m o d u l a r · l a b o r a t o r y · p r o g r a m · i n · c h e m i s t r y

REAC
715

publisher: H.A. Neidig

organic editor: Joe Jeffers

# Reducing Benzil Using Sodium Borohydride

*prepared by* **Joseph W. LeFevre**, SUNY Oswego

**PURPOSE OF THE EXPERIMENT**

Reduce benzil using sodium borohydride. Identify the resulting product using melting point, mixture melting point, thin-layer chromatography, and/or infrared spectroscopy.

**EXPERIMENTAL OPTIONS**

Using Microscale Techniques to Reduce Benzil . . . . . 6
Using Semi-Microscale Techniques to Reduce Benzi . . . . . 7
Identifying the Product . . . . . 9

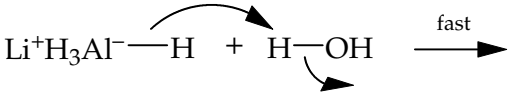
**BACKGROUND REQUIRED**

You should be familiar with melting point and mixture melting point measurements, recrystallization, thin-layer chromatography, and infrared spectroscopy.

**BACKGROUND INFORMATION**

In organic chemistry, **reduction** occurs when hydrogen is added to or oxygen is lost from an organic molecule. Among the many types of reducing reagents, the most common are the complex metal hydrides: lithium aluminum hydride ($LiAlH_4$) and sodium borohydride ($NaBH_4$). At room temperature, $LiAlH_4$ is a very powerful reducing reagent. $LiAlH_4$ is capable of reducing a wide variety of compounds, including carboxylic acids, esters, nitriles, amides, aldehydes, and ketones. Sodium borohydride, at room temperature, reduces only aldehydes and ketones to the corresponding alcohols. Specific reactions using these reagents are shown in Figure 1 on page 2. The aqueous acid is used to free the reduced product from a complex mixture.

Because hydrogen is more electronegative than aluminum, the hydrogen atoms in $LiAlH_4$ carry significant negative charge. As a result, $LiAlH_4$ reacts violently with protic solvents such as water or alcohols to form flammable hydrogen gas ($H_2$), as shown in Equation 1.




(Eq. 1)

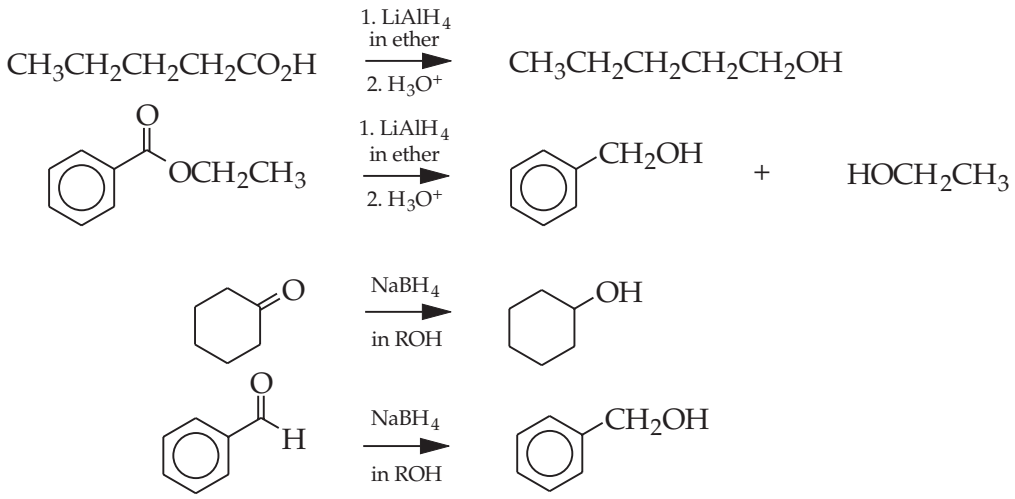
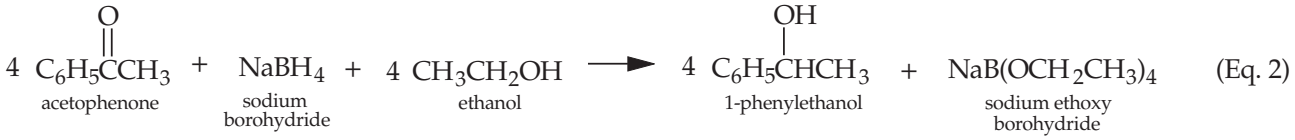



**Figure 1** Reduction reactions using $LiAlH_4$ or $NaBH_4$

Consequently, $LiAlH_4$ must be used in an inert, anhydrous solvent, such as diethyl ether or tetrahydrofuran.

Sodium borohydride is much easier to use than $LiAlH_4$ because it reacts very slowly with protic solvents at room temperature. As a result, $NaBH_4$ reductions can be conveniently conducted using alcohols as solvents. However, $NaBH_4$ decomposes in the presence of acidic functional groups, such as carboxylic acids. Therefore, acid groups must first be neutralized with a base such as sodium hydroxide before an aldehyde or a keto group can be reduced.

Reduction reactions using $NaBH_4$ or $LiAlH_4$ proceed by the addition of a hydride ion, $H^-$, to the organic substrate. Because each molecule of reducing agent contains four hydride ions, one $NaBH_4$ or $LiAlH_4$ molecule is capable of reducing up to four molecules of a ketone that contains a single carbonyl group. A typical $NaBH_4$ reduction is shown in Equation 2 for the reduction of acetophenone to 1-phenylethanol, using ethanol as the solvent.




(Eq. 2)

The CH hydrogen in the product, 1-phenylethanol, comes from $NaBH_4$ and the OH hydrogen comes from ethanol.

The mechanism of this reaction involves irreversible nucleophilic addition of $H^-$ to the carbonyl group of acetophenone. The oxygen atom of the carbonyl group is then protonated by ethanol. One molecule of 1-phenylethanol is formed along with sodium ethoxyborohydride, which, in turn, can react with three more acetophenone molecules.

Closer examination of the reaction reveals that the trigonal planar carbonyl group of the ketone can be attacked from either side of the molecule by $H^-$. These two modes of attack are labeled (a) and (b) in Figure 2.

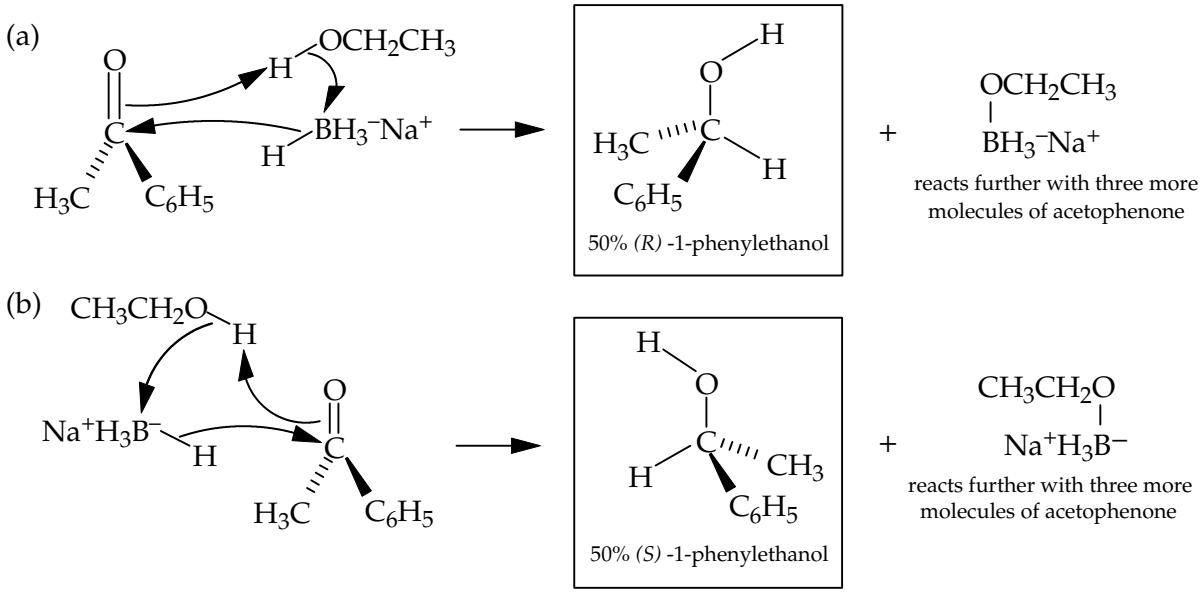



**Figure 2** Reduction of acetophenone to form: (a) *(R)*-1-phenylethanol and (b) *(S)*-1-phenylethanol

The resulting alcohols contain one chiral center and, therefore, exist as a pair of non-superimposable mirror image stereoisomers called **enantiomers**. Because $H^-$ can attack either face of the ketone, the two enantiomeric alcohols are formed, producing a **racemic mixture**.

In this experiment, you will use $NaBH_4$ to reduce benzil, a compound with two chemically equivalent carbonyl groups. The reaction could produce five different products, as shown in Figure 3.

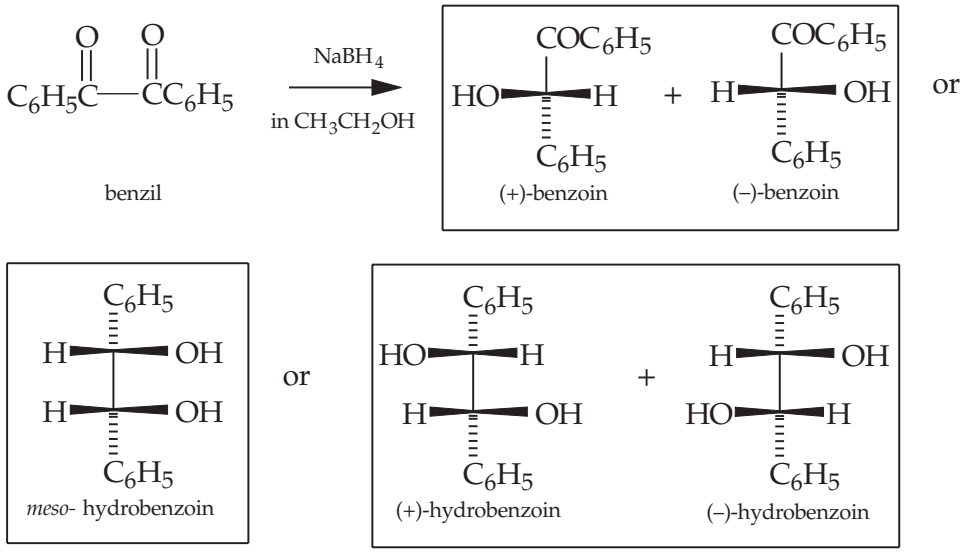



**Figure 3** Possible products resulting from the $NaBH_4$ reduction of benzil

The first two products result from reduction of only one of the two carbonyl groups of benzil. Two enantiomers, called (+)-benzoin and (–)-benzoin, result. These two compounds have identical physical

properties and are isolated together under the conditions employed in this experiment. The racemic mixture is designated (±)-benzoin.

The remaining three products result from the reduction of *both* carbonyl groups of benzil to form **vicinal** diols, alcohols containing two OH groups attached to adjacent carbon atoms. Because each of the OH-bearing carbons is chiral, a maximum of four stereoisomers could be produced. In this case, only three stereoisomers exist because one of the compounds produced is a ***meso*-compound**, a molecule that is optically inactive even though it contains more than one chiral center. *Meso*-hydrobenzoin contains a plane of symmetry and is superimposable on its mirror image. The remaining two compounds are (+)-hydrobenzoin and (–)-hydrobenzoin, which are enantiomers.

(±)-Hydrobenzoin can be distinguished from (±)-benzoin or *meso*-hydrobenzoin by melting point. Because (±)–hydrobenzoin and *meso*-hydrobenzoin are **diastereomers**, stereoisomers that are not mirror images, they have different physical properties. (±)-Hydrobenzoin melts at 122–123 °C, while *meso*-hydrobenzoin melts at 137–139 °C. By chance, (±)-benzoin, a compound not isomeric with the hydrobenzoins, melts at 135–137 °C. Any one of the following three methods may be used to distinguish between *meso*-hydrobenzoin and (±)-benzoin.

The first method is mixture melting point. When two different compounds with the same melting point are mixed together, the resulting mixture almost always shows a lower melting point and a broader melting point range. By mixing your reaction product separately with standard samples of *meso*-hydrobenzoin and (±)-benzoin, you can identify the product. If your sample shows no melting point depression with one of the two standard samples, then your sample and the standard must be the same compound.

Thin-layer chromatography (TLC) can also be used to distinguish between *meso*-hydrobenzoin and (±)-benzoin. This method involves spotting your sample on a TLC plate next to standard samples of these compounds. The plate is then developed in an eluent, such as ethyl acetate, that is able to separate the *meso*-hydrobenzoin and (±)-benzoin. By comparing the $R_f$ of your product with those of the standard samples, a positive identification can be made.

The third method utilizes infrared spectroscopy (IR). The IR spectrum of (±)-benzoin shows both a carbonyl and an –OH stretch, while that of *meso*-hydrobenzoin is lacking the carbonyl stretch. Comparing the IR spectrum of your product with those of the standard compounds allows identification. A flowchart summarizing these three identification methods is shown in Figure 4.

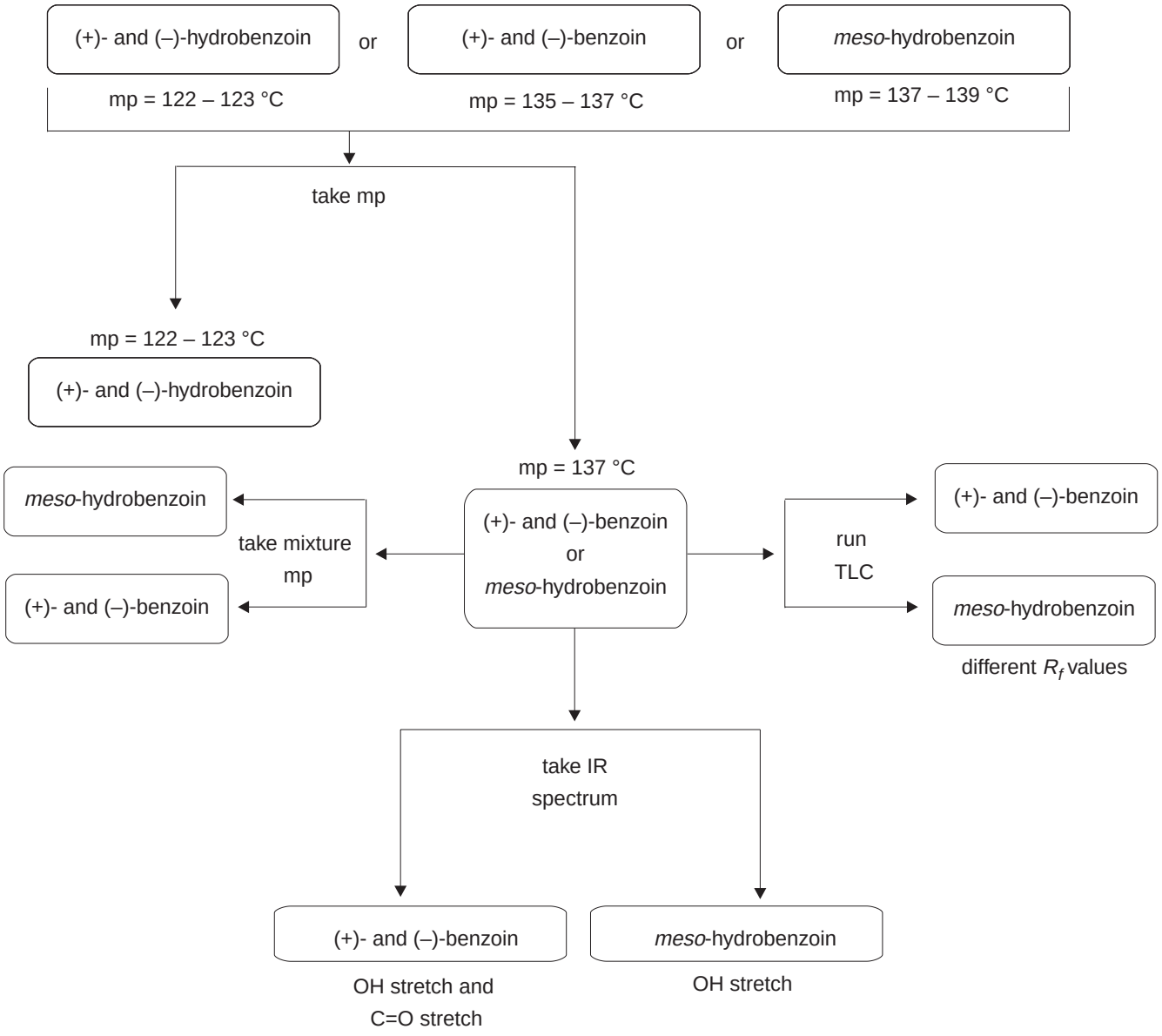



**Figure 4** Flowchart used to identify the reduction product

# USING MICROSCALE TECHNIQUES TO REDUCE BENZIL

### *Equipment*

50-mL beaker*
cotton
2 Erlenmeyer flasks, 10-mL
25-mL filter flask, with vacuum tubing
10-mL graduated cylinder
Hirsch funnel, with filter paper
microspatula
2 Pasteur pipets, with latex bulb
1-mL pipet, with rubber bulb
sand bath†
13 × 100-mm test tube
thermometer, –10 to 260 °C

*for ice bath

†sand in crystallizing dish on electric hot plate or sand in electric heating well with heat controller

### *Reagents and Properties*

| *substance* | *quantity* | *molar mass (g/mol)* | *mp (°C)* | *bp (°C)* |
|---|---|---|---|---|
| benzil | 100 mg | 210.23 | 94–95 | |
| (±)-benzoin* | | 212.25 | 135–137 | |
| ethanol, 95% | 1 mL | 46.07 | | 78 |
| (±)-hydrobenzoin* | | 214.27 | 122–123 | |
| *meso*-hydrobenzoin* | | 214.27 | 137–139 | |
| sodium borohydride | 20 mg | 37.83 | 400 | |

*potential product

### *Preview*

- Recrystallize benzil from 95% ethanol
- Reduce benzil using $NaBH_4$
- Collect the product using a Hirsch funnel
- Weigh the product

## PROCEDURE

### *Chemical Alert*

benzil—*irritant*

95% ethanol—*flammable and toxic*

sodium borohydride—*flammable and corrosive*

***Caution:*** Wear departmentally approved safety goggles at all times while in the chemistry laboratory.

### 1. Recrystallizing Benzil

***Caution:*** Benzil is an irritant. Ethanol is flammable and toxic. Keep away from flames or other heat sources. Prevent eye, skin, and clothing contact. Avoid inhaling and ingesting these compounds.

Preheat a sand bath to 60 °C. Weigh 100 mg of benzil to the nearest 0.001 g and record the mass. Place the benzil into a 10-mL Erlenmeyer flask. Using a 1.0-mL pipet, add 1.0 mL of 95% ethanol.

Heat the solution in the sand bath for 3–4 min with gentle swirling until the benzil dissolves. Remove the flask from the sand bath. Allow the flask to slowly cool to room temperature. Observe the very fine crystals of benzil that precipitate out of solution as the flask cools. Use an ice bath to cool the solution for 5 min.

**2. Reducing Benzil**

***Caution:*** Sodium borohydride ($NaBH_4$) is flammable and corrosive. It can react violently with acidic solutions. Keep acids away. Keep away from flames or other heat sources. Prevent eye, skin, and clothing contact. Avoid inhaling and ingesting $NaBH_4$.

While swirling the flask in the ice bath, add 20 mg of $NaBH_4$ to the chilled solution. Remove the flask from the ice bath. Continue to gently swirl the flask for 2–3 min. Observe and record the color of the reaction mixture.

Let the flask stand for 10 min at room temperature, during which time most of the precipitate will dissolve. Add 1.0 mL of distilled or deionized water to the flask and thoroughly mix the solution with gentle swirling.

Using a sand bath, heat 5 mL of water in a 10-mL Erlenmeyer flask for later use. In the same sand bath, heat the reaction mixture to the boiling point (~75 °C). If the solution is not clear at this point, filter it through a Pasteur filter pipet.

Precipitate the product by using a Pasteur pipet to add 30–50 drops of hot water (70–80 °C) to the flask, with swirling, until cloudiness develops. Let the solution slowly cool to room temperature.

Prepare an ice bath using a 50-mL beaker. Then place the flask into the ice bath for 5 min to complete the product precipitation. Add 2 mL of water to a test tube. Place the test tube in the ice bath to chill the water.

**3. Collecting the Product**

Using vacuum filtration, collect the product in a Hirsch funnel. Wash the product with two 1-mL portions of ice-cold water. Leave the water aspirator on for 5 min to dry the product.

Weigh the product to the nearest 0.001 g and record the mass. Proceed to the Identifying the Product section on page 9.

# USING SEMI-MICROSCALE TECHNIQUES TO REDUCE BENZIL

*Equipment*

500-mL beaker*
boiling chip
Büchner funnel, 5-cm, with adapter
2 Erlenmeyer flasks, 125-mL
125-mL filter flask, with vacuum tubing
filter paper, 5-cm
10-mL graduated cylinder
50-mL graduated cylinder
hot plate
metal spatula
18 × 150-mm test tube
thermometer, –10 to 260 °C
watch glass

*for ice bath

***Reagents and Properties***

| *substance* | *quantity* | *molar mass (g/mol)* | *mp (°C)* | *bp (°C)* |
|---|---|---|---|---|
| benzil | 1 g | 210.23 | 94–95 | |
| (±)-benzoin* | | 212.25 | 135–137 | |
| ethanol, 95% | 10 mL | 46.07 | | 78 |
| (±)-hydrobenzoin* | | 214.27 | 122–123 | |
| *meso*-hydrobenzoin* | | 214.27 | 137–139 | |
| sodium borohydride | 0.2 g | 37.83 | 400 | |

*potential product

***Preview***

- Recrystallize benzil from 95% ethanol
- Reduce benzil using $NaBH_4$
- Collect the product using vacuum filtration
- Weigh the product

## PROCEDURE

***Chemical Alert***

benzil—*irritant*

95% ethanol—*flammable and toxic*

sodium borohydride—*flammable and corrosive*

***Caution:*** Wear departmentally approved safety goggles at all times while in the chemistry laboratory.

### 1. Recrystallizing Benzil

***Caution:*** Benzil is an irritant. Ethanol is flammable and toxic. Keep away from flames or other heat sources. Prevent eye, skin, and clothing contact. Avoid inhaling and ingesting these compounds.

Weigh 1 g of benzil to the nearest 0.01 g and record the mass. Place the benzil into a 125-mL Erlenmeyer flask. Add 10 mL of 95% ethanol.

With gentle swirling, heat the solution on a hot plate to 50–60 °C until the benzil dissolves. Remove the flask from the hot plate and let the solution slowly cool to room temperature. Observe the very fine crystals of benzil that precipitate out of solution as the flask cools. Place the flask into an ice bath for 5 min to complete the precipitation of the product.

### 2. Reducing the Benzil

***Caution:*** Sodium borohydride ($NaBH_4$) is flammable and corrosive and can react violently with acidic solutions. Keep acids away. Keep away from flames or other heat sources. Prevent eye, skin, and clothing contact. Avoid inhaling and ingesting $NaBH_4$.

Weigh 0.2 g of $NaBH_4$ and record the mass. Add the $NaBH_4$ to the chilled solution in approximately eight portions over a period of 2 min. Swirl the flask during the additions.

Remove the flask from the ice bath. Continue to swirl the flask gently for 2–3 min. Observe and record the color of the reaction mixture. Let the flask stand at room temperature for 10 min, during which time most of the precipitate will dissolve.

Heat 30 mL of distilled or deionized water in a 125-mL Erlenmeyer flask on a hot plate.

Add 10 mL of hot water to the reaction flask and thoroughly mix the solution with gentle swirling. Add a boiling chip to the reaction mixture and heat the mixture to the boiling point (~75 °C). If the solution is not clear at this point, filter it through a Büchner funnel.

Use a spatula to remove the boiling chip. Over a 1-min period, add 15–20 mL of hot water (70–80 °C), with swirling, to the reaction mixture. Let the solution slowly cool to room temperature.

Prepare an ice bath using a 500-mL beaker. Place the flask into the ice bath for 5 min to complete the precipitation of the product. Add 10 mL of water to a test tube. Place the test tube into the ice bath to chill the water.

**3. Collecting the Product**

Using vacuum filtration, collect the product in a Büchner funnel. Wash the product with two 5-mL portions of ice-cold water. Leave the water aspirator on for 2–3 min to remove most of the water from the product.

Place the crystals on a watch glass and break up any lumps with a spatula. To dry the product, place the watch glass into a 100-°C oven for 10 min.

Weigh the product to the nearest 0.01 g and record the mass. Proceed to the Identifying the Product section.

# IDENTIFYING THE PRODUCT

### *Equipment*

2 capillary tubes, open-end*
10-mL graduated cylinder
marking pen
4 melting point capillary tubes
microburner†
microspatula
2 Pasteur pipets, with latex bulb
pellet press‡
pencil*
ruler, mm*
screw cap jar, 4-oz, with lid* §
3 × 6-cm silica gel plate*
3 vials, 3-mL*

*for TLC
†or Bunsen burner to make micropipets for TLC
‡for IR
§or 250-mL beaker with plastic wrap for cover

### *Reagents and Properties*

| *substance* | *quantity* | *molar mass (g/mol)* | *mp (°C)* | *bp (°C)* |
|---|---|---|---|---|
| (±)-benzoin | 7 mg | 212.25 | 135–137 | |
| ethyl acetate* | 2.2 mL | 88.11 | –84 | 76–77 |
| *meso*-hydrobenzoin | 7 mg | 214.27 | 137–139 | |
| *n*-hexane* | 4 mL | 86.18 | –95 | 69 |
| potassium bromide† | 100 mg | | | |

*for TLC †for KBr pellet

*Preview*

- Identify product using melting point and mixture melting point or TLC or IR spectroscopy

## PROCEDURE

***Chemical Alert***

ethyl acetate—*flammable and irritant*

*n*-hexane—*flammable and irritant*

potassium bromide—*irritant and hygroscopic*

***Caution:*** Wear departmentally approved safety goggles at all times while in the chemistry laboratory.

**NOTE 1:** Your laboratory instructor will designate which of the following methods you will use to distinguish between (±)-benzoin and meso-hydrobenzoin.

### 1. Measuring the Melting Point

Measure the melting point of the dry product using the melting point apparatus provided by your laboratory instructor. Use the flow diagram shown in Figure 4 on page 5 to identify your product. [NOTE 1]

### 2. Using Mixture Melting Points to Distinguish Between (±)-Benzoin and *meso*-Hydrobenzoin

**NOTE 2:** You need not weigh the 5-mg quantities. Use the 5-mg sample provided by your laboratory instructor as a guide.

Divide approximately 10 mg of your product into two 5-mg piles. [NOTE 2] *Thoroughly* mix one pile with an equal amount of a standard sample of (±)-benzoin. *Thoroughly* mix the other pile with an equal amount of a standard sample of *meso*-hydrobenzoin.

Measure the melting points of the two mixtures in separately labeled capillary tubes. Record the temperature range at which each sample melts. Based on your observations, identify your product. Record your finding.

### 3. Using Thin-Layer Chromatography to Distinguish Between (±)-benzoin and *meso*-Hydrobenzoin

***Caution:*** Hexane and ethyl acetate are flammable and irritating. Use a ***fume hood***. Keep away from flames or other heat sources. Prevent eye, skin, and clothing contact. Avoid inhaling vapors and ingesting these solvents.

Place 1–2 mg of your product into a 3-mL vial. Use a Pasteur pipet to add 2–3 drops of ethyl acetate to dissolve the sample. In the same way, prepare standard samples of *meso*-hydrobenzoin and (±)-benzoin in separately labeled vials.

Obtain a 3 × 6-cm silica gel TLC plate. Using a ruler, draw a *very faint* pencil line across the plate 1 cm from the bottom. Mark three small vertical lines that intersect the horizontal line at 6, 16, and 24 mm from the left side of the plate.

Prepare three micropipets from open-end capillary tubes. Use a microburner to heat the center of a tube. Then quickly pull out on the softened glass to form the micropipets. Carefully break the pipets apart, making certain each pipet has a small opening at its tip.

Use a micropipet to spot your sample in the middle of the TLC plate. Using separate micropipets for each compound, spot (±)-benzoin to the left and *meso*-hydrobenzoin to the right of your sample, as shown in Figure 5.

Place 4 mL of *n*-hexane and 2 mL of ethyl acetate into a 4-oz jar and thoroughly mix. Put the plate in the jar and cover the jar. Develop the TLC plate until the eluent is approximately 1 cm from the top of the plate. Remove the plate from the jar. *Immediately* mark the eluent front with a pencil. Allow the plate to dry.

***Caution:*** Ultraviolet(UV) radiation can cause severe damage to the eyes. Wear goggles. Do not look directly into the UV lamp.

View the plate under long-wave UV light. Circle the spots with a pencil. Identify your product. Record your findings.

**4. Using Infrared Spectroscopy to Distinguish Between (±)-Benzoin and *meso*-Hydrobenzoin**

***Caution:*** Potassium bromide (KBr) is irritating and hygroscopic. Prevent eye, skin, and clothing contact. Avoid inhaling dust and ingesting KBr.

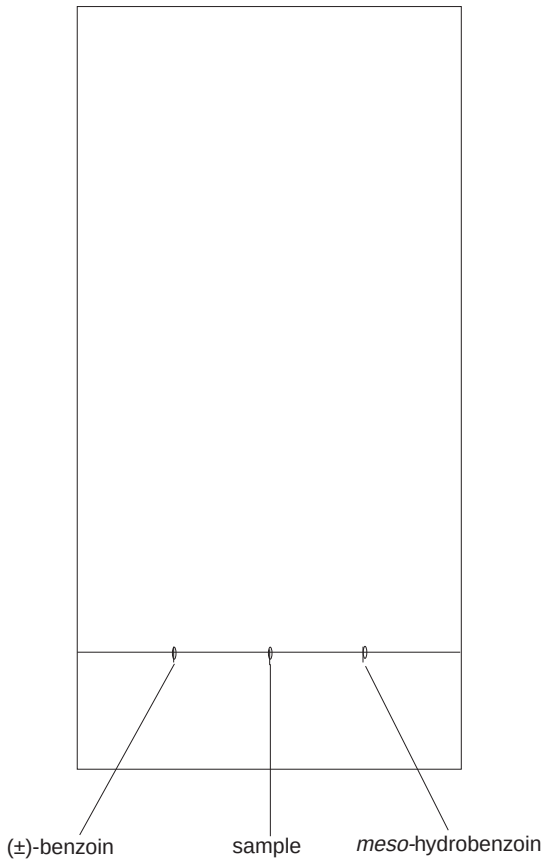
Prepare a KBr pellet of your product and record the IR spectrum as directed by your laboratory instructor. Compare your spectrum with standard spectra of *meso*-hydrobenzoin and (±)-benzoin, provided by your laboratory instructor. Based on your comparisons, identify your product. Record your findings.

**5. Cleaning up**

Place your recovered materials in the appropriate labeled collection containers as directed by your laboratory instructor. Clean your glassware with soap or detergent.

***Caution:*** Wash your hands thoroughly with soap or detergent before leaving the laboratory.

**Figure 5** Spotted silica gel TLC plate



## POST-LABORATORY QUESTIONS

1. Calculate the theoretical mass of $NaBH_4$ needed to reduce 100 mg of benzil to (±)-benzoin.
2. Calculate the theoretical mass of benzil that can be reduced to hydrobenzoin using 100 mg of $NaBH_4$.
3. Using your results, explain how you can use each of the following techniques to identify your product:
   (a) melting point
   (b) mixture melting point
   (c) TLC
   (d) IR spectroscopy
4. Calculate the following quantities using your experimental data:
   (a) the limiting reagent
   (b) the theoretical amount of product that could be produced
   (c) the percent yield
5. Compare the IR spectrum of benzil with that of your product. Considering carbonyl, OH, aromatic CH, and aliphatic CH absorption bands, describe the similarities and differences you find.

NAME SECTION DATE

*REAC 715/Reducing Benzil Using Sodium Borohydride*

## Pre-Laboratory Assignment

1. Briefly define the following terms and give an example of each:
   (a) reduction

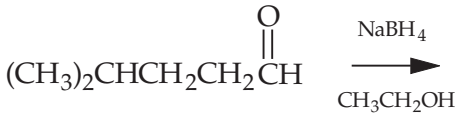
   (b) enantiomers

   (c) racemic mixture

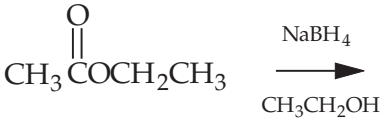
   (d) diastereomers

   (e) *meso*-compound

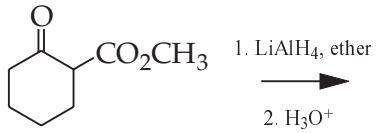
2. Predict the product(s) for the following reactions:



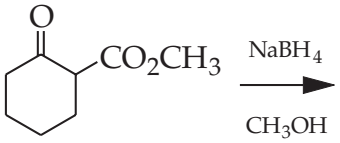

(a)




(b)

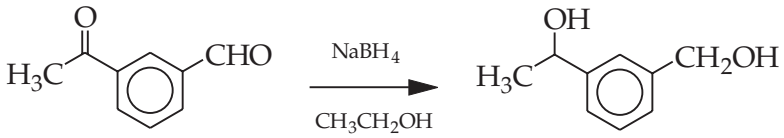



(c)

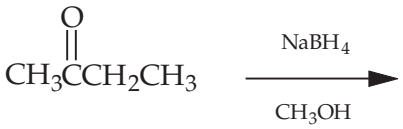


(d)

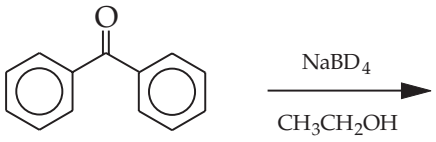
**3**. Explain why one molecule of $NaBH_4$ will reduce only two molecules of *m*-acetylbenzaldehyde to form the corresponding product.



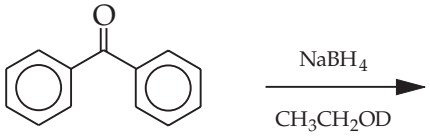

**4**. Predict the stereochemical outcome of the following reaction:




**5.** Predict the product for each of the reactions shown below:
(a)



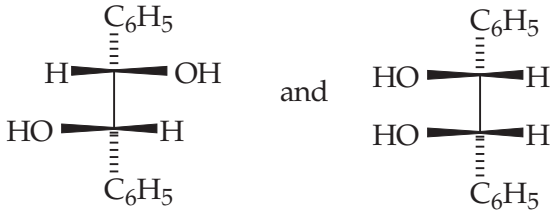

(b)



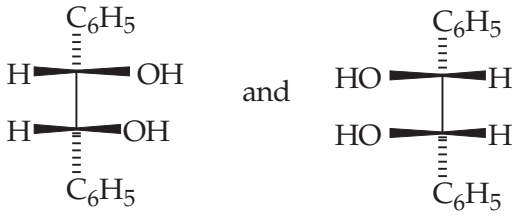
**6**. Choosing from the following list of terms, briefly explain how these pairs of molecules are related.

- enantiomers
- diastereomers
- different compounds, not isomeric
- identical

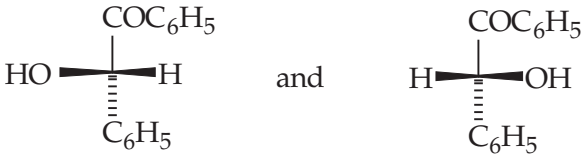
(a)



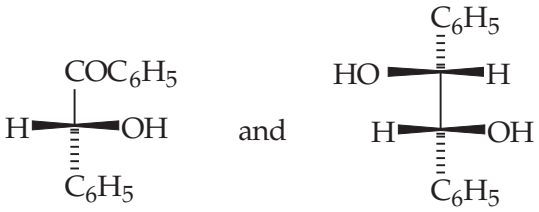

(b)




(c)




(d)



ISBN: 0-87540-715-3