

Achievement Standard 91391

Demonstrate understanding of the properties of organic compounds

CHEMISTRY

3.5

Externally assessed 5 credits

Chains, isomers and functional groups

A **homologous series** increases by $-\text{CH}_2-$ every step. A **functional group** is a specific arrangement of elements in a compound responsible for characteristic chemical reactions.

Alkanes

Alkanes ($\text{C}_n\text{H}_{2n+2}$) only contain carbon and hydrogen atoms (**hydrocarbons**) and only have single bonds (**saturated** with hydrogens).

Formula		Ethane	2-methylpropane
Empirical	Simplest ratio of atoms present	CH_3	C_2H_5
Molecular	Number of each type of atom present	C_2H_6	C_4H_{10}
Structural (Constitutional)	Arrangement of atoms and groups of atoms	CH_3CH_3	$\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$
or	Two-dimensional arrangement		
or	Structural formula showing stereochemistry		

Types of formulae

The carbon atom chain of the longest length in a compound determines the prefix; the homologous series or functional group determines the suffix. You need to know prefix names for molecules containing up to 8 carbon atoms.

Physical properties

Melting and boiling points are low and increase with the length of carbon chain. C_1 – C_4 are gases, C_5 – C_{16} are oily liquids, C_{17+} are waxy solids. Alkanes are insoluble in water because they are non-polar, but they are soluble in non-polar solvents such as hexane or petrol. Alkanes do not conduct in any state as there are no free ions or electrons.

Structural isomers

Structural isomers have the same molecular formula but a different arrangement of atoms, have similar chemical properties but different physical properties (due to the shape and size of isomers, which weakens the intermolecular forces between molecules and lowers the melting and boiling points).

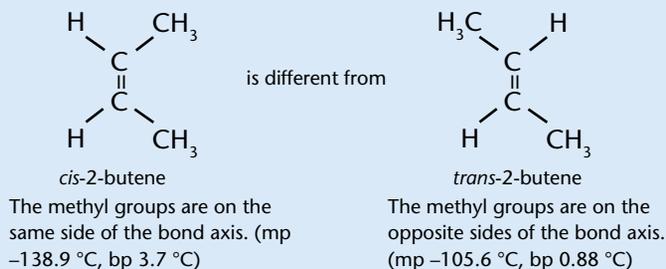
The numbering of a functional group on a parent chain has preference on the lowest number first.

Alkenes

Alkenes contain a carbon-to-carbon double bond (C=C) as the functional group making them **unsaturated**, and if there is more than one C=C, **polyunsaturated**. They have the general formula C_nH_{2n} , and similar physical properties to alkanes. When naming alkenes, include the C=C in the parent chain and give it the lowest possible carbon number.

Geometric isomers

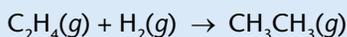
Cis isomers have the same groups on the same side of the bond, **trans isomers** have the same groups on different sides of the bond.



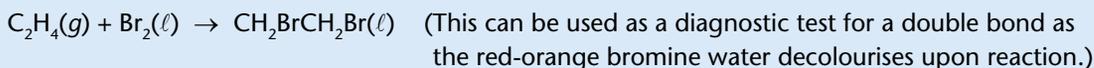
Geometric isomers of 2-butene

Reactions

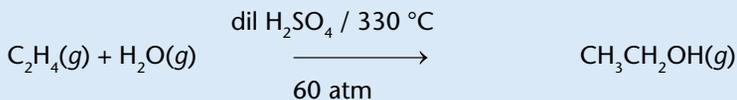
- **Adding hydrogen** gas produces an alkane, e.g. ethene becomes ethane:



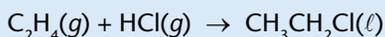
- **Adding a halide** (e.g. bromine) produces a dibromoalkane, e.g. ethene becomes 1,2-dibromoethane:



- **Adding water** to form an alcohol requires dilute H_2SO_4 , pressure and a catalyst; e.g. ethene becoming ethanol:



- **Adding hydrogen halide** such as HCl produces a haloalkane, e.g. ethene becomes chloroethane:



- **Addition polymerisation** involves adding together many molecules of ethene or ethene derivatives to form long-chain molecules called polymers.

Markovnikov's rule determines the major and minor product of an addition reaction involving an unsymmetrical alkene.

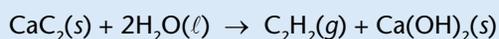
'The hydrogen atom from the molecule being added will join onto the carbon atom with the most hydrogen atoms already as the major product, but a small amount of the other possibility will also form as the minor product.'

Alkynes

Alkynes contain a carbon-to-carbon triple bond (C≡C) as the functional group, making them **unsaturated**. They have the general formula C_nH_{2n-2} , and similar physical properties to alkanes. When naming alkynes, you must include the C≡C in the parent chain and give it the lowest possible carbon number.

Addition reactions of alkynes are like that of alkenes, but each addition occurs twice.

Ethyne (acetylene) can be made from a reaction of calcium carbide with water:



Alcohols

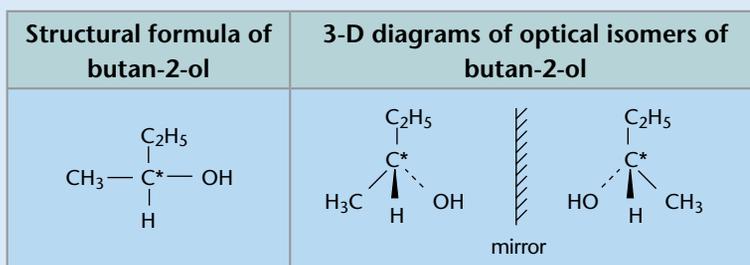
Alcohols contain a hydroxyl group (–OH) attached to one of the carbons. They have the general formula $C_nH_{2n+1}OH$, the suffix –ol, and the parent chain always contains the –OH group, which has the lowest number possible.

Melting and boiling points of alcohols are higher than those of similar hydrocarbons because the intermolecular forces between the molecules are strengthened by hydrogen bonding between –OH groups. Alcohols one to eight carbons long are liquids at room temperature, and alcohols up to **four carbons long** are **soluble** in water because they can establish a hydrogen bond with a neighbouring water molecule.

Class of alcohol	Characteristic structure	Examples
Primary (1°): one alkyl group and two hydrogen atoms attached to carbon of C–OH	$\begin{array}{c} \text{OH} \\ \\ \text{R} - \text{C} - \text{H} \\ \\ \text{H} \end{array}$ or R–CH ₂ OH	propan-1-ol pentan-1-ol hexan-1-ol methanol CH ₃ OH or HCH ₂ OH
Secondary (2°): two alkyl groups and one hydrogen atom attached to carbon of C–OH	$\begin{array}{c} \text{OH} \\ \\ \text{R} - \text{C} - \text{R}' \\ \\ \text{H} \end{array}$ or R–CHOH–R'	propan-2-ol butan-2-ol pentan-3-ol and pentan-2-ol hexan-2-ol and 3-methylbutan-2-ol
Tertiary (3°): three alkyl groups and no hydrogen atoms attached to carbon of C–OH	$\begin{array}{c} \text{OH} \\ \\ \text{R} - \text{C} - \text{R}' \\ \\ \text{R}'' \end{array}$ or R–COH(R'')–R'	methylpropan-2-ol 3-methylpentan-3-ol

Primary, secondary and tertiary alcohols

Alcohol isomers can sometimes exhibit **optical isomerism**. The central **asymmetric** carbon is bonded to four different atoms or groups of atoms. The molecule is said to be a **chiral** molecule with two **enantiomers**, which are **non-superimposable** mirror images of the same molecule and rotate the plane of polarised light in different directions.



C* = asymmetric carbon atom

Optical isomers of butan-2-ol

Chemical reactions (properties) of alcohols

Combustion in oxygen – small-chain alcohols burn more cleanly than similar alkanes.

Oxidation – acidified dichromate ($\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$) or permanganate ($\text{MnO}_4^-/\text{H}^+$) can be used. **Primary** alcohols oxidise to form **aldehydes**, which oxidise further to **carboxylic acids** (usually leaving a mixture of the two). **Secondary** alcohols oxidise to form **ketones**. Tertiary alcohols do not oxidise.

Chlorination – a substitution reaction using conc HCl, phosphorous trichloride (PCl_3), phosphorous pentachloride (PCl_5), or thionyl chloride (SOCl_2) to produce a chloroalkane.

Lucas test – a chlorination reaction used to determine between 1°, 2°, and 3° alcohols. A solution of ZnCl_2 in conc HCl is added to the alcohol, and the chloroalkane produced forms a cloudy suspension in the solution.

Type of alcohol	Example	Observations	Product
Primary	1-butanol	No cloudiness (reaction very slow if at all).	1-chlorobutane (if any product forms)
Secondary	2-butanol	Cloudiness after 5–15 minutes (reaction rate moderate).	2-chlorobutane
Tertiary	2-methyl-2-propanol	Cloudiness after 1–2 minutes (reaction rapid).	2-chloro-2-methylpropane

Reaction between alcohols and Lucas reagent

Dehydration – a water molecule can be removed using concentrated sulfuric acid at 170 °C or Al_2O_3 . This elimination or dehydration reaction is subject to Saytzeff's rule if the alcohol is unsymmetrical. The $-\text{OH}$ is removed and the $-\text{H}$ on the adjoining C that has the least H's forms the major product.

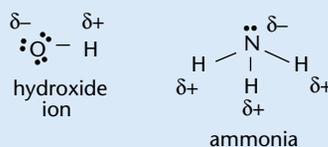
Haloalkanes (alkyl halides)

Haloalkanes contain a halogen (F, Cl, Br, or I) attached to one of the carbons. They have the general formula $\text{C}_n\text{H}_{2n+1}\text{X}$ (where X is a halogen), the prefix fluoro-, chloro-, bromo-, or iodo-, and the parent chain always contains the $-\text{X}$ group, which has the lowest number possible.

Alkyl halides can also be classified as primary, secondary, or tertiary, depending on how many other groups are attached to the carbon the halide is attached to.

The bond is slightly polar towards the halide ($\delta^+\text{C}-\text{X}\delta^-$), but this does not strengthen the intermolecular forces greatly (i.e. mps and bps are low); haloalkanes with up to eight carbon atoms per molecule are liquids at room temperature (25 °C), except for fluoro-, chloro- and bromo-methane, all of which are gases at room temperature; all alkyl halides are insoluble in water but soluble in non-polar solvents such as cyclohexane.

The chemical reactions (properties) of alkyl halides involve **substitution** or **elimination** reactions. The weak positivity (δ^+) on the carbon attracts small compounds with lone pairs of electrons (**nucleophiles**).



The nucleophiles hydroxide ion and ammonia

Nucleophilic substitution

The halogen is substituted (replaced) by the nucleophile:

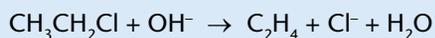
- with hydroxide (dilute KOH), haloalkanes form an alcohol and the halide ion; e.g. chloroethane:

$$\text{CH}_3\text{CH}_2\text{Cl} + \text{OH}^- \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{Cl}^-$$
- with concentrated ammonia, NH_3 , dissolved in ethanol and at high pressure, haloalkanes form an amine (aminoalkane) and an ammonium salt; e.g. chloroethane:

$$\text{CH}_3\text{CH}_2\text{Cl} + 2\text{NH}_3 \rightarrow \text{CH}_3\text{CH}_2\text{NH}_2 + \text{NH}_4\text{Cl}$$

Elimination

The halogen atom and a hydrogen atom are removed to form an alkene; e.g. chloroethane, concentrated KOH in ethanol is needed to prevent the OH substitution:



Use Saytzeff's rule if the alkyl halide is unsymmetrical.

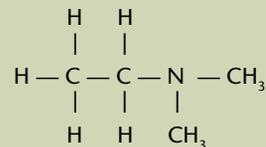
Amines (aminoalkanes)

Amines contain a carbon-to-nitrogen bond (C–N) as the functional group. They have the suffix -amine or the prefix amino-, and can have di- or tri- prefixes if there is more than one –NH₂ in a molecule. They have similar physical properties to alcohols due to the hydrogen bond strengthening the intermolecular forces between molecules.

When naming amines, include the C–N in the parent chain and give it the lowest possible carbon number. Chains attached to the nitrogen are considered to be alkyl groups and their position is identified as 'N'.

Example

N,N-dimethylethanamine



Primary, secondary and tertiary amines depend on the number of different species attached to the nitrogen (not the carbon).

Class of aminoalkane (amine)	Structure	Examples
Primary amines contain N (as a –NH ₂ group) attached to one alkyl group: R–NH ₂		C ₂ H ₅ NH ₂ aminoethane (ethylamine) R = –C ₂ H ₅
Secondary amines contain N (as a –NH– group) attached to two alkyl groups: R–NH–R'		CH ₃ NHCH ₃ N-methylaminomethane (dimethylamine) R = –CH ₃ and R' = –CH ₃
Tertiary amines contain a N atom attached to three alkyl groups: R–N(R'')–R'		C ₂ H ₅ N(CH ₃) ₂ N,N-dimethylaminoethane R = –C ₂ H ₅ , R' = –CH ₃ and R'' = –CH ₃

Primary, secondary and tertiary aminoalkanes

The chemical properties of amines are similar to those of ammonia because they are structurally similar.

- **Adding water** – amines accept protons from water as they are weak bases; e.g. aminoethane forms the ethylammonium ion:



- **Forming a salt** – amines react with mineral acid to form crystalline salts; e.g. aminoethane and hydrochloric acid form ethylammonium chloride:



- **Complex ions** – aminomethane and aminoethane form complex ions by co-ordinate bonds with metal ions; e.g. aminomethane and copper(II) ion form a royal blue tetraaminomethanecopper(II) complex ion:



- **With haloalkanes** – amines can act as nucleophiles, using their lone pair of electrons to attach to the δ^+ C on a haloalkane and forming a secondary amine. This can go on to react with another molecule of haloalkane and form a tertiary amine; e.g. aminomethane reacts with chloroethane to form N-methylaminoethane and HCl:



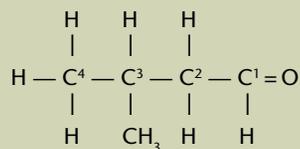
Aldehydes and ketones

Aldehydes and ketones are known as **carbonyl compounds** as they contain the carbonyl group C=O.

Aldehydes have the C=O as the end C of a chain with an H as the other atom. They have the suffix -al, and the carbon in the C=O must be numbered 1 and included in the parent chain of isomers.

Example

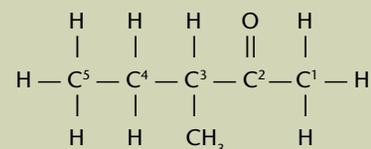
3-methylbutanal



Ketones have the C=O *not* on the end of the chain. They have the suffix -one, and the parent chain of an isomer must include the C=O with the smallest number possible.

Example

3-methylpentan-2-one



The polarity of the carbonyl group ($\delta^+ \text{C} = \text{O} \delta^-$) increases the intermolecular van der Waals forces between the molecules. Methanal is a gas but most ketones and aldehydes are volatile liquids. Aldehydes have unpleasant pungent smells, ketones have pleasant sweet smells.

The lone pairs of electrons on the carbonyl forms hydrogen bonds with water molecules, making small aldehydes (C_1 – C_3) and ketones (C_3 and C_4) soluble. Most are soluble in non-polar solvents and many ketones are used as solvents.

Oxidation and reduction

Aldehydes are made from the oxidation of primary alcohols. The aldehyde product is distilled out of the reaction mixture as it forms to prevent it oxidising further to a carboxylic acid.

Ketones are made from the oxidation of secondary alcohols. To ensure that all the alcohol has reacted, the mixture is refluxed.

Both aldehydes and ketones can be **reduced** back to their appropriate alcohol with **sodium borohydride**, NaBH_4 .

Tests for aldehydes vs ketones

Aldehydes are more reactive and react quickly, producing a colour change (whereas a ketone reacts very slowly or not at all).

Oxidising agent	Colour change
Potassium dichromate (acidified)	Orange solution to green
Potassium permanganate (acidified)	Purple solution to colourless
Tollens' reagent – ammoniacal silver nitrate	Colourless solution forms silver precipitate or silver mirror
Fehling's solution	Blue solution forms orange / red precipitate
Benedict's solution	Blue solution forms orange / red precipitate

Colour changes associated with reduction of oxidising agents by aldehydes

Questions: Chains, isomers and functional groups

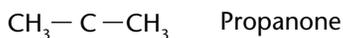
Question One: Functional group chemistry

 Year 2017
 Ans. p. 113

- a. Complete the table below to indicate the IUPAC name, functional group, and/or the structural formula for organic compounds that contain **only four carbon atoms**. The first row has been completed for you.

Functional group	Structural formula	IUPAC (systematic) name
Alkene	$\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$	but-1-ene
		2-methylpropan-1-amine
Acyl chloride		
		propyl methanoate
	$\begin{array}{c} \text{CH}_3\text{CH}_2 - \text{C} - \text{CH}_3 \\ \parallel \\ \text{O} \end{array}$	
Aldehyde		
Amide		butanamide

- b. Complete the following reaction scheme by drawing the structural formulae of both organic compounds **A** and **B**, as well as the major and minor products **C** and **D**. Identify both reagents 1 and 2, and indicate the type of reaction occurring at each step.



Type of reaction: _____



Reagent 1: _____

A.

Type of reaction: _____



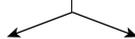
Reagent 2: _____

B.

Type of reaction: _____



Reagent 3: HCl



C. Major product

D. Minor product

- c. Some organic compounds can exist as enantiomers (optical isomers). An example is a secondary alcohol with the molecular formula $\text{C}_4\text{H}_9\text{OH}$.

- i. Draw the enantiomers of $\text{C}_4\text{H}_9\text{OH}$ in the box.

- ii. Explain what is meant by the term enantiomers (optical isomers). In your answer, you should:
- identify the structural requirement for a molecule, such as $\text{C}_4\text{H}_9\text{OH}$, to exist as enantiomers
 - explain how enantiomers can be distinguished from each other.

Answers and explanations

Achievement Standard 91390 (Chemistry 3.4): Demonstrate understanding of thermochemical principles and the properties of particles and substances

3.4 Electron configurations, bonding and periodic trends

Question One: Electron attractions

p. 4

a.	Symbol	Electron configuration	Charge	Atomic number
	Cl	$1s^2 2s^2 2p^6 3s^2 3p^5$	0	17
	Ca ²⁺	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^0$	+2	20
	Mn ²⁺	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$	+2	25

4s may be omitted when the electron count is 0.

- b. i. Electronegativity is a measure of the attraction from an atom's nucleus to a covalently bonded pair of electrons.
ii. Chlorine is to the right of phosphorus in the same period. Moving across a period the electronegativity increases due to an increasing number of positive protons in the nucleus having an increased positive charge. However, the outer bonding electrons are in the same energy level and so experience a greater attraction towards the nucleus, i.e. increased electronegativity.

The definition of electronegativity along with the trends moving across a period or down a group need to be known.

- c. i. $\text{Ca}(g) \rightarrow \text{Ca}^+(g) + e^-$
ii. The trend shown is a decrease in first ionisation energy (1st I.E.) moving down group 2 elements. 1st I.E. is the minimum amount of energy required to remove 1 mol of the outer electrons from 1 mole of gaseous atoms. The 1st I.E. is decreasing because the outer electron is in a higher energy level which is further from the positive protons' attractive pull in the nucleus. In addition to being further away, the outer electrons experience inner electron shielding from the protons' attraction. These factors mean that the outer electrons are not held as strongly in elements further down the group, and so less energy is required to remove the first outer electron.

(A – 3 of: five boxes correct in a., b. i., c. i., or 1st I.E. definition correct in c. ii.;

M – 2 of: all correct boxes in a., electronegativity trend correctly linked to elements in b. ii., 1st I.E. trend correctly explained in terms of increased distance only for c. ii.;

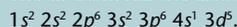
E – M and also b. ii. fully explained in terms of attractions between nucleus and outer bonding electrons, and two factors that affect 1st I.E. fully explained in c. ii.)

Question Two: Periodicity and shapes

p. 5

- a. Cl: $1s^2 2s^2 2p^6 3s^2 3p^5$
Zn: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10}$
Cr³⁺: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^3$

The Cr atom has the electron configuration:



So, to form the Cr³⁺ ion the 4s¹ electron is lost first and then 2 more electrons from 3d⁵ are lost.

- b. i. Cl atom has an equal amount of positively charged protons and negatively charged electrons, whereas the Cl⁻ ion has one additional electron that has added into the outermost energy level which causes increased repulsions with the other surrounding electrons. The Cl⁻ ion has the same amount of protons and thus the same attraction to the electrons as the Cl atom, thus the effect of the additional electron repulsions causes the outer electrons to be further from the nucleus and increases the radius for the ion.

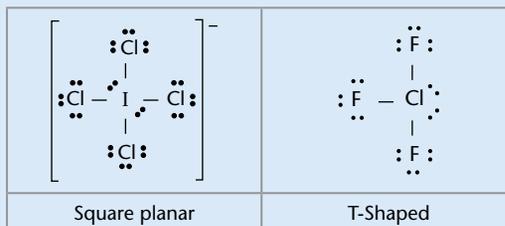
- ii. Electronegativity is a measure of an atom's ability to attract and hold an electron from a covalent bond. Moving down a group, electronegativity decreases due to the outermost bonding electrons being in progressively higher energy levels that are further from the attractive pull of the protons in an atom's nucleus and which also experience shielding of this attraction by inner electrons on the atom.

First ionisation energy (1st I.E.) is the minimum amount of energy needed to remove 1 electron each from 1 mole of atoms in the gas state.

Moving down a group, the 1st I.E. decreases due to the outermost or most easily removed electron being in a higher energy level that is further from, and also shielded from by inner electrons, the attractive pull of the atom's nucleus. Thus a lower amount of energy is required to remove this outer electron which is further away. In comparison, both electronegativity and 1st I.E. decrease moving down a group for the same reasons of reduced attraction of the outermost electrons to protons in the central nucleus of the atom.

Essential definitions of electronegativity, 1st I.E., and also atomic radii, need to be rote learned.

- c. i.



- ii. No

SeF₆ has six regions of negative charge equally repelling each other and surrounding the central atom. All six regions are bonded, so SeF₆ is octahedral in shape. Each of the Se–F bonds is polar due to the difference in electronegativity between the atoms; however, the

molecule is symmetrical, so the effect of the polar bonds is cancelled to leave a non-polar molecule. As a non-polar molecule, SeF_6 would be unable to form attractions with polar water molecules that would otherwise enable the SeF_6 to mix and dissolve in water, and so SeF_6 is insoluble in water.

(A – 3 of: 2 correct in a., identifies Cl- as having 1 more e- than p in b. i., electronegativity or 1st I.E. definition in b. ii., one correct box in c. i., states 'No' and non-polar in c. ii.; M – 2 of: electronegativity or 1st I.E. correctly defined and trend explained in b. ii., 3 of 4 boxes in c. i., shape or polarity correctly explained in c. ii.; E – 2 of: b. i. fully explained link reasons for radii differences, b. ii. correctly explains and compares both electronegativity and 1st I.E. (error in one definition OK), c. ii. shape explained and linked to polarity correctly and then fully linked to solubility)

Question Three: Electron configurations and ionisation energy

p.7

- a. Al: $1s^2 2s^2 2p^6 3s^2 3p^1$
 Cu²⁺: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^9$
 Sc: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$

The $4s^0$ may be omitted since there are no electrons in the $4s$ orbital, but it can be helpful as a reference point for yourself that you have removed the electrons required for the ion.

- b. Electronegativity: A measure of an atom's ability to attract and hold the bonding electrons from a covalent bond.
 First ionisation energy: The minimum energy required to remove the outermost electron from one mole of atoms in their gas state.

This is straight bookwork – a number of definitions need to be learnt in detail.

- c. The trend shows an increase in 1st ionisation energy moving from left to right across the (third) period. An increase in the number of (positive) protons in the nucleus causes a greater attraction on the outermost (negative) electrons. Since all the outer electrons of the four elements are in the same (third) energy level, as the number of protons increases it requires more energy to remove an electron. The largest value for the Ar is due to Ar not only having the greatest number of protons but also that Ar gains additional stability from a complete energy level of electrons. The atomic radii trend is for a decrease in size moving from left to right across a period. The decrease is also due to an increasing amount of protons causing an increase in attraction between the central positive protons and the outer negative electrons, which draws the electrons closer and reduces the radius of an atom.

(A – two correct in a., either of b. and states of number of protons affects either I.E. or radii; M – all of a. and b., and either I.E. linked to increased protons on same energy level or radii linked to increased proton attraction on outer energy level; E – M with full explanation for both I.E. and radii linked to the increasing attraction forces between nucleus and the outer energy level)

Question Four: Some atomic properties

p.8

- a. K: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
 Cr: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$
 As: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$

Ensure that you write neatly so that the number of electrons in each orbital set is shown as a superscript.

- b. The radius of a K^+ ion is smaller than the radius of a K atom. This is due to the ion not having the electron that was present in the outer energy level of a K atom. Thus the remaining outer electrons on the K^+ ion are in a level closer to the nucleus. The ion's nucleus has one more proton than there are electrons, so the electrons experience a greater attractive force due to this and are drawn further towards the nucleus, reducing the radius.
- c. Lowest IE: $\text{B} < \text{N} < \text{Ne} < \text{He}$

- d. i. $\delta^- \quad \delta^+ \quad \delta^+ \quad \delta^-$
 1. $\text{F} - \text{Cl}$ 2. $\text{At} - \text{Cl}$

- ii. Br circled.

Electronegativity is a measure of an atom's ability to attract and hold the shared electrons from a covalent bond. Electronegativity increases moving up a group on the periodic table due to the outer bonding electrons being in energy levels closer to the nucleus, where they experience a greater attraction with the protons. Br is above I in group 17, so the Br will have its outer electrons closer to its nucleus than the I does and thus the Br will have a greater electronegativity value.

(A – two correct in a., recognising the ion is smaller in b. and either c. or d. i. correct; M – A with full answer in b. and electronegativity trends correct in d. ii.; E – M with correct linking of Br to electronegativity)

Question Five: Copper and germanium

p.10

- a. Ge: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^2$
 Cu: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$
 Cu⁺: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^{10}$ $4s^0$ can be absent,
 i.e. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$

Take extra care to ensure the configuration of an ion is correct.

Transition metals lose their $4s$ electrons first; so, for the Cu⁺ ion, it still has complete $3d$ orbitals.

- b. The colour of transition metals is due to having incomplete d -orbital electrons that are able to be excited to higher energy levels by absorbing some colour wavelengths of light from the white spectrum. Copper has the ability to have an incomplete d -orbital arrangement of $[\text{Ar}] 4s^2 3d^{10}$ in some compounds, so these compounds are coloured. Copper also can have the complete d -orbital arrangement of $[\text{Ar}] 4s^1 3d^{10}$, which is not coloured because there are no unpaired d -orbital electrons.
- c. Ge: 128
 Cu: 123
 Cu⁺: 77

Cu is a transition metal which means it will have a smaller radius than most other elements of the fourth period. This is because when moving across the period, the transition metal electrons are filling lower energy $3d$ orbitals. Moving across the period from Cu to Ge, there is an increase in the number of protons in the nucleus, which creates a greater attraction to the outermost electrons and reduces the radius of the atoms.

The ions of metals have smaller radii than their atomic radii because the atom has lost an energy level to become an ion – in the case of Cu^+ , the $4s$. A cation also has more protons than electrons in the nucleus, which causes a greater attraction on the remaining electrons and draws them closer. Thus Cu^+ is smaller than Cu, and Cu is smaller than Ge.

This is a hard question because it deviates from the usual rule that moving across a period reduces atomic radii, as the transition metals are an exception. Ensure that you show your understanding of the link between the attractions of protons in the nucleus and the position of the outer electrons on atomic radii.

(A – two from a. correct and either b. or c. with limited explanation; M – a. all correct and full discussion for b. or c.; E – M with full discussion for both b. and c.)

3.4 Lewis diagrams, shapes and polarity

Question One: Halogens

p.13

- a. i. Temporary dipole-dipole attractions ✓
 ii. Bromine has a higher mass and greater number of electrons than chlorine. The higher electron density