

Structure – Property Relationships

Why is a particular drug effective? Why is a certain chemical toxic? Why does a particular pesticide not break down in the environment? Why does a bullet-proof vest work the way it does? The answer to all of these questions is that the structure of the molecules comprising these materials determines the properties that the materials have.

“**Structure Determines Properties**” is a powerful concept in chemistry and in all fields in which chemistry is important including, but not limited to, environmental science, biology, biochemistry, polymer science, medicine, engineering, and nutrition.

What is meant by structure? How does one describe the structure of a molecule? This can be done at various levels of sophistication.

- The molecular formula, e.g., $C_{12}H_{17}ClNO_3$, tells us which elements are present and in what ratio.
- The relative overall size and 3-dimensional shape, known as the steric properties, give additional detail.
- Functional groups in the molecule indicate electrostatic properties (Polarity, Hydrogen Bonding).
- A description of chirality is necessary to account for the spatial relationship of the atoms.
- A further piece of information at a still higher level of sophistication would be the heat of formation.
- To be precise, a description of the exact structure would require defining the exact positions of all atoms in the molecule.

Simple molecular model kits and molecular modeling software are very helpful in visualizing the structure of a molecule. High-level calculations can accurately describe structures. Experimental methods of studying structure include spectroscopy such as NMR spectroscopy and X-ray crystallography, which can define the exact positions of the atoms in a molecule.

What is meant by properties? These fall into three general categories.

- Chemical (e.g., reaction rates, position of equilibria). Why does an S_N2 reaction occur well on a primary center but not at all on a tertiary center? Answer: steric effects. Why is trichloroacetic acid 10,000 times more acidic than acetic acid? Answer: electrostatic or polar effects.
- Physical (e.g., melting points, boiling points, solubility, spectra) Compare dimethyl ether, CH_3-O-CH_3 (BP -24°) and its isomer, ethanol, CH_3CH_2-OH (BP 78°). Structure determines the boiling points. The molecules of alcohol, having the ability to H-bond, attract

one another with stronger forces (H-bonds) than do the molecules of ether, which only have normal dipole-dipole forces holding them together.

- Biological (e.g., odor, color, taste, drug action, toxicity) Why does vanilla taste so different than chocolate? Why do we perceive the color of a banana as yellow and an orange as orange? Different molecules, because of their structures fit differently into the biological receptors present in living systems, consequently causing different neural responses.

(Note that biological properties are actually a subset of chemical properties, in which at least one of the interacting chemicals is a biological chemical such as an enzyme.)

Why is chirality such an important structural characteristic? As an example, compare the enantiomers of thalidomide. Thalidomide was used as an anti-nausea medication for pregnant women in the 1950's in Europe. The drug was a mixture of the two enantiomers. Severe birth defects resulted. It turns out that one enantiomer is an effective antidepressant while the other is teratogenic (causes birth defects). Why might this be? The biologically active sites in living systems are chiral themselves. Thus, enantiomers fit differently into those sites and consequently have different biological effects.

