Chemical Bonding and Molecular Structure

Standard difficulty · 20 questions · 40 marks · Time: 38 minutes

Name: _____ Date: _____ Score: ____ / 40

Show your working for Sections B and C. Answers are on the last page — try every question first!

Section A — Choose the correct answer 8 × 1 = 8 marks

1. The octet rule says atoms combine so that each has:

(a) eight neutrons **(b)** eight bonds

(c) eight protons **(d)** eight electrons in its outer shell

2. According to VSEPR theory, the shape of PH_3 is:

(a) trigonal pyramidal **(b)** square planar

(c) square pyramidal **(d)** see-saw

3. The hybridisation of the central atom in PH_3 is:

(a) sp^3d **(b)** sp^3d^2 **(c)** sp **(d)** sp^3

4. The bond order of O_2^- is:

(a) 1.5 **(b)** 2 **(c)** 1 **(d)** 0

5. Which of these is paramagnetic?

(a) H_2 **(b)** N_2 **(c)** N_2^- **(d)** O_2^{2-}

6. Which of these molecules has a dipole moment (is polar)?

(a) CCl_4 **(b)** CO_2 **(c)** XeF_4 **(d)** H_2O

7. How many σ and π bonds are there in $CH_3–C\equiv C–CH_3$?

(a) 9σ and 3π **(b)** 9σ and 2π **(c)** 11σ and 0π **(d)** 8σ and 3π

8. Assertion (A): SF_4 has zero dipole moment.
Reason (R): A molecule's dipole moment is the vector sum of its bond dipoles, so it is zero only when the shape is symmetrical and they cancel.

(a) Both A and R are true, and R is the correct explanation of A.

(b) Both A and R are true, but R is not the correct explanation of A.

(c) A is true, but R is false.

(d) A is false, but R is true.

Section B — Short answer 8 × 2 = 16 marks

9. Define bond order. How is it related to bond length and bond stability?

10. Use VSEPR theory to predict the shape of CH_4. State the numbers of bond pairs and lone pairs on the central atom.

11. Write the molecular orbital configuration of O_2^+. Find its bond order and say whether it is paramagnetic or diamagnetic.

12. Arrange N_2^+, O_2^-, O_2^{2-} in order of increasing stability.

13. Give the hybridisation of each carbon atom in $CH_3–CH_3$, from left to right.

14. Arrange NH_3, H_2O, CH_4 in order of decreasing bond angle.

15. Show how calcium (Z = 20) and sulphur (Z = 16) form an ionic compound by transfer of electrons, and give its formula.

16. Which bond is more polar, Al–H or P–F? Which atom carries the partial negative charge in it? (Pauling electronegativities: Al 1.5, H 2.1, P 2.1, F 4.0)

Section C — Word problems — 4 × 4 = 16 marks

17. Explain sp, sp^2 and sp^3 hybridisation with one example each, giving the shape and bond angle.

18. Using molecular orbital theory, compare He_2 and He_2^+: (a) write their MO configurations, (b) find their bond orders, (c) state their magnetic behaviour, (d) say which is more stable.

19. For XeF_4 and CH_4, give (a) the hybridisation of the central atom, (b) the numbers of bond pairs and lone pairs on it, (c) the shape and bond angle, (d) whether the molecule is polar.

20. For $CH_2{=}CH_2$: (a) how many σ and π bonds does it have? (b) give the hybridisation of each carbon atom, from left to right; (c) state the bond angle around each kind of carbon present.

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Answer key

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Q	Answer	Working
1	**(d) eight electrons in its outer shell**	Kössel and Lewis
2	**(a) trigonal pyramidal**	3 bond pairs and 1 lone pair on the central atom
3	**(d) sp^3**	4 electron pairs around it
4	**(a) 1.5**	½ (bonding − antibonding electrons); $\sigma1s^2\ \sigma^*1s^2\ \sigma2s^2\ \sigma^*2s^2\ \sigma2pz^2\ \pi2px^2\ \pi2py^2\ \pi^*2px^2\ \pi^*2py^1$
5	**(c) N_2^-**	N_2^-: 1 unpaired electron
6	**(d) H_2O**	H_2O is bent (V-shaped): its bond dipoles do not cancel
7	**(b) 9σ and 2π**	every single bond is σ; a double bond is σ + π; a triple bond is σ + 2π
8	**(d) A is false, but R is true.**	A is false: it is see-saw. R is true.
9	**Bond order = ½ (bonding electrons − antibonding electrons). The higher the bond order, the shorter and stronger (more stable) the bond. A bond order of zero means the molecule does not exist.**	—
10	**4 bond pairs, 0 lone pairs; tetrahedral**	4 electron pairs: sp^3
11	**$\sigma1s^2\ \sigma^*1s^2\ \sigma2s^2\ \sigma^*2s^2\ \sigma2pz^2\ \pi2px^2\ \pi2py^2\ \pi^*2px^1$; bond order 2.5; paramagnetic (1 unpaired)**	15 electrons
12	**$O_2^{2-} < O_2^- < N_2^+$**	bond orders: N_2^+ 2.5, O_2^- 1.5, O_2^{2-} 1; higher bond order means shorter, stronger bond
13	**sp^3, sp^3**	four single bonds: sp^3; one double bond: sp^2; a triple bond or two double bonds: sp
14	**$CH_4 > NH_3 > H_2O$**	NH_3 107°, H_2O 104.5°, CH_4 109.5°
15	**Each Ca (2, 8, 8, 2) loses 2 electrons to give Ca^{2+} (2, 8, 8); each S (2, 8, 6) gains 2 to give S^{2-} (2, 8, 8). One of each balances the charges: CaS.**	both ions reach a noble-gas configuration
16	**P–F (difference 1.9 against 0.6); δ− on F**	the larger the electronegativity difference, the more polar the bond; the more electronegative atom is δ−
17	**sp: one s + one p orbital give two hybrids at 180°: $BeCl_2$ is linear. sp^2: one s + two p give three hybrids at 120°: BF_3 is trigonal planar. sp^3: one s + three p give four hybrids at 109.5°: CH_4 is tetrahedral.**	—
18	**(a) He_2: $\sigma1s^2\ \sigma^*1s^2$; He_2^+: $\sigma1s^2\ \sigma^*1s^1$. (b) 0 and 0.5. (c) He_2 diamagnetic; He_2^+**	—

Q	Answer	Working
	paramagnetic (1 unpaired). (d) He_2^+ (higher bond order).	
19	**XeF_4: sp^3d^2, 4 bond pairs and 2 lone pairs, square planar, 90°, non-polar. CH_4: sp^3, 4 bond pairs and 0 lone pairs, tetrahedral, 109.5°, non-polar.**	—
20	**(a) 5σ and 1π; (b) sp^2, sp^2; (c) sp^2: 120°**	single bond σ; double σ + π; triple σ + 2π

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