



Cambridge International AS & A Level

CHEMISTRY

9701/11

Paper 1 Multiple Choice

May/June 2022

1 hour 15 minutes

You must answer on the multiple choice answer sheet.

You will need: Multiple choice answer sheet
Soft clean eraser
Soft pencil (type B or HB is recommended)

INSTRUCTIONS

- There are **forty** questions on this paper. Answer **all** questions.
- For each question there are four possible answers **A**, **B**, **C** and **D**. Choose the **one** you consider correct and record your choice in soft pencil on the multiple choice answer sheet.
- Follow the instructions on the multiple choice answer sheet.
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- Do **not** use correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.

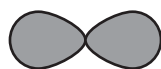
INFORMATION

- The total mark for this paper is 40.
- Each correct answer will score one mark.
- Any rough working should be done on this question paper.
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **16** pages.



- 1 Which atom has its outermost electron in an orbital of the shape shown, with principal quantum number 3?



- A sodium
B chlorine
C calcium
D bromine
- 2 Which atom has the same number of electrons as the hydroxide ion, OH^- ?
- A F B Ne C Na D Mg
- 3 In separate experiments, 5.0 g samples of each of four s-block metals are added to an excess of water. The gas evolved is collected and its volume measured under the same conditions of temperature and pressure for each sample.

Which metal produces the largest volume of gas?

- A calcium
B potassium
C rubidium
D strontium
- 4 A student reacts 1 mol of copper with concentrated nitric acid to produce 1 mol of copper(II) nitrate, 2 mol of water and substance X. No other product is formed.

Substance X does not contain copper or hydrogen.

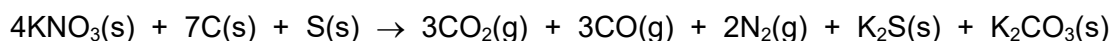
What could be substance X?

- A N_2 B N_2O C NO D NO_2
- 5 In which structure are three atoms bonded together in a straight line?
- A poly(ethene), $-\text{CH}_2\text{CH}_2-\text{CH}_2\text{CH}_2-$
B propane, C_3H_8
C silicon tetrachloride, SiCl_4
D sulfur hexafluoride, SF_6

6 Which statement about aluminium chloride is correct?

- A Aluminium chloride has a much higher melting point than magnesium chloride due to the small size of the aluminium ion.
- B Anhydrous aluminium chloride reacts vigorously with water to form a solution with a pH greater than 7.
- C Each Al_2Cl_6 molecule found in aluminium chloride vapour contains two coordinate bonds.
- D The bonding between aluminium and chlorine is strongly ionic due to the large difference in electronegativity.

7 'Black powder' is a mixture of potassium nitrate, carbon and sulfur. The mixture reacts as shown.



A sealed tube containing black powder has a volume of 10.0 cm^3 . When all of the black powder reacts, the reaction causes a pressure of $2 \times 10^6 \text{ Pa}$ and a temperature of 2500 K .

The volume of the K_2CO_3 and K_2S produced can be ignored.

How many moles of KNO_3 are contained in the sealed tube?

- A 4.81×10^{-4} B 9.63×10^{-4} C 1.93×10^{-3} D 9.63×10^{-1}

8 For which pair is the boiling point of the first compound **higher** than the boiling point of the second compound?

- A CH_3CH_2OH and CH_3CH_2SH
- B $CH_3CO_2CH_3$ and $CH_3CH_2CO_2H$
- C CH_3OCH_3 and CH_3CH_2OH
- D CH_3CH_2CHO and $CH_3CH_2CO_2H$

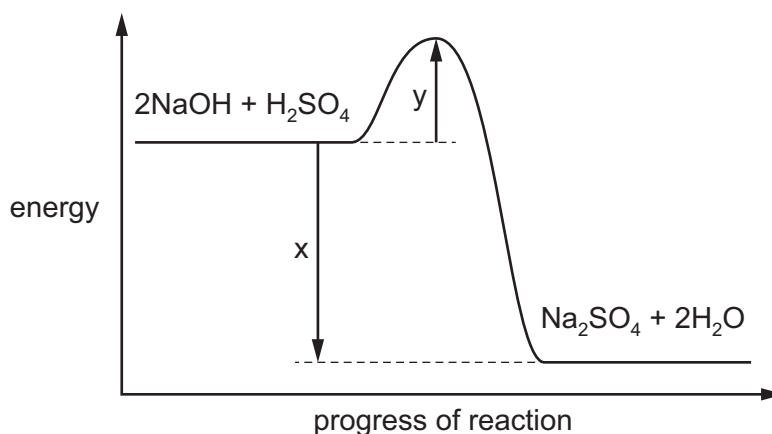
9 The equation for an enthalpy change is shown. The enthalpy change is Q.



What is the correct expression to calculate Q?

- A $2 \times \Delta H_c^\ominus [CO_2(g)] - 3 \times \Delta H_f^\ominus [H_2(g)]$
- B $3 \times \Delta H_f^\ominus [H_2O(g)] + 2 \times \Delta H_c^\ominus [CO_2(g)]$
- C $2 \times \Delta H_f^\ominus [CO_2(g)] - 3 \times \Delta H_f^\ominus [H_2(g)]$
- D $3 \times \Delta H_f^\ominus [H_2O(l)] + 2 \times \Delta H_f^\ominus [CO_2(g)]$

- 10 A reaction pathway diagram for the reaction of aqueous sodium hydroxide and dilute sulfuric acid is shown.



What is the value of the enthalpy change of neutralisation, ΔH_{neut} ?

- A x B $x - y$ C $\frac{x}{2}$ D $\frac{(x - y)}{2}$
- 11 A student reacts 4 mol of ammonia with oxygen to produce an oxide of nitrogen and water only. Each nitrogen atom increases its oxidation state by 5 in the reaction.

How many moles of oxygen gas react with 4 mol of ammonia in this reaction?

- A 4 mol B 5 mol C 7 mol D 10 mol
- 12 In the treatment of domestic water supplies, chlorine is added to water to kill bacteria. Some ClO^- ions are formed.

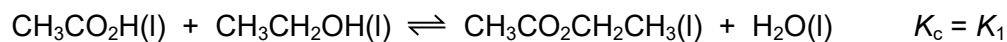
What is the change in oxidation number of chlorine when forming the ClO^- ion from aqueous chlorine?

- A -1 B 0 C $+1$ D $+2$

13 Ethanoic acid is mixed with ethanol.

The ethanol is contaminated with a small amount of methanol.

The following equilibria are established.



Which statement about the equilibrium mixture is correct?

- A** Only ethyl ethanoate will be formed because there is much more ethanol present than methanol.
- B** In this mixture $\frac{[\text{CH}_3\text{CO}_2\text{CH}_2\text{CH}_3]}{[\text{CH}_3\text{CO}_2\text{CH}_3]} = \frac{K_1}{K_2}$.
- C** Adding water to the mixture will alter the mole ratio of the two esters.
- D** Adding methyl ethanoate to the mixture will increase the number of moles of ethyl ethanoate.

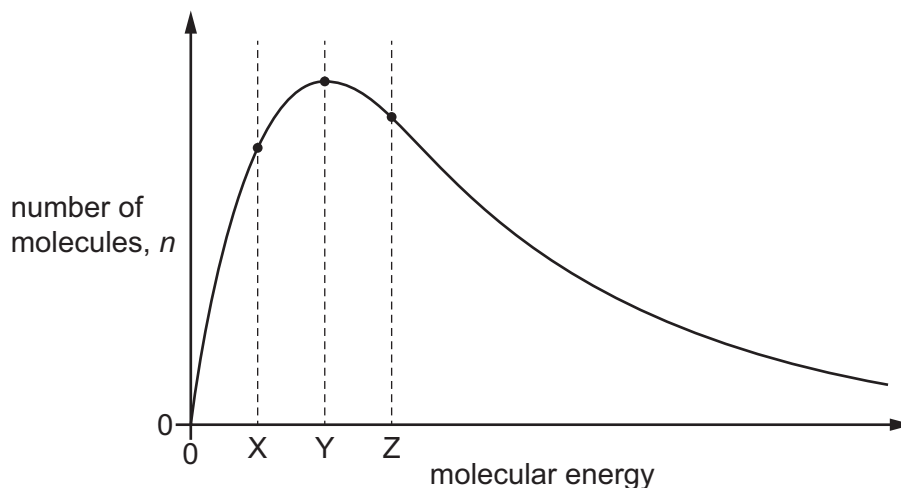
14 SO_3 is manufactured from SO_2 and O_2 in the Contact process.

The reaction is exothermic.

Which row shows the effect on the equilibrium yield obtained in the Contact process of increasing the temperature and of adding a vanadium(V) oxide catalyst?

	increasing the temperature	adding vanadium(V) oxide as catalyst
A	equilibrium yield decreases	equilibrium yield increases
B	equilibrium yield decreases	equilibrium yield unchanged
C	equilibrium yield increases	equilibrium yield unchanged
D	equilibrium yield increases	equilibrium yield increases

- 15 The Boltzmann distribution for a gas at a constant temperature of 50 °C is shown.

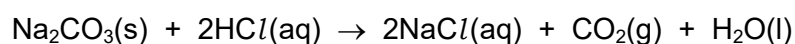


If the temperature of the gas is **reduced** by 10 °C, the graph changes shape.

What happens to the values of n for the molecular energies X, Y and Z?

	X	Y	Z
A	higher	lower	higher
B	higher	lower	lower
C	lower	higher	lower
D	lower	lower	lower

- 16 A 3.0 g sample of Na_2CO_3 powder is stirred into 50 cm³ of 1.0 mol dm⁻³ HCl. The volume of CO_2 produced is 600 cm³.



[M_r : Na_2CO_3 , 106.0]

Which volume of CO_2 is produced if 1.0 g of Na_2CO_3 powder is stirred into 50 cm³ of 1.0 mol dm⁻³ HCl under the same conditions?

- A** 600 cm³ **B** 452 cm³ **C** 226 cm³ **D** 200 cm³
- 17 Solid sodium iodide reacts with concentrated sulfuric acid to form more than one product that contains sulfur.

What is the lowest oxidation number of sulfur in these products?

- A** -2 **B** 0 **C** +4 **D** +6

18 Which statement for the element in Period 3 and Group 13 of the Periodic Table is correct?

- A It has the highest melting point of the elements in its period.
- B It has exactly one electron in its shell with principal quantum number 3.
- C It forms an oxide that reacts with aqueous sodium hydroxide.
- D It forms a chloride that dissolves in water to give a neutral solution.

19 A student reacts 0.100 mol of each of sodium, magnesium and phosphorus atoms separately with an excess of oxygen.

Which rows are correct?

	oxide	mass of oxide formed / g
1	sodium	3.10
2	magnesium	4.03
3	phosphorus	7.10

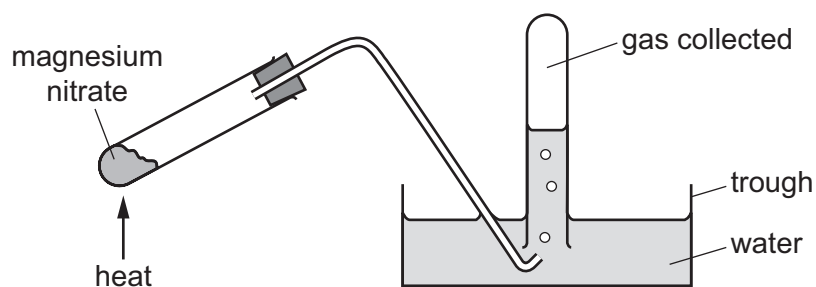
- A 1, 2 and 3 B 1 and 2 only C 1 and 3 only D 2 and 3 only

20 A mixture contains magnesium carbonate and barium carbonate only. A sample of the mixture is dissolved in nitric acid to produce a solution.

How could this solution be processed into a magnesium compound and a separate barium compound?

- A Add $\text{HCl}(\text{aq})$, filter off the solid barium chloride.
- B Add $\text{HCl}(\text{aq})$, filter off the solid magnesium chloride.
- C Add $\text{H}_2\text{SO}_4(\text{aq})$, filter off the solid barium sulfate.
- D Add $\text{H}_2\text{SO}_4(\text{aq})$, filter off the solid magnesium sulfate.

21 A sample of magnesium nitrate is heated in the apparatus shown.



The pH of the solution in the trough is measured.

The gas collected is tested with a glowing splint.

What are the results?

	pH of solution in trough	splint test
A	8	relights
B	2	relights
C	8	extinguished
D	2	extinguished

22 The results of tests performed on a white crystalline solid, X, are given in the table.

reagent and conditions	observation
X is gently heated	X sublimes
X is shaken with H_2O	a colourless solution, Y, forms
Y is warmed with NaOH(aq)	a gas is given off
$\text{AgNO}_3\text{(aq)}$ is added to Y	a white precipitate, Z, forms
Z is shaken with $\text{NH}_3\text{(aq)}$	a colourless solution forms

What is the identity of X?

- A** aluminium bromide
- B** aluminium chloride
- C** ammonium bromide
- D** ammonium chloride

23 Silicon is heated in an excess of chlorine, producing compound J.

An excess of water is added to the sample of J produced.

Which row is correct?

	structure of J	Is HCl produced when water is added to J?
A	giant molecular	no
B	giant molecular	yes
C	simple molecular	no
D	simple molecular	yes

24 In a catalytic converter, 5.6 g of carbon monoxide react with an excess of nitrogen monoxide.

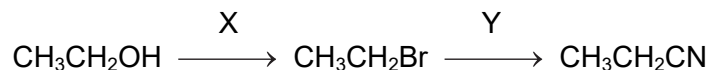
What is produced in this reaction?

- A** 2.4 g of C and 6.0 g of NO_2
- B** 2.4 g of C and 9.2 g of NO_2
- C** 8.8 g of CO_2 and 1.4 g of N_2
- D** 8.8 g of CO_2 and 2.8 g of N_2

25 Which reaction mixture produces an acidic gas?

- A** aqueous ammonium nitrate and solid calcium oxide
- B** calcium and aqueous hydrochloric acid
- C** potassium chloride and concentrated sulfuric acid
- D** sodium oxide and water

- 26 Ethanol can be used to make propanenitrile in two steps.



What types of reaction are X and Y?

	X	Y
A	free-radical substitution	electrophilic substitution
B	free-radical substitution	nucleophilic substitution
C	nucleophilic substitution	nucleophilic substitution
D	nucleophilic substitution	electrophilic substitution

- 27 Which compound will react with LiAlH_4 to form two optical isomers?

- A** $\text{CH}_3\text{CH}_2\text{COCH}_3$
B $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$
C $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_3$
D $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CO}_2\text{H}$

- 28 How many esters have the molecular formula $\text{C}_4\text{H}_8\text{O}_2$?

- A** 2 **B** 3 **C** 4 **D** 5

- 29 Carbon monoxide, CO , nitrogen dioxide, NO_2 , and sulfur dioxide, SO_2 , are all atmospheric pollutants.

Which reaction occurs in the atmosphere?

- A** CO is spontaneously oxidised to CO_2 .
B NO_2 is reduced to NO by SO_2 .
C NO_2 is reduced to NO by CO .
D SO_2 is oxidised to SO_3 by CO_2 .

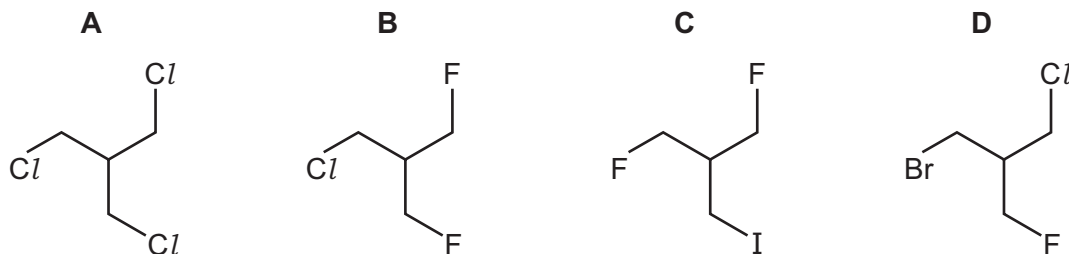
- 30 Oct-1-ene, $\text{CH}_3(\text{CH}_2)_5\text{CH}=\text{CH}_2$, can be thermally cracked.

Which of the compounds W, X, Y and Z can be obtained by thermally cracking oct-1-ene?

W	X	Y	Z
$\text{CH}_2=\text{CH}_2$	$\text{CH}_3\text{CH}=\text{CH}_2$	$\text{CH}_3\text{CH}_2\text{CH}_3$	$\text{CH}_2=\text{CHCH}=\text{CH}_2$

- A W, X, Y and Z
 B W, X and Y only
 C W, X and Z only
 D W and X only
- 31 Structural isomerism and stereoisomerism should be taken into account when answering this question.
- How many isomeric alkenes with formula C_5H_8 are present in the mixture produced when 1,4-dibromopentane is reacted with NaOH in ethanol?
- A 1 B 2 C 3 D 4
- 32 The presence of a halogen in an organic compound may be detected by warming the organic compound with aqueous silver nitrate.

Which compound would be the quickest to produce a precipitate?



- 33 17.6 g of pentan-1-ol is completely combusted.

Which volume of gaseous products is formed when measured at s.t.p.?

- A 22.4 dm^3 B 24.0 dm^3 C 49.3 dm^3 D 52.8 dm^3

- 34** Crotyl alcohol, $\text{CH}_3\text{CH}=\text{CHCH}_2\text{OH}$, is a colourless liquid which is used as a solvent.

Crotyl alcohol will react separately with Br_2 , $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}^+$, conc. KMnO_4/H^+ and PCl_5 under suitable conditions.

Which row is correct?

	reactant	conditions	main product
A	Br_2	room temperature	$\text{CH}_3\text{CH}=\text{CHCH}_2\text{Br}$
B	$\text{K}_2\text{Cr}_2\text{O}_7/\text{H}^+$	heat under reflux	$\text{CH}_3\text{CH}=\text{CHCHO}$
C	conc. KMnO_4/H^+	heat under reflux	$\text{CH}_3\text{CH}=\text{CHCO}_2\text{H}$
D	PCl_5	room temperature	$\text{CH}_3\text{CH}=\text{CHCH}_2\text{Cl}$

- 35** The skeletal formulae of two organic compounds are shown.



Which reagents can be used to distinguish these two compounds?

- 1 alkaline $\text{I}_2(\text{aq})$
- 2 acidified $\text{K}_2\text{Cr}_2\text{O}_7$
- 3 2,4-dinitrophenylhydrazine (2,4-DNPH reagent)

- A** 1, 2 and 3 **B** 1 and 3 only **C** 2 and 3 only **D** 2 only

- 36** A carbonyl compound, X, reacts with HCN in the presence of NaCN to make a compound with M_r 85. Compound X does **not** react with Fehling's reagent.

What is compound X?

- A** butanal
B butanone
C propanal
D propanone

37 Which compound produces butan-2-ol and ethanoic acid on hydrolysis?

- A** $\text{CH}_3\text{CO}_2\text{CH}(\text{CH}_3)_2$
B $\text{CH}_3\text{CO}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
C $\text{CH}_3\text{CH}(\text{CH}_3)\text{CO}_2\text{CH}_2\text{CH}_3$
D $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$

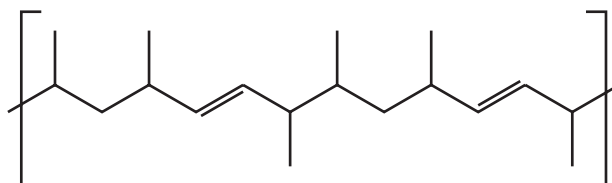
38 Two 1 g samples of Y are reacted separately and completely with sodium and with sodium carbonate. The volumes of the gases produced are collected and measured.

	relative volumes of gases	
	with Na	with Na_2CO_3
Y	2	1

What could Y be?

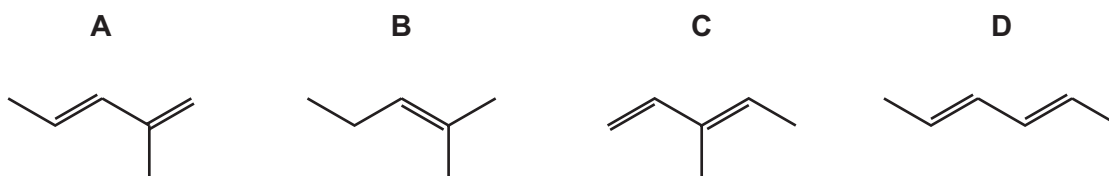
- A** $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{OH}$
B $\text{CH}_3\text{CH}(\text{OH})\text{CO}_2\text{H}$
C $\text{CH}_3\text{COCH}_2\text{OH}$
D $\text{CH}_3\text{COCO}_2\text{H}$

39 The diagram shows a section of an addition polymer formed from two different monomers.



One of the monomers is propene.

What is the other monomer?



- 40 A scientist chooses either infrared spectroscopy or mass spectrometry to find a particular piece of information.

In which row has the **best** choice been made?

	target information	analytic method used
A	identities of functional groups in an organic compound	infrared spectroscopy
B	identities of functional groups in an organic compound	mass spectrometry
C	values of successive ionisation energies of Na	infrared spectroscopy
D	values of successive ionisation energies of Na	mass spectrometry

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

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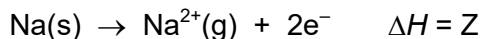
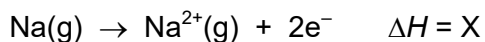
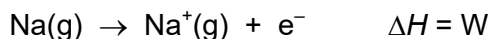
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- 1 Equations involving four enthalpy changes are shown.



Which equation represents the second ionisation energy of sodium?

- A** X **B** X + Y – W **C** X – W **D** Z – W

- 2 This question refers to isolated gaseous atoms in the ground state.

In which atom are all electrons paired?

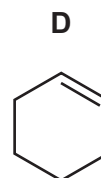
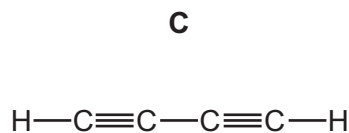
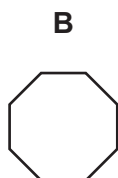
- A** Ba **B** Br **C** S **D** Si

- 3 Which sample contains the most iodine?

- A** 1 g of CaI_2 **B** 1 g of KI **C** 1 g of NaI **D** 1 g of NH_4I

- 4 When a small sample of hydrocarbon Q is completely combusted, it produces 3.52 g of carbon dioxide and 1.44 g of water.

What could be the structure of hydrocarbon Q?



- 5 Ethane and ethene are both hydrocarbon molecules.

What is a feature of **both** molecules?

- A** a planar structure
B bond angles of 109°
C σ covalent bonds
D π covalent bonds

- 6 Elements J and L are both in Group 15.

J and L each form a gaseous covalent hydride in which their oxidation number is -3 .

In the liquefied forms of these hydrides, significant hydrogen bonding occurs only in the hydride of L.

Which row about J and L could be correct?

	identity of J	identity of L	outer shell electron configuration
A	As	N	p^5
B	As	N	s^2p^3
C	N	As	p^5
D	N	As	s^2p^3

- 7 Which gas will behave **least** like an ideal gas at 150°C and 101 kPa ?

- A** ammonia
- B** fluorine
- C** krypton
- D** steam

- 8 When an evacuated glass bulb of volume 200 cm^3 is filled with a gas at 300 K and 101 kPa , the mass of the bulb increases by 0.68 g . The gas obeys the ideal gas equation.

What is the identity of the gas?

- A** argon
- B** krypton
- C** neon
- D** nitrogen

- 9 The standard enthalpy of formation of $\text{NO}_2(\text{g})$ is $+33.2 \text{ kJ mol}^{-1}$.

The standard enthalpy of formation of $\text{N}_2\text{O}_4(\text{g})$ is $+9.2 \text{ kJ mol}^{-1}$.

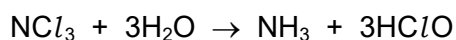
What is the standard enthalpy change for the reaction $2\text{NO}_2(\text{g}) \rightarrow \text{N}_2\text{O}_4(\text{g})$?

- A $-57.2 \text{ kJ mol}^{-1}$
 B $-24.0 \text{ kJ mol}^{-1}$
 C $+42.4 \text{ kJ mol}^{-1}$
 D $+75.6 \text{ kJ mol}^{-1}$
- 10 Separate samples of 25.0 cm^3 of 0.1 mol dm^{-3} $\text{NaOH}(\text{aq})$ are added to each of three different acid solutions, as described. The temperature of each of the solutions was 298 K before mixing.

sample	acid	type of acid	concentration / mol dm^{-3}	volume / cm^3
1	H_2SO_4	strong	0.05	25.0
2	HCl	strong	0.05	25.0
3	$\text{CH}_3\text{CO}_2\text{H}$	weak	0.05	25.0

Which statement describes the temperature rises that occur on mixing each of these three acids separately with NaOH ?

- A The temperature rise in all three mixtures is the same.
 B The temperature rise using H_2SO_4 and HCl is the same.
 C The temperature rise using $\text{CH}_3\text{CO}_2\text{H}$ is greater than using HCl .
 D The greatest temperature rise occurs using H_2SO_4 .
- 11 NCl_3 reacts with H_2O .



The oxidation state of nitrogen does not change in this reaction.

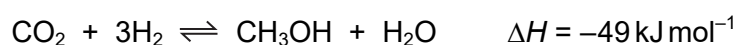
Which statement is correct?

- A Chlorine is reduced.
 B Chlorine is oxidised.
 C Hydrogen is both oxidised and reduced.
 D This is not a redox reaction.

12 In which row do the oxidation numbers of vanadium increase?

	smallest	→	largest
A	VO_4^{3-}	VO_3^-	VO_2^+
B	VO^{2+}	V_2O_3	VO_4^{3-}
C	V_2O_3	VO^{2+}	VO_3^-
D	VO_4^{3-}	VO_2^+	VO^{2+}

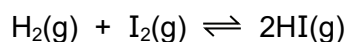
13 A synthesis for methanol is shown.



Which conditions would produce the greatest yield of methanol at equilibrium?

	pressure	temperature / °C
A	high	80
B	high	20
C	low	80
D	low	20

14 Hydrogen and iodine can react reversibly to produce hydrogen iodide. The equation is shown.



4.00 mol of hydrogen gas and X mol of iodine vapour are mixed in a sealed container of volume 1.00 dm^3 at a temperature of 460 K. The system is allowed to reach equilibrium.

The equilibrium mixture contains 2.00 mol of hydrogen iodide. The equilibrium constant, K_c , for the reaction at 460 K is 4.0.

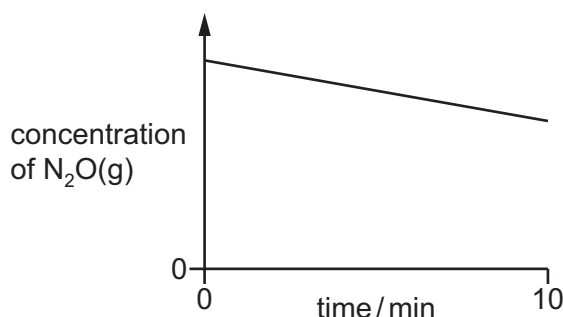
What is the value of X?

- A** 0.50 mol **B** 1.17 mol **C** 1.33 mol **D** 2.50 mol

- 15** A large amount of $\text{N}_2\text{O}(\text{g})$ decomposes into nitrogen gas and oxygen gas in the presence of a tiny amount of a gold foil catalyst.

The gold foil provides a solid surface on which the catalysed reaction takes place.

The graph shows the concentration of $\text{N}_2\text{O}(\text{g})$ against time as it decomposes. The graph is a straight line.

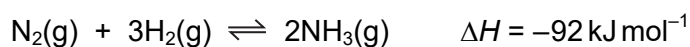


Which row describes:

- the change in rate of reaction as $\text{N}_2\text{O}(\text{g})$ decomposes from 0 to 10 minutes
- the effect of adding more gold foil catalyst on the rate of decomposition of the same amount and concentration of $\text{N}_2\text{O}(\text{g})$?

	change in rate of reaction as $\text{N}_2\text{O}(\text{g})$ decomposes	effect of adding more gold foil on the rate of decomposition
A	none	increases
B	none	none
C	decreases	increases
D	decreases	none

- 16** The Haber process for the manufacture of ammonia is represented by the equation shown.



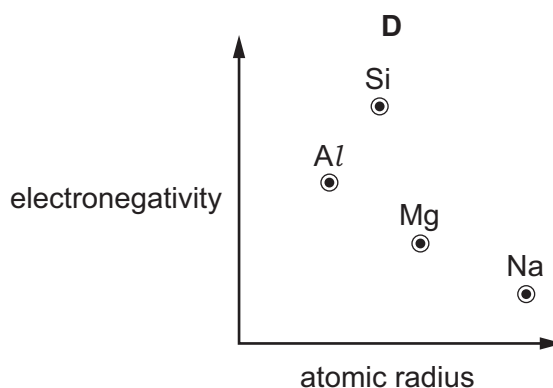
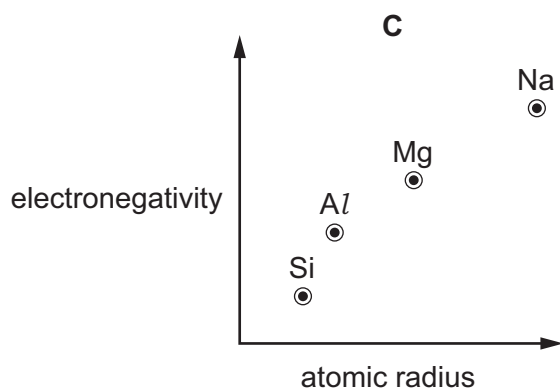
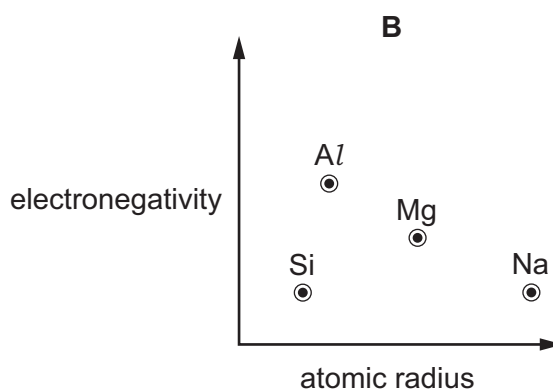
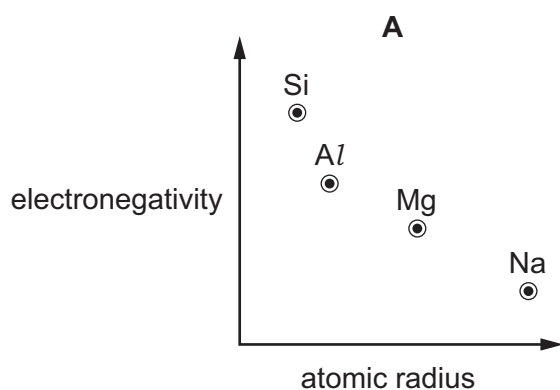
Which statement is correct about this reaction when the temperature is increased?

- A** Both forward and backward rates increase.
- B** The backward rate only increases.
- C** The forward rate only increases.
- D** There is no effect on the backward or forward rates.

- 17 $\text{NH}_3(\text{aq})$ is added to separate samples of $\text{NaCl}(\text{aq})$, $\text{MgCl}_2(\text{aq})$, $\text{BaCl}_2(\text{aq})$ and $\text{SiCl}_4(\text{l})$. Under the conditions of this experiment, only two samples will produce a white precipitate when $\text{NH}_3(\text{aq})$ is added.

What are these two samples?

- A $\text{MgCl}_2(\text{aq})$ and $\text{BaCl}_2(\text{aq})$
 B $\text{MgCl}_2(\text{aq})$ and $\text{SiCl}_4(\text{l})$
 C $\text{NaCl}(\text{aq})$ and $\text{BaCl}_2(\text{aq})$
 D $\text{NaCl}(\text{aq})$ and $\text{SiCl}_4(\text{l})$
- 18 Why is the ionic radius of a sulfide ion larger than the ionic radius of a potassium ion?
- A Ionic radius always decreases with increasing atomic number.
 B Positive ions always have smaller radii than negative ions.
 C The potassium ion has more protons in its nucleus than the sulfide ion.
 D The sulfide ion is doubly charged; the potassium ion is singly charged.
- 19 Which graph correctly shows relative electronegativity plotted against relative atomic radius for the elements Na, Mg, Al and Si?



20 The table gives information about calcium carbonate and calcium hydroxide.

Which row is correct?

	calcium carbonate is more soluble in water than calcium hydroxide	calcium hydroxide can be manufactured using calcium carbonate as a starting material
A	no	no
B	no	yes
C	yes	no
D	yes	yes

21 Q is a Group 2 metal.

An excess of $\text{QCO}_3(\text{s})$ is added to $\text{H}_2\text{SO}_4(\text{aq})$ followed by filtration. A sample of QSO_4 is then obtained by evaporation of the filtrate.

What could be the identity of Q?

- A** barium, calcium or magnesium
- B** barium or calcium only
- C** calcium only
- D** calcium or magnesium only

22 X, Y and Z are three elements in Group 17.

X_2 has weaker covalent bonds than Y_2 .

X_2 has stronger instantaneous dipole–induced dipole forces between its molecules than Z_2 .

Y_2 is a stronger oxidising agent than Z_2 .

What could be X, Y and Z?

	X	Y	Z
A	Br	Cl	I
B	Cl	Br	I
C	I	Br	Cl
D	I	Cl	Br

- 23** Chlorine reacts with aqueous sodium hydroxide forming two chlorine-containing products.

Which row shows the oxidation states of chlorine in the products under the conditions stated?

	conditions	oxidation state of Cl in products
A	cold NaOH(aq)	-1 and +3
B	cold NaOH(aq)	-1 and +5
C	hot NaOH(aq)	-1 and +3
D	hot NaOH(aq)	-1 and +5

- 24** A catalytic converter reduces the amount of pollutants in the fumes from a car exhaust.

Which row identifies a pollutant and shows how it is removed by the action of the catalyst?

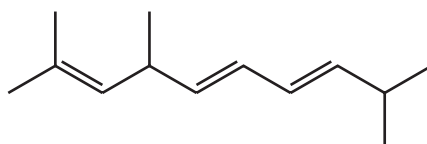
	pollutant	chemical removal
A	carbon dioxide	reduced to carbon
B	carbon monoxide	oxidised to carbon dioxide
C	oxides of nitrogen	oxidised to nitric acid
D	unburnt hydrocarbons	oxidised to carbon dioxide and hydrogen

- 25** Solid R is added to a solution of ammonium nitrate and the mixture is heated. A gas is given off which turns red litmus to blue.

What could be R?

- A** aluminium chloride
- B** magnesium chloride
- C** sodium oxide
- D** phosphorus oxide

- 26** A skeletal formula is shown.



What is the total number of stereoisomers including the one shown?

- A** 4
- B** 6
- C** 8
- D** 16

- 27 The molecular formula CH_3 can represent an anion, a cation or a free radical. Species with the molecular formula CH_3 can act as an electrophile, a free radical or a nucleophile depending on the number of outer shell electrons on the central carbon atom.

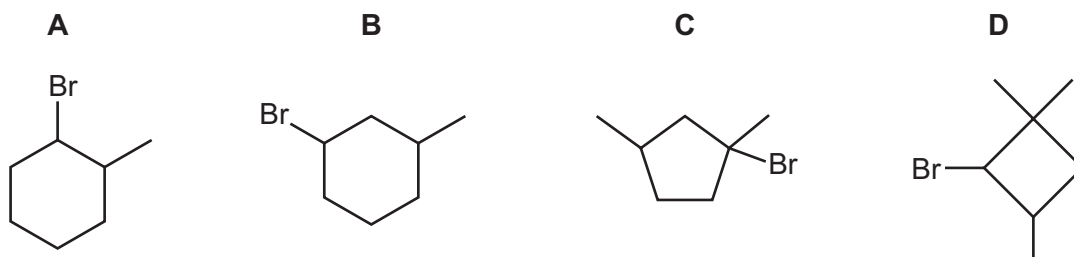
How many outer shell electrons on the central carbon atom must be present for CH_3 to act in these different ways?

	CH_3 as an electrophile	CH_3 as a free radical	CH_3 as a nucleophile
A	6	7	8
B	6	8	7
C	7	6	8
D	8	7	6

- 28 Compound Z, $\text{C}_7\text{H}_{13}\text{Br}$, has two chiral centres. A sample of Z contains all four possible optical isomers.

This sample of Z reacts with hot ethanolic NaOH to produce a mixture of **only** three isomers. Two of these isomers are optical isomers of each other.

What could be the formula of Z?

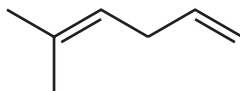


- 29 The free-radical substitution reaction between methane and chlorine involves initiation, propagation and termination stages.

Which row is correct?

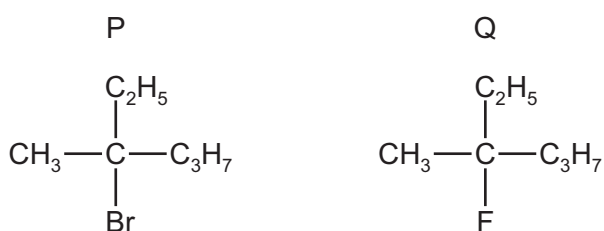
	involved in initiation stage	radical produced in a propagation stage
A	homolytic fission	$\text{H}\cdot$
B	homolytic fission	$\text{CH}_3\cdot$
C	heterolytic fission	$\text{H}\cdot$
D	heterolytic fission	$\text{CH}_3\cdot$

- 30 The alkene shown reacts with an excess of HBr via an electrophilic addition reaction.



What is the **major** product formed?

- A 3,5-dibromo-2-methylhexane
 B 2,5-dibromo-2-methylhexane
 C 2,6-dibromo-2-methylhexane
 D 3,6-dibromo-2-methylhexane
- 31 The diagram shows the structures of two halogenoalkanes, P and Q.

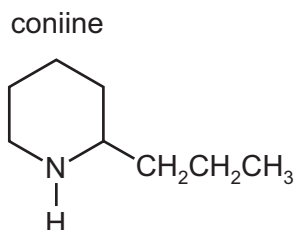


Both compounds can be hydrolysed.

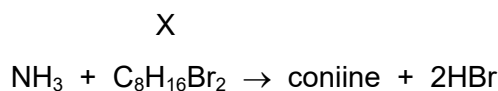
Which row is correct?

	compound more readily hydrolysed	reaction mechanism
A	P	S _N 1
B	P	S _N 2
C	Q	S _N 1
D	Q	S _N 2

32 The structure of coniine is shown.



Coniine can be synthesised by reacting ammonia with a dibromo compound, X.



What is compound X?

- A 1,1-dibromo-2-propylcyclopentane
- B 1,2-dibromo-2-propylcyclopentane
- C $\text{Br}(\text{CH}_2)_3\text{CHBr}(\text{CH}_2)_3\text{CH}_3$
- D $\text{Br}(\text{CH}_2)_4\text{CHBr}(\text{CH}_2)_2\text{CH}_3$

33 Primary alcohols can be oxidised to aldehydes using either acidified potassium dichromate(VI) or acidified potassium manganate(VII). The reaction mixtures change colour as the oxidising agent is reduced.

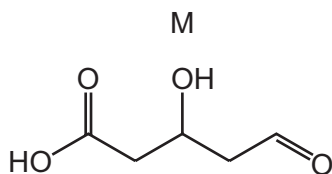
What are the colour changes seen?

	acidified potassium dichromate(VI)		acidified potassium manganate(VII)	
	before	after	before	after
A	green	orange	purple	colourless
B	orange	green	colourless	purple
C	orange	green	purple	colourless
D	purple	colourless	orange	green

34 Which reaction has a product that gives a yellow precipitate when treated with alkaline $\text{I}_2(\text{aq})$?

- A 2-chloropropane is warmed with a dilute aqueous solution of sodium hydroxide.
- B Ethanal is heated under reflux with acidified potassium dichromate(VI).
- C Methyl ethanoate is heated under reflux with dilute sulfuric acid.
- D Propanal is reacted with NaBH_4 , followed by dilute sulfuric acid.

35 The skeletal formula of M is shown.

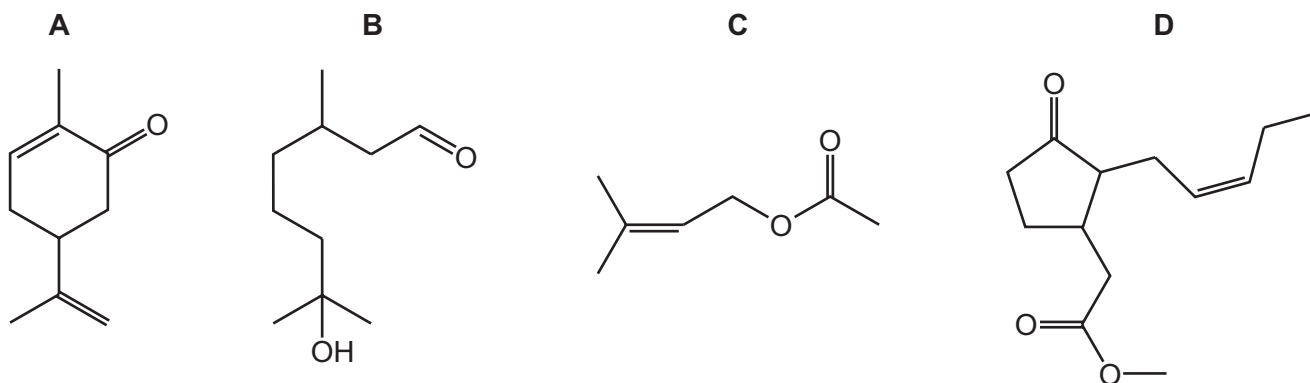


M is reacted with an excess of LiAlH_4 . Dilute acid is then added.

What is the molecular formula of the final organic product?

- A** $\text{C}_5\text{H}_6\text{O}_5$ **B** $\text{C}_5\text{H}_{10}\text{O}_4$ **C** $\text{C}_5\text{H}_{10}\text{O}_3$ **D** $\text{C}_5\text{H}_{12}\text{O}_3$

36 Which compound forms a precipitate when mixed with 2,4-DNPH reagent and also forms a precipitate when mixed with Fehling's reagent?

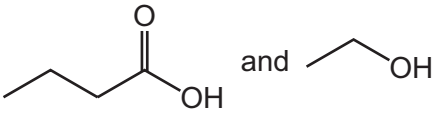
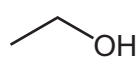
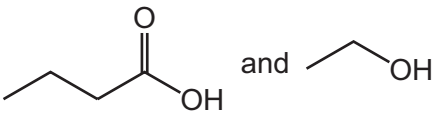
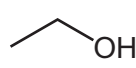
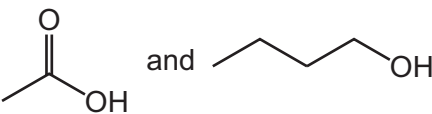
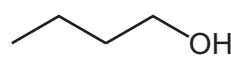
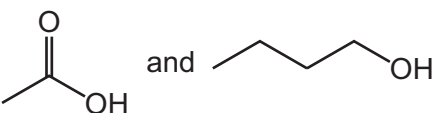
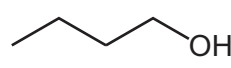


37 Which reaction is a redox reaction?

- A** ethanenitrile heated under reflux with dilute hydrochloric acid
B ethanoic acid reacted with aqueous sodium hydroxide
C ethanoic acid reacted with sodium
D ethyl ethanoate heated under reflux with dilute hydrochloric acid

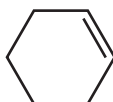
38 Ethyl butanoate is a flavouring, with a fruity flavour.

Which row is correct?

	alcohol and acid that react to form ethyl butanoate	the mass of water formed when 2.32 g of ester is formed
A	 and 	0.36 g
B	 and 	0.40 g
C	 and 	0.36 g
D	 and 	0.40 g

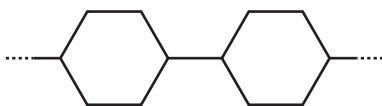
39 Cyclohexene, as shown in the diagram, can form an addition polymer.

cyclohexene

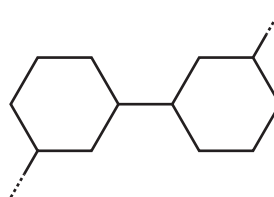


Which structure represents a section of the polymer?

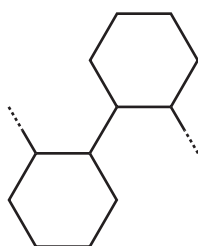
A



B



C



D



40 Three organic compounds are listed.

- 1 ethanal
- 2 propan-1-ol
- 3 propan-2-ol

Which compounds will have a mass spectrum that contains a fragment peak at $m/e = 43$?

- A** 1 only **B** 1 and 2 only **C** 2 and 3 only **D** 1, 2 and 3

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ($4.18 \text{ J g}^{-1} \text{ K}^{-1}$)

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Cambridge International AS & A Level

CHEMISTRY

9701/13

Paper 1 Multiple Choice

May/June 2022

1 hour 15 minutes

You must answer on the multiple choice answer sheet.

You will need: Multiple choice answer sheet
Soft clean eraser
Soft pencil (type B or HB is recommended)

INSTRUCTIONS

- There are **forty** questions on this paper. Answer **all** questions.
- For each question there are four possible answers **A, B, C** and **D**. Choose the **one** you consider correct and record your choice in soft pencil on the multiple choice answer sheet.
- Follow the instructions on the multiple choice answer sheet.
- Write in soft pencil.
- Write your name, centre number and candidate number on the multiple choice answer sheet in the spaces provided unless this has been done for you.
- Do **not** use correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.

INFORMATION

- The total mark for this paper is 40.
- Each correct answer will score one mark.
- Any rough working should be done on this question paper.
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **20** pages. Any blank pages are indicated.

- 1 Which atom has exactly three unpaired electrons in the ground state?
- A an isolated gaseous aluminium atom
B an isolated gaseous carbon atom
C an isolated gaseous chromium atom
D an isolated gaseous phosphorus atom
- 2 Which element has the **second** smallest atomic radius in its group and the **second** highest electrical conductivity in its period?
- A boron
B calcium
C magnesium
D sodium

- 3 Analysis of the hormone thyroxine gives the results shown.

Heating 0.500 g of thyroxine with aqueous silver nitrate produces 0.604 g of silver iodide. All of the iodine in the thyroxine sample is converted to silver iodide.

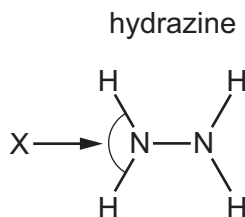
Complete combustion of 0.500 g of thyroxine produces 232 cm³ of carbon dioxide and 7.72 cm³ of nitrogen, measured under room conditions.

Which molecular formula of thyroxine agrees with these values?

- A C₁₅H₁₁NO₄I₄ $M_r = 776.6$
B C₁₅H₇NO₄I₈ $M_r = 1280.2$
C C₃₀H₂₅NO₆I₄ $M_r = 1002.6$
D C₃₀H₂₁NO₆I₈ $M_r = 1506.2$
- 4 How many moles of oxygen, O₂, are needed to burn 1 mol of ethane if the products of the reaction are water and carbon only?
- A 1.5 B 3 C 3.5 D 5
- 5 Which compound has the smallest difference in electronegativity between its two elements?
- A KF B KBr C LiF D LiBr

- 6 VSEPR theory should be used to answer this question.

Hydrazine has the following structure.



What is the predicted bond angle X?

- A** 90° **B** 107° **C** 109.5° **D** 120°
- 7 This question is about buckminsterfullerene, graphite, iodine and diamond.
- How many of these substances have a simple molecular structure?
- A** 0 **B** 1 **C** 2 **D** 3
- 8 A student reacts 1 mol of magnesium powder in a sealed 0.030 m^3 container of oxygen at a pressure of $2.0 \times 10^5 \text{ Pa}$ and a temperature of 600 K. The magnesium reacts completely to form MgO.
- Which percentage of the oxygen will be used up?
- A** 5.0% **B** 10% **C** 42% **D** 83%
- 9 Which equation represents an enthalpy change that is the average bond energy of the C–H bond in methane?
- A** $\frac{1}{4} \text{C(g)} + \text{H(g)} \rightarrow \frac{1}{4} \text{CH}_4\text{(g)}$
- B** $\frac{1}{4} \text{CH}_4\text{(g)} \rightarrow \frac{1}{4} \text{C(g)} + \text{H(g)}$
- C** $\text{CH}_4\text{(g)} \rightarrow \text{C(g)} + 4\text{H(g)}$
- D** $\text{CH}_4\text{(g)} \rightarrow \text{CH}_3\text{(g)} + \text{H(g)}$

- 10** Magnesium carbonate decomposes when heated in a Bunsen burner flame.

Values for the standard enthalpies of formation, $\Delta H_f^\ominus$, of the species involved are shown.

$$\Delta H_f^\ominus \text{MgCO}_3 = -1095.8 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus \text{MgO} = -601.7 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus \text{CO}_2 = -393.5 \text{ kJ mol}^{-1}$$

What is the standard enthalpy change for the decomposition of magnesium carbonate?

- A** +100.6 kJ mol⁻¹
B +887.6 kJ mol⁻¹
C +1095.8 kJ mol⁻¹
D +2091 kJ mol⁻¹
- 11** NH₄NO₃ decomposes into N₂O and H₂O on heating.

Which statements are correct?

- 1 The ammonium ion is behaving as a reducing agent.
- 2 The nitrate(V) ion is behaving as an oxidising agent.
- 3 It is a redox reaction.
- 4 It is a disproportionation reaction.

- A** 1, 2, 3 and 4
B 1, 2 and 3 only
C 3 and 4 only
D 3 only
- 12** A student adds 3 mol of acidified K₂Cr₂O₇ to an excess of I⁻ ions.

The chromium is all reduced to Cr³⁺ and I⁻ ions are oxidised to I₂.

The I₂ released is reduced back to I⁻ ions by X mol of S₂O₃²⁻ ions.

1 mol of I₂ is reduced by 2 mol of S₂O₃²⁻ ions.

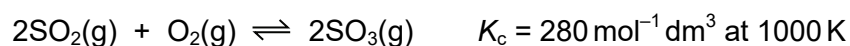
What is the value of X?

- A** 3 **B** 6 **C** 9 **D** 18

13 Which statement about acids and bases is **always** correct?

- A An acid with two H atoms per molecule will be stronger than an acid with one H atom per molecule.
- B A concentrated solution of a strong acid will have a lower pH than a dilute solution of a weak acid.
- C A concentrated solution of a strong base will have a lower pH than a dilute solution of a weak base.
- D A strong acid is more dissociated in solution than a strong base.

14 The reaction between sulfur dioxide and oxygen is reversible.



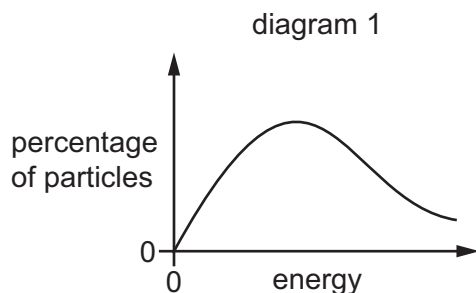
In an equilibrium mixture at 1000 K the sulfur trioxide concentration is 6.00 mol dm^{-3} .

The sulfur dioxide concentration is twice the oxygen concentration.

What is the sulfur dioxide concentration?

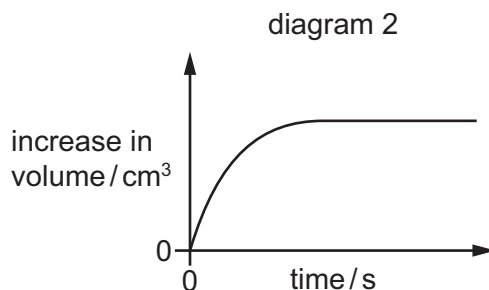
- A $0.175 \text{ mol dm}^{-3}$
- B $0.252 \text{ mol dm}^{-3}$
- C $0.318 \text{ mol dm}^{-3}$
- D $0.636 \text{ mol dm}^{-3}$

- 15 The Boltzmann distribution of the particles in a mixture of gas X and gas Y is shown in diagram 1.

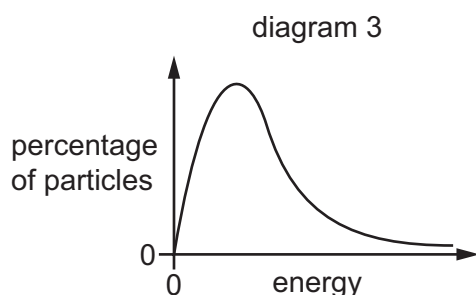


X and Y react and the reaction causes an increase in gas molecules present. The reaction goes to completion.

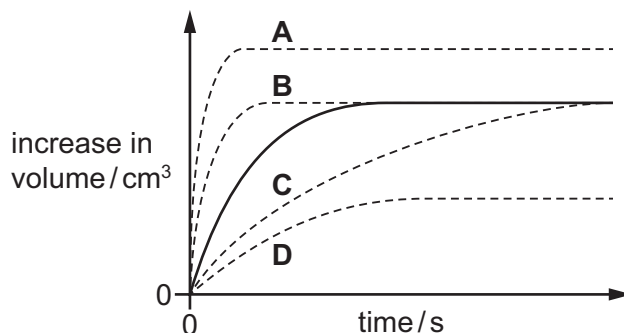
In experiment 1, the increase in volume is measured every 10 seconds. During the reaction, the temperature and pressure remain constant. The increase in volume is shown in the volume–time graph in diagram 2.



In experiment 2, the experiment is repeated using identical amounts of X and Y. A different temperature is used compared to experiment 1. The same pressure is used. The Boltzmann distribution of the second mixture of X and Y is shown in diagram 3. During the reaction the temperature and pressure remain constant.



Which curve on the volume–time graph would show the increase in volume against time for experiment 2? (The original line for experiment 1 is redrawn as a solid line.)



- 16 When the temperature of a particular reaction is increased by 10 °C (e.g. from 20 °C to 30 °C) the rate of the reaction approximately doubles.

What is the **most** significant reason for this increase?

- A a different mechanism for the reaction
- B an increased collision frequency of the reactant molecules
- C more collisions have energy greater than the activation energy
- D a reduced activation energy for the reaction

- 17 Which ion has the smallest radius?

- A Al^{3+} B Ba^{2+} C Mg^{2+} D Na^{+}

- 18 Which row is correct?

	element with the greater fifth ionisation energy	element with an amphoteric oxide
A	aluminium	aluminium only
B	aluminium	both aluminium and phosphorus
C	phosphorus	aluminium only
D	phosphorus	both aluminium and phosphorus

- 19 Each of the chlorides listed is added to water.

- 1 aluminium chloride
- 2 magnesium chloride
- 3 silicon tetrachloride
- 4 phosphorus pentachloride

Which chlorides form an aqueous solution that reacts with sodium carbonate to produce carbon dioxide?

- A 1 and 2 only
- B 3 and 4 only
- C 1, 3 and 4 only
- D 1, 2, 3 and 4

20 NaOH(aq) is added to separate samples of magnesium chloride and barium chloride solutions.

H₂SO₄(aq) is then added slowly to each reaction mixture until in excess.

What is observed at the **end** of the reaction sequence?

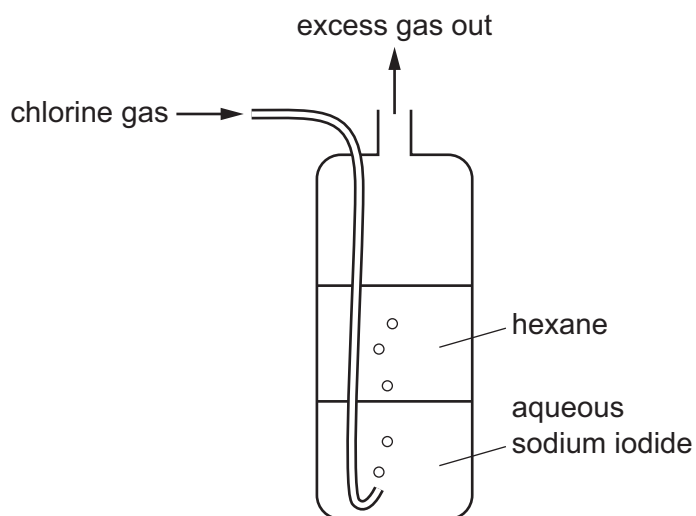
	MgCl ₂ (aq)	BaCl ₂ (aq)
A	colourless solution only	colourless solution only
B	colourless solution only	white precipitate
C	white precipitate	colourless solution only
D	white precipitate	white precipitate

21 A 4.00 g sample of an anhydrous Group 2 metal nitrate, Z, is heated strongly until there is no further change of mass. A solid residue of mass 1.37 g is formed.

Which metal is present in Z?

- A** barium
- B** calcium
- C** magnesium
- D** strontium

- 22** Chlorine is bubbled through a cylinder containing aqueous sodium iodide and an immiscible layer of hexane.



As the bubbles pass through the cylinder, what is observed in the lower and upper layers?

	lower aqueous layer	upper hexane layer
A	colourless solution becomes brown	colourless liquid becomes coloured
B	colourless solution becomes brown	colourless liquid is unchanged
C	brown solution becomes colourless	colourless liquid becomes coloured
D	brown solution becomes colourless	colourless liquid is unchanged

- 23** Chlorine and bromine have different volatilities.

Which row identifies the more volatile of the two elements, and gives the correct explanation?

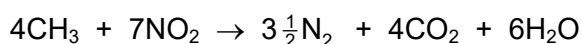
	identity of the more volatile element	explanation for the difference in volatility
A	bromine	intermolecular forces are greater in bromine than they are in chlorine
B	bromine	intermolecular forces are greater in chlorine than they are in bromine
C	chlorine	intermolecular forces are greater in bromine than they are in chlorine
D	chlorine	intermolecular forces are greater in chlorine than they are in bromine

24 Ammonium chloride dissolves readily in water.

Which statement about the colourless solution formed is correct?

- A** Ions in the solution can form hydrogen bonds with water molecules.
- B** The solution is slightly basic.
- C** The solution would smell of chlorine.
- D** When sodium hydroxide is added, a gas is formed which turns damp blue litmus paper red.

25 At 550 °C nitrogen dioxide reacts with unburnt hydrocarbon fragments, such as CH₃, in the catalytic converter of a motor vehicle.

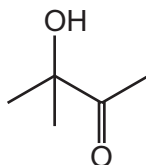


Which row gives the energy change for this reaction and a possible reason for it?

	energy change of reaction	reason why the reaction is endothermic or exothermic
A	endothermic	chemical energy is converted to heat energy
B	endothermic	the N≡N bond energy is very high
C	exothermic	CO ₂ and H ₂ O have negative ΔH_f° values
D	exothermic	double bonds are broken in NO ₂

26 Compound X contains an alcohol group and a carbonyl group.

compound X

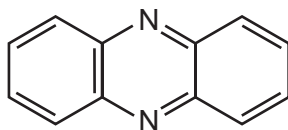


Which row is correct?

	type of alcohol group	type of carbonyl group
A	primary	aldehyde
B	primary	ketone
C	tertiary	aldehyde
D	tertiary	ketone

- 27 The diagram shows the skeletal formula of phenazine.

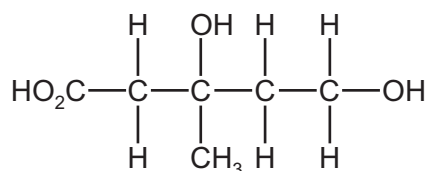
phenazine



What is the empirical formula of phenazine?

- A C_6H_4N B C_6H_6N C $C_{12}H_8N_2$ D $C_{12}H_{12}N_2$
- 28 The diagram shows the structural formula of mevalonic acid.

mevalonic acid

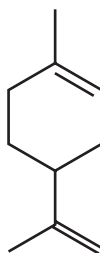


Which reagent and conditions will react with mevalonic acid to produce an organic compound **without** a chiral carbon atom?

- A heat under reflux with CH_3OH/H^+
 B heat under reflux with $Cr_2O_7^{2-}/H^+$
 C Na at room temperature
 D PCl_5 at room temperature
- 29 Structural isomerism and stereoisomerism should be considered when answering this question.
- Y is a gaseous hydrocarbon which decolourises aqueous bromine.
- 10.0 g of Y occupies a volume of 3.43 dm^3 under room conditions.
- How many isomeric structures are possible for Y?
- A 4 B 5 C 6 D 7

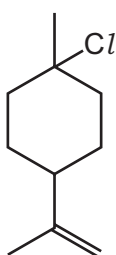
30 Limonene is found in lemon and orange oils.

limonene

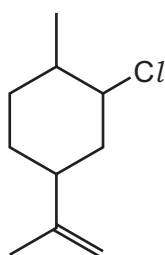


What is the major product when limonene reacts with an excess of dry hydrogen chloride?

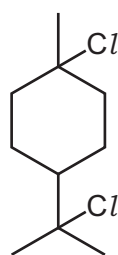
A



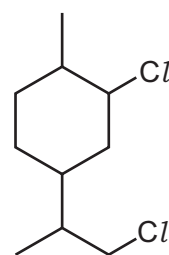
B



C



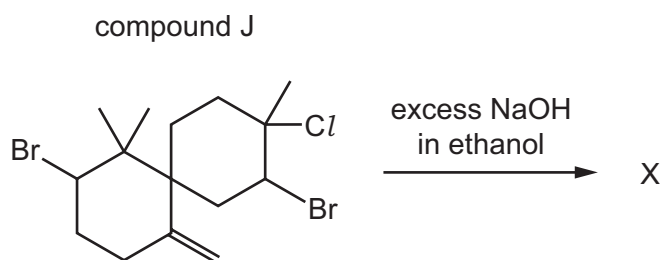
D



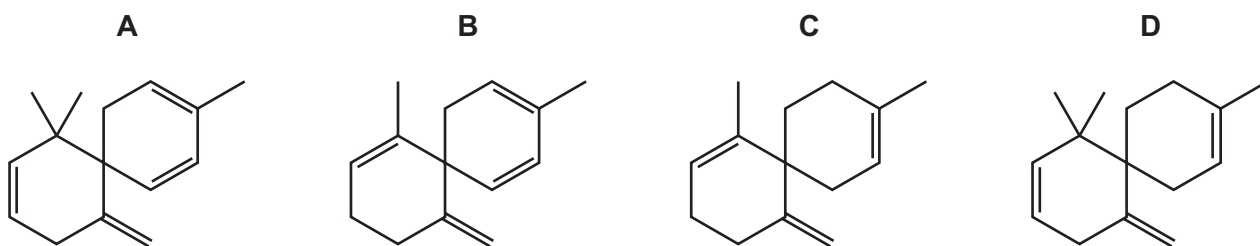
31 Which statement concerning the hydrolysis of 1-bromopropane with water is correct?

- A** The hydrolysis reaction between water and 1-iodopropane is faster because the C–Br bond is less polar than the C–I bond.
- B** The hydrolysis reaction with water is very slow because water is a weak electrophile.
- C** The mechanism of the reaction involves the formation of a stable carbocation.
- D** The reaction is slower with 1-chloropropane because the C–Cl bond is stronger than the C–Br bond.

- 32 Compound J, $C_{15}H_{23}Br_2Cl$, is reacted with an excess of a hot concentrated solution of sodium hydroxide in ethanol. One of the products is X.



What could be the skeletal formula of X?



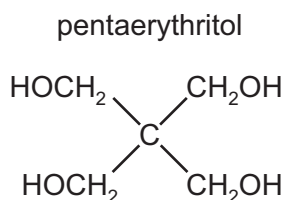
- 33 Structural isomerism only should be considered when answering this question.

Several compounds with molecular formula $C_4H_8O_2$ have **one** carbonyl group and **one** OH group.

How many of these compounds produce yellow crystals with alkaline $I_2(aq)$ at room temperature?

- A 2 B 3 C 4 D 5

- 34 Pentaerythritol is used as an intermediate in the manufacture of paint.



Which statement is correct?

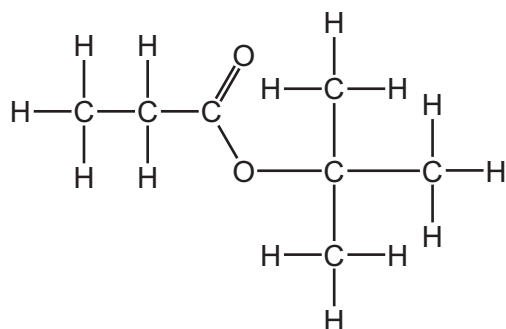
- A Pentaerythritol can be dehydrated by concentrated sulfuric acid to form an alkene.
- B The empirical formula and molecular formula of pentaerythritol are different.
- C Pentaerythritol does not react with acidified potassium manganate(VII).
- D One mole of pentaerythritol gives two moles of hydrogen gas on reaction with an excess of sodium.

- 35** Which reaction has a nucleophilic addition mechanism and gives a good yield of product under the stated conditions?
- A** 1-bromopropane reacting with hot ethanolic sodium hydroxide
- B** 2-iodopropane reacting with hot aqueous sodium hydroxide
- C** propanal reacting with hydrogen cyanide under alkaline conditions
- D** propanal reacting with hydrogen cyanide under acidic conditions
- 36** A carbonyl compound has the structural formula CH_3COCHO .

Which row is correct for the observations made when this compound is treated with the given reagents?

	2,4-DNPH reagent	Fehling's reagent
A	silver mirror	red precipitate
B	silver mirror	orange precipitate
C	orange precipitate	silver mirror
D	orange precipitate	red precipitate

- 37** An ester is shown.



Which two compounds react to form this ester?

- A** 2-methylpropan-1-ol and propanoic acid
- B** 2-methylpropan-2-ol and propanoic acid
- C** propan-1-ol and 2-methylpropanoic acid
- D** 2-methylpropan-2-ol and ethanoic acid

38 Which compound can be used to make propanoic acid by treatment with a single reagent?

- A $\text{CH}_2=\text{CHCH}_2\text{CH}_3$
- B $\text{CH}_3\text{CH}_2\text{CH}_2\text{CN}$
- C $\text{CH}_3\text{CH}(\text{OH})\text{CN}$
- D $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$

39 A sample of sulfur consists mostly of ^{32}S . It also contains 4.2% ^{34}S and 2.8% ^{36}S . No other isotopes of sulfur are present.

What is the relative atomic mass, A_r , of **this** sample of sulfur?

- A 32.1 B 32.2 C 34.0 D 34.3

40 One molecule of an addition polymer containing 2000 repeat units has an M_r of 112 000.

The polymer molecule contains chiral centres.

What is a possible monomer for this polymer?

- A $\text{CH}_2=\text{CHCH}_3$
- B $\text{CH}_2=\text{C}(\text{CH}_3)_2$
- C $\text{CH}_2=\text{CHCH}_2\text{CH}_3$
- D $\text{CH}_2=\text{CHCH}_2\text{CH}_2\text{CH}_3$

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

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The Periodic Table of Elements

Group																			
1	2	1 H hydrogen 1.0												13	14	15	16	17	18
		Key atomic number atomic symbol name relative atomic mass																	
3 Li lithium 6.9	4 Be beryllium 9.0													5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3													13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8		
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3		
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —		
87 Fr francium —	88 Ra radium —	89–103 actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —		
118 Og oganeson —																			
lanthanoids																			
57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0					
actinoids																			
89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —					