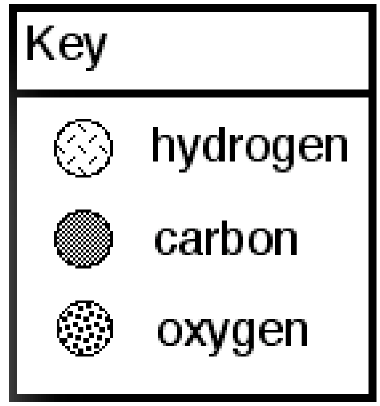
Chapter 8: Organics Containing Oxygen

Organic Functional Groups

(containing oxygen)

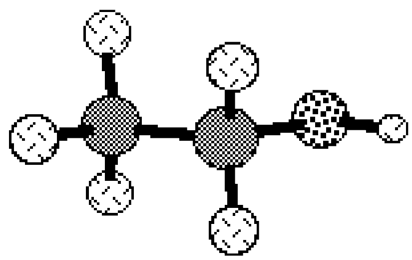


Alcohols:

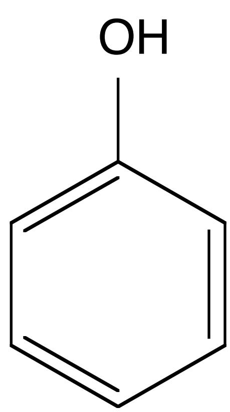
These compounds contain an –OH group. This group is bonded to some organic backbone. For example, ethanol consists of an –OH group bonded to an ethyl (2 carbon) backbone.

ethanol

H_3C —— CH_2 —— OH



Alcohols can also be formed utilizing aromatic backbones. The simplest aromatic alcohol is called phenol. It is used in many applications, including uses as a hospital disinfectant and in chemical peel procedures:



Phenol

Ethers:

These compounds consist of an oxygen atom bridging two separate carbon backbones. The two backbones may be identical, or they may be different.

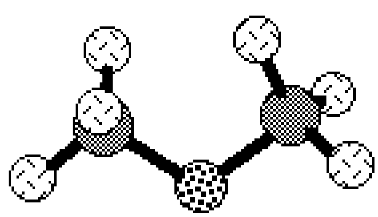
We sometimes denote an organic backbone as R. When there are two backbones, we denote them R and R', or, sometimes R_1 and R_2. Thus we say that an alcohol has a general structure of:

R-O-H

whereas an ether has a generic structure given by:

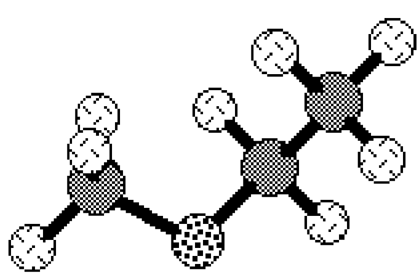
R'-O-R''

Here are a couple of common ethers, one symmetric and one asymmetric (different R's on each side of the O atom):



H_3C — O — CH_3

dimethylether



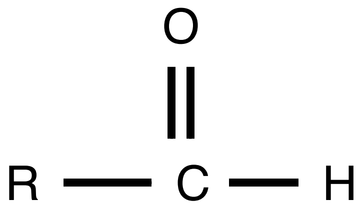
H_3C — O — CH_2 — CH_3

ethyl methylether

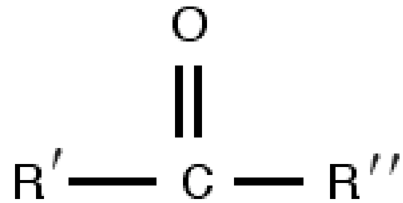
Aldehydes:

The next two series of compounds contain a single oxygen atom, but this time the oxygen atom is bonded via a double bond to a carbon atom. When this occurs at the end of the molecule, we have an aldehyde. When it occurs in the middle we have a ketone:

A generic aldehyde:



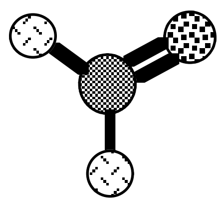
A generic ketone:



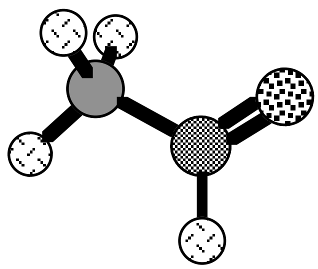
The carbon doubly bonded to the oxygen is sometimes called a carbonyl group. Aldehydes and ketones both contain carbonyl groups, as you can see.

Some examples of aldehydes:

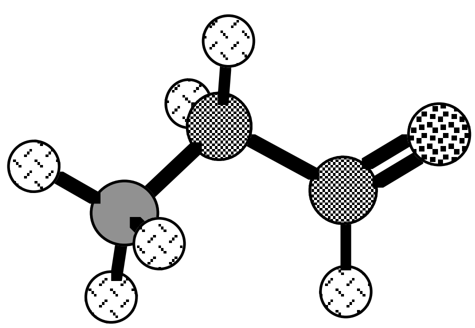
methanal
(formaldehyde)



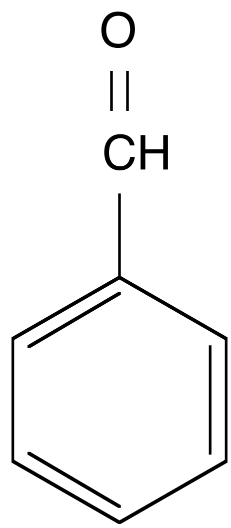
ethanal
(acetaldehyde)



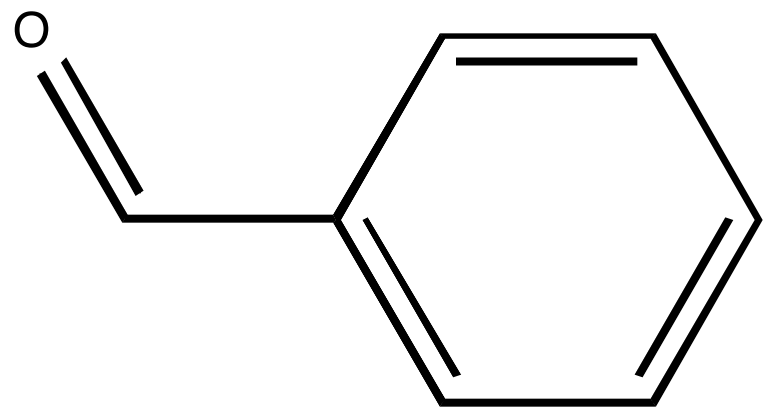
propanal
(propionaldehyde)



An example of an aromatic aldehyde is benzaldehyde, which has an aroma reminiscent of almonds. In fact, it is one of the primary flavors in almonds, and is the chief active component of almond extract, used in flavoring cakes and icings. Here are 2 different but equivalent views of benzaldehyde:

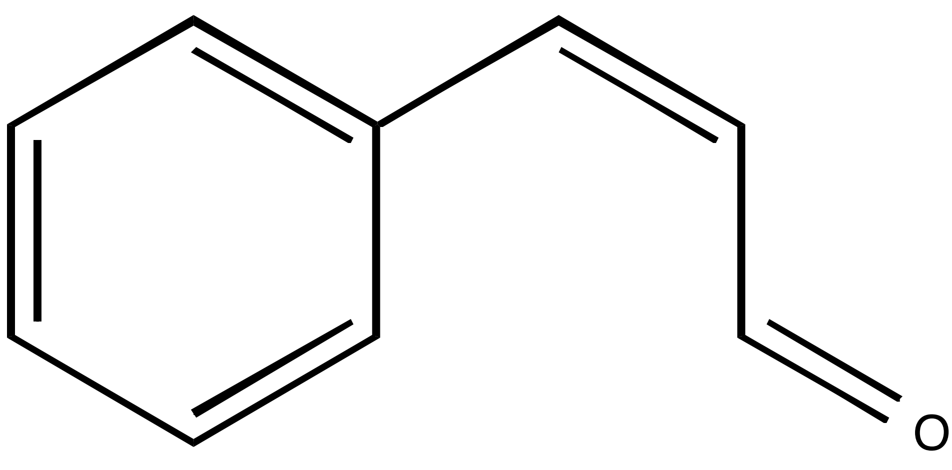


benzaldehyde

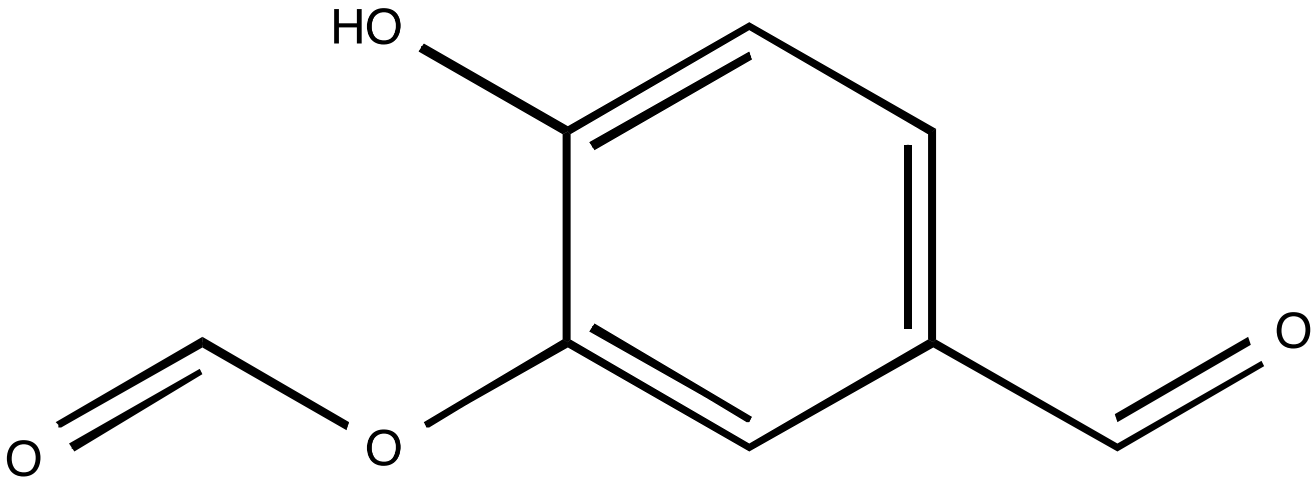


benzaldehyde (almond extract)

Aldehydes are also the principal components in the flavors we associate with cinnamon and vanilla:



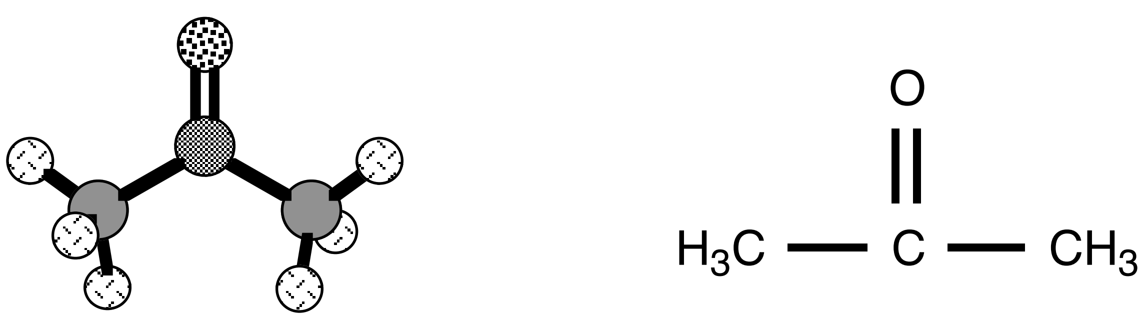
cinnamaldehyde



vanillinaldehyde

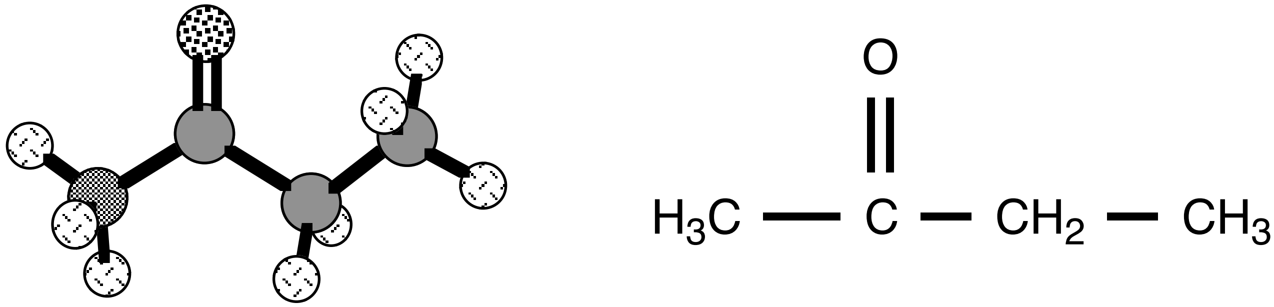
Ketones:

As noted above, ketones contain a carbonyl group sandwiched between two carbon skeletons. The fact that the carbonyl group is not on the end of the molecule makes it less reactive. Below are a few examples of ketones.



2-propanone
(acetone)
(propan-2-one)
(dimethylketone)

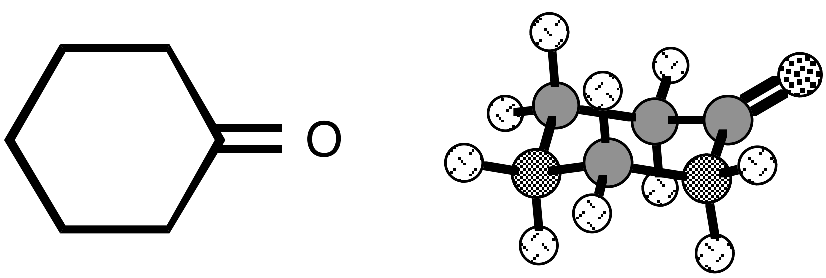
This is the world famous acetone of chemistry lab and nail-polisher remover fumes.



2-butanone
(butan-2-one)
(ethyl methylketone)

If the carbonyl group were to be relocated on the #1 carbon, this would become butanal, an aldehyde. Butanal and 2-butanone are isomers.

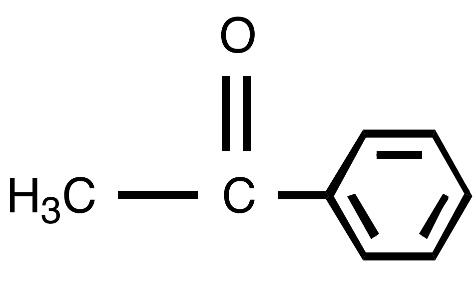
Here is a compound which is a cyclic ketone:

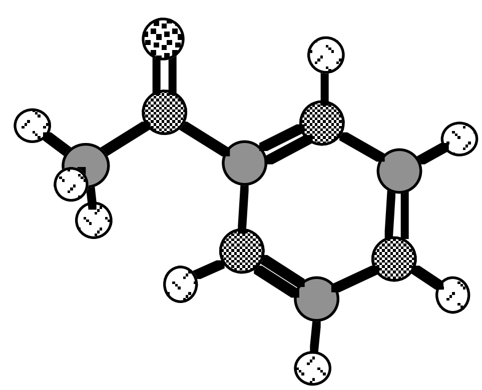


cyclohexanone

There cannot be a truly cyclic aldehyde, one involving a carbon atom which is a member of the ring in a cyclic compound. Can you see why?

Finally, an aromatic ketone:

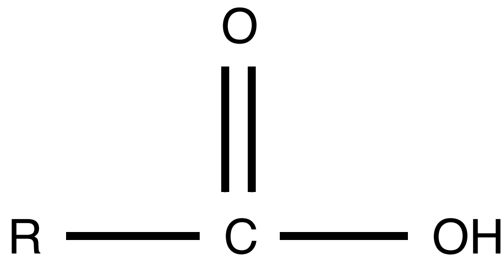




1-Phenyl-ethanone
(acetophenone)
(methyl phenylketone)

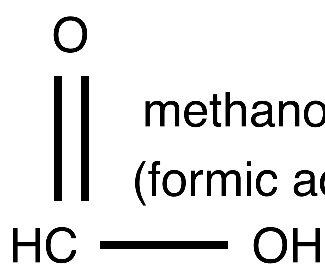
Carboxylic Acids:

A carbonyl group with an oxygen attached to the carbonyl carbon is called a carboxyl group. Add an H atom to this and you have a carboxylic acid. The generic formula for a carboxylic acid is:

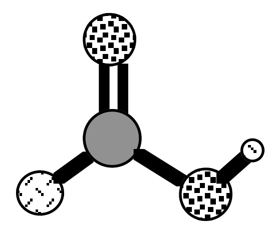


Note that the acidic hydrogen is the one attached to the oxygen atom. Common mistakes that students make is to assume that, because this is an –OH group, we must have an alcohol. Absolutely untrue!!! When the –OH is attached to a carbonyl group, we have a carboxylic acid. ANother mistake is to see the –OH and think “base”. These are not bases, they are acids; in general the hydrogen ion detaches from the oxygen, and the oxygen stays put.

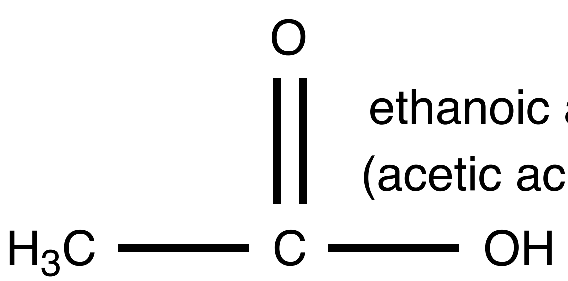
Here are some examples of carboxylic acids:



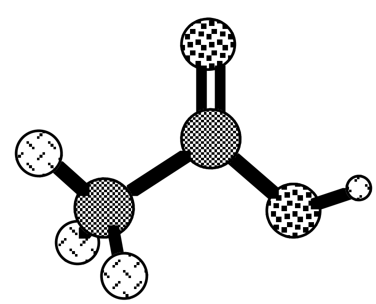
methanoic acid
(formic acid)



In Latin, formica stands for ant, and this acid gets its name because it is a component of ant venom, and the venom of many other stinging insects.



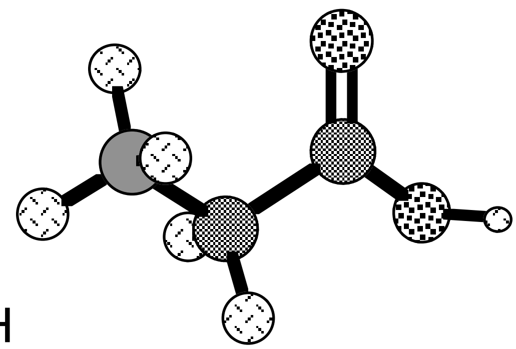
ethanoic acid
(acetic acid)



Good old vinegar! The hydrogen ions supply the sourness, and the acetate ion the characteristic “vinegar” taste.

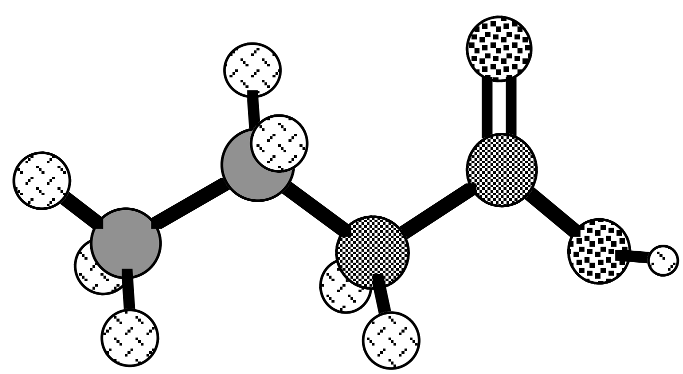
propanoic acid
(propionic acid)

$H_3C - CH_2 - C(=O) - OH$



butanoic acid
(butyric acid)

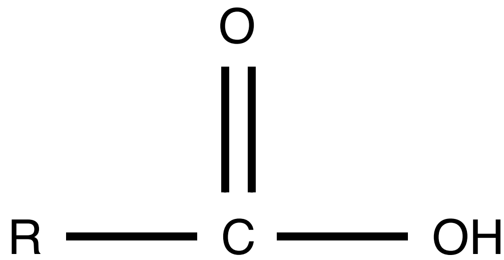
$H_3C - CH_2 - CH_2 - C(=O) - OH$



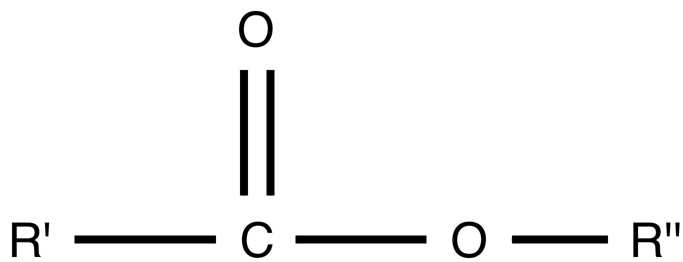
Butyric acid is found in rancid butter and vomit--sorry folks but it is the truth--and it is also found in parmesan cheese. Depending on context and concentration, chemical compounds can be foul smelling or part of a complex and pleasurable flavor. Butyric acid is also present in foot perspiration. Dogs are particularly sensitive to the smell of this compound. Lately, butyric acid has been used in “stink bomb” attacks on abortion clinics by the more militant elements of the anti-abortion movement.

Esters:

A carbonyl group with an oxygen attached to the carbonyl carbon is called a carboxyl group. Add an H atom to this and you have a carboxylic acid. We wrote down the generic formula for a **carboxylic acid** above. It looked like this:



If you replace the acidic hydrogen in a carboxylic acid with a hydrocarbon skeleton, you get a compound with two carbon skeletons connected together with a carboxyl group. It is called an **ester**, and it looks like this:



Central to understanding an ester, is understanding how esters are formed. The process is really very simple. You simply react an alcohol with a carboxylic acid. The reaction is just a "switch your partner" reaction, and it goes like this:

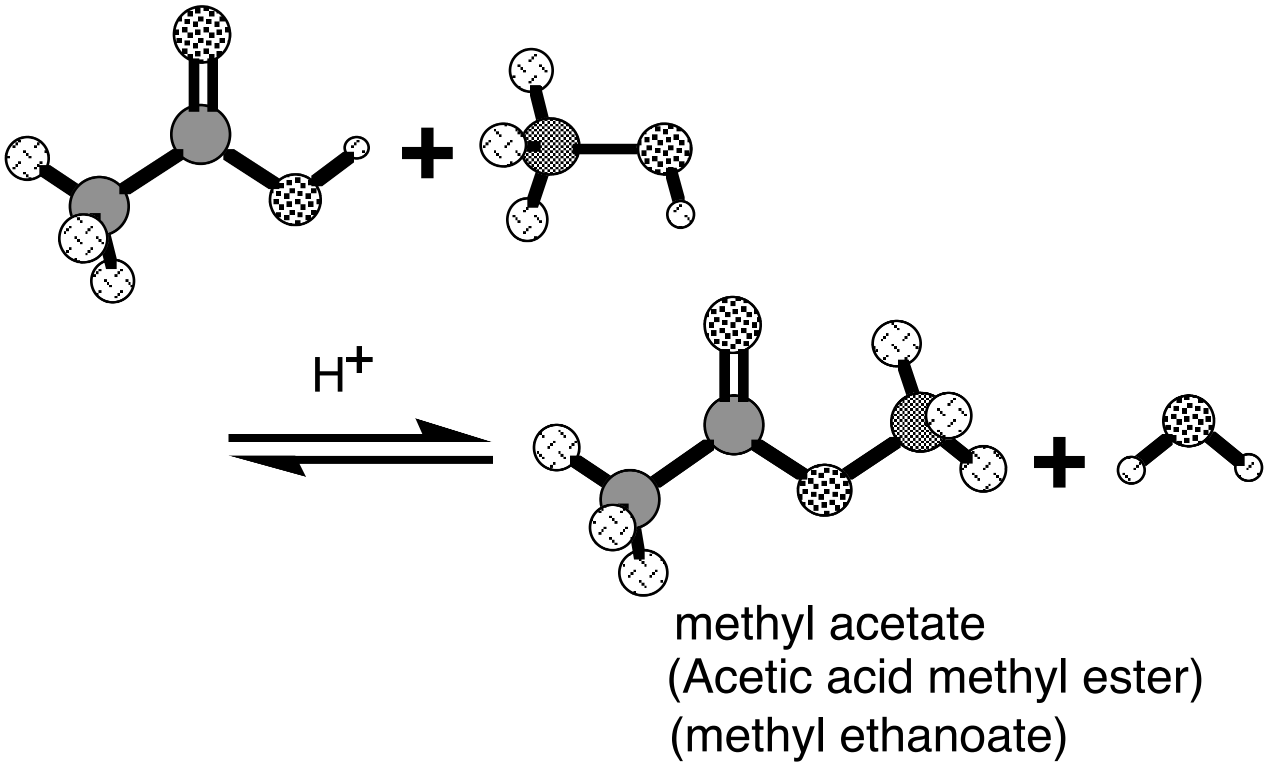
$$\text{Carboxylic Acid} + \text{Alcohol} \xrightleftharpoons{H^+} \text{Ester} + \text{water}$$

A simple example of an esterification reaction (which is what the ester-formation reaction is called) is shown below:

$$\text{acetic acid} + \text{methanol} \xrightleftharpoons{H^+} \text{methyl acetate} + \text{water}$$

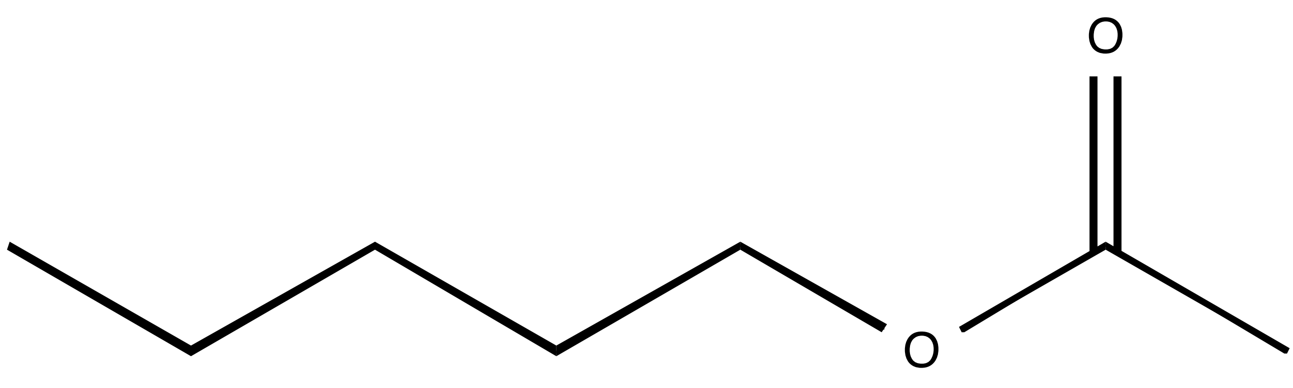
This is actually a metathesis reaction (a double displacement reaction), the kind of reaction where the reactants "switch partners" to form the products. In this reaction, a hydrogen splits off from the alcohol, and an –OH splits off from the carboxylic acid to form water. The remaining organic fragments unite to form the ester. Note that the reaction proceeds fastest in the presence of hydrogen ions; we say the reaction is acid catalyzed, and we symbolize this by writing a hydrogen ion above the reaction arrow.

The double displacement nature of the reaction is best understood by studying a picture of the ball and stick reaction models depicting the reaction between an alcohol and a carboxylic acid:

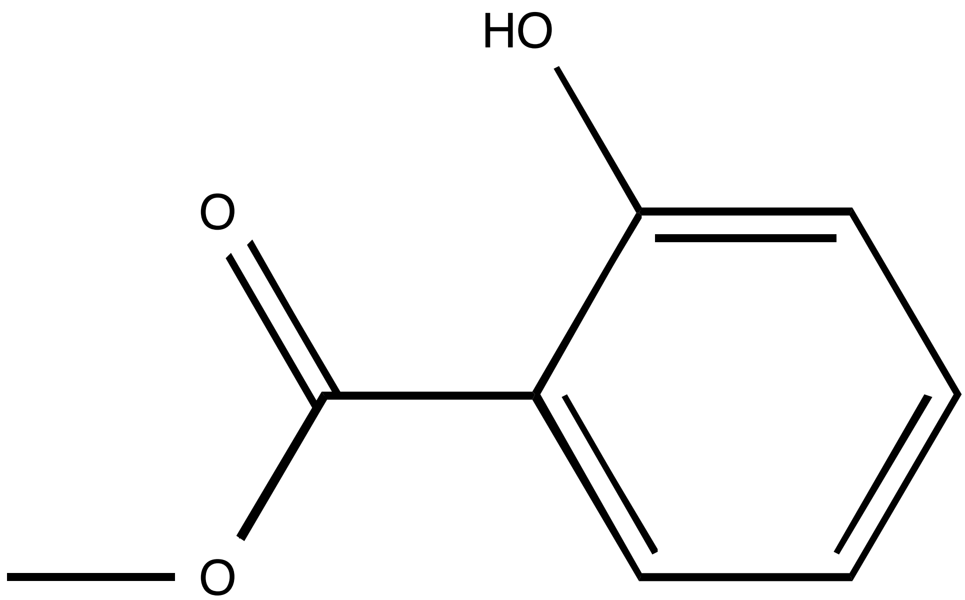


Note how the ester is named after its parents: it is called methyl acetate because its mommy was methanol and its daddy was acetic acid.

Esters are responsible for many fruity flavors. For example, pentyl acetate, also known as amyl acetate, is one of the principal components of the flavor in bananas. Methyl salicylate is the primary flavor in oil of wintergreen.



amyl acetate (pentyl acetate)



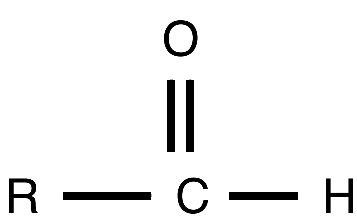
methyl salicylate

Summary

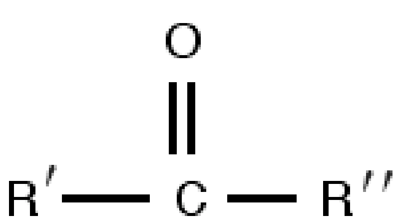
Let’s summarize the functional groups containing only oxygen:

R-O-H Alcohols

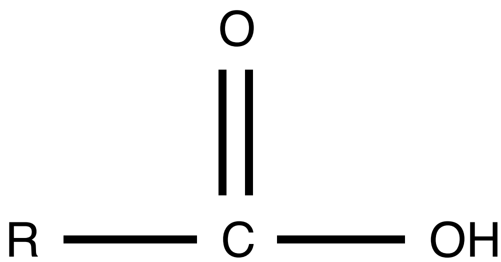
R′-O-R″ Ethers



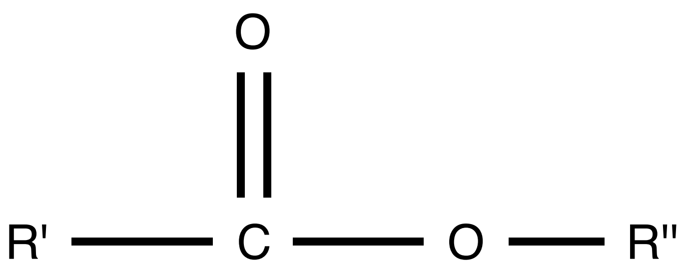
Aldehydes



Ketones



Carboxylic Acids



Esters