1 mechanism.

B 2-bromo-2-methyl butane predominately follows an S_N2 mechanism.

C Reaction with 1-bromopentane occurs at a slower rate than with 1-chloropentane.

D Reaction with 1-bromopentane occurs at a slower rate than with 2-bromo-2-methyl butane.

14 Which statement is correct about the major reaction between 1-chloropropane, $CH_3CH_2CH_2Cl$, and dilute sodium hydroxide solution, NaOH (aq)?

A The rate equation is second order.

B Water is a product.

C The reaction has two elementary steps.

D The hydroxide ion acts a base.

15 Why does the reaction $CH_3CH_2X + OH^- \rightarrow CH_3CH_2OH + X^-$ take place more rapidly in dilute aqueous solution when X is Br than when X is Cl?

A The Br^- is a stronger nucleophile than Cl^-.

B The C–Br bond is weaker than the C–Cl bond.

C The C–Cl bond is more polar than C–Br bond.

D The Br^- is less hydrated in solution than Cl^-.

16 The acidity of boric acid can be described by the following equilibrium:

$B(OH)_3\ (aq) + H_2O\ (l) \rightleftharpoons B(OH)_4^-\ (aq) + H^+\ (aq)$

Which of the following statements related to this interpretation of the acidity of boric acid is correct?

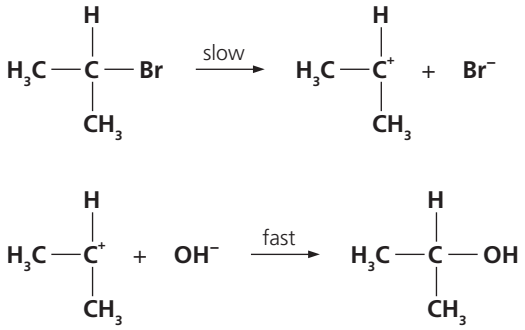
A Boric acid donates a pair of electrons to form a new bond.

B Boric acid is a Brønsted–Lowry acid.

C Boric acid is a Lewis acid.

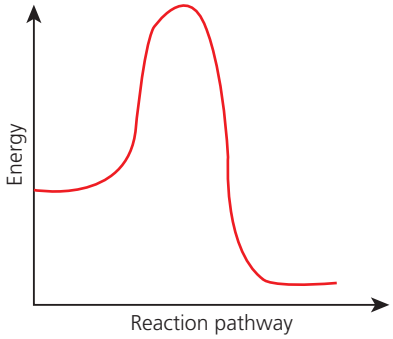
D Boric acid is a weak diprotic acid.

17 2-bromopropane undergoes nucleophilic substitution with aqueous NaOH via the following mechanism.



Which of the reaction pathway diagram fits the above mechanism?

a



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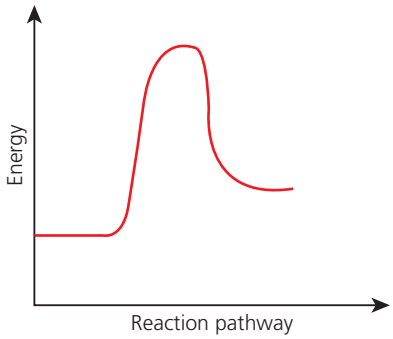

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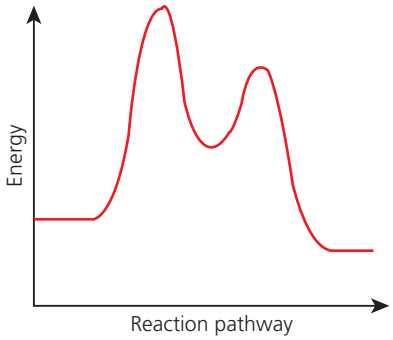

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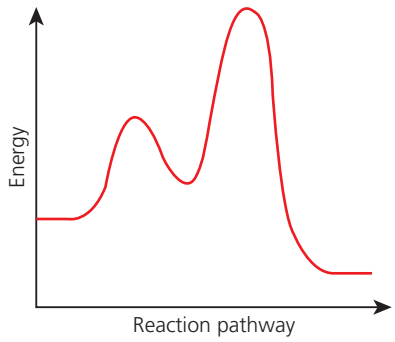
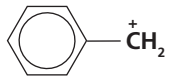


18 Which species could be an intermediate in an S_N1 substitution?

a



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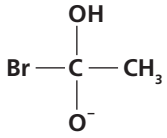

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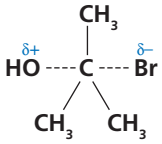

19 Which statement regarding the nucleophilic substitution reaction between 3-bromo-3-methylhexane, $CH_3CH_2C(CH_3)BrCH_2CH_2CH_3$, and water is incorrect?

A The reaction has two elementary steps.

B The substitution occurs mainly by the S_N1 mechanism.

C A single optical isomer will be produced.

D The rate of reaction would be unaffected by changing concentration of the nucleophile.

20 Which of the following will not react with benzene in an electrophilic substitution reaction?

A Cl^-

B R^+

C NO_2^+

D Cl^+

21 Which of the following would form the most stable carbocation in an electrophilic addition reaction with hydrogen bromide?

A CH_2CH_2

B CH_3CHCH_2

C $CH_3CH_2CHCHCH_2CH_3$

D $(CH_3)_2C{=}C(CH_3)_2$

Paper 2

1 Heterolytic fission of the hydrogen–chlorine bond occurs when hydrogen chloride molecules are dissolved in water.

a Complete the equation and add curly arrows to show the fission process occurring. [1]

$$H{-}Cl \rightarrow$$

Hydrogen chloride in the gaseous phase will react with gaseous ethene to form X.

$HCl + CH_2CH_2 \rightarrow X$

b i State the type of reaction occurring and name X. [2]

ii suggest a suitable nucleophile to turn X into ethanol. [1]

(Questions 2–4 HL only)

2 Describe an experiment to compare the rates of hydrolysis of 2-chlorobutane, 2-bromobutane and 2-iodobutane. State and explain the trend in the rates of reaction. [6]

3 Alkenes react readily with the interhalogen compound, iodine monochloride, I–Cl to give a halogenalkane containing both I and Cl. ICl reacts faster with alkenes than pure halogens. [1]

a Suggest why ICl reacts with alkenes faster than the pure halogens, Cl_2, Br_2 and I_2. [1]

b Name and draw the mechanism of reaction between propene and ICl to give the major product. [5]

c Draw the pair of enantiomers of the major product from the reaction between propene and ICl. [1]

4 This question is about the reactions of benzene and its derivatives.

When Z is treated with a strong Lewis acid such as aluminium chloride, it forms a powerful electrophile, $CH_3CH_2^+$, which can react with benzene, C_6H_6.

a Suggest the identity of Z and draw the mechanism for the reaction between benzene and $CH_3CH_2^+$. [3]

The reaction between the primary halogenoalkane, benzyl chloride, $C_6H_5CH_2Cl$, and sodium hydroxide is known follow the rate equation:

rate = k [benzyl chloride]

b i State the name of and draw the mechanism of the reaction which is consistent with the rate equation. [3]

ii Suggest a possible reason why, despite being a primary halogenoalkane, benzyl chloride adopts the mechanism you have drawn. [2]

When phenylamine, $C_6H_5NH_2$, is added to an aqueous solution of copper(II) ions the solution turns a deeper shade of blue due to the formation of a new complex ion involving phenylamine.

c i What name is given to the bond between the copper and phenylamine? [1]

ii Define a Lewis acid and identify the Lewis acid in the complex ion. [2]