IB 4 HL EQ P2 4Students 16w to 08s Sections A and B

IB Diploma Chemistry

Higher Level Paper 2 Topic 4

From summer 2008 to 2016 winter marks in total

Name:__________________

Contents

Topic 4

Chem 4 2 **Q# 1/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q4

(h) Describe the structure and bonding in solid magnesium oxide. [2]

Chem 4 3 **Q# 2/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q2

(c) 5.00 g of an impure sample of hydrated ethanedioic acid, $(COOH)_2 \cdot 2H_2O$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a 0.100 $mol\,dm^{-3}$ solution of sodium hydroxide using a suitable indicator.

$$(COOH)_2(aq) + 2NaOH(aq) \rightarrow (COONa)_2(aq) + 2H_2O(l)$$

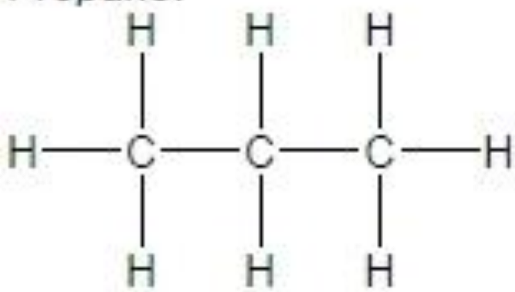
(d) Draw the Lewis (electron dot) structure of the ethanedioate ion, $^{-}OOCCOO^{-}$. [1]

(e) Outline why all the C–O bond lengths in the ethanedioate ion are the same length and suggest a value for them. Use section 10 of the data booklet. [2]

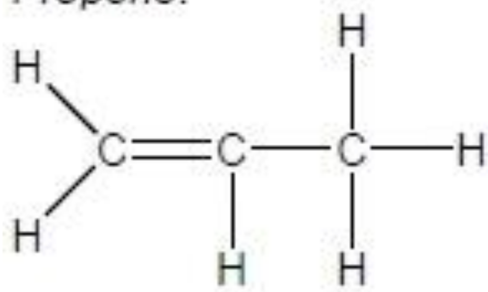
Chem 4 4 **Q# 3/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Not with Q5 (a)

5. Propane and propene are members of different homologous series.

Propane:



Propene:



(b) (i) Draw diagrams to show how sigma (σ) and pi (π) bonds are formed between atoms. [2]

Sigma (σ):   Pi (π):

(ii) State the number of sigma (σ) and pi (π) bonds in propane and propene. [2]

	Number of sigma (σ) bonds	Number of pi (π) bonds
Propane	....	....
Propene	....	....

Chem 4 2 **Q# 4/** IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, $HOCH_2CH_2OH$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

Ethene has the formula CH_2CH_2

(d) Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene. [2]

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Chem 4 19 **Q# 5/** IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

6. Ozone, dinitrogen monoxide, CFCs, sulfur hexafluoride and methane are all examples of greenhouse gases.

(a) (i) Draw one valid Lewis (electron dot) structure for each molecule of the greenhouse gases listed below. *[2]*

	Lewis (electron dot) structure
Ozone	
Sulfur hexafluoride	

(ii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule listed below. *[2]*

	Electron domain geometry	**Molecular geometry**
Ozone	. . . .	. . . .
Sulfur hexafluoride	. . . .	. . . .

(iii) Identify which molecule(s) given in part (a) (i) has/have an extended octet of electrons. *[1]*

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(iv) State the bond angles for each species in part (a) (ii). *[1]*

Ozone:

. . . .

Sulfur hexafluoride:

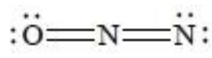
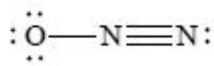
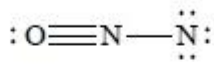
. . . .

(v) Draw all the resonance structures of ozone. Lone pairs should be shown. *[1]*

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

(i) 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. *[2]*

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

	Lewis (electron dot) structure	**FC of O on LHS**	**FC of central N**	**FC of N on RHS**
A				
B				
C				

(ii) FC can be useful in electron book-keeping, but electronegativity values are ignored when FCS are assigned.

Based on the assignment of FCS of the atoms in part (i), deduce which Lewis (electron dot) structure of N_2O (**A**, **B** or **C**) is expected to be the preferred structure. Explore why another factor needs to be considered. *[2]*

(d) (i) The concentration of ozone in the upper atmosphere is maintained by the following three reactions, I, II and III.

I $O_2 \xrightarrow{h\nu} 2O\bullet$

II $O_2 + O\bullet \rightarrow O_3$

III $O_3 \xrightarrow{h\nu} O_2 + O\bullet$

Explain by reference to the bonding in O_2 and O_3, which of the reactions, I or III, needs more energy. *[3]*

(ii) Using dichlorodifluoromethane, CCl_2F_2, as an example, outline the reactions in which ozone depletion occurs in the upper atmosphere. Formulate an equation for each step in this process and explain the initial step by reference to the bonds in CCl_2F_2. *[5]*

Chem 4 4 **Q# 6/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q3

(c) 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:

(i) Analyse the bonding in dinitrogen monoxide in terms of σ-bonds and π-bonds. [3]

(ii) State what is meant by resonance. [1]

Chem 4 5 **Q# 7/** IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3.

(a) (i) Draw a Lewis (electron dot) structure of phosphine. [1]

(ii) State the hybridization of the phosphorus atom in phosphine. [1]

(iv) Outline whether you expect the bonds in phosphine to be polar or non-polar, giving a brief reason. [1]

(v) Phosphine has a much greater molar mass than ammonia. Explain why phosphine has a significantly lower boiling point than ammonia. [2]

Chem 4 15 **Q# 8/** IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q6

(c) (i) Deduce the type of hybridization shown by the nitrogen atoms in NF_4^+, N_2H_2 and N_2H_4. [3]

	NF_4^+	N_2H_2	N_2H_4
Hybridization			

(ii) Describe how sigma (σ) and pi (π) bonds form. [2]

(iii) Draw the Lewis (electron dot) structures of SF_4 and SF_6. Use the valence shell electron pair repulsion (VSEPR) theory to predict the name of the shape of each molecule. [4]

(d) (i) List the following compounds in order of **increasing** boiling point:
CH_3CHO, $CH_3CH_2CH_3$, CH_3COOH, CH_3CH_2OH. [2]

(ii) Explain the order of boiling points in the compounds listed in part (d) (i), in terms of intermolecular forces. [4]

Chem 4 3 **Q# 9/** IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q5

(b) Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group whereas the melting points of the group 7 elements (F → I) increase down the group. [3]

Chem 4 14 **Q# 10/** IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q9

(c) Consider the molecules PBr_3 and SF_4.

(i) Deduce the Lewis (electron dot) structure of both molecules. [2]

(ii) Predict the shapes of the two molecules, giving the Br–P–Br bond angle in PBr_3 and the F–S–F bond angles in SF_4. [4]

PBr_3	SF_4
Shape:	Shape:
Bond angle:	Bond angles:

(iii) Explain why both PBr_3 and SF_4 are polar. [2]

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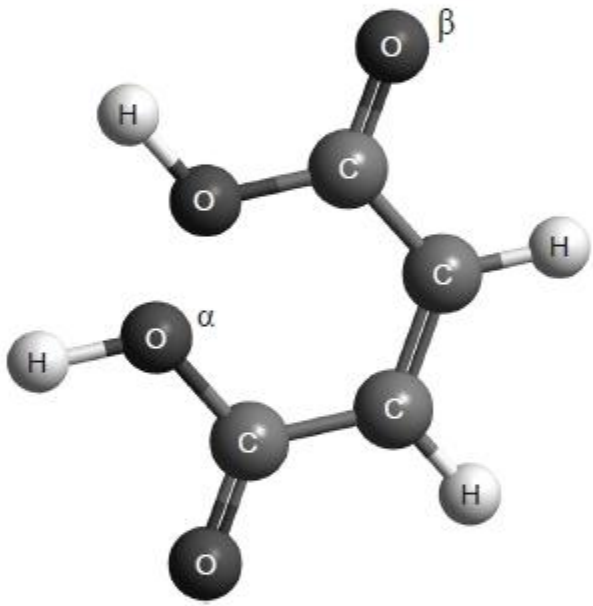
(d) The structure of *cis*-but-2-ene-1,4-dioic acid is shown below.



(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed. [2]

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(ii) Deduce the hybridization of the oxygen atoms labelled α and β. [1]

α:

β:

(iii) Describe sigma (σ) and pi (π) bonds between atoms. [2]

σ bond:

π bond:

(iv) Identify the number of sigma (σ) and pi (π) bonds present in a molecule of *cis*-but-2-ene-1,4-dioic acid. [1]

Chem 4 4 **Q# 11/** IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q8

(b) (i) State the name of Cr_2O_3. [1]

(ii) Describe the ionic bonding present in Cr_2O_3 and how the ions are formed. [2]

(iii) Suggest why solid Cr_2O_3 does **not** conduct electricity. [1]

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Chem 4 2 **Q# 12/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(f) Describe the formation of σ and π bonds in an alkene. [2]

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Chem 4 4 **Q# 13/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(g) Identify **three** allotropes of carbon and describe their structures. [4]

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Chem 4 3 **Q# 14/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

(f) SCl_2 and $SClF_5$ are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules. [3]

Molecule	Shape	Bond angle	Polarity
SCl_2	. . . .	. . . .	. . . .
$SClF_5$	. . . .	. . . .	. . . .

Chem 4 4 **Q# 15/** IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q2

(b) (i) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure. [2]

(ii) Predict whether phosphorus(V) oxide and sodium oxide conduct electricity in their solid and molten states. Complete the boxes with "yes" or "no". [2]

	Phosphorus(V) oxide	Sodium oxide
Solid state		
Molten state		

Chem 4 2 **Q# 16/** IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/ Q4

(c) Describe the bonding in solid copper. [2]

Chem 4 5 **Q# 17/** IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

1. Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, HOOC−COOH•xH_2O, by titrating a known mass of the acid with a 0.100 mol dm^{-3} solution of NaOH(aq).

(c) Identify the strongest intermolecular force in solid ethanedioic acid. [1]

(d) Deduce the Lewis (electron dot) structure of ethanedioic acid, HOOC–COOH. [1]

(e) Predict and explain the difference in carbon-oxygen bond lengths in ethanedioic acid and its conjugate base, $^{-}OOC–COO^{-}$. [3]

Chem 4 11 **Q# 18/** IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

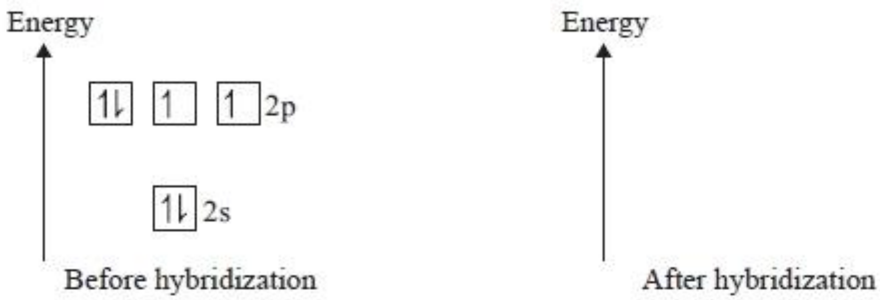
(c) (i) Magnesium reacts with oxygen to form an ionic compound, magnesium oxide. Describe how the ions are formed, and the structure and bonding in magnesium oxide. *[2]*

(ii) Carbon reacts with oxygen to form a covalent compound, carbon dioxide. Describe what is meant by a covalent bond. *[1]*

(iii) State why magnesium and oxygen form an ionic compound while carbon and oxygen form a covalent compound. *[1]*

(d) (i) Predict the type of hybridization of the carbon and oxygen atoms in CO_2. *[2]*

(ii) Sketch the orbitals of an oxygen atom in CO_2 on the energy level diagram provided, including the electrons that occupy each orbital. *[2]*



(iii) Define the term *electronegativity*. *[1]*

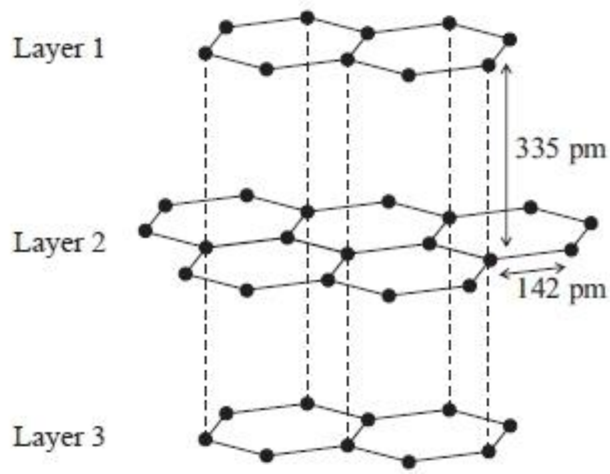
(iv) Explain why oxygen has a larger electronegativity than carbon. *[2]*

Chem 4 2 **Q# 19/** IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(b) The oxygen in half-equation 2 is atmospheric oxygen that is found dissolved in water in very small concentrations. Explain, in terms of intermolecular forces, why oxygen is not very soluble in water. *[2]*

Chem 4 5 **Q# 20/** IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/

5. Graphite has a layered structure of carbon atoms. A section of the structure is shown below.



(a) Identify the type of attraction represented by the dotted lines shown between the layers. *[1]*

(b) Graphite is used as a lubricant. Discuss **two** other uses of graphite with reference to its layered structure. *[4]*

(f) Magnesium metal is mainly used as a component in lightweight alloys, particularly in combination with aluminium and titanium.

(i) Describe the bonding present in magnesium metal. *[2]*

(ii) Suggest why magnesium is harder than sodium. *[1]*

(iii) Outline why alloys are generally less malleable than their component metals. *[1]*

Chem 4 7 **Q# 22/** IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/

4. Ozone, O_3, in the upper atmosphere prevents harmful UV radiation reaching the surface of the Earth.

(a) Draw the Lewis structure for ozone. *[1]*

(b) State the shape of the ozone molecule and estimate the bond angle. *[2]*

Shape:

. . . .

Bond angle:

. . . .

(c) State the hybridization of the central oxygen atom. *[1]*

. . . .

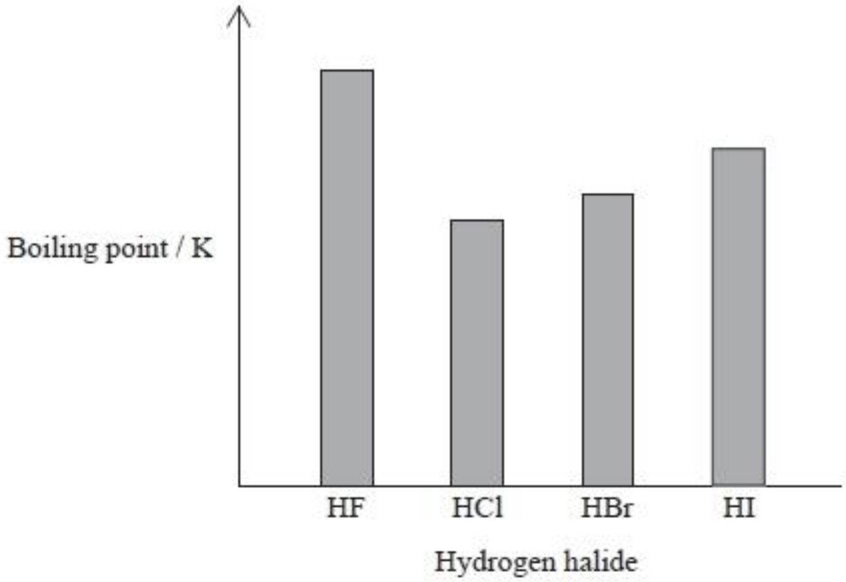
(d) In terms of σ and π bonds, describe the two oxygen-oxygen bonds in the Lewis structure. *[1]*

. . . .

. . . .

(e) The two oxygen-oxygen bonds in ozone are in fact of equal length. Deduce why this is the case and how the length of these would compare to oxygen-oxygen bond lengths in hydrogen peroxide, H_2O_2, and in the oxygen molecule, O_2. *[2]*

(c) The hydrogen halides do not show perfect periodicity. A bar chart of boiling points shows that the boiling point of hydrogen fluoride, HF, is much higher than periodic trends would indicate.



(i) Explain why the boiling point of HF is much higher than the boiling points of the other hydrogen halides. *[1]*

(ii) Explain the trend in the boiling points of HCl, HBr and HI. *[2]*

Chem 4 6 **Q# 24/** IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Q1

(d) Magnesium sulfate is one of the products formed when acid rain reacts with dolomitic limestone. This limestone is a mixture of magnesium carbonate and calcium carbonate.

(i) State the equation for the reaction of sulfuric acid with magnesium carbonate. *[1]*

(ii) Deduce the Lewis (electron dot) structure of the carbonate ion, giving the shape and the oxygen-carbon-oxygen bond angle. *[3]*

Lewis (electron dot) structure:

Shape:

Bond angle:

(iii) There are three possible Lewis structures that can be drawn for the carbonate ion, which lead to a resonance structure. Explain, with reference to the electrons, why all carbon-oxygen bonds have the same length. *[1]*

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(iv) Deduce the hybridization of the carbon atom in the carbonate ion. *[1]*

. . . .

Chem 4 5 **Q# 25/** IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/

3. Calcium nitrate contains both covalent and ionic bonds.

(a) (i) State the formula of **both** ions present and the nature of the force between these ions. *[2]*

Ions:

. . . .

Nature of force:

. . . .

(ii) State which atoms are covalently bonded. *[1]*

. . . .

(b) Bonding in the nitrate ion involves electron delocalization. Explain the meaning of electron delocalization and how it affects the ion. *[2]*

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Chem 4 4 **Q# 26/** IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q4

(b) Identify the intermolecular forces present in hydrogen iodide in the liquid state, HI (l). *[1]*

. . . .

. . . .

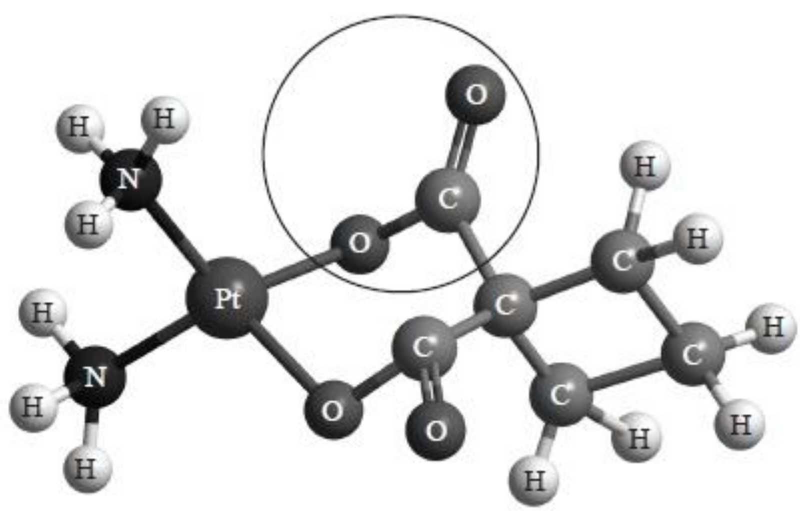
(c) Consider the compounds $(CH_3)_2NH$ and CH_4.

(i) State and explain which compound can form hydrogen bonds **with water**. *[2]*

(ii) Draw a diagram showing the resulting hydrogen bonds between water and the compound chosen in (i). *[1]*

Chem 4 1 **Q# 27/** IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

3. Carboplatin used in the treatment of lung cancer has the following three-dimensional structure.



(b) State the type of bonding between platinum and nitrogen in carboplatin. *[1]*

. . . .

Chem 4 14 **Q# 28/** IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q6c

(ii) Deduce the Lewis structures for PCl_3 and PCl_5. *[2]*

PCl_3	PCl_5

(iii) Predict the shapes and the bond angles in the two molecules. *[4]*

	PCl_3	**PCl_5**
Shape	. . . .	. . . .
Bond angles	. . . .	. . . .

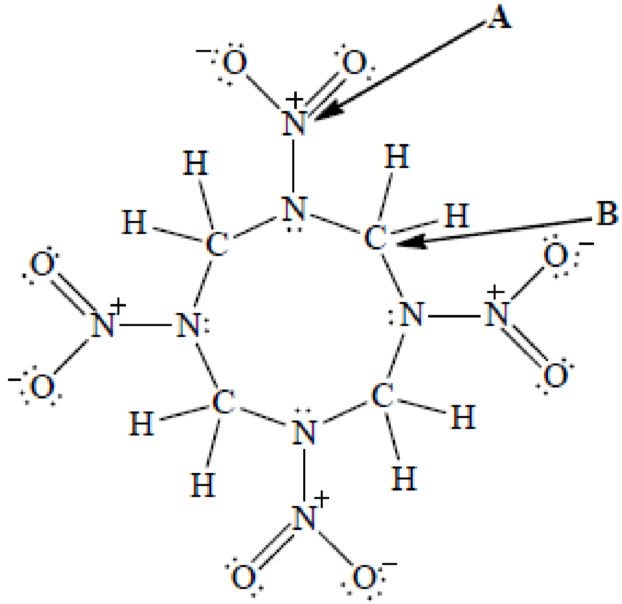
(iv) Identify the type of hybridization present in PCl_3. *[1]*

(v) Compare the melting points of PCl_3 and PCl_5 and explain the difference. *[3]*

(e) Explain the delocalization of π electrons using the O_3 molecule as an example, including **two** facts that support the delocalization. *[4]*

This molecule is needed in the question that follows

1,3,5,7-tetranitro-1,3,5,7-tetrazocane, shown below, can be used as an explosive.



(ii) The CO molecule has dative covalent bonding. Identify a nitrogen-containing positive ion which also has this type of bonding. *[1]*

. . . .

(iii) Describe in words and with the aid of a suitable diagram the difference between sigma (σ) and pi (π) bonds. *[3]*

....

....

....

....

(iv) Determine the number of σ and π bonds in 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, using the Lewis structure shown on page 16. *[2]*

σ bonds: ....

π bonds: ....

(v) Explain the term *hybridization* and deduce the hybridization (sp, sp^2 or sp^3) of the atoms labelled **A** and **B** in the diagram on page 16. *[3]*

Chem 4 2 **Q# 30/** IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q2

(b) (i) Explain why metals are good conductors of electricity and why they are malleable. *[2]*

Chem 4 2 **Q# 31/** IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

(b) Although the molar masses of ICl and Br_2 are very similar, the boiling point of ICl is 97.4 °C and that of Br_2 is 58.8 °C. Explain the difference in these boiling points in terms of the intermolecular forces present in each liquid. *[2]*

Chem 4 4 **Q# 32/** IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

(e) When iodine reacts with excess chlorine, ICl_3 can form. Deduce the Lewis (electron dot) structure of ICl_3 and ICl_2^- and state the name of the shape of each species. *[4]*

	ICl_3	ICl_2^-
Lewis structure		
Name of shape		

Chem 4 2 **Q# 33/** IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5

(d) Silicon tetrachloride, $SiCl_4$, is a volatile colourless liquid first prepared by Jöns Jakob Berzelius in 1823.

(d) (i) SiCl4 for Mark Scheme an acidic solution when added to water

(ii) Explain why the aqueous solution formed in (d) (i) conducts electricity whereas liquid silicon tetrachloride does not. *[2]*

5. Ethane, C_2H_6, and disilane, Si_2H_6, are both hydrides of group 4 elements with similar structures but with different chemical properties.

(a) (i) Deduce the Lewis (electron dot) structure for Si_2H_6 showing all valence electrons. *[1]*

(ii) State and explain the H–Si–H bond angle in Si_2H_6. *[2]*

(iii) Identify the type of hybridization shown by the silicon atoms in Si_2H_6. *[1]*

(iv) State which of the bonds, Si–H or C–H, is more polar. Explain your choice. *[2]*

(v) Predict, with an explanation, the polarity of the two molecules. *[2]*

(vi) Explain why disilane has a higher boiling point than ethane. *[2]*

(b)

(iii) Compare the structure and bonding in carbon dioxide and silicon dioxide. *[3]*

(c) For each of the species PBr_3 and SF_6:

(i) deduce the Lewis structure.

(ii) predict the shape and bond angle.

(iii) predict and explain the molecular polarity. *[8]*

PBr_3	**SF_6**
(i) Lewis structure:	(i) Lewis structure:
(ii) Shape:	(ii) Shape: ....
Bond angle:	Bond angle: ....
(iii) Polarity:	(iii) Polarity: ....
Explanation:	Explanation: ....

Chem 4 3 **Q# 36/** IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/Q1

(c) The chemistry of the airbag was found to involve three reactions. The first reaction involves the decomposition of sodium azide to form sodium and nitrogen. In the second reaction, potassium nitrate reacts with sodium.

$$2KNO_3(s) + 10Na(s) \rightarrow K_2O(s) + 5Na_2O(s) + N_2(g)$$

(i) Suggest why it is necessary for sodium to be removed by this reaction. *[1]*

. . . .

. . . .

(ii) The metal oxides from the second reaction then react with silicon dioxide to form a silicate in the third reaction.

$$K_2O(s) + Na_2O(s) + SiO_2(s) \rightarrow Na_2K_2SiO_4(s)$$

Draw the structure of silicon dioxide and state the type of bonding present. *[2]*

Structure:

Bonding: . . . .

1. Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate and silicon dioxide have been used in one design of airbag.

[Source: www.hilalairbag.net]

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

$$2NaN_3(s) \rightarrow 2Na\,(s) + 3N_2(g)$$

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.

(a) Sodium azide involves ionic bonding, and metallic bonding is present in sodium. Describe ionic and metallic bonding. *[2]*

6. Carbon and silicon belong to the same group of the periodic table.

(a) Describe and compare **three** features of the structure and bonding in the three allotropes of carbon: diamond, graphite and C_{60} fullerene. *[6]*

(b) Both silicon and carbon form oxides.

(i) Describe the structure and bonding in SiO_2. *[2]*

(ii) Explain why silicon dioxide is a solid and carbon dioxide is a gas at room temperature. *[2]*

(c) Describe the bonding within the carbon monoxide molecule. *[2]*

(d) Describe the delocalization of pi (π) electrons and explain how this can account for the structure and stability of the carbonate ion, CO_3^{2-}. *[3]*

(e) Explain the meaning of the term *hybridization*. State the type of hybridization shown by the carbon atoms in carbon dioxide, diamond, graphite and the carbonate ion. *[5]*

(f) (i) Explain the electrical conductivity of molten sodium oxide and liquid sulfur trioxide. *[2]*

(ii) Samples of sodium oxide and solid sulfur trioxide are added to separate beakers of water. Deduce the equation for each reaction and predict the electrical conductivity of each of the solutions formed. *[3]*

Chem 4 9 **Q# 39/** IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/

7. Hydrazine, N_2H_4, is a valuable rocket fuel.

(a) (i) Draw the Lewis (electron dot) structure for N_2H_4 showing all valence electrons. *[1]*

(ii) State and explain the H–N–H bond angle in hydrazine. *[3]*

(b) Hydrazine and ethene, C_2H_4, are hydrides of adjacent elements in the periodic table. The boiling point of hydrazine is much higher than that of ethene. Explain this difference in terms of the intermolecular forces in each compound. *[2]*

(d) The reaction between $N_2H_4(aq)$ and $HCl(aq)$ can be represented by the following equation.

$$N_2H_4(aq) + 2HCl(aq) \rightarrow N_2H_6^{2+}(aq) + 2Cl^-(aq)$$

(i) Identify the type of reaction that occurs. *[1]*

(ii) Predict the value of the H–N–H bond angle in $N_2H_6^{2+}$. *[1]*

(iii) Suggest the type of hybridization shown by the nitrogen atoms in $N_2H_6^{2+}$. *[1]*

(c) Describe the bonding in iron and explain the electrical conductivity and malleability of the metal. *[4]*

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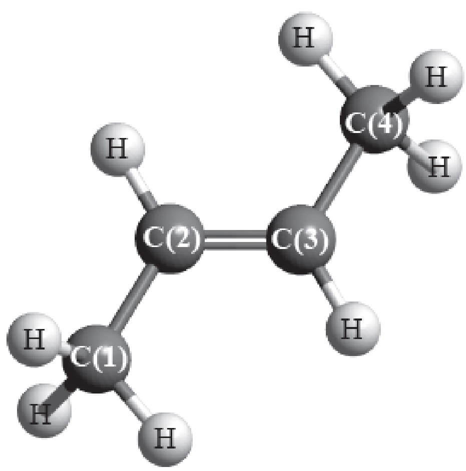
Chem 4 3 **Q# 41/** IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) But-2-ene is a straight-chain alkene with formula C_4H_8. The molecule contains both σ and π bonds.



(i) Explain the formation of the π bond. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) For each of the carbon atoms, C(1) and C(2), identify the type of hybridization shown. *[1]*

C(1): . . . .

C(2): . . . .

Chem 4 4 **Q# 42/** IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(ii) Describe the acid-base behaviour of $AlCl_3$, Na_2O and P_4O_{10}. Include suitable equations in your answer. *[4]*

Chem 4 5 **Q# 43/** IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(h) (i) Compare the structure and bonding in $AlCl_3$ and Al_2O_3. *[2]*

(iii) Explain whether $AlCl_3$ and Al_2O_3 will conduct in the solid or molten state. *[3]*

Chem 4 6 **Q# 44/** IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

2. SF_2, SF_4 and SF_6 have different shapes. Draw their Lewis structures and use the VSEPR theory to predict the name of the shape of each molecule. *[6]*

	SF_2	SF_4	SF_6
Lewis structure			
Name of shape	. . . .	. . . .	. . . .

Chem 4 18 **Q# 45/** IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) Draw the Lewis structures, state the shape and predict the bond angles for the following species.

(i) PCl_3 *[3]*

(ii) NH_2^- *[3]*

(iii) XeF_4 *[3]*

(c) (i) Compare the formation of a sigma (σ) and a pi (π) bond between two carbon atoms in a molecule. *[2]*

(ii) Identify how many sigma and pi bonds are present in propene, C_3H_6. *[2]*

(iii) Deduce all the bond angles present in propene. *[2]*

(iv) Explain how the concept of hybridization can be used to explain the bonding in the triple bond present in propyne. *[3]*

Chem 4 1 **Q# 46/** IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

5. Sodium oxide, Na_2O, is a white solid with a high melting point.

(a) Explain why solid sodium oxide is a non-conductor of electricity. *[1]*

. . . .

. . . .

Chem 4 8 **Q# 47/** IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b) Draw the Lewis structures of the following molecules. Use the VSEPR theory to predict the shape of each molecule.

(i) XeF_4 and XeO_4 *[4]*

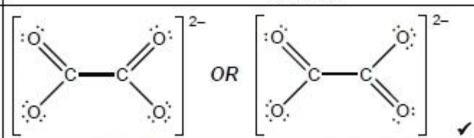
(ii) PF_5 and IF_5 *[4]*

Topic 4 Mark Scheme

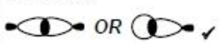
Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

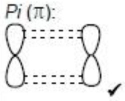
4.	h		«3-D/giant» regularly repeating arrangement «of ions» *OR* lattice «of ions» ✓ electrostatic attraction between oppositely charged ions *OR* electrostatic attraction between Mg^{2+} and O^{2-} ions ✓	*Accept "giant" for M1 unless "giant covalent" stated.* *Do **not** accept "ionic" without description.*	2

Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
2.	d		 ✓	*Accept single negative charges on two O atoms singly bonded to C.* *Do not accept resonance structures.* *Allow any combination of dots/crosses or lines to represent electron pairs.*	1
2.	e		electrons delocalized «across the O–C–O system» *OR* resonance occurs ✓ 122 «pm» < C–O < 143 «pm» ✓	*Accept delocalized π-bond(s).* *No ECF from (d).* *Accept any answer in range 123 «pm» to 142 «pm».* *Accept "bond intermediate between single and double bond" or "bond order 1.5".*	2

Q# 3/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

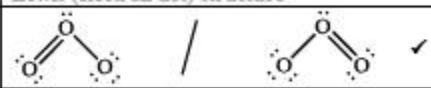
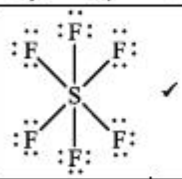
<table>
<tr><td>5.</td><td>b</td><td>i</td><td>Sigma (σ):
 ✓

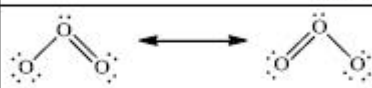
Pi (π):
 ✓</td><td></td><td>2</td></tr>
<tr><td>5.</td><td>b</td><td>ii</td><td><table><tr><td></td><td>Number of sigma (σ) bonds</td><td>Number of pi (π) bonds</td></tr><tr><td>Propane</td><td>10</td><td>0</td></tr><tr><td>Propene</td><td>8</td><td>1</td></tr></table> ✓✓</td><td>Award [1] for two or three correct answers.
Award [2] for all four correct.</td><td>2</td></tr>
</table>

Q# 4/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
1.	d		ethane-1,2-diol can hydrogen bond to other molecules «and ethene cannot» *OR* ethane-1,2-diol has «significantly» greater van der Waals forces ✓ hydrogen bonding is «significantly» stronger than other intermolecular forces ✓	*Accept converse arguments.* *Award **[0]** if answer implies covalent bonds are broken.*	2

Q# 5/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>6.</td><td>a</td><td>i</td><td>
<table>
<tr><th></th><th>Lewis (electron dot) structure</th></tr>
<tr><td>Ozone</td><td></td></tr>
<tr><td>Sulfur hexafluoride</td><td></td></tr>
</table>
</td><td>Lines, x's or dots may be used to represent electron pairs.
Charges may be included in Lewis structures of ozone but are not required.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>ii</td><td>
<table>
<tr><th></th><th>Electron domain geometry</th><th>Molecular geometry</th></tr>
<tr><td>Ozone</td><td>trigonal/triangular planar</td><td>v-shaped/bent/angular ✓</td></tr>
<tr><td>Sulfur hexafluoride</td><td>octahedral/square bipyramidal</td><td>octahedral/square bipyramidal ✓</td></tr>
</table>
</td><td>Award [1 max] for either both electron domain geometries correct OR for either both molecular geometries correct.</td><td>2</td></tr>
<tr><td></td><td>a</td><td>iii</td><td>sulfur hexafluoride/SF_6 ✓</td><td></td><td>1</td></tr>
<tr><td></td><td>a</td><td>iv</td><td>Ozone: Accept any angle greater than 115° but less than 120°
and
Sulfur hexafluoride: 90° (and 180°) ✓</td><td>Experimental value of bond angle in O_3 is 117°.</td><td>1</td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>6.</td><td>a</td><td>v</td><td> ✓</td><td>Double-headed arrow not necessary for mark.
Lines, x's or dots may be used to represent electron pairs.</td><td>1</td></tr>
<tr><td></td><td>b</td><td>i</td><td>
<table>
<tr><th></th><th>Lewis (electron dot) structure</th><th>FC of O on LHS</th><th>FC of central N</th><th>FC of N on RHS</th></tr>
<tr><td>A</td><td>:Ö=N=N̈:</td><td>0</td><td>+1</td><td>–1</td></tr>
<tr><td>B</td><td>:Ö—N≡N:</td><td>–1</td><td>+1</td><td>0</td></tr>
<tr><td>C</td><td>:O≡N—N̈:</td><td>+1</td><td>+1</td><td>–2</td></tr>
</table>
</td><td>Award [2] for all nine FCs correct, [1] for six to eight FCs correct.</td><td>2</td></tr>
<tr><td></td><td>b</td><td>ii</td><td>smallest FC difference for A or B, so either is preferred ✓

however B is preferred as oxygen is more electronegative than nitrogen, even though FC per se ignores electronegativity ✓</td><td>Reason required for M1.

OWTTE</td><td>2</td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>6.</td><td>d</td><td>i</td><td>O_2 has a double bond ✓

O_3 has intermediate bonds between double and single bonds
OR
O_3 has a bond order of 1½ ✓

bond in O_2 is stronger therefore I needs more energy ✓</td><td>Do not award mark for I on its own with no justification.</td><td>3</td></tr>
<tr><td></td><td>d</td><td>ii</td><td>C–Cl ‹bond› breaks since weakest bond ✓

$CCl_2F_2 \xrightarrow{h\nu} \cdot CClF_2 + Cl\cdot$ ✓

$Cl\cdot + O_3 \rightarrow ClO\cdot + O_2$ ✓

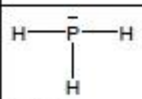
$ClO\cdot + O\cdot \rightarrow O_2 + Cl\cdot$ ✓

$ClO\cdot + O_3 \rightarrow Cl\cdot + 2O_2$ ✓</td><td>Allow representation of radicals without • as long as consistent throughout.</td><td>5</td></tr>
</table>

Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
3.	c	i	**ALTERNATIVE 1:** σ-bond from N to N ***AND*** from N to O ✓ π-bond from N to N ✓ <u>delocalized</u> π-bond/π-electrons «extending over the oxygen and both nitrogens» ✓ **ALTERNATIVE 2:** both have 2 σ-bonds «from N to N and from N to O» ***AND*** π-bond from N to N ✓ one structure has second π-bond from N to N and the other has π-bond from N to O ✓ delocalized π-bond/π-electrons ✓	*Award **[1 max]** if candidate has identified both/either structure having 2 σ-bonds and 2 π-bonds.*	3
3.	c	ii	more than one possible position for a multiple/π-/pi- bond ✓	*Accept "more than one possible Lewis structure".* *Accept reference to delocalisation if M3 not awarded in c (i).* *Accept reference to fractional bond orders.*	1

Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

Question			Answers	Notes	Total
1.	a	i	 ✓	*Accept structures using dots and/or crosses to indicate bonds and/or lone pair.*	1
1.	a	ii	sp^3 ✓	*Do not allow ECF from a (i).*	1
1.	a	iii	Lewis base ***AND*** has a lone pair of electrons «to donate» ✓		1
1.	a	iv	non-polar ***AND*** P and H have the same electronegativity ✓	*Accept "similar electronegativities".* *Accept "polar" if there is a reference to a small difference in electronegativity and apply ECF in 1 a (v).*	1
1.	a	v	PH_3 has London «dispersion» forces ✓ NH_3 forms H-bonds ✓ H-bonds are stronger ***OR*** London forces are weaker ✓	*Accept van der Waals' forces, dispersion forces and instantaneous dipole – induced dipole forces.* *Accept "dipole-dipole forces" as molecule is polar.* *H-bonds in NH_3 (only) must be mentioned to score **[2]**.* *Do **not** award M2 or M3 if:* • *implies covalent bond is the H-bond* • *implies covalent bonds break.* *Accept "dipole-dipole forces are weaker".*	2 max
1.	a	vi	*Weak:* only partially dissociated/ionized «in dilute aqueous solution» ✓ *Brønsted–Lowry base:* an acceptor of protons/H^+/hydrogen ions ✓	*Accept reaction with water is reversible/an equilibrium.* *Accept "water is partially dissociated «by the weak base»".*	2
1.	b	i	P_4 is a molecule «comprising 4P atoms» ***AND*** 4P is four/separate «P» atoms ***OR*** P_4 represents «4P» atoms bonded together ***AND*** 4P represents «4» separate/non-bonded «P» atoms ✓		1

(c) (i)

	NF_4^+	N_2H_2	N_2H_4
Hybridization	sp^3;	sp^2;	sp^3;

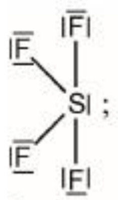
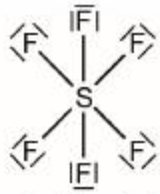
[3]

Do not penalize if it is not superscript.

(ii) *sigma bond:* overlapping of orbitals end to end/head on / overlapping of orbitals along internuclear axis;
Accept "axial overlapping of orbitals".

pi bond: side-ways/parallel overlapping of <u>p orbitals</u> (above and below internuclear axis);
Accept "overlapping of <u>p orbitals</u> above and below the internuclear axis".
Accept suitable labelled diagrams.

[2]

(iii)  ;  ;

See saw; Octahedral; *[4]*

Accept any combination of lines, dots or crosses to represent electron pairs.
Penalize missing lone pairs on fluorine atoms once only.
For SF_4, lone pair on S required for the mark.
Do not allow ECF for a wrong Lewis structure.
Accept saw horse/distorted tetrahedron instead of see-saw.

(d) (i) $CH_3CH_2CH_3 < CH_3CHO < CH_3CH_2OH < CH_3COOH$;; *[2]*
*Award **[2]** for correct order.*
*Award **[1]** for $CH_3COOH > CH_3CH_2OH > CH_3CHO > CH_3CH_2CH_3$ as compounds are not listed in order of increasing boiling point.*
*Award **[1]** if one error in the order.*

(ii) $CH_3CH_2CH_3$ /London/dispersion/instantaneous induced dipole-induced dipole forces
CH_3CHO dipole-dipole forces (and London/dispersion forces)
CH_3CH_2OH H-bonding (and dipole-dipole and London/dispersion forces)
CH_3COOH H-bonding (and dipole-dipole and London/dispersion forces);;
*Award **[2]** for all four correct.*
*Award **[1]** for two or three correct.*

H-bonding strongest / London/dispersion forces weakest / dipole-dipole stronger than London/dispersion / dipole-dipole weaker than H-bonding;

Accept van der Waals' forces for London/dispersion forces.

CH_3COOH forms more/stronger H-bonds than CH_3CH_2OH / CH_3COOH is more polar than CH_3CH_2OH; *[4]*
Accept CH_3COOH has more electrons/higher molar mass than CH_3CH_2OH.

(e) ionization **and** (bombardment) by high energy/fast moving electrons/electron gun (to form positive ions);
acceleration **and** passing through electric field/potential difference/oppositely charged plates;
deflection **and** passing through magnetic field/electromagnet; *[3]*
*Award **[1]** for naming 3 processes (ionization, acceleration, deflection) in the correct order with incorrect details.*

Q# 9/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q5

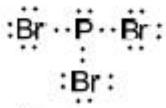
(b) *(Li → Cs)* atomic/ionic radius increases;
force of attraction between metal ions and <u>delocalized</u> electrons decreases;
Accept metallic bonding gets weaker.

(F → I) London/dispersion/instantaneous induced dipole-induced dipole forces increase;
Accept vdW/van der Waals' forces for London/dispersion forces.

with increasing number of electrons/molar mass/surface area/size of electron cloud; *[3 max]*
Do not accept "with increasing size" or "with increasing mass" only.

Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q9

(c) (i)



;

; **[2]**

Penalize lone pairs missing on Br and F once only.
Accept any combination of lines, dots or crosses to represent electron pairs.

(ii)

PBr_3	SF_4
Shape: trigonal pyramidal; *Accept triangular pyramidal.*	*Shape:* see-saw/K-shaped; *Accept distorted tetrahedral.*
No ECF for shape if Lewis structure is incorrect.	
Bond angle: *Any value 99°<109°;* *Literature value = 101°.*	*Bond angle:* *Any two for **[1]** of:* (F_{eq}–S–F_{eq}): *Any value* 100°<120° *Literature value = 103°* (F_{ax}–S–F_{ax}): *Any value* 175°<185° *Literature value = 179°/180°* (F_{ax}–S–F_{eq}): *Any value* 85°< 95° *Literature value = 89°*
No ECF for angle if shape is incorrect. *Do not award mark for correct angles if shape is incorrect.*	

[4]

(iii) P–Br and S–F bonds are polar / bonds in both molecules are polar;
non-symmetrical distribution of electron cloud / polar bonds/dipoles do not cancel because of non-symmetrical shape; **[2]**
M2 may also be scored with a suitable diagram showing the vectorial addition of the individual S–F dipole moments to show a net dipole moment centred along the axis between the F_{eq}–S–F_{eq} bond.

(d) (i) *EITHER*
(electrostatic) attraction between (positively charged) nuclei and a pair of electrons;
formed as a result of electron sharing (between the carbon and hydrogen nuclei);

OR

sigma bond formed by overlap of atomic orbitals;
s orbital from H and p/sp^2 from carbon; **[2]**

(ii) *α*: sp^3 **and** *β*: sp^2; **[1]**
Accept if numbers are given as subscripts.

(iii) *σ bond:*
end-on / axial overlap of two orbitals;

π bond:
sideways overlap of two (parallel) p orbitals; **[2]**

Accept suitable diagrams for both marks.

(iv) 11 σ **and** 3 π; **[1]**

Q# 11/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q8

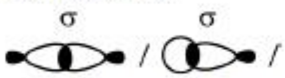
(b) (i) chromium(III) oxide; **[1]**
Do not award the mark for chromium oxide.

(ii) (electrostatic) attraction between positive and negative ions/oppositely charged ions/Cr^{3+} and O^{2-};
formed as a result of electron transfer from chromium atoms to oxygen atoms / *OWTTE*; **[2]**
Ignore reference to number of electrons transferred or charges of ion for M2.

(iii) ions are not free to move (when solid) / ions in rigid lattice / *OWTTE*; **[1]**

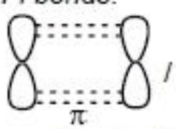
Q# 12/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(f) *Sigma bonds*:



result from head-on/end-on overlap of orbitals / *OWTTE*;
Accept axial overlap of orbitals.
Accept "symmetric orbital" with respect to same plane / OWTTE.

Pi bonds:



result from sideways overlap of orbitals / *OWTTE*; **[2]**
Accept "antisymmetric orbitals" with respect to (defining) plane (containing at least one atom) / OWTTE.

Q# 13/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(g) *Allotropes:*
Any ***three*** *allotropes for* ***[1]*** *from:*
diamond
graphite
fullerene
graphene;
Allow (carbon) nanotubes for graphene.
Accept C_{60} /C_{70} /buckminsterfullerene/bucky balls for fullerene.

Structures:
Any three for ***[3]*** *from:*
Diamond:
tetrahedral arrangement of (carbon) atoms/each carbon bonded to four others / sp^3 **and** 3D/covalent network structure;
Graphite:
each carbon bonded to three others (in a trigonal planar arrangement) / sp^2 **and** 2D / layers of (carbon) atoms;
Fullerene:
each (carbon) atom bonded to three others (in a trigonal arrangement) / sp^2 **and** joined in a ball/cage/sphere/connected hexagons and pentagons;
Accept "trigonal planar" for "each carbon atom bonded to three others" part in M4.
Graphene:
each carbon bonded to three others (in a trigonal arrangement) / sp^2 **and** 2D structure; **[4]**

Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

(e) Cl has 7 valence electrons **and** is in group 7;
Accept "group 17" as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3; **[2]**

(f)

Molecule	Shape	Bond angle	Polarity
SCl_2	bent/angular/ v-shaped	< 109.5° *Accept 100° – 108°. Literature value is 103°.*	polar
$SClF_5$	Octahedral *Accept square bipyramidal.*	90° (180°)	polar

;;; **[3]**

Do not accept ECF for bond angles and polarities from incorrect shapes.
*Award **[3]** for all six correct.*
*Award **[2]** for four or five correct.*
*Award **[1]** for two or three correct.*

Q# 15/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q2

(b) (i) Na_2O ionic **and** P_4O_{10} covalent (within molecule);
Na_2O in giant/3D/network/lattice structure with strong (ionic) bonds **and** P_4O_{10} has a (simple) molecular structure/weak intermolecular forces (between molecules); **[2]**
*Award **[1]** for stating that bonds require more energy to break in Na_2O than in P_4O_{10}.*

(ii)

	Phosphorus(V) oxide	Sodium oxide
Solid state	no	no
Molten state	no	yes

;; **[2]**

*Award **[2]** for four correct.*
*Award **[1]** for two or three correct.*

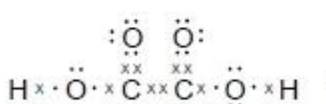
Q# 16/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q4

(c) electrostatic attraction;
between (a lattice of) cations/positive ions **and** delocalized/sea of electrons; **[2]**
Do not award any mark for only stating "metallic bonding".

Q# 17/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q1

(c) hydrogen bonding; **[1]**

(d)



; **[1]**

Mark cannot be scored if lone pairs are missing on oxygens.
Accept any combination of lines, dots or crosses to represent electron pairs.

(e) *Acid*:
one double and one single bond / one shorter and one longer bond;
Accept "two double and two single".

Conjugate base:
two 1.5 bonds / both bonds same length;
Accept "four / all".

electrons delocalized / resonance forms; **[3]**
Award marks for suitable diagrams.

Q# 18/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

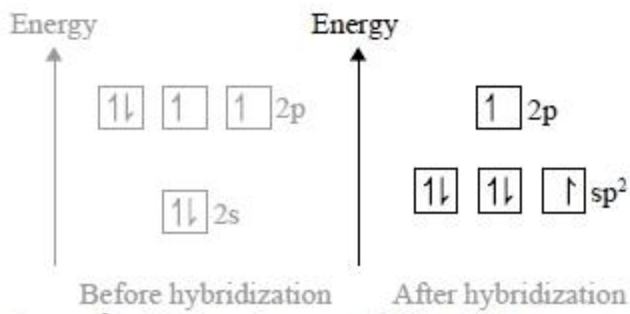
(c) (i) magnesium (atom) gives two electrons to oxygen (atom) / oxygen (atom) takes two electrons from magnesium (atom) / magnesium (atom) loses two electrons **and** oxygen (atom) gains two electrons;
3-dimensional/3-D arrangement of ions / lattice of ions;
(electrostatic) attraction between oppositely charged ions/Mg^{2+} and O^{2-}; *[2 max]*

(ii) electrostatic attraction between a pair of electrons and (positively charged) nuclei; *[1]*
Accept a/two pairs of shared electrons.

(iii) difference in electronegativity is larger between Mg and O/smaller between C and O; *[1]*
Accept reference to a numerical value of difference in electronegativity such as above and below 1.80.

(d) (i) C: sp hybridization;
O: sp^2 hybridization; *[2]*
Award [1] if the answer is sp without specifying C or O atoms.

(ii)



three sp^2 orbitals **and** one p-orbital at higher energy;
sp^2 orbitals contain: two, two and one electron **and** p-orbital contains one electron; *[2]*
Do not allow ECF from (d)(i).

(iii) ability of atom/nucleus to attract bonding/shared pair of electrons / attraction of nucleus for bonding/shared pair of electrons / *OWTTE*; *[1]*

(iv) (same number of shells but) increase in nuclear charge/atomic number/number of protons increases electronegativity / O has more protons than C;
Accept oxygen has a higher effective nuclear charge.
decrease in radius along the period increases electronegativity / O has smaller radius than C; *[2]*

Q# 19/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(b) oxygen is non-polar;
needs to break strong hydrogen bonds/H–bonds between water molecules (to dissolve) / oxygen cannot form hydrogen bonds/H–bonds with water;
oxygen can only form (weak) van der Waals'/vdW/LDF/London/dispersion forces with water; *[2 max]*

Q# 20/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) van der Waals'/vdW/London/dispersion (forces)/LDF / temporary/instantaneous/ induced dipoles; *[1]*

(b) *Two of the following pairs:*

used as pencil (lead);
layers can flake off/slide off/break off/stick to paper / *OWTTE*;
M2 must contain concept of separation of layers, so do not award mark for phrases like "layers can slide over each other" on their own.

OR

used as carbon fibre / *OWTTE*;
bonding within layer is strong / layers are extensive / layers are strong;

OR

used as electrodes/conductor/in batteries;
has mobile/free/delocalized electrons (between layers) / electricity flows parallel to layers;

OR

used for thermal insulation;
vibrations are not easily passed between layers; *[4 max]*

Accept other valid uses of graphite along with a suitable explanation.

Q# 21/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

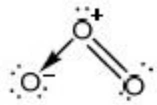
(f) (i) lattice/layers/framework of cations/magnesium ions/Mg^{2+};
surrounded by delocalized electrons / in a sea/flux of delocalized electrons; *[2]*
Accept "mobile" instead of "delocalized".

(ii) Mg has more delocalized electrons (than Na); *[1]*
Accept "Mg has more valence electrons than Na" / "Mg is Mg^{2+} but Na is only Na^{+}".

(iii) layers of ions/atoms/particles cannot slide over each other so easily (as different sized ions/atoms/particles) / *OWTTE*; *[1]*

Q# 22/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/

4. (a)



[1]

Accept lines, dots or crosses to represent electron pairs.
*Formal charges and arrow for dative bond **not** required.*
*If Lewis structure incorrect remember to take into account possible ECF on parts (b)–(d) based on the number of electron domains and bond types in the Lewis diagram in part (a) and do **not** award marks for these if they are inconsistent with the structure given in (a).*

(b) *Shape:* non-linear / bent / v-shaped / angular;

Bond angle: 117° ; *[2]*
Accept values from 115° to 119° / <u>just/slightly</u> less than 120°.

(c) sp^2; *[1]*

(d) one is just one σ **and** one has one σ and one π; *[1]*
Accept "both bonds comprise one σ and a shared π "/ OWTTE.

(e) delocalization occurs / delocalized π-bond / (has two) resonance structures / it is a resonance hybrid;
length intermediate between H_2O_2 and O_2 / *OWTTE*; *[2]*

Q# 23/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

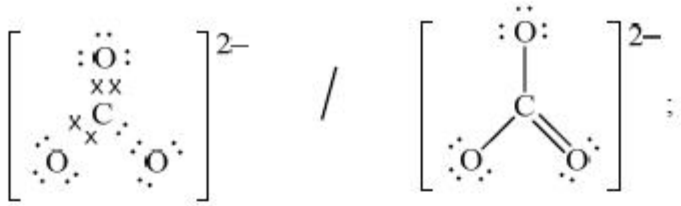
(c) (i) HF has hydrogen bonds (between molecules); *[1]*

(ii) strength of van der Waals'/London/dispersion forces increases;
as mass/size/number of electrons of halogen atom/molecule increases; *[2]*

Q# 24/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Q1

(d) (i) $H_2SO_4(aq) + MgCO_3(s) \rightarrow MgSO_4(aq) + CO_2(g) + H_2O(l)$; *[1]*
Ignore state symbols.
Do not accept H_2CO_3.

(ii)



Accept crosses, lines or dots as electron pairs.
Accept any correct resonance structure.
Award [0] if structure is drawn without brackets and charge.
Award [0] if lone pairs not shown on O atoms.

shape: trigonal/triangular planar;
bond angle: 120°;
Accept answers trigonal/triangular planar and 120° if M1 incorrect, but no other answers should be given credit. *[3]*

(iii) (pi/π) electrons are delocalized/spread over more than two nuclei / charge spread (equally) over all three oxygens; *[1]*

(iv) sp^2; *[1]*

Q# 25/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) (i) Ca^{2+} **and** NO_3^-;
electrostatic (attraction); *[2]*
Do not accept ionic.

(ii) nitrogen/N **and** oxygen/O; *[1]*
Do not accept nitrate/NO_3^-.
Accept atoms in nitrate/NO_3^-.

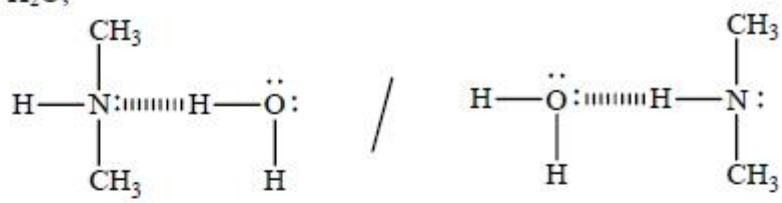
(b) <u>pi/π-</u>electrons shared by more than two atoms/nuclei / a <u>pi/π-</u>bond/overlapping p-orbitals that extends over more than two atoms/nuclei;
all (N–O) bonds equal length/strength/bond-order / charge on all oxygen/O atoms equal / increases stability/lowers PE (of the ion); *[2]*
Accept a diagram that clearly shows one or both points.

Q# 26/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q4

(b) van der Waals'/London/dispersion **and** dipole-dipole; *[1]*
Allow abbreviations for van der Waals' as vdW or for London/dispersion as FDL.

(c) (i) $(CH_3)_2NH$;
(intermolecular) attraction between hydrogen (atom) in O–H/N–H (polar) bond and (lone pair on) <u>electronegative</u> N/O / hydrogen between two very <u>electronegative</u> elements (nitrogen and oxygen) / *OWTTE*; *[2]*
Accept hydrogen bonded to nitrogen which is electronegative/has lone pair.
Do not allow ECF if M1 is incorrect.

(ii) representative drawing showing hydrogen bond between $(CH_3)_2NH$ and H_2O; *[1]*



Do not penalize if lone pair as part of hydrogen bond is not shown.
Allow any representation of hydrogen bond (for example, dashed lines, dots etc.) which differs from full stick representation of the other covalent bonds in amine and water molecules.
Allow full line if labelled as hydrogen bond.
Lone pairs on oxygen not necessary.
Award mark if two hydrogen bonds drawn between the molecules from the lone pair and the H on the N.

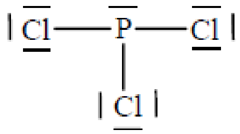
Q# 27/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q3

(b) dative (covalent) / coordinate; *[1]*
Do not allow just covalent or co-dative.

Q# 28/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q6c

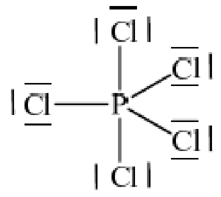
(c) (i) $1s^2 2s^2 2p^6 3s^2 3p^3$; **[1]**

(ii) *PCl_3*



;

PCl_5



; **[2]**

Penalize missing lone pairs on chlorine only once.
Accept any combination of lines, dots or crosses to represent electron pairs.

(iii)

	PCl_3	PCl_5
Shape	trigonal/triangular pyramidal;	trigonal/triangular bipyramidal;
Bond angles	any angle between 99˚ and 108˚;	90˚ **and** 120˚; *ignore* 180˚

[4]

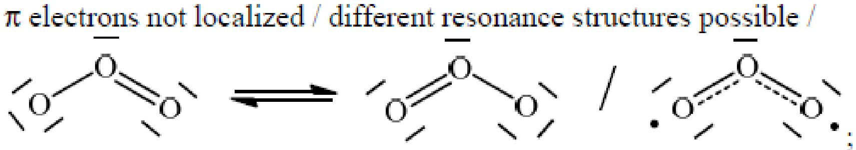
Shape and bond angle must be consistent with the number of electron domains given in the diagram in (ii).

(iv) sp^3 (hybridization); **[1]**

(v) PCl_5 has higher melting point than PCl_3;
PCl_5 has stronger intermolecular/London/dispersion/van der Waals' forces;
(because of) more electrons/greater mass; **[3]**
Accept the opposite argument for PCl_3.
*Award **[1 max]** for answers suggesting PCl_3 has higher melting point because it is polar and PCl_5 is not.*

(vi) $PCl_5(s) + 4H_2O(l) \rightarrow H_3PO_4(aq) + 5HCl(aq)$; **[1]**
Ignore state symbols.

(e) overlap of *p* orbitals / *p* electrons of double/π bond and non-bonding/lone pair on oxygen interact / *OWTTE*;
π electrons not localized / different resonance structures possible /



;

both bonds/O–O and O=O have equal length / *OWTTE*;
both bonds/O–O and O=O have equal bond energy / *OWTTE*; **[4]**

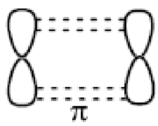
Q# 29/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q5

(ii) NH_4^+/ammonium / $N_2H_5^+$/hydrazinium / $CH_3NH_3^+$/methylammonium/ methanaminium / $H_2NO_3^+$ /nitrooxonium; ***[1]***

(iii) *Sigma bonds*:

result from head-on/end-on overlap of orbitals / *OWTTE*;
Allow symmetric (orbital) with respect to same plane / OWTTE.

Pi bonds:



result from sideways overlap of orbitals / *OWTTE*;
Allow antisymmetric (orbitals) with respect to (defining) plane (containing at least one atom) / OWTTE.

suitable diagrams showing σ **and** π bonds after formation; ***[3]***

*Award **[1 max]** for correct diagram without description given or **[2 max]** for description given without diagram.*

(iv) *σ bonds*: 28;
π bonds: 4; ***[2]***

(v) mixing/combining/merging of atomic orbitals to form new/molecular orbitals (for bonding);
A: sp^2;
B: sp^3; ***[3]***
*Award **[1 max]** for M2 and M3 for sp^2 **and** sp^3 if **A** and **B** are not identified explicitly but do not award M2 and M3 if sp^3 is given for **A** and sp^2 for **B**.*

Q# 30/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q2

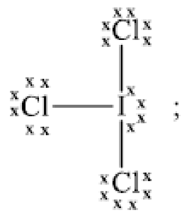
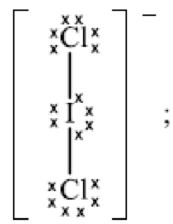
(b) (i) metals have delocalized electrons / sea of electrons which are mobile/can move / *OWTTE*;
layers/positive ions/cations/atoms slide past/over each other / *OWTTE*; ***[2]***
Do not accept nuclei for M2.

Q# 31/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

(b) Br_2 has London/dispersion/van der Waals' forces/vdW **and** ICl has (London/ dispersion/van der Waals' forces/vdW and) dipole–dipole forces;
dipole–dipole forces are stronger than London/dispersion/van der Waals'/vdW forces ; ***[2]***
Allow induced dipole-induced dipole forces for London forces.
Allow interactions instead of forces.
Do not allow ICl polar and Br_2 non-polar for M1.
Name of IMF in both molecules is required for M1 and idea of dipole-dipole stronger than vdW is required for M2.

Q# 32/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

(e)

	ICl_3	ICl_2^-
Lewis (electron dot) structure		
	Do not penalize for an incorrect shape for Lewis structures. *Accept lines, dots or crosses for electron pairs for both Lewis structures.* *Penalize missing lone pairs <u>on Cl</u> once only.* *Square brackets and negative charge must be shown for Lewis structure of* $[ICl_2]^-$.	
Name of shape	T-shaped;	linear;

[4]

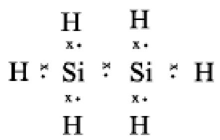
No ECF for shape if Lewis structure is incorrect.

Q# 33/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5d

(ii) *Aqueous solution:*
mobile ions/charged particles present;

Liquid:
molecular covalent / no (mobile) charged particles/ions; *[2]*

5. (a) (i)



;

[1]

Accept any combination of lines, dots or crosses to represent electron pairs.

(ii) 109° / 109.5° / 109° 28' ;

four/tetrahedrally arranged negative charge centres/electron domains/electron pairs (around central/silicon atom) / equal repulsion between bonding pairs (around central/silicon atom) / *OWTTE*; *[2]*

M2 is an independent marking point.

Reference must be made to negative or electron.

Do not accept tetrahedral molecule.

(iii) sp^3; *[1]*

(iv) C–H;

larger difference in electronegativity (for C–H bond) / smaller difference in electronegativity (for Si–H bond) / ΔEN (CH) = 0.4 **and** ΔEN (SiH) = 0.3; *[2]*

(v) both (molecules) non-polar;

both (molecules) symmetrical / polar bond effects cancel out / *OWTTE*; *[2]*

(vi) stronger/larger/greater van der Waals'/London/dispersion forces;

Do not accept stronger/larger/greater intermolecular forces.

more electrons / stronger instantaneous dipole; *[2]*

Do not accept larger mass.

(b)

(iii) *Structure:*

CO_2 molecular **and** SiO_2 three-dimensional/network/giant lattice/giant covalent/macromolecular/repeating tetrahedral units;

CO_2 linear **and** SiO_2 tetrahedral;

Intramolecular Bonding:

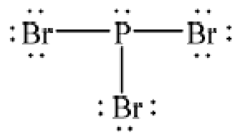
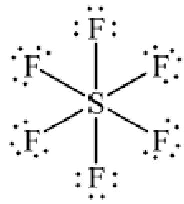
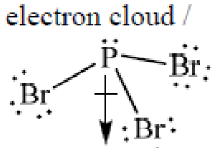
covalent bonds in CO_2 **and** SiO_2;

double bonds in CO_2 **and** single bonds in SiO_2; *[3 max]*

Accept diagrams showing bonding types (double and single) within the structures.

Q# 35/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q6

(c)

PBr_3	SF_6
(i) *Lewis structure:*  ; *Allow x's, dots or lines to represent electrons.* *Penalize missing lone pairs on terminal atoms once only for the two Lewis structures.*	(i) *Lewis structure:*  ; *Allow x's, dots or lines to represent electrons.* *Penalize missing lone pairs on terminal atoms once only for the two Lewis structures.*
(ii) *Shape:* trigonal/triangular pyramidal; *Bond angle:* less than 109.5° ; *Allow any angle less than 109.5° but greater than or equal to 100° (experimental value is 101°).*	(ii) *Shape:* octahedral; *Bond angle:* 90° ; *Ignore extra correct bond angles (e.g. 90° and 180° scores but not 90° and 120°).*
(iii) *Polarity:* polar **and** *Explanation:* net dipole (moment) / polar PBr bonds **and** molecule not-symmetrical / bond dipoles do not cancel / asymmetric distribution of electron cloud /  / *OWTTE*;	(iii) *Polarity:* non-polar **and** *Explanation:* no net dipole (moment) / polar SF bonds but molecule symmetrical / bond dipoles cancel / symmetric distribution of electron cloud / *OWTTE*;

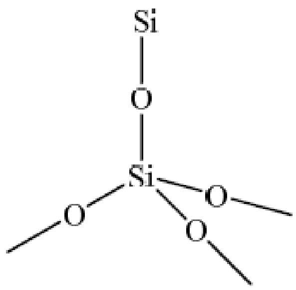
[8]

Do not allow ECF in this question from incorrect Lewis structure.
*Allow **[1 max]** for stating that PBr_3 is polar and SF_6 is non-polar without giving a reason or if explanations are incorrect.*
Allow polar bonds do not cancel for PBr_3 and polar bonds cancel for SF_6.
Do not allow asymmetric molecule as reason for PBr_3 or symmetric molecule for SF_6 as reason alone.

Q# 36/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/Q1

(c) (i) sodium could react violently with any moisture present / sodium is (potentially) explosive / sodium (is dangerous since it is flammable when it) forms hydrogen on contact with water / *OWTTE*; *[1]*
Do not accept answers such as sodium is dangerous or sodium is too reactive.

(ii) *Structure:*
drawing of giant structure showing tetrahedrally arranged silicon;
Minimum information required for mark is Si and 4 O atoms, in a tetrahedral arrangement (not 90° bond angles) but with each of the 4 O atoms showing an extension bond.



Bonding:
(giant/network/3D) covalent; ***[2]***

Q# 37/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) *Ionic:*
(electrostatic) attraction between oppositely charged ions/cations and anions/positive and negative ions;
Do not accept answers such as compounds containing metal and non-metal are ionic.

Metallic:
(electrostatic attraction between lattice of) positive ions/cations/nuclei and delocalized electrons / (bed of) positive ions/cations/nuclei in sea of electrons / *OWTTE*; ***[2]***

Q# 38/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) *Award **[2 max]** for three of the following features:*

Bonding

*Graphite **and** C_{60} fullerene:* covalent bonds **and** van der Waals'/London/dispersion forces;
Diamond: covalent bonds (and van der Waals'/London/dispersion forces);

Delocalized electrons

*Graphite **and** C_{60} fullerene:* delocalized electrons;
Diamond: no delocalized electrons;

Structure

Diamond: network/giant structure / macromolecular / three-dimensional structure **and** *Graphite:* layered structure / two-dimensional structure / planar;
C_{60} fullerene: consists of molecules / spheres made of atoms arranged in hexagons/pentagons;

Bond angles

Graphite: 120° **and** *Diamond:* 109°;
C_{60} fullerene: bond angles between 109–120°;
*Allow Graphite: sp^2 **and** Diamond: sp^3.*
*Allow C_{60} fullerene: sp^2 **and** sp^3.*

Number of atoms each carbon is bonded to

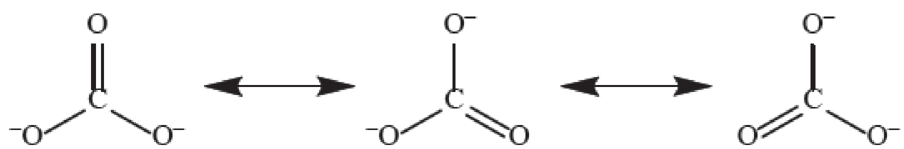
*Graphite **and** C_{60} fullerene:* each C atom attached to 3 others;
Diamond: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms); ***[6 max]***

(b) (i) network/giant structure / macromolecular;
each Si bonded covalently to 4 oxygen atoms **and** each O atom bonded covalently to 2 Si atoms / single covalent bonds; ***[2]***
*Award **[1 max]** for answers such as network-covalent, giant-covalent or macromolecular-covalent.*
Both M1 and M2 can be scored by a suitable diagram.

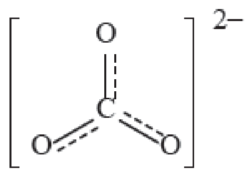
(ii) *Silicon dioxide:* strong/covalent bonds in network/giant structure/macromolecule;
Carbon dioxide: weak/van der Waals'/dispersion/London forces between molecules; ***[2]***

(c) triple (covalent) bond;
one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond; ***[2]***
*Award **[1 max]** for representation of* $C\equiv O$.
*Award **[2]** if CO shown with dative covalent bond.*

(d) delocalization/spread of pi/π electrons over more than two nuclei;
equal bond order/strength/length / spreading charge (equally) over all three oxygens;
gives carbonate ion a greater stability/lower potential energy; ***[3]***
M3 can be scored independently.
Accept suitable labelled diagrams for M1 and M2 e.g.



OR



Do not penalize missing brackets on resonance structure but 2– charge must be shown.
Allow –2 for charge on resonance structure.

(e) mixing/combining/merging of (atomic) orbitals to form new orbitals (for bonding);
Allow molecular or hybrid instead of new.
Do not allow answers such as changing shape/symmetries of atomic orbitals.

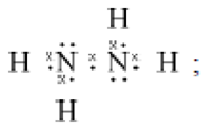
Carbon dioxide: sp;
Diamond: sp^3;
Graphite: sp^2;
Carbonate ion: sp^2; ***[5]***

(f) (i) *Molten sodium oxide:* conducts because of free moving/mobile ions in molten state;
Sulfur trioxide: doesn't conduct because no free moving/mobile charged particles/it has neutral molecules; ***[2]***
*Award **[1 max]** for stating molten sodium oxide conducts but sulfur trioxide doesn't.*
Do not award M2 for "just sulfur trioxide does not conduct because it is molecular."

(ii) $Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$;
$SO_3(l) + H_2O(l) \rightarrow H_2SO_4(aq)$;
both solutions conduct; ***[3]***
Ignore state symbols.

Q# 39/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) (i)



[1]

Accept x's, dots or lines for electron pairs

(ii) H–N–H < 109 / any angle between 104° and 109°;
due to four centres of electron/negative charge / four electron pairs (one of which is a lone e- pair) / four electron domains;
extra repulsion due to lone electron pairs; *[3]*
Do not allow ECF for wrong Lewis structures.

(b) weaker van der Waals'/London/dispersion/intermolecular forces in ethene;
stronger (intermolecular) hydrogen bonding in hydrazine; *[2]*
If no comparison between strengths then [1 max].

(d) (i) acid-base/neutralization; *[1]*

(ii) 109°/109.5°; *[1]*

(iii) sp^3; *[1]*
No ECF if bond angle incorrect in (ii).

Q# 40/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(c) metallic (bonding);
positive ions/cations **and** delocalized/sea of electrons;
electrostatic attraction between the two;
Award [2 max] for description of bonding

Conductivity:
electrons delocalised/free to move;

Malleability:
atoms/ions/cations can move without breaking bonds / atoms/ions/cations can slide past each other; *[4]*

Q# 41/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) (i) (bond formed by) sideways overlap;
(of) p orbitals; *[2]*
Marks awarded either from sketch or from explanation.

(ii) C(1) is sp^3 **and** C(2) is sp^2; *[1]*

Q# 42/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(h) (i) $AlCl_3$ covalent **and** Al_2O_3 ionic;
$AlCl_3$ (simple) molecular **and** Al_2O_3 (giant ionic) lattice;

OR

$AlCl_3$ is covalent <u>and</u> simple molecular/small molecules held together by dipole–dipole attractions;
Al_2O_3 is ionic and Al^{3+} and O^{2-} ions are held together in a (giant) lattice; *[2 max]*

(ii) $AlCl_3$ is acidic and Na_2O is basic and P_4O_{10} is acidic;

$AlCl_3 + 3H_2O \rightarrow Al(OH)_3 + 3HCl$ / $AlCl_3 + 6H_2O \rightarrow [Al(H_2O)_6]^{3+} + 3Cl^-$ **and**

$[Al(H_2O)_6]^{3+} \rightarrow [Al(H_2O)_5OH]^{2+} + H^+$;

Accept suitable alternative hydrolysis expressions or reactions with a base.

$Na_2O + H_2O \rightarrow 2NaOH$;
$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$; *[4]*
Accept suitable reactions with an acid or base.

(iii) $AlCl_3$ does not conduct in the solid/molten state;
Al_2O_3 conducts when molten (but not when solid);
Al_2O_3 contains mobile ions when molten **and** $AlCl_3$ has neither mobile ions nor delocalized electrons / *OWTTE*; *[3]*
Reference to mobile ions or electrons must be made.

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(h) (i) $AlCl_3$ covalent **and** Al_2O_3 ionic;
$AlCl_3$ (simple) molecular **and** Al_2O_3 (giant ionic) lattice;

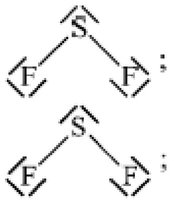
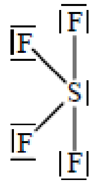
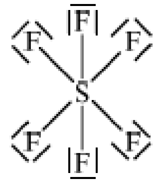
OR

$AlCl_3$ is covalent <u>and</u> simple molecular/small molecules held together by dipole–dipole attractions;
Al_2O_3 is ionic and Al^{3+} and O^{2-} ions are held together in a (giant) lattice; *[2 max]*

(iii) $AlCl_3$ does not conduct in the solid/molten state;
Al_2O_3 conducts when molten (but not when solid);
Al_2O_3 contains mobile ions when molten **and** $AlCl_3$ has neither mobile ions nor delocalized electrons / *OWTTE*; *[3]*
Reference to mobile ions or electrons must be made.

Q# 44/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

2.

	SF_2	SF_4	SF_6	
Lewis structure	 ; ; *2 lone pairs on S required for the mark*	 ; *1 lone pair on S required for the mark*	 ;	
Name of shape	bent/angular/V shaped;	Seesaw/distorted tetrahedral;	octahedral; *Accept square bipyrimidal*	*[6]*

Penalise missing lone pairs on fluorine atoms once in correct structures only.
For Lewis structures candidates are not expected to draw exact shapes of molecules.
Do not allow ECF for wrong Lewis structures.
Accept dots or crosses instead of lines.

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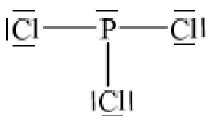
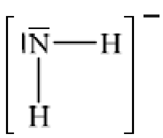
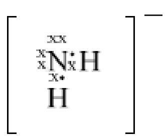
6. (a) (i)

 /  ;

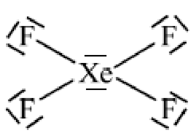
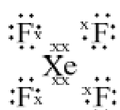
trigonal pyramid;
in the range of 100 – 108˚ ; *[3]*

(ii)

 /  ;

Must include minus sign for the mark.
bent/V–shaped;
in the range of 100 – 106˚ ; *[3]*

(iii)

 /  ;

square planar;
90˚ ; *[3]*
Penalize once only if electron pairs are missed off outer atoms.

(c) (i) sigma bonds are formed by end on/axial overlap of orbitals with electron density between the two atoms/nuclei;
pi bonds are formed by sideways overlap of parallel p orbitals with electron density above **and** below internuclear axis/ σ bond; ***[2]***
Accept suitably annotated diagrams

(ii) 8 sigma/σ ;
1 pi/π ; ***[2]***

(iii) 109˚/109.5˚;
120˚; ***[2]***

(iv) sp hybridization;
1 sigma and 2 pi;
sigma bond formed by overlap between the two sp hybrid orbitals (on each of the two carbon atoms) / pi bonds formed by overlap between remaining p orbitals (on each of the two carbon atoms) / diagram showing 2 sp hybrid orbitals and 2 p orbitals; ***[3]***

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5. (a) in the solid state ions are in fixed positions / there are no moveable ions / *OWTTE*; ***[1]***
Do not accept answer that refers to atoms or molecules.

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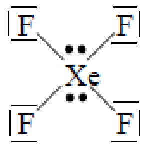
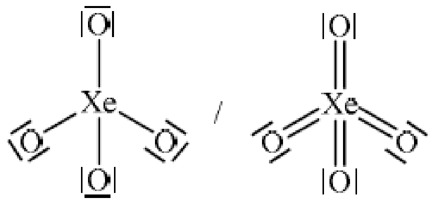
(b) (i)


;

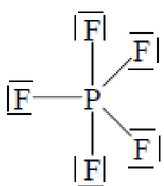
square planar/coplanar;


;

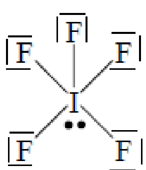
Tetrahedral/tetrahedron; *[4]*

Do not accept two double and two single bonds around Xe.

(ii)


;

trigonal bipyramidal;


;

square pyramidal/square-based pyramidal; *[4]*

In part (i) and (ii), penalize missing lone pairs on fluorine and oxygen atoms once only.

Penalize missing or extra lone pairs on central atom every time.

Do not allow ECF for wrong Lewis structure.

Accept correct Lewis structures that does not display 3D shape.

Accept dots or crosses instead of lines.