

1 (a) Carbon is less electronegative than chlorine.

(i) Define *electronegativity* and explain the above statement with reference to your definition. [2]

B1 – Definition

Ability of an atom to attract electrons in a covalent bond to itself / its nucleus.

A1 – Correct interpretation

In a carbon-chlorine bond, the 2 electrons are less attracted to the carbon nucleus than to the chlorine nucleus.

(Do not accept reverse interpretation, more attracted to chlorine. Answer must be direct where possible.)

(ii) Explain how the electronegativity of an element varies

- Across the Period
- Down the Group

[2]

A1 each – Correct trend with comparative explanation

Across the period, electronegativity increases because nuclear charge increases but shielding effect remains relatively constant, effective nuclear charge increases so the nucleus can attract electrons in a covalent bond to itself more strongly.

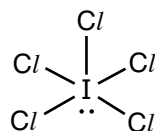
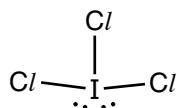
Down the group, electronegativity decreases because the nucleus is further away from the valence electrons.

(b) Iodine is less electronegative than chlorine too.

Both ICl_3 and ICl_5 are possible compounds containing chlorine and iodine.

(i) Draw the *Lewis* structure of both compounds. [2]

A1 each for correct structure.



Geometry must be correct, **Lone pairs on central atom** must be indicated.

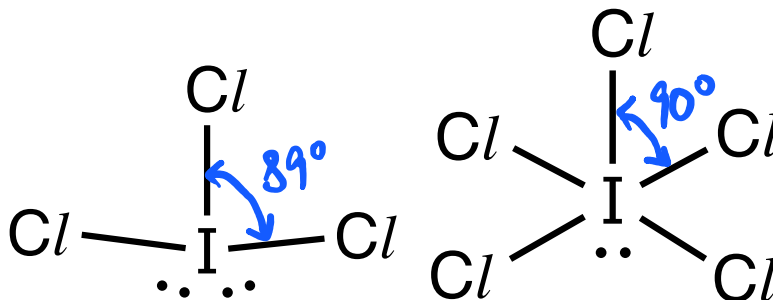
(ii) Explain the geometry of ICl_3 and ICl_5 with respect to the central atom using the Valence Shell Electron Pair Repulsion Theory. [2]

B1 each

ICl_3 – 3 bond pairs + 2 lone pairs → 'T'-shape

ICl_5 – 5 bond pairs + 1 lone pairs → Square pyramidal

- (iii) Label the bond angle for both compounds in the Lewis structure you have drawn in (i). [1]



Award 0.5 pts for each correctly labelled bond angle up to 1 mark.

ICl_3 – slightly below 90 degrees (accept 85 to 90 degrees)

ICl_5 – 90 degrees

- (iv) State the type(s) of intermolecular forces of attraction between molecules of ICl_5 . Explain how they arise. [3]

B1 – Identifies permanent dipole-permanent dipole (pd-pd) **and** dispersion forces. (Penalise 0.5 pts for pd-pd / id-id without spelling out in full)

A1 – Explains pd-pd formation

ICl_5 molecules are polar because individual net dipole moments do not cancel out → net dipole moment present → pd-pd interaction is the electrostatic attraction between molecules in the direction of the net dipole moment

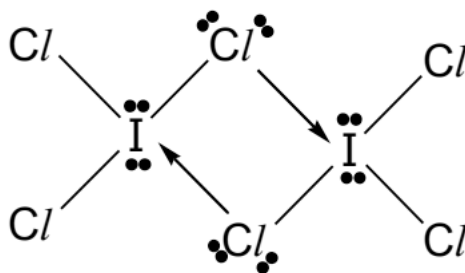
A1 – Explains dispersion forces formation (or instantaneous dipole-induced dipole)

Electron cloud from 1 ICl_5 molecule will induce a temporary dipole moment in another ICl_5 molecule (because the electron cloud repels electrons in the ICl_5 molecule facing this electron cloud, so there's a temporary partial positive charge)

- (v) ICl_3 can form a dimer with itself like aluminium chloride to form I_2Cl_6 . There are co-ordinate bonds formed in I_2Cl_6 .

Explain what are *co-ordinate bonds*, with reference to the structure of this dimer. [2]

A1 – Correct structure with co-ordinate bonds indicated as arrows



A1 – Correct explanation

1 co-ordinate bond in I_2Cl_6 is where electrons in 1 I-Cl covalent bond is contributed solely by a Cl atom to an I atom.

- (c) Sodium is less electronegative than chlorine too.

When sodium metal and chlorine gas are mixed, a reaction occurs, forming sodium chloride, commonly known as table salt.

- (i) With the aid of a labelled diagram, describe the structure and bonding in sodium. [3]

A1 – Labelled diagram

- Shows a regular lattice of Na^+ atoms
- Equal number of electrons

A1 – Describes structure

- Giant metallic structure/lattice
- Lattice of positively charged Na^+ cations
- Sea of delocalised electrons
 - OR labels 'sea' of delocalised electrons in diagram

A1 – Describes bonding

- Strong electrostatic attraction between
- oppositely charged electrons and Na^+ cations

- (ii) Write a balanced chemical equation of the formation of sodium chloride. [1]



(Accept answer where stoichiometric coefficient of Na is 1)

- (iii) With reference to structure and bonding, predict and explain the difference between the melting point of sodium chloride and ICl_5 . [2]

A2 – Deduct 0.5 pts per missing point up to 2 pts

- (structure) Sodium chloride has a giant ionic lattice
- (bonding) Where there are strong electrostatic forces of attraction (or strong ionic bonds) between oppositely charged Na^+ and Cl^- ions.
- (structure) ICl_5 has a simple molecular structure

- (bonding) Where there are weak dispersion forces between molecules
- Because ionic bonds are stronger than dispersion forces
- **More** heat is needed to break the ionic bonds in sodium chloride than to overcome the dispersion forces between ICl_5 molecules.

Note the usage of break and overcome, break a bond, overcome a force

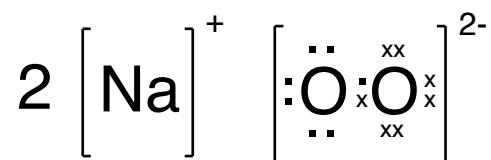
- (iv) When a sample of bare sodium is left in air, a coating of sodium peroxide, Na_2O_2 , is formed. The oxidation state of sodium is +1.

Draw the dot-and-cross diagram of sodium peroxide.

[1]

B1 – Correct dot-and-cross

There is no need to indicate the extra electron with another symbol on each O atom. If you do, you have to make sure that every atom has a different symbol for each extra electron.



- 2 (a) In organic chemistry, the use of a solvent to conduct a reaction matters.
- (i) One type of solvent is a *protic* solvent. This means that molecules of such solvents have the ability to form hydrogen bonds with itself, and different molecules.

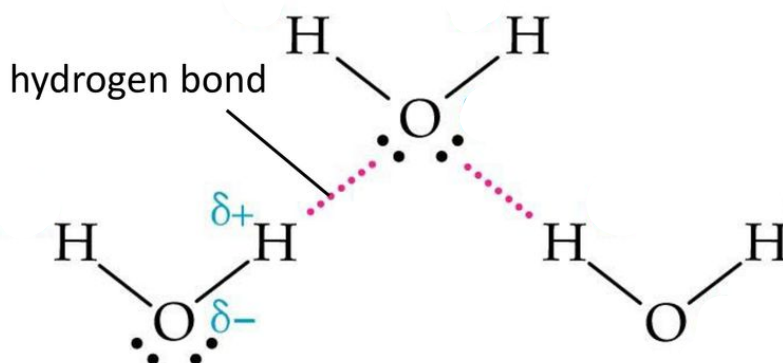
Name a *protic* solvent. With the aid of labelled diagrams, explain why this solvent is a *protic* solvent.

[3]

B1 – Any acceptable protic liquid solvents

Water, ethanol etc. (Do not accept chemical formula because the command word is 'Name'.)

A1 – Diagram (forms H-bonds with itself)



Candidates must label (deduct 0.5 pts per mistake up to 1 pt)

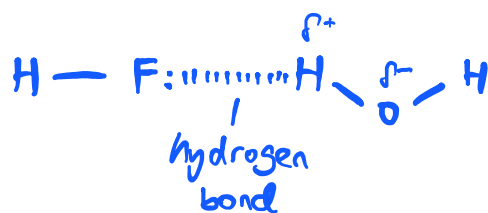
- Lone pair on the O, N or F atom
- Delta +ve/-ve pair on other molecule
- Draw H-bond with dotted lines
- Labels 'hydrogen bond'

A1 – Diagram (forms H-bonds with different molecules)

- No double penalty for poor labelling/drawing

A0 – Conclusion (Deduct 0.5 pts if conclusion is not present)

Water can form H-bonds with other water molecules and a different molecule such as... (e.g. NH₃, HF etc.), hence water is a protic solvent.



Command word of labelled diagrams **s** means that more than 1 diagram must be used.

Another type of solvent is a *polar aprotic* solvent. Molecules of such solvents cannot form hydrogen bonds with itself, but are *polar*.

- (ii) Explain what makes a molecule *polar*. [1]

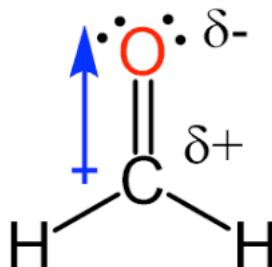
B1 – Mentions presence of net dipole moment

Accept: Individual dipole moments do not cancel each other.

- (iii) Formaldehyde, CH₂O, is a *polar aprotic* solvent. Draw the structure of formaldehyde, and label all dipole moments in formaldehyde. [2]

B1 – Correct structure (apparent geometry doesn't need to be correct but should be where possible)

B1 – Labels correct dipole moment for C=O, C—H bond can be omitted.



Dipole moment label: Delta +ve and -ve, with correct dipole moment (positive to negative)

- (iv) Explain if formaldehyde and water are miscible. [2]

A0 – They are miscible. (No credit awarded)

A2 – Correct explanation (deduct 0.5 pts per point up to 2 pts)

- Formaldehyde and water form favourable hydrogen bonds
- releasing enough energy to
- break the hydrogen bonds formed between water molecules
- and disrupt the permanent dipole-permanent dipole (pd-pd) interactions between formaldehyde molecules.

- (v) Another solvent is a *non-polar* solvent. 2 examples are liquid carbon dioxide and hexane.

Explain why *non-polar* solvents and protic solvents are generally not miscible. [2]

A2 – Correct explanation (deduct 0.5 pts per point up to 2 pts)

- Hydrogen bonds formed between protic solvents are **much** stronger
- than the dispersion forces (or permanent dipole-induced dipole interactions) between the non-polar molecule and protic molecule
- that there is insufficient energy released from the latter

- to break the former.

There is no need to talk about the dispersion forces between non-polar molecules because they are too insignificant.

Usage of the rule “like dissolve like” is not accepted. This “rule” is just a saying, not an explanation.

(b) The carbon atom in formaldehyde is sp^2 hybridised.

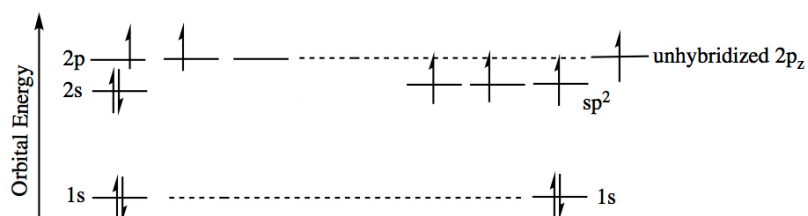
(i) State the electronic configuration of carbon.

[1]

B1 – $1s^2 2s^2 2p^2$

(ii) Draw 2 energy level diagrams to illustrate sp^2 hybridisation for carbon.

[2]



Good illustration above

A1 – Correct ground state (shows the electronic configuration of $1s^2 2s^2 2p^2$)

A1 – Correct hybridised state (sp^2 and unhybridized p orbital)

- Note: p orbital need not be the p_z orbital (no penalty for indicating p_z orbital)
- The 1s orbital can be omitted
- The label of the axis can be “energy”

(iii) Draw and name **all** the outer orbitals in carbon.

[2]

A2 – All 4 correct (Award 1 pt for any 3 correct)

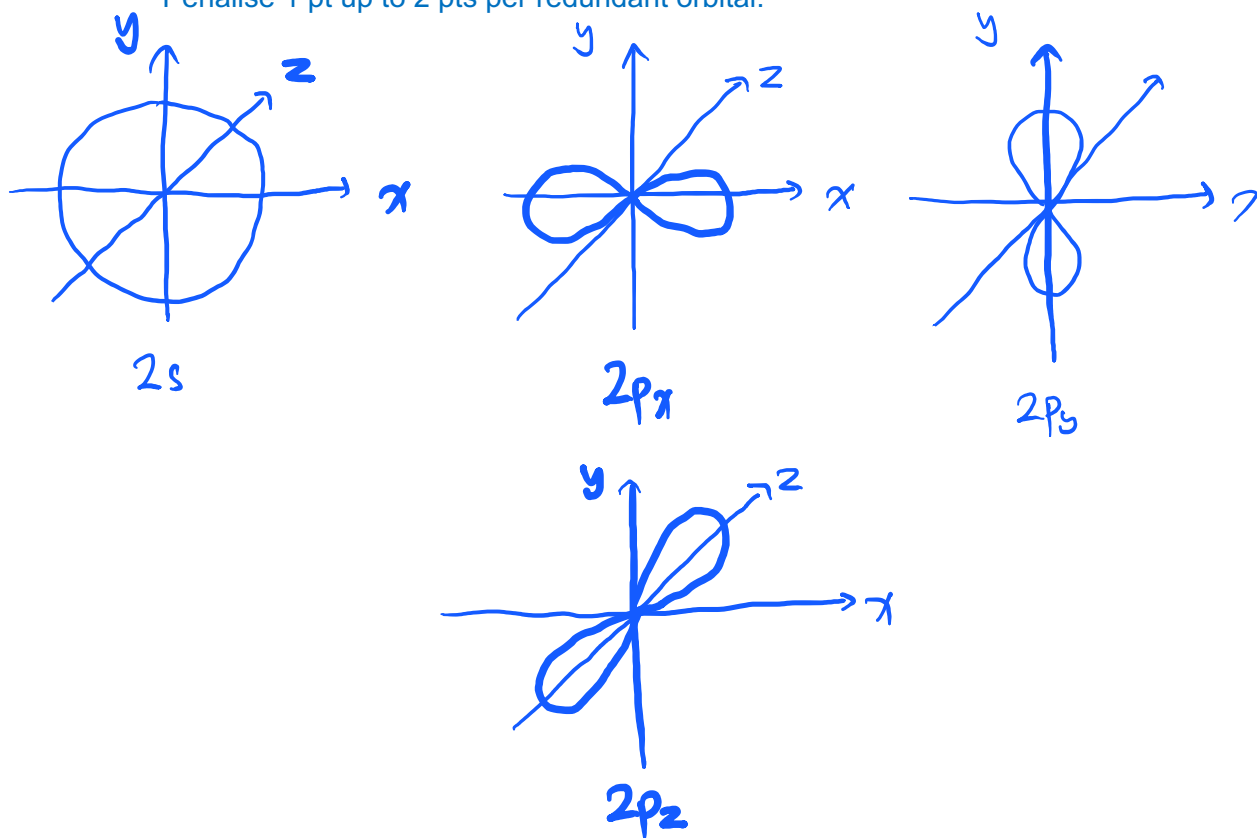
2s, 2p_x, 2p_y, 2p_z

1 correct drawing must have

- Axes labelled
- Correct drawing and symmetry
- Name of the orbital should be clear

Penalise 0.5 pts once for not writing the principal quantum number.

Penalise 1 pt up to 2 pts per redundant orbital.



(iv) Illustrate the type(s) of bonding in the C-O bond of formaldehyde.

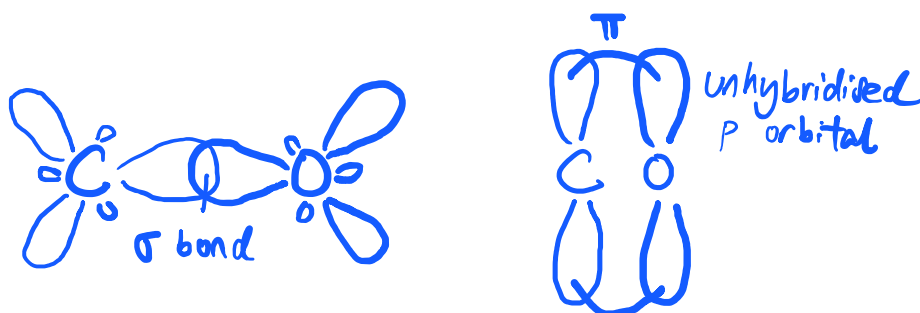
[2]

A1 – sigma bond

- Shows sp² hybridised carbon and oxygen (An 'awareness' is sufficient)
- Head on sp²-sp² overlap (labels area of overlap as "sigma")

A1 – pi bond

- Shows unhybridized p orbitals
- Side on p-p overlap (labels area of overlap as "pi")



- (c) When iodine is dissolved in hexane, a purple colouration is observed.

However, iodine is much less soluble in water compared to hexane. Aqueous iodine is light yellowish brown in colour.

A test tube of hexane contains iodine. Then, some water was added into the test tube. The test tube was then shaken vigorously, and left to stand.

Draw the appearance of the test tube after the solution was left to stand.

[2]

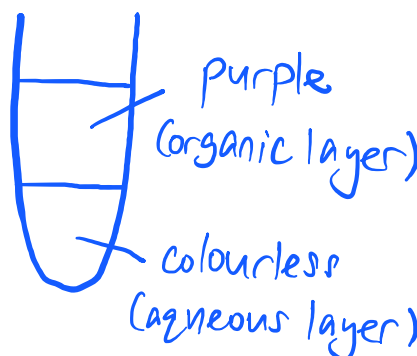
The density of hexane is lower than that of water.

A1 – Correct colour of aqueous and organic layers

- Purple organic layer
- Colourless (accept light yellow)

A1 – Correct positions of layers

- Organic layer is on top
- Aqueous layer is below

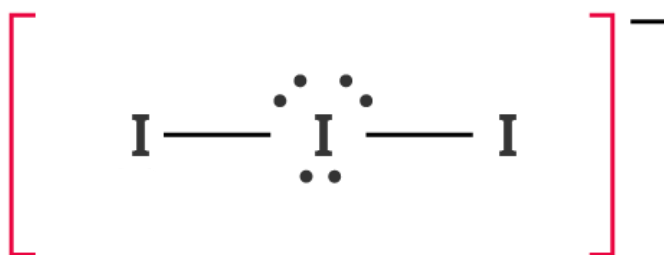


- (d) When iodine is dissolved in aqueous potassium iodide, a brown colouration is observed. This is due to the formation of the triiodide ion, I_3^- .

- (i) On page 9, draw the Lewis structure of the triiodide ion.

[1]

B1 – Correct structure



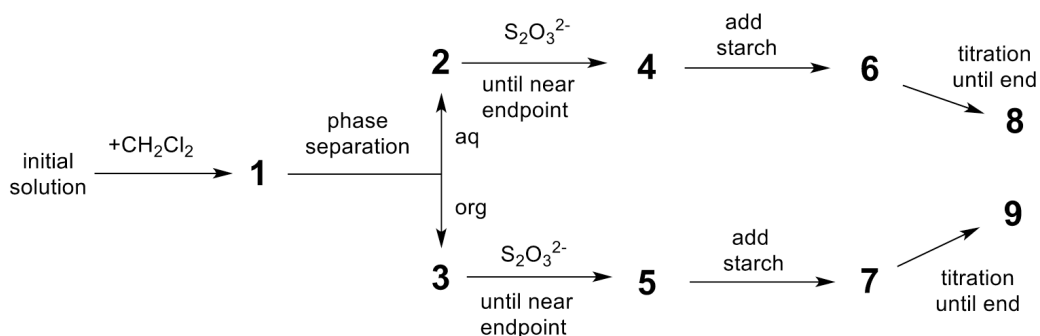
Correct shape shown – Linear (Implicit in candidate's answer)

Lone pairs on terminal iodine atoms should not be shown

- (ii) The following procedure was conducted:

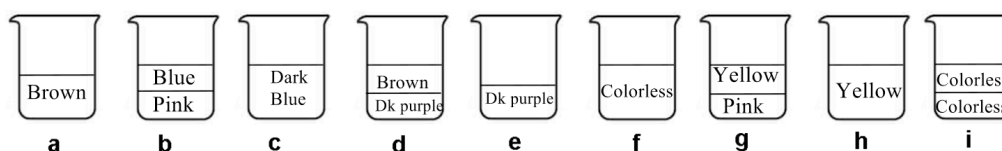
A few crystals of solid iodine were dissolved in 50.0 cm^3 of an aqueous solution of potassium iodide. Then, 50.0 cm^3 of dichloromethane, CH_2Cl_2 , was added, and the mixture was vigorously shaken until equilibration. After phase separation, each phase was titrated by 16.20 cm^3 (organic phase) and by 8.00 cm^3 (aqueous phase)

of the standard aqueous solution of sodium thiosulfate in the presence of starch. The process is schematically represented below:



Sodium thiosulfate reacts with iodine to form colourless iodide ions. A dilute solution of aqueous iodine appears as yellow. When starch is added to iodine, a dark blue colouration is formed.

The figure below shows 9 different illustrations of the solutions at different stages of this process. ['Dk' means dark.]



Match the stages on the scheme (1 to 9) to the schematic illustrations representing them (a to i).

[4]

Stage	Illustration	Stage	Illustration	Stage	Illustration
1	d	4	h	7	b
2	a	5	g	8	f
3	e	6	c	9	i

All correct – 4 pts

Deduct 0.5 pts per wrong answer up to 4 pts

[Total: 24]