Unit 5 · Chemical Bonding and Shapes of Molecules

ANSWER KEY · FOR TEACHERS

Full marks 33

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

K · 4

i. ✓ **True**
ii. ✗ **False**: In a coordinate covalent bond, both electrons of the shared pair come from one atom.
iii. ✓ **True**
iv. ✗ **False**: A pi bond is formed by the sideways overlap of two p orbitals; head-on overlap gives a sigma bond.
v. ✓ **True**
vi. ✗ **False**: The sp^3 hybrid orbitals point to the corners of a tetrahedron, 109.5° apart (sp^2 orbitals are 120° apart).
vii. ✗ **False**: A hydrogen bond forms when hydrogen is bonded to F, O or N, and is attracted to a lone pair on another such atom.
viii. ✓ **True**

Each carries 0.5 mark.

2 Label the diagram

U · 2

1. Na^+
2. O ends ($\delta-$) face Na^+
3. Cl^-
4. H ends ($\delta+$) face Cl^-

Each carries 0.5 mark.

3 Multiple choice

i. **b.** PCl_5 — K · 1

Phosphorus in PCl_5 has five bond pairs, 10 electrons round it. BF_3 has an incomplete octet (6 round boron); N in NH_3 and O in H_2O have octets.

ii. **a.** NO — K · 1

NO has $5 + 6 = \mathbf{11}$ valence electrons, an odd number, so one electron is unpaired and nitrogen can't have an octet. CO has 10, CO_2 16 and N_2 10.

iii. **b.** sp^2, 120° — U · 1

Boron has three bond pairs and no lone pair: three sp^2 hybrid orbitals in a plane, **120**° apart, so BF_3 is trigonal planar.

iv. **d.** CCl_4 — A · 1

CCl_4 is tetrahedral, with four equal C–Cl dipoles that cancel: $\mu = 0$. In CH_3Cl the one C–Cl dipole isn't canceled; NH_3 (pyramidal) and H_2O (bent) have dipoles that add up.

v. **c.** 2 sigma, 2 pi — A · 1

Each double bond is one sigma bond and one pi bond. Two C=O double bonds: $\mathbf{2}\,\sigma + \mathbf{2}\,\pi$.

4 Short answers

a. MARKING SCHEME — U · 2

✓ Four pairs round oxygen, two of them lone pairs.
✓ Lone pairs repel more than bond pairs and squeeze the bond angle to 104.5°.

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b. MARKING SCHEME U · 2

- ✓ Ethanol's O–H group forms hydrogen bonds with water.
- ✓ Ethane is non-polar and can't hydrogen bond, so it doesn't dissolve.

c. MARKING SCHEME A · 3

- ✓ The Lewis structure: three O–H bonds and one lone pair on oxygen.
- ✓ The bond to the added H^+ is the coordinate bond, both electrons from oxygen.
- ✓ Formal charge on O = +1.

5 Long answer

ANSWER U · 4

Hybridization is the mixing of atomic orbitals of nearly the same energy on one atom to give the same number of new, identical **hybrid orbitals**.

Carbon's ground state is $1s^2\ 2s^2\ 2p^2$, with only two unpaired electrons. One 2s electron moves up into the empty 2p orbital (the excited state $2s^1\ 2p^3$), giving four unpaired electrons.

The 2s and the three 2p orbitals mix into **four sp^3 hybrid orbitals**, each with one electron, of equal energy.

They point to the corners of a regular **tetrahedron**, as far apart as possible, at **109.5**°. Each overlaps head-on with the 1s orbital of a hydrogen atom, giving four equal C–H **sigma bonds**: methane is tetrahedral, with H–C–H angles of 109.5°.

MARKING SCHEME

- ✓ Hybridization defined.
- ✓ Ground state to excited state: four unpaired electrons.
- ✓ 2s + three 2p → four equal sp^3 orbitals.
- ✓ Tetrahedral, 109.5°, four C–H σ bonds by overlap with H 1s.

6 Numerical problems

a. ANSWER A · 4

i. HF: $\mu = e \times d = 1.602 \times 10^{-19} \times 92 \times 10^{-12} = 1.474 \times 10^{-29}$ C m = **4.42 D**.

HBr: $1.602 \times 10^{-19} \times 141 \times 10^{-12} = 2.259 \times 10^{-29}$ C m = **6.77 D**.

ii. HF: 1.82 ÷ 4.42 × 100 = **41%**. HBr: 0.80 ÷ 6.77 × 100 = **12%**.

iii. **H–F** is more ionic: its electronegativity difference, 4.0 − 2.2 = 1.8, is larger than H–Br's, 3.0 − 2.2 = 0.8.

MARKING SCHEME

- ✓ Completely ionic dipoles 4.42 D and 6.77 D.
- ✓ HF 41% ionic.
- ✓ HBr 12% ionic.
- ✓ H–F more ionic, with $\Delta\chi$ 1.8 against 0.8.

b. ANSWER A · 4

i. Sigma: 3 C–H, one in C=C, one C–C, one in C≡N: **6** σ. Pi: one in C=C and two in C≡N: **3** π.

The CH_2 and CH carbons (each with a double bond) are **sp^2**; the carbon of C≡N is **sp**.

ii. Carbon: 4 − 2 − ½ × 6 = **−1**. Oxygen: 6 − 2 − ½ × 6 = **+1**. They add up to 0, the charge of the molecule.

MARKING SCHEME

- ✓ 6 σ bonds.
- ✓ 3 π bonds.
- ✓ sp^2, sp^2, sp.
- ✓ Formal charges C −1, O +1.

7 Think

ANSWER

No. Melting or boiling a molecular substance separates **whole molecules**: it overcomes the weak forces **between** molecules, not the covalent bond inside each X_2, which stays whole.

Between non-polar molecules the forces are **London (van der Waals) forces**. They grow with the

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size of the molecule, its number of electrons: I_2 is far larger than F_2, so its molecules hold each other more strongly, and it needs more energy to separate them: solid at room temperature.

MARKING SCHEME

- ✓ Melting and boiling overcome forces between molecules, not covalent bonds.
- ✓ The forces between non-polar molecules are London (van der Waals) forces.
- ✓ They grow with molecular size (electrons), so $I_2 > Br_2 > Cl_2 > F_2$.

8 Activity: Balloon shapes

(not marked)

WHAT STUDENTS SHOULD FIND

Two balloons point in opposite directions, in a straight line (180°, like $BeCl_2$ or CO_2); three spread flat in a triangle (120°, like BF_3); four point to the corners of a tetrahedron (109.5°, like CH_4), not a flat square. Each balloon pushes the others away and takes as much room as it can, so they settle as far apart as possible, just as VSEPR theory says the electron pairs round a central atom do.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	6	11	13	3	**33**

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