Synthesis and Rotational Barrier in Dibenzalacetone

PreLab
Draw the three possible isomers of dibenzalacetone: cis,cis; cis,trans; trans,trans. For one of these, draw a structure with the p orbitals and π bonds shown explicitly.

Introduction
The reaction of an aldehyde with a ketone employing sodium hydroxide as the base is an example of a mixed aldol condensation reaction, the Claisen-Schmidt reaction. Dibenzalacetone is readily prepared by condensation of acetone with two equivalents of benzaldehyde. The aldehyde carbonyl is more reactive than that of the ketone and therefore reacts rapidly with the anion of the ketone to give a [α]-hydroxyketone, which easily undergoes base-catalyzed dehydration. Depending on the relative quantities of the reactants, the reaction can give either mono- or dibenzalacetone.

Dibenzalacetone is a fairly innocuous substance; its spectral properties indicate why it is used in sun-protection preparations. In the present experiment, sufficient ethanol is present as solvent to readily dissolve the starting material, benzaldehyde, and also the intermediate, benzalacetone. The benzalacetone, once formed, can then easily react with another mole of benzaldehyde to give the product, dibenzalacetone.

Synthesis of Dibenzalacetone
Obtain a sample of fresh pure benzaldehyde prepacked in a shorty vial from the hooded shelf or the stockroom. Weigh 0.212 g of pure benzaldehyde directly into a 10 x 100 mm reaction tube. Add 1.5 mL 95% ethanol and 2 mL of 3M sodium hydroxide solution. Using a micropipetter add 75 uL of acetone place 2 mL of. To this solution add 1.6 mL of 95% ethanol and 0.212 g of pure benzaldehyde. Then add 0.058 g of acetone to the reaction mixture. Cap the tube immediately with a septum, and shake the mixture vigorously. Continue to shake the tube, from time to time, for the next 30 minutes. The benzaldehyde, initially insoluble, goes into solution, and a water-clear, pale yellow solution results. After a few minutes, it suddenly becomes cloudy, and a yellow precipitate of the product forms. Continue to shake the tube from time to time for the next 30 min. If the product fails to crystallize, open the tube and scratch the inside of the tube with a glass rod.

Isolation and Purification
Remove the liquid from the tube using a Pasteur pipette by squeezing the bulb of the pipette, pressing the tip against the bottom of the tube, and bringing the liquid into the pipette, leaving the crystals in the tube (pipet filtration technique). Add 3 mL of water, cap, and shake the tube vigorously. Remove the wash liquid as before and wash the crystals twice more with 3-mL portions of water.

After the final washing, add 3 mL of water to the tube and collect the crystals on a Hirsch funnel using vacuum filtration. Use a few mLs of water to wash all the crystals into Hirsch funnel. Squeeze the product between sheets of filter paper to dry it, and then recrystallize the crude dibenzalacetone from 70:30 ethanol water. Insert a wooden boiling stick to promote even boiling. Remove the boiling solution from the hot sand bath, and place it in a beaker of glass wool to insulate it so it cools slowly to room temperature.
Should the product separate as an oil, try to obtain a seed crystal, heat the solution to dissolve the oil, and add the seed crystal as the solution cools. If it continues to oil out, add a bit more ethanol. Collect the product on the Hirsch funnel or by removing the solvent with a pipette after cooling the tube for several minutes in ice. Wash the crystals once with about 0.5 mL of ice-cold 70% ethanol while the tube is in ice. Dry the product under vacuum by attaching the tube to an aspirator for a few minutes. Determine the weight of the dibenzalacetone and its melting point, and calculate the percentage yield. In a typical experiment, the yield would be 0.10 g, melting point 110.5-112°C.

**Analyses:** Analyze sample by melting point and UV spectrum. UV analysis should be quantitative so you can calculate the extinction coefficient. Assign $\lambda_{\text{max}}$ to isomers based on the extent of conjugation.

**Cleaning Up** Dilute the filtrate from the reaction mixture with water, and neutralize it with dilute hydrochloric acid before flushing down the drain. The ethanol filtrate from the crystallization should be placed in the organic solvents container.

In the last step of the aldol condensation, loss of water from the IB-hydroxyketone can form molecules in which the alkene hydrogen atoms are either cis or trans to each other. The name dibenzalacetone does not completely characterize the molecules made in this experiment. There are 3 isomeric dibenzalacetones, one melting at 100-110°C, $\lambda_{\text{max}}$ 330 nm, $\epsilon$ 34,300; another melting at 60°C, $\lambda_{\text{max}}$ 295 nm, $\epsilon$ 20,000; and a third, a liquid with $\lambda_{\text{max}}$ 287 nm $\epsilon$ 11,000.

Both the melting points and the UV spectral data give some hints regarding the structures of these molecules. The first one is very symmetrical and can pack well into a crystal lattice. The long wavelength of the ultraviolet light absorption maximum and the high value of the molar absorbance $\epsilon$ indicate a long, planar conjugated system. The other two molecules are increasingly less able to pack nicely into a crystal lattice or to have a planar conjugated system. In your Final Report, include the structures of the three geometric isomers of dibenzalacetone, and assign each one to the three molecules described above in your discussion.

**Final Report Questions**

1. Why is the C=O peak of your product showing up at lower wavenumbers (1639 cm$^{-1}$) than standard C=O frequency (1715 cm$^{-1}$)?

2. How would you change the procedures in this experiment if you wished to synthesize benzalacetone, C$_6$H$_5$CH=CHCOC$_2$H$_5$? Benzalacetophenone, C$_6$H$_5$CH=CHCOC$_2$H$_5$?

3. Write the detailed mechanism for the formation of dibenzalacetone from benzalacetone and benzaldehyde.

**Molecular Modeling:**

In this lab, you will calculate the rotational barrier in the enone single bond. Here, we will use methylbenzalacetone as a model for dibenzalacetone to simplify the calculations. Remembering that the "single bond" in the enone has partial double bond character, the rotation about that bond is shown below.

![Diagram](image)

Before you start, make sure that you understand what is meant by partial double bond character in terms of pi bonds and resonance structures.

As discussed above, the three isomeric benzalacetones can actually be isolated. By using the dihedral driver in Spartan, we can "lock in" a particular conformation for the enone. Once a particular conformation
has been chosen, the ground state energy of each of these isomers can be determined using computational
methods, and thus the rotational barrier.

We will use Spartan to calculate the ground state energy of isomers 1-3. Enter Spartan and open the
Model Kit("File/New"). Assemble isomer 1, the s-cis conformation, using the phenyl ring, “Make Bond,”
etc. (Note: Select a bond, then hold down the space bar and the left mouse button at the same time to
rotate an atom around a bond. Now, we must "lock-in" this conformation. Select the ice cube with the
atom in it from the menu at left. Select the three carbons and one oxygen of the enone (the ones that rotate
in the diagram on the previous page). Having done this, "Minimize" your structure. Save this molecule as
"Metbenzalcetone-s-cis_AM1" in an appropriate location.

The energy of this conformation can be calculated using semi-empirical methods. Under the "Setup"
pulldown, select "Calculation" and select an equilibrium geometry calculation using AMI. Be sure to check
"Frozen atoms." This tells the system to use the constrained dihedral angle that you specified in the
builder. Click "OK," and then select "Submit," which is also under the "Setup" pulldown menu. A
conformation box will appear on the screen telling you that your job is running.

While this calculation is proceeding, assemble the other isomeric methylbenzalacetones. Remember to
use appropriate frozen angles in each case, using an angle of 180 for the s-trans conformation, and an angle
of 90 for the orthogonal carbonyl system. Run AM1 geometry optimization for these isomers. When all
of the calculations have completed examine the output to obtain the final output to obtain the heats of
formation and final dihedral angle for each compound. Examine each structure and make sure that it appears
reasonable given the starting geometry.

<table>
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<tr>
<th>Isomer</th>
<th>Heat of Formation</th>
<th>Final Dihedral</th>
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<tbody>
<tr>
<td>s-cis</td>
<td></td>
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<tr>
<td>s-trans</td>
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<tr>
<td>orthogonal carbonyl</td>
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Questions:

1. What isomer is the most stable and which is the least? Draw a reaction diagram with the product as the
   most stable isomer and the orthogonal isomer as the transition state. Does this diagram fit your
   predictions?

2. What is the change in enthalpy (ΔH) and the activation energy (Ea) for rotation about the enone bond (in
   the exothermic direction)?

3. Are there any energetic benefits to rotating the carbonyl out of the plane of the extended π system?
   How do these factors compare to energetic losses?

4. How would you experimentally measure the rotational barrier? (To answer this, you may need to do
   some library research.)