

Structured Questions

The Covalent Model

Covalent Bonds / Lewis Formulas / Multiple Bonds / Coordinate Bonds / Shapes of Molecules / Bond Polarity / Molecular Polarity / Giant Covalent Structures / Intermolecular Forces / Physical Properties of Covalent Substances / Chromatography / Resonance Structures (HL) / Benzene (HL) / Expansion of the Octet (HL) / Formal Charge (HL) / Sigma & Pi Bonds (HL) / Hybridisation (HL)

Easy (16 questions)	/142
Medium (20 questions)	/206
Hard (15 questions)	/179
Total Marks	/527

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Easy Questions

- 1 (a) Using Section 9 of the data booklet to state which of the following single covalent bonds is the most polar.

C-O

C-H

O-H

(1 mark)

- (b) Using Section 11 of the data booklet, list the following molecules in order of increasing bond length between the carbon atoms.

C₂H₆

C₂H₄

C₂H₂

(1 mark)

- (c) Using Section 12 of the data booklet, list the following molecules in order of decreasing bond strength between the carbon atoms.

C₂H₆

C₂H₄

C₂H₂

(1 mark)

- (d) CO contains three covalent bonds, one of which is a coordinate bond.

Describe how a coordinate bond arises in CO.

(1 mark)

2 (a) Calcium nitrate contains both covalent and ionic bonds.

State the formula of both ions present and the nature of the force between these ions.

(2 marks)

(b) State the formula of the compound that boron forms with chlorine.

(1 mark)

(c) Draw the Lewis structure for boron chloride.

(1 mark)

(d) Explain why boron trichloride is able to form coordinate (covalent) bonds with other molecules.

(1 mark)

3 (a) State the formula for benzene and draw the displayed structure.

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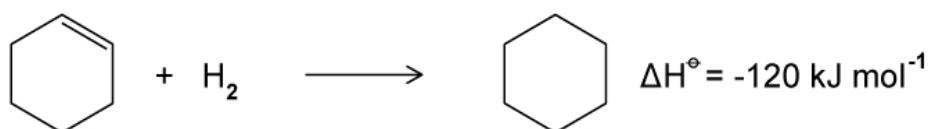
(2 marks)

(b) State the bond angle in the planar regular hexagon structure of benzene.

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(1 mark)

(c) Cyclohexene is an unsaturated hydrocarbon and can undergo hydrogenation as shown below.



When benzene undergoes the same reaction with three hydrogen molecules the expected enthalpy change of the reaction is lower than expected.

State the expected value of the hydrogenation of benzene.

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(1 mark)

(d) Explain why the enthalpy value for the hydrogenation of benzene is lower than expected.

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(2 marks)

4 (a) Two types of covalent bond are sigma and pi bonds.

i) Describe how a sigma (σ) bond is formed

[1]

ii) Describe how a pi (π) bond is formed

[1]

(2 marks)

(b) Describe the difference in the location of the electron dense regions in sigma (σ) and pi (π) bonds.

(2 marks)

(c) Deduce the number of sigma (σ) and pi (π) bonds in methane, CH_4 .

(2 marks)

(d) Deduce the number of sigma (σ) and pi (π) bonds in oxygen, O_2 .

(2 marks)

5 (a) Sulfur can form bonds with six fluorine atoms to form sulfur hexafluoride, SF₆.

i) How many electrons are in the outer shell of the sulfur in SF₆? [1]

ii) State the minimum and maximum numbers of electrons possible in the outer shell of sulfur. [1]

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(2 marks)

(b) Sulfur has no lone pairs when bonded to fluorines in SF₆. Predict the molecular geometry of sulfur hexafluoride, SF₆.

.....

(1 mark)

(c) State the F-S-F bond angles in SF₆.

.....

(1 mark)

(d) Phosphorus pentafluoride, PF₅, is also a molecule with an expanded octet around the central atom.

i) Draw a Lewis (electron dot) structure for PF₅ [1]

ii) Predict the molecular geometry of PF₅ [1]

iii) State the F-P-F bond angle(s) [1]

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(3 marks)

6 (a) Although noble gases do not normally react, a few compounds are possible. One is xenon tetrafluoride.

Draw the Lewis structure (electron dot) for XeF₄.

(2 marks)

(b) Predict the molecular geometry and electron domain geometry for the XeF₄ molecule.

(2 marks)

(c) Predict and explain the F-Xe-F bond angle in XeF₄

(2 marks)

(d) The formal charge on an atom can be calculated by the following:

$$\text{FC} = (\text{Number of valence electrons}) - \frac{1}{2}(\text{Number of bonding electrons}) - (\text{Number of non-bonding electrons})$$

Calculate the formal charge on the xenon and the fluorines in xenon tetrafluoride, XeF₄.

(2 marks)

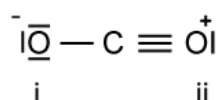
7 (a) Draw a Lewis (electron dot) structure for carbon dioxide, CO₂.

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(2 marks)

(b) Predict the molecular geometry and the O-C-O bond angle in carbon dioxide, CO₂.

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(2 marks)

(c) An alternative way to draw the carbon dioxide molecule is:



Identify the formal charge on each of the oxygen atoms.

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(2 marks)

(d) State which of the Lewis structures, that from part a) or part c), is preferable and explain your choice.

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(2 marks)

8 (a) There are a number of different types of intermolecular force possible between molecules.

Which types of forces can be classified as 'van der Waals' forces?

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(2 marks)

(b) Methanol, CH_3OH , is a small alcohol molecule that forms hydrogen bonds with water.

Sketch 2 different hydrogen bonding interactions between methanol and water.

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(2 marks)

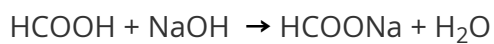
(c) Methanol, CH_3OH can be oxidised to methanal, CH_2O and then to methanoic acid, HCOOH .

Identify the strongest type of intermolecular force between:

- i) Methanal molecules [1]
- ii) Methanoic acid molecules [1]
- iii) Water and methanal [1]
- iv) Water and methanoic acid [1]

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(4 marks)

(d) Methanoic acid reacts with sodium hydroxide to form sodium methanoate:



Explain why sodium methanoate is a solid at room temperature and methanoic acid is a liquid.

(3 marks)

9 (a) Group 17 of the Periodic Table contain non-metals that are often referred to as the halogens.

Iodine, I_2 , is one of these halogens. At room temperature and pressure it exists as a grey-black solid.

Describe the bonding and forces present in I_2 in the solid state.

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(2 marks)

(b) The state of the halogens changes down the group, with fluorine being a gas and astatine being a solid.

Explain why the melting point of the halogens increases down the group.

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(2 marks)

(c) The halogens are all diatomic covalent molecules.

Predict the most probable physical properties shown by all of the elements in Group 17.

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(3 marks)

(d) The halogens can also form interhalogen compounds, such as iodine monochloride, ICl .

Predict the state of iodine monochloride at room temperature and pressure, and explain your answer with reference to the intermolecular forces present.

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(3 marks)

10 (a) State what is meant by the term delocalisation of electrons.

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(1 mark)

(b) Delocalisation is common in some types of organic molecule.

i) Identify whether ethanoic acid, CH_3COOH , has delocalised π electrons. [1]

ii) Identify where the ethanoate ion, CH_3COO^- , has delocalised electrons. [1]

iii) Give a reason for your choices. [1]

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(3 marks)

(c) Draw two resonance structures for the ethanoate ion, CH_3COO^- .

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.....
(2 marks)

11 (a) Benzene, C_6H_6 , has two resonance structures. Draw skeletal formulae of these two structures.

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.....
(1 mark)

(b) Benzene is commonly drawn in the following manner:



Explain what this represents and why this is a useful way to draw benzene.

.....
.....
(2 marks)

(c) Some of the sigma bonds in benzene are formed from hybrid orbitals. The type of hybridisation present is sp^2 .

State which orbitals hybridise to form sp^2 orbitals.

.....
.....
(2 marks)

(d) The sp^2 hybridized orbitals form sigma bonds in the benzene molecule. The delocalised electrons from pi bonds.

i) Deduce the number of sigma (σ) bonds in benzene.

[1]

ii) Deduce the number of pi (π) bonds in benzene.

[1]

(2 marks)

12 (a) Methane contains sp^3 hybridised orbitals.

i) Explain the formation of sp^3 hybridised orbitals. [2]

ii) How many sp^3 hybridised orbitals are present in methane? [1]

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(3 marks)

(b) Ethyne, C_2H_2 , is another hydrocarbon, in this case containing sp hybrid orbitals.

i) Explain the formation of the sp hybrid orbitals in ethyne [2]

ii) Deduce the number of sp hybrid orbitals in a molecule of ethyne. [1]

iii) State if these sp hybrid bonds form sigma (σ) or pi (π) (bonds) [1]

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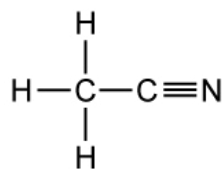
(4 marks)

(c) Explain, using the concept of hybridisation, how the triple bond in ethyne, C_2H_2 , forms.

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(2 marks)

- (d) Ethanenitrile, CH_3CN , is an organic molecule with a tetrahedral molecular geometry around one carbon and a linear molecular geometry around the other carbon. The structure is shown below:



- i) Identify how many sp^3 hybrid orbitals are present in this molecule. [1]
- ii) Identify how many sp hybrid orbitals are present in this molecule. [1]

(2 marks)

13 (a) Yellow phosphorus reacts with chlorine to form phosphorus trichloride, PCl_3 .

i) Draw the Lewis (electron dot) structure of phosphorus trichloride. [1]

ii) Predict the Cl-P-Cl bond angle and molecular geometry of the phosphorus trichloride molecule. [2]

(3 marks)

(b) Phosphorus trichloride, PCl_3 , can form a co-ordinate bond with a hydrogen ion to form HPCl_3^+ .

i) Draw the Lewis (electron dot) structure of HPCl_3^+ . [2]

ii) Predict the bond angle and molecular geometry of HPCl_3^+ . [2]

(4 marks)

(c) BCl_3 has three electron domains in a trigonal planar structure.

BCl_3 is not a polar molecule, but PCl_3 is.

Explain this difference using section 9 of the Data booklet.

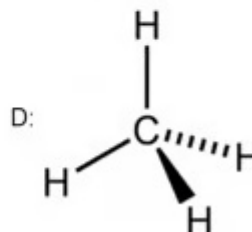
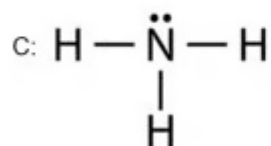
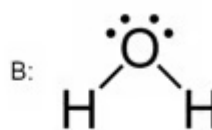
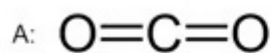
(4 marks)

(d) PCl_4^+ has the same electron domain geometry as HPCl_3^+ .

Explain why PCl_4^+ is not a polar molecule.

(2 marks)

14 (a) This question is about the geometry of a number of common molecules.



- i) Which molecule(s) has/ have tetrahedral structures with respect to the electron domain geometry? [1]
- ii) What is the molecular geometry of CO_2 ? [1]
- iii) Draw the 3D representation of ammonia, NH_3 . [1]

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(3 marks)

(b) Estimate the H-O-H bond angle in water, H_2O , using VSEPR theory.

Explain your answer.

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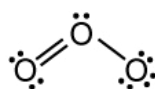
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(3 marks)

(c) Suggest a way in which the bond angle in ammonia / NH_3 could become 109.5° and explain your answer.

(3 marks)

(d) Ozone, O_3 , is another simple molecule which has the following structure:



i) Estimate the O-O-O bond angle in ozone using VSEPR theory.

[1]

ii) Explain why the actual bond lengths present in ozone are equal.

[2]

(3 marks)

15 (a) Carbon has three naturally occurring allotropes; diamond, graphite and buckminsterfullerene, C₆₀.

State how many atoms each carbon is directly bonded to in each of the allotropes, explaining any differences.

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(4 marks)

(b) Describe the differences in the structures of the three allotropes of carbon.

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(3 marks)

(c) Describe and explain the differences in electrical conductivity between the three allotropes of carbon.

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(4 marks)

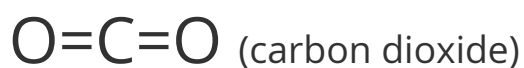
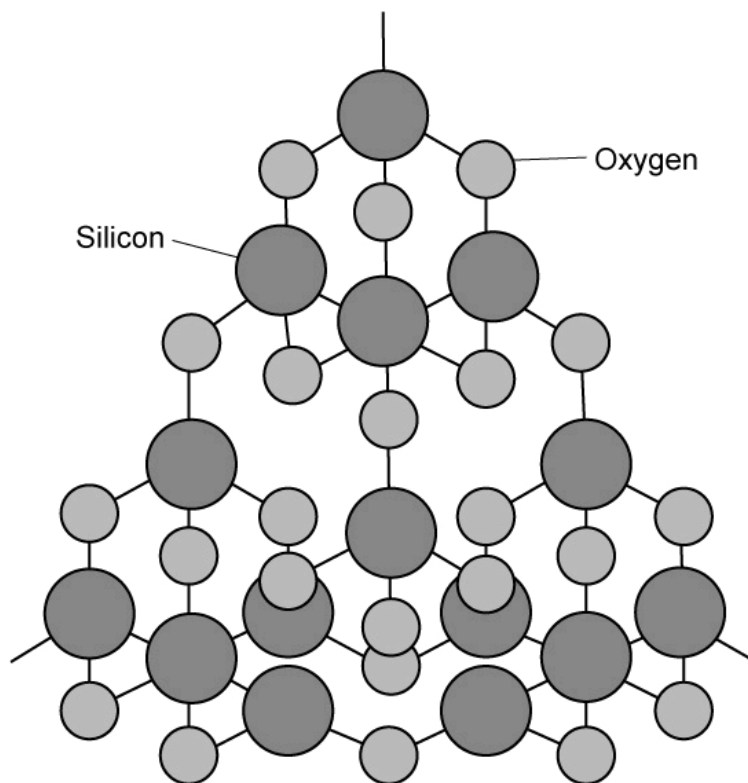
(d) Graphene can be made from graphite.

Describe a similarity and difference between these two structures.

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(2 marks)

16 (a) Silicon and carbon are in the same group of the Periodic Table. They both form covalent bonds.



Both silicon and carbon form dioxides, but silicon dioxide has a melting point of 1710 °C whilst carbon dioxide has a melting point of -78 °C.

Explain this difference with reference to the structure and bonding present in each dioxide.

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(4 marks)

(b) How many oxygen atoms are bonded to each carbon and to each silicon?

Explain how this links to the formula of each compound.

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(3 marks)

(c) Predict the O-C-O and O-Si-O bond angles respectively in CO₂ and in SiO₂.

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(2 marks)

Predict and explain the solubility of both SiO₂ and CO₂ in water.

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(d)

(4 marks)

Medium Questions

- 1 (a) For each of the molecules below, draw the Lewis (electron dot) structure and use the valence shell electron pair repulsion theory (VSEPR) to predict the shape of each molecule.

Oxygen difluoride (OF_2), phosphorus trifluoride, (PF_3) and boron trichloride, (BCl_3).

(6 marks)

- (b) Crystalline ionic compounds do not conduct electricity.

State and explain in which states ionic compounds conduct electricity.

(2 marks)

- (c) The melting point of sodium chloride, NaCl , is 801°C .

Explain, with reference to structure and bonding, why sodium chloride melts at such a high temperature.

(3 marks)

- (d) We can use electronegativity values to deduce whether a compound is likely to be ionic or covalent.

Use Section 9 of the Data Booklet to state and explain whether each of the following compounds are ionic or covalent:

ICl

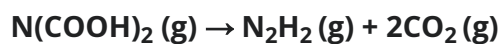
SrCl₂

RbI

HI

(2 marks)

- 2 (a) Diimide, N_2H_2 , is a useful reagent in organic synthesis and can be made by the thermal decomposition of azodicarboxylic acid.



Another useful compound of nitrogen is hydrazine, N_2H_4 .

Draw Lewis (electron dot) structures for diimide and hydrazine.

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(2 marks)

- (b) Deduce the molecular geometry of diimide and estimate its H-N-N bond angle.

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(2 marks)

- (c) List, with an explanation, the three compounds in order of increasing carbon to oxygen bond length (shortest first).



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(3 marks)

(d) Use Section 9 of the Data Booklet to predict which bond in each of the following pairs is more polar:

i) C-H or C-Cl

[1]

ii) Si-Li or Si-Cl

[1]

(2 marks)

3 (a) Three types of covalent bonds are present in the molecules in the following equation.



Identify **one** bond in these molecules that is correctly described by the following:

i) A polar single bond.

[1]

ii) A non-polar double bond.

[1]

iii) A non-polar triple bond.

[1]

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(3 marks)

(b) Explain which of the bonds in part (a) is the shortest.

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(2 marks)

(c) **Table 1** shows the carbon-carbon bond enthalpy values for three different hydrocarbons.

Table 1

Hydrocarbon	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
Bond enthalpy / kJ mol ⁻¹	346	614	839

Explain the difference in carbon-carbon bond enthalpy values for the three hydrocarbons.

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(3 marks)

- (d) We can use electronegativity values to deduce whether a compound is likely to be pure covalent (non-polar) or polar covalent.

Use Section 9 of the Data Booklet to state and explain whether each of the following covalent compounds is polar or non-polar:



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(2 marks)

- 4 (a)** Ammonia, NH_3 , is a chemical that is key in the manufacture of certain fertilisers and cleaning products.

An ammonia molecule will react with an H^+ ion, to form the ammonium ion, NH_4^+ .

Draw a Lewis (electron dot) diagram to show the bonding in the ammonium ion and name the type of bond formed between the ammonia molecule and the hydrogen ion.

(2 marks)

- (b)** Lewis (electron dot diagrams) are used to show the electron arrangement in the valence shells of covalently bonded molecules.

Draw Lewis diagrams for the following molecules:

i) Hydrogen cyanide.

[1]

ii) Carbon dioxide.

[1]

iii) Boron trifluoride.

[1]

(3 marks)

- (c)** Using your answer to part (b), identify and explain the species that is likely to form a coordinate covalent bond.

(2 marks)

- (d)** Using your answer to part (c), Explain, with the help of a diagram, the covalent bond formed between the species in part (c) and ammonia.

(3 marks)

5 (a) Benzene is an aromatic hydrocarbon which is often drawn as **Figure 1**.

Discuss the physical evidence that justifies this structure for benzene.

Figure 1



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.....
(2 marks)

(b) Benzene and cyclohexene are both *unsaturated* molecules, but cyclohexene reacts with bromine water and benzene does not.

i) State the meaning of the terms *saturated* and *unsaturated* as applied to organic molecules.

[1]

ii) Explain this difference in reactivity and write an equation for the reaction between cyclohexene and bromine.

[2]

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(3 marks)

(c) **Table 1** below shows the enthalpy changes for the hydrogenation of cyclohexene, benzene, and the theoretical molecule 1,3,5-cyclohexatriene.

Table 1

Compound	Enthalpy of hydrogenation
Cyclohexene, C ₆ H ₁₀	-120
Benzene, C ₆ H ₆	-208
1,3,5-cyclohexatriene, C ₆ H ₆	?

The equations for the hydrogenation reactions are:



- i) Use the data in **Table 1** to determine the enthalpy of hydrogenation of the theoretical molecule 1,3,5-cyclohexatriene. [1]
- ii) Discuss the difference between the enthalpy of hydrogenation of benzene and of 1,3,5-cyclohexatriene. [2]

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(3 marks)

- (d) An unknown aromatic compound has the molecular formula C₈H₈O₂.

Deduce the structural formula of **two** isomers of this compound which contain an ester group.

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(2 marks)

- 6 (a)** Phosphorus tribromide and sulfur tetrafluoride are two colourless compounds which both react with water to form toxic products.

Deduce the Lewis (electron dot) structure of both molecules.

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(2 marks)

- (b)** Predict the shapes of the two molecules of phosphorus tribromide and sulfur tetrafluoride

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(2 marks)

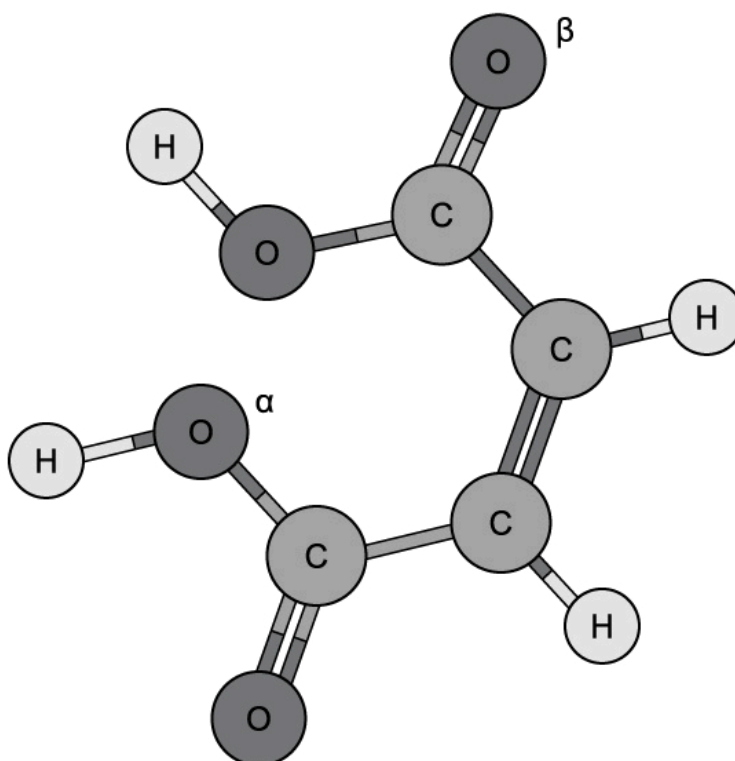
- (c)** Explain why both phosphorus tribromide and sulfur tetrafluoride are polar.

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(2 marks)

Compare the formation of a sigma (σ) and a pi (π) bond between two carbon atoms in a molecule.

- (d)** **(2 marks)**

- 7 (a) But-2-ene-1,4-dioic acid exists as both cis and trans isomers. The cis isomer is shown below:



Describe the type of covalent bond between carbon and hydrogen in the molecule shown above and how it is formed.

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(2 marks)

- (b) Identify how many sigma bonds and how many pi (π) bonds are present in cis but-2-ene-1,4-dioic acid.

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(2 marks)

Draw the Lewis structures, predict the shape and deduce the bond angles for xenon tetrafluoride.

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(c)

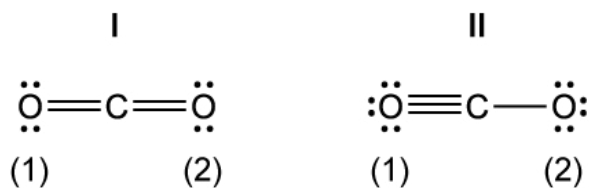
(3 marks)

Compare the polarity of xenon tetrafluoride with chlorine trifluoride.

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(d)

(3 marks)

8 (a) Carbon dioxide can be represented by at least two resonance structures, I and II.



Calculate the formal charge on each oxygen atom in the two structures.

Structure	I	II
O atom labelled (1)		
O atom labelled (2)		

(2 marks)

(b) Deduce, giving a reason, the more likely resonance structure from part a)

(2 marks)

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

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

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

	Lewis (electron dot) structure	FC of O on LHS	FC of central N	FC of N on RHS
A	$\text{:}\ddot{\text{O}}=\text{N}=\ddot{\text{O}}\text{:}$			
B	$\text{:}\ddot{\text{O}}-\text{N}\equiv\ddot{\text{O}}\text{:}$			
C	$\text{:}\text{O}\equiv\text{N}-\ddot{\text{N}}\text{:}$			

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(3 marks)

- (d) Based on the formal charges assigned in part c), deduce which Lewis (electron dot) structure of N_2O (A, B, or C) is preferred.

Explain another factor that also must be taken into account in determining the preferred structure.

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(3 marks)

9 (a) Use the concept of formal charge to explain why BF_3 is an exception to the octet rule.

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(2 marks)

(b) Compounds containing two different halogen atoms bonded together are called interhalogen compounds. They are interesting because they contain halogen atoms in unusual oxidation states. One such compound is BrF_3 .

Deduce the electron domain geometry and molecular geometry of BrF_3 .

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(2 marks)

(c) Give the approximate bond angle(s) and a valid Lewis (electron dot) structure for BrF_3 .

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(2 marks)

(d) Explain why bromine trifluoride, BrF_3 has its lone pairs of electrons located in equatorial positions.

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(2 marks)

- 10 (a) Draw two different Lewis (electron dot) structures for SO_4^{2-} , one of which obeys the octet rule for all its atoms, the other which has an octet for S expanded to 12 electrons.

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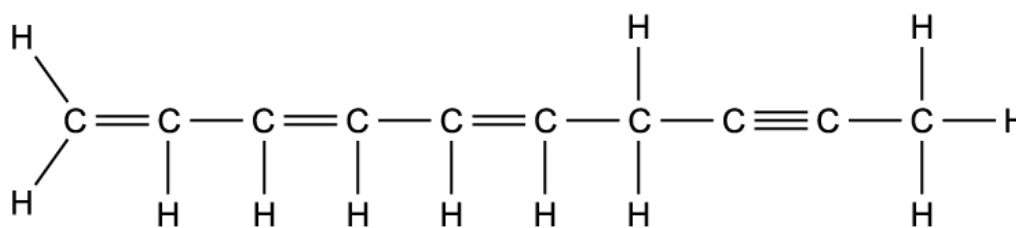
 (2 marks)

- (b) Explain which of the two SO_4^{2-} structures is preferred using formal charges.

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 (2 marks)

- (c) Consider the molecule shown below.

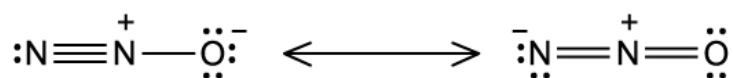


Identify the number of sigma and pi bonds in this molecule.

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 (2 marks)

- (d) One of the intermediates in the reaction between nitrogen monoxide and hydrogen is dinitrogen monoxide, N_2O . This can be represented by the resonance structures below



Analyse the bonding in dinitrogen monoxide in terms of sigma and pi bonds.

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(3 marks)

11 (a) Based on the type of intermolecular force present, explain why butan-1-ol has a higher boiling point than butanal.

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(2 marks)

(b) Ethane, C_2H_6 , and disilane, Si_2H_6 , are both hydrides of Group 4 elements with similar structures but different chemical properties.

Explain why disilane has a higher boiling point than ethane.

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(2 marks)

(c) Put the following molecules in order of increasing boiling point and explain your choice:



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(3 marks)

(d) Based on the type of intermolecular force present, explain the difference in solubility in water between ethane and ethanol.

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(4 marks)

12 (a) The melting points of some Group 1 elements are listed in **Table 1**.

Table 1

	Na	K	Rb
Melting point / °C	98	63	

Predict, with a reason, the melting point of Rb.

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(3 marks)

(b) Explain why ammonia, NH_3 , is a gas at room temperature.

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(2 marks)

(c) Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3 . Phosphine has a much greater molar mass than ammonia.

Explain why phosphine has a significantly lower boiling point than ammonia.

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(3 marks)

(d) Identify the type of interaction that must be overcome when liquid hydrazine, N_2H_4 , vaporizes. Suggest, with a reason, whether hydrazine has a lower or higher boiling point than diimide, N_2H_2 .

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(2 marks)

13 (a) Cyclohexane C_6H_{12} has a puckered, non-planar shape whereas benzene C_6H_6 is planar.

Explain this difference by making reference to the C–C–C bond angles and the type of hybridisation of carbon in each molecule.

(4 marks)

(b) Urea, $CO(NH_2)_2$, is present in solution in animal urine.

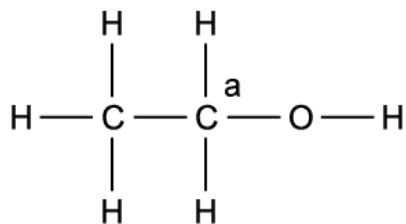
What is the hybridisation of C and N in the molecule, and what are the approximate bond angles?

(4 marks)

(c) Describe the hybridisation of the carbon atom in methane and explain how the concept of hybridisation can be used to explain the shape of the methane molecule

(4 marks)

(d) A molecule of ethanol is shown below.



Deduce the hybridisation of the carbon atom marked in the diagram below.

(1 mark)

- 14 (a)** Carbonation is the process of increasing the concentration of carbonate ions in water to produce carbonated drinks.

Identify the hybridisation of the central carbon atom.

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(1 mark)

- (b)** Explain, with the use of diagrams, how there are three valid structures for the carbonate ion.

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(3 marks)

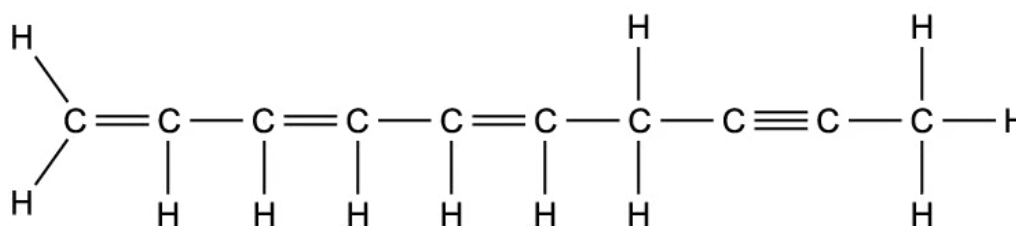
- (c)** Describe the distribution of pi (π) electrons and explain how this can account for the structure and stability of the carbonate ion, CO_3^{2-} .

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.....
(3 marks)

15 (a) Explain how the concept of hybridisation can be used to explain the triple bond present in propyne.

(3 marks)

(b) Consider the molecule below which contains both sigma and pi bonds.



How many carbon atoms exhibit sp^2 hybridisation in this molecule?

(1 mark)

(c) Deduce the hybridisation shown by the nitrogen atoms in NF_4^+ , N_2H_2 and N_2H_4 .

	NF_4^+	N_2H_2	N_2H_4
Hybridisation			

(3 marks)

16 (a) Draw the structure of silicon dioxide and state the type of bonding present.

.....
.....
(2 marks)

(b) Describe the similarities and differences you would expect in the properties of silicon and diamond.

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.....
(3 marks)

(c) The boiling point of diamond is 3550 °C, but for carbon dioxide it is -78.5 °C. Both are covalent substances.

Explain this difference with reference to structure and bonding.

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(4 marks)

(d) Silicon dioxide has a similar name to carbon dioxide, but its boiling point is 2230 °C.

Briefly outline the reason for this difference.

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.....
(2 marks)

17 (a) In 1996 the Nobel prize in Chemistry was awarded for the discovery of a new carbon allotrope, known as fullerenes.

Outline the structure of buckminsterfullerene.

.....
.....

(2 marks)

(b) Like carbon dioxide, graphite is also a covalent substance, but it is a solid at room temperature. Graphite has a melting point of around 3600 °C.

Describe the structure and bonding of graphite and explain why it has such a high melting point.

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(5 marks)

(c) Graphite is made purely of carbon, a non-metal, yet it conducts electricity. Diamond, which is also made purely of carbon, cannot conduct electricity.

i) Explain this difference in electrical conductivity between graphite and diamond.

[3]

ii) Give one other difference in the properties of graphite and diamond.

[1]

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(4 marks)

- (d)** Graphite is soft and so is used as a lubricant, whereas diamond is hard and so is used in many cutting tools. Both are giant covalent structures.

Explain this difference with reference to structure and bonding.

(4 marks)

- 18 (a)** The Valence Shell Electron Pair Repulsion Theory (VSEPR) is used to predict the shapes of many chemical molecules.

Describe the main features of the VSEPR theory for predicting shapes of molecules.

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(3 marks)

- (b)** State and explain the bond angle F-O-F in OF₂.

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(3 marks)

- (c)** Deduce whether each of the three molecules oxygen difluoride, OF₂, phosphorus trifluoride, PF₃, and boron trichloride, BC₃, are polar or non-polar.

Give a reason in each case.

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(3 marks)

(d) Predict and explain the shapes and bond angles of the following molecules:



[2]



[2]

(4 marks)

- 19 (a)** Ethene, C_2H_4 , and hydrazine, N_2H_4 , are hydrides of adjacent elements in the periodic table.

State and explain the H C H bond angle in ethene and the H N H bond angle in hydrazine.

(5 marks)

- (b)** Hydrazine can be oxidised to form diimide, which is a useful compound used in organic synthesis.

Deduce the molecular geometry of diimide, N_2H_2 , and estimate its H-N-N bond angle.

(2 marks)

- (c)** Explain whether ethene and hydrazine are polar or non-polar.

(4 marks)

- (d)** Hydrazine forms a cation with an ethane-like structure called hydrazinedium, $N_2H_6^{2+}$.

Predict the value of the H-N-H bond angle in $N_2H_6^{2+}$.

(1 mark)

20 (a) Draw the resonance structures for the following ions:

i) Methanoate, HCOO^- .

[1]

ii) Nitrate(III), NO_2^- .

[1]

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(2 marks)

(b) Deduce the resonance structures of the carbonate ion, giving the shape and the oxygen-carbon-oxygen bond angle.

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(3 marks)

(c) In December 2010, researchers in Sweden announced the synthesis of N,N-dinitronitramide, $\text{N}(\text{NO}_2)_3$. They speculated that this compound, more commonly called trinitramide, may have significant potential as an environmentally friendly rocket fuel oxidant.

Deduce the N–N–N bond angle in trinitramide and explain your reasoning.

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(3 marks)

(d) Predict, with an explanation, the polarity of the trinitramide molecule.

(2 marks)

Hard Questions

- 1 (a) Silver chloride, AgCl, is a chloride compound that has uses in photography films as well as having antiseptic properties.

Silver chloride has a high melting point and a structure similar to sodium fluoride.

Explain why, with reference to structure and bonding, why silver chloride has such a high melting point.

(3 marks)

- (b) Cyanide is a fast-acting chemical, which can be found in various forms and can have toxic effects on the body.

Draw the Lewis structure for a CN^- ion.

Show the outer electrons only.

(1 mark)

- (c) Ammonia, NH_3 , and boron trifluoride, BF_3 , react together to form NH_3BF_3 . Each of the molecules NH_3 and BF_3 have different features of its electronic structure which allows them to bond together.

Explain how the two molecules bond together and what type of bond is formed between NH_3 and BF_3 .

You may use a labelled diagram to help you.

(3 marks)

- (d)** Aluminium chloride, Al_2Cl_6 , does not conduct electricity when molten but aluminium oxide, Al_2O_3 , does.

Explain this in terms of the structure and bonding of the two compounds.

(4 marks)

2 (a) State why magnesium and oxygen form an ionic compound while carbon and oxygen form a covalent compound.

.....
.....
(1 mark)

(b) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure.

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.....
(2 marks)

(c) N, N-dinitronitramide $\text{N}(\text{NO}_2)_3$, also known as trinitramide, has been identified as a potentially more environmentally friendly rocket fuel oxidant.

Using Section 11 of the data booklet, outline how the length of the bond between nitrogen atoms in trinitramide compares with the bond between nitrogen atoms in nitrogen gas, N_2 .

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(2 marks)

(d) Describe the bonding within the carbon monoxide molecule.

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(2 marks)

3 (a) Draw a diagram to show the resonance structure in a molecule of benzene.

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(2 marks)

(b) The energy change for hydrogenation of cyclohexene is -120 kJ mol^{-1} . However, when benzene undergoes hydrogenation, the energy change is 152 kJ mol^{-1} less than expected.

Use this data to explain the relative stabilities of benzene and the theoretical cyclohexa-1,3,5-triene molecule.

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(3 marks)

With reference to bonding and hybridisation, describe the structure of benzene.

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(c)

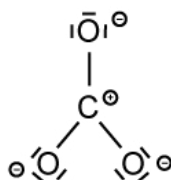
(4 marks)

- 4 (a) Deduce the number of possible resonance structures for the carbonate ion, CO_3^{2-} , and draw two of them.

Include the formal charges for each oxygen.

(4 marks)

- (b) An alternative structure for the carbonate ion is proposed:



Explain why this structure is not accepted as another resonance structure for the carbonate ion.

(2 marks)

- (c) Deduce the number of sigma (σ) and pi (π) bonds present in any of the resonance structures of the carbonate ions shown in part a).

(2 marks)

5 (a) Silicon can form silicon tetrachloride SiCl_4 and also silicon hexachloride, SiCl_6^{2-} .

- i) Draw the Lewis structure for SiCl_4 and SiCl_6^{2-} . [2]
- ii) Use VSEPR theory to deduce the Cl-Si-Cl bond angles in both the SiCl_4 and SiCl_6^{2-} molecules. [2]
- iii) Predict the molecular geometry of each molecule. [2]

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(6 marks)

(b) Carbon can form CCl_4 but cannot form CCl_6^{2-} . Explain why.

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(3 marks)

(c) Deduce which, if any, of SiCl_4 and SiCl_6^{2-} , are polar molecules and explain your choice.

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(2 marks)

(d) Formal charge can be used to decide on the most stable, and therefore most likely, form a molecule can take. Resonance structures occur when more than one Lewis diagram describes a structure equally well.

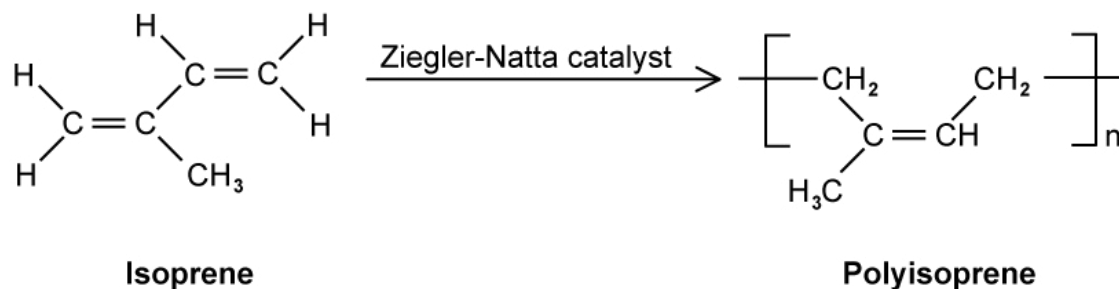
i) Deduce the formal charge on the silicon and each chlorine within SiCl_4 and SiCl_6^{2-} [2]

ii) Predict which will be the most stable molecule and explain your answer. [2]

iii) Predict if any resonance structures are possible for SiCl_6^{2-} and explain your answer. [2]

(6 marks)

6 (a) Natural rubber, polyisoprene, forms a flexible polymer in the following reaction:



i) Deduce the number of sigma (σ) and pi (π) bonds in the monomer. [2]

ii) Deduce the number of sigma (σ) and pi (π) bonds in the repeating unit. [2]

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(4 marks)

(b) Deduce the number of carbons with a tetrahedral geometry in both the monomer, isoprene, and the repeating unit of the polymer, polyisoprene.

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(2 marks)

(c) Polymer formation involves a radical intermediate to lengthen the polymer chain.

The radical in the formation of polyisoprene is shown below, where X represents the existing chain:

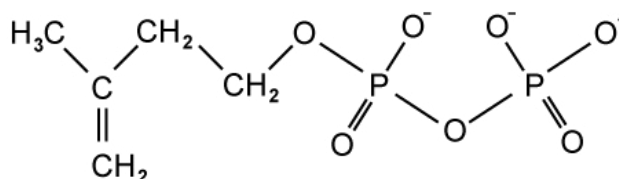


- i) Identify the atom that is the radical in the structure shown. [1]
- ii) Deduce the formal charge on the radical atom. [1]
- iii) Use the information above, and your knowledge of structure and bonding, to predict if the structure is stable or not. [2]

(4 marks)

(d) Isoprene is not produced directly by the rubber tree, but is the product of a series of biochemical reactions from the isopentenyl pyrophosphate molecules present in the tree.

The structure of isopentenyl pyrophosphate is shown below:



Deduce the number of sigma (σ) and pi (π) bonds present in one molecule of isopentenyl pyrophosphate.

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(2 marks)

7 (a) One interhalogen compound is IF_5 .

i) Draw the Lewis structure for IF_5 . [1]

ii) Use VSEPR theory to deduce the bond angles in IF_5 . [1]

iii) Predict whether IF_5 will be a polar molecule and explain your choice. [2]

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(4 marks)

(b) Iodine can also form the triiodide ion, I_3^- .

i) Draw the Lewis structure for I_3^- . [1]

ii) Use VSEPR theory to deduce the bond angles in I_3^- . [1]

iii) Explain the position of the lone pairs on the central iodine. [2]

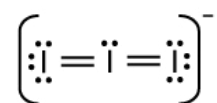
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(4 marks)

(c) Deduce the formal charge on each of the iodine atoms in the triiodide molecule, I_3^- .

(2 marks)

(d) An alternative Lewis structure for the triiodide ion, I_3^- , is suggested:



Deduce the formal charges and use them to suggest if the structure is stable and likely to occur.

(3 marks)

8 (a) Explain why methanol is soluble in water.

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(3 marks)

(b) Methanol, ethanol and propan-1-ol are all primary alcohols. Describe and explain the trend in their melting points shown below.

Alcohol	Methanol CH ₃ OH	Ethanol C ₂ H ₅ OH	Propan-1-ol C ₃ H ₇ OH
Melting point / °C	-97	-114	-126

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(4 marks)

(c) These longer primary alcohols have the following melting points:

Alcohol	C ₄ H ₉ OH	C ₅ H ₁₁ OH	C ₆ H ₁₃ OH	C ₇ H ₁₅ OH	C ₈ H ₁₇ OH	C ₉ H ₁₉ OH	C ₁₀ H ₂₁ OH
Melting point / °C	-90	-79	-52	-34	-16	-6	6

Describe and explain this trend.

(4 marks)

(d) Predict, with a reason, whether ethanol or ethane-1,2-diol will have the higher melting point?

(2 marks)

9 (a) C_2H_6 , C_4H_{10} and C_3H_8 are alkanes.

i) Put them in order of increasing boiling point and explain your answer.

[3]

ii) Put them in order of increasing volatility and explain your answer.

[3]

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(6 marks)

Predict, with a reason, whether the alkanes are soluble in water and propanone.

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(b)

(5 marks)

(c) Pentane can exist as isomers, including pentane, $CH_3CH_2CH_2CH_2CH_3$ and 2,2-dimethylpropane, $CH_3C(CH_3)_2CH_3$.

i) Draw skeletal formula for each isomer shown above.

[2]

ii) Predict and explain which isomer of pentane would have the greater volatility.

[3]

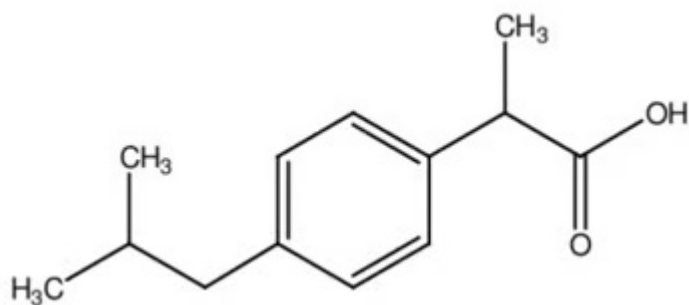
(5 marks)

(d) There are two isomers possible with the molecular formula C_2H_6O .

- i) Draw the skeletal formulae of both isomers [2]
- ii) Identify the strongest type of intermolecular force present in each isomer [2]
- iii) Predict which isomer would have the higher melting point [1]

(5 marks)

- 10 (a) Ibuprofen is a common non-steroidal anti-inflammatory drug (NSAID). It contains a benzene ring and a carboxylic acid at the end of one of the branches.



Deduce the number of resonance structures possible in the deprotonated form of ibuprofen.

(1 mark)

(b) Deduce the number of:

i) Sigma (σ) bonds in ibuprofen

[1]

ii) Pi (π) electrons in ibuprofen

[1]

(2 marks)

(c) The ibuprofen molecule contains both sp^3 and sp^2 hybridised orbitals.

i) Identify how many sp^3 hybrid orbitals are present.

[1]

ii) Identify how many sp^2 hybrid orbitals are present.

[1]

(2 marks)

(d) Explain why the benzene ring is a regular, planar hexagon.

(3 marks)

- 11 (a)** 2-hydroxypropanenitrile, CH_3CHOHCN , is a hydroxynitrile that can be formed from ethanal in a nucleophilic addition reaction.

Deduce the number of sigma (σ) and pi (π) bonds in a molecule of 2-hydroxypropanenitrile.

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(2 marks)

- (b)** Deduce the number of sp^3 , sp^2 and sp hybrid orbitals in a molecule of 2-hydroxypropanenitrile.

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(3 marks)

- (c)** Describe how the concept of hybridisation can be used to explain the formation of the triple bond and C-C-N bond angle in 2-hydroxypropanenitrile.

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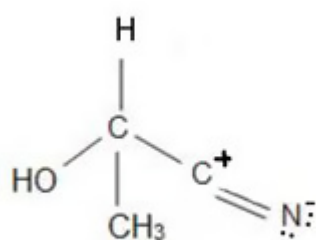
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(5 marks)

- (d)** Explain why, despite the high electron density in the triple bond, the triple bonded nitrile group is a more stable structure than the following alternative Lewis structure:



(3 marks)

12 (a) A simple amide is HCONH_2 .

Draw the Lewis (electron dot) structure for this molecule.

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(2 marks)

(b) Predict and explain the bond angle around the C and N atoms.

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(6 marks)

(c) Predict the molecular geometry and the electron domain geometry around the C and N in HCONH_2 .

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(4 marks)

(d) State, with a reason, whether HCONH_2 is a polar molecule.

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(3 marks)

- 13 (a)** Tetrafluoroethene, C_2F_4 , and tetrafluorohydrazine, N_2F_4 , are fluorides of adjacent elements in the Periodic Table.

Draw the Lewis (electron dot) structures for C_2F_4 and N_2F_4 showing all valance electrons.

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(2 marks)

- (b)** Predict and explain the F-C-F bond angle in tetrafluoroethene and the F-N-F bond angle in tetrafluorohydrazine.

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(5 marks)

- (c)** Tetrafluorohydrazine is a polar molecule but tetrafluoroethene is not.

Explain the difference in molecular polarity.

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(4 marks)

14 (a) Draw the Lewis (electron dot) structure of the carbonate ion, CO_3^{2-} .

(3 marks)

(b) Deduce the number of possible resonance structures for the carbonate ion, CO_3^{2-} , and draw two of them.

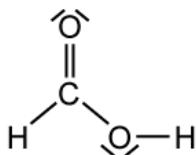
(3 marks)

(c) Discuss how the bonding in the carbonate ion, CO_3^{2-} , evidences the presence of the resonance structures.

(3 marks)

(d) Organic molecules can also show resonance. The methanoate ion, HCOO^- , shows similar resonance forms to the carbonate ion, CO_3^{2-} .

The corresponding organic acid, methanoic acid, also has resonance structures.



Draw another resonance structure of methanoic acid.

(2 marks)

15 (a) Some of the physical and structural properties of diamond and graphite are shown below:

Property	Diamond	Graphite
Melting Point at 1 atmosphere / K	4200	4300
Density / g cm ⁻³	3.51	2.26
Average bond length / nm	0.155	0.142
Delocalisation	No	Yes
Hybridisation	sp ³	sp ²
Electron mobility / cm ² V ⁻¹ s ⁻¹	1000 - 2000	15000 - 200000

Suggest why the melting point of graphite is higher than that of diamond, using the information in the table.

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(2 marks)

(b) Graphene has the structure of a single layer of graphite.

Suggest, giving a reason, the electron mobility of graphene compared to graphite.

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(2 marks)

(c) Graphite is a layered giant structure, containing London dispersion forces between the layers, whereas diamond has covalent bonds across all planes.

Describe and explain, based on structure and bonding, the differences expected when each of graphite and diamond are moved across a paper surface.

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(6 marks)