Expt 7: Preparation of Isobutyl Propionate (or Isobutyl Propanoate)

INTRODUCTION

Esters are an important class of carbonyl compounds that are formally derived by combining a carboxylic acid and an alcohol. Notably, most low molecular weight esters are volatile and have distinctive odors. The structures of several different esters are shown below along with their corresponding odors:

This experiment involves the preparation of isobutyl propionate (1), an ester that is responsible for the "essence" of rum. Esters may be prepared in several ways: (a) the reaction of a carboxylic acid and an alcohol in the presence of acid (the Fischer Esterification), and (b) the reaction of an acid chloride and an alcohol. Method (a) is an equilibrium reaction, so the yield of the ester is not as good as that obtained in Method (b). Also, Method (a) requires heating at reflux for a reasonable period of time and a more involved purification process. On the other hand, Method (b) requires less time for reaction and a less involved purification procedure, and because it does not involve equilibrium, the yield of ester is better. For these reasons, this preparation utilizes the reaction between an acid chloride (propionyl chloride) and an alcohol (isobutyl alcohol) to produce the ester, isobutyl propionate [see Note 1], as shown in equation (1). This reaction is an example of nucleophilic acyl substitution, and its mechanism is presented in your lecture textbook and may be discussed by your laboratory instructor.
The reaction is carried out by placing propionyl chloride in a conical reaction vial, followed by heating to reflux, and then adding isobutyl alcohol. No solvent is used for rapidly occurring reaction. Hydrogen chloride is evolved as a gas, thus accounting for the irreversible nature of this reaction. The experimental procedure provides a technique for keeping the HCl gas (noxious odor!) out of the laboratory.

**ISOALATION AND PURIFICATION OF PRODUCT**

After the reaction is complete, the contents of the conical vial are transferred to a large sample vial to which water is added. Water serves several purposes: (a) it hydrolyses unreacted propionyl chloride (if any remains) to propionic acid which is water-soluble, (b) it helps remove any residual amounts of HCl from the reaction mixture and (c) it removes unreacted isobutyl alcohol (if any remains) which is also water-soluble. The product, isobutyl propionate, is insoluble in aqueous solution. The organic layer is then washed with aqueous NaOH solution to neutralize any HCl that remains, to convert propionic acid to its water-soluble sodium salt and to further dissolve and remove water-soluble isobutyl alcohol. A final wash with water removes residual traces of NaOH and helps ensure removal of isobutyl alcohol. The net effect of the washes with base and water is to remove unreacted isobutyl alcohol, unreacted propionyl chloride (in the form of propionic acid) and HCl that is formed during the reaction.

After these washings, the organic layer is dried over anhydrous calcium chloride. The dry organic product can then be placed in a conical vial equipped with a Hickman Still, which is an apparatus that permits the distillation and purification of small quantities of liquid. The distillate collected from the Hickman Still is pure isobutyl propionate. The Hickman Still will be further discussed during prelab discussion. You may safely smell the isobutyl propionate to confirm the rum odor.

**NOTES FOR THIS EXPERIMENT**

**Note 1:** Common names are provided in equation (1) and will be used through this experiment. However, the IUPAC names are propanoyl chloride, 2-methyl-1-propanol, and 2-methylpropyl propanoate, respectively.
REAGENT/PRODUCT TABLE:

<table>
<thead>
<tr>
<th>Reagents</th>
<th>MW (g/mol)</th>
<th>MP (ºC)</th>
<th>BP (ºC)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>propionyl chloride</td>
<td>92.53</td>
<td>-94</td>
<td>77-79</td>
<td>1.065</td>
</tr>
<tr>
<td>isobutyl alcohol</td>
<td>74.12</td>
<td>-108</td>
<td>108</td>
<td>0.803</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>MW (g/mol)</th>
<th>MP (ºC)</th>
<th>BP (ºC)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>isobutyl propionate</td>
<td>130.19</td>
<td>137-39</td>
<td></td>
<td>0.869</td>
</tr>
</tbody>
</table>

EXPERIMENTAL PROCEDURE

FOR YOUR SAFETY
1. **Wear gloves** at all times when handling propionyl chloride. Transfer it to the conical vial in the hood and avoid inhaling it. If any should come in contact with your skin, rinse immediately with cold running water.
2. Hydrogen chloride is a highly corrosive gas. Pay special attention to Step 4 which describes the technique for removing HCl gas from the reaction as it is formed, thus keeping it out of the laboratory.
3. When smelling the isobutyl propionate, gently waft the vapors towards your nose.

1. Place the aluminum heating block (Section A.4, Figure A.4) on the hot plate set to 2.5.

2. Clean and dry a 5-mL conical reaction vial with spin vane inside. Add a clean cap (with a septum), and record the mass of the vial and cap. You will also need a clean, dry Claisen adapter, water condenser and micro-syringe, with needle.

3. In the hood, add 2.0-mL of propanoyl chloride to the conical vial. Cap the vial then reweigh on the balance to determine the mass of propionyl chloride contained in it. Record the weight in order to determine the mass of propanoyl chloride used.

4. As near as possible to one of the house mini-hoods, assemble the apparatus as described in Section A.5 (Figure A.5D), but replace the drying tube with the water condenser. Place the apparatus in the aluminum heating block and support the apparatus with a clamp on the condenser. **Be sure water is running through the condenser before the acid chloride is refluxing!** A mini-hood should be placed above the apparatus once it is lowered into the heating block (Section A.6, Figure A.6). This removes the gaseous HCl that is evolved as the reaction occurs.
5. Obtain the mass of a clean, dry small sample vial and cap. Transfer 1.9 mL of isobutyl alcohol to the vial and reweigh it to determine the mass of the alcohol that you are using. Record the vial weights of the alcohol.

6. Commence stirring the contents of the conical vial. Increase the heat until the propionyl chloride starts to reflux. Do not add any alcohol until the acid chloride is boiling. Propionyl chloride often foams up into the adapter at its boiling point; the foaming will stop when the alcohol is added and the reaction occurs. Clean and dry the 1-mL syringe in your microscale kit and fill it with isobutyl alcohol from the alcohol sample vial. Add the alcohol drop-wise, using the syringe from your kit, to the refluxing propionyl chloride. The syringe will not hold all the alcohol so it will have to be refilled. The addition should take 5-10 minutes. Keep the reaction mixture refluxing during the slow addition of the alcohol.

7. When the addition of the alcohol is complete, remove the apparatus from the aluminum block, but do not disassemble it yet. Cool the conical vial to room temperature by placing it in a beaker of cold tap water. Turn off the hot plate and allow it to cool.

8. Remove the Claisen adapter and water condenser from the conical vial. Pour the reaction mixture to a clean, large sample vial from your locker.

9. Add approximately 4 mL of water to the sample vial, cap it tightly and shake vigorously with periodic venting. Allow the two layers to separate completely, carefully remove the lower water layer with a Pasteur pipette and transfer to a small beaker, labeled "bottom basic layer".

10. Repeat Step 9 two more times using 4 mL of 3\textit{M} NaOH solution during each washing. Each time, you should vigorously shake the capped vial, with venting, and remove the lower aqueous layer and transfer this lower layer to the same “bottom basic” beaker. Repeat this procedure again using about 4 mL of water. In the last separation, be careful to remove the entire lower aqueous layer. No water may be present before proceeding on to Step 11, when the organic layer must be dried.

11. To start the drying process, add 10-12 pellets of anhydrous calcium chloride (CaCl$_2$) and check your vial after a minute to see if a water layer has developed. If so, remove this water layer with a pipette before adding any more drying agent. If not, add another 12-15 pellets of CaCl$_2$. If the drying agent clumps up and isn’t freely moving after a few minutes, add a few more pieces of CaCl$_2$. After \textbf{5-10 minutes}, the organic layer should be completely clear, instead of cloudy. \textbf{The product must}
be clear after drying; if not, add a few more pieces of calcium chloride and wait another 5-10 minutes.

12. Using a clean dry pipette, transfer the dried product, into a clean, dry preweighed small sample vial. Be sure not to remove any of the drying agent when you remove the dried product. Re-weigh the vial so you can determine the mass of the product contained in the vial then obtain an IR spectrum of your product. Properly label the product vial and hand it in.

WASTE DISPOSAL

1. Place the basic lower layers from Steps 9 and 10 and the water extracts in the “aqueous basic waste” container.
2. Carefully (wear gloves) carefully wash the pipettes that contained propionyl chloride and isobutyl alcohol, and place these washes in the “aqueous acid waste” container.
3. Carefully wash the remainder of the apparatus and the syringe with water at the sink.

CALCULATIONS

1. Calculate the moles of propionyl chloride used (make sure to use the mass of propionyl chloride and not the volume)
2. Calculate the moles of isobutyl alcohol used (make sure to use the mass of isobutyl alcohol and not the volume).
3. Determine which compound is the limiting reagent.
4. Calculate the theoretical yield of isobutyl propionate.
5. Calculate the percent yield of isobutyl propionate.
isobutyl alcohol (2-methyl-1-propanol)