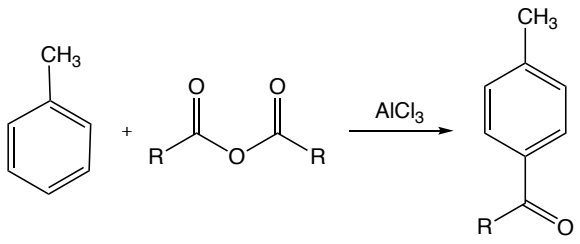
Experiment 14: Friedel-Crafts Acylation of an Unknown Acid Anhydride

A Friedel-Crafts acylation is an electrophilic aromatic substitution reaction that introduces an acyl group onto an aromatic ring. The electrophile is an acyl cation that is coupled to a Lewis acid catalyst, such as aluminum chloride. Carboxylic acid anhydrides are often used as acylating agents. In order for the reaction to take place, the aromatic ring system must be electron rich and thus cannot contain any electron withdrawing groups. In today's experiment, you will react toluene with an unknown carboxylic acid anhydride in the presence of aluminum chloride. You will identify the anhydride by interpreting the IR and NMR spectra of the reactant and product.



The three unknown acid anhydrides are:

Acetic anhydride
M.W. 102.09 g/mol; density 1.08 g/mL
Propionic anhydride
M.W. 130.14 g/mol ; density 1.02 g/mL
Pentanoic anhydride (also known as valeric anhydride)
M.W. 186.25 g/mol; density 0.944 g/mL

The heating step of today's Friedel-Crafts reaction will take place in a microwave reactor. Reports of the use of microwaves to heat chemical reactions were first published in 1986. Microwave radiation is a low frequency form of energy that causes molecules to rotate and oscillate. The movement of the molecules generates friction and consequently, heat. Polar molecules rotate more frequently than non-polar molecules and therefore generate more heat. Organic reactions that take place in polar solvents are heated more efficiently in a microwave environment than reactions that occur in non-polar solvents.

Although typical kitchen ovens were utilized by the chemists who initially experimented with microwaves as a heat source, specially designed microwave reactors are now available that have significant advantages over products intended for domestic use. These laboratory microwave systems are safer to use with hazardous chemicals, can accurately measure the temperature inside the reaction vessel and can precisely control and monitor the power. The MARS 6 Synthesis microwave reactor that will be used in today's experiment can accommodate up to 24 reaction vessels at one time. The vessels are tightly sealed before being placed in the instrument, which causes the mixture to become pressurized as it heats. The reaction can thus be heated to a temperature that is significantly higher than the boiling point of the solvent.

There are several advantages to using a microwave reactor to heat a chemical reaction in comparison to conventional heating methods, such as a hot plate or thermowell. Because the microwaves interact directly with the molecules, energy is not expended in heating up the reaction vessel; thus, the process is more energy efficient. As with cooking, chemical reactions are completed in a shorter amount of time. In general, fewer decomposition byproducts are formed, which results in higher yields and allows for easier purification of the products. Because

of these advantages, microwave reaction systems have become pervasive in synthetic laboratories and are used extensively for research and industrial applications.

Outline the steps of the following procedure.

Procedure (work with a partner)

Aluminum chloride is very hygroscopic! Keep the bottle capped when not in use.

The acid anhydrides are corrosive. The fumes may be irritating, and they can react violently with water. Wear gloves and work with the liquid under a hood; avoid contact, do not breathe the vapors and keep away from water.

Obtain a small magnetic stirring bar and place it in a 40 mL vial. Add 0.8 g of aluminum chloride, $AlCl_3$, to the vial. Measure 5 mL of toluene in a graduated cylinder. Measure 0.36 mL of the unknown acid anhydride with a syringe and pipet assembly and add it to the toluene. Mix the contents of the graduated cylinder with a pipet.

Place a beaker containing ice and water on a hot plate/stirrer. Clamp the vial that contains $AlCl_3$ in the ice bath and turn on the stirrer. Using a pipet, add the toluene and acid anhydride mixture to the vial *slowly*. This addition should require at least two minutes. Use the pipet to transfer the mixture from the vial to a microwave vessel. If solid material is present in the vial, do *not* transfer it to the vessel. Using a spatula, transfer the magnetic stirring bar to the vessel.

Place the vent plug on top of the vessel, cover it with the cap and twist until the cap is finger tight. Under TA supervision and using the special tool, turn the cap until it clicks into place. Wipe off the outside of the vessel with a Kimwipe. Write your names on the vessel using a marker. If there appears to be any solid on the sides, tilt the vessel so the solid will dissolve in the liquid. Your TA will place the vessel in the carousel. Record the number of the position.

The TA will place the carousel in the MARS reactor. The reaction conditions will be as follows:

Power = 200 Watts
Temperature = 110°C
Ramp time = 5 minutes
Hold time = 12 minutes

After the heating step is finished, the reaction mixture will be allowed to cool in the instrument. When the temperature reaches 50°, the TA will distribute the vessels to the students. In a fume hood, use the special tool to *slowly* loosen the cap while pointing the vessel toward the back of the hood. Do not loosen the cap rapidly or gases contained within will escape too quickly.

Obtain the mass of a 25 mL side-arm filter flask.

Add 4 mL of deionized water to the microwave vessel, place the vent plug on top, cap the vessel (finger tight) and shake the mixture vigorously. Transfer the contents of the vessel to a separatory funnel, being careful to remove the stirring bar. Place the stirring bar in the labeled beaker in the dispensing hood. Rinse the vessel with an additional 10 mL of water and then with 3 mL of diethyl ether. Add these rinses to the sep funnel.

Add 5 mL of diethyl ether to the sep funnel and mix the layers *very gently* to avoid emulsions. Drain the two layers into separate flasks labeled "aqueous" and "organic". Return the aqueous layer to the sep funnel and continue extracting with two more 8 mL portions of diethyl ether. Return the combined organic layers to the sep funnel and wash with three 8 mL portions of saturated sodium bicarbonate solution, venting frequently. Wash the organic layer with two 10 mL portions of saturated sodium chloride solution; if it is still cloudy after the second wash, repeat a third time. Dry the organic layer over anhydrous magnesium sulfate, then filter it into a 40 mL vial.

Evaporate the solvent in the Centrifan until approximately 5 mL of liquid remains. Transfer the solution from the vial into the tared side-arm flask. Use a small amount of ether to rinse the vial, and add this to the filter flask. Place a #5 rubber stopper in the mouth of the flask and attach the side-arm to the vacuum outlet. Slowly open the valve. Using a steam bath, evaporate the remaining solvent (which is mostly toluene) under vacuum. Turn off the vacuum when a dark colored oil remains. Record the mass of the product.

IR spectra

Obtain IR spectra of your product and unknown acid anhydride as neat liquids. You will prepare the samples by placing 2 drops of the compound on a salt plate and then placing another salt plate on top of the liquid.

After you have obtained your spectrum, clean both salt plates by rinsing them with dichloromethane (CH_2Cl_2) **(Caution! Toxic and suspected carcinogen. Wear gloves.)** and drying with a Kimwipe. Place all waste solvent in the appropriate **Byproducts** jar. ***Never rinse a salt plate with water or even with acetone, which may contain enough water to damage it.***

NMR spectra

Obtain NMR spectra of your product and unknown acid anhydride as neat liquids. Place 2 drops of your compound in a small vial. Using the pipet and syringe assembly provided, add 0.70 mL of $CDCl_3$ solvent **(Caution! Toxic and suspected carcinogen. Wear gloves.)** to the vial. Transfer the solution to an NMR tube using a Pasteur pipet.

Make sure the height of the liquid in the tube is at 5 cm (compare to the marked NMR tube provided). If it is too low, add some drops of $CDCl_3$ until it reaches the proper height. Attach a cap to the NMR tube. Your TA will assist you with obtaining a spectrum of your sample using the NMReady instrument.

After you have obtained your spectrum, empty the contents of the NMR tube into the **Chloroform-d Byproducts** jar. Place the tube in the beaker labeled "Dirty NMR tubes".

Name _____ Date _____

T. A. _____ Lab period _____

Results and Calculations (to be handed in at the next lab period)

Each student must write his/her own Results and Calculations sheet for this experiment. Do *not* hand in one sheet per pair. Do *not* hand in identical spectral analyses.

Calculate the percent yield of the Friedel-Crafts reaction.

Identify your unknown acid anhydride.

Unknown code number: _____

Write the structures of the unknown acid anhydride reactant and the Friedel-Crafts product you obtained. Using these structures, analyze the IR and NMR spectra. **Note:** The integrals that are provided by the NMReady are often not very accurate.