

## 1.4: Symmetry and Physical Properties

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Carrying out a symmetry operation on a molecule must not change any of its physical properties. It turns out that this has some interesting consequences, allowing us to predict whether or not a molecule may be chiral or polar on the basis of its point group.

### Polarity

For a molecule to have a permanent dipole moment, it must have an asymmetric charge distribution. The point group of the molecule not only determines whether the molecule may have a dipole moment, but also in which direction(s) it may point.

If a molecule has a  $C_n$  axis with  $n > 1$ , it **cannot** have a dipole moment perpendicular to the axis of rotation (for example, a  $C_2$  rotation would interchange the ends of such a dipole moment and reverse the polarity, which is not allowed – rotations with higher values of  $n$  would also change the direction in which the dipole points). Any dipole must lie parallel to a  $C_n$  axis.

Also, if the point group of the molecule contains any symmetry operation that would interchange the two ends of the molecule, such as a  $\sigma_h$  mirror plane or a  $C_2$  rotation perpendicular to the principal axis, then there cannot be a dipole moment along the axis.

The only groups compatible with a dipole moment are  $C_n$ ,  $C_{nv}$  and  $C_s$ . In molecules belonging to  $C_n$  or  $C_{nv}$  the dipole must lie along the axis of rotation.

### Chirality

One example of symmetry in chemistry that you will already have come across is found in the isomeric pairs of molecules called enantiomers. Enantiomers are non-superimposable mirror images of each other, and one consequence of this symmetrical relationship is that they rotate the plane of polarized light passing through them in opposite directions. Such molecules are said to be chiral,<sup>2</sup> meaning that they cannot be superimposed on their mirror image. Formally, the symmetry element that precludes a molecule from being chiral is a rotation-reflection axis  $S_n$ . Such an axis is often implied by other symmetry elements present in a group.

For example, a point group that has  $C_n$  and  $\sigma_h$  as elements will also have  $S_n$ . Similarly, a center of inversion is equivalent to  $S_2$ . As a rule of thumb, a molecule definitely cannot have be chiral if it has a center of inversion or a mirror plane of any type ( $\sigma_h$ ,  $\sigma_v$  or  $\sigma_d$ ), but if these symmetry elements are absent the molecule should be checked carefully for an  $S_n$  axis before it is assumed to be chiral.

<sup>2</sup> The word *chiral* has its origins in the Greek word for hand ( $\chi\epsilon\rho\iota$ , pronounced 'cheri' with a soft ch as in 'loch'). A pair of hands is also a pair of non-superimposable mirror images, and you will often hear chirality referred to as 'handedness' for this reason.

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