In at least one version of the story of the Greek mythological hero Narcissus, he becomes infatuated with his own reflection in a pool of water, and does not recognize that this is just himself until he tries to kiss his image in the water. Narcissus becomes so distraught at this discovery that he kills himself. Fortunately, humans do not seem to have any difficulty recognizing that our reflection in a mirror or pool of water is not a friend or an enemy. The fact that in our “mirror image” our left hand becomes our right hand, our hair is parted on the other side, and the logo on our shirt has “backward” letters (STATEU becomes UETATSE) is normal once we get past the fascination with mirrors of our early childhood. Our image of ourselves is really our mirror image rather than our true image (the one that others see) because this is the one that we see every day in the mirror.

As scientists have become more capable of probing the structure of three-dimensional objects at the molecular and atomic levels, the need to understand the concept and consequences of mirror-image symmetry has increased enormously.
As we will see, there are very important aspects of nuclear physics that directly involve mirror-image relationships between fundamental particles, and to a chemist, knowledge of the mirror-image symmetry of molecular structures has become essential in efforts to understand the mechanisms of biological processes and drug activity. The presence or lack of mirror-image symmetry has also become an important probe in developmental biology and related areas. The macroscopic world in which we live also has many important and interesting properties that are connected to mirror-image symmetry. We begin this book and this chapter with a number of definitions, and some nomenclature.

**Handedness**

Throughout this book you will see the terms *right-handed* and *left-handed*. What do we mean when something is called *right-handed*? For a human being, the answer is pretty clear. It means that people use their *right hand* predominately for actions that they perform daily. But we all know people who may throw a ball with their right hand, and perhaps play golf the way most right-handers do, but write with their left hand. There are certainly degrees of handedness among people, and the question sometimes becomes not whether a person is right- or left-handed, but the extent or degree of the person’s right- or left-handedness. If you throw a ball, raise your hand, comb your hair, sign your name, brush your teeth, and point with your right hand, then you are said to be right-handed. You probably also kick with your right foot, fold your arms with your right arm on top, and wink with your right eye. As we see in Chapter 7, most of us *Homo sapiens* are dominantly right-handed, and we call ourselves right-handed, but there are obviously people who are very left-handed, and a range of people in between.
Of course, the words left and right have interesting connotations. Right (rectus in Latin) is associated with strong, correct, clever, and so on, and left (sinister in Latin, gauche in French) connotes evil, clumsy, untactful, etc. In this discussion we are omitting all the possible political interpretations of these two terms (see Sidebar 1.A). In this book we are interested in studying the absolute nature of right- and left-handed symmetry in our world, and the first thing we should recognize is that we should limit as much as possible the use of the terms left-handed and right-handed unless we have very clear definitions of what these terms mean. In fact, maybe we should only apply these terms to people or other mammals that have hands!

Sidebar 1.A

**Right-Wing ↔ Left-Wing Politics.** In politics, the terms left wing and right wing originated from the seating arrangement in various legislative bodies in France during the French revolutionary period at the end of the eighteenth century. The aristocracy sat to the right of the leader or speaker, and the commoners sat on the left. At this time in history, right-wing politics were associated with the interests of the church and royalty; the left wing was opposed to these interests, and represented the rising capitalist class, the so-called bourgeoisie. So the left wing was supporting laissez-faire capitalism and free markets. This is generally opposite to what would be called “left wing” in modern times. (Wikipedia.)

So, how do we study and talk about this important property of our world in an unambiguous way? We first need a term to apply to a static or dynamic system in which this type of mirror-image symmetry is present. We could and will use the term handed, but for the reasons given above, we will more often use the slightly more general term chiral (pronounced kai-ral)
and call this property *chirality*. Not surprisingly, this word is derived from the Greek word *χειρ* (cheir), meaning *hand*. The first use of this term and its definition occurred in a lecture by Lord Kelvin (Sir William Thomson) in 1884 [1]. Very specifically, a system is *chiral* if the mirror image of the system is not “superimposable” on the original system. The best example is, of course, the human hand which we depict in Figure 1.1. The mirror image of the right human hand is the left human hand. These are distinct structures and are not identical. In this very special case, we can certainly talk about a right hand and a left hand, and know exactly what we mean.

In Figure 1.2 we show the picture of a house, and its mirror image. These two structures are obviously not identical, but we really can’t describe one of them as a right-handed house, and the other as left-handed. We can describe the house by saying that the door or window is on the left or right as we face the front, and so on, but in this case, of course, we don’t really need a nomenclature. We will call knowing exactly which mirror
image we are referring to as “knowing the absolute structure.” In fact, in some situations for molecules it is not really necessary, or in other situations for various reasons it is not even possible to know the absolute structure. At the microscopic molecular level, however, a nomenclature that allows one to describe an absolute three-dimensional (3D) structure is essential, if we are attempting to communicate structural information in order, for example, to understand how biologically important chiral molecules interact and function. We will discuss the importance of knowing the absolute structure in Chapter 2, but for now we will focus on introducing the basis for the classification of 3D structures as chiral, and discuss the nomenclature that chemists and biologists use to identify which mirror-image molecule they are talking about. The various nomenclature systems will be presented here in some detail, but some readers might choose simply to scan this section to get some idea of the basis for this aspect of chiral structure.

**The Symmetry of Nonsuperimposable Mirror Images**

With just a little practice it is easy in most cases to determine whether an object has a nonsuperimposable mirror image—in other words, whether the object is chiral. This is especially true for objects that have “no” symmetry, or more properly no *symmetry elements*. The concept of symmetry elements is an important one for many scientists and mathematicians. In the language of symmetry theory an object is said to possess a set of *symmetry elements*. For our purposes we will focus primarily on the existence of symmetry planes and inversion centers, and refer the reader to the many textbooks dealing with the concept of symmetry groups for a more complete analysis of that topic. Some suggested books on symmetry classifications and theory are listed at the end of this chapter.
A three-dimensional object possesses a symmetry plane, if reflection of the object through the plane produces the other half of the object. Obviously, the plane must pass through the center of the object. Examples of objects that possess symmetry planes are shown in Figure 1.3. This might not be so obvious, but every object that has a plane of symmetry is achiral, that is, not chiral, and the mirror image is superimposable. You can see this with the objects depicted in Figure 1.3. You will have to imagine taking the mirror image and rotating it around (if necessary) to see that it is identical to the original object. If an object possesses an
inversion center then it also will not be chiral. An example of this special case is given in Figure 1.4, where we show a cubic structure with colored balls at the corners. The center of inversion is in the middle of the cube. For every part of this structure, for example, a red ball, an identical part (another red ball) is located on a line through the center and out the other side at the exact distance from the center. We give both the structure and its mirror image, and you should be able to convince yourself that these two structures are superimposable, and therefore not chiral. There are also some very special cases of objects that have no symmetry planes, and no inversion center, but are still achiral. These extraordinarily rare structures possess a rotation/reflection symmetry element, but this topic will not be discussed here [2].

A major focus of this book is the connection between the microscopic molecular world and the macroscopic world that we live in. With this in mind, we need to describe the nomenclature used for molecular structures that are chiral. It is sometimes useful (but not universally applied) to classify chiral structures that have no symmetry elements as asymmetric and those that have some symmetry elements but are still chiral as dissymmetric. Using this distinction,

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1Formally, in the theory of symmetry groups, every structure has one trivial element, called the identity element, which simply does nothing to the structure.
we would classify the hand and house pictured in Figure 1.2 as being asymmetric. An example of a dissymmetric structure is the propeller shown in Figure 1.5. You can see that the propeller has no planes of symmetry or an inversion center, but what it does have is a rotation axis. Spinning this three-bladed propeller by 120° around an axis oriented perpendicular to the plane of the page yields the identical structure. One way to understand this is to look at an object and then, closing your eyes, have someone perform the symmetry operation. If after opening your eyes you can’t tell whether the symmetry operation has been performed, then this is, indeed, a symmetry element. In the specific case of the three-bladed propeller, we say that the object has a threefold rotation axis, since it would take three rotations of 120° to get back to the original structure. Starting with the Wright brothers’ plane, which used two two-bladed propellers, the absolute structure of the propellers used is an important consideration (see Sidebar 1.B).
Sidebar 1.B

Wright Propellers. The Wright brothers spent several years designing and testing efficient propellers after realizing that the existing propellers used for watercraft would not work in their new flying machine. This photograph below, which was taken at the Air and Space Museum in Washington, DC, shows that the two propellers that pushed, rather than pulled, the machine were mirror images of each other. This design serves to compensate for a force that would tend to cause the airplane to twist, and thus makes their airplane net achiral. In modern airplanes with two or more propellers, the propellers all turn in the same direction. This is convenient, of course, since the airplane mechanic doesn’t need to worry about the side of the plane on which the engine is being installed. Modern airplane control systems are much more sophisticated than those of the Wright brothers, and it is easy to compensate for any net twisting force because all the propellers are turning in the same direction.
The nomenclature used to describe the absolute structure of a dissymmetric structure such as a propeller is somewhat easy to understand, because we have experience with the terms used to describe the threads on screws and pipes. A right-handed screw is defined as one that if turned clockwise penetrates the substance being screwed into. [We will discuss the terms clockwise and counterclockwise (or anticlockwise) in Chapter 7.] Figure 1.6 shows a few right-handed screws. The common definition of a right-handed propeller is one in which the blade, as you go from front to back, tilts in a clockwise direction. Propellers are, of course, normally driven by a motor, and the definition that you will often find for a right-handed propeller is one that, when viewed from the back, if driven clockwise will push the air or water out toward the front of the propeller, which, of course, is pointed out the back of the vehicle. If you think this is confusing...well, you’re correct! The propeller shown in Figure 1.5 is right-handed.

Why is the term right-handed used for screws and why are most screws right-handed? It’s because most of us are right-handed, and if you are trying to drive a screw into something with some force, your hands, if you are right-handed, do a
much better job when you turn the screw clockwise. So we call this natural direction or screw chirality *right-handed*. This seems to be a pretty loose connection between the fact that most people are right-handed, and the direction that a screw turns, but it is the basis for this nomenclature. It is useful sometimes to think about how one would describe this to an interested alien over a voice-only line! You will see that the use of the term *right-handed* or *left-handed* for all the cases described below may give the wrong impression that the various types of chirality that are sometimes considered as right-handed have some fundamental symmetry property in common.

Rather than calling this form of mirror-image symmetry right-handed or left-handed, some other notations have been defined. In various contexts for this type of dissymmetry, scientists use P or M (which actually stand for plus and minus), the uppercase Greek letters lambda (Λ) or delta (Δ), and R or S (rectus or sinister). Our intention here is not to concentrate on the precise naming of molecules, but it is important to recognize the utility, proper use, and limitations of this nomenclature. We begin by noting that these nomenclatures all deal with a three-dimensional *structure* and not some measurable property, as we will see below.

**Nomenclature for Chiral Molecules**

A large number of important chemical compounds contain a central carbon atom (C) and four attached substituents oriented to the alternating corners of a cube as shown in Figure 1.7. The overall geometry is that of a tetrahedron, and the carbon atom is referred to as being *tetrahedral*. Chemists have worked hard at defining an unambiguous nomenclature for chiral carbon atoms since it was discovered by the Dutch graduate student Jacobus Henricus van’t Hoff (Biographic Photo 1.1) and independently by the French chemist Joseph-Achille Le Bel (Biographic
Photo 1.2) in 1874 that carbon atoms could be tetrahedral and that this led to mirror-image isomers (see Sidebar 1.C). Most of the nomenclature associated with the naming of chiral molecules actually preceded knowledge of the absolute structure. In fact, the first determination of the absolute structure of a chiral molecule containing an asymmetric carbon didn’t occur until 1951!
Sidebar 1.C

**Jacobus Hendricus van't Hoff.** While a graduate student at the University of Utrecht, van't Hoff was trying to understand experimental results on how many compounds existed with the same chemical formula (isomers). For example, there appeared to be only one molecule with the formula \( \text{CH}_2\text{Cl}_2 \) (i.e., one carbon, two hydrogen, and two chlorine atoms). His explanation was that four substituents on carbon were arranged in a tetrahedron. He also concluded that, if correct, this would lead to mirror-image isomers for molecules with four different substituents. This idea was at first ridiculed by his senior colleagues, but, now, of course, is recognized as the basis for organic (carbon-based) molecular structure. He was the recipient of the first Nobel Prize in Chemistry for this contribution in 1901.
Sidebar 1.D

**Origin of the Cahn–Ingold–Prelog Rules.** After a scientific meeting organized by the Royal Chemical Society in Manchester, England in 1954, a dance was organized. While most participants were dancing, a few drank beer and discussed chemistry. Among them were the Royal Society President Sir Christopher Ingold, the editor of the *Chemical Society Journal*, Robert Cahn, and Swiss chemist Vladimir Prelog. Apparently, after a “vigorous” criticism by Dr. Prelog of a recent paper, he was invited by Drs. Ingold and Cahn to join them in sorting out this nomenclature. After several meetings, the principles of the new nomenclature system were published in the Swiss journal *Experientia* in 1956. (Current Contents, Dec. 13, 1982, p. 18.)

In order to name these structures in an unambiguous way, European chemists Robert S. Cahn, Sir Christopher Ingold, and Nobel Prize winner Vladimir Prelog (see Sidebar 1.D) devised a system (often called the CIP system) in which the chirality of a chiral carbon atom is based on an ordering of the four substituents using established priority rules depending on atomic number (the highest atomic number equals the highest priority, i.e., 1). Additional rules are used to establish priority numbers for situations in which the connected atoms are the same, but differ in their attachments. Once the priority numbers are determined, the structure is oriented such that the lowest priority number (4) is aligned to the rear of the structure, and determining whether the priority order of the other three substituents represents a clockwise (R) or counterclockwise (S)

![Figure 1.8. Bromochlorofluoromethane enantiomers.](image-url)
direction in going from 1 to 2 to 3. This will make sense only with an example! Let’s consider a real chiral molecule with the formula CHFClBr as shown in the two mirror-image structures drawn in Figure 1.8. From the periodic table of the elements we know that the atomic numbers of these elements are H = 1, F = 9, Cl = 17, and Br = 35. With this knowledge we order the substituents in Figure 1.8 and orient the molecules so that H, the lightest and therefore lowest-priority molecule, is oriented away from us. This is done in Figure 1.9. Hopefully, in the molecule on the left, you can see how proceeding from 1 to 2 to 3 involves a clockwise motion, and similarly on the right, a counterclockwise rotation.

In most cases the R,S notation is straightforward and unambiguous, but it is important to realize that the connection between notation and structure is often ill-defined. In other words, the symbol R or S is not always useful for comparison of similar structures. For example, if chlorine (Cl) is replaced by iodine (I, atomic number = 53), then the structures, priority, and names of these compounds would be as shown in Figure 1.10. So the structures on the left (or right) in Figures 1.9 and 1.10 are very similar, but in the accepted nomenclature have different designations for the absolute chiral structure. If a researcher is interested in reaching conclusions based on

![FIGURE 1.9. Tetrahedral chiral nomenclature: (a) (R)-bromochlorofluoromethane; (b) (S)-bromochlorofluoromethane.](image-url)
comparative structures, then, although the CIP nomenclature is clear and exact, it may lead to some confusion if nomenclature rules are not completely understood and applied correctly.

Preceding the formulation and introduction of the CIP nomenclature, and decades before absolute structures were known, Professor Emil Fischer of the University of Würzburg (later the University of Berlin) suggested a system in which chiral compounds were related to chemical transformations of the known compound glyceraldehyde. At this time, two forms of glyceraldehyde were known. These two forms were identical in composition and had identical physical properties. The only difference was that one form (isomer) rotated the plane of a polarized beam of light to the left, and the other isomer rotated the plane of polarization to the right. We will discuss the measurement and causes of optical rotation in Chapter 2, but, very briefly, if a plane-polarized beam of light passes through a container containing a chiral substance, then the plane of the polarization will be rotated to either the left or the right as shown in Figure 1.11. In this figure the plane of polarization, indicated by the arrow, is rotated in a clockwise direction (viewed from the source looking in the direction in which the light is traveling) as the beam passes through the sample containing chiral molecules. A rotation in this direction would
be designated as positive, and the molecule under study would have the prefix \((+)\) attached to the name. The fact that certain molecules or mixtures could rotate the plane of polarized light led to the separation of substances into those that were called "optically active" and those that were called "optically inactive." These terms are still used today to describe whether a molecule is chiral (optically active).

So the two forms of glyceraldehyde that Fischer studied were called \((+)\)-glyceraldehyde and \((-)\)-glyceraldehyde. A convention was established for orienting the molecule to be named. Fischer decided on the nomenclature presented in Figure 1.12. The conventional drawings given in this figure are intended to represent the tetrahedral geometry of a carbon atom.
with the solid horizontal line in front of the plane of the paper and the vertical line representing substituents in the back of the plane of the paper. The enantiomeric identity denoted by small capital letters is D and L. In 1891, how did Fischer know that the structure of glyceraldehyde that gave a positive rotation was the D form shown? He actually couldn’t have known this until the absolute structure of a chemically related compound was determined by X-ray crystallographic methods in 1951. He had a 50% chance of getting it right, and it turns out that he did!

There are problems with this older nomenclature that led to the CIP system, but this D,L notation is based on structures and not atomic numbers, so it is still used in some applications. Of special interest is the structure of chiral amino acids. The proteins of the human body are composed of long polymeric chains containing a sequence consisting of only 20 amino acids. Amino acids have the general structure given in Figure 1.13 (using the Fischer “projection” method of drawing them). The R in this figure denotes 1 of the 20 different molecular fragments or residues, and not the R as in R/S. (This might be a bit confusing!) When R is H (hydrogen), this is the simplest amino acid, glycine (see Figure 1.14) and is not chiral, because two of the substituents are the same, two hydrogens. In the nomenclature introduced by Fischer the other 19 amino acids are all L-amino acids. That’s right; all the chiral amino acids in our proteins are L! Do you think that they all rotate light to the left? In other words, are they all L-(−)? The answer is “no.”; 8 are L- (+), 11 are L-(−), and, of course, glycine, where the R group is H does not rotate the plane
at all since it is not chiral. How about the $R,S$ nomenclature? In fact, in all of the $L$-amino acids the central carbon atom is an $S$ structure except cysteine (see Figure 1.14) because in this amino acid, one of the carbon atoms attached to the chiral tetrahedral carbon is attached to a sulfur atom, $S$ (atomic number 16). This changes the priority numbering, the order is changed, and this amino acid is denoted $R$-cysteine. Chemists often used the term stereochemistry when they are studying the three-dimensional structure of chiral compounds.

**Nomenclature for Dissymmetric and Other Chiral Molecules**

Although tetrahedral carbon is probably the most important and certainly the most common chiral structure, many other chiral molecular structures can be classified as asymmetric or dissymmetric. In the very late nineteenth century, the “father of coordination chemistry” Professor Alfred Werner of the University of Zurich developed a theory for the structure of compounds where a central atom other than carbon could form bonds to different numbers of atoms. This “coordination theory” was most successful and applicable to structures in which the number of bonds (the coordination number) was 6. Werner was very familiar with the work of van’t Hoff and Le Bel on tetrahedral carbon, and he spent many years trying to synthesize and separate compounds that were based on octahedral geometry.
It was easy to see that in an octahedral structure four different compounds could be made with a central metal atom with two each of three different substituents. This compound would have the general formula $MA_2B_2C_2$. Different compounds that could be formed with identical formula are called isomers. It was also easy to see that two of the six possible isomers were chiral. All of the possible isomers of octahedral $MA_2B_2C_2$ are drawn in Figure 1.15. The solid lines in this figure represent the bonds from the central metal atom to the substituents, and the dashed lines have been added to show the outline of the octahedron, which contains eight triangular faces. A real proof of the coordination theory of Werner was the successful measurement of optical rotation in octahedral complexes in 1911 [3].
Modern rules for the naming of structures such as those given in Figure 1.15 are based on the CIP \([R/S]\) system introduced above for carbon. It is still the case that the clockwise or anticlockwise (i.e., counterclockwise) sequence of bonded atoms on the basis of their priority number is used to define the overall chirality of the structure, but using the symbol \(C\) (clockwise) and \(A\) (anticlockwise) instead of \(R\) and \(S\) is now recommended. The rules for determining priority are unchanged. In octahedral structures, the reference axis is the one that contains the highest-priority atom, with the lowest-priority atom on the opposite side of the metal. One then looks from the highest-priority substituent toward the central metal atom, and determines the priority sequence in the perpendicular square plane. In these cases, the clockwise direction from high to low sequence is designated as \(C\) and the anticlockwise one as \(A\). This is illustrated in Figure 1.16 for the octahedral complex \([\text{Co(CN)}_2(\text{NH}_3)_2(\text{H}_2\text{O})_2]^+\). The priority numbers (1 2 3) are assigned according to the atomic numbers of oxygen (8), nitrogen (7), and carbon (6). The sense of rotation is shown around the axis determined from the line from \(\text{H}_2\text{O}\) to \(\text{Co}\) to \(\text{CN}\).

The CIP nomenclature has been applied to virtually all chiral molecules, such that chemists are able to communicate to each other the absolute structure of such species in an unambiguous

![Figure 1.16](image-url)
way. The International Union of Pure and Applied Chemistry (IUPAC) maintains a Website (www.iupac.org/publications/books/seriestitles/nomenclature.html) containing links and reference material on current nomenclature recommendations. As we saw for amino acids as described above, however, some of the older nomenclatures or conventions commonly used for specific classes of chiral molecules are somewhat more useful, since they are based on structural similarities.

As introduced above, dissymmetric structures include propellers, screws, and other “twisted” structures. In this category, of particular importance to modern biochemistry and molecular biology is the helix, so we will spend some time describing the chirality of helices as drawn in Figure 1.17.

The definition of chirality of helices is the same as that for screws given above. More formally, a right-handed helix is one that turns clockwise as you move along the length of the helix. This is often related to a right hand. If you move your right thumb along the long axis of a helix, then the curvature is the same as that of your curled fingers. By definition, right-handed helices are called \( P \) for plus [of course, the plus sign (+) means something different!], and this is also designated as being \( \Delta \). Left-handed helices are \( M \) and \( \Lambda \). Most importantly, DNA, which is actually a double helix, is normally right-handed.

![Diagram of helices](image)

**FIGURE 1.17.** Nomenclature for helices: (a) left-handed helix, \( M \) or \( \Lambda \); (b) right-handed helix, \( P \) or \( \Delta \).
Sidebar 1.E

**Left-Handed DNA.** Although it is possible for DNA to occur in a left-handed helix (the so-called z form, which is not a mirror image of right-handed DNA), the overwhelmingly dominant natural form of DNA is right-handed. This is so important and so fundamental to molecular biology that it is amazing how many times DNA is drawn with the incorrect helicity. Dr. Thomas Schneider, a research biologist at the Center for Cancer Research Nanobiology Program at the National Institutes of Health, has long maintained a Website of errors in the depiction of DNA. His Website is named the Left-Handed DNA Hall of Fame (http://www.lecb.ncifcrf.gov/~toms/LeftHanded.DNA.html). My favorite is the October 23, 1998 cover of *Science* magazine, the “Genome Issue”: (Permission for use granted from *Science* magazine. See color insert.)
Summary

Our world is full of chiral objects from the microscopic molecular to the macroscopic! This is a simple and obvious conclusion that everyone in our world can make. However, it takes more work and thought to define and communicate the exact (absolute) three-dimensional structure of objects in our world. In certain situations it suffices to know that something is chiral, but a complete understanding of biological and chemical processes requires that one be exact in the articulation of chiral structures. We have described several ways of doing this, and exactly how we choose to define a chiral structure varies a bit with the particular system under investigation and the nature of the asymmetry or dissymmetry. In virtually every case, our frame of reference for nomenclature is the fact that we are “handed,” and objects are often referred to as being right-handed or left-handed. Hopefully, it is obvious to the reader of this chapter that the connection between right-handed people and right-handed helices or right-handed amino acids and so on is, however, not very meaningful.

Suggestions for Further Reading


References


List of Biographic Photographs, Sidebars, and Figures

Biographic Photo 1.1. Jacobus Henricus van’t Hoff

Biographic Photo 1.2. Joseph-Achille Le Bel

Sidebar 1.A. Right-wing ↔ left-wing politics

Sidebar 1.B. Wright propellers

Sidebar 1.C. Jacobus Henricus van’t Hoff


Sidebar 1.E. Left-handed DNA

Figure 1.1. A left hand and a right hand as mirror images

Figure 1.2. Mirror-image houses

Figure 1.3. Objects with symmetry planes

Figure 1.4. Mirror-image cubes with inversion symmetry

Figure 1.5. A three-bladed right-handed propeller

Figure 1.6. Right-handed screws

Figure 1.7. Tetrahedral enantiomers

Figure 1.8. Bromochlorofluoromethane enantiomers

Figure 1.9. Tetrahedral chiral nomenclature

Figure 1.10. Enantiomers of iodobromofluoromethane

Figure 1.11. Schematic diagram of optical rotation

Figure 1.12. Fischer projections of glyceraldehyde enantiomers
Figure 1.13. Structure of L-amino acids
Figure 1.14. Molecular drawings of glycine and L-cysteine
Figure 1.15. The six possible isomers of octahedral $MA_2B_2C_2$
Figure 1.16. $A$ and $C$ enantiomers of $[\text{Co(CN)}_2(\text{NH}_3)_2(\text{H}_2\text{O})_2]^+$
Figure 1.17. Nomenclature for helices