SYMMETRY ELEMENTS

We encounter symmetry in our everyday life. Flowers, diamonds and cut stones, and even insects are highly symmetrical. An object is said to have symmetry *if two or more orientations in space are indistinguishable*. A glass without markings sitting on a table can be rotated to an infinite number of indistinguishable different positions. We decide if two orientations are indistinguishable on the basis of *symmetry elements* and symmetry operations.

A symmetry operation moves an object about an axis, a point, or a plane into a position that is indistinguishable from the original position. A symmetry element is the **axis**, **point**, or **plane** about which the object is moved. A square piece of blank paper (■) can be rotated (the symmetry operation) to four different indistinguishable orientations about an imaginary axis (the symmetry element) perpendicular to the plane of the paper.

The mirror plane (a plane of symmetry). If you hold your right hand in front of a mirror, you will see your left hand in the mirror at a distance that corresponds exactly to the distance your right hand is in front of the mirror. If you fold a blank 8.5" x 11" sheet of paper down the middle, then lay it flat, the crease represents a mirror plane perpendicular to the page. Every point to the right of the crease would have a corresponding indistinguishable point to the left the crease if you were to look into the perpendicular mirror on the crease. The letters **A** and **V** have mirror planes (|) which bisect them perpendicular to the page. Similarly, your right glove is a mirror image of your left glove; your right shoe is a mirror image of your left shoe.

From VSEPR we know the molecule H_2O is V-shaped. This V-shaped molecule has two mirror planes, one plane that bisects the H-O-H angle and a second perpendicular plane that slices through the two H atoms and the O atom.

Axis of rotation. Rotating an object by 360°, or $2\pi/1$, is equivalent to not rotating it at all, since this rotation put the object back into its original position. The rotation axis about which the object is rotated is called a **C_1 axis**, the **1** comes from $2\pi/\mathbf{1}$. If we rotate a blank 8.5" x 11" piece of paper 180°, or $2\pi/2$, about an axis that goes through the exact center of the page and is $\perp$ to the plane of the paper, we obtain an indistinguishable orientation. We call this rotation axis a **C_2 axis**. The letter **A** has one **C_2 axis**, ↓, in the plane of the paper; the number **0** has three **C_2 axes**, two in the plane of the page, one ↓ and the other →, and the third $\perp$ to the page. The planar symbol ■ has four **C_2 axis**, one ↓, one →, one ↗ and one ↖, and one **C_4 axis** with a coincident C_2 axis that is $\perp$ to the plane of the paper. The V-shaped H_2O molecule has one C_2 axis and two planes of symmetry coincident with the axis. The pyramidal molecule NH_3 has one **C_3 axis** and three mirror planes coincident with the C_3 axis.

Center of symmetry. A molecule (or object) has a center of symmetry if it is possible to move in a straight line from every atom in it through a single point (the center) to an identical atom at the same distance on the other side of the center. The letters O, H, I, S and X have centers of symmetry, but letters A, C, and D, among others, do not. The molecules H_2O and NH_3 and tetrahedral CH_4 do not have a center of symmetry, but linear CO_2 (O=C=O), square planar XeF_4 and octahedral SF_6 do.