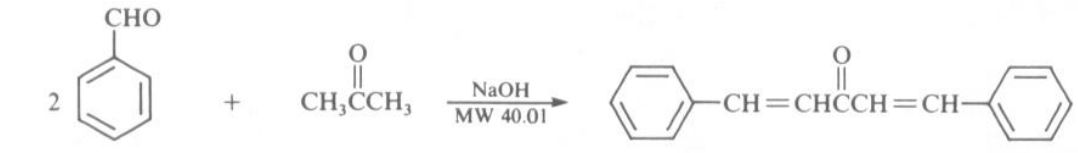
# Aldol Condensation – Synthesis of Dibenzalacetone
## Organic Chemistry II CHM2211

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 /3-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 (UV absorbance) 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. The reaction we will carry out is:

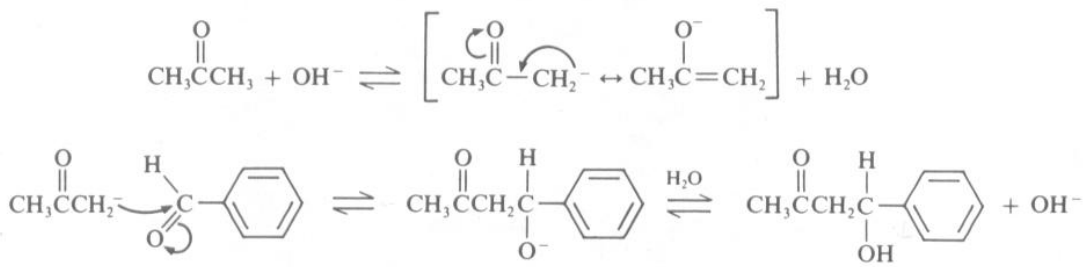


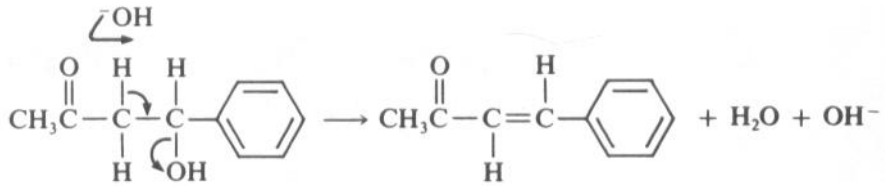

**Benzaldehyde**
MW 106.13, bp 178°C
den. 1.04

**Acetone**
**(2-Propanone)**
MW 58.08, bp 56°C
den. 0.790

**Dibenzalacetone**
**(1,5-Diphenyl-1,4-pentadien-3-one)**
MW 234.30

The mechanism for the formation of benzalacetone is shown below. Dibenzalacetone is formed when benzalacetone reacts with another equivalent of benzaldehyde following the same mechanism.




**Benzalacetone**
**4-Phenyl-3-butene-2-one**
mp 42°C

## *Procedure*

Prepare a shallow ice-water bath in a 100-mL beaker. Place 1.6 mL of USP ethanol and 2.0 mL of aqueous 10% NaOH into a large test tube. Add a stir bar. Place the tube into the ice-water bath. Set the entire assembly onto a magnetic stirrer and clamp the tube in place, positioned so that the stirring bar mixes the solution when the stirrer is on. While stirring, cool the solution to 20 °C. After the solution reaches 20 °C, remove the ice bath. Continue to stir the solution.

Prepare a mixture of 210 mg (200 μL) of fresh benzaldehyde and 60 mg (75 μL) of reagent-grade acetone in a test tube. Add the benzaldehyde–acetone mixture to the ethanol–NaOH solution in two portions (about 140 μL each), 5 min apart. Then stir the reaction for another 30 min.

Cool the mixture in an ice-water bath. Use a Pasteur pipet to remove the solvent, taking care to leave the crystals in the flask. Place the solvent into the container labeled "Aldol Waste", found in the waste disposal hood. Rinse the crystals with 4 mL of distilled or deionized water. Using a Pasteur pipet, remove the water. Rinse again with 2 mL of water. Remove the water and pipet it into a watch glass. Check the filtrate on the watch glass using red litmus paper. If the litmus turns blue, rinse the crystals again until the red litmus does not turn blue but remains red.

Prepare a hot-water bath by placing 50 mL of water into a 100-mL beaker. Place the beaker on a hot plate and heat the water to boiling. To recrystallize the product from ethanol, add ethanol and swirl the tube in the hot-water bath. While keeping the solution at or near its boiling point, add more ethanol in small amounts until all the solid is dissolved or no more solid appears to dissolve. Do not add more than 4.0 mL of ethanol. Use a hot Pasteur pipet to transfer the solution to a small test tube. Allow the solution to cool slowly to room temperature. If the product does not crystallize, scratch the bottom of the tube with a glass stirring rod to induce crystallization.

Clamp the tube to a support stand. Then cool the tube in ice water for 5–10 min. Collect the crystals removing the solvent using a Pasteur pipette or by vacuum filtration using the Hirsch funnel. To dry the product crystals, spread them thinly over a clean watch glass and allowing them to stand for 30 min. Do not place the crystals in the drying oven! Stir the crystals occasionally to allow any remaining ethanol to evaporate. Once the solvent has evaporated as indicated by a constant weight for the watch glass and crystals, determine the mass of the product. Measure its melting point and obtain an IR spectrum using the ATR attachment on the Thermo-Nicolet FTIR. Place the product in a properly labeled product vial. Rinse all glassware and the Hirsch funnel with acetone before washing with water.

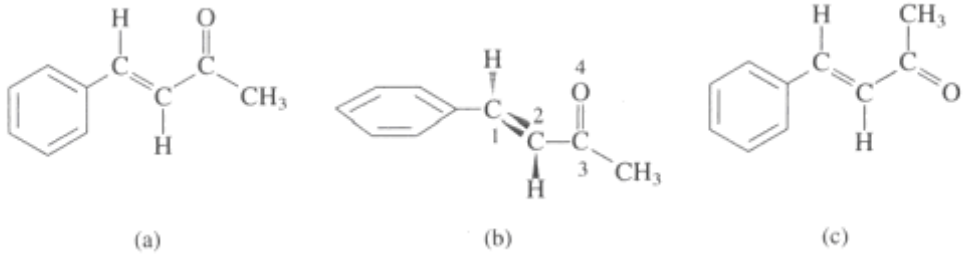
## *Molecular Modeling (10 Points Extra Credit)*

The name dibenzalacetone does not completely characterize the molecule made in this experiment. There are actually three isomeric dibenzalacetones, one melting at 110 to 111°C, $\lambda_{max}$ 330 nm, ε 34,300; another melting at 60°C, $\lambda_{max}$ 295 nm, ε 20,000; and a third, a liquid with $\lambda_{max}$ 287 nm, ε 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 ε indicate a long, planar conjugated system (see Chapter 14). The other two molecules are increasingly less able to pack nicely into a crystal lattice or to have a planar conjugated system. In the last step of the aldol condensation, loss of water from the β-hydroxyketone can form molecules in which the alkene hydrogen atoms are either *cis* or *trans* to each other. Write the structures of the three geometric isomers of dibenzalacetone, and assign each one to the three molecules described above.

Enter the structures of these three isomers into PC Model 7, and carry out an energy minimization to calculate the relative steric energies or heats of formation of each molecule. Note, once the calculation is complete, that the lowest energy conformation of each isomer will be as planar as possible in order that there can be maximum overlap of the p orbitals on each $sp^2$ hybridized carbon. To test this idea, calculate the steric energy or heat of formation of benzalacetone [(a) Shown below] using the usual energy minimization procedure. The result should be an almost planar molecule. Then deliberately hold the dihedral angle defined by atoms 1, 2, 3, and 4 at 90° [(b) Shown below], and again calculate the energy of the molecule. In the latter conformation, the p orbitals of the carbonyl group are orthogonal to the p orbitals of the alkene.




As you may discover in calculating the energies of the three geometric isomers of benzalacetone, there is still another form of isomerization entering into the conformations of these molecules: single-bond cis and trans isomers, exemplified by isomers (a) and (c) of benzalacetone (Figure shown above). Both these conformers are planar in order to achieve maximum overlap of p orbitals, but in (a) the carbonyl group is *cis* to the alkene bond, while in (c) it is *trans*. The barrier to rotation about the single bond is not very high, so these isomers cannot be isolated at room temperature. If your molecular modeling program has a "dihedral driver" routine, you can calculate the heats of formation of benzalacetone as a function of the dihedral angle defined by atoms 1, 2, 3, and 4 and thus determine the barrier to rotation around this bond in kilocalories per mole.

Draw the structures of all the single-bond *cis* and *trans* isomers for each of the three geometric isomers of <u>di</u>benzalacetone. There are a total of ten such isomers. Pick out the one you regard as the most stable and calculate its steric energy. Which three are represented by the solid (mp 110–111 °C), the solid (mp 60°C), and the liquid?

***Report:*** Turn in the data sheet with the labeled IR of your compound attached. If you wish to earn the extra credit points answer the questions below on a separate sheet(s) of paper and turn in <u>separately</u> from the data sheet and spectrum.

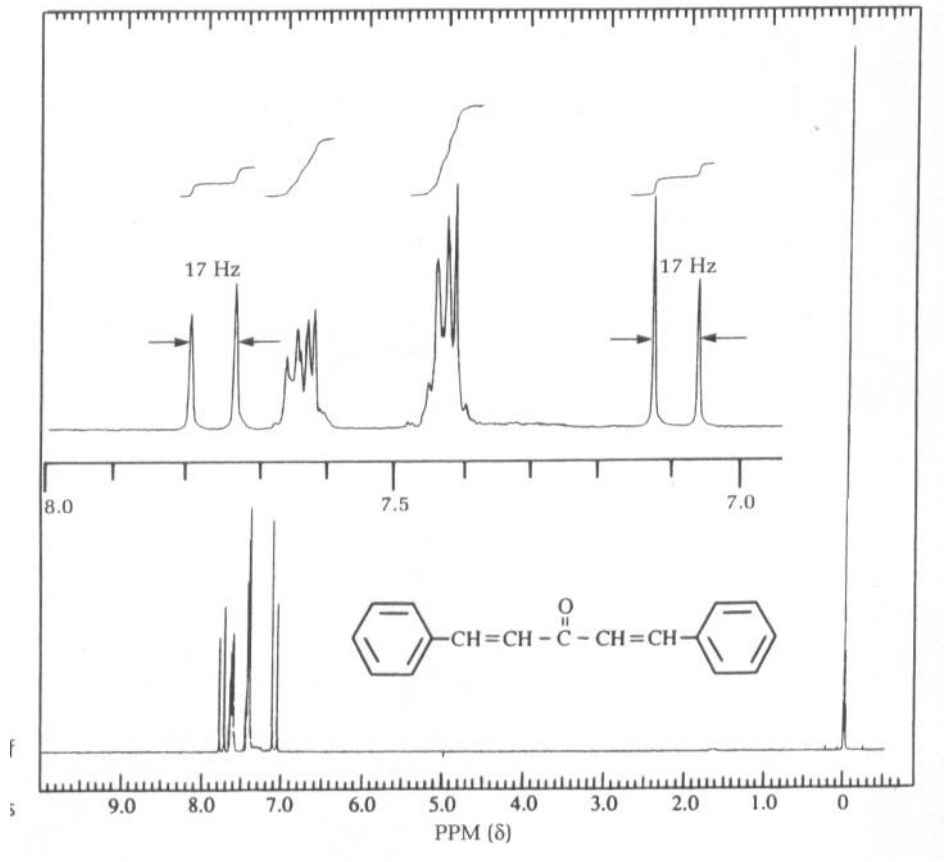
## *Questions*

1. Why is it important to maintain equivalent proportions of reagents in this reaction?

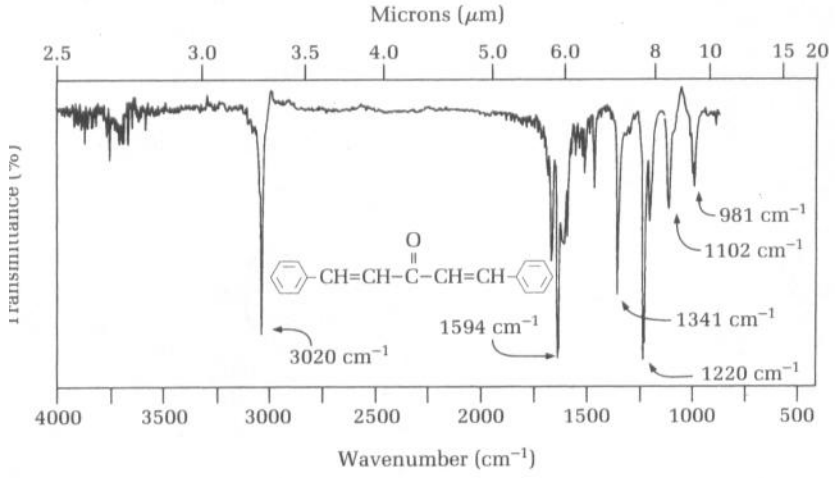
2. What side products do you expect in this reaction? How are they removed?

3. What evidence do you have that your product consists of a single geometric isomer or a mixture of isomers? Does the melting point give such information?

4. From the $^{1}H$ NMR spectrum of dibenzalacetone (Shown below), can you deduce what geometric isomer(s) is (are) formed? Hint – Check coupling constants for *cis* and *trans* H's.




6. Assign the peak at 1639 cm-1 in the IR spectrum of dibenzalacetone shown below.




Revision –

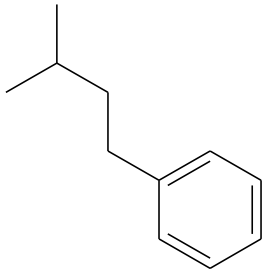
7. Write the structures of the three geometric isomers of dibenzalacetone, and assign each one to the three molecules described. Disregard *s-cis* and *s-trans* isomerism.

8. Draw the structures of all the single-bond *cis* and *trans* isomers for each of the three geometric isomers of dibenzalacetone. There are a total of ten such isomers.

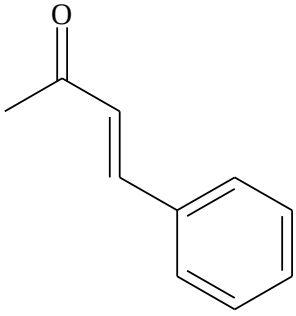
9. Use PC Model to answer the questions underlined within the instructions below.

## Using PC Model 7 to Study Conformations of Benzalacetone

1. Open PCModel 7
2. Click the ***Ring*** button.
3. Click on the ***Phe*** button to insert a benzene ring.
4. Click on the ***PT*** button and select the ***C*** button. Then click on the H atom located at about 10 o'clock on the ring. Close the ***PT*** Box.
5. Click the ***Draw*** button, click on the atom you just converted to C then click above the atom to add a new carbon atom.
6. Click about 45° above and to the left from the atom just added to add another carbon atom. Repeat at 45° down and to the left to add a third carbon atom.
7. Click the ***Draw*** button again and then click the next to last atom you added. Click above that atom to add another atom. This will become the oxygen of the carbonyl.
8. Click the ***H/AD*** button off then on and then off again to shrink the structure and make it easier to manipulate.
9. Your structure should look like this:

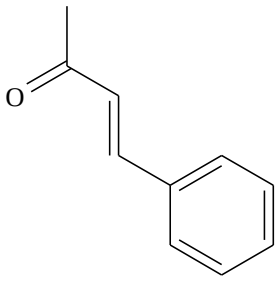


10. Click the ***Add_B*** button and then click on the middle of a bond you wish to make a double bond. Repeat to convert the second bond which will be the carbonyl double bond.
11. Click on the ***PT*** button and select the ***O*** button. Then click on the atom you want to make the carbonyl oxygen atom. Your structure should now look like this:

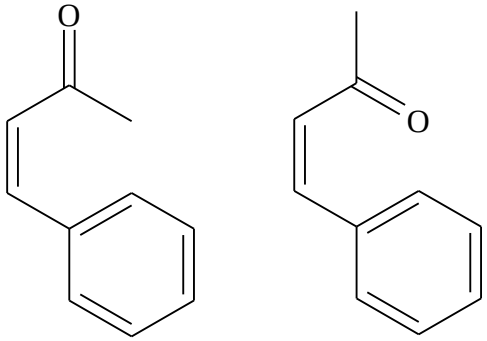



12. Click on the ***H/AD*** button to add hydrogen atoms back to the structure.

13. Under the ***Mark*** tab on the menu, click the ***pi Atoms*** button and answer ***All*** to the question. When marked, all $sp^2$ carbon atoms should have a ~ symbol by them.
14. Under the ***Compute*** tab on the menu, click ***Minimize*** to find a low energy state for the molecule. This should generate a completely flat molecule (except for 2 hydrogen atoms).
15. Rotate and observe the molecule's structure. Is it in the *cis* or *trans* conformation? Is it planar so that all the *p* orbitals are perpendicular (required for conjugation).
16. If the molecule is NOT in the *trans* conformation you must turn off the hydrogen atoms and use the ***Move*** function to get the molecule into something close to a *trans* conformation. To move an atom, click the ***Move*** button then click on the atom you want to move. Then click where you want the atom to be. Repeat for the other atoms you need to move. Add hydrogen atoms back and minimize the structure. You should now have a planar structure. Draw the structure and record the MMX energy of the molecule.
17. Click the ***Sel-Atm*** button and select atoms 1-4 as instructed in the handout. Using the dihedral driver under the Compute Menu tab, enter 0 and 90 for your starting and ending angles and then 10 for the increment. Answer the prompts and watch as the molecule rotates. Record the final energy when the carbonyl is at 90° to the plane of the rest of the molecule. Your carbonyl oxygen atom should be 90° from the plane of the rest of the molecule (see structure (b). Draw the structure and record the energy.
18. Turn off the hydrogens using ***H/AD*** and use the ***Move*** tool to switch the positions of the methyl carbon and carbonyl oxygen. Add the hydrogens back and minimize to get structure (c). Record the energy. Your structure should look like this (H atoms not shown in this drawing but will appear on your computer image). You may also generate this structure by starting again at Step 2 and choosing the other atom to change to oxygen in Step 11.




19. Using the procedure above, you should examine the *cis* isomers (shown below) and determine their energies. In Step 6 you need to move to the right rather than the left to draw the *cis* isomer. Who is more stable, *cis* or *trans*? Explain your observations.



# Organic Laboratory Data Sheet

**Name _____ Partner _____**

**Experiment: Dibenzalacetone via Aldol Condensation**

**I. Reaction equation(s) using structures and names:**

| |
|---|
| |

**II. Theoretical yield (recovery) and literature melting/boiling point:**

| | |
|---|---|
| Theoretical Yield: | Literature MP: |

**III. Data:**

| | |
|---|---|
| Amount obtained: | Observed MP: |

**IV. Calculations (Use back of page to show work):**

| | |
|---|---|
| Crude Yield before purification: | Final Yield after purification: |

**V. Isomer Formed**

| |
|---|
| Draw a 3D representation of the stereoisomer you most likely made: |

**VI. Spectra or chromatographic analysis (Attach labeled spectra and/or chromatogram to report):**

| |
|---|
| Discuss spectrum or chromatogram here: |

**VII. Technique – Provide a self-evaluation and grade yourself on your technique (percentage out of 100%):**

| |
|---|
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