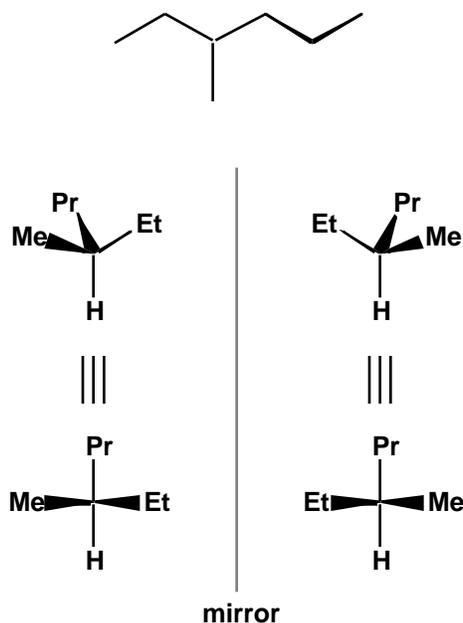


Text Related to Segment 4.01 ©2002 Claude E. Wintner

It is first among the C_7H_{16} cases we run into a new — and wonderful! — complication, which perhaps may be best introduced by the statement that instead of the nine different C_7H_{16} hydrocarbons that we would expect to be capable of independent, long-lived existence (in "separate bottles") on the basis of the above analysis, there are, in fact, *eleven*. This discrepancy comes about as a result of two of the constitutions among the nine: 3-methylhexane and 2,3-dimethylpentane. Thus, in the case of 3-methylhexane there exist *two* molecules, *both* having the constitution ("connectedness") defined by the name 3-methylhexane and the corresponding line formula, but separated by a *high* energy barrier. The two molecules differ in their *configuration* about the carbon atom labeled with the small triangle, and thus are termed *configurational isomers*. This situation arises as a result of a tetrahedral carbon atom being connected to four different substituent groups, or ligands; in the case of 3-methylhexane these are n-propyl, ethyl, methyl, and hydrogen. Such a carbon atom is termed *stereogenic*. The interchange of any two ligands of a stereogenic carbon atom leads to a molecule that is non-congruent with the original. *Differing configurations within a given constitution have different spatial arrangements of the atoms, without regard to arrangements which differ only by torsion about one or more single bonds; that is, the energy barriers separating configurational isomers are high.* (Compare the definition for differing *conformations*, above.)



the two configurational isomers (enantiomers) having the constitution 3-methylhexane

To aid in a clear understanding of the foregoing discussion, the two configurations of 3-methylhexane can be depicted as above in three-dimensional formulae using both the wedge and the Fischer projection conventions. (Once again, a model should be consulted at this juncture!). The ligands on the stereogenic carbon atom can be arranged tetrahedrally in space in two distinct ways, and these two arrangements cannot be made congruent. They are separated from each other by a high energy barrier, for the tetrahedral bonds of carbon are fixed in space. There is a further, and exceedingly important, observation to be made: the two arrangements have a special relationship, in that *they are non-congruent mirror images of one another*. They are termed *chiral*, a chiral object being one which has the property that its image in a plane mirror cannot be made congruent with itself. The pair is known as an *enantiomeric* pair, and each molecule of the pair as the *enantiomer* of the other. (An equimolar mixture of both members of an enantiomeric pair is termed a *racemate*, or *racemic mixture*. Separation of a racemate into its

component enantiomers is termed *resolution*.) In sum, the two configurational isomers having the constitution 3-methylhexane are non-congruent mirror images of one another, are chiral, and comprise an enantiomeric pair. Exactly the same situation holds also for 2,3-dimethylpentane, in which the isopropyl ligand replaces the normal propyl ligand of 3-methylhexane. Thus, eleven models, none of them congruent, *can* be built to represent eleven different hydrocarbon molecules having the molecular formula C_7H_{16} , each of which can be put in a "separate bottle." We simply needed a three-dimensional consideration of the problem to realize this. Note, however, that it remains true that there are only nine *constitutions* possible within the molecular formula C_7H_{16} .

From an historical perspective it should be stressed that it was precisely the existence of two (and only two) separable configurational isomers in cases such as 3-methylhexane that provided early, and lasting, substantiation for the model of tetrahedral carbon capable of forming bonds that are not fluxional but, on the contrary, of fixed tetrahedral directionality. Indeed, the original model of tetrahedral carbon, proposed in 1874 independently by van't Hoff and Le Bel, was based almost entirely on this single line of evidence. In this connection, it is important to emphasize here that we have just described the phenomenon of *configurational* enantiomerism, as opposed to *conformational* enantiomerism. Indeed, we already have met the latter in passing, when we considered the two gauche conformations of n-butane. Conformational enantiomers are separated by *low*, not high, energy barriers; hence, conformational enantiomers are easily interconverted, one to the other. This stands in sharp contrast to configurational enantiomers which, to repeat, are separated by *high* energy barriers: one configurational enantiomer cannot be converted to the other without violating the integrity of the directionality in tetrahedral carbon. Nevertheless, it is general common usage to employ the term "enantiomer" when, in fact, "*configurational enantiomer*" is meant.

The concept of chirality, or "handedness" can, of course, be recognized all around us in the natural world — our hands providing just the most familiar example. However, it is a non-trivial problem to place stereochemically correct labels, exemplified by the formulae we have drawn above, on our two bottles containing the two enantiomers of 3-methylhexane, so that the molecule *in* each bottle corresponds in its so-called *absolute* configuration to the label *on* each bottle. How can we tell? Each bottle contains a colorless liquid. In principle, the physical and spectroscopic properties of constitutionally isomeric molecules are entirely different, but this is *not* the case for enantiomers, which share a single constitution. However, there do exist significant differences, relevant to our conundrum, in the interactions of enantiomers with some forms of electromagnetic radiation. First of all (although not first in terms of historical order of discovery, and in practice extremely complex), it is possible to carry out asymmetric x-ray diffraction experiments on samples of each member of an enantiomeric pair in the crystalline state. In effect, a three-dimensional snapshot of each molecule can be taken, thus solving the problem. (In fact, of course, examination of just one member of an enantiomeric pair will suffice!)

In a much simpler (and much older) and entirely independent experiment, samples of each of the two members of an enantiomeric pair can be placed in a polarimeter, an instrument which subjects the material to illumination by a beam of plane polarized light. The sample of one of the enantiomers will rotate the plane of the beam in a clockwise manner; the sample of the other enantiomer will rotate the plane of the beam in a counterclockwise manner. Given identical concentrations, path lengths, wave lengths, and temperatures, the absolute magnitudes of the rotations will be identical. The difference will be only in sign: by convention (+) if clockwise from the point of view of the observer, and (-) if counterclockwise. (Note that the observed rotation for a racemate is zero, as a result of net cancellation of rotations.) There is no easily discussed *a priori* correlation between the sign of rotation and the

absolute configuration. Nevertheless, once an asymmetric x-ray determination *has* been carried out for one member of an enantiomeric pair, then that result can be correlated with the sign of rotation in a polarimetric determination. From that point forward, it only is necessary to subject a new unknown sample of one or both of the enantiomers to the simple method of polarimetric analysis. The sign of the rotation, now correlated with the absolute configuration through the x-ray result, suffices to determine the absolute configuration of the enantiomer in excess, while the magnitude of the rotation provides a measure of the enantiomeric excess. In the case presently under consideration, the molecule drawn on the left hand side in our figure above happens to rotate the plane of polarized sodium light in the counterclockwise (-) sense; and its enantiomer, depicted on the right hand side, rotates the plane of polarized light in the clockwise (+) sense.

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