Experiment 2 - Synthesis of *trans*-Cinnamic Acid

Old-School Background Reading: Breslow, D. S.; Hauser, C. R. *J. Amer. Chem. Soc*. **1939**, *61*, 786.

How to Prepare for Lab + Assignments: Follow Canvas Exp 2 Module…

Before Lab

- Read this PDF – procedure, safety, pre-lab questions, & lab report criteria
- Attend and/or watch **lab lecture**
- Practice the lab online *via* **Slugs@home platform** - sites.google.com/ucsc.edu/slugshome/home
- Complete the **pre-lab questions** at the end of this doc - incorporated into Canvas quiz
- **Pre-lab quiz** on Canvas due midnight Monday before your enrolled section
- Use **Exp 2 worksheet** as template for preparing lab notebook pages – see below

During Lab (Tu-Th)

- Arrive early, dressed for lab; Show your TA: completed notebook pages
- Perform the lab as you fill out data in notebook

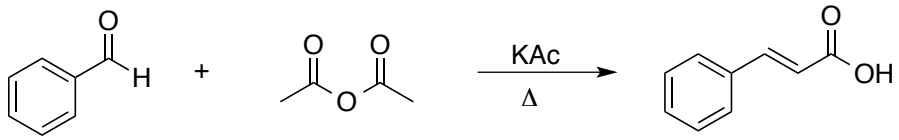
After Lab

- Upload **Exp 2 Notebook Pages** to Canvas by midnight on lab day
- Complete & upload the **Exp 2 Lab Report** on GradeScope (GS) one week after lab

Notebook Preparation

*Students work individually on this experiment

- *Purpose:* To synthesize *trans*-cinnamic acid from benzaldehyde and acetic anhydride under basic, refluxing conditions to exemplify the Perkin condensation.



- *Reagent table*: List the amounts (mg or mL and mmol), molar equivalents ("equiv.")*, and physical properties (MW, bp or mp, density, one-word hazard) of each chemical in the reaction scheme.
    - Molar equivalents (equiv) represent the mole ratio of each chemical relative to the limiting reagent. Calculate the moles of starting materials (Ac_2O and PhCHO) to determine the limiting reagent (potassium acetate is a catalyst). The LR should be entered in the table as "1 equiv." Other reagents have more or less than "1 equiv" unless there is exactly the same number of moles.

- *Procedure* – hand-drawn comic strip, flow chart, bullet-points, or whatever format works for you. Avoid copying the procedure word-for-word. Break it up and make it easy for anyone to follow your procedure without referring to this document.
    - **Purpose, reagent table, & procedure diagrams** – complete before you can start lab
    - All **labeled equipment, chemical names** with **amounts**, **transfers**, **cleanup & safety** notes
        - Help w diagrams: Slugs@home Exp 2 website & class notes

- *Safety & Clean*-up*:* copy table that follows the procedure

EXPERIMENTAL PROCEDURE

The two italicized sections below are the abbreviated form of the procedure understood by experienced organic chemists. The procedure is described in more detail in the paragraphs following.

Reaction Setup "*To a 15-mL RBF equipped with magnetic stir bar was added benzaldehyde (xx mmol, xx mL), potassium acetate (xx mmol, xxx mg), and acetic anhydride (xx mmol, xx mL). A water-jacketed condenser and drying tube ($CaCl_2$) was attached and the system was heated to reflux in a sand bath (xxx °C) for 1 hour."*

Heat a sand bath on a hot plate upon entering the lab. Ensure that the necessary glassware is clean and dry: 15-mL round-bottom flask (RBF), microscale water-jacketed condenser, and a drying tube ($CaCl_2$, pre-made for students). Pre-heat a sand bath on a hot plate (medium setting) to 170 – 190 °C while obtaining reagents. Monitor and record the temperature regularly with a thermometer. Please do not leave the thermometer unattended in the sand bath to prevent breakage.

Add a small magnetic stir bar then dispense the following into the RBF: 1 mL of benzaldehyde, 600 mg of potassium acetate (KAc), and 1.4 mL of acetic anhydride (fume hood only). Be careful not to cross-contaminate reagents by touching the pipet to the flask or its contents. Assemble the reflux apparatus by attaching the condenser (water hoses attached) with a Keck clip, then the drying tube. Place the RBF halfway into the sand bath and clamp the condenser. Be sure the water is flowing through and filling the condenser and heat for 1 hour.

In the meantime, obtain the IR of benzaldehyde and begin writing the **experimental methods section** of the report using the italicized headings provided. Be sure to revise these statements with the actual amounts of reagents used, including proper significant figures.

Reaction Workup *"The reaction mixture was cooled, quenched with water (40 mL), made basic with saturated Na_2CO_3 (pH 8-10), then extracted with 2 x 10 mL BME. Crude product was cooled in an ice bath, precipitated from the aqueous layer with 6 M HCl (pH 2), then isolated as a white solid via vacuum filtration (xx mg, xx% yield)."*

Turn off the heat, carefully lift the apparatus from the sand bath, and let the system cool for 5 minutes. While still warm, slowly pour the contents of the flask into 40 mL of water in a 100 mL beaker. Take an initial pH measurement of the solution and add saturated Na_2CO_3 until the pH is 8-10. Use your best judgment in determining the proper amount and rate of addition of the basic solution. Bubbling will occur due to the formation of CO_2. Use a glass stir rod to break up any precipitate that may appear. After the system has equilibrated (bubbling has subsided and system is at room temperature), transfer this aqueous solution to a separatory funnel and extract two times with 10 mL of *tert*-butyl methyl ether (BME). The organic extracts will be discarded at the end of the experiment.

Transfer the aqueous layer (contains product as a salt) to a 250-mL Erlenmeyer flask and cool the solution in an ice-water bath. In the fume hood, acidify with 6 M HCl to pH 2, being especially careful with this corrosive solution.* Gently scratch the walls of the flask to induce precipitation of product. Allow the crystals to form undisturbed in the ice bath for another 10 minutes. Filter the solid using a Hirsch funnel. Wash the solid with cold water and dry on the filter with the vacuum on for 10-15 minutes. Weigh the crude product and calculate the percent yield to determine whether the product requires additional drying time. Obtain the IR spectrum and melting point of the dry product.

* Change gloves after dispensing HCl and any other time there is potential contamination.

Spectroscopic Analysis: *"($CDCl_3$, 500 MHz) δ (ppm): [list each signal's chemical shift (splitting, integration)]. IR (neat or nujol): [list wavenumber(s) of key functional group]."*

IR – Predict the bonds and wavenumber ranges absorbed benzaldehyde and *trans*-cinnamic acid. Obtain IR spectra of benzaldehyde on NaCl plates. The IR spectrum of *trans*-cinnamic acid is obtained as a nujol mull on NaCl plates. Assign th

NMR – Students will prepare NMR samples with the help of the T. Weigh approximately 10 mg of product into a dram vial and dissolve in 800 uL of $CDCl_3$. Transfer this to an NMR tube with a clearly written label containing "Last Name, First Initial, Lab Day, Time, and TA."

You're encouraged to preview the IR and NMR spectra to analyze on the Slugs@home website.

Experimental Methods

Students are strongly encouraged to write a draft of the experimental methods section, including NMR and IR data, before leaving lab. Use the description on page 10, your results, and the *italicized sentences in the procedure*. Your TA is happy to provide feedback on a draft after lab – check Canvas assignment for comments.

Table 1. Clean up and safety notes

Clean-up	**Safety**
Solid waste: pipets, filter papers, capillary tubes	Acetic anhydride is bad news – corrosive, lachrymator, & irritant
Liquid Waste: filtrates and BME	HCl is corrosive; be extra careful with 6 M HCl
Return equipment to proper place – keep those ring stands organized please!	Benzaldehyde is a possible mutagen
Clean up inevitable the sandstorm of sand from sand baths!	BME is flammable
**Be sure to label every vessel before the first drop or crystal enters the container! Remove all labels before washing.	
Refresh your memory on the Safety Rules on Canvas.	

References

- Palleros, D. R. *Experimental Organic Chemistry*; Wiley: New York, **2000**; pp. 433 – 437.
- Perkin, W. H. *J. Chem. Soc.* **1868**, *21*, 181 – 186.
- Breslow, D. S.; Hauser, C. R. *J. Amer. Chem. Soc*. **1939**, *61*, 786.

Pre-Lab Questions

Take the Canvas pre-lab quiz the Monday *before* lab.

- The quiz incorporates the questions below – the questions may be reworded.
- **Be prepared with your responses to the pre-lab questions *before* starting the quiz.**
- There is a 20-minute time limit on the quiz and you get two attempts.
  - Make sure you have enough time to complete the quiz – you can't save and come back later.
  - If you choose to re-take the quiz, your grade will be the highest of the two attempts.

1. Briefly describe the role of each chemical used in the reaction: benzaldehyde, acetic anhydride, and potassium acetate. Possibilities for roles include nucleophile, electrophile, acid catalyst, or base catalyst.

2. Draw the arrow-pushing mechanism for the synthesis of *trans*-cinnamic acid.

3. It's helpful to make the reagent table with molecular weights and densities before doing the following calculations. Show your work with units on every value.
   a) Convert the amounts of potassium acetate and acetic anhydride given in the procedure into mmoles.
   b) Identify the limiting reagent and calculate the theoretical yield of *trans*-cinnamic acid.

4. Briefly describe the role of water, Na_2CO_3, and HCl in the isolation of the product. Draw the structure of the product at basic pH (after Na_2CO_3 addition) and at acidic pH (after HCl addition).

5. The organic (BME) washes are discarded. What is in these organic washes?

6. Predict the IR spectrum of benzaldehyde: identify functional groups, bonds, and expected wavenumber ranges. Enter this into the IR table in the worksheet at the end of this document).

7. Predict the ^{1}H and ^{13}C NMR spectra of benzaldehyde.

Though we encourage collaboration in this class, this is an individual quiz.

- The responses should be a product of your original work so that you are assessed on *your* understanding of the material.
- Sharing your quiz or your responses in any format (screenshots, email, CHEGG, social media, text, carrier pigeon, etc.) is in violation of the UCSC academic integrity policy.

LAB REPORT, Part 1 of 2

In-Lab Questions

1. Report the volume of benzaldehyde used in the reaction. Calculate the theoretical yield from that amount (mmol and mg). Show your work.

2. Report the crude yield of the reaction (mg and %). Discuss all sources of product loss (be specific – list the part of the procedure, why product was lost, and where it ended up).

3. Report the melting point range of the product. Discuss any difference in the melting point compared to the literature value.

4. Interpret the IR spectra of benzaldehyde and *trans*-cinnamic acid. Include only the stretches for C=O, C=C, and O-H bonds. Use the following table format (one table per compound). IR tables for expected stretches are online. Which bands would you use to tell the two apart?

Table x. IR Analysis of (Compound Name)

Functional Group	Bond	Expected from tables (cm^{-1})	Observed (cm^{-1})

5. Interpret the ^{1}H NMR of *trans*-cinnamic acid using the following table format. Draw the structure of *trans*-cinnamic acid and label each proton. Indicate the number of H's responsible for each signal (Integration) and splitting pattern. Calculate the expected chemical shifts using the correlation tables on the 110L website and assign to the literature spectrum provided in lecture as well as the student sample posted online (observed).

Table x. ^{1}H NMR Analysis of (Compound Name)

Signal	Integration (#H's)	Splitting	Chemical Shift, Expected (ppm)	Chemical Shift, Literature (ppm)	Chemical Shift, Observed (ppm)
A					

6. Interpret the ^{13}C NMR of *trans*-cinnamic acid. Assign as many peaks as possible to the structure (re-draw this structure with assignments as part of your answer). You do not need to calculate expected chemical shifts, but do provide estimated values. Make a note of the label to confirm which spectrum you are reporting.

Table x. ^{13}C NMR Analysis of (Compound Name)

Signal	Chemical Shift, Expected (ppm)	Chemical Shift, Literature (ppm)	Chemical Shift, Observed (ppm)
A'			

7. Draw the arrow-pushing mechanism for the synthesis of *trans*-cinnamic acid, including the addition of water and Na_2CO_3 in the reaction work-up.

LAB REPORT, Part 2 of 2

Experimental Methods & Characterization

- **Reaction scheme** - including reactants, reagents, products, solvent(s), and % yield (structures and reaction schemes can be hand-written)

- **Full chemical name of product in bold** (common and/or IUPAC)

- Brief description of **reaction set up** and **workup** including…
  - Names and amounts of each reactant and reagent (mmol and mL or mg)
  - Name and amount of solvent, if applicable (mL)
  - Order of addition, if pertinent, and reaction conditions (time, temperature)
  - Description, name, and amount of product obtained and % yield:
    - Ex. “Benzhydrol was obtained as a clear liquid (1.00 g, 87% yield).”

Characterization of the product follows in the same paragraph (after reporting the yield) and includes some or all of the following.

- Melting point

- All NMR signals
  - ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): *[list each signal’s chemical shift (splitting, integration)].*
  - ^{13}C NMR ($CDCl_3$, 500 MHz) δ (ppm*): [list chemical shifts]*

- Distinctive IR stretch(es) – one or two distinguishing peaks, such as carbonyl or O-H stretches
  - *IR (neat or nujol): [list wavenumber(s) of key functional group].*