IB Chemistry HL
Topic4 Questions

1. What is the best description of the carbon-oxygen bond lengths in CO_3^{2-}?

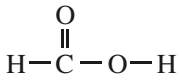
A. One short and two long bonds

B. One long and two short bonds

C. Three bonds of the same length

D. Three bonds of different lengths

2. What is the number of sigma (σ) and pi (π) bonds and the hybridization of the carbon atom in



	Sigma	Pi	Hybridization
A.	4	1	sp^2
B.	4	1	sp^3
C.	3	2	sp^3
D.	3	1	sp^2

3. Which of the following contain a bond angle of 90°?

I. $PC1_4^+$

II. PCl_5

III. PCl_6^-

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

4. Which allotropes contain carbon atoms with sp^2 hybridization?

I. Diamond

II. Graphite

III. C_{60} fullerene

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

5. What is the molecular shape and the hybridization of the nitrogen atom in NH_3?

	Molecular shape	Hybridization
A.	tetrahedral	sp^3
B.	trigonal planar	sp^2
C.	trigonal pyramidal	sp^2
D.	trigonal pyramidal	sp^3

6. Which statement about sigma and pi bonds is correct?

A. Sigma bonds are formed only by s orbitals and pi bonds are formed only by p orbitals.

B. Sigma bonds are formed only by p orbitals and pi bonds are formed only by s orbitals.

C. Sigma bonds are formed by either s or p orbitals, pi bonds are formed only by p orbitals.

D. Sigma and pi bonds are formed by either s or p orbitals.

7. Consider the following statements.

I. All carbon-oxygen bond lengths are equal in CO_3^{2-}.

II. All carbon-oxygen bond lengths are equal in CH_3COOH.

III. All carbon-oxygen bond lengths are equal in CH_3COO^-.

Which statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

8. Which statement is correct about multiple bonding between carbon atoms?

A. Double bonds are formed by two π bonds.

B. Double bonds are weaker than single bonds.

C. π bonds are formed by overlap between s orbitals.

D. π bonds are weaker than sigma bonds.

9. Which particles can act as ligands in complex ion formation?

I. $C1^-$

II. NH_3

III. H_2O

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

10. Which statements correctly describe the NO_2^- ion?

I. It can be represented by resonance structures.

II. It has two lone pairs of electrons on the N atom.

III. The N atom is sp^2 hybridized.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

11. Which is the smallest bond angle in the PF_5 molecule?

A. 90°

B. 109.5°

C. 120°

D. 180°

12. Which types of hybridization are shown by the carbon atoms in the compound $CH_2 = CH–CH_3$?

I. sp

II. sp^2

III. sp^3

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

13. Identify the types of hybridization shown by the carbon atoms in the molecule

$$CH_3CH_2CH_2COOH$$

I. sp

II. sp^2

III. sp^3

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

14. Which molecule is square planar in shape?

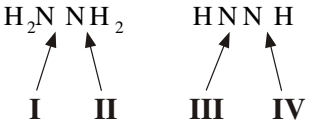
A. XeO_4

B. XeF_4

C. SF_4

D. SiF_4

15. What is the hybridization of nitrogen atoms I, II, III and IV in the following molecules?



	I	II	III	IV
A.	sp^2	sp^2	sp^3	sp^3
B.	sp^3	sp^3	sp^2	sp^2
C.	sp^2	sp^2	sp	sp
D.	sp^3	sp^3	sp	sp

16. What is the molecular geometry and the Cl–I–Cl bond angle in the ICl_4^- ion?

A. Square planar 90°

B. Square pyramidal 90°

C. Tetrahedral 109°

D. Trigonal pyramidal 107°

17. What is the geometry of the bonds around an atom with sp^2 hybridization?

A. 2 bonds at 180°

B. 3 bonds at 120°

C. 2 bonds at 90°, 1 bond at 180°

D. 4 bonds at 109°

18. How many sigma (σ) and pi (π) bonds are present in the structure of HCN?

	σ	π
A.	1	3
B.	2	3
C.	2	2
D.	3	1

19. How many lone pairs and bonding pairs of electrons surround xenon in the XeF_4 molecule?

	Lone pairs	Bonding pairs
A.	4	8
B.	0	8
C.	0	4
D.	2	4

20. (a) Explain the meaning of the term *hybridization*.

.....

.....

(1)

(b) State the type of hybridization shown by the carbon atom in the H–C≡N molecule, and the number of σ and π bonds present in the C≡N bond.

.....

.....

(2)

(c) Describe how σ and π bonds form.

.....

.....

.....

.....

(4)

(Total 7 marks)

21. (i) Draw the Lewis structures for carbon monoxide, carbon dioxide and the carbonate ion.

.....

.....

.....

.....

.....

.....

.....

.....

(3)

(ii) Identify the species with the longest carbon-oxygen bond and explain your answer.

.....

.....

.....

.....

.....

.....

(3)
(Total 6 marks)

22. In 1954 Linus Pauling was awarded the Chemistry Nobel Prize for his work on the nature of the chemical bond. Covalent bonds are one example of intramolecular bonding.

Explain the formation of the following.

(i) σ bonding

……

……

……

(2)

(ii) π bonding

……

……

……

(2)

(iii) double bonds

……

……

……

(1)

(iv) triple bonds

……

……

……

(1)

(Total 6 marks)

23. Atomic orbitals can mix by hybridization to form new orbitals for bonding.

Identify the type of hybridization present in each of the **three** following molecules. Deduce and explain their shapes.

(i) OF_2

……

……

……

……

(3)

(ii) H_2CO

……

……

……

……

(3)

(iii) C_2H_2

……

……

……

……

(3)

(Total 9 marks)

24. For the following compounds

PCl_3, PCl_5, $POCl_3$

(i) Draw a Lewis structure for each molecule in the gas phase.
(Show all non-bonding electron pairs.)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(3)

(ii) State the shape of each molecule and predict the bond angles.

.....

.....

.....

.....

.....

.....

(6)

(iii) Deduce whether or not each molecule is polar, giving a reason for your answer.

.....

.....

.....

.....

.....

.....

(3)

(Total 12 marks)

25. (i) Explain the meaning of the term *hybridization*.

.....

.....

.....

(1)

(ii) Discuss the bonding in the molecule CH_3CHCH_2 with reference to

- the formation of σ and π bonds
- the length and strength of the carbon-carbon bonds
- the types of hybridization shown by the carbon atoms

.....

.....

.....

.....

.....

.....

.....

.....

(6)
(Total 7 marks)

26. (a) Draw the Lewis structures for the compounds XeF_4, PF_5 and BF_4^-.

(3)

(b) Use the valance shell electron pair repulsion (VSEPR) theory to predict the shapes of the three compounds in (a). State and explain the bond angles in each of the three compounds.

(3)
(Total 6 marks)

27. (a) State the meaning of the term hybridization. State the type of hybridization shown by the nitrogen atoms in N_2, N_2H_2 and N_2H_4.

(4)

(b) By referring to the N_2H_2 molecule describe how sigma (σ) and pi (π) bonds form and describe how single and double bonds differ.

(4)
(Total 8 marks)

28. (i) Explain why the first ionization energy of magnesium is lower than that of fluorine.

(2)

(ii) Write an equation to represent the third ionization energy of magnesium. Explain why the third ionization energy of magnesium is higher than that of fluorine.

(3)
(Total 5 marks)

29. Draw the Lewis structures, state the shapes and predict the bond angles for the following species.

(i) PCl_5

(3)

(ii) SCl_2

(3)

(iii) ICl_4^-

(3)

(Total 9 marks)

30. (a) (i) State the meaning of the term *hybridization*.

(1)

(ii) State the type of hybridization around the carbon atoms in C_{60} fullerene, diamond and graphite.

(3)

(iii) Explain why graphite and C_{60} fullerene can conduct electricity.

(2)

(b) (i) Compare how atomic orbitals overlap in the formation of sigma (σ) and pi (π) bonds.

(2)

(ii) State the number of sigma bonds and pi bonds in $H_2CC(CH_3)CHCH_2$.

(2)

(Total 10 marks)

31. (i) Apply the VSEPR theory to deduce the shape of NO_2^-, ICl_5 and SF_4. For each species, draw the Lewis (electron dot) structure, name the shape, and state the value of the bond angle(s).

(9)

(ii) Discuss the bond angle(s) in SF_4.

(1)

(iii) Explain the hybridization involved in the C_2H_4 molecule.

(4)

(iv) State the hybridization involved in the NO_2^- ion and comment on the nitrogen-oxygen bond distances.

(2)

(v) Using Table 7 of the Data Booklet, predict and explain which of the bonds O-H, O-N or N-H would be most polar.

(2)

(Total 18 marks)

1. C

2. A

3. C

4. C
5. D

6. C

7. B

8. D
9. D

10. B

11. A

12. C

13. C

14. B

15. B

16. A

17. B

18. C

19. D

20. (a) mixing/joining together/combining/merging of atomic orbitals to form molecular orbitals/new orbitals/orbitals of equal energy; 1

Accept specific example such as mixing of s and p orbitals.

(b) sp;

Do not award mark if sp^2 or sp^3 is also stated.

one sigma and two pi (bonds); 2

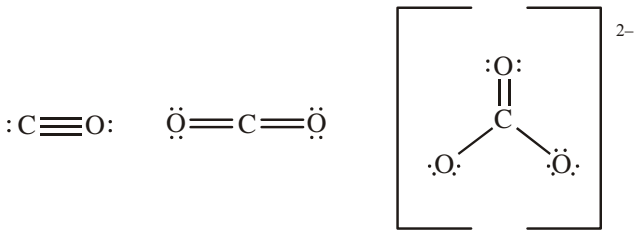
(c) (σ bond formed by) end-on/axial overlap;
electrons/electron density between the two (carbon) atoms/*OWTTE*;
(π bond formed by) sideways/parallel overlap;
electrons/electron density above and below σ bond/*OWTTE*; 4

Marks can be scored from a suitable diagram.

Do not award 2^{nd} and 4^{th} marks if electrons are not mentioned.

[7]

21. (i)



OTTWE 3

*Award **[1]** each. Need charge on CO_3^{2-} for **[1]**.*
Penalize missing lone electron pairs only once.

(ii) CO_3^{2-};
bond order $1\frac{1}{3}$ / $1\frac{1}{3}$ bonds each compared to double bonds in CO_2 and triple bond in CO;
the fewer the number of bonding electrons, the less tightly nuclei are held together, the longer the bond; 3

[6]

22. (i) "head on" overlap of (2) orbitals;
along axial symmetry/along a line drawn through the 2 nuclei/*OWTTE*; 2
Accept suitable diagram for 2nd mark.

(ii) parallel p orbitals overlap sideways on;
above and below the line drawn through the 2 nuclei/*OWTTE*; 2
Accept suitable diagram for 2nd mark.

(iii) 1 σ and 1 π/σ and π; 1

(iv) 1 σ and 2 π/σ and π; 1

[6]

23. (i) *OF_2*
sp^3;
V-shaped/bent/angular;
2 bonding + 2 non-bonding (electron pairs); 3

(ii) *H_2CO*
sp^2;
trigonal planar;
2 areas of electron density/negative charge centres; 3

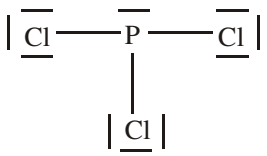
(iii) *C_2H_2*
sp;
linear;
2 areas of electron density/negative charge centres; 3
Accept suitable diagrams for shapes.
*Allow **[2]** for ECF if correct explanation given for incorrect formula, e.g. C_2H_4.*

[9]

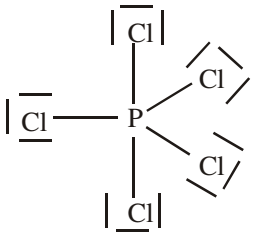
24. (i)

*Award **[1]** for each correct Lewis structure.*

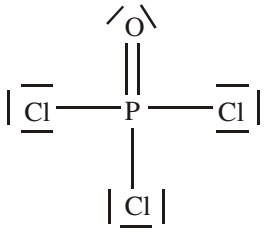
PCl_3



PCl_5

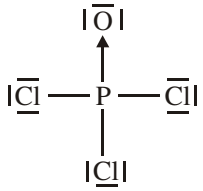


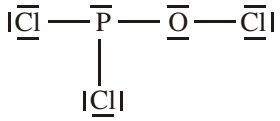
$POCl_3$



3

Accept use of dots or crosses to represent electron pairs.
*Subtract **[1]** if non-bonding pair on P in PCl_3 is missing.*
*Subtract **[1]** if non-bonding pair(s) on Cl or O are missing.*
Accept legitimate alternatives for $POCl_3$, e.g. see below.





(ii)

PCl_3	PCl_5	$POCl_3$
trigonal pyramid;	trigonal bipyramid;	tetrahedral;
Accept answers in range 100° to 108°;	90° **and** 120°;	*Accept answers in range* 100° to 112°;

Allow ECF if based on legitimate chemical structure. 6

(iii)

PCl_3	PCl_5	$POCl_3$
polar, polarities do not cancel/OWTTE;	non-polar, polarities cancel/OWTTE;	polar, polarities do not cancel/OWTTE;

3

*Award **[2]** for three polarities correct, **[1]** for two polarities correct, and **[1]** for correct reason(s).*

Accept argument based on dipole moments.

Allow ECF if based on legitimate chemical structure.

[12]

25. (i) combining of atomic orbitals to form new orbitals/*OWTTE*; 1

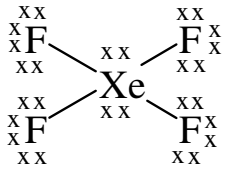
(ii) σ : overlap of orbitals between nuclei/end-on overlap;
π : overlap above and below line joining nuclei/sideways overlap;
*Award **[1]** if candidate counts bonds (8 σ, 1 π), or describes all three types of bonds (i.e. C—H is σ, C—C is σ, C=C is σ and π).*

single bonds longer than double;
double bonds stronger than single;

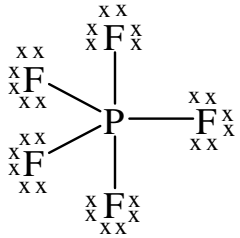
C of CH_3 is sp^3;
other two C are sp^2; 6
Accept suitable diagrams.

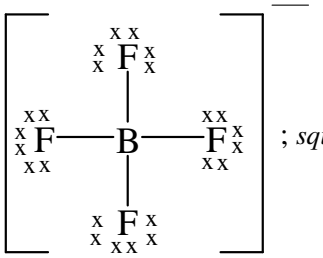
[7]

26. (a) 3



; lone pairs on Xe required for the mark.





; *square brackets and charge required for the mark.*

Accept any combination of dots, crosses and lines.
Penalise missing fluorine lone pairs once only.

(b) XeF_4
Square planar and 90°;
PF_5
trigonal bipyramid and 90° and 120°;
BF_4^-
Tetrahedral and 109.5°/109°; 3
Allow clear suitable diagrams instead of name.
No ECF from (a).

[6]

27. (a) hybridization: mixing/merging of atomic orbitals;
N_2 –sp;

N_2H_2 –sp^2;

N_2H_4 –sp^3; 4

(b) σ bonds (result from the) overlapping of orbitals end to end/along inter-nuclear axis;
π bonds (result from the) overlapping of parallel/sideways p orbitals;
(single bonds) σ bonds only;
(double bonds) have a σ bond and a π bond; 4
Suitable clear and labelled diagrams acceptable for all marks.

[8]

28. (i) electron removed from higher energy level/further from nucleus/greater atomic radius;

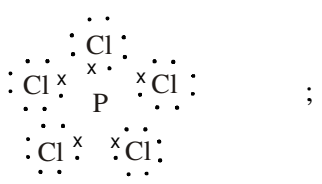
increased repulsion by extra inner shell electrons/increased shielding effect; 2

(ii) $Mg^{2+}(g) \rightarrow Mg^{3+}(g) + e$;

(even though) valence electrons in the same shell/main energy level/
Mg^{2+} has noble gas configuration;
Mg has greater nuclear/core charge/more protons; 3

[5]

29. (i)



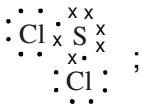
;

trigonal bipyramidal;
90°;

120°;
180°; 3

*Award **[1]** for 2 correct bond angles.*

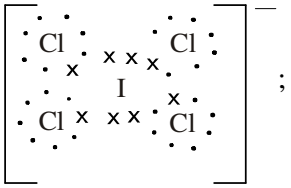
(ii)



;

Bent/angular/V-shaped;
100°–107°; 3

(iii)



;

square planar; 3
90°;
No ECF allowed.

*Penalize once only **[1]** mark for missing lone pairs.*

Accept structures using lines to represent bonding and lone electron pairs.

[9]

30. (a) (i) mixing/combining of atomic orbitals/OWTTE; 1

(ii) C_{60} *fullerene*: sp^2;

graphite : sp^2;

diamond: sp^3; 3

(iii) each carbon atom is bound to 3 other carbon atoms/π bonding;
leading to delocalized electrons; 2

(b) (i) sigma/σ bonds are formed by orbitals overlapping end to end/
along the internuclear axis/along line directly between nuclei;

Accept suitable diagram.

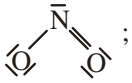
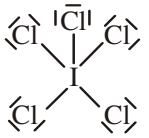
pi/π bonds are formed by p orbitals overlapping sideways; 2

Accept suitable diagram.

(ii) 12 sigma bonds;
2 pi bonds; 2

[10]

31. (i)

Species	*Lewis (electron-dot) structure*	*Shape*	*Bond angle(s)*
NO_2^-	 ;	Bent/V-shaped/angular;	109.5° < θ < 120°;
ICl_5	 ;	Square pyramidal;	|Inplane Cl-I-out-of-plane Cl| < 90°; *Allow corresponding correct statement for other correctly identified bond angles.*
SF_4	 ;	See-saw;	|Equatorial F-S-Equatorial F| < 120°; *Allow corresponding correct statement for axial-equatorial and axial-axial F-S-F angles.*

9

Accept crosses and dots for electrons in the Lewis structures also.
If all ideal bond angles are given, penalize once only.
As the Lewis structures were asked for, and not 3D representations, do not penalize incorrectly drawn geometries.

(ii) (equatorial F-S-equatorial F) less than 120° since non-bonding electron pairs (exert greater repulsive forces and thus) compress the bond angles/*OWTTE;* 1

(iii) orbital diagram representation of carbon ground-state going to carbon excited-state electron configuration;
mixing of orbitals to give three new entirely equivalent hybrid orbitals, $\underline{sp^2}$, on each carbon;
sp^2 orbitals trigonal (triangular) planar in shape;
unhybridized orbitals overlap to give π-bond; 4

(iv) sp^2;
both N-O bond lengths equal, (intermediate between double and single bonds) due to <u>resonance/delocalisation</u>; 2

(v) O-H is most polar;
O-H has greatest difference between electronegativities/calculation showing values of 1.4, 0.5 and 0.9 respectively; 2

[18]