Acknowledge your group members by noting their names on your problem set when you hand it in. Answer all questions using your own words. Show all your work by outlining your reasoning in a clear and concise manner.

1) Determine the symmetry elements of:
   a) an s-orbital
   b) a p orbital
   c) a d$_{xy}$ orbital
   d) a d$_{z^2}$ orbital

2) In the last problem set we determined the point group of the molecule SF$_4$ of the conformation shown in I. Depending on the location of the lone pair electrons the molecule may actually exist in a pyramidal or a "seesaw" structure derived from the trigonal bipyramid. The seesaw results from placing the lone pair at one of the equatorial sites as seen in I, whereas the pyramidal structure is generated by placement of the lone pair at one of the axial sites, as shown in II.

   ![Chemical structures](image)

   a) What is the point group of the conformation shown in II?
   b) For each structure, work out the number of S-F stretching modes that are infrared active. Identify the irreducible representations to which these vibrations belong. Could the infrared spectrum of SF$_4$, in principle, distinguish between these two possible structures?
   c) Repeat this analysis to determine the vibrational stretching modes that are Raman active.

   --OVER--
3) Consider the molecule of B$_2$F$_4$ (containing a B-B bond) whose structure may fall into one of the point groups D$_{2h}$ or D$_{2d}$.
   a) Draw clear diagrams that show the structure of the molecule in each of these point groups.
   b) Could infrared and Raman spectroscopy help distinguish between these possible structures?

4) From x-ray diffraction data, the carbonate ion, CO$_3^{2-}$, has a trigonal planar geometry with identical carbon oxygen bond lengths corresponding to D$_{3h}$ symmetry. Use the D$_{3h}$ character table to determine the number of carbon-oxygen stretching vibrations expected to be observed in the IR and Raman spectrum of the carbonate ion.