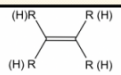
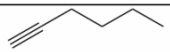
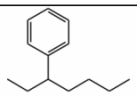
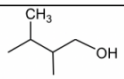
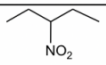
2.3: Functional Groups

Functional groups are the most reactive parts in organic compounds, and determine the major properties of compounds. The summary of common functional groups is included in **Table 2.2**. Knowing the functional groups well is one of the fundamental skills required for this course. It is required in order for students to quickly identify and name the functional groups included in molecules, as well as to understand, interpret and draw the specific structure of each functional group clearly. The IUPAC naming of compounds containing a couple of functional groups is required as well.

Class of Compounds	General Structure*	Specific Example	Notes
Alkene			
Alkyne			
Aromatic ring			
Alkyl halide (Haloalkane)	R-X X: F, Cl, Br or I		$R\text{-}CH_2\text{-}X$: 1° halide $R_2\text{-}CH\text{-}X$: 2° halide $R_3\text{-}C\text{-}X$: 3° halide
Alcohol	R-OH		$R\text{-}CH_2\text{-}OH$: 1° alcohol $R_2\text{-}CH\text{-}OH$: 2° alcohol $R_3\text{-}C\text{-}OH$: 3° alcohol
Ether	R-O-R'	$CH_3—O—CH_2CH_3$ ethyl methyl ether (common name)	**Common name:**** Alkyl alkyl ether (alphabetic order)
Nitrile	$R—C\equiv N$	$H_3C—C\equiv N$	
Nitro	$R—NO_2$		
Amine	RNH_2 R_2NH R_3N	$CH_3CH_2NH_2$: ethyl amine (common name) $(CH_3CH_2)_3N$: triethyl amine (common name)	**Common name:**** Alkyl alkyl alkyl amine (alphabetic order)

** R: hydrocarbon group, alkyl or phenyl; for structure with multiple R, they can be same or different groups.*
*** These common names are accepted by IUPAC.*

Figure 2.3a Table 2.2 Common Organic Functional Groups

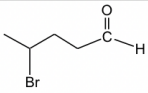
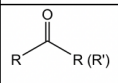
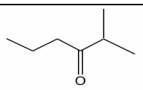
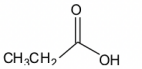
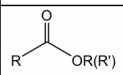
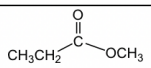
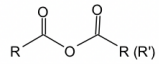
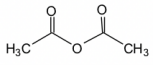
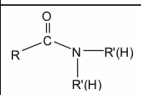
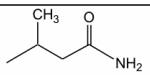
Class of Compounds	General Structure	Specific Example	Notes
Aldehyde	 or: R-CHO		C=O double bond is usually called as a **"carbonyl"** group. The function groups on this page all contain carbonyl group.
Ketone			
Carboxylic acid	 *or:* R-COOH		Reaction with base gives salt of carboxylic acid, $RCOO^-M^+$
Ester			Carboxylic acid derivative.
Anhydride			Carboxylic acid derivative.
Amide			Carboxylic acid derivative

Figure 2.3b Table 2.2 Common Organic Functional Groups (continued)

Alkene and alkynes are hydrocarbon functional groups; the π bond in multiple bonds accounts for the reactivity of alkenes and alkynes.

Benzene rings (C_6H_6) are a special type of hydrocarbon. Historically, because of the special aroma (sweet smelling) that benzene and its derivatives release, they are called aromatic compounds. The structure of benzene can be represented as three C=C double bonds alternate with single bonds, however, the actual structure of benzene has nothing to do with alkenes. Detailed discussions on the structure of benzene, which is a big conjugation system, and the chemistry definitions of aromatic/aromaticity will be a topic of Organic Chemistry II. Benzene rings can be shown with any of the following structure drawings.

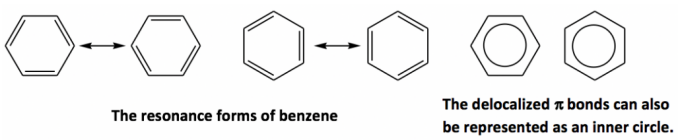


Figure 2.3c Benzene

When a halogen is connected with carbon, the group is called **alkyl halide (**or **haloalkane)**. The halide can be categorized as a primary (1°), secondary (2°) or tertiary (3°) halide, depending on what category the carbon connected with the halogen is in.

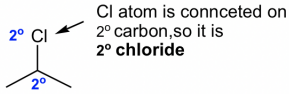


Figure 2.3d Chloride on 2° carbon

Alcohol is a functional group that you probably are familiar with. In organic chemistry, the term alcohol refers to a compound containing the OH (hydroxy) group. Depending on the position of the OH group, alcohols can also be categorized as primary (1°), secondary (2°) or tertiary (3°).

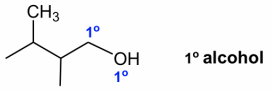


Figure 2.3e 1° alcohol

Another functional group that contains the oxygen atom in single bonds is **ether**. In ether, the O atom connects with two carbon-containing R groups through two C-O σ bonds. For compounds with ether as the only functional group, it is usually named with the common name "alkyl alkyl ether". When the two alkyl groups are the same, they can be combined as "dialkyl".

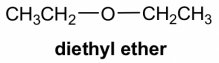


Figure 2.3f diethyl ether

Ether can be in cyclic structure as well. It may not be that intuitive to recognize the following structure as ether, and labelling the carbon atom will be helpful for identification.

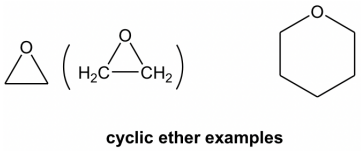


Figure 2.3g Cyclic ether examples

Both **nitrile** and **nitro** groups contain nitrogen atom, and it might be easy to get them mixed up. Nitrile has a C≡N triple bond, and therefore can only be at the end of a structure, while nitro (NO_2) can be in any position on the carbon chain or ring.

Amine is the organic derivative of ammonia, NH_3. When the hydrogen atom(s) in NH_3 is replaced with R groups, it produces amine. The amine can be primary (1°), secondary (2°) or tertiary (3°) depending on how many R groups are connected with nitrogen. The amines can also be named with common names.

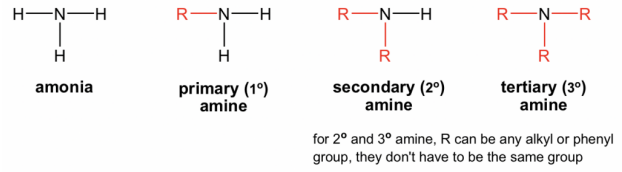


Figure 2.3h Primary, secondary, & tertiary amine

For the functional groups on the 2nd part of **Table 2.2**, they all have a common structural unit of a carbonyl group C=O; the different structure of "W" in the general formula determines the nature of the functional group. It is usually more challenging to identify and draw these functional groups correctly, because they are kind of similar. More practice is needed.

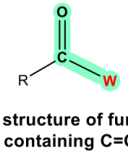


Figure 2.3i General structure of functional groups containing c=o bond

Aldehyde and **ketone** are similar in terms of their structures and properties. Aldehyde can be regarded as a special case of ketone since "H" can be *regarded* as an R with zero carbon. Because H has to be connected on one side of the C=O group in aldehyde, aldehyde can only be at the end of a structure. Ketone, on the other hand, must be in the middle position to ensure both sides of the C=O groups are connected with R groups. Ketone can also be in a cyclic structure.

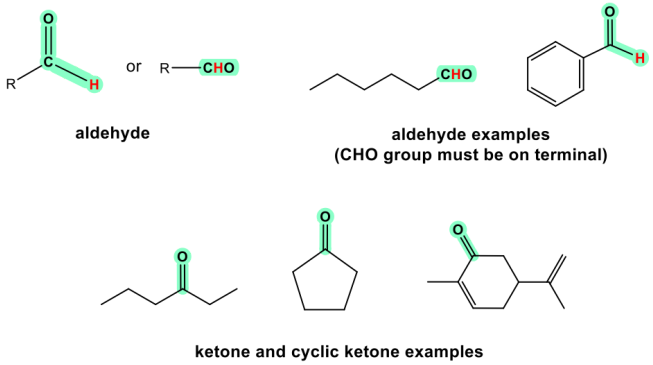


Figure 2.3j Ketone and cyclic ketone examples

The last four functional groups are related in terms of structures and chemical properties. When an OH group is connected with C=O, the whole COOH is called a **carboxylic acid** functional group. The other three, **ester**, **anhydride** and **amide,** are all *derivatives* of carboxylic acid, meaning they can be prepared with carboxylic acid as the starting material. For these three

functional groups, it is important to remember that the “W” part has to be considered together with the C=O, and overall it determines the functional group correctly. For example, the COOR is ester; it **can not** be recognized as a “ketone” plus an “ether”.

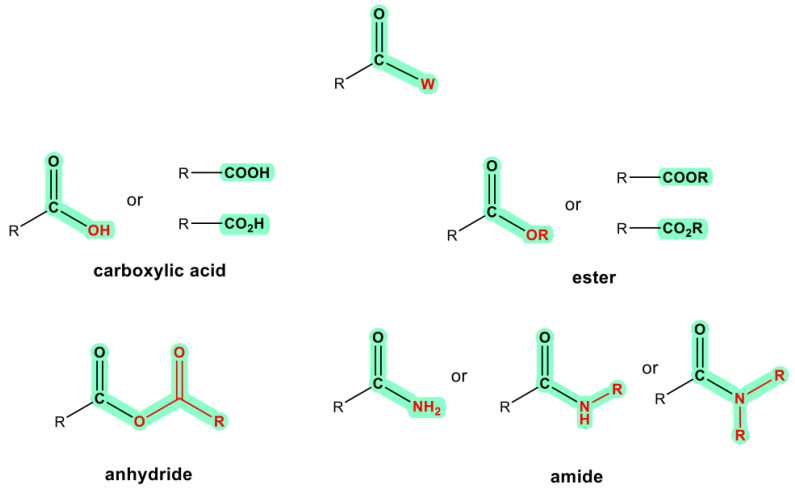


Figure 2.3k Carboxylic acid (COOH/CO2H), ester (COOR/CO2R), anhydride, & amide