1.) Supply the missing names or formulas:
   a. aluminum sulfite \( Al_2(SO_3)_3 \)
   b. chlorous acid \( HClO_2 \)
   c. AuBr_3 gold(III) bromide
   d. \( N_2O_3 \) dinitrogen trioxide

2.) A compound contains only C, H and N. Combustion of 2.103 mg of the compound produced 5.840 mg CO_2 and 1.200 mg H_2O. What is the empirical formula of the compound?

   \[
   \begin{align*}
   \text{mass of C:} & \quad 5.84 \text{ mg CO}_2 \times \frac{1 \text{ mmol CO}_2}{44 \text{ mg CO}_2} \times \frac{1 \text{ mmol C}}{1 \text{ mmol CO}_2} = 0.134 \text{ mg C} \\
   \text{mass of H:} & \quad 1.20 \text{ mg H}_2\text{O} \times \frac{1 \text{ mmol H}_2\text{O}}{18.0 \text{ mg H}_2\text{O}} \times \frac{2 \text{ mmol H}}{1 \text{ mmol H}_2\text{O}} = 0.134 \text{ mg H} \\
   \text{mass of N:} & \quad \text{difference between “total” and “C” and “H”}. \\
   & \quad 2.10 \text{ mg} - (1.60 \text{ mg} + 0.134 \text{ mg}) = 0.375 \text{ mg N}
   \end{align*}
   \]

   \[
   \begin{array}{c|c|c|c}
   \text{mass (g)} & \text{mmoles} & \text{divide by} & \text{nearest integer ratio} \\
   \hline
   \text{C} & 1.60 & 0.133 & 5.0 \\
   \text{H} & 0.134 & 0.133 & 5.0 \\
   \text{N} & 0.375 & 0.0268 & 1 \\
   \end{array}
   \]

   \[
   \therefore \ C_5H_5N
   \]

3.) Hydrogen cyanide is produced industrially from the reaction of gaseous ammonia, oxygen and methane:

\[
2 \text{NH}_3(\text{g}) + 3 \text{O}_2(\text{g}) + 2 \text{CH}_4(\text{g}) \rightarrow 2 \text{HCN}(\text{g}) + 6 \text{H}_2\text{O}(\text{g})
\]

If 120 kg of ammonia, 300 kg of oxygen and 150 kg of methane were used, calculate the amount (in kg) of hydrogen cyanide produced assuming the reaction efficiency is 80%.

Use the following molar masses: \( \text{NH}_3 = 17.031 \text{ g/mol} \), \( \text{O}_2 = 32.000 \text{ g/mol} \), \( \text{CH}_4 = 16.043 \text{ g/mol} \), \( \text{HCN} = 27.026 \text{ g/mol} \), \( \text{H}_2\text{O} = 18.016 \text{ g/mol} \)

Determine amt of product from each reactant:

\[
\begin{align*}
120 \text{ kg NH}_3 & \times \frac{1 \text{ kmol NH}_3}{17.0 \text{ kg NH}_3} \times \frac{2 \text{ kmol HCN}}{2 \text{ kmol NH}_3} = 7.05 \text{ kmol HCN} \\
300 \text{ kg O}_2 & \times \frac{1 \text{ kmol O}_2}{32.0 \text{ kg O}_2} \times \frac{2 \text{ kmol HCN}}{3 \text{ kmol O}_2} = 6.25 \text{ kmol HCN} \\
150 \text{ kg NH}_3 & \times \frac{1 \text{ kmol CH}_4}{16.0 \text{ kg CH}_4} \times \frac{2 \text{ kmol HCN}}{2 \text{ kmol CH}_4} = 9.35 \text{ kmol HCN}
\end{align*}
\]

\( \text{O}_2 \) is L.R. (limiting reactant), since it produces the least amt of product.

Actual yield:

\[
6.25 \text{ kmol HCN} \times \frac{27.0 \text{ kg HCN}}{1 \text{ kmol HCN}} \times 0.8 = 135 \text{ kg HCN}
\]

from 80% yield
4.) Draw the correct Lewis dot structure and indicate the expected geometry around each central atom. To receive full marks, indicate the number of valence electrons, the number of unshared electrons and formal charges for each atom. If necessary, draw resonance structures.

a. HCO$^-$

\[ N_v = 1 + 4 + (3 \times 6) + 1 = 24 \]

\[ N_u = 26, \text{must remove } 2 \text{e'}s \]

Total # of lone pairs (= unshared e' s ) in the most reasonable resonance structures = 7

Geometry acc. to VSEPR:
on C : 3 e’ groups; therefore, trigonal planar e’ and atom arrangement
on O carrying the H: 4 e’ groups; therefore, tetrahedral e’ arrangement and bent atom arrangement.

b. Briefly explain why the HOH bond angle in water is smaller than the HNH bond angle in ammonia. Indicate which theory you are basing your explanation on.

Lone pairs (LP) require more space than bonding pairs (BP) and will “squeeze” the bonding angle.

H$_2$O has 2 LP’s, while NH$_3$ has only 1 LP.

Consequently, the bonding angle in H$_2$O is somewhat smaller.

5.) a. Write the electron configuration for tin.

[Kr] 5s$^2$4d$^10$5p$^2$

b. Give the maximum number of e’ s in an atom that can have these quantum numbers:

\[ n = 5 \text{ and } m_l = +2 \]

OK, the question is somewhat ambiguous. Let’s reword it:

We deal with an atom that has all orbitals up to $n = 5$ occupied with e’ s.

6.) a. Give/Explain in your words: Hund’s rule.

In general, if orbitals are degenerate (have same energy) they will be filled singly first (with spin aligned in the same direction) before being filled doubly.

b. Explain the bonding and hybridization in CO$_2$.

Using Lewis theory we find

\[ \cdot\cdot\cdot C\equiv O\cdot\cdot\cdot \]

Acc. to VSEPR there are 2 e’ groups on C; therefore we get linear electron and atom arrangement around C.

Acc to VB theory, C is sp hybridized leaving 2 unhybridized p AO’s.
The sp orbitals form $\sigma$ bonds while the p orbitals form $\pi$ bonds
No hybridization on the terminal O’s.
Therefore, each C,O double bond consists of a (sp,p)$\sigma$ bond and a (p,p)$\pi$ bond.
7.) Consider the acetylide anion, \( \text{C}_2^2^- \), and analyze it by various bonding theories.

a. Derive its Lewis structure.

\[
N_t = (2 \times 4) + 2 = 10
\]

\[
N_e = 14 \text{ from CC}
\]

remove 4 e\(^-\)'s; try to obey octet rule

\[
\text{C} = \text{C} \quad \rightarrow \quad \text{C} = \text{C} \quad \Phi \quad \Phi
\]

b. What are the number of e\(^-\) groups around each C?

2 ; a triple bond and a lone pair

c. Are there any formal charges? If so, where?

yes, as indicated under a.

d. Describe the bonding acc. to the VB theory.

There are two possibilities: with and without hybridization. Try your hands at both.

i. If we allow hybridization, we would say that the C atoms are sp hybridized.

Consequently, the C atoms are bound by a (sp,sp)\( \sigma \) bond and 2 (p,p)\( \pi \) bonds.

The lone pairs occupy sp hybrid orbitals.

ii. If we consider the C atoms terminal and don’t allow hybridization,

we form a (p,p)\( \sigma \) bond and two (p,p)\( \pi \) bonds.

The lone pairs would be located in unhybridized s orbitals.

We don’t commit here; in an exam I would allow both answers.

e. Sketch the MO energy diagram, label the energy levels and indicate their occupation by e\(^-\)'s.

\[\text{MO energy diagram}
\]

f. Assess magnetic properties by MO theory.

All e\(^-\)'s are paired; therefore, the anion is diamagnetic.

8.) Application of MO theory. For the following species sketch those bonding MO’s that are not cancelled by antibonding orbitals,

a. \( \text{Li}_2 \)    b. \( \text{C}_2^2^- \)

a.) In \( \text{Li}_2 \), a \( \sigma \) MO is formed from 2 originating 2s AO’s.

This looks similar to the \( \sigma \) MO in \( \text{H}_2 \).

b.) In \( \text{C}_2^2^- \), the relevant bonding MO’s are \( \sigma_{2p_z}, \pi_{2px} \), and \( \pi_{2py} \).

If we align, the C,C bond with the z axis; then the MO’s look roughly as shown below.

\[\text{MO diagrams for Li}_2 \text{ and C}_2^2^-\]
9.) a. Indicate formal charges on the following structures.

\[ \text{b.) and c.) are related by resonance. Explain.} \]

b.) and c.) are related by resonance. The connectivities are the same; only the location of e⁻'s has changed: bonding e⁻'s have become lone pairs and v.v.
In a.) the connectivity (atom skeleton) is clearly different; e.g., the left hand C in a.) is connected to 2 H's, while in b.) it is connected to 3 H's.

c. Which of those related by resonance contributes most to the resonance hybrid?

In both structures we have octets everywhere and both have one F.C. = -1.
In c.) the neg. charge is located on the more e/n atom, so we expect this structure to contribute more.