## **Experiment 20:** Green Chemistry: A Solvent-Free Aldol Condensation

The word "green" has become synonymous with sustainability. The chemical manufacturing industry uses the term "green chemistry" to mean the design of processes that reduce or eliminate negative environmental impacts, such as the production of hazardous waste. Federal statutes, like the Resource Conservation and Recovery Act (RCRA), require specific disposal procedures for wastes that are defined as hazardous. This definition is based on factors that include ignitability, corrosiveness, reactivity, or toxicity. Proper management of hazardous wastes can be quite costly for chemical manufacturing companies. For example, DuPont's 1996 research and environmental compliance budgets amounted to $1 billion.[1] In order to control these costs, DuPont has actively pursued Green Chemistry as a way to reduce their hazardous waste. For more information on the 12 Principles of Green Chemistry, read Chapter 2 in *LTOC*, especially Table 2.1 on page 24.

The pharmaceutical industry is engaged primarily in the synthesis of organic compounds and produces a significant amount of chemical waste. GlaxoSmithKline performed a study that showed approximately 80% of their waste arises from the use of organic solvents.[2] Therefore, one way to make a manufacturing process more "green" is to reduce the ratio of solvent waste per kilogram of product. Another thing to consider is the kind of solvent being used. You have worked with several different organic solvents this year in the laboratory course. One characteristic that makes a solvent hazardous is toxicity. Solvents can be placed into different classes based on potential toxicity to humans or the environment.

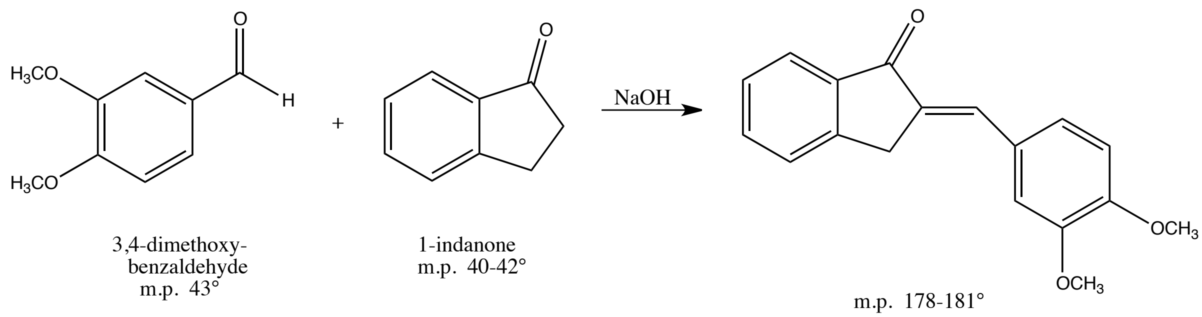
Class I: significant environmental impact
Class II: moderate environmental impact
Class III: low environmental impact

You and your classmates will categorize eight commonly used organic solvents into these classes using the information found on Material Safety Data Sheets or MSDS's (see p. 19 in *LTOC*). The solvents are: acetic acid, acetone, dichloromethane, ethanol, ethyl acetate, hexane, methanol and toluene.

In some instances, it is possible to eliminate the solvent from a reaction altogether, resulting in a solvent-free process. In today's experiment, you will carry out an aldol condensation reaction without the use of a solvent. The two reactants, 3,4-dimethoxybenzaldehyde and 1-indanone, each have very low melting points. When they are mixed together, their melting points are lowered, in the same way that impurities will lower the melting point of any organic compound. These two compounds will actually become liquids at room temperature when mixed together, which allows the molecules to interact with each other. Solid sodium hydroxide is added to the liquid mixture to facilitate the reaction. An aldol condensation-dehydration product results, as shown in the following equation:

[1] http://www.zerowaste.org/publications/06j_gc_pres.pdf

[2] Cue, B. W.; Zhang, J. *Green Chemistry Letters and Reviews* **2009**, 1-19.




3,4-dimethoxy-
benzaldehyde
m.p. 43°

1-indanone
m.p. 40-42°

m.p. 178-181°

Since the resulting product is impure, it will be recyrstallized from an ethanol-water mixture. Thus, the entire procedure is not completely solvent-free. Into which class of solvents does ethanol fall?

**Outline** the steps of the following procedure:

Place 0.25 g of 3,4-dimethoxybenzaldehyde and 0.20 g of 1-indanone in a 50 mL beaker. Crush and scrape the two solids together with a spatula until they become a colored oil (this will take some time). Note that pressing harder will *not* speed the process. Once the oil has formed, add 0.05 g of ground sodium hydroxide, crushed by your TA with a mortar and pestle. Continue to mix and scrape until the mixture becomes solid. Let this substance stand for 15 minutes.

Add 2 mL of 10% hydrochloric acid solution. It is important to thoroughly mix all of the solid material with the acid. Test the pH of the solution by transferring a drop to Alkacid paper. If the solution is not acidic, add more acid and continue to mix. Collect the product by vacuum filtration in a Buchner funnel.

The product must be recrystallized. Heat about 30 mL of a 9:1 ethanol-water mixture on a steam bath. Add the hot solvent to the solid until the bulk of the material dissolves (do not use more than 20 mL of the ethanol-water mixture). You will need to filter this mixture by gravity to remove solid impurities (see Technique 9.2 on pp 134-5 in *LTOC*). Cover the bottom of a 50 mL Erlenmeyer flask with a small amount of ethanol-water, and place it on a steam bath. Filter the solution containing your product through fluted filter paper in a stemless funnel into the warm Erlenmeyer flask. Allow the filtrate to cool to room temperature. Collect the product by vacuum filtration.

Place the solid product on a watchglass and set it in a warm oven for 10 minutes. Obtain the melting point.

Pour the filtrate that contains ethanol into the liquid **Laboratory Byproducts** jar. Place the product in the **Laboratory Byproducts** jar for solid compounds. In addition, scrape the residue from the fluted filter paper into the solid **Byproducts** jar, and dispose of the paper in the trash.

# Classifying the Solvents

Using information from the MSDS sheets provided, complete a table like the one pictured for each of the eight solvents. Definitions for relevant abbreviations are given below.

## Solvent

| | |
|---|---|
| *Health Hazards* | |
| Skin | |
| Ingestion | |
| Inhalation | |
| Eyes | |
| Carcinogen | |
| *Exposure limits* | |
| OSHA (PEL) | |
| Solubility in water | |
| *Toxicity* | |
| Routes of entry | |
| LD50 and LC50 data for animals | |
| Chronic effects on humans | |
| Products of biodegradation | |

TWA from OSHA (PEL): The Permissible Exposure Limit (Time Weighted Average, usually over 8 hours) from the Occupational Safety and Health Administration: A legal limit in the US for exposure of an employee to a chemical substance. The lower the PEL, the more toxic the compound. ppm = parts per million STEL = Short Term Exposure Limit

Substances that are water soluble are more likely to be dispersed throughout the environment at a low concentration, causing less harm to organisms.

LD50 (median lethal dose): The amount of the substance required (usually per body weight) to kill 50% of the test population. The lower the LD50, the more toxic the compound.

LC50 (lethal concentration): The concentration of the chemical in air or water that kills 50% of the test animals. The lower the LC50, the more toxic the compound.

Using the information compiled in the tables, categorize the eight solvents by class, according to their potential toxicity to humans or the environment.

Class I: significant environmental impact
Class II: moderate environmental impact
Class III: low environmental impact