# Chirality Made Simple: A 1- and 2-Dimensional Introduction to Stereochemistry

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> Things should be kept as simple as possible, but not any simpler than that.
>
> *Albert Einstein*

Chirality, which is central to understanding much of organic chemistry, biochemistry, and molecular biology, is often introduced in introductory organic chemistry books by illustrating a pair of hands and other chiral and achiral objects. Thus, the instructor is forced to introduce the concept in three-dimensional (3-D) space, and some clever approaches have been offered *(1–3)*. However, this is analogous to teaching someone to swim by throwing them into deep water: sometimes it works, but the student who struggles fears the idea henceforth. That chirality is usually taught in 3-D is not surprising, since Kelvin's original definition refers to a comparison of "a geometrical figure, or group of points, [with] its image in a plane mirror" *(4)*.

Nonetheless, it is possible to introduce chirality at a much simpler level: in one- and two-dimensional space and thereby gain the advantage of introducing the complex topics of chirality and symmetry in a context that is familiar and trivially easy to understand. In this article, I briefly outline the concepts of chirality in 1-D and 2-D space and show that by applying simple internal and external reflection to line segments, triangles, and letters of the alphabet, one can introduce the concept of chirality and enantiomorphism in a context that is comfortable to the student. The popular video game Tetris, which is familiar to virtually all teenage students from the last 10 years, is really a 2-D chirality puzzle. One can use the concepts of internal and external reflection to show how the game is best won (or lost!). This introduction is sufficiently simple as to be amenable to incorporation into courses for nonscience students (or to explain symmetry elements and chirality to your neighbor!).

Following such a short introduction (it takes only about 10 minutes in lecture), chirality in 3-D can be introduced using a regular tetrahedron with colored corners, pictures of a hand, conch shell, and so forth. Using a projector to cast a shadow of a hand, it is easy to show how the concepts of 2-D chirality can be used to depict 3-D chirality, if certain ground rules are followed. Thus, Fischer projections and Newman projections simplify 3-D space by projecting three dimensions back to two.

## One and Two Dimensions

Figure 1 illustrates how, in 1-D space, a line segment is achiral, whereas a vector is chiral. It is obvious that in one dimension, a line segment has an internal mirror point while a vector does not. For reasons that become obvious in the

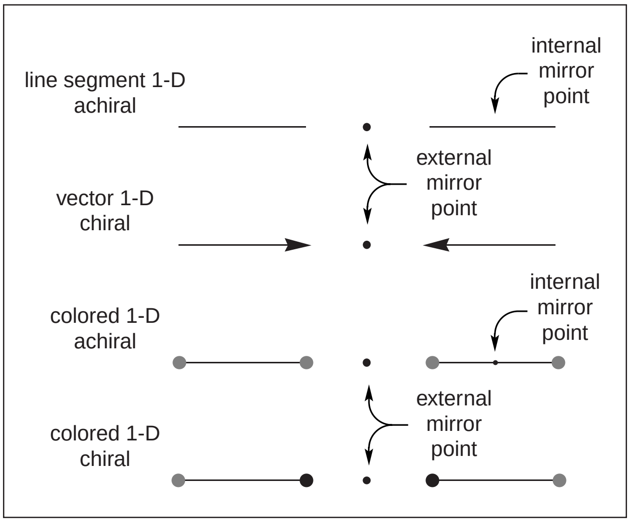


Figure 1. Chirality in one dimension.

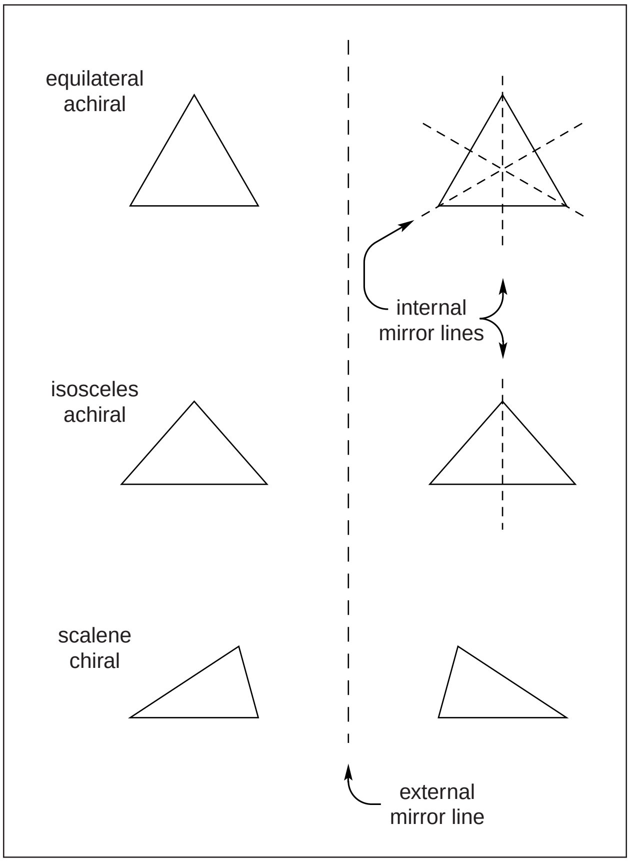


Figure 2. Chirality in two dimensions.

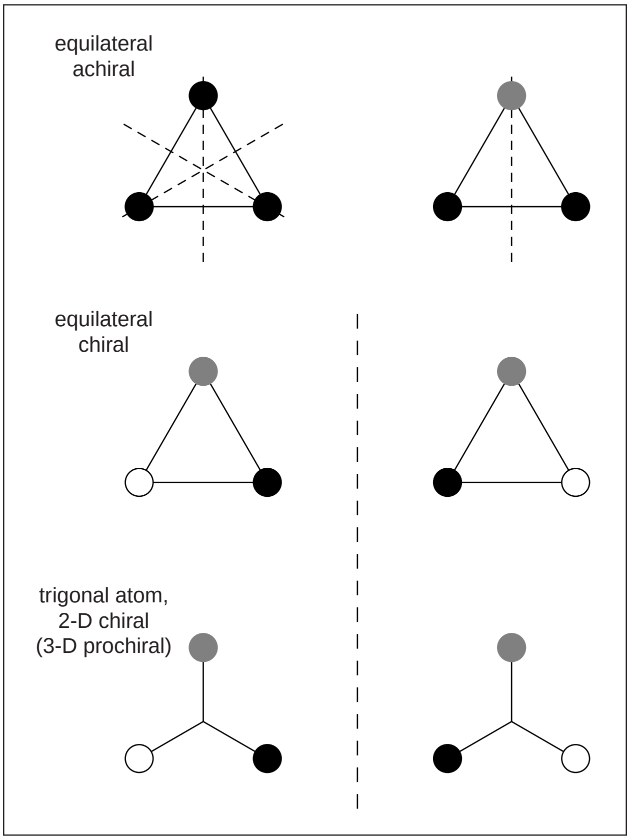


Figure 3. 2-D chirality in equilateral triangles and trigonal atoms.

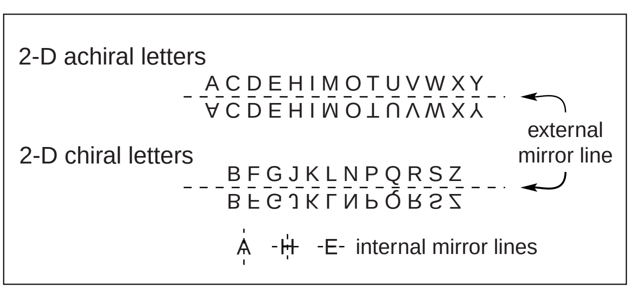


Figure 4. 2-D chirality in letters of the alphabet. Note: The letter "B" may, or may not, be chiral, depending on the font. In this case, the lower lobe of the B is slightly larger.

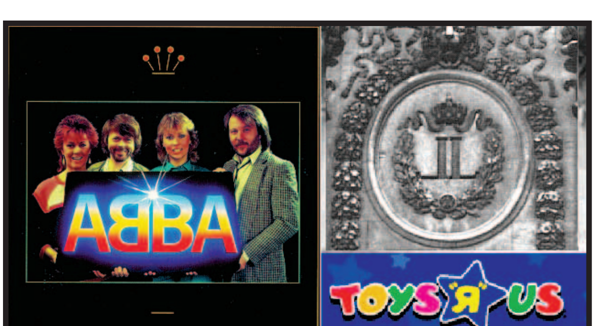

Figure 5. 2-D chirality in culture. Clockwise from left: Cover of a pop music album, the emblem of Louis XIV (east wall of the Louvre, Paris), and a toy store logo.

higher dimensions, it is convenient to illustrate the same concept by placing colored dots at the ends of each line. Note that in 1-D, you can only translate (but not rotate) the line in order to achieve superimposition. A pair of dowels, colored on the ends, may be used as props if desired.

In 2-D, equilateral and isosceles triangles are achiral, because they have at least one internal mirror line (Figure 2). The equilateral triangle has three mirror lines, and therefore has higher symmetry. Nevertheless, it only takes one internal mirror line to render the triangle achiral in two dimensions. In contrast, a scalene triangle is chiral in 2-D because it has no internal mirror line. This can be illustrated by external reflection, and showing that the two are not superimposable. Note that in 2-D, both translation and rotation (in the plane) are permitted to achieve superimposition. Here, cardboard cutouts may be used as props. Interested students may be directed to the book *Flatland: A Romance of Many Dimensions,* by Edwin A. Abbott *(5),* to see how two dimensional chirality has been used in fiction.

To relate these concepts to trigonal atoms, we must color the corners of an equilateral triangle. Here, triangles having three corners and two corners of the same color can be shown to have the same symmetry properties as equilateral and isosceles triangles, respectively. It is not until the three corners are different colors that all symmetry is lost and the figure becomes chiral (Figure 3). Several years ago, Wintner elaborated on the concepts of 2-D chirality as they apply to 3-D chemistry such as enantiotopic and diastereotopic ligands and faces, pseudoasymmetry, and relative configuration *(6).*

Block letters of the alphabet can be divided into 2-D chiral and achiral groups (Figure 4). The reflected 2-D achiral letters (A, C, D, etc.) can be superimposed on the original by translation and rotation in the plane; the 2-D chiral letters (B, F, G, etc.) cannot. Furthermore, all the achiral ones have at least one internal mirror line. It is also interesting to note occurrences of 2-D chirality in culture (Figure 5).

It is claimed by its creators that the video game Tetris is the most popular video game ever written. Since it first appeared in the mid 1980s, it has been ported to some 60 computer platforms, including the Nintendo GameBoy handheld device and, more recently, cellular telephones. For the past 10 years, virtually all my students (under the age of 25) admit to familiarity with Tetris. The game is played with puzzle pieces such as those illustrated in Figure 6A. The pieces are named after letters of the alphabet that they most closely resemble; note that some of them are achiral in 2-D (see above!) whereas others are chiral. The game is played by placing pieces, which fall from the top of the screen, in an orderly fashion, along the bottom of the screen, in such a way as to avoid leaving any holes. Translation and rotation of the piece, but not reflection, are allowed. Consider the situation encountered in Figure 6B, when the S piece falls and must be placed. There is no way that you can place this piece without leaving a hole. In contrast, if the next piece had been the Z (Figure 6C), the situation would have been much better. In my experience, most students nod in agreement *and understanding*. The relationship between the S and Z pieces in 2-D is enantiomorphous, as are the L and the J. If you happen to be teaching a class where biological receptors are mentioned, this game could be used to introduce Fischer's "lock and key" hypothesis!

### Three Dimensions

In 3-D, the standard explanation of colored balls on the corners of a regular tetrahedron, or on a tetrahedral atom are readily understood (Figure 7). Note, however, that irregular tetrahedra, like scalene triangles in 2-D, are chiral even with corners of the same color (also, bonds around a tetrahedral atom of different lengths) *(7)*. Since the concepts of internal and external reflection have already been explained in 1-D (mirror *point*) and 2-D (mirror *line*), the concept of a mirror *plane* is an extension of a familiar concept. Note that the use of a mirror with a set of models is particularly effective here *(3)*.

### Projections

Fischer projections and Newman projections are 2-D representations of 3-D space. Inherent in their use are assumptions about how they are drawn. To illustrate, consider the picture of right and left hands in Figure 8. If one imagines their projection to 2-D (which can be illustrated by placing your own right or left hand in a projector beam), it is impossible to distinguish right from left. This can also be demonstrated by reversing your own hand in the projector beam. However, if we agree on an assumption that the palm is always facing toward the viewer, the handedness (chirality sense) of the projected image is clear.

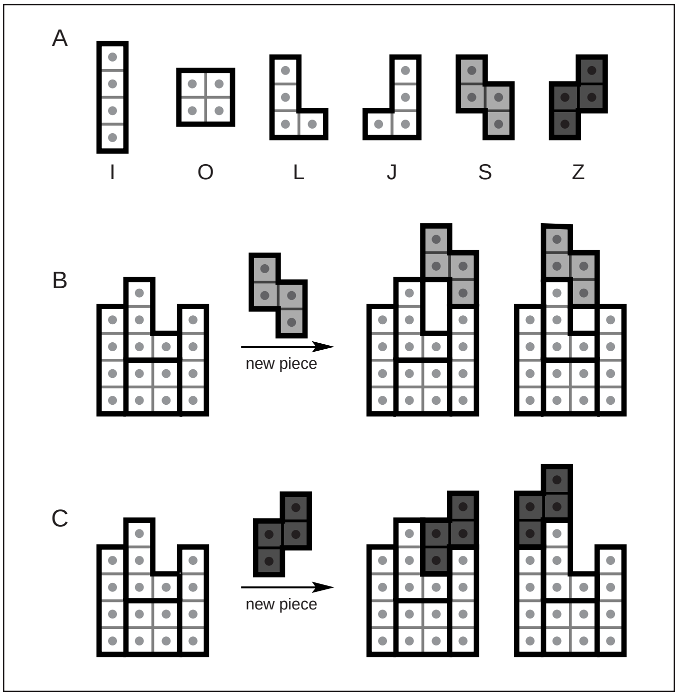


Figure 6. Tetris video game: (A) Several game pieces, note 2-D chirality in all but I and O; (B) S piece drops: a hopeless situation; (C) a winning situation with the Z instead of the S.

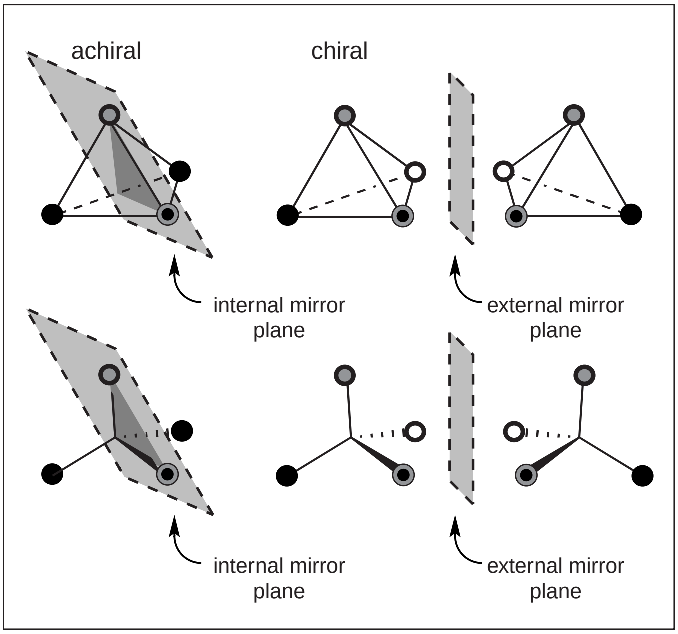


Figure 7. Chirality in 3-D with a regular tetrahedron (top) and with tetrahedral atoms (bottom).

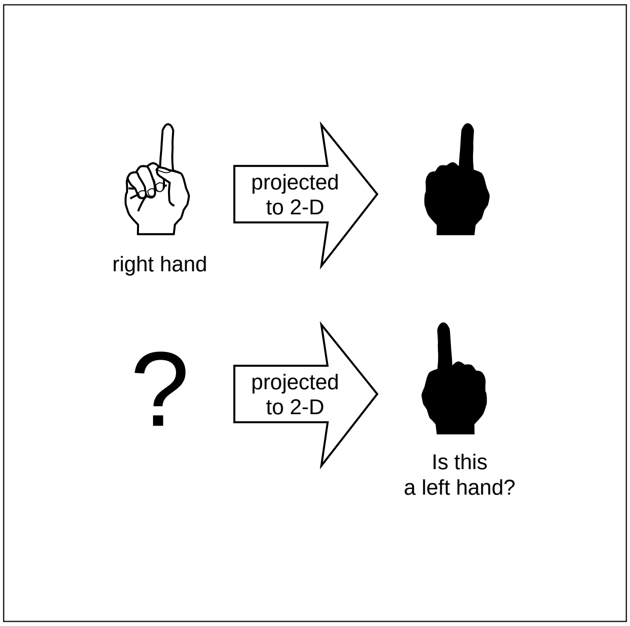


Figure 8. The projection, or shadow, of a right hand. Inspection of the shape of the lower shadow reveals handedness if one agrees that the palm is facing you.

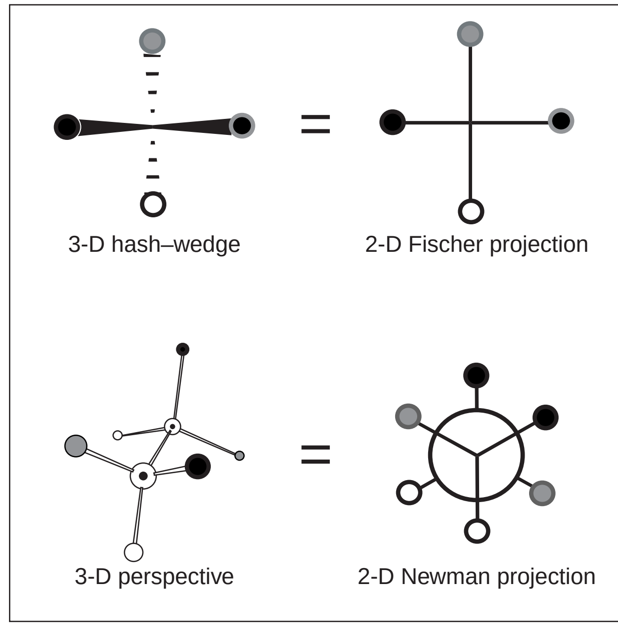


Figure 9. Fischer projections have the horizontal bonds of a tetrahedral atom projecting toward the viewer, and Newman projections have the joined bonds (Mercedes emblem) in front.

Fischer projections and Newman projections, which depict molecules in 3-D space, are meaningless in an absolute sense unless we agree on a set of rules, just as we had to do with the shadow (projection) of a hand. Thus, a hash-wedge illustration meant to depict 3-D can be simplified to a cross, when we agree on the premise that the horizontal bonds in the cross project toward the viewer (Figure 9). Similarly, a 3-D drawing of a staggered conformation can be projected to a 2-D Newman projection, but chirality sense is only preserved if the carbon in front of the 3-D drawing is in front in the Newman projection, as indicated by the joined bonds.

## Summary

The introduction of chirality in one and two dimensions, along with the concepts of internal and external reflection, can be combined with concepts familiar to all students: line segments, vectors, letters of the alphabet, and puzzle pieces. Once familiar with 1-D and 2-D chirality, the same concepts can be extended to 3-D. By projecting three dimensions back to two, as illustrated with the shadow of a hand, it is possible to interpret the rules of 3-D chirality in the more comfortable space of two dimensions.

## Acknowledgments

I am grateful to the late Vladimir Prelog for a private tutorial on stereochemistry in his office in 1994, in which he showed me the simplicity of 1-D and 2-D chirality, and to the students with whom I have tried the concepts described here, for their feedback.

## [W]Supplemental Material

A PowerPoint presentation to accompany the article is available in this issue of *JCE Online*.

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