Functional Groups and Chemical Families

Although there are a wide variety of organic compounds, most of them are composed of the elements from the upper right hand portion of the periodic chart: C, H, N, O, S, Halogen. These compounds can be categorized by certain structural and reactive features, dictated by the way carbon bonds to itself or another element, e.g. carbon double bonded to oxygen. Such a grouping of compounds provides us with the concept of chemical families. These special bonding arrangements have different reactivities or functions and associated with each family is particular functional group.

Rigorously speaking the functional group is not the whole molecule but only that collection of atoms that provides a specific chemical function. For example, the chemical family of alcohols is characterized by the function of the hydroxyl (OH) group, and aldehydes, ketones are characterized by carbonyl groups (C=O). There are various combinations of hydroxyl groups in molecules along with carbonyl groups and these combinations can lead to hydroxyketones and aldehydes (the basis for sugars) as well as to carboxylic acids. Indeed, esters, and amides also have carbonyl groups (C=O) but differ in their combination with an additional structural feature. To understand the reactivity of chemical families one must consider the interplay between the various structural features in that molecule, and identifying the fundamental functional groups is a good place to start.

Within a given family family members are arranged by the length of the longest carbon chain. Typically an organic compound will have a base name composed of a suffix to identify the family and a prefix to identify the length of the longest carbon chain. The first 10 prefixes are

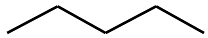
meth-	1	hex-	6
eth-	2	hept-	7
prop-	3	oct-	8
but-	4	non-	9
pent-	5	dec-	10

The following provides a list of the more common chemical families exemplified as their pent-member.

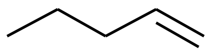
Hydrocarbons (all C,H)

Alk<u>anes</u>

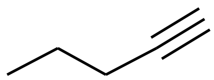
Molecular formula C_nH_{2n+2}

C_5H_{12}  **pent***ane*

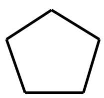
Alkenes
Molecular formula C_nH_{2n}

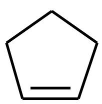
C_5H_{10}  **pent***ene*

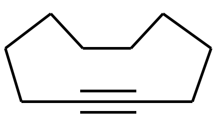
Alkynes
Molecular formula C_nH_{2n-2}

C_5H_8  **pent***yne*

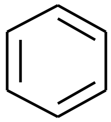
Cyclo(-alkanes, -alkenes, -alkynes)

C_5H_{10}  **cyclopent** *ane*

C_5H_8  **cyclopent** *ene*

$C_{10}H_{16}$  **cyclodec** *yne*

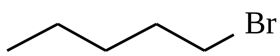
Arenes

C_6H_6  **benzene**

Heteroatom Substituted Hydrocarbons

Alkylhalides

(haloalkanes)

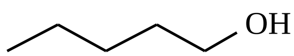
$C_5H_{11}Br$ 

bromopent *ane*

pentyl *bromide*

This example uses bromine but any halogen (ie group VIIb) element applies: fluorine; chlorine; bromine; iodine.

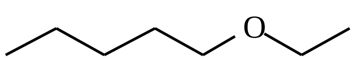
Alcohols

$C_5H_{12}O$ 

pentan*ol*

pentyl *alcohol*

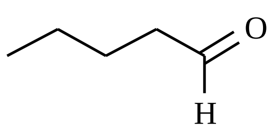
Ethers

$C_5H_{12}O$ 

ethoxy *pentane*

pentyl ethyl *ether*

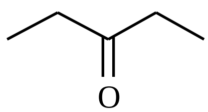
Aldehydes

$C_5H_{10}O$ 

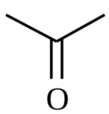
pentan*al*

valeraldehyde

Ketones

$C_5H_{10}O$ 

pentan*one*

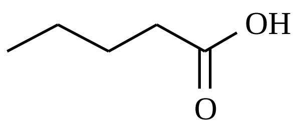
C_3H_6O 

propan *one*

acetone

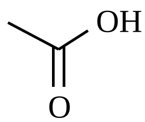
Carboxylic Acids

$C_5H_{10}O_2$



pentan*oic acid*

$C_2H_4O_2$

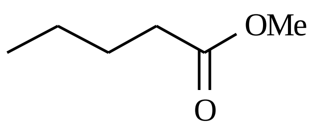


ethan*oic acid*

acetic acid

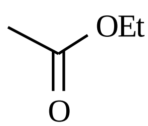
Esters

$C_6H_{12}O_2$



methyl *pentanoate*

$C_4H_8O_2$

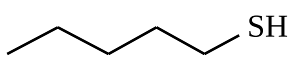


ethyl *ethanoate*

ethyl acetate

Thiols

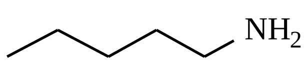
$C_5H_{12}S$



pentane *thiol*

Amines

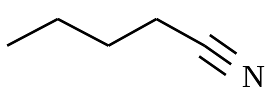
$C_5H_{13}N$



pentan*amine*

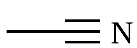
Nitriles

C_5H_9N



pentane *nitrile*

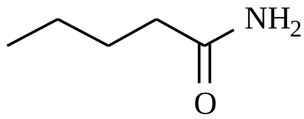
C_2H_3N

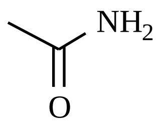


ethane *nitrile*

acetonitrile

Amides

$C_5H_{11}NO$  **pentan**<u>*amide*</u>

C_2H_5NO  **ethan**<u>*amide*</u>

acetamide

Using functional groups to predict reactivity.

Once having a list of common functional groups, the organization of those functional groups by oxidation state is another useful way to see reactivity patterns. To simplify the method, look first to the one carbon members of the oxahydrocarbon families (alkanes to carbon dioxide). Hydrogen and oxygen are redox standards at +1 and –2, respectively. Thus, the carbon oxidation state in methane is –4, in methanol it is –2, in formaldehyde (methanal) it is 0, in formic acid (methanoic acid) it is +2, and in carbon dioxide it is +4. From these few examples, one sees that carbon is very versatile in the oxidation states it can adopt. Crudely separating reactivity into redox and acid/base character, it should be clear that the conversion of methane to methanol cannot proceed by simply by acid/base reagents by requires redox character, specifically an oxidizing reagent. Once the oxidation state of carbon is assigned for these functional groups it is possible to relate other functional groups to these redox archetypes in order to form a sort of periodic table of the functional groups (Table).

Table. Periodic Table of the Functional Groups (Chemical Families).

Redox ->	-4	-2	0	+2	+4
Elements	Methane	Methanol	Formaldehyde	Formic Acid	Carbon Dioxide
CHO	Alkanes	Alcohols Ethers	Aldehydes Ketones	Acids Esters	Carbon Dioxide

	(Alkenes)	Acetals Ketals (Alkynes)		
Halide X	Alkyl Halides	Gem-dihalides	Gem-trihalides Acid Halides	Carbon tetrachloride
Nitrogen	Amines Nitriles** Azides	Imines	Amides Imidines Nitriles**	Carbo-dimides
Sulfur	Thiols Mercaptans	Thioketones Thio ketals	Thio esters	Carbon disulfide
Phosphorous	Phosphines			

From this table of the functional groups one recognizes that any transformation between columns must involve a redox process whereas transformations between rows can be accomplished by acid/base processes. It forms a scaffolding on to which we can hang our knowledge of reactivity, and at the same time it prepares us to think of yet unseen transformations on the basis of how those transformations might be effected. This abstraction of chemical structure into a focused relationship of functional group types can be one the most powerful tools for understanding and simplifying organic chemical reactivity.