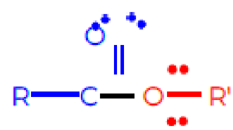
Experiment 10:
Fischer Esterification: An ester from a carboxylic acid and an alcohol

Objectives

The purpose of this experiment is to provide a practical example of the synthesis of an ester, using the Fischer esterification method. The product is formed during reflux, and will be purified by distillation, and assessed by refractive index. Also further practice in obtaining and interpreting infrared spectra and ^{1}H-NMR will be provided.

Introduction

Esters are naturally abundant and readily synthesized, but all have the same following structure,



Everyday fragrances, such as the 'rich smell' of fresh ground coffee, are a combination of esters (>200 identifiable esters found so far in coffee!!). However, some esters are readily recognized by their very characteristic flavour or odour.

Esters are derivatives of carboxylic acids, and are mainly prepared by one of four methods:

1. Direct esterification of a carboxylic acid with an alcohol (Fischer Esterification).
2. Alcoholysis of acid chlorides, anhydrides, or nitriles.
3. Reaction of a carboxylic acid salt with an alkyl halide or sulfate.
4. Via the trans-esterification reaction.

Table 10.1. Combinations of carboxylic acids and alcohols resulting in 'familiar' esters

Ester	Structure	Fragrance/Flavour	Carboxylic acid	Alcohol
iso-butyl formate	$HCO_2CH_2CH(CH_3)_2$	Raspberry essence	formic acid	*iso*-butanol
Propyl acetate	$CH_3CO_2CH_2CH_2CH_3$	Pear essence	acetic acid	1-propanol
iso-amyl acetate	$CH_3CO_2(CH_2)_2CH(CH_3)_2$	Banana essence	acetic acid	*iso*-amyl alcohol
Octyl acetate	$CH_3CO_2CH_2(CH_2)_6CH_3$	Orange essence	acetic acid	octanol
Benzyl acetate	$CH_3CO_2CH_2C_6H_5$	Peach essence	acetic acid	benzyl alcohol
iso-butyl propionate	$CH_3CH_2CO_2CH_2CH(CH_3)_2$	Rum essence	propionic acid	*iso*-butyl alcohol
Ethyl butyrate	$CH_3CH_2CH_2CO_2CH_2CH_3$	Pineapple essence	butyric acid	ethanol
Methyl butyrate	$CH_3CH_2CH_2CO_2CH_3$	'Apple like' essence	butyric acid	methanol
iso-amyl butyrate	$CH_3CH_2CH_2CO_2(CH_2)_2CH(CH_3)_2$	Apricot essence	butyric acid	*iso*-amyl alcohol
iso-amyl valerate	$CH_3(CH_2)_3CO_2(CH_2)_2CH(CH_3)_2$	'real' Apple essence	valeric acid	*iso*-amyl alcohol
Methyl anthranilate	$H_2NC_6H_4CO_2CH_3$	Grape essence	anthranilic acid	methanol
Ethyl laurate	$CH_3(CH_2)_{10}CO_2CH_2CH_3$	Tuberose essence	lauric acid	ethanol
Methyl salicylate	$HOC_6H_4CO_2CH_3$	Oil of wintergreen	salicylic acid	methanol

iso-butanol = 2-methyl-1-propanol,
iso-amyl alcohol = 2-methyl-1-butanol
Tuberose is the fragrance of a tropical flowering plant with 'funnel' shaped flowers (Tuber + Rose).

In the Fischer esterification reaction, esters can be prepared by the **reversible**, acid- catalysed, combination of a carboxylic acid with an alcohol. Because it is reversible, the reaction must be shifted to the product side by using excess reagent or removing one of the products. This reaction is also limited by any steric hindrance in the carboxylic acid or the alcohol. The general equation for a Fischer esterification is summarized below in Fig. 10.2.

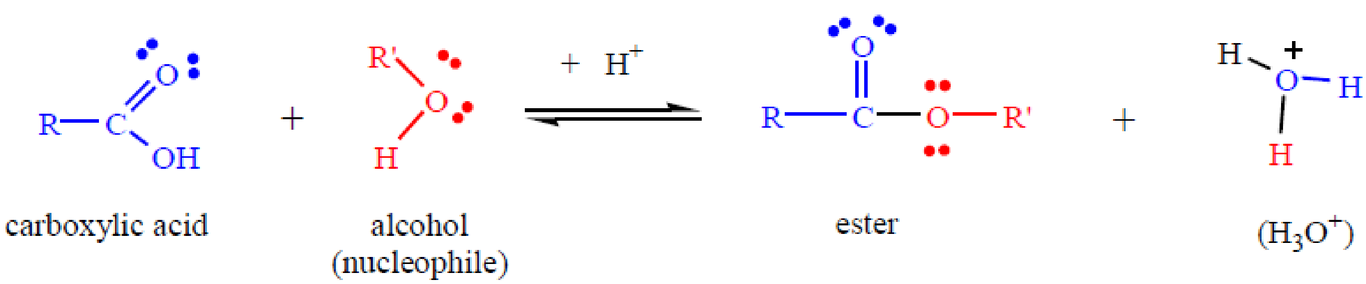


Figure 10.2 Fischer esterification reaction for ester formation from a carboxylic acid.

The acid catalysed mechanism for a Fischer esterification is shown on the next page in Figure 10.3. Equilibrium is reached at every step in the reaction's multi-step mechanism. The reaction is driven to the right, towards the desired end product (i.e., Le Châtelier's Principle). In this experiment, a large excess of one of the reactants is used. The acids used in this experiment have a strong dehydrating capability and help 'soak up' the reaction water, also assisting in pulling the reaction to the right.

Fischer Esterification Reaction Mechanism (nucleophilic acyl substitution)

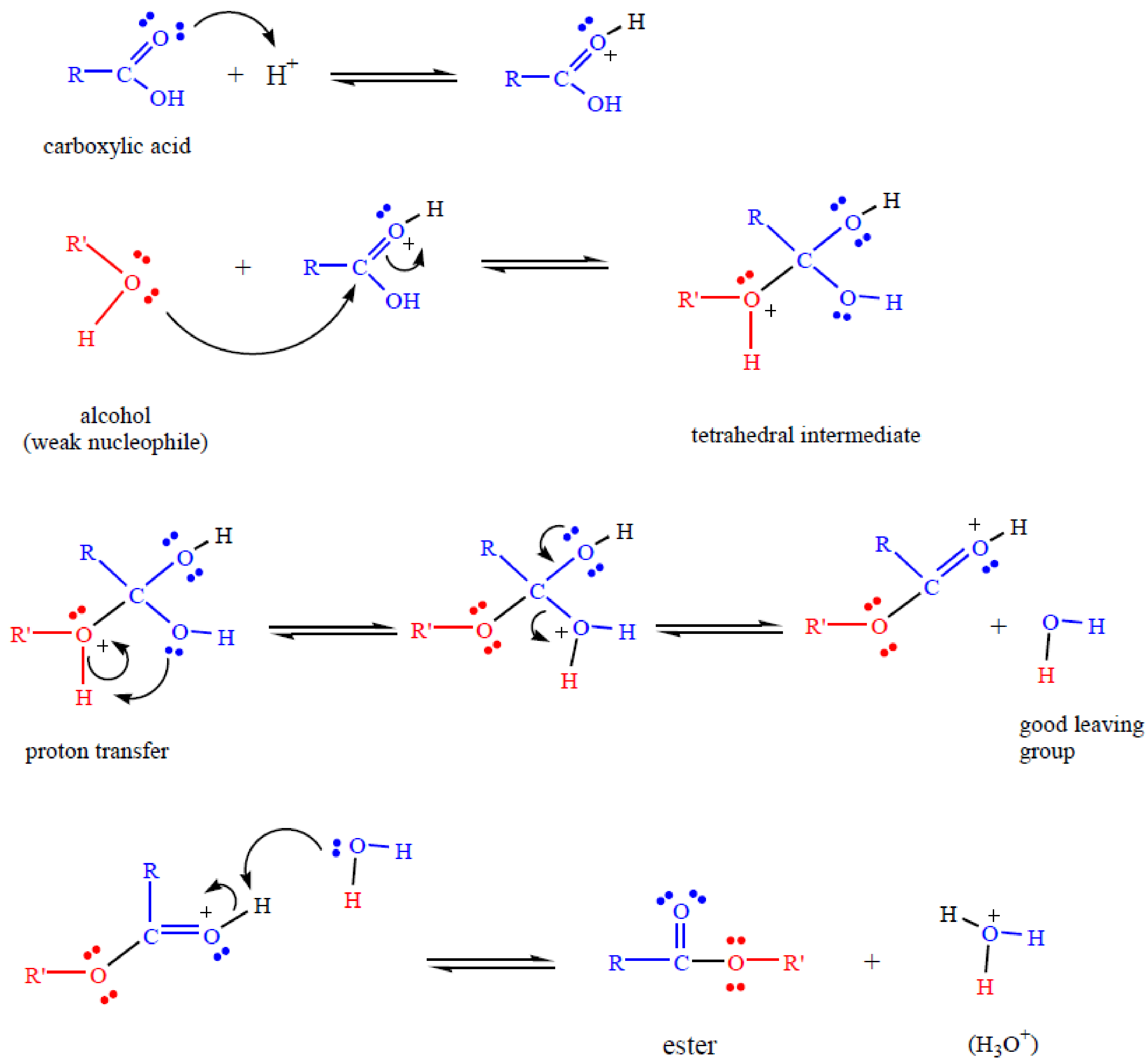
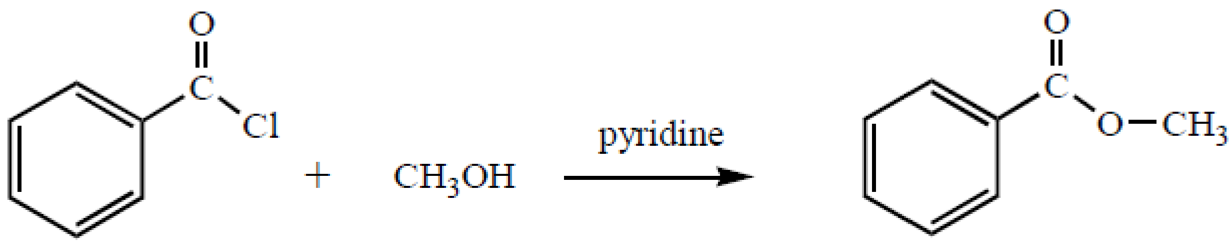


Figure 10.3 Reaction mechanism for the Fischer esterification (under acidic conditions)

Additional Information on the Synthesis of Esters

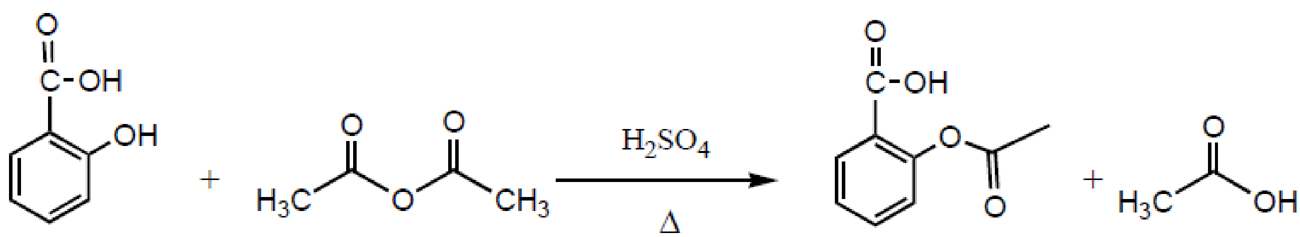
The best and most efficient way to synthesize an ester is to convert an acid chloride via alcoholysis (Fig. 10.4a). For more information, see 'Chemistry of Acid Halides' and 'Chemistry of Esters' in your textbook.



acid chloride (benzoyl chloride) | alcohol (methanol) | ester (methyl benzoate)

Figure 10.4a Esters from acid chlorides.

Another example of alcoholysis is when alcohols and phenols react with acetic anhydride (Figure 10.4b), in the presence of an acid catalyst, to yield esters. However, there are serious limitations to the formation of esters by this method, some of which are discussed in your text under 'Chemistry of Ester'; i.e., please note that half the acetic anhydride molecule is 'wasted' by this method.



salicylic acid
(2-hydroxybenzoic acid)
mp= 159° C
Mwt= 138.12 g/mol
amt used = ?
moles = ?

acetic anhydride
mp = -73.1° C
d=1.08 g/mL
Mwt = 102.09 g/mol
amt used = ?
moles = ?

aspirin
(acetylsalicylic acid)
mp=135° C
Mwt = 180.17 g/mol
max. moles = ?
Theor. Yield = ?

acetic acid
(ethanoic acid)
mp=16.6° C
Mwt = 60.05 g/mol

Figure 10.4b Salicylic acid's reaction with acetic anhydride to form an ester.

Final Additional Background Information

About Boiling Points

To correct for barometric pressure (**BP**) effects on the boiling point (bp) of a liquid, use the following formula to approximate the effect, or use a nomograph.

Corrected bp = observed bp + ((760 mm Hg – **BP** mm Hg)/10 mmHg)* 0.5 °C where **BP** is the observed barometric pressure.

About Refractive Indexes

To correct for temperature effects on the refractive index (n_D) of a liquid, use the following formula, assuming that the sample temperature is equal to room temperature:

Corrected Refractive Index = observed n_D + (Room Temp – **20° C**)* 0.00045. (to 20° C)