Preparation of Aspirin

Objectives:

To prepare a sample of an organic compound.
To calculate percent yield of a reaction.

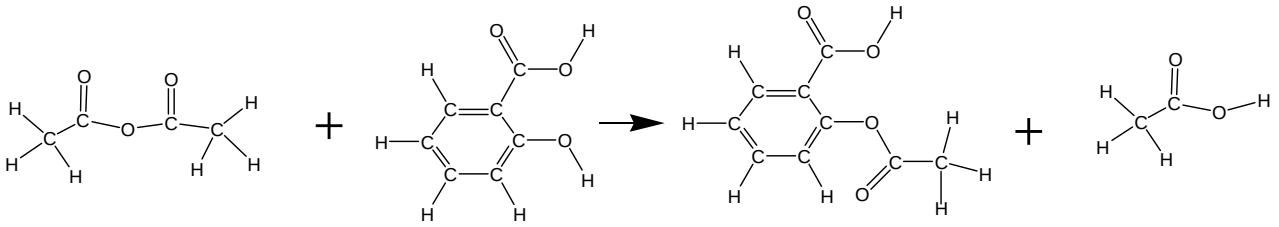
Text references:

stoichiometric calculations, limiting reactant, percent yield

Discussion:

High molecular weight molecules such as aspirin are generally insoluble in water and can be separated from a reaction mixture by crystallization. Aspirin can be prepared by the reaction of salicylic acid with acetic anhydride.

$C_4H_6O_3(l)$ + $C_7H_6O_3(s)$ → $C_9H_8O_4(s)$ + $C_2H_4O_2(l)$

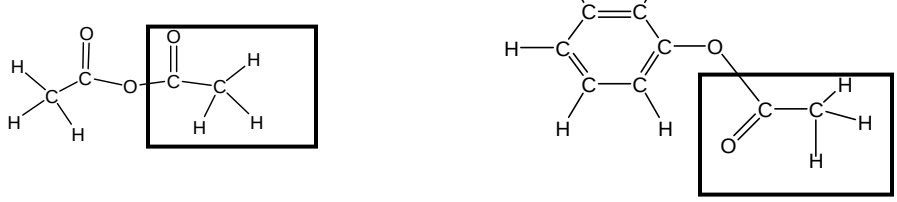


acetic anhydride	**salicylic acid**	**aspirin**	**acetic acid**
Molar Mass	Molar Mass	Molar Mass	Molar Mass
102.09 g/mol	138.12 g/mol	180.16 g/mol	60.05 g/mol

NOTE: In the equation above, the lone pairs on oxygen atoms have been omitted. Based on what you know about Lewis Dot Structures (and the octet rule), fill in lone pairs in all molecules above where they are needed.

Can you identify what changes occur over the course of this reaction? How do the products differ from the reactants?

Note that the reactant acetic anhydride could be described as two acetate groups (CH_3COO) connected to one another by sharing their second oxygen. In producing aspirin, the acetic anhydride molecule is cleaved—half of the acetic anhydride molecule replaces hydrogen (H) of the hydroxyl group (–OH) attached to the six-carbon ring of the salicylic acid molecule.



The other half of the acetic anhydride molecule accepts the hydrogen (H) that has been replaced and becomes acetic acid in solution.

As soon as acetic anhydride and salicylic acid are mixed, this reaction starts to take place—although at a rate that is too slow to be completed during the time constraints of a lab session. Therefore, concentrated phosphoric acid is used as a ***catalyst*** that will speed up the reaction without changing its own chemical composition after the reaction.

It is likely that your aspirin will "crash out" of solution as crystals (***crystallize***) just as it cools on the bench top. However, if you have waited an exceedingly long time without observing crystallization, you may need to add chilled water and put the flask in an ice bath.

Large organic molecules such as aspirin are generally insoluble in ice-cold water, but the other components are soluble. Therefore, by lowering the temperature of the mixture, pure aspirin will come out of solution as a solid, while the other impurities remain dissolved in water. Exercise patience before resorting to adding the water, as it may take time for the crystals to form. If you do add ice-cold distilled water, make sure to cool the solution slowly, or you are likely to end up with a solid mixture of salicylic acid and aspirin.

Even at a heated temperature after 10 - 15 minutes, not all of the salicylic acid will be converted into aspirin. This means you will have a mixture, rather than pure aspirin in your flask. To be specific, your reaction flask will contain unreacted salicylic acid, aspirin (your desired product), and acetic acid. (In addition to quenching the reaction, water also converts unreacted acetic anhydride to acetic acid.) Because of this, it is necessary to isolate the aspirin from the mixture once you've added water. This will require you to do a filtration to separate the solid product from the rest of the mixture. If you have not already added water at this point, you may add ~25 mL now to aid in the transfer of the crystallized aspirin.

CAUTION*: The aspirin you prepare in this experiment is impure and must not be taken internally!*

Procedure:

I. Synthesis of Aspirin

A. Chemicals

1) Weigh 1.5 $\pm$ 0.1 g of salicylic acid onto a folded and tared piece of weighing paper. Record the exact mass (to 2 decimal places) of the salicylic acid onto your data report sheet.

2) Transfer the salicylic acid to a clean, dry 125 mL Erlenmeyer flask. (Your instructor will demonstrate this procedure to you)

   CAUTION! *Both acetic anhydride and phosphoric acid are reactive, corrosive chemicals that can produce serious burns on contact with skin. These should be handled in the hood, and great care must be taken when working with them. If you spill even one single drop of either of these substances, you must alert your instructor and classmates immediately!!*

3) Carefully add 2 mL of acetic anhydride (this is in the fume-hood) to the salicylic acid in the flask. ***Use the graduated cylinder provided for this purpose. Close the lid of the acetic anhydride bottle after you use it; otherwise the absorbed moisture can destroy the reaction.***

4) Add 4 drops of concentrated phosphoric acid (this is in the fume-hood) to the mixture; ***Use the pipette dropper provided for this purpose;*** swirl the flask gently. ***Close the lid of the phosphoric acid bottle after you use it.***

B. Heating the Mixture (your instructor will demonstrate this)

1) Your instructor may have you set up your apparatus at the beginning of the lab to get your water bath preheating.

2) In the big 400 mL beaker provided to you, take warm water from the tap **to no more than two-thirds level** of the beaker. Place this beaker of water (water-bath) on a hot-plate.

3) Connect the hot-plate to the electrical outlet and turn the "heat" knob to the highest heating mode.

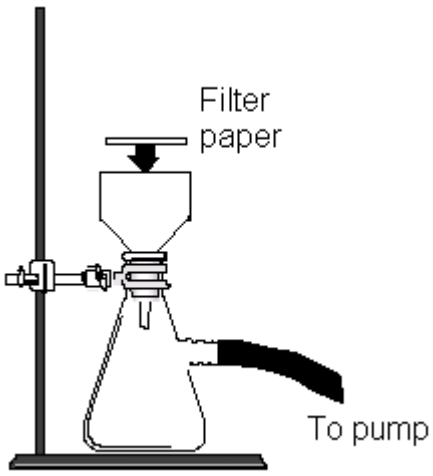
4) Clamp the Erlenmeyer flask that has all the added chemicals, to the clamp-stand and gently lower the clamp into the water-bath, to immerse the bottom of the flask into it and tighten the clamp.

5) Heat the flask until the water in the beaker is ~ 80°C. Turn off the hot plate and swirl your flask to ensure that all of the (white, powdery) salicylic acid dissolves. After swirling, you may see small, needle-like, glassy crystals of aspirin also in the flask. Do not worry about getting these to dissolve. Return the flask to the warmed water bath for another 5 minutes.

6) Raise the clamp with flask far above the water-bath, and let the flask cool to room temperature in air. (Or you may choose to take your flask to your station and let it cool there. Check with your instructor to find out his/her preference). You might start seeing crystals of aspirin as the flask starts to cool. **DO NOT shake or stir the contents of flask while it is cooling!**

7) If you do not observe crystals after waiting for 10 minutes or more, consult your instructor.

C. Filtration of Crystals (your instructor will demonstrate this)



1) Write your name with ***pencil*** on the edge of a piece of filter paper. Place the filter paper on a watch glass. **Weigh and record the total mass of filter paper and the watch glass in your data report sheet.**
2) Put the filter paper into the Buchner funnel (as shown on the right) with your name side up.
3) If you have not already done so, add approximately 25 mL of ice-cold chilled distilled water to your flask. Break the large chunks of white crystals into small pieces with a glass stirring rod. Be Gentle!
4) Wet the filter paper with **cold** distilled water.
5) Turn on the electric pump which creates a vacuum drawing the cold liquid through the Buchner funnel.
6) Swirl the aspirin/liquid mixture in your Erlenmeyer flask and *quickly* dump into the funnel apparatus.
7) Use cold distilled water to rinse as much aspirin out of the flask as possible. Rinse the aspirin on the filter paper with the remaining cold distilled water. Continue to draw air through the funnel for a few minutes to help dry the crystals.
8) Carefully lift the filter paper that now has crystals of aspirin and place it on the watch glass you had weighed before. DO NOT weigh again today since it is necessary to dry the product before weighing!

D. Drying the crystals: Store the watch glass on the tray provided by your instructor until next week to allow time for your product to dry.

E. Clean Up and Waste Disposal:

- The filtrate (the aqueous waste inside the filter flask) can be flushed down the sink.
- Place the <u>rinsed</u> Erlenmeyer flask at the designated area.
- Obtain and place a clean, dry Erlenmeyer flask at your station.
- Keep <u>rinsed</u> micro-spatula and glass stirring rod at your station.

The following procedures will be finished in the next lab session. Make sure to bring back this protocol and data sheet. You will also be doing another experiment in the same week that you finish aspirin, so bring both protocols with you!

F. Weigh the total mass of the watch glass, filter paper and aspirin product. Record the mass in the data report sheet.

II. Purity Test:

1) Watch instructor's demonstration of 1% iron(III) chloride with pure salicylic acid and pure aspirin, respectively. Record the observation in the table on the date sheet.
2) To test the purity of your aspirin product, transfer a SMALL amount of your product (spatula tipful) to a small test tube. Add 2 drops of 1% iron (III) chloride solution.
3) Compare your result with the observations of pure salicylic acid and pure aspirin. Which one is your product more similar to?
4) Based on your observations, write a conclusion with regard to the purity of the aspirin you have prepared.
5) Dispose of the content of the test tube in the sink. Rinse the tube with tap water.
6) Dispose of the remaining aspirin and the filter paper into a provided waste beaker. Rinse the watchglass and place it in a designated area.

III. Calculations:

To calculate the ***theoretical yield*** of aspirin in this lab activity (the amount of aspirin one would predict could be generated), it is important to know which of the two reactants is the ***limiting reactant***. The limiting reactant "limits" the amount of product that can be formed, because it "runs out" or is "used up" before any other reactants. When you prepared aspirin, the salicylic acid was the limiting reactant, and an ***excess*** of acetic anhydride was used.

Therefore to calculate the theoretical yield of aspirin, you will need the mass of salicylic acid used in the reaction. With the initial mass of salicylic acid and the balanced equation on p.1, you can calculate how much aspirin theoretically can be made in this reaction by using the following plan:

Mass of Salicylic Acid (g) → Moles Salicylic Acid → Moles Aspirin → Mass of Aspirin (g)

The molar masses of relevant substances are provided on p.1. Check the balanced chemical equation on that page carefully to figure out the molar ratio between salicylic acid and aspirin.

In reality, it is highly unlikely that you were able to produce ALL the aspirin that is predicted in a theoretical yield calculation and, instead, you will have a lower ***actual yield***. The actual yield refers to the mass of aspirin that you isolate (and weigh) at the end of the activity. When scientists prepare or synthesize new compounds, they often assess how close their actual yield is to the theoretical yield for that particular reaction. A value commonly used to communicate this is the ***percent yield***.

Percent yield is calculated based on the following equation:

$$\textbf{percent yield} = \frac{\textbf{actual yield}}{\textbf{theoretical yield}} \times \textbf{100\%}$$

There are many reasons for why it is typically not possible to have a percent yield of 100%. Product can be lost when it is transferred from one container to another or during filtrations (some of the product may remain dissolved in the filtrate). Additionally, optimum reaction conditions are necessary in order for all of the reactant(s) to be converted to product. These are just a few reasons for why a less than 100% yield might be obtained. Try to name others.

Preparation of Aspirin Data Sheet

Name_____ Date_____ Lab Section_____

Balance number_____

All measurements must have: quantity & units.

I. Data:

mass of salicylic acid _____

mass of watch glass + filter paper _____

(next week) mass of watch glass + filter paper + aspirin _____

II. Purity Test:

Pure Aspirin	**Pure Salicylic Acid**	**Your Product (Crude Aspirin)**
Observations:	**Observations:**	**Observations:**

What do you conclude about the purity of your aspirin?

III. Uncertainty:

The uncertainty associated with mass measurements for this lab is _____, which means the actual amount of salicylic acid initially weighed out is somewhere between _____.
(include units for both answers in this section)

IV. Calculations
(SHOW WORK FOR A, B & C AND FOLLOW SIGNIFICANT FIGURE RULES!!):

A. actual yield of aspirin _____

B. theoretical yield of aspirin _____ (based on mass of salicylic acid)

C. percent yield _____

Pre-lab exercise Preparation of Aspirin

(Complete and check answers before coming to lab)

1. During the preparing aspirin lab activity, a student attempts to determine how much aspirin she made. She looked back at her data:

mass of flask	73.86 g
mass of flask and salicylic acid	77.88 g
mass of salicylic acid	4.02 g
mass of watch glass + filter paper	34.63 g
mass of watch glass, filter paper and aspirin	38.29 g

a) What mass of aspirin did she generate?

b) This mass of aspirin she got by actually doing the experiment is called _____yield.

c) The molar mass of salicylic acid is 138.12 g/mol. How many moles are there in 4.02g?

d) **The limiting reactant in this reaction is salicylic acid.** The stoichiometry between salicylic acid and aspirin in the balanced chemical equation is 1:1. So, how many moles of aspirin are theoretically generated from the moles of salicylic acid used?

e) The molar mass of aspirin is 180.16g/mol. So, what is the theoretical yield in grams, for the number of moles of aspirin she theoretically obtained above?

f) What is the percent yield?

2. List any potentially harmful chemicals you will work with today. Explain why they are harmful, and what precautions you will take with them.

3. What factors could lead to a low yield of aspirin during this activity? (Besides accidental spills or other similar human errors).