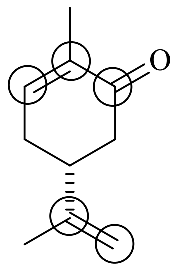
Marks
2

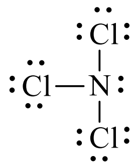
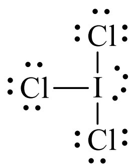
- (*R*)-Carvone is a typical terpene, a class of compounds widely distributed in nature. On the structure of (*R*)-carvone below, circle all of the carbon atoms with trigonal planar geometry.



(*R*)-carvone

Marks

- Complete the following table for the molecules NCl_3 and ICl_3. **3**

Molecule	Total number of valence electrons	Lewis structure	Shape of molecule
NCl_3	**26**		**trigonal pyramidal**
ICl_3	**28**		**T-shaped**

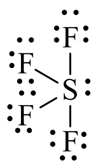
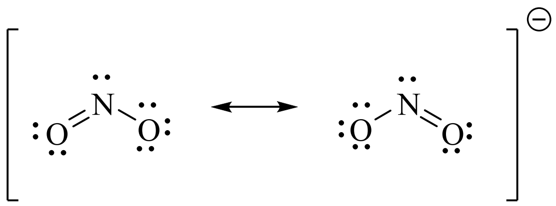
- Thionyl chloride ($SOCl_2$) is a common chlorinating agent in organic chemistry. Draw two possible Lewis structures for this molecule, assigning formal charges where appropriate. **3**

Which is the more stable resonance form? Give a reason for your answer.

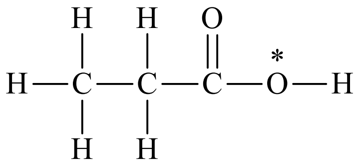
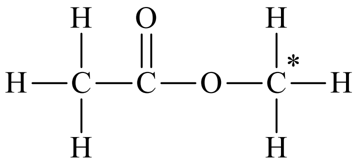
The first structure is more stable as it has minimised the formal charges.

Marks 4

- Draw the Lewis structure of the following species. The central atom is underlined. Give resonance structures where applicable and indicate whether the species has a dipole moment?

Species	Lewis structure	Dipole moment
<u>S</u>F_4		**<u>Yes</u>** / No
<u>N</u>O_2^-		**<u>Yes</u>** / No

- Complete the table concerning two of the isomers of $C_3H_6O_2$. Identify the geometry around each atom marked with an asterisk and the list the major intermolecular forces present in the liquid. **5**

Isomer	A	B
Chemical structure		
Geometry	**bent**	**tetrahedral**
Major intermolecular forces in liquid	**H-bonding, dipole-dipole and dispersion**	**dipole-dipole and disperson**

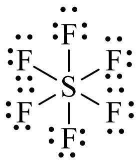
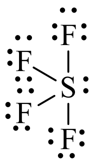
The boiling point of isomer A is 141 °C and that of isomer B is 60 °C. Explain why the boiling point of A is higher than B?

The molecules are very similar in size so dispersion forces will be of similar magnitude in each.

The strong hydrogen bonding possible for A is the major reason for its higher boiling point.

Marks
6

- Complete the following table for the molecules SF_6 and SF_4.

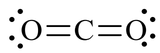
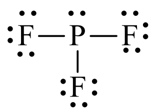
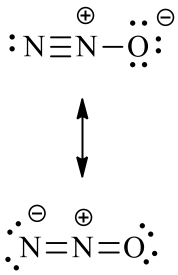
Molecule	Total number of valence electrons	Lewis structure	Shape of molecule
SF_6	**48**		**octahedral**
SF_4	**34**		**"see saw"**

Sulfur hexafluoride (SF_6) is quite inert, whilst sulfur tetrafluoride (SF_4) is highly reactive. Suggest a reason for the difference in reactivity between SF_6 and SF_4.

There is a lone pair of electrons on the S that can participate in reactions for SF_4, but not for SF_6.

Marks 5

- Complete the following table. The central atom is underlined. Carbon dioxide is given as an example. Where applicable, give all resonance structures and identify the major contributors according to the theory of formal charges.

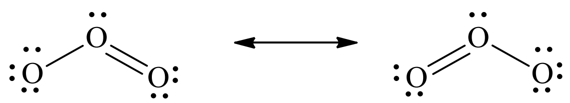
Molecule	Lewis structure	Shape of molecule	Dipole? (Y/N)
$\underline{C}O_2$		linear	N
$\underline{P}F_3$		**trigonal pyramidal**	**Yes**
$N\underline{N}O$		**linear**	**Yes**

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

- The σ-bonding in two plausible structures of ozone, O_3, is shown below. Complete each structure by adding electrons and/or π-bonds as appropriate. **4**

Predict the geometry of ozone? Give reasons for your answer.

Ozone adopts the non-cyclic structure. The cyclic structure is very strained with bond angles of 60° instead of 109.5°, making it very unstable. In contrast, the second structure is stabilised by resonance.



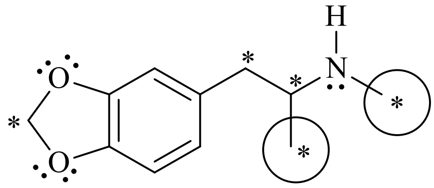
Ozone does not contain 1 double and 1 single bond. Both the O-O bonds are exactly the same length and true structure is a sort of average of the two Lewis structures shown. The energy of the true structure is lower than the theoretical energy for either of the given structures. This energy difference is known as resonance stabilisation energy.

Marks 3

- The stick representation of 3,4-methylenedioxy-*N*-methylamphetamine ("ecstasy") is shown in the box below.

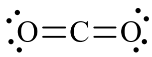
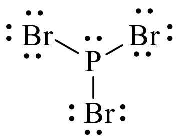
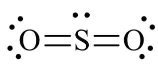
  (a) Identify clearly with asterisks (*) ALL the carbon atoms that have a tetrahedral geometry.

  (b) Circle all the CH_3 groups.



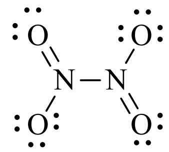
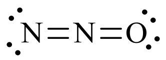
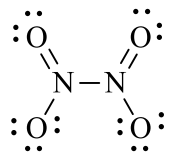
Name the N-containing functional group in ecstasy. **amine**

- Complete the following table. The central atom is underlined. Carbon dioxide is given as an example. **3**

Molecule	Lewis structure	Shape of molecule
<u>C</u>O_2		linear
<u>P</u>Br_3		**trigonal pryamidal**
<u>S</u>O_2		**bent (~120°)**

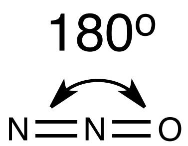
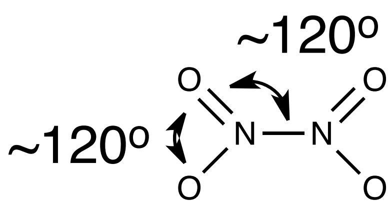
Marks 6

g) In the atmosphere, nitrogen oxides exist in many forms, including NO and NO_2. Two other forms are N_2O and N_2O_4 (the dimer of NO_2). Draw Lewis structures for both N_2O and N_2O_4. Examine your structures closely. If you can draw a second, valid, Lewis structure, draw it underneath.

N_2O structure	N_2O_4 structure
	
Second structure, if appropriate	Second structure, if appropriate
	

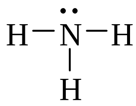
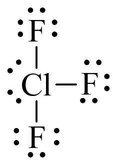
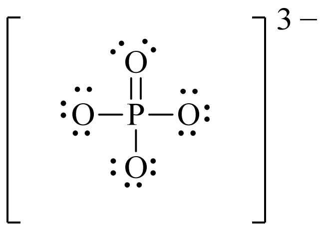
4

h) Use VSEPR theory to determine the shape of N_2O and N_2O_4. Sketch the shape below and indicate the approximate bond angle for all angles in the molecule. Be clear in your sketch as to planar and non-planar structures where appropriate. Hence, or otherwise, indicate whether either molecule has a permanent dipole moment.

N_2O	N_2O_4
	
Dipole moment? **<u>YES</u>** / NO	Dipole moment? YES / **<u>NO</u>**

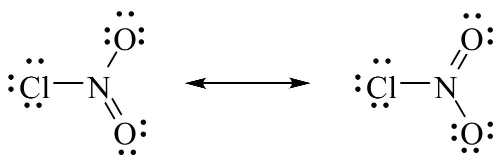
Marks
6

- Complete the table below showing the number of **valence** electrons, the Lewis structures and the predicted shapes of the following species. Ammonia, NH_3, is given as an example.

Formula	Number of electron pairs on central atom (discounting multiple bonds)	Lewis Structure	Name of molecular shape
NH_3	4		trigonal pyramidal
ClF_3	**5**		**T-shaped**
PO_4^{3-}	**4**		**tetrahedral**

Marks

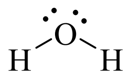
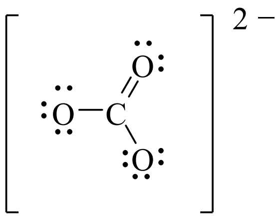
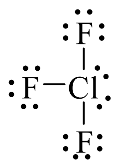
- Draw the major resonance contributors of nitryl chloride, $ClNO_2$. **2**



What is the bond order of the N–O bonds?

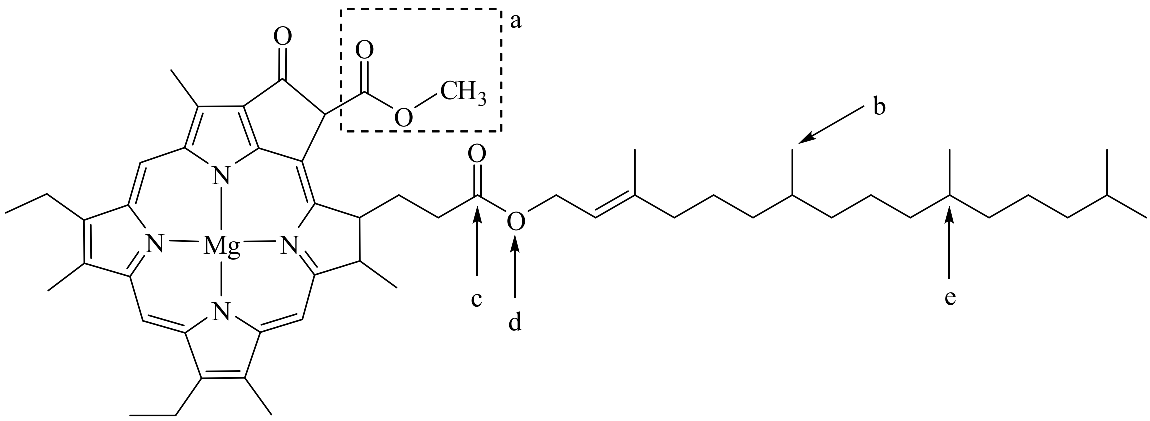
The bond order is an average over the resonance structures: 1.5

- Complete the following table showing the number of valence electrons, a Lewis structure and the predicted shape of each of the following species. **5**

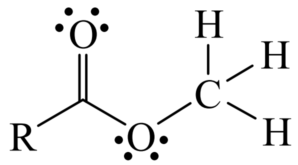
Molecule name	Chemical formula	Number of valence electrons	Lewis structure	Geometry of species
e.g. water	H_2O	8		bent
carbonate ion	$\mathbf{CO_3^{2-}}$	**24**		**trigonal planar**
chlorine trifluoride	$\mathbf{ClF_3}$	**28**		**T-shaped**

Marks
4

- Modern plants, algae and cyanobacteria contain a class of pigments called chlorophyll. The structure of "chlorophyll *a*", which absorbs both red and blue light, is shown below.



Draw the full Lewis structure of the functional group shown in box "a".



where 'R' represents the rest of the molecule

What type of functional group is it?

It is an ester.

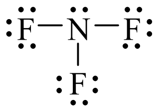
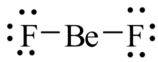
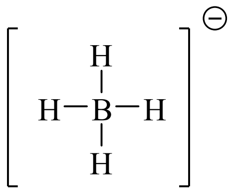
Determine the local geometry of all other atoms bonded to each atom labelled on the structure above, and complete the table below.

Site	b	c	d	e
Geometry	tetrahedral	**trigonal planar**	**bent**	**tetrahedral***

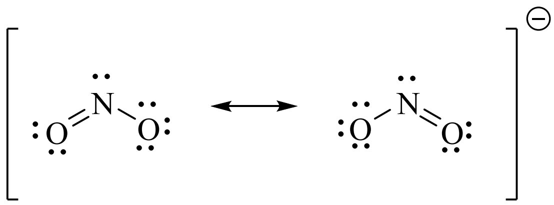
*** remember that this carbon atom has 2 hydrogen atoms attached to it that are not shown in the stick structure.**

Marks 4

- Complete the following table showing the number of valence electrons, a Lewis structure and the predicted shape of each of the following species.

Formula	Number of valence electrons	Lewis structure	Name of molecular shape
e.g. NF_3	26		trigonal pyramidal
BeF_2	**16**		**linear**
BH_4^-	**8**		**tetrahedral**

Draw the major resonance contributors of the nitrite ion, NO_2^-. **2**



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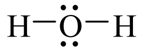
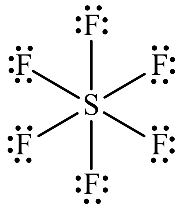
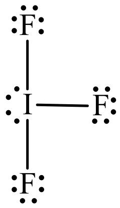
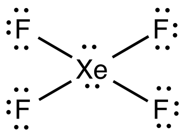
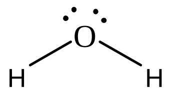
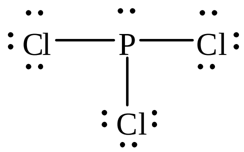
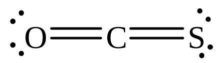
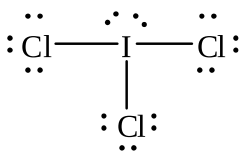
Marks
6

- Complete the following table. Water is given as an example.

Name	Lewis structure	Number of valence electron pairs on central atom	Geometric arrangement of valence electron pairs on central atom	Molecular shape
water		4	tetrahedral	bent
sulfur hexafluoride		**6**	**octahedral**	**octahedral**
iodine trichloride		**5**	**trigonal bipyramidal**	**T-shaped**
xenon tetrafluoride		**6**	**octahedral**	**square planar**

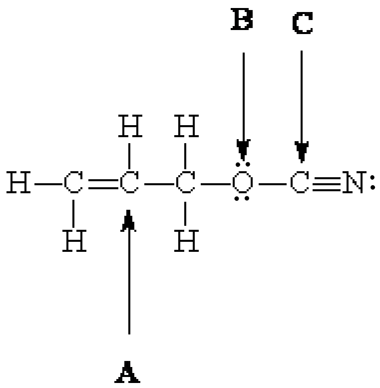
Marks 7

- Complete the table below showing the number of valence electrons, the Lewis structure and the predicted shape of each of the following species.

Formula	Total number of valence electrons	Lewis structure	Geometry of species
H_2O	8		V-shaped or bent
PCl_3	**26**		**trigonal pyramdial**
COS	**16**		**linear**
ICl_3	**28**		**T-shaped**

Marks

- With respect to the molecule sketched below, answer the following questions concerning the selected atoms indicated by arrows as **A**, **B** and **C**. **3**



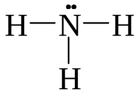
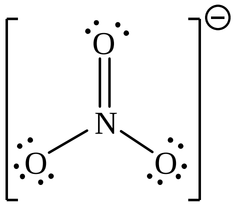
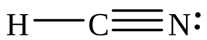
Selected Atom	Number of Lone Pairs about the Selected Atom	Number of σ Bonds associated with the Selected Atom	Geometry of σ Bonds about the Selected Atom
A	**0**	**3**	**trigonal planar**
B	**2**	**2**	**bent**
C	**0**	**2**	**linear**

- Identify two factors that explain the origin of the discrete energy levels of electrons in atoms? **2**

- **The wave-like nature of electrons**
- **The restricted motion of the electrons caused by the electrostatic attraction of the nucleus**

Marks
5

- Complete the table below showing the number of valence electrons, the Lewis structure and the predicted shape of each of the following species.

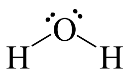
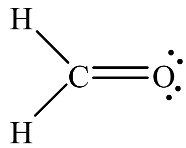
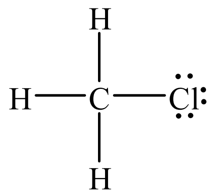
Formula	Total number of valence electrons	Lewis structure	Geometry of species
e.g. NH_3	8		trigonal pyramidal
NO_3^-	**24**		**trigonal planar**
HCN	**10**		**linear**

Which of NH_3, NO_3^- and HCN have a non-zero dipole moment?

NH_3 and HCN both have dipole moments. Although the N-O bonds in NO_3^- are polar, the trigonal planar shape means that these cancel and there is no overall dipole moment.

Marks

- Complete the table below showing the number of valence electrons, a Lewis structure and the predicted shape of each of the following species. **5**

Formula	Number of valence electrons	Lewis structure	Name of molecular shape
e.g. H_2O	8		Bent (angular)
H_2CO	**12**		**three bonds on carbon: trigonal planar**
CH_3Cl	**14**		**four bonds on carbon: tetrahedral**

Which, if either, of H_2CO and CH_3Cl will have a dipole moment?	**both**

- Using the following electronegativity data, decide which one or more of the oxides of C, Te, Zn and Mg would be classified as containing ionic bonds. Briefly explain your answer. **2**

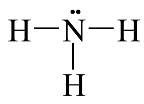
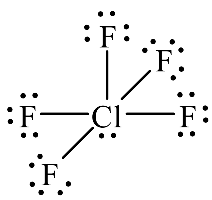
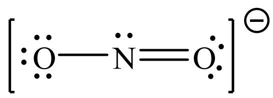
Element	Electronegativity
O	3.5
C	2.5
Te	2.1
Zn	1.4
Mg	1.2

An electronegativity (χ) difference > 2 is classified as ionic:

C: $\Delta\chi = 3.5 - 2.5 = 1.0$ → not ionic
Te: $\Delta\chi = 3.5 - 2.1 = 1.4$ → not ionic
Zn: $\Delta\chi = 3.5 - 1.4 = 2.1$ → ionic
Mg: $\Delta\chi = 3.5 - 1.2 = 2.3$ → ionic

Marks

• Complete the table below showing the number of valence electrons, the Lewis structure and the predicted shape of each of the following species. 5

Formula	Number of valence electrons	Lewis structure	Geometry of species
e.g. NH_3	8		trigonal pyramidal
ClF_5	**42**		**5 bonds and 1 lone pair on chlorine: square-based pyramid**
NO_2^-	**18**		**2 bonds and 1 lone pair on nitrogen: bent**

Which of NH_3, ClF_5 and NO_2^- have a non-zero dipole moment?

All three have dipole moments

• What is the approximate value of the most intense wavelength emitted by the star Proxima Centauri, which has a temperature of 2700 K? 2

The maximum intensity in a thermal spectrum is approximately at a transition energy ΔE= 4.5k_BT where k_B is Boltzmann's constant (1.381×10^{-23} J K^{-1} mol^{-1}). Using T = 2700 K, the transition energy can be calculated:

$$\Delta E = 4.5k_BT == 4.5\times(1.381\times10^{-23})\times2700 = 1.68\times10^{-19}\ J$$

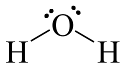
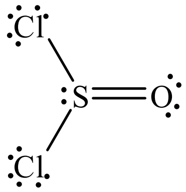
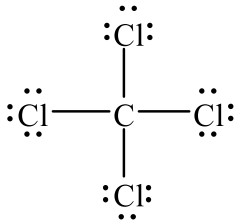
To convert this energy into a wavelength, Planck's relationship must be used:

$$\lambda = \frac{hc}{E} = \frac{(6.626\times10^{-34})(2.998\times10^{8})}{1.68\times10^{-19}} = 1.18\times10^{-6}\ m\ or\ 1180\,nm$$

Answer: **1.18×10^{-6} m or 1180 nm**

Marks
5

- Complete the table below showing the number of valence electrons, a Lewis structure and the predicted shape of each of the following species.

Formula	Number of valence electrons	Lewis structure	Name of molecular shape
e.g. H_2O	8		Bent (angular)
$SOCl_2$	**26**		**3 bonds and 1 lone pair on sulfur: trigonal pyramdial**
CCl_4	**32**		**4 bonds and no lone pairs on carbon: tetrahedral**

Which, if either, of $SOCl_2$ and CCl_4 will have a dipole moment?	**$SOCl_2$**

- Using the following electronegativity data, decide which one or more of the oxides of C, Te, Zn and Mg would be classified as containing ionic bonds. Briefly explain your answer. **2**

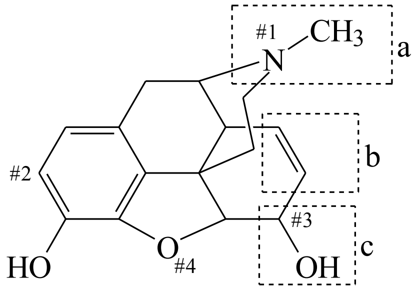
Element	Electronegativity
O	3.5
C	2.5
Te	2.1
Zn	1.4
Mg	1.2

An electronegativity (χ) difference > 2 is classified as ionic:

C: $\Delta\chi = 3.5 - 2.5 = 1.0$ → not ionic
Te: $\Delta\chi = 3.5 - 2.1 = 1.4$ → not ionic
Zn: $\Delta\chi = 3.5 - 1.4 = 2.1$ → ionic
Mg: $\Delta\chi = 3.5 - 1.2 = 2.3$ → ionic

Marks 5

- The structure of morphine is given below.



Name the functional groups in morphine that have been highlighted by the boxes.

a = **amine (3°)**
b = **alkene**
c = **alcohol**

What are the approximate bond angles at the labelled atoms?

Atom	Bond angles
#1 N	**~109.5°**
#2 C	**~120°**
#3 C	**~109.5°**
#4 O	**~109.5°**

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY