### What is organic chemistry?

**Functional Groups in Organic Chemistry:**

<table>
<thead>
<tr>
<th>Group</th>
<th>Structure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkanes</td>
<td>R-H</td>
<td></td>
</tr>
<tr>
<td>Alkenes</td>
<td>R₂C=CR₂</td>
<td></td>
</tr>
<tr>
<td>Alkynes</td>
<td>R-C≡C-R</td>
<td></td>
</tr>
<tr>
<td>Alkyl Halides</td>
<td>R-X X=F, Cl, Br, I</td>
<td></td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td><img src="image" alt="Aromatic Ring" /></td>
</tr>
<tr>
<td>Alcohol</td>
<td>R-OH</td>
<td></td>
</tr>
<tr>
<td>Ether</td>
<td>R-O-R</td>
<td></td>
</tr>
<tr>
<td>Amine</td>
<td>RNH₂, R₂NH, etc</td>
<td></td>
</tr>
<tr>
<td>Aldehyde</td>
<td>R-C-H</td>
<td></td>
</tr>
<tr>
<td>Ketone</td>
<td>R-C-R'</td>
<td></td>
</tr>
<tr>
<td>Carboxylic Acid</td>
<td>R-C-OH</td>
<td></td>
</tr>
<tr>
<td>Ester</td>
<td>R-C-O-R'</td>
<td></td>
</tr>
<tr>
<td>Amide</td>
<td>R-C-NR₂</td>
<td></td>
</tr>
<tr>
<td>Acyl Halide</td>
<td>R-C-X</td>
<td></td>
</tr>
<tr>
<td>Anhydride</td>
<td>R-C-O-C-R</td>
<td></td>
</tr>
<tr>
<td>Nitrile</td>
<td>R-C≡N</td>
<td></td>
</tr>
</tbody>
</table>

### Why study organic chemistry?
Case Studies from the internet:

Case 1. Antibacterials in Soap.
Triclocarban (also called TCC, Cutisan, Solubacter, and trichlorocarbanilide) is a trivial name for 3-(4-chlorophenyl)-1-(3,4-dichlorophenyl)urea:

![Triclocarban](image)

Triclocarban. Click on the structures for a 3D Chime molecular model.

Triclosan (also known as CH 3635, Irgasan Ch 3635, Irgasan DP 300, and Ster-Zac) is shown at left; it has a similar structure.

Triclosan and triclocarban have been used as effective antiseptics [1] in soap since the 1960's. Triclosan has been incorporated into a wide range of consumer goods, including cosmetics, toothpaste, and plastics for children's toys and kitchen and table utensils.

Neither substance is very soluble in water, but both are fat-soluble and easily cross cell membranes. Once inside the cell, triclosan poisons a specific enzyme that many bacteria and fungi need for survival [2,3]. Triclosan blocks the active site of an enzyme called enoyl-acyl carrier-protein reductase (ENR for short), preventing the bacteria from manufacturing fatty acids it needs for building cell membranes and other vital functions. Humans don't have this enzyme, so triclosan is harmless to them. One molecule of triclosan permanently disables an ENR molecule, which explains why triclosan has powerful antibiotic action even at very low concentrations. Triclocarban's structural similarity suggests a similar mode of action.

The highly specific way that triclosan kills has researchers concerned about its role in fostering antibiotic-resistant strains of bacteria [2]. Researchers have recently demonstrated that mutations in the bacterial gene that produces ENR can produce triclosan-resistant bacteria. Because triclosan is now so widespread in the environment, it's likely that new antibiotics targeting ENR would be ineffective.


Case 2: Pharmaceuticals: New Antimalarial Drug

A cheap anti-malarial drug based on an ancient Chinese medicine is going into human trials in the United Kingdom. OZ, a synthetic peroxide, is believed to have similar mode-of-action as the most effective antimalarial drug currently available -- artemisinin, a herbal remedy based on the Artemisia annua plant. However, because of the costly and lengthy extraction process from the plant, artemisinins are at least ten times more expensive than the cheap standard antimalarials. Although artemisinin-based combination therapies (ACTs) are currently the best cure for drug resistant malaria, access to ACTs in disease endemic countries has been limited due to their cost. An effective synthetic drug would be superior to the current ACTs as it will not be dependent on the artemisia plant and will likely be much cheaper to manufacture.


From [http://www.artesunate.com/cqdf/7.htm](http://www.artesunate.com/cqdf/7.htm)
Case 3: Sunscreen chemicals:

4-Methylbenzylidene camphor
Octyl methoxycinnamate

THERE ARE TWO basic types of active ingredients: inorganic and organic. Both afford protection against UV-B rays in the 280- to 320-nm range, the primary culprits in sunburn. Some offer additional protection from UV-A rays in the 320- to 400-nm range, which can penetrate more deeply into the skin and do greater long-term damage.

Inorganic sunscreens use titanium dioxide and zinc oxide. They work primarily by reflecting and scattering UV light. The organics include widely used ingredients such as octyl methoxycinnamate (OMC), 4-methylbenzylidene camphor (4-MBC), avobenzone, oxybenzone, and homosalate. They work primarily by absorbing UV light and dissipating it as heat.

Recent scientific work by environmental toxicologist Margaret Schlumpf and colleagues at the University of Zurich’s Institute of Pharmacology & Toxicology suggests that OMC and 4-MBC--two widely used organic sunscreens--are potential endocrine disrupters. But industry research and government advisory committee reviews have disputed the work. The Food & Drug Administration still approves OMC for use in the U.S., though it never approved 4-MBC. The European Union’s Scientific Committee for Cosmetic Products & Non-Food Products continues to approve OMC and 4-MBC.

From MARC REISCH, June 24, 2002 Volume 80, Number 25, CENEAR 80 25 p. 38, ISSN 0009-2347 – web site: http://pubs.acs.org/cen/whatstuff/stuff/8025sunscreens.html

Case 4: Artificial Sweeteners

Aspartame is synthesized from aspartic acid and phenylalanine. The body breaks down aspartame into these amino acids along with a small amount of methanol. Methanol is metabolized to formaldehyde and formic acid. Formaldehyde is classified by the World Health Organization as a probable human carcinogen and is the major source of controversy over aspartame’s safety.

However, Walters says, people with the rare genetic disorder phenylketonuria (PKU) lack an enzyme for properly metabolizing phenylalanine, so they need to regulate their aspartame intake. In the U.S., all products containing aspartame must, by law, carry a warning for PKU patients.

Neotame, a new FDA-approved sweetener derived from aspartame, has a structure that prevents the peptide bond between phenylalanine and aspartic acid from breaking, making it safer for PKU patients.

Orbitals and Bonding. Review of atomic orbitals:

Draw an s orbital:

\[ \text{Nu} \]

For the s orbital: Where is an electron likely to be found?

Draw the 3 p orbitals:

\[ \text{Nu} \quad \text{Nu} \quad \text{Nu} \]

For p orbitals: Where is an electron likely be found? Where is an electron not likely be found?

Which orbital is more stable? What is the meaning of expanded shells?

\[ \begin{array}{c}
4p \\
3d \\
4s \\
3p \\
3s \\
2p \\
2s \\
1s \\
\end{array} \]

Atomic orbitals organic molecules might know about
AUFBAU Principal:
Using s and p orbitals, we can describe most of the properties of the non-metallic atoms and some metals.
Let’s get reacquainted around the periodic table:
The top row: H  He
   1s  1s
The main row: Li  Be  B  C  N  O  F  Ne
[1s²]  2s  2s  2p  2p  2p  2p  2p
The next row:
Na  Mg  Al  Si  P  S  Cl  Ar
[1s² 2s²2p⁶]  3s  3s  3p  3p  3p  3p  3p
Next: some metals: Cr, Mn, Ni, Cu, Zn  Br
[Ar]4s²3d¹⁰  4p
Next: more metals: Pd, Ag, Sn  I
[Kr]5s²4d¹⁰  5p
Finally: more metals: Os, Pt, Hg, Pb

VALENCE and the Octet Rule: The number of electrons (Group #) or the # of deficient electrons to the closed shell (octet) will give an approximation of how many other atoms can be attached to this atom.
Go through the top row.  The main row.  The 3rd row..
What are the main differences between the main row and the next row?
General Bonding Rules for neutral molecules.

<table>
<thead>
<tr>
<th>Atom</th>
<th>H</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>F,Cl,Br,I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examples</td>
<td></td>
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</tr>
</tbody>
</table>

This is simplified, we will look at charged molecules after Lewis Structures.

**Lewis Structures:**
Basic Concepts for drawing molecules correctly:
1. Total # of electrons = Sum(# of electrons from each atom)  Anion => add e⁻; Cation => subtract e⁻.
2. Arrange atoms, unique atom almost always in the center.
3. Arrange electrons to make **octets around all “main row”** atoms.  Row 3 can **expand octets**.
4. Match the electron count with total number of electrons and assign **formal charge**.
5. The least formal charge is the best structure.  Other structures may be possible: **Resonance**.

Electron counting.  How many electrons?  Then fill in the bonds and lone pairs.

```
H  H  H  H
H  C  C  H  C  C  H  C  C  H
H  H  H  H
```
**The first organic reaction.** In the 1860’s, a German chemist Friedrich Wöhler found that if he heated the salt, ammonium cyanate, he made something that smelled familiar. He verified it was what he thought it was.

Draw proper structures for the following reaction: \( \text{NH}_4^+ \text{OCN}^- \rightarrow \text{H}_2\text{NCONH}_2 \)

Now some more application.

Draw lone pairs and bonds for these molecules.

Fusing valence bond theory and Lewis structures.

The simple neutral hydrogen forms of the elements:

<table>
<thead>
<tr>
<th>Element</th>
<th>Compound</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P (trivalent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P (pentavalent)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Charged Molecules

General Bonding Rules for charged molecules.

<table>
<thead>
<tr>
<th>Atom</th>
<th>H⁺</th>
<th>C⁺</th>
<th>C⁻</th>
<th>N⁺</th>
<th>N⁻</th>
<th>O⁺</th>
<th>O⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Examples</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Consider these charged structures:

O⁻ H⁺ (⁺) H N⁺ H⁻ (⁻) C⁻ C⁻ C⁻

Sigma and Pi bonds.

**Sigma bonds** form the framework of molecules.

Which of the following are sigma bonds?

Identify the sigma bonds in the structures above.

What happens when you break a sigma bond?

**Pi bonds** are formed outside the main framework of the molecule.

Which of the following are pi bonds?

Identify the pi bonds in the structures above. What happens when you break a pi bond?

Where do the terms sigma and pi bonds come from?

Using toothpicks and paper clips make some sigma and pi bonds.
Here is summary picture showing both sigma and pi bonds in ethylene.

![Graph showing sigma and pi bonds in ethylene](http://home.att.net/~cat6a/carb_bonds-I.htm)

**Pi Bonds Give Special Properties to Organic Molecules**

![Atomic p orbitals and bonding pi orbitals](http://invsee.asu.edu/nmodules/Carbonmod/pibond.html)

**Hybridization**: a simple labeling system that explains molecular shape and reactivity. To assign hybridization count the number of areas of electron density around an atom. Because of the limitation of the octet rule: we consider the case of 2, 3 and 4 areas. This leads to the possibility of 2, 3, or 4 bonds for C. Here are the energy levels of the 2\(^{nd}\) row.

Atomic orbitals in 2nd row

\[
\begin{array}{c}
2s \\
\hline
2p \quad \quad \quad \quad \\
\hline
\end{array}
\]

For 4 sigma bonds, we would need \(s + p + p + p = sp^3\)

Consequently, there would be the possibility of _____ pi bonds.

For 4 sigma bonds, we would need \(s + p + p = sp^2\)

Consequently, there would be the possibility of _____ pi bonds.

For 4 sigma bonds, we would need \(s + p = sp\)

Consequently, there would be the possibility of _____ pi bonds.

Shapes can be predicted by the same theory.
Count the areas of electron density around the following atoms A. These are the basic shapes. **Linear 180°; trigonal planar 120°; tetrahedral 109.5°.**

Now for some real structures:

Note LP count as attachments and double/triple bonds don’t count; only sigma bonds. Figuring out hybridization is straightforward. For the 2nd row, we have one 2s orbital and 3 2p type orbitals. 2s is more stable than p, so it is always included in the new hybrid orbital. We use hybrids to describe bonding between 2 atoms, 3 atoms, and 4 atoms. Hybrid orbitals are just the mix of the s and the p orbitals.

**For 4 attachments**, s+p+p+p, called sp³. All possible s and p orbitals are used. This is called saturated. For sp³, we have 1 part s and 3 parts p.

The percentage of s = _________ The percentage of p = ____.

Describe the shape and structure of CH₄.

Describe the shape and structure of NH₃.

Describe the shape and structure of H₂O.
For 3 attachments, s+p+p = .
2 parts p and 1 part s. The percentage of s = _______ The percentage of p = ___.

For 2 attachments, s + p =
2 parts p and 1 part s. The percentage of s = _______ The percentage of p = ___.

Describe the bonding in CH₂=CH₂.

Describe the bonding in BH₃.

Describe the bonding in HCN.

Describe the bonding in CO.
The systematic consequences of hybridization.

Comparison of bond types. You need to know relative values.

<table>
<thead>
<tr>
<th>Systematic name</th>
<th>Ethane</th>
<th>Ethene</th>
<th>Ethyne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid orbitals of C</td>
<td>$sp^3$</td>
<td>$sp^2$</td>
<td>$sp$</td>
</tr>
<tr>
<td>Structural formula</td>
<td>$\text{H}_3\text{C-CH}_3$</td>
<td>$\text{H}_2\text{C=CH}_2$</td>
<td>$\text{H-C≡C-H}$</td>
</tr>
<tr>
<td>C-C Bondlength pm</td>
<td>154</td>
<td>134</td>
<td>120</td>
</tr>
<tr>
<td>C-H Bondlength pm</td>
<td>112</td>
<td>110</td>
<td>106</td>
</tr>
<tr>
<td>bond angle (H-C-C)$^\circ$</td>
<td>110</td>
<td>121</td>
<td>180</td>
</tr>
<tr>
<td>C-C BE kcal/mol</td>
<td>88</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>C-H BE kJcal/mol</td>
<td>100</td>
<td>110</td>
<td>130</td>
</tr>
</tbody>
</table>

Indicate weak to strong. Indicate short to long?

More in depth picture of bonding

Imagine what happens when 2 $\text{H}^+$ atoms come together from infinite distance in space.
Valence Bond Model of Molecular Bonding

Hybrid orbitals are very useful and are in the common language of organic chemistry. Valence bond orbitals are simple to understand. But neither of these models are mathematically correct. So, we need a better model.

**Molecular Orbitals**

Atomic orbitals come together to make molecular orbitals. Here are some basic rules:

1. Start with the atomic orbitals and electrons.
2. Sum of atomic orbitals and the # of electrons. For every atomic orbital, there is a Molecular orbital. # of electrons in the molecule = # of electrons from atoms
3. Build the orbitals from most stable to least stable from bottom up.
4. Fill the electrons in the orbitals according to Hund’s Rule using Pauli Exclusion Principle..
5. For neutral even number electron systems, there are as many filled orbitals as unfilled.

Construct an MO picture of H₂. Label the new orbitals drawn.

\[ \text{H} \quad \text{H} \]

\[ \text{1} \text{ bond of H}_2 \]

\[ \text{Overlap of two half-filled Hydrogen 1s orbitals} \]

\[ \begin{array}{c}
\text{H} \\
\text{1s} \\
\text{H}
\end{array} \quad \begin{array}{c}
\text{H} \\
\text{1s} \\
\text{H}
\end{array} \]

\[ \begin{array}{c}
\text{σ bond of H}_2
\end{array} \]
Here is the MO diagram for the sigma and sigma* orbitals for H$_2$.

**Meaning of MO diagrams**

**Bond order.**

The bond order is based on the number of bonding orbitals (pi and sigma) minus the number of antibonding orbitals (pi* or sigma*).

H$_2$ has a bond order =

Is H$_2$ a stable molecule? Why or why not?

Next, we consider the situation with He$_2$.

What is the bond order for He$_2$? 

Is He$_2$ predicted to be stable or not?
What is the bond order for Li₂? Is Li₂ predicted to be stable or not? Which molecule is more stable? H₂ or Li₂? What is the difference for N₂? Which way is higher energy? Which way is stable?
Putting it all together. Sigma and Pi

Ethylene can be analyzed in the same manner. For molecules with p orbitals, the highest energy occupied molecular orbitals (HOMO) is always a pi orbital and lowest energy unoccupied orbital (LUMO) is always pi*. There are many orbitals too stable to react. The reactive orbitals are classified as HOMO and LUMO.

How many orbitals are left out. Are they bonding?


Draw the Lewis Structure for ethylene.

H   H
C  C
H   H

How many sigma bonds?

How many pi bonds?

How do the VB and MO analyses differ?