


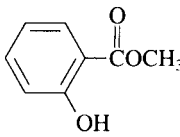
## Going Bananas Over Isoamyl Acetate

Adapted by Kurt Rublein and T. Prueksaritanon from *Introduction to Organic Laboratory Techniques, A Microscale Approach* by D. L. Pavia, G. M. Lampman, G. S. Kriz, and R. G. Engel, 1990. 10/18/06

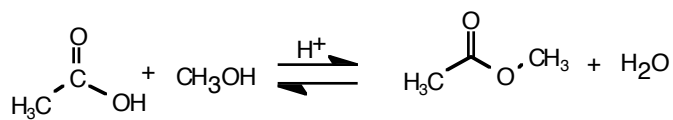
### Introduction

The ester group is an important functional group that can be synthesized in a number of different ways. The low-molecular-weight esters have very pleasant odors and indeed are the major components of the flavor and odor aspects of a number of fruits. Although the natural flavor may contain nearly a hundred different compounds, single esters approximate the natural odors and are often used in the food industry for artificial flavors and fragrances. For example, isoamyl acetate (shown in the table below) has the fragrance of banana. This experiment is the synthesis of this fruity ester.

**TABLE 33.1** Fragrances and Boiling Points of Esters

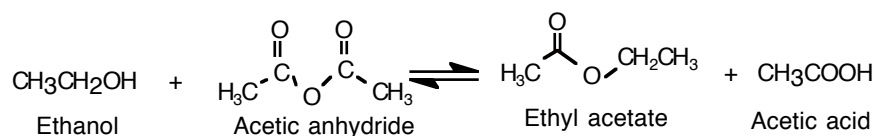
Ester	Formula	Boiling Point (°C)	Fragrance
Isobutyl formate	$\text{HCOCH}_2\overset{\text{CH}_3}{\text{CH}}\text{CH}_3$	98.4	Raspberry
<i>n</i> -Propyl acetate	$\text{CH}_3\overset{\text{O}}{\parallel}\text{COCH}_2\text{CH}_2\text{CH}_3$	101.7	Pear
Methyl butyrate	$\text{CH}_3\text{CH}_2\text{CH}_2\overset{\text{O}}{\parallel}\text{COCH}_3$	102.3	Apple
Ethyl butyrate	$\text{CH}_3\text{CH}_2\text{CH}_2\overset{\text{O}}{\parallel}\text{COCH}_2\text{CH}_3$	121	Pineapple
Isobutyl propionate	$\text{CH}_3\text{CH}_2\overset{\text{O}}{\parallel}\text{COCH}_2\overset{\text{CH}_3}{\text{CH}}\text{CH}_3$	136.8	Rum
Isoamyl acetate	$\text{CH}_3\overset{\text{O}}{\parallel}\text{COCH}_2\text{CH}_2\overset{\text{CH}_3}{\text{CH}}\text{CH}_3$	142	Banana
Benzyl acetate	$\text{CH}_3\overset{\text{O}}{\parallel}\text{COCH}_2\text{-}$ 	206	Peach
Octyl acetate	$\text{CH}_3\overset{\text{O}}{\parallel}\text{COCH}_2(\text{CH}_2)_6\text{CH}_3$	210	Orange
Methyl salicylate		222	Wintergreen

Esters can be prepared by the reaction of a carboxylic acid with an alcohol in the presence of a catalyst such as concentrated sulfuric acid, hydrogen chloride, *p*-toluenesulfonic acid, or the acid form of an ion exchange resin:

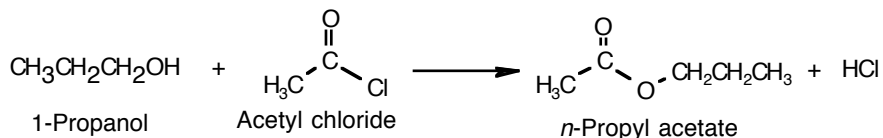


This Fischer esterification reaction reaches equilibrium after a few hours of refluxing. The position of the equilibrium can be shifted by adding more of the acid or of the alcohol, depending on cost or availability. The mechanism of the reaction involves initial protonation of the carboxyl group, attack by the nucleophilic hydroxyl, a proton transfer, and loss of water followed by loss of the catalyzing proton to give the ester. Because each of these steps is completely reversible, this process is also, in reverse, the mechanism for the hydrolysis of an ester.

Other methods are available for the synthesis of esters, most of them more expensive but readily carried out on a small scale. For example alcohols react with acid anhydrides to form esters:

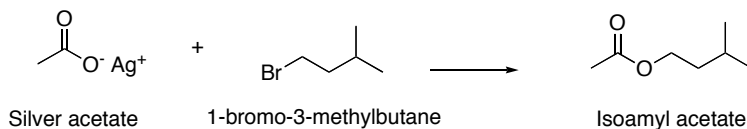
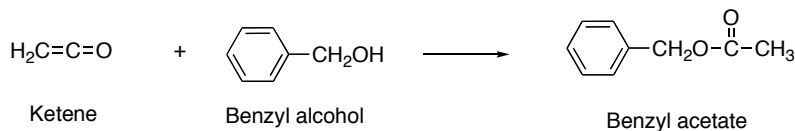
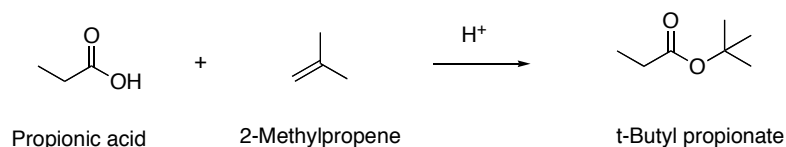


Acid chlorides form esters by reaction with alcohols.

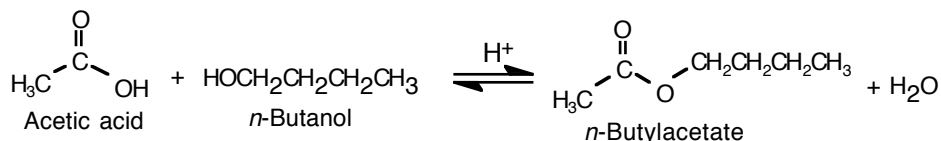


In the latter reaction, an organic base such as pyridine is usually added to react with the hydrogen chloride.

A number of other methods can be used to synthesize the ester group. Among these include the addition of 2-methylpropene to an acid to form *t*-butyl esters, the addition of ketene to an alcohol to make acetates, and the reaction of a silver salt with an alkyl halide.



As noted above, Fischer esterification is an equilibrium process. Consider the reaction of acetic acid with 1-butanol to give *n*-butyl acetate:



The equilibrium expression for this reaction is

$$K_{\text{eq}} = \frac{\left[ \begin{array}{c} \text{O} \\ \parallel \\ \text{H}_3\text{C}-\text{C}-\text{O}-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \end{array} \right] [\text{H}_2\text{O}]}{\left[ \begin{array}{c} \text{O} \\ \parallel \\ \text{H}_3\text{C}-\text{C}-\text{OH} \end{array} \right] [\text{HOCH}_2\text{CH}_2\text{CH}_2\text{CH}_3]}$$

For primary alcohols reacting with unhindered carboxylic acids,  $K_{\text{eq}} \sim 4$ . If equal quantities of 1-butanol and acetic acid are allowed to react, the theoretical yield of ester is only 67% at equilibrium. To upset the equilibrium we can, by Le Chatelier's principle, increase the concentration of either the alcohol or acid, as noted above. If either one is doubled, the theoretical yield increases to 85%. When one is tripled, it goes to 90%. But note that in the example cited the boiling point of the relatively nonpolar ester is only about 8° C higher than the boiling points of the polar acetic acid and 1-butanol, so a difficult separation problem exists if either starting material is increased in concentration and the product is isolated by distillation.

Another way to upset the equilibrium is to remove water. This can be done by adding to the reaction mixture molecular sieves, an artificial zeolite, which preferentially adsorb water. Most other drying agents, such as anhydrous sodium sulfate or calcium chloride, will not remove water at the temperatures used to make esters.

A third way to upset the equilibrium is to preferentially remove the water as an azeotrope. Water can form an azeotrope with certain alcohols at specific concentrations. A special apparatus, called a Dean-

Stark apparatus or trap, can be used to distill off the water as an azeotrope while the ester being is formed. Removing water from the reaction in this way will favor ester formation.

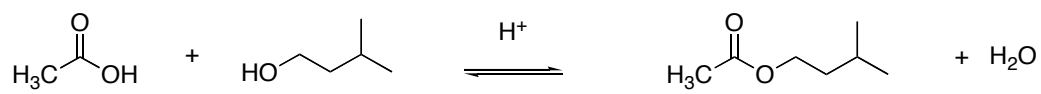
### Cautions

Glacial acetic acid (pure acetic acid) is corrosive and soaks into the skin quickly. Wear gloves when handling. Clean up any spills immediately. Concentrated sulfuric acid is also a corrosive hazard; wear gloves.

### PreLab Exercise

1. Why should the sodium bicarbonate solution be added slowly? What by-product is generated?
2. Write balanced equations for all reactions that take place during the neutralization.

### Synthesis



Place a 25-mL round bottom flask (19/22 from blue kit) into a small beaker and tare them on the balance. Weigh 3.2 g of isoamyl alcohol directly into the flask. Add 5 mL of glacial acetic acid and 3 boiling chips to the flask. Finally, use a clean pipet to add 6 drops of concentrated sulfuric acid. Connect the water-cooled condenser (fitted with water-inlet tubing) to the flask and clamp the flask in a heating mantle with little or no sand in it. Heat the mixture gently to reflux, from that point, reflux the reaction for 30 min. At the end of the reflux period, remove the flask from the heat and let the mixture cool to room temperature. This takes about 10 min.

While the flask is cooling, obtain about 9 mL of 5% aqueous sodium bicarbonate solution in a clean 10-mL graduated cylinder. Use a pipet to SLOWLY add about 3 mL of the sodium bicarbonate solution to the cooled reaction mixture. After bubbling has subsided, gently swirl the flask to mix the two layers. Use a pipet to remove the aqueous layer (which one is aqueous?--do a drop test to be sure!) and set aside for now. Repeat the addition/swirling/removing aqueous layer steps twice more, using fresh 3 mL of 5% aqueous sodium bicarbonate solution each time. The last time, remove all of the aqueous layer, leaving the organic layer. Add sodium sulfate to the organic layer (add enough until it no longer clumps), swirl, and let stand for 5 min. During this time, tare a 20-mL vial with cap. Use pipet filtration method to remove the liquid, but leave the drying agent and boiling chips behind. Place the organic liquid into the long-neck round-bottomed flask from your microscale kit. Add 3 boiling chips and distill the liquid using simple distillation. Record the temperature range over which the distillate is collected. The collected liquid should be placed into the tared shorty vial. Weigh the capped shorty vial and contents and calculate the mass of product by the difference in masses.

### Cleaning Up

The aqueous layers from the sodium bicarbonate washings can go down the drain with flushing water. The distillation residue should be discarded in the organic waste container.

### Analyses

The product can be analyzed by GC, GC-MS, IR, NMR, or by RI. Analyze your sample according to your assignment sheet and prepare it as per the instructions on Sample Preparation in the Lab Guide

(inside back cover).

**Postlab Questions**

1. The workup for this product is easier when the excess reagent is the acetic acid. What step would have to be included if the alcohol were the excess reagent?
2. According to an Aldrich entry, there are significant amounts of 2-methyl-1-butanol in the isoamyl alcohol (3-methyl-1-butanol). What effect does this have on the product? Draw the structures of all "product" molecules.
3. How could you quantify the purity of the starting material and of the major product?