1. (5) Name each of the following:

\[ [\text{Co}(en)_2(CN)_2]\text{ClO}_3 \text{ dicyno bis(ethylenediamine)cobalt(III) chlorate} \]

\[ K_4[\text{Co}(CN)_6] \text{ potassium hexacyanocobaltate (II)} \]

\[ [\text{Ni}(NH_3)_6][\text{Co(NO}_2)_6]_2 \text{ hexammine nickel(II) hexanitro cobaltate(III)} \]

Write formulas for the following compounds or ions:

**bis(ethylenediamine)nickel(II) ion**

\[ N_i(\text{en})^2^{\text{2+}} \]

**bromochlorotetraamminechromium(III) sulfate**

\[ \left[\text{CrBrCl(NH}_3)_4\right]_2\text{SO}_4 \]

2. (2) The complex ion \([\text{M(CN)}(\text{NO}_2)(\text{H}_2\text{O})(\text{NH}_3)]^+\) was found to be optically active. What does this finding signify about the coordination sphere?

- **be tetrahedral**
- may be **square planar**

3. (3) A solution of \([\text{Ni}(\text{H}_2\text{O})_6]^{2+}\) is green, but a solution of \([\text{Ni(CN)}_4]^{2+}\) is colorless. Suggest an explanation for these observations.

- \(\text{CN}^-\) increases \(\Delta_D\) (ligand field splitting) to u.v. range.
- \([\text{Ni}(\text{H}_2\text{O})_6]^{2+}\)
- \([\text{Ni(CN)}_4]^{2+}\)
- \(\Delta_D\) less
- **square planar**
4. (5) Classify each the following molecules and ions into its respective point group.

1. POCl$_3$  — $C_3v$
2. CBr$_4$  — $T_d$
3. CO$_2$  — $D_{2d}$
4. PF$_5$  — $D_3h$
5. CH$_2$Cl$_2$  — $C_{2v}$

5. (15) Find the number and symmetry species of the Raman and infrared active vibrations of boron trichloride ($D_{3h}$).

\[
\begin{array}{c|cccc|ccc}
D_{3h} & E & 2C_3 & 3C_2 & 3\sigma_v & 3\sigma_v \\
12 & 0 & -2 & 4 & -2 & 2 \\
\end{array}
\]

\[\Gamma \rightarrow A_1^1 + A_2^1 + 3E^1 + 2A_2^2 + E^2\]

\[\Gamma_{rot} = A_2^1 + E^2\]

\[\Gamma_{trans} = E^1 + A_2^1\]

\[\Gamma_{vib} = A_1^1 + 2E^1 + A_2^2\]

\[IR = 2E^1 + A_2^2\]

\[Raman = A_1^1 + 2E^1\]

6. (15) Sketch the energy levels and the molecular orbitals for the H$_3^+$ ion, using linear geometry. Include symmetry labels for the orbitals.
7. (20) The compounds Ru(CO)\(_3\)(P\(\Phi\)_3)_2, Fe(CO)\(_3\)(P\(\Phi\)_2)_2, Ru(CO)\(_3\)(As\(\Phi\)_3)_2, (\(\Phi\) = phenyl) each exhibit just a single ir active CO stretching mode. Six plausible structures for these compounds are drawn below, in which dark circles indicate CO ligands. How many ir and Raman bands are expected in the carbonyl-stretching region for each structure? With which structure is the spectrum consistent?

<table>
<thead>
<tr>
<th>Ir Active</th>
<th>C(_5)</th>
<th>C(_{2v})</th>
<th>C(_5)</th>
<th>D(_{3h})</th>
<th>C(_{2v})</th>
<th>C(_5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raman</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

↑ must be the structure IR consistent with this structure

8. (15) Propose a molecular orbital scheme for the pi electrons of allene, H\(_2\)C=C=CH\(_2\), (D\(_{2d}\)). Indicate the symmetry of bonding and non-bonding orbitals.

\[
\begin{array}{c|ccccc}
\hline
\text{D}_{2d} & E & 2\sigma_1 & C_2 & 2\sigma_1^\prime & 2\pi_d \\
\hline
4\text{C}(2p) & 4 & 0 & -4 & 0 & 0 \Rightarrow 2e \\
\hline
\end{array}
\]

\[
\begin{array}{cccc}
\rho & e & \rho & \quad \Rightarrow 2e \\
\rho & e & \rho & \quad \Rightarrow 1e \\
\end{array}
\]
9. (10) What molecular state of $O_2^+$ is produced by the lowest energy ionization of $O_2$ ($^3\Sigma_g^+$)?

$^3\Sigma_g^-\ O_2$ configuration is .... $(1\Pi_g)^2$

Lowest energy ionization yields ... $(1\Pi_g)^1 \Rightarrow ^2\Pi_g$ state

$^1\Delta_g\ O_2$ has same configuration as $^3\Sigma_g^- (O_2)$

10. (10) What molecular state of $O_2^+$ is produced by the lowest energy ionization of $O_2$ ($^1\Delta_g$)?

Since $^1\Delta_g\ O_2$ has same configuration as $^3\Sigma_g^-\ O_2$, it yields the same excited state $\Rightarrow ^2\Pi_g$. 