A functional group is a specific group of atoms within a molecule that is responsible for a characteristic of that molecule. Many biologically active molecules contain one or more functional groups. In BIS2A, we will review the major functional groups found in biological molecules. These include the following: hydroxyl, methyl, carbonyl, carboxyl, amino, and phosphate (see Figure 1).

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Structure</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxyl</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Polar</td>
</tr>
<tr>
<td>Methyl</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Nonpolar</td>
</tr>
<tr>
<td>Carbonyl</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Polar</td>
</tr>
<tr>
<td>Carboxyl</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Charged; ionizes to release H⁺. Since carboxyl groups can release H⁺ ions into solution, they are considered acidic.</td>
</tr>
<tr>
<td>Amino</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Charged, accepts H⁺ to form NH₃⁺. Since amino groups can remove H⁺ from solution, they are considered basic.</td>
</tr>
<tr>
<td>Phosphate</td>
<td><img src="https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_(Easlon)/Readings/03.4%25%E2%80%A6" alt="Structure" /></td>
<td>Charged; ionizes to release H⁺. Since phosphate groups can release H⁺ ions into solution, they are considered acidic.</td>
</tr>
</tbody>
</table>
Figure 1.
The functional groups shown here are found in many different biological molecules. "R" represents any other atom or extension of the molecule.

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A functional group may participate in a variety of chemical reactions. Some of the important functional groups in biological molecules are shown above: hydroxyl, methyl, carbonyl, carboxyl, amino, phosphate, and sulfhydryl (not shown). These groups play an important role in the formation of molecules like DNA, proteins, carbohydrates, and lipids. Functional groups can sometimes be classified as having polar or nonpolar properties depending on their atomic composition and organization. The term polar describes something that has a property that is not symmetric about it—it can have different poles (more or less of something at different places). In the case of bonds and molecules, the property we care about is usually the distribution of electrons and therefore electric charge between the atoms. In a nonpolar bond or molecule, electrons and charge will be relatively evenly distributed. In a polar bond or molecule, electrons will tend to be more concentrated in some areas than others. An example of a nonpolar group is the methane molecule (see discussion in Bond Types Chapter for more detail). Among the polar functional groups is the carboxyl group found in amino acids, some amino acid side chains, and the fatty acids that form triglycerides and phospholipids.

Nonpolar functional groups

Methyl R-CH₃

The methyl group is the only nonpolar functional group in our class list above. The methyl group consists of a carbon atom bound to three hydrogen atoms. In this class, we will treat these C-H bonds as effectively nonpolar covalent bonds (more on this in the Bond Types chapter). This means that methyl groups are unable to form hydrogen bonds and will not interact with polar compounds such as water.
Figure 2.
The amino acid isoleucine is on the left, and cholesterol is on the right. Each has a methyl group circled in red.
Attribution: created by Marc T. Facciotti (own work adapted from Erin)
The methyl groups highlighted above are found in a variety of biologically relevant compounds. In some cases, the compound can have a methyl group but still be a polar compound overall due to the presence of other functional groups with polar properties (see the discussion on polar functional groups below).

As we learn more about other functional groups, we will add to the list of nonpolar functional groups. Stay alert!

**Polar functional groups**

**Hydroxyl R-OH**

A hydroxyl (alcohol group) is an -OH group covalently bonded another atom. In biological molecules the hydroxyl group is often (but not always) found bound to a carbon atom, as depicted below. The oxygen atom is much more electronegative than either the hydrogen or the carbon, which will cause the electrons in the covalent bonds to spend more time around the oxygen than around the C or H. Therefore, the O-H and O-C bonds in the hydroxyl group will be polar covalent bonds. Figure 3 depicts the partial charges, δ⁺ and δ⁻, that are associated with the hydroxyl group.
Figure 3.
The hydroxyl functional group shown here consists of an oxygen atom bound to a carbon atom and a hydrogen atom. These bonds are polar covalent, meaning the electron involved in forming the bonds...
is not shared equally between the C-O and O-H bonds.

Attribution: created by Marc T. Facciotti (own work)
Figure 4.
The hydroxyl functional groups can form hydrogen bonds, shown as a dotted line. The hydrogen bond will form between the δ- of the oxygen atom and the δ+ of the hydrogen atom. Dipoles are shown in blue arrows.
Attribution: Marc
Hydroxyl groups are very common in biological molecules. Hydroxyl groups appear on carbohydrates (A), on some amino acids (B), and on nucleic acids (C). Can you find any hydroxyl groups in the phospholipid in (D)?
Hydroxyl groups appear on carbohydrates (A, glucose), on some amino acids (B, Serine), and on nucleotides (C, adenosine triphosphate). D is a phospholipid.

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**Carboxyl R-COOH**

Carboxylic acid is a combination of a carbonyl group and a hydroxyl group attached to the same carbon, resulting in new characteristics. The carboxyl group can ionize, which means it can act as an acid and release the hydrogen atom from the hydroxyl group as a free proton (H⁺). This results in a delocalized negative charge on the remaining oxygen atoms. Carboxyl groups can switch back and forth between protonated (R-COOH) and deprotonated (R-COO⁻) states depending on the pH of the solution.
The carboxyl group is very versatile. In its protonated state, it can form hydrogen bonds with other polar compounds. In its deprotonated state, it can form ionic bonds with other positively charged compounds. This will have several biological consequences that will be explored more when we discuss enzymes.

Can you identify all the carboxyl groups on the macromolecules shown above in Figure 5?

**Amino R-NH₃**

The amino group consists of a nitrogen atom attached by single bonds to hydrogen atoms. An organic compound that contains an amino group is called an amine. Like oxygen, nitrogen is also more electronegative than both carbon and hydrogen, which results in the amino group displaying some polar character.

Amino groups can also act as bases, which means that the nitrogen atom can bond to a fourth hydrogen atom, as shown in Figure 6. Once this occurs, the nitrogen atom gains a positive charge and can now participate in ionic bonds.
Figure 6.
The amine functional group can exist in a deprotonated or protonated state. When protonated, the nitrogen atom is bound to three hydrogen atoms and has a positive charge. The deprotonated form of this
A phosphate group is a phosphorus atom covalently bound to four oxygen atoms and contains one P=O bond and three P-O⁻ bonds. The oxygen atoms are more electronegative than the phosphorous atom, resulting in polar covalent bonds. Therefore, these oxygen atoms are able to form hydrogen bonds with nearby hydrogen atoms that also have a δ⁺ (hydrogen atoms bound to another electronegative atom). Phosphate groups also contain a negative charge and can participate in ionic bonds.

Phosphate groups are common in nucleic acids and on phospholipids (the term "phospho" referring to the phosphate group on the lipid). In Figure 7 are images of a nucleotide, deoxyadenosine monophosphate (left), and a phosphoserine (right).

Figure 7. A nucleotide, deoxyadenosine monophosphate, is on the left, and phosphoserine is on the right. Each has a phosphate group circled in red.

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