

## Chapter 17 Carboxylic Acids and their Derivatives

### Carboxylic Acids

Carboxylic acids are easily converted to esters and amides and back again. The reactivity of the carboxylic acids makes it possible to form polymers (synthetic and biological)...the most notable is the making of proteins!

Carboxylic acids have an  $\text{-OH}$  Group bonded to the carbonyl Carbon and the carboxyl group is abbreviated as  $\text{-COOH}$ .

Esters have an  $\text{-OR}$  group bonded to the carbonyl Carbon.

Amides have an  $\text{-NH}_2$ ,  $\text{-NHR}$  or  $\text{-NH}_2$  group bonded to the carbonyl C.

### All of these compounds have some things in common!

- A carbonyl Carbon bonded either to an O or a N.
- They have polarity of their functional groups
- All are higher boiling than comparable alkanes
- Carboxylic acid and amides can also Hydrogen-Bond
- They commonly undergo carbonyl-group substitution reactions
- The portion of the carboxylic acid that does NOT change during reactions is called the *aryl group*.

Bond Angles!

### Carbonyl-Group Substitution Reactions

This is how we go from one compound to the other!

### Carboxylic Acids

Though the most significant property of CAs is their behavior as weak acids, they are not strong enough to be generally hazardous to human health. They can H-Bond with each other so that even the most simple one is liquid at room temp and has a boiling point of 101-degrees Celsius.

The carboxyl group has TWO polar groups. This double-polarity leads to CAs having high boiling points...even higher



So...when using common names:

1. Instead of numbering, the carbon atoms attached to the  $\text{-COOH}$  group are identified by Greek letters (alpha, beta, etc...)
2.  $\text{-oic}$  becomes  $\text{-ionic}$
3. The acyl group that remains when a CA loses its  $\text{-OH}$  group is named by replacing the  $\text{-ic}$  at the end of the acid name with  $\text{-oyl}$ ...one exception is the acyl group from acetic acid, which is called an *acetyl group*.

Naming dicarboxylic acids, which have two  $\text{-COOH}$  groups

1. Named systematically
2. Add ending  $\text{-dioic acid}$  to the alkane name (keep the  $\text{-e}$ )
3. Common names are pretty common for the simple ones!
  - a. Oxalic, succinic, glutaric...

Naming unsaturated acids IUPAC

1. Use the ending  $\text{-enoic}$

## Some Common Carboxylic Acids

- Formic Acid (HCOOH) is the chemical that makes ant bites sting.
- Acetic Acid (CH<sub>3</sub>COOH) is in vinegar
- Butyric Acid is what is in rancid butter (stinky!)
- Caproic Acid is on goats

Acetic Acid: Vinegar is solution of 4-8% acetic acid in water  
Corrosive in concentrations over 50% (takes a while to burn though)  
Pure Acetic Acid is *glacial acetic acid*  
Reactant in many industrial processes  
Sometimes used as a solvent  
Used to adjust acidity

Citric Acid: Produced by almost all plants and animals during metabolism  
Normal concentration in blood is 2mg/100mL  
White, crystalline solid  
Very soluble in water  
Used extensively in pharmaceuticals, foods and cosmetics

## Acidity of Carboxylic Acids

CAs are the most acidic of all organic compounds. MUCH more acidic than phenols, which are more acidic than alcohols. However, they are considerably weaker acids than the “strong acids” like HCl, H<sub>2</sub>SO<sub>4</sub>, etc...

Note that acidity increases with the increasing ability of a compound to donate protons to a base. Acidity for a series of compounds containing the –OH group depends on the strength of the O-H bond. Phenol is more acidic than R-OH because the ring is more electron-hungry than the R group. RCOOH (a CA) is even more acidic because the C=O is even more electron-hungry than the benzene ring. HCl is the strongest acid because Cl is even more electron-hungry than C=O.

Carboxylic Acids are WEAK acids that establish equilibria in aqueous solutions with *carboxylate ions* (RCOO<sup>-</sup>).

### Acidity Comparison

Many CAs have about the same acid strength as acetic acid. One notable exception is *trichloroacetic acid*.

To name the ions:

1. Change the ending of the name from *-ic acid* to *-ate*.

CA undergo neutralization rxns with bases just like other acids do. With strong bases such as sodium hydroxide, a carboxylic acid reacts to give water and a carboxylic acid salt. To name these ionic salts:

1. Name the CA from which the salt is derived
2. Change the ending of the name from *-ic acid* to *-ate*.
3. Place the name of the inorganic ion before the name of the CA

## **Esters**

An ester is formed when the  $\text{-OH}$  group of the CA is replaced by an  $\text{-OR}$  group. The molecule can no longer hydrogen bond as an ester ☹️ Esters are much more volatile than CAs, but they have pleasant odors of flower and fruit.

### Naming Esters

1. Ester names consist of two words
2. The first is the name of the alkyl group R in the ester group ( $\text{-COOR}$ )
3. The second name is the name of the parent acid
4. Replace *-ic acid* with *-ate*
5. NOTE that the order of the two parts of the name are the reverse of the way the condense formulas are written. Jolly!

## Amides

Amides are formed with the  $\text{-OH}$  group is replaced by an  $\text{-NH}_2$ ,  $\text{-NHR}$  or  $\text{-NH}_2$ .

### Amides & Hydrogen Bonding

- Low-molecular weight amides are solids that are soluble in both water and organic solvents.
- Monosubstituted amides ( $\text{RCONHR}'$ ) can form H-Bonds with each other and so have higher boiling points.
- Disubstituted amides ( $\text{RCONR}'_2$ ) cannot H-Bond with each other, and are therefore lower boiling.

**Q:** What is the difference between an AMIDE and an AMINE?

**A:** In an amide, the nitrogen is bonded to a carbonyl-group. The positive end of the carbonyl group attracts the lone pair on N so strongly that it does not accept a hydrogen atom. This prevents the amide from acting as a base. **AMIDES ARE NOT BASIC LIKE AMINES!**

### Naming Amides with an unsubstituted $\text{-NH}_2$ group

1. Replace the *-ic acid* or *-oic acid* of the corresponding CA name with *-amide*

If there are substituents:

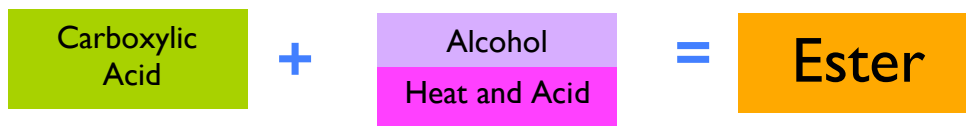
1. First specify the alkyl group
2. Identify the amide name
3. Alkyl subs are preceded by the letter *N* to show they are attached to Nitrogen

### Properties of Amides

- Amides are somewhat higher boiling than carboxylic acids. Wow! This is due to their exceptionally high polarity which results from interaction between the carbonyl group and the nonbonded electron pair on the Nitrogen.
- Undergoes carbonyl-substitution reactions (along with CAs and esters)
- Made from CAs (along with esters)
- All unsubstituted amides except formamide are solids
- Amids are neither acids or bases (pH neutral)
- Small amides are water-soluble

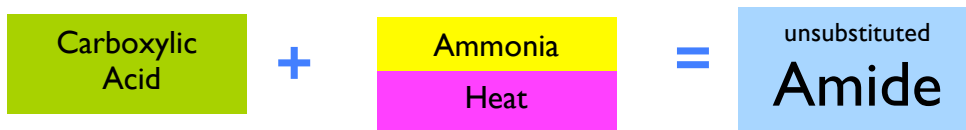
## Reactions: Ester Formation

To form an ester, you mix a carboxylic acid with an alcohol (and an acid catalyst). This is called esterification. Note that heat needs to be involved, otherwise nothing happens. These reactions are reversible! Isn't that fun???



## Reactions: Amide Formation

To make an **unsubstituted amide**, you mix a carboxylic acid with ammonia.



**Substituted amides** are made by mixing a carboxylic acid with a primary or secondary amine.



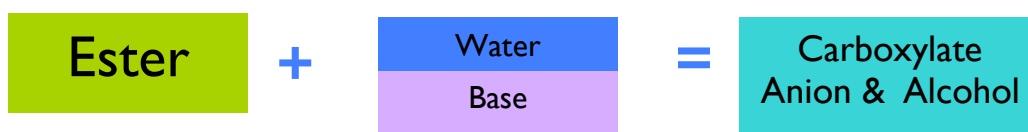
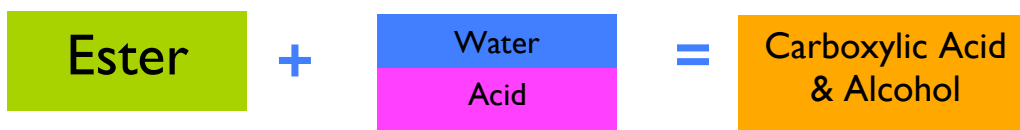


## Hydrolysis of Esters and Amides

Hopefully you remember that in hydrolysis bonds are broken and the H and OH from water add to atoms that were part of the broken bond. Hydrolysis converts esters and amides back to carboxylic acids. When esters hydrolyze they yield alcohols as well...and when amides hydrolyze they give back amines.

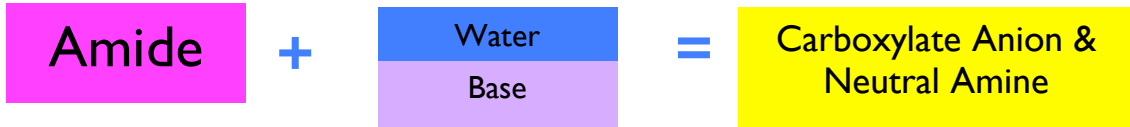
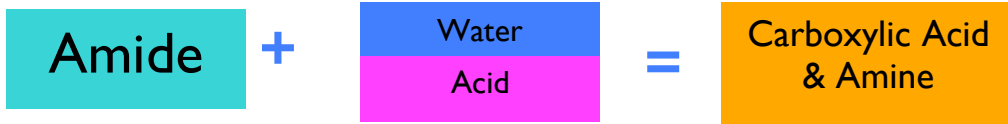
### Ester Hydrolysis

The great thing about ester hydrolysis is that it can be catalyzed by ACID or BASE! When it is acid-catalyzed it is essentially just the reverse of the esterification process. When it is base-catalyzed, then it is known as **saponification** and the product is a carboxylate anion rather than a free carboxylic acid.



### Amide Hydrolysis

Though amides are extremely stable in water, they will undergo hydrolysis if they are HEATED in the presence of an acid or a base. The resulting products are the CA and the amine that started the whole process! When an acid is used, the CA and amine salt are obtained. When a base is used, you get the neutral amine and carboxylate anion.



### **Over the Counter CA Derivatives**

Aspirin is actually acetylsalicylic acid and is a white, crystalline solid. Basically it is a combination of an ester and a salicylic acid. Though a wonderful pain reliever, aspirin's side effects include GI bleeding and GI distress. It should never be given to someone with a bleeding problem or even before surgery.

Acetaminophen is a better choice for anyone who is prone to bleeding, but it's not quite as effective as aspirin because it is not an anti-inflammatory. However, overdoses of this drug can cause liver damage. Don't overdo it!

Benzocaine is a local anesthetic that is used in topical pain relievers. It is related to lidocaine which is used for dental work. These work by blocking the transmission of impulses by sensory nerves.

### **Polyamids and Polyesters**

When a molecule with two amides reacts with a molecule with two amino groups you get a polyamide such as nylon or Kevlar. When a diacid and dialcohol react you get polyester. Isn't this exciting? Some common polyesters are Dacron/Mylar.

### **Phosphoric Acid Derivatives**

Phosphoric Acids are going to come up when we get to biochem. Can't wait! A phosphoric acid is an inorganic acid with three ionizable hydrogen atoms, and this allows it to form three different anions.

Notice the similarities between phosphoric acid and carboxylic acid. Fun stuff!

Phosphoric acid reacts with alcohols to form phosphate esters. This esterification can occur at one, two or three of the  $-OH$  groups. When it reacts with one group you get a monoester, ditto for diester and triester:

Note that monoesters and diesters are acidic because they still have a H. So, in body fluids or other neutral or alkaline solutions they are present as ions. For example, glyceraldehyde monophosphate is usually written as an ion in one of these two ways:

If two molecules of phosphoric acid combine to lose water they will form a phosphoric acid anhydride. The resulting acid reacts with another phosphoric acid to give triphosphoric acid. These groups contain one or two P-O-P anhydride linkages.

The  $-\text{PO}_3^{2-}$  group as part of a larger molecule is a phosphoryl group.

These acids can also form ESTERS, which are known as diphosphates and triphosphates. When you transfer a phosphoryl group from one molecule to another this is called phosphorylation. In biology, the phosphoryl groups are usually donated by triphosphate (ATP) which is converted to a diphosphate (ADP)...this is accompanied by a release of energy...but you already knew that!

Phosphorylation is the transfer of a phosphoryl group from one molecule to another.