Objectives

After completing this section, you should be able to

1. use molecular models to show that only a tetrahedral carbon atom satisfactorily accounts for the lack of isomerism in molecules of the type CH₂XY, and for the existence of optical isomerism in molecules of the type CHXYZ.

2. determine whether two differently oriented wedge-and-broken-line structures are identical or represent a pair of enantiomers.

Key Terms

Make certain that you can define, and use in context, the key term below.

- enantiomer

Study Notes

Stereoisomers are isomers that differ in spatial arrangement of atoms, rather than order of atomic connectivity. One of the most interesting types of isomer is the mirror-image stereoisomer, a non-superimposable set of two molecules that are mirror images of one another. The existence of these molecules are determined by a concept known as chirality. The word "chiral" was derived from the Greek word for hand, because our hands are a good example of chirality since they are non-superimposable mirror images of each other.

Introduction

The opposite of chiral is achiral. Achiral objects are superimposable with their mirror images. If the molecules are superimposable, they are identical to each other. For example, two pieces of paper are achiral. In contrast, chiral objects, like our hands, are non-superimposable mirror images of each other. Try to line up your left hand perfectly with your right hand, so that the palms are both facing in the same directions. Spend about a minute doing this. Do you see that they cannot line up exactly?
The same thing applies to some molecules. A chiral molecule has a mirror image that cannot line up with it perfectly - the mirror images are non-superimposable. This pair of non-superimposable mirror image molecules are called enantiomers. But why are chiral molecules so interesting? Just like your left hand will not fit properly in your right glove, one of the enantiomers of a molecule may not work the same way in your body, as the other. It turns out that many of the biological molecules such as our DNA, amino acids and sugars, are chiral molecules.

This must mean that enantiomers have properties that make them different from their mirror image molecule. One of these properties is that chiral molecules do not have a plane of symmetry or an internal mirror plane. So, a chiral molecule cannot be divided into two identical halves. Another property of chiral molecules is optical activity.

Organic compounds, molecules created around a chain of carbon atoms (more commonly known as the carbon backbone), play an essential role in the chemistry of life. These molecules derive their importance from the energy they carry, mainly in a form of potential energy. Since potential energy can be widely affected due to changes in atomic placement, it is important to understand the concept of an isomer, a molecule sharing the same atomic connectivity as another but differing in structural arrangements. This section is devoted to a specific type of isomer called stereoisomers and their property of chirality (Figure 5.1.1).

**Figure 5.1.1. Two enantiomers of a tetrahedral complex. Image used with permission from Wikipedia**

The concepts of stereoisomerism and chirality command great deal of importance in modern organic chemistry, as these ideas help to explain the physical and theoretical reasons behind the formation and structures of numerous organic molecules, the main reason behind the energy embedded in these essential chemicals. In contrast to more well-known
constitutional isomerism, which develops isotopic compounds simply by different atomic connectivity, stereoisomerism generally maintains equal atomic connections and orders of building blocks as well as having same numbers of atoms and types of elements.

What, then, makes stereoisomers so unique? To answer this question, the learner must be able to think and imagine in not just two-dimensional images, but also three-dimensional space. This is due to the fact that stereoisomers are isomers because their atoms are different from others in terms of spatial arrangement.

Spatial Arrangement

First and foremost, one must understand the concept of spatial arrangement in order to understand stereoisomerism and chirality. Spatial arrangement of atoms concern how different atomic particles and molecules are situated about in the space around the organic compound, namely its carbon chain. In this sense, spatial arrangement of an organic molecule are different another if an atom is shifted in any three-dimensional direction by even one degree. This opens up a very broad possibility of different molecules, each with their unique placement of atoms in three-dimensional space.

Stereoisomers

Stereoisomers are, as mentioned above, contain different types of isomers within itself, each with distinct characteristics that further separate each other as different chemical entities having different properties. Type called entaniomer are the previously-mentioned mirror-image stereoisomers, and will be explained in detail in this article. Another type, diastereomer, has different properties and will be introduced afterwards.

Enantiomers

This type of stereoisomer is the essential mirror-image, non-superimposable type of stereoisomer introduced in the beginning of the article. Figure 5.1.2 provides a perfect example; note that the gray plane in the middle denotes the mirror plane between the two molecules.
Figure 5.1.2.

Note that even if one were to flip the left molecule over to the right, the atomic spatial arrangement will not be equal. This is equivalent to the left hand - right hand relationship, and is aptly referred to as 'handedness' in molecules. This can be somewhat counter-intuitive, so this article recommends the reader try the 'hand' example. Place your hands next to each other with the palms facing up. Now flip either side over to the other. One hand should be showing the back of the hand, while the other one is showing the palm. They are not same and non-superimposable. This is where the concept of chirality comes in as one of the most essential and defining idea of stereoisomerism.

**Chirality**

*Chirality* essentially means 'mirror-image, non-superimposable molecules', and to say that a molecule is chiral is to say that its mirror image (it must have one) is not the same as itself. Whether a molecule is chiral or achiral depends upon a certain set of overlapping conditions. Figure 5.1.1 shows an example of two molecules, chiral and achiral, respectively. Notice the distinct characteristic of the achiral molecule: it possesses two atoms of same element. In theory and reality, if one were to create a plane that runs through the other two atoms, they will be able to create what is known as bisecting plane: The images on either side of the plane is the same as the other (Figure 5.1.3).
In this case, the molecule is considered ‘achiral’. In other words, to distinguish chiral molecule from an achiral molecule, one must search for the existence of the bisecting plane in a molecule. All chiral molecules are deprived of bisecting plane, whether simple or complex. As a universal rule, no molecule with different surrounding atoms are achiral. Chirality is a simple but essential idea to support the concept of stereoisomerism, being used to explain one type of its kind. The chemical properties of the chiral molecule differs from its mirror image, and in this lies the significance of chilarity in relation to modern organic chemistry.

It is pretty interesting that our hands seem to serve the same purpose but most people are only able to use one of their hands to write. Similarly this is true with chiral biological molecules and interactions.

Contributors

- Dr. Dietmar Kennepohl FCIC (Professor of Chemistry, Athabasca University)
- Prof. Steven Farmer (Sonoma State University)


• Jim Clark (Chemguide.co.uk)