1) What is the Russell-Saunders ground state for the following electron configurations?
   a) \( p^4 \) \( ^3P \)
   b) \( p^2 \) \( ^3P \)
   c) \( f^8 \) \( ^7F \)
   d) \( f^{12} \) \( ^3H \)

2) How would the ground state Russell-Saunders term for 1b be split in a square planar environment? Same as the \( p \) orbitals so into a doubly degenerate set (like \( p_x \) and \( p_y \)) and a singly degenerate set (like \( p_z \)). In other words into \( ^3E \) and \( ^3A \) terms.

3) Write all the microstates arising from a \( p^2 \) electron configuration in order to determine all the Russell-Saunders terms, not just the ground state.

   The table of microstates (partial) is as follows; we are expecting \( 6 \times 5/2 = 15 \) microstates so this checks correctly when we include the \( M_L = -1 \) and \( M_L = -2 \) cells.

   \[
   \begin{array}{c|ccc}
   \text{MS} \rightarrow & 1 & 0 & -1 \\
   \text{ML} \downarrow & \text{} & \text{1+ 1-} & \text{} \\
   2 & (1+ 1-) & \text{} & \text{} \\
   1 & (1+ 0+) & (1+ 0-) & (1- 0-) \\
   & (1- 0+) & \text{} & \text{} \\
   0 & (1+ -1+) & 1+ & (1- -1-) \\
   & (0+ 0-) & \text{} & \text{} \\
   \end{array}
   \]

   From this you should get \(^1D\), \(^3P\) and \(^1S\) terms with \(^3P\) being the ground state. Note this correctly matches the total degeneracy: \( 1D = (1)(5) = 5; \) \( 3P = (3)(3) = 9; \) \( 1S = (1)(1) = 1 \) for total of \( 5 + 9 + 1 = 15 \) microstates.

4) What is the total degeneracy of a \(^4G\) Russell-Saunders term? For \( G, L = 4 \) so
   \[
   (2S+1)(2L+1) = 4[(2)(4)+1] = 36
   \]
5) How many $f \rightarrow f$ electronic transitions will there be for an $f^1$ ion in an octahedral crystal field? Indicate what these transitions will be (like $^{2}T_{2g} \rightarrow ^{5}E_{g}$, for example).

An $f^1$ ion will have a $^{2}F$ ground state and will split like $f$ orbitals into a $T$, $T$, and $A$ set so transitions would be expected between $^{2}T$ and the other $^{2}T$ and $^{2}A$ states for a total of two transitions. This is the only Russell-Saunders term for an $f^1$ ion (check degeneracy = $2 \times 7 = 14$ which matches the number of possible ways one electron can be placed in the 7 $f$ orbitals) so no other transitions are possible.

6) Explain why $[\text{FeF}_6]^{3-}$ is colourless while $[\text{CoF}_6]^{3-}$ is coloured but shows only one band in the visible region.

High spin Fe$^{3+}$ is likely with a weak field ligand like F so this is a high spin $d^5$ ion and no $d \rightarrow d$ transitions are possible from the $^6S$ ground state because there are no other sextet states possible. In the case of Co$^{3+}$, this is a high spin $d^6$ ion and the $^4D$ ground state is split into $^4E_g$ and $^4T_{2g}$ states by the $O_h$ crystal field. The only spin allowed transition will be between these states because there are no other Russell-Saunders quartet terms.

7) Theoretically $[\text{Cr(OH}_2)_6]^{2+}$ should only show one $d \rightarrow d$ transition in the visible. However close inspection of the broad visible absorption suggests there is at least two and possibly as many as four, closely overlapping bands. Use your knowledge of crystal field theory to explain this observation.

This is an octahedral high spin $d^4$ ion so a Jahn-Teller distortion is expected. This will split the $^5D$ ground state into more than just $^5E_g$ and $^5T_{2g}$. In fact, both the $^5E_g$ and $^5T_{2g}$ levels will split into two levels each (one doubly degenerate for the $T_{2g}$) giving rise to 4 levels total. Transitions between these levels will probably overlap (at least the higher energy transitions will) but more than one band is expected.
8) Suggest a reason why \( \text{Fe(CO)}_5 \) is colourless while \( \text{Fe(bipy)(CO)}_3 \) is intensely purple in colour.

The intense colour of the latter complex is strongly suggestive of a charge transfer transition and since the metal is already fully reduced (zero oxidation state), it is highly likely that this involves a MLCT transition. The \( \pi^* \) levels of the bipy or CO ligands are possible acceptors but the fact that \( \text{Fe(CO)}_5 \) doesn’t show this colour suggests that it is the bipy \( \pi^* \) levels that are involved in \( \text{Fe(bipy)(CO)}_3 \). Since there should be MLCT transitions to the CO \( \pi^* \) levels as well, we assume that the lack of colour for \( \text{Fe(CO)}_5 \) means that these transitions fall in the UV rather than the visible.