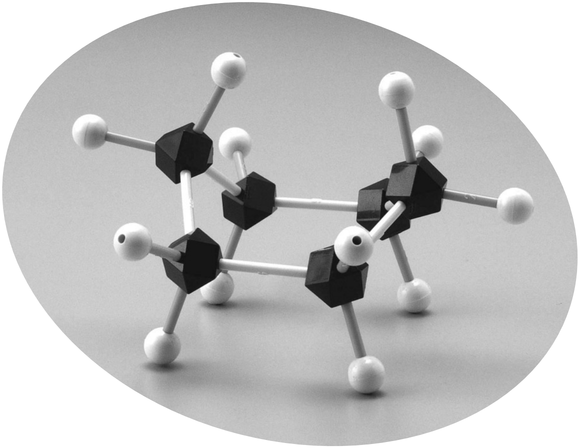
HGS

Organic Chemistry Set for Student



URL :http://www.hgs-model.com
E-MAIL :hgs@po.sphere.ne.jp

Hinomoto Plastics Co. Ltd.

Organic Chemistry Set for Student

Atom

Item No.	Parts cords	Color	Use	Quantity
1	H	White	*sp*	30
2	C^4	Black	sp^3	9
3	N^4	Blue	sp^3	2
4	O^4	Red	sp^3	4
7	S^4	Yellow	sp^3	1
8	Cl^4	Green	sp^3	2
9	C^5_{20}	Black	sp^2, dsp^3	6

Bond

Item No.	Bond Distance Å	Color	Use	Quantity
#2	1.20	Pink	C—H	30
#4	1.40	Green	C$\overset{\cdots}{=}$C	7
#6	1.54	White	C—C	20
#10	1.33	Blue	C=C	12

Orbital plate

Item No.	Color	Quantity
B*p*B-1	Blue	3
B*p*G-2	Green	1

There is a bond-puller to pull out the bond from atom

1. Molecules are Three Dimensional

A methane gas contained in natural gas consists of molecules called methane. Methane is a molecule that consists of one carbon atom and four hydrogen atoms and it changes to one carbon dioxide and two water molecules when completely ignited. Burning means that molecules are decomposed and bonded with oxygen atoms. Methane burns very well because all the atoms of methane can be bonded with oxygen atoms.

How are connected one carbon and four hydrogen atoms in a methane molecule? A carbon atom is bonded to four hydrogen atoms. The hydrogen atoms are not bonded to the other hydrogen atoms. As shown in **Fig.1**, a carbon atom is just at the center of a regular tetrahedron and hydrogen atoms are at each apex. Methane is not a two-dimensional molecule. Most molecules have beautiful three-dimensional structures like methane. There are various kinds of molecules working in our living body that would lose their properties completely if the three-dimensional structures were broken.

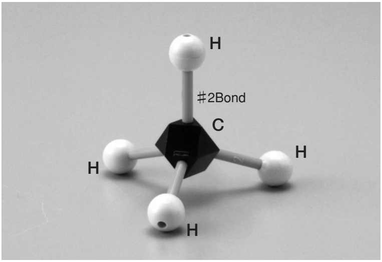


Fig.1: Molecular model of methane

Therefore, the three-dimensional structure of molecules plays a significant role in determining the properties of molecules.
It is very difficult to depict a three-dimensional structure in a textbook and it is also hard to understand no matter how it is described. The best way to understand the structure of molecules is to play with a three-dimensional model in your hands. While grasping the model parts in your hands, you can understand the structure of molecules naturally and become better able to picture the images three-dimensionally. Now, actually make some molecular models by yourself!

2. Make Some Simple Molecules

With the parts in this small box, you can make almost all the three-dimensional models of organic compounds described in your basic chemical text book. Generally, the organic compounds are more complicated than inorganic compounds. Therefore, if you understand the structure of organic compounds three-dimensionally, it would be easier to understand those of inorganic compounds(Of course, there are inorganic compounds with complicated structures).

There are two types of parts in the set: atoms and bonds (covalent bonds) that connect the atoms. The number of connectors (atomic valence) differs depending on the type of atoms and also the bond differs according to the circumstances. Next, we will discuss the carbon atom more specifically.

All black plastic polyhedrons in the set represent the carbon atoms. If you look carefully, you can see that there are two types of polyhedrons: Part #9 has a zonal part on its side and part #2 has four holes facing each apex of a regular tetrahedron.

First, make a methane molecule. A methane molecule has one carbon atom and four hydrogen atoms. Light blue spheres are the hydrogen atoms (#1). Use the part #2 for carbon atoms. When you bond the carbon atom and hydrogen atoms, use four pink connectors (connecting part #2) that correspond to the bond length of 1 Å (Å=10^{-10}m). With these parts, you can complete the methane molecule as shown in **Figure 1**.

In these models, 1 Å is almost equivalent to 2.5cm. That means you see the world of molecules 250 million times their actual size. To know the actual size of molecules make a ruler of 1 Å=2.5cm with cardboard and measure the size of molecules and the distance between atoms.

An ethane molecule has two carbon atoms and six hydrogen atoms. Two carbon atoms are bonded to one another and the distance is approximately 1.5 Å. Use the connecting part #6 for this bond. The carbon-hydrogen bonds are the same as methane. With these parts, you can complete the molecule as shown in **Figure 2**.

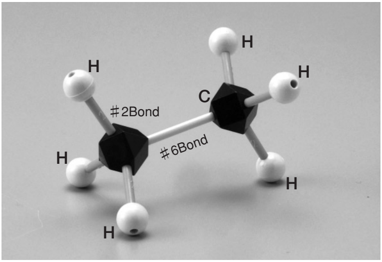


Fig.2: Molecular model of ethane

Ethylene is a colorless gas with a slight sweet scent that is produced by mature fruits and is important as an industrial material. An ethylene molecule has two carbon atoms and four hydrogen atoms. Use the carbon atom (#9). While an ethane molecule has only one bond between carbon atoms, ethylene has two bonds. This is called a double bond. To realize this with the models, use the connector (#10) that differs from the single bond. It is a curved blue connector. Connect two carbon atoms with two blue connectors. You

may need to use a little muscle power to connect these.
Connect the hydrogen atoms in the same way as the other molecules to create the ethylene molecule as shown in **Figure 3**.

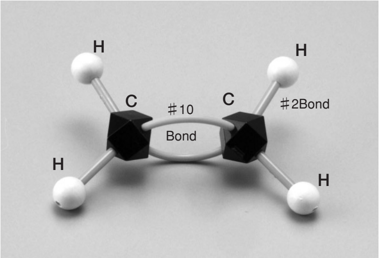


Fig.3: Molecular model of ethylene

Benzene is generally used as a solvent and starting materials for chemical synthesis because it dissolves other organic materials very well. A benzene molecule includes six carbon atoms and six hydrogen atoms. The structure is often expressed as shown in **Figure 4a**. Actually, electrons (π-electrons) are moving in the ring so that each bond has an intermediate property between a double bond and a single bond as shown in **Figure 4b**. To build a model of a benzene

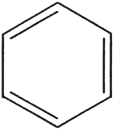


Fig. 4a

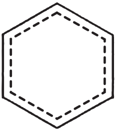


Fig. 4b

molecule, use the #9 carbon atoms and #4 connectors (1.40 Å) that represent this characteristic. The #9 carbon atom has 3 holes at 120-degree intervals. Connect the carbon atoms and hydrogen atoms with these holes. For the carbon-hydrogen bond, use the #2 connector. The completed structure will be as shown in **Figure 5**.

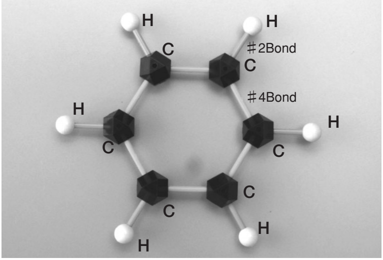


Fig. 5:Molecular model of benzene

As described above, you can make various kinds of molecular models with the atoms and bonds in this kit.

3. Make Some Molecules Including Other Atoms

There are many colorful polyhedrons other than black/light blue spheres in the set. As described in the attached table, each polyhedron represents a different atom: Red/orange represents oxygen, blue represents nitrogen, yellow represents phosphorous/sulfur, and green represents halogens such as chlorine. Make some simple molecules that

include atoms other than carbon atoms.
A water molecule has one oxygen atom and two hydrogen atoms. With one oxygen atom (#4), two hydrogen atoms (#1), and two connectors (#2), you can make a water molecule. To realize two lone pairs of electrons in the oxygen atom, you can use the board included in the set. You can use either blue or green ones. The water molecule will be completed as shown in **Figure 6.** The right model has lone pairs. You can see how the lone pairs and hydrogen atoms are far apart from each other. This is especially important in deciding the nature of a water molecule.

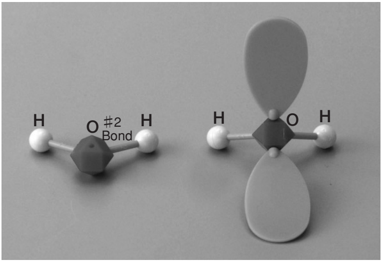


Fig. 6: Molecular model of water

An ammonia molecule has one nitrogen atom and three hydrogen atoms when it is neutral. With one nitrogen atom (#4), three hydrogen atoms, and three connectors (#2), you can make an ammonia molecule as shown in **Figure 7**. The nitrogen atom has a lone pair of electrons and you can show this in the model you will create. The right model has the lone pair.

The lone pair juts out of the molecule as well as in the oxygen atom of the water molecule. When the lone pair is coordinated to a hydrogen ion, it becomes an ammonium ion. You just exchange the lone pair with a hydrogen atom. Note that an ammonium ion is not two-dimensional but pyramidal like methane.

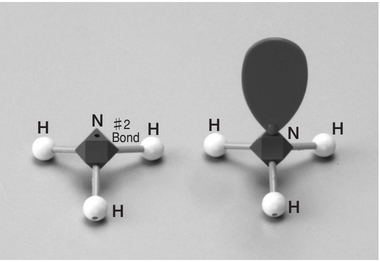


Fig. 7:
Molecular model
of ammonia

Next, make a methanol molecule that is used for an alcohol lamp. As described in the formula below, methanol is a molecule that has a hydroxyl group exchanged with a hydrogen atom in a methane molecule.

$$CH_3 — OH$$

You need: one carbon (#2), one oxygen (#4), four hydrogen (#1), four connectors (#2), and one connector (#4) for the carbon-oxygen bond. The actual distance of the carbon-oxygen bond is approximately 1.47 Å. Though it is a little shorter, we substitute a 1.40 Å connector for it. It would not be a big problem to see the whole image of a molecule. You may also use the #6 connector, which is a little longer. Though the structural formula of a methanol molecule appears two-dimensional, it actually has a three-dimensional structure **(Figure 8)**. The model shows lone pairs of an oxygen atom.

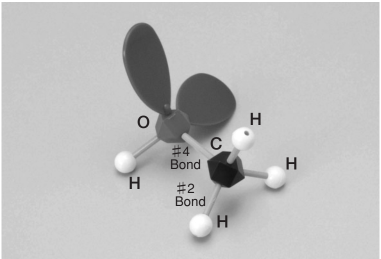


Figure 8: Molecular model of methanol

When a hydrogen atom of a benzene molecule is substituted with a chlorine atom, it becomes a chlorobenzene. You may make the model easily now. You just replace one of the hydrogen atoms with the #8 atom (green). However, you cannot use the #2 connector interchangeably because the bond length between the chlorine atom and the carbon atom is far longer than the carbon-hydrogen bond. The #7 connector (1.80 Å) is the most appropriate in the set.

With the combinations of various kinds of atoms and connectors in the set, you can make many types of molecules. The most amazing thing in chemistry is the tremendous range of possibilities that lie in such a small quantity of parts (elements). Furthermore, the model parts in this kit are logically consistent with the universal principles. For example, note the number and placement of holes on each atom. With all the parts included in this set, you can make at least 100 different varieties of organic molecules that you need to study in basic chemistry!

4. Similar but Different Molecules

Cyclohexane and Benzene

The chemical structures of cyclohexane and benzene are shown in **Figure 9**. They look similar but the three-

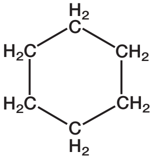


Fig.9-a

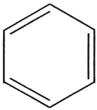


Fig.9-b

dimensional structures are totally different. We have already made a molecular model of benzene and know that a benzene ring is completely planar. However, cyclohexane cannot be two-dimensional. Build a cyclohexane model to learn the reason why it cannot be planar.

If you try to force it to become planar, you will find that the connectors will bend. This never occurs in the natural world. The most natural three-dimensional structure of cyclohexane is shown in **Figure 10**. This is called a “chair form” structure.

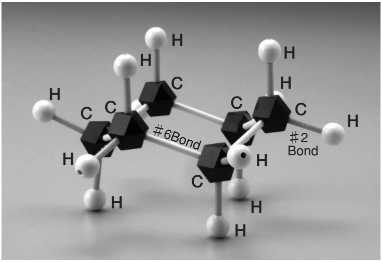


Fig.10: Molecular model of cyclohexane (chair form)

1, 2-dichloroethane and 1, 2-dichloroethylene

Both ethane and ethylene have two carbon atoms distinguished with the numbers 1 and 2. **Figures 11a** and **11b** show the chemical structures of 1, 2-dichloroethane and 1, 2-dichloroethylene, respectively. You can build these models quite easily.

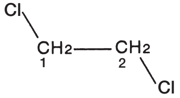


Fig. 11a

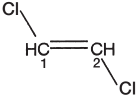


Fig. 11b

Figure 12 shows the three-dimensional structure of 1, 2-dichloroethane. Two carbon atoms are singly bonded and both atoms can rotate around the bond.

However, two carbon atoms of 1, 2-dichloroethylene **(Figure 13a)** are doubly bonded and they cannot rotate at all around the bond. Therefore, the molecule with two chlorine atoms at the same side (cis) as shown in Figure 13a and at the opposite side (trans) as shown in Figure 13b are different. In other words, both molecules have the same number of atoms but their properties significantly differ from each other. These different compounds are called geometrical isomers. Compare the different properties of these two geometrical isomers by using your molecular model kit.

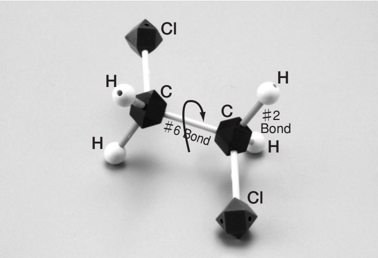


Fig. 12: Molecular model of 1, 2-dichloroethane

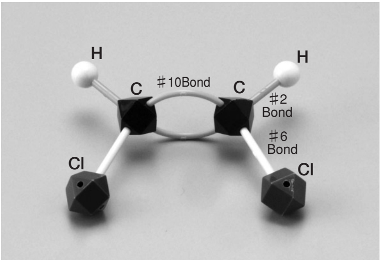


Fig. 13a: Molecular model of cis-1, 2-dichloroethylene

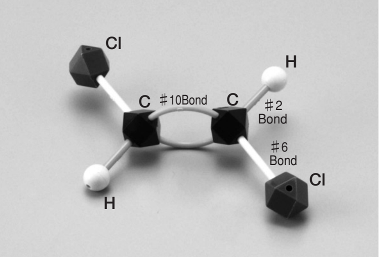


Fig. 13b: Molecular model of trans-1, 2-dichloroethylene

n-butane and isobutane

These molecules consist of four carbon and ten hydrogen atoms. While n-butane has a long chain structure, isobutane is branched. Though these molecules made of only carbon and hydrogen (hydrocarbons) have the same number of carbon and hydrogen atoms, their three-dimensional structures differ significantly as well as their properties. These are called structural isomers. It is not hard to build the molecular models of n-butane and isobutane **(Figure 14a** and **14b**, respectively) and compare them.

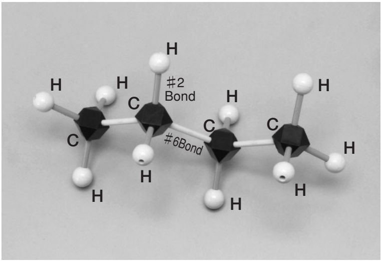


Fig. 14a: Molecular model of n-butane

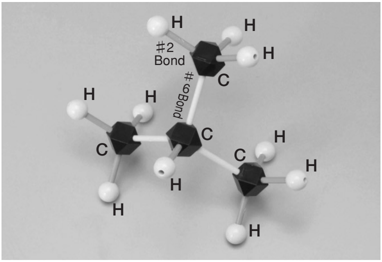


Fig. 14b: Molecular model of isobutane

Molecules with a Relationship of Right / Left Hand

An amino acid called L- alanine is used for the production of proteins in our body. The chemical structure is shown in **Figure 15**. You can make a model of this molecule with three carbon

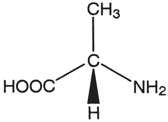


Fig. 15

(#2), two oxygen (#4), one nitrogen (#3), and 7 hydrogen atoms. You also need connectors: two #6, two #4, two #10, and seven #2. One of C-O bonds in carboxylic acid is double. As shown in **Figure 16a**, when you see the molecule with a methyl group on the top, carboxylic acid on the left, and an amino group (NH_2) on the right side, the hydrogen atom bonded to the carbon atom should be facing you. Now for comparison, make another model with the hydrogen atom facing in the opposite direction. The structure should be like **Figure 16b**. As shown in **Figure 16c**, you see that it is just like a reflection in a mirror. Also you know that both molecules can never be superimposed on one another. These molecules with a mirror structure (enantiomeric isomer) are called optical isomers. The amino acids working in our living body are typical optical isomers. The molecule in **Figure 16a** is called L-alanine and its enantiomeric isomer in **Figure 16b** is called D-alanine

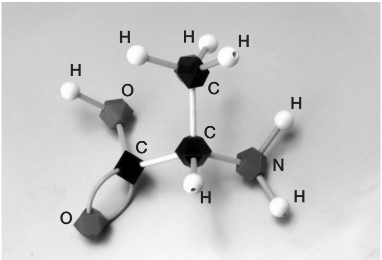


Fig.16a: Molecular model of L-alanine

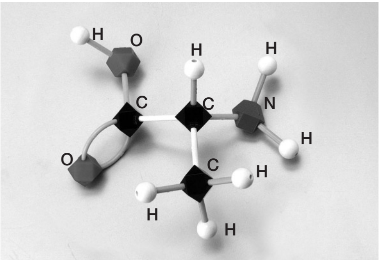


Fig.16b: Molecular model of D-alanine

Though the optical isomers have the same number and kind of atoms and relative way of bonding, their behaviors in the living body are considerably different. D-alanine has a very similar structure with L-alanine but it cannot be used in our body. We can use only L-amino acids, not D-amino acids. Our living body strictly distinguishes between these optical isomers.

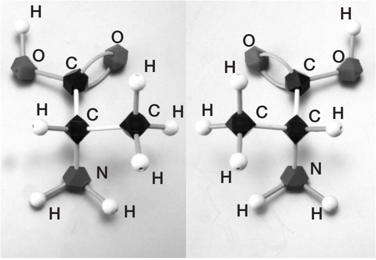


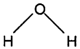
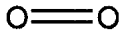
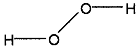
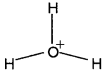
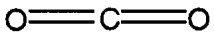
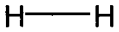
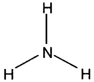
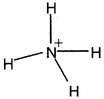
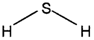
Fig. 16c
L-alanine and D-alanine are mirror images of each other

5. Build Various Kinds of Molecular Models

There are about 100 organic molecules in basic chemistry books. Try to make those structures one by one. With this small set, you can build at least 120 examples of molecules as described in the appendix. This will help you to understand not only the structures of molecules but also the chemistry more profoundly. Of course you can make other molecules that are not explained in this booklet. Why don't you study the structures of other molecules that make up common materials around you and try to build their molecular models? Hereinafter, some basic molecules that appear in your chemistry text book are classified and some brief notes on making those molecular models are described.

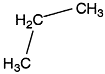
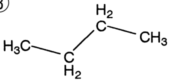
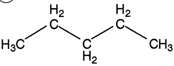
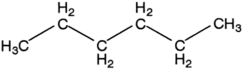
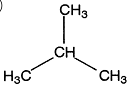
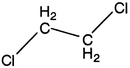
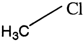
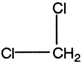
(1) Simple Molecules

To build nitrogen and nitrogen monoxide molecules with a triple bond, you need to bend the connector (#10) quite a bit. You may check the three-dimensional structure of the molecules in your chemistry textbook first, and then build a molecular model.

① 	② 	③ 
④ 	⑤ 	⑥ 
⑦ 	⑧ 	⑨ 
⑩ 	⑪ 	

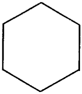
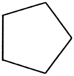
(2) Alkane

It is easy to build these models. Try to build possible structural isomers of butane etc. and study the relations between three-dimensional structures and their properties (i.e. boiling point etc.).

① CH_4	② 	③ 
④ 	⑤ 	
⑥ 	⑦ 	⑧ 
⑨ 		

(3) Cycloalkane

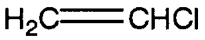
Cyclohexane consisting of six carbon atoms basically has a chair-form structure. Try to make and see other possible structures with your model. Also think about the possible structures of a five-membered ring.

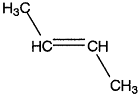
① 	② 	

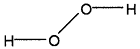
(4) Alkene/Alkyne

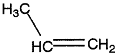
Look at the possibility of geometrical isomers of molecules with double bonds and also consider the structural changes of the six-membered ring. Check that alkynes are fixed firmly with triple bonds.

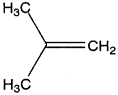
①

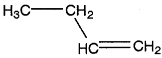

②


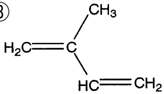
③


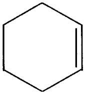
④


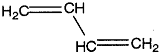
⑤


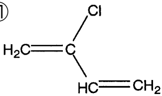
⑥


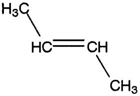
⑦


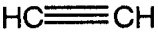
⑧


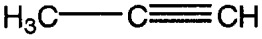
⑨


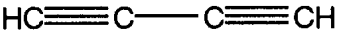
⑩


⑪


⑫


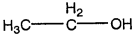
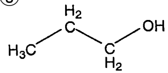
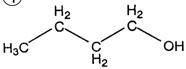
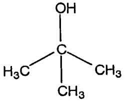
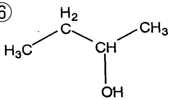
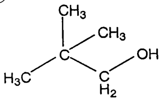
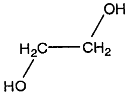
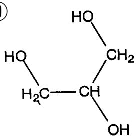
⑬


⑭


⑮


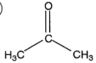
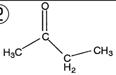
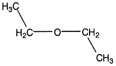
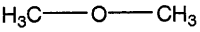
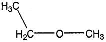
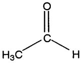
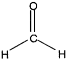
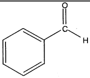
(5) Alcohol

Check that there are many structural isomers as well as alkanes.

① 	② 	③ 
④ 	⑤ 	⑥ 
⑦ 	⑧ 	⑨ 

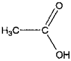
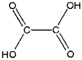
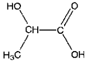
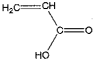
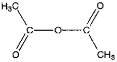
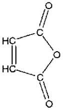
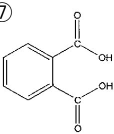
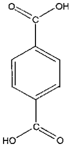
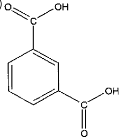
(6) Ketone/Ether

Try to build the molecular models of formaldehyde (the most significant source of the sick house syndrome), acetaldehyde (gives a hangover), and ether (used as an anesthetic).

① 	② 	③ 	④ 
⑤ 	⑥ 	⑦ 	⑧ 

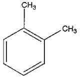
(7) Acid

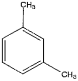
Try to build various kinds of acids.

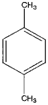
① 	② 	③ 	④ 
⑤ 		⑥ 	⑦ 
⑧ 	⑨ 		

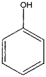
(8) Aromatic Ring

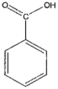
Try to build various kinds of aromatic rings. There are many industrial materials and pharmaceuticals that contain aromatic rings.

①


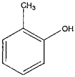
②


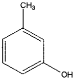
③


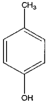
④


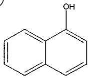
⑤


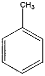
⑥

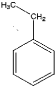

⑦


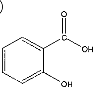
⑧


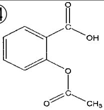
⑨


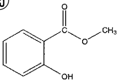
⑩


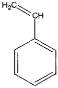
⑪


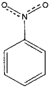
⑫


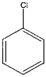
⑬


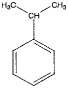
⑭


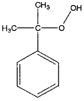
⑮


⑯


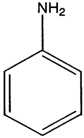
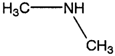
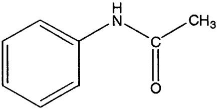
⑰


⑱


⑲


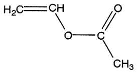
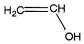
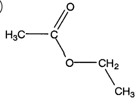
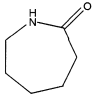
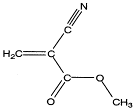
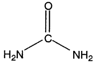
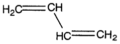
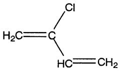
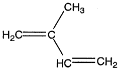
⑳


(9) Compounds including an Amino Group

① 	② H_3C-NH_2	③ 
④ 		

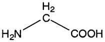
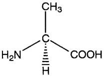
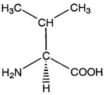
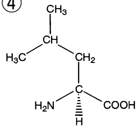
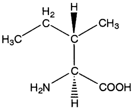
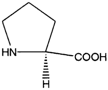
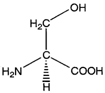
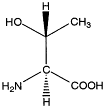
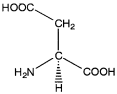
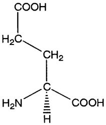
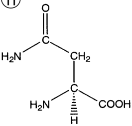
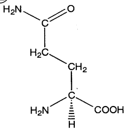
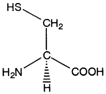
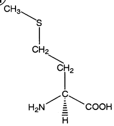
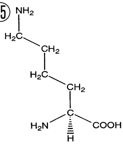
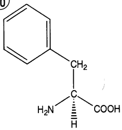
(10) Monomer (fundamental unit of polymer molecules)

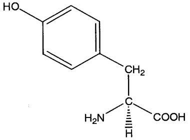
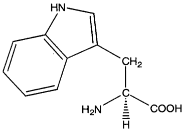
Try to build various kinds of molecular models of monomers. If you have extra parts, also build up a polymer connecting these monomers.

① 	② 	③ 
④ 	⑤ 	⑥ 
⑦ 	⑧ 	⑨ 

(11) Amino Acid

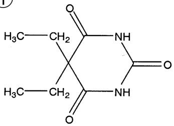
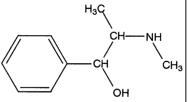
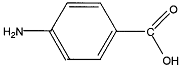
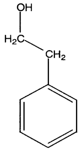
L-amino acids are shown in the table below. Also build D-amino acids and compare them with L-amino acids.

① 	② 	③ 	④ 
⑤ 	⑥ 	⑦ 	⑧ 
⑨ 	⑩ 	⑪ 	⑫ 
⑬ 	⑭ 	⑮ 	⑯ 

⑰ 	⑱ 

(12) Pharmaceuticals

Some structures of pharmaceuticals are shown in the table below. Try to build the molecular models of these and consider how they work.

① 	② 	③ 
④ 		

6. Bond lengths between common Atoms

The bond lengths between atoms provide very important data for building the models. The bond lengths between common atoms are listed below. The lengths and angles differ to some extent depending on the molecular environments. The values below are typical. Please select connectors with the most approximate length.

Typical bond lengths (Å).' ar' and' R' mean aromatic and aliphatic group, respectively

C—C	sp^3—sp^3	1.54	C—P	C(sp^3)—P	1.84
	sp^3—sp^2	1.51	C—H	C(sp^3)—H	1.10
	sp^3—sp	1.46		C(ar)—H	1.08
C—C	Aromatic	1.39	C—F	C(sp^3)—F	1.38
C=C	>C=C<	1.33		C(sp^2)—F	1.33
	>C=C=C<	1.31	C—Cl	C(sp^3)—Cl	1.77
	>C=C=C=C<	1.28		C(sp^2)—Cl	1.71
C=C		1.20		C(sp)—Cl	1.64
C—N	sp^3—sp^3	1.47	C—Br	C(sp^3)—Br	1.94
C=N		1.27		C(sp^2)—Br	1.87
C≡N		1.16		C(sp)—Br	1.80
C—O	R—O—O	1.43	C—I	C(sp^3)—I	2.14
	RCO—OR	1.34		C(sp^2)—I	2.07
	RCO—OH	1.31	N—H		1.01
	RCOO—R	1.44	O—H		
	C(ar)—OR	1.36	S—S	RS—S	2.05
C—O	$RCOO^-$	1.25	O—O	RO—OR	1.48
C=O	>C=O	1.20	N—N	>N—N<	1.45
	=C=O	1.16	N=N	—N=N—	1.25
C—S	C(sp^3)—S—	1.82	N—O	>N—O—	1.36
	C(sp^2)—S—	1.76		>N→O	1.30
C=S		1.71		—NO_2	1.22
C—Si	C(sp^3)—Si—	1.87	N=O	—N=O	1.20

G.Gilli
Fundamentals of Crystallography, P.503, Edited by C.Giacovazzo Oxford Science Publicatirs (1985)

Safety Guidelines:

1. Do not put the parts into orifices such as mouths, nostrils, ears, etc.
2. Keep the parts away from small children.
3. Do not give the parts to small children as misuse could result in permanent injury to the child.
4. Do not use the parts near fire, flame or hot surfaces.
5. Recycle the plastic rather than dispose of it in the garbage.
6. Protect our environment; do not throw kit and its parts into a river, sea or body of water.

Instruction prepared by
Noriaki Hirayama
Tokai University