Experiment 1: Recrystallization of Acetanilide

Learning Objectives

- Understand principles behind purification and recrystallization
- Critical analysis of recrystallization technique
- Analyze data to assess purity and success of experiment
- Understand the role H-bonding plays in dissolving, precipitation, and melting point
- Predict sources of intrinsic error and understand their effects on results

---

How to Prepare for Lab + Assignments - Follow Canvas Exp 1 Module…

Before Lab

- Read this PDF – background, procedure, safety, pre-lab and in-lab questions
  - Option to listen to **Exp 1 Podcast** on Canvas = Caitlin reads this document ☺
- Attend **lab lecture** and take notes on **templates** provided on Canvas
- 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
- Download the **Exp 1 worksheet** on Canvas and prepare your **lab notebook**…

Lab Notebook Preparation – *Required before lab; worksheet provided as suggested template on Canvas*

- **Purpose:** one-sentence summary of the main lab goals plus the recrystallization scheme (**Figure 2**).
- **Reagent Table** – add chemical properties; Wikipedia is a reliable source for chemical info!
- **Procedure with Diagrams** – complete before starting lab; sample on Canvas
  - Use the procedure that follows to create your hand-drawn experimental instructions
    - Simple sketches & labels for all **equipment, chemical names** with **amounts**, & **transfers**
  - Format: Break it up with flow charts, bullet-points, comic strip, and/or whatever works for you!
    - Avoid copying the procedure word-for-word.
    - Make it easy for anyone to follow your procedure without referring to this document.
  - **Slugs@home Exp 1 website** - Equipment & Safety pages; pictures & videos of the whole lab
  - The **class notes** include useful diagrams as well

During Lab (Tu-Th)

- Check the **safety rules** to dress for lab and arrive a few minutes early to **Thimann Labs**
- **Pre-lab talk:** tips for success and open Q&A
- Show your **lab notebook pages** to your TA
- Perform the experiment with a partner, fill out data & observations in **lab notebook**

After Lab – each partner submits separate, individual assignments

- Upload **Notebook Pages** to Canvas by midnight on lab day – graded on completeness / participation
- Complete & upload the **Lab Report** on GradeScope (GS) – due date on Canvas
  - Guidelines at end of this document

Background Theory

Paracetamol, the active ingredient in **Tylenol®**, is commonly used for pain relief (analgesic) and to reduce fevers (**Figure 1**). The synthesis of pharmaceutical agents like Tylenol requires pure starting materials to avoid complications from impurities. Purification is a tedious part of synthetic organic chemistry. Often product recoveries are sacrificed in favor of more pure materials. Solids can be purified *via* recrystallization or sublimation and liquids *via* distillation. Acetanilide has a similar structure to Tylenol and is also an analgesic. Acetanilide is no longer marketable due to toxic effects when ingested, but it is safe to use in the organic teaching lab as it is only a mild skin irritant. Acetanilide recrystallizes well from water due to its high solubility in hot water and low solubility in cold water. The purification of acetanilide serves an excellent introduction to recrystallization (**Figure 2**).

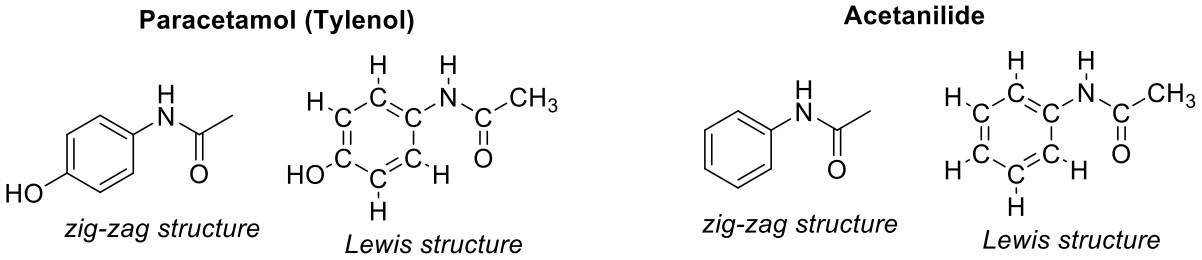

Figure 1. Structures of paracetamol and acetanilide

The basic steps of recrystallization are as follows.

1. Choose a good recrystallization solvent
2. Dissolve the sample in the *minimum* amount of boiling solvent
3. Hot filtration to remove insoluble impurities
4. Cool the solution to induce crystallization
5. Cold filtration to separate the solid from the solution (mother liquor or filtrate)
6. Wash the solid with a small amount of cold solvent
7. Dry the solid to remove traces of solvent

The crude, impure solid is dissolved in the smallest possible amount of solvent of choice; in this case, the solvent is water. Acetanilide (Ac) has a much higher solubility in hot water than in cold water. If too much hot solvent is added in the beginning, little-to-no Ac will recrystallize from cold water at the end of the experiment. Activated charcoal is added to remove **colored impurities**. These impurities are often non-polar organic compounds that have an affinity for activated charcoal, a non-polar fine, black powder. Any **insoluble impurities** (including those that have adsorbed onto the charcoal) are removed during the **hot filtration** step, while acetanilide remains in solution (filtrate). This solution is gradually cooled in an ice bath to induce crystallization. **Cold filtration** is performed under reduced pressure (vacuum). Any **soluble impurities** remain in the filtrate and the recrystallized solid is collected from the filter paper.

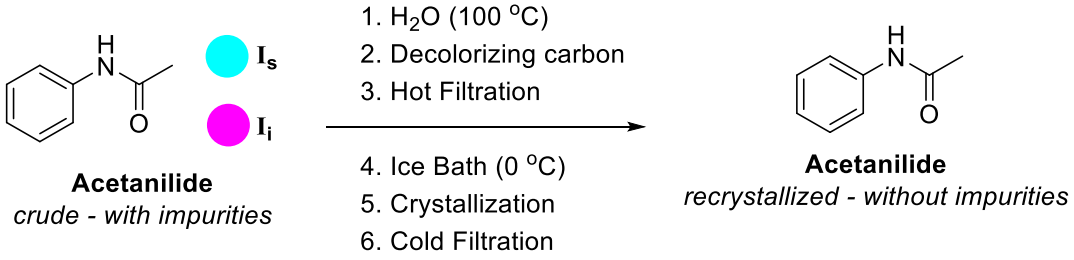

Figure 2. Recrystallization of acetanilide overview – *use this in the Purpose of lab notebook*

Finding the proper **recrystallization solvent** has to be determined experimentally. This can be tricky if there is no literature precedent for the compound (luckily it is known that water works for acetanilide!). A successful recrystallization requires that the compound be *highly soluble at the solvent's boiling point* and significantly *less soluble at low temperature*. The masses of recrystallized product (m_{recrys}) after cold filtration and the original crude starting material (m_{crude}) are used to calculate the **percent recovery of recrystallization** according to **eq 1**.

$$\% \text{ Recovery} = \frac{m_{recrys}}{m_{crude}} \times 100\% \qquad \textbf{(eq 1)}$$

A **theoretical recovery** represents the maximum amount of material that can be obtained if the experiment were carried out flawlessly; assuming no product is lost in transferring solutions, particularly in the hot and cold filtrations. It is unrealistic to carry out this 'perfect' experiment due to the nature of recrystallization. Mass recoveries are expected to be quite low. This is generally acceptable due to the high purity of recrystallized material.

Theoretical recovery is calculated using the known solubilities of acetanilide in water at a cold temperature (S^c = 0.53 g Ac / 100 mL at 0 °C), and high temperature, (S^H = 5.50 g Ac / 100 mL at 100 °C). The maximum mass recoveries from the hot and cold filtrations are calculated by multiplying each solubility by the solvent volume used in the experiment. The **theoretical mass recovery (g)** is the difference between the resulting S^H and S^c, accounting for solvent volume.

It is useful to know how much recrystallized sample could be recovered in a perfect experiment as a measure of experiment success, or at least set a more realistic expectation than 100%. This **theoretical % recovery** is determined by dividing the theoretical mass recovery by the initial mass of crude sample (m_{crude}), expressed in **eq 2**. Note that the percent *recovery* and theoretical *recovery* are different from the theoretical *yield*. Theoretical *yield* applies to a chemical reaction and *recovery* refers to a physical process.

$$\text{Theoretical \% Recovery} = \frac{S^H - S^c}{m_{crude}} \times 100\% \qquad \textbf{(2)}$$

The purity of commercially available (crude) and recrystallized acetanilide will be assessed by **MelTemp analysis**. Colligative properties predict that impurities lower melting temperature and increase melting ranges. The melting range is the temperature recorded when the solid begins to melt and again when all is converted to liquid. The recrystallized product should have fewer impurities and a more ordered structure based on intermolecular forces (IMFs) like hydrogen bonding (H-bonds) (**Figure 4**). The impurities interfere with H-bonds, creating weaker IMFs that take less energy (lower temperature) to break and cause the phase change. Purity may also be apparent in the appearance of the solid before and after the experiment.

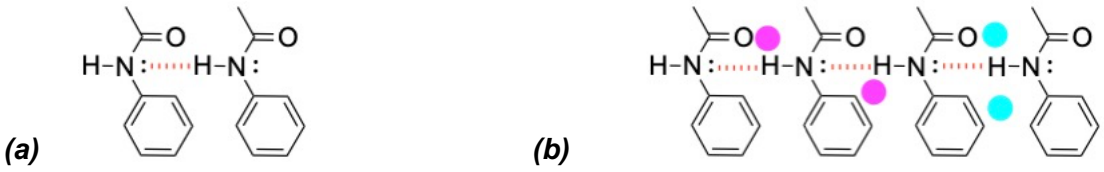

Figure 4. H-bonding patterns in **(a)** pure acetanilide and **(b)** acetanilide with impurities.

LAB PROCEDURE

Students work in pairs on the lab work and complete the Exp 1 notebook pages & report individually.
Pro-tip for notebook prep: circle / highlight each all equipment & chemical names with amounts.

Part 1. Dissolving the Sample. Place *approximately* 2 g of crude acetanilide in a labeled 125-mL Erlenmeyer flask. Record the actual mass obtained. Please ***DO NOT LEAVE ANY SOLID ON OR AROUND THE BALANCES.*** Add 35.0 mL water and two *black* boiling chips. Bring the mixture to a boil on a hot plate (hot plates should *never* go past a medium setting). Stir the system frequently with a glass rod. Allow the solution to boil for a few minutes then, if necessary, add more water drop-wise (up to 5 mL max) until all solid dissolves. Adding more water may decrease the percent recovery, however, solvent evaporates as the solution boils so more water may be necessary. *Record the total amount of water added.* Some material may melt (aka "oil out") and oily droplets appear on the top of the solution. Not to worry – proceed to the next step.

Addition of Activated Charcoal. Once all acetanilide has dissolved, remove the flask from the hot plate using **two hot mitts** and place on the counter to cool (do not add charcoal to a boiling solution or risk creating a volcano!). Slowly add a spatula-ful of activated charcoal to create a black, opaque suspension. It is normal for crystals to form at this stage. Place the flask back on the hot plate and boil the solution to re-dissolve solid. In the meantime, follow the instructions below to set up the ***hot filtration*** apparatus.

Part 2. Hot Filtration. Label two clean 125-mL Erlenmeyer flasks ("filtrate" and "water"). Place two boiling chips and 5 mL of water into each. Place a small (~1 inch) piece of copper wire, bent into a U, and over the lip of the filtrate flask, then add a short-stem funnel with a fluted piece of filter paper. This will provide space for steam to escape between the "filtrate" flask and funnel. Heat both flasks on medium while charcoal

suspension warms. Keep in mind that as steam escapes, the water is evaporating! Be sure that these flasks do not boil to dryness or the glass will crack. Once the steam has heated the funnel, immediately before filtering the acetanilide-charcoal suspension, pour some of the hot water from the second flask through the funnel to heat the filter paper.

Swirl the acetanilide-charcoal suspension, hold the bottom of the flask with **hot mitts,** and quickly transfer into the fluted filter paper *portion-wise.* Use a glass rod to direct the solution into the funnel and prevent dripping down the side of the flask. Fill the funnel no more than half full at any given time, being careful not to poke or tear the filter paper. Frequently place the flasks back on the hot plate to maintain the temperature of both solutions. Rinse the pre-mature crystals on the filter into the filter with small portions of boiling water. It may be necessary to restart the hot filtration if too much solid is on the filter. The bulk of the acetanilide should be dissolved in the filtrate.

Cooling Down. After completing the hot filtration, discard the filter paper in solid waste and allow the flask containing the filtrate to cool to *room temperature* then place it in an ice-water bath. If the system cools down too quickly, small crystals form and adsorb a large amount of impurities from the filtrate. Place 5 mL of distilled water in the ice bath to wash the crystals later during the cold filtration. Allow crystals to form for 10 minutes (note initial time of crystal formation as it may not happen immediately). Scratch the inside bottom of the flask with a glass stir rod to release seed crystals. Drawing a star and circle across the bottom of the flask tends to do the trick! Otherwise, do not disturb the flask once crystal formation has begun.

Part 3. Cold Filtration. After crystallization is complete, collect the crystals by vacuum filtration. Attach thick-walled vacuum tubing to a 125-mL filter flask then securely clamp the filter flask to a ring stand. Place a rubber “filter vac” seal on top to create a seal with a porcelain Buchner funnel. Obtain the correct size filter paper that covers all the holes of the filter but does not fold up the walls. Pre-weigh the filter paper, position it on the funnel, turn the vacuum on, and wet the filter paper with 5-10 mL of *cold* water. This will adhere the paper to the funnel and prevent it from moving during the cold filtration. Gently swirl the contents of the Erlenmeyer flask then pour the suspension into the funnel. Keep the liquid filtrate until the end of lab, then dispose in liquid waste.

Wash and Dry the Solid. Turn off the vacuum once the entire solution has been transferred and the liquid stops dripping from the funnel. Add 2-5 mL of ice-cold water to the funnel to wash the crystals. Turn the vacuum on and press the crystals with a spatula (tip should be slightly bent) to remove as much water as possible. Let the solid dry on the filter with the vacuum on for 20 minutes and proceed to ***melting point analysis*** while the solid continues to dry. If you hear a *hissing* sound, the vacuum seal is not tight. Re-adjust until the hissing stops. Keep the vacuum on to dry the remaining solid for an additional 30 minutes, until solid is dry. Transfer the solid and filter paper to a pre-weighed watch glass. Spread out the solid and carefully remove the boiling chips with tweezers. Weigh the dried solid and calculate the mass of pure acetanilide by difference. Calculate

percent recovery and *record a description of the product*. If the recovery is greater than 100%, the solid requires further drying in the Buchner funnel.

Part 4. MelTemp Analysis. Once the solid has been drying with the vacuum on for 20 minutes, take a small sample for MelTemp analysis (negligible effect on mass recovery). Spread the solid on a porous plate with a spatula for at least one minute to remove water. This is essential for accurate MelTemp determination, as water will significantly lower the melting temperature.

Obtain the melting ranges of very small samples of crude solid simultaneously with recrystallized solid. The settings on the MelTemp indicate the *rate of temperature increase.* Use a medium setting until the temperature is 20 degrees below the melting point of acetanilide, then lower the setting for a slower temperature increase. Closely observe and record the melting ranges of both samples: record the temperature when the sample begins to melt (looks like it is sweating) and again when the entire sample is in the liquid phase. Dispose of recrystallized product in the solid waste after analysis.

Clean-up and Waste	**Safety Hazards**
* *Solid waste*: Filter paper, acetanilide (crude and recrystallized), and used capillaries * *Liquid waste*: Filtrates aka mother liquor * Rinse the *charcoal-containing flask* with water into the liquid waste. Fill ~$^1/_3$ full with soapy water and warm (not boil) on hot plate before cleaning with a large brush.	* Be careful with hot glassware. Use both hands in hot mitts to handle hot glassware. Do not use clamps, paper towels, or bare hands. * Do not let acetanilide come in contact with eyes, mouth, or skin (irritant).
* Wipe down all bench tops with a sponge then dry with paper towel – no solid left behind.	
* Stack hotplates and ring stands neatly. Separate clamps from holders and return to proper drawer.	
* Remove gloves to wash glassware. Conserve soap and water when washing. Rinse cleaned glassware twice with tap water and once again with distilled water. Let it dry on a paper towel for a few minutes before drying further by hand and returning equipment to drawer.	

Pre-lab Questions & Quiz

The pre-lab quiz is due before lab – check Canvas for due date

- 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.
  - Email your TA if you have technical issues and need an extra attempt at the quiz.

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.

Pre-Lab Questions

1. List the *basic steps* in the recrystallization of acetanilide in order. Include the **identity of the solvent** that will be used and what is added before hot filtration.

2. What **bonds** are present in acetanilide (ex. C-C)? Identify each as **polar or non-polar**. Use this information to **explain why water** is a good recrystallization solvent for acetanilide.

3. Why should a **minimum amount of *hot* solvent** be used for dissolving the crude solid? Why should the recrystallized solid be **washed with *cold* solvent**?

4. The solubility of acetanilide in hot water is 5.50 g/100 mL at 100 °C and its solubility in cold water is 0.53 g/100 mL at 0 °C. Use the following steps to calculate the theoretical percent recovery for a recrystallization that uses with 2.00 g of crude acetanilide (m_{crude}) and 35.0 mL of water, assuming no product loss or solvent evaporation.

   - How much acetanilide (g) should dissolve in the **hot water** before hot filtration? This result is S^H.

   - How much acetanilide (g) should remain in the **cold water** before cold filtration? This result is S^c.

   - What is the **maximum amount of acetanilide (g)** that could be recovered in a perfect (unrealistic) experiment - assume no solvent evaporation or product loss in transfers. This is ($S^H - S^c$).

   - Use equation **(2)** and the steps above to calculate the theoretical % recovery of acetanilide in a perfect (unrealistic) experiment.

$$\text{Theoretical \% Recovery} = \frac{S^H - S^c}{m_{crude}} \times 100\% \qquad \textbf{(2)}$$

5. What effect does an **impurity** have on the **melting point** of organic compounds? What effect does an impurity have on the **boiling point** of a solvent?

LAB REPORT – upload to GradeScope / Canvas
No abstract for the Exp 1 report.

In-lab Questions – numbered responses that incorporate the questions, no need to include the exact question

1. **Describe what happens to the molecules** when acetanilide dissolves in hot water. Are any **covalent bonds** broken or formed in the recrystallization?
    a. Include **diagrams** to depict the hydrogen-bonding (H-bond) patterns involved before and after Ac dissolves in water. These should be original, hand-drawn figures - do not copy / paste from online sources. *Hint: review lecture notes and the Exp 1 lab-site.*
        i. solute
        ii. solvent
        iii. solution

2. What is the **role of the activated charcoal** in this experiment? What is another **application** of activated charcoal in everyday life?

3. After hot filtration removes insoluble impurities, the remaining solution (filtrate) is cooled in an ice bath without being disturbed. Explain what happens to the acetanilide molecules during the **crystallization process** and what happens if **crystals form too quickly**. Use a few sentences and diagrams in your response.

4. Report the starting **mass of crude acetanilide (Ac)** and **total volume of water used**. Re-calculate the **theoretical recovery (g)** and **theoretical percent recovery** from *your* recrystallization experiment, taking into account the actual mass of crude acetanilide and the amount of water used in the experiment through the hot filtration. **Show your work** for the theoretical percent recovery calculation – steps outlined in pre-lab #2 (typed or by hand).

5. Report the **mass of recrystallized acetanilide (g)** obtained at the end of the lab. Calculate the **percent recovery** of the recrystallization of acetanilide from water. Show your work.

6. Report the **melting temperature ranges of the crude and recrystallized acetanilide**. Compare this to the **literature melting point** of acetanilide (is it higher or lower?). *Briefly* explain your results in terms of expected **colligative properties** (what's supposed to happen to the melting point when impurities are present vs. removed?).