Optical activity of sucrose solution *

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In this think aloud activity we will rotate the plane of polarization of light using *optically active* medium. What are the basic properties of optically active medium and why are they important? Here is a brief overview of these materials.

1 Introduction

1.1 Chirality

Imagine trying to wear the same shoe on both of your feet. Would you be able to do that? Most probably no. The human foot is a chiral entity. That is why a right shoe cannot fit on the left foot and a left shoe cannot fit on the right foot. However, the traditional footwear, the *khussa* can, as it cannot distinguish between "leftness" and "rightness". The shoe is a chiral probe whereas the khussa is an achiral entity. With this example in mind, consider a molecule, a network of atoms arranged in three dimensional space. Two molecules may have an identical composition of atoms and the same bonding network, however they may still differ in their detailed three dimensional arrangement. Surprisingly, these variants of molecules can have totally different physical and even chemical properties. The mirror image has a distinct configurational arrangement and cannot be superposed onto the original molecule (without of course, reflection through the mirror plane). The molecule and its non-superposable mirror image are enantiomers of each other and the corresponding property is called chirality. Only chiral molecules are optically active.

The experiment that performs this probing is in fact, very simple and it is illustrated in Figure 1. Shine polarized light onto an optically active substance. The plane of polarization rotates in one direction or the other. For example, the chiral molecule *d*-glucose bends light to the right (when viewed along the direction of propagation) and this is experimentally determined. The prefixes *d* and *l* signify 'dextro' (right) and 'levo' (left) physical rotations.

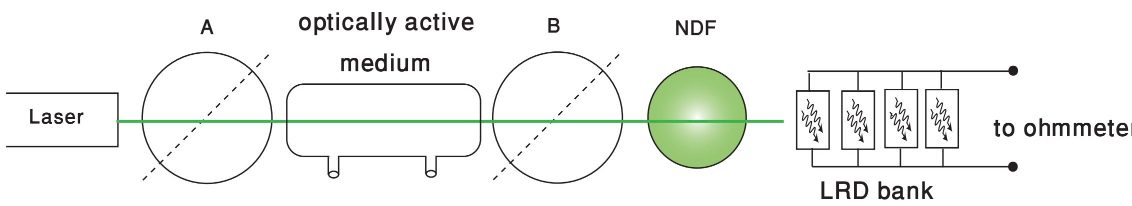

Figure 1: Optically active solution rotating a polarized light

1.2 Examples of chiral molecules

An example of a chiral molecule is bromochlorofluoromethane. Its structure is shown in Figure 2.

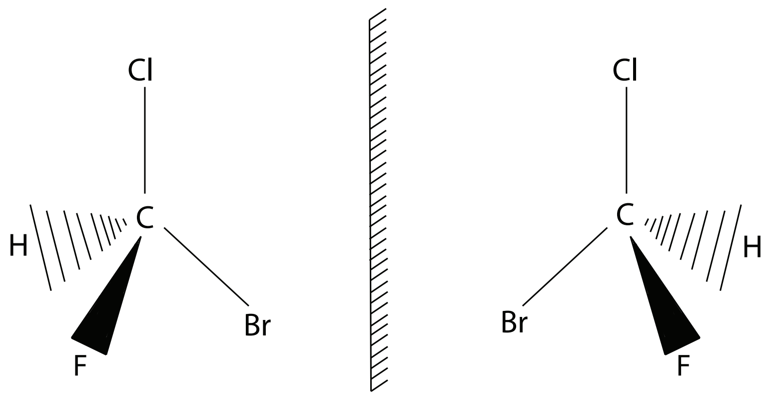

Figure 2: Structure of bromochlorofluoromethane shown along with the mirror image. The wedge shape arrows represent chemical bonds pointing into or out of the plane of the paper.

Now place a mirror next to the molecule and observe the image. The mirror image has a distinct configurational arrangement and **cannot** be superposed onto the original molecule(Hence the molecule is chiral and optically active).

Q 1. Identify the chiral molecules: (a) 3-methylhexane (b) 3-methylpentane (c) the amino acid glycine and (d) dibromochlorofluoromethane. The structures are shown in Figure(3).

1.3 Chirality in the biological world and its applications in pharmaceutical industries

Chirality is seen throughout the biological world. With the exception of inorganic salts and a few low molecular weight organic substances, molecules in living systems, both plant and animal, are generally chiral. For example, only one of the stereoisomers called (S)-alanine occurs naturally. Enzymes that catalyze biochemical reactions are also highly stereoselective, i.e, they will speed up reactions only with one enantiomer of the chiral pair. Chymotrypsin, a chiral intestinal enzyme will break down only the corresponding peptide enantiomer during digestion. This 'chiral favouritism' in nature is one of the open questions in the life science.Researchers have been linked this with the similar question in cosmology of why the universe is made up of matter and not of antimatter!

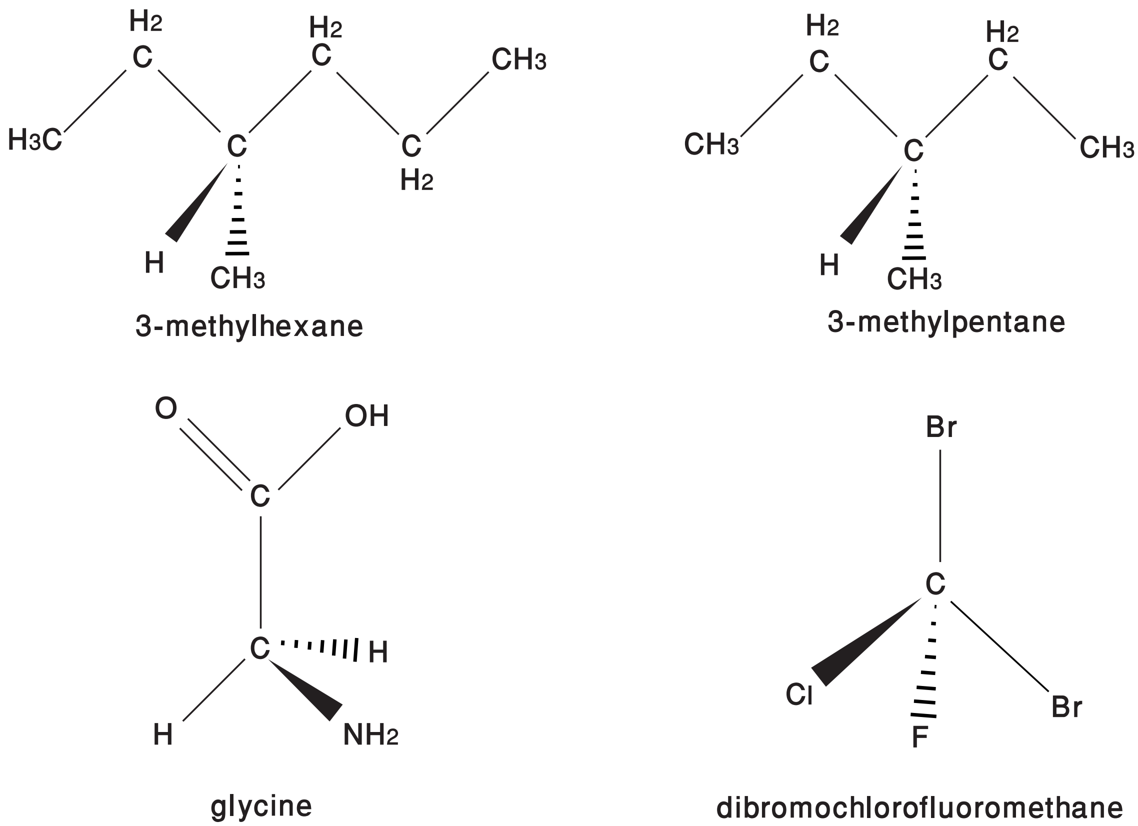

Figure 3: Chemical structures for the molecules named in Q1.

In the chemical industry too, there is a drive towards synthesizing chiral catalysts for developing stereoselective reactions. Chirality is also an important factor in drug efficiency and design. Drugs that are packed as *racemic* mixtures, comprise equal amounts of the two enantiomers. However in most cases, only one of these molecules is biologically active. For example in *ibuprofen*, sold as an analgesic in Pakistan in the racemic form, only the (S)-enantiomer is active. Chiral drugs now have become a focus of most pharmaceutical companies. For example *Naproxen* available in this country is a chiral molecule and is sold in the enantiomerically pure form. Statistic shows that about 56% of the drug in present use are chiral molecules.

1.4 Some background questions

Q 2. Why is plane polarized light chiral? Why is randomly polarized light achiral? *HINT*: Draw a one sided arrow pointing upwards representing plane polarized light and reflect it across a plane perpendicular to the arrow.

Q 3. Polarized light is shone through a racemic mixture of glucose. In which direction will the plane of polarization rotate?

Q 4. A mixture of *l*-2-butanol and *d*-2-butanol rotates the polarization plane in the left direction through 10°. If pure *l*-2-butanol has a rotation of 13.5° in the same direction, determine the composition of the mixture.

Q 5. A liquid is made up of molecules randomly jostling in all directions. Think why this randomly oriented jumble-up can, in fact, rotate light so coherently in one direction?

In a chiral medium, each molecule contributes to the optical rotation. More molecules would imply stronger rotation. So a longer path length and a more concentrated solution would result in greater rotation angles. For comparison, we often normalize with respect to the length of the sample and concentration, resulting in the specific optical activity.

$$[\theta] = \frac{\theta}{c\ell}$$

where c is the concentration and ℓ is the path length. It is also important to menton the temperature and wavelength of the light used.

Q 6. What are the units of $[\theta]$?

2 Experimental procedure

Turn on the laser. Power up the multimeter and change the mode to “Resistance”(Ω). Adjust the height and orientation of Polarizer A, and align the polarizer B in the path of the optical beam.Note the reading on the rotation mount A. Call it α. What is the uncertainty in α?

Now rotate the angle of the analyzer B and call it β, in steps of 20 deg, keeping all rotations clockwise or anti-clockwise. Take approximately 20 readings. At each step, record the resistance. Keep α fixed throughout.

Use Malus’s principle and come up with a set of variables to plot. Then fit your data to a suitable function. In Matlab you may use the application `cftool` which also returns the uncertainties in the respective fit parameters.

Perform the experiment again, but this time place the optically active solution between the holders. Find the optical activity of the sucrose solution.

References

[1] M.A. Vaksma, J.W. Lane, “Using guided inquiry to study optical activity and optical rotary dispersion in a cross-disciplinary chemistry lab”, J. Chem. Ed. **78**, 1507–1590 (2001).