CHEM 324

Experiment 43

Effect of Reaction Conditions on the Condensation of Furfural with Cyclopentanone

Introduction:

The purpose of this experiment is to perform two Claisen-Schmidt reactions (similar to aldol condensation) between cyclopentanone and furfural used different conditions which will yield two different products. Reaction A was done without a PTC and reaction B was done with a PTC, the phase transfer catalyst is tricaprylmethylammonium chloride. The products from the two separate reactions will be purified via either liquid-liquid extraction, recrystallization or column chromatography. Then, they will be identified via H-NMR and melting point analysis.

The Claisen-Schmidt reactions which is similar to an aldol condensation reactions, this is because they both release water, and the aldol condensation reaction occurs between two aldehydes whereas the Claisen-Schmidt reaction occurs between an aldehyde (furfural) and a ketone (cyclopentanone). The reaction begins when the compound containing the carbonyl carbon is deprotonated and the formation of the enolate ion is created. The enolate ion can then resonate, performing a nucleophilic attack on the carbonyl carbon on the furfural containing the aldehyde. This is then followed by protonation, forming a beta-hydroxy carbonyl compound. This compound is then deprotonated again at the alpha position via a base, and a base catalyzed dehydration reaction following a E1cb[1] mechanism occurs. This then finally yields the alpha-beta unsaturated ketone.

One of the methods of purification used in this experiment is column chromatography, this method used a mobile phase in which the sample flows through and a stationary phase where the sample is purified. Column chromatography is a method used to to purify the crude product, based on the affinity/polarity of the compounds in the crude product to the compounds in stationary phase and their solubility in the mobile phase. Compounds with high affinity to the alumina which is the stationary phase and low solubility in the mobile phase will then elute last, because the compounds will be stuck in the stationary phase for longer. Whereas compounds with low a affinity to the alumina and high solubility in the mobile phase will elute first.

One of the method of identification is H-NMR analysis, which works by inducing the compound of interest to a magnetic field which which leads to a change in the nuclear spin of the hydrogen atoms in the compound of interest based on the relative environment of the hydrogens, allowing for the determination of different functional groups and the molecular structure of the desired compound. The structure is the determined via analysis of the H-NMR spectrum which gives clarity on the purity of the synthesized product.

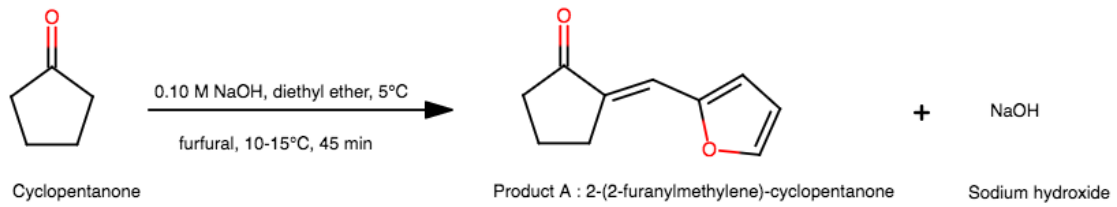

Figure 1.Claisen-Schmidt reaction forming product A which is 2-(2-furanyl methylene)-cyclopentanone, under the presented reactions conditions. Drawn using Marvin JS

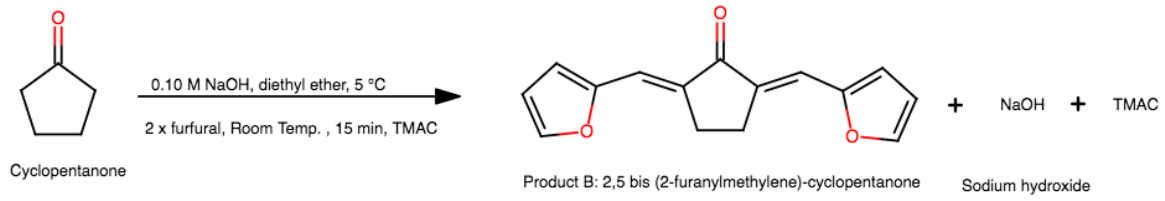

Figure 2. Claisen-Schmidt reaction forming product B which is 2,5 bis (2-furanyl methylene)-cyclopentanone, under the presented reaction conditions. Drawn using Marvin JS

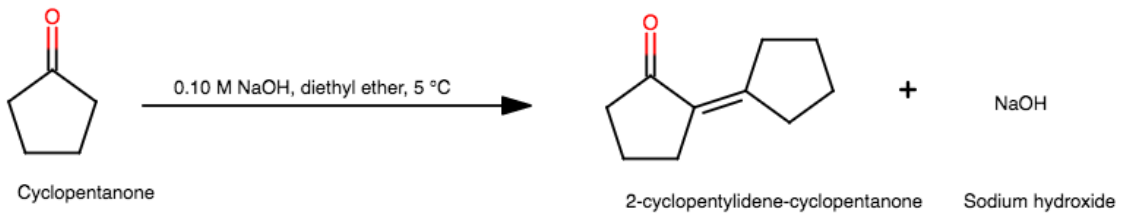

Figure 3. Self condensation of cyclopentanone yielding 2-cyclopentylidene-cyclopentanone via a Perkins reaction, but we want to minimize this reactions as much as possible. Drawn using Marvin JS.

Experimental Data:

A. Claisen-Schmidt Reaction of Cyclopentanone and Furfural			
Compound	Mass (g)	Volume (ml)	Moles (mol)
Cyclopentanone	-	4.43	0.0499
NaOH	-	45	-
Furfural	-	4.15	0.05
Product A	4.137	-	0.026

Table 1. Raw data from the experiment tabulating the amount of each reactant and product obtained and used in part A of the experiment.

B. Claisen-Schmidt Reaction of Cyclopentanone and Furfural using a PTC			
Compound	Mass (g)	Volume (ml)	Moles (mol)
Cyclopentanone	-	0.90	0.0102
NaOH	-	12	-
Furfural	-	2 ml	0.0241
TMAC	-	6 drops	-
Diethyl ether	-	10 ml	-
Product B	0.759	-	0.00316

Table 2. Raw data from the experiment tabulating the amount of each reactant and product obtained and used in part B of the experiment.

Observations:A	
1	When the cyclopentanone, NaOH and diethyl ether were mixed together, the reaction was a grey yellow colour
2	Once the furfural was added to the solution, it turned a bright yellow colour, fumes were emitted
3	Product was a yellow liquid
Observations B:	
1	Again, upon the addition of furfural the solution became yellow
2	10 minutes into the 15 minute reaction, the solution was a dark yellow colour, almost black
3	The final product was a neon orange solid

Table 3. Observations noted throughout the experiment.

Compound	Mol. wt. (g/mol)	mp (°C)	bp (°C)	d (g/ml)
furfural	96.1	-39	162	1.159
cyclopentanone	84.1	-51	131	0.949
2-butanone	72.1	-86	80	0.805
tricaprylmethylammonium chloride	404.2	-	-	0.884
product A	162.2	60.5	154	-
product B	240.3	162	-	-

Table 4. Chemical properties of the compounds used in this experiment.

Results and Calculations:

Compound	Melting point range (°C)	Clear melting point (°C)	Theoretical melting point (°C)	% Error
Product B	165.0 - 167.9	166.5	162	2.8

Table 4. Melting point analysis data for product B

Compound	Theoretical yield (g)	Theoretical yield (mol)	Actual Yield (g)	Actual Yield (mol)	% Yield	% Error
Product A	8.09	0.0499	4.137	0.026	51.1 %	48.9 %
Product B	0.858	0.0102	0.759	0.00316	88.5%	11.5 %

Table 5. Yield and efficiency summary for the experiment

Chemical shift	Integration/ # on figure A	Relative # of H	Multiplicity	ID
1.931 - 2.132	3.28 / 2	4H	Multiplet	[CH-C**H$_2$**-CH=C] x 2
2.333 - 2.386	1.67 / 1	2H	Triplet	CH_2-C**H$_2$**-CH=O
2.927 - 3.036	1.72 / 3	2H	Triplet	CH_2-C**H$_2$**-C-O
6.493 - 6.503	1.20 / 6	1H	Singlet	CH-C**H**-C=
6.644 - 6.655	1.00 / 5	1H	Singlet	CH-C**H**-C=
7.138 - 7.143	0.75 / 4	1H	Singlet	CH-C**H**-C=
7.548	1.00 / 7	1H	Singlet	C=O

Table 6. H NMR spectrum analysis for product A

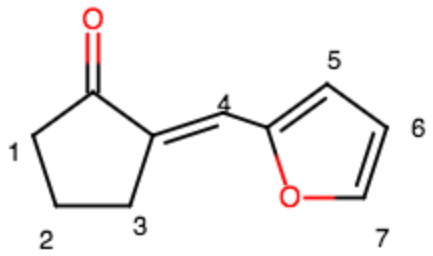

Figure A. The seven signals of product A, respective signal shown on table 6

Chemical shift	Integration	Relative # of H	Multiplicity	ID
3.072	2.13	2H	Singlet	
6.529 - 6.544	1.01	1H	Singlet	
6.687 - 6.697	1.02	1H	Singlet	
7.347	0.98	1H	Singlet	
7.585	1.00	1H	Singlet	

Table 7. H NMR spectrum analysis for product B

Calculations:

Theoretical yield: ***Part A***

- Cyclopentanone:

(4.43 ml) x (0.949 g/ml) = 4.204 g

(4.204 g) / (84.1 g/mol) = 0.0499 mol **(limiting)**

- Furfural:

(4.15 ml) x (1.159 g/ml) = 4.81 g

(4.81 g) / (96.1 g/mol)= 0.0500 mol **(excess)**

- Therefore the theoretical yield (product A) is:

(0.0499 mol) x (162.2 g/mol) = **8.09 g**

- Experimental yield (product A):

(**4.137g**) / (162.2 g/mol)= **0.026 mol**

% Yield = $\frac{Experimental\ Yield}{Theoretical\ Yield} = \frac{4.137\ g}{8.09 g}$ = 51.1 %

% Error= $\frac{|Experimental - Theoretical\ Yield|}{Theoretical\ Yield} = \frac{|4.137\ g - 8.09\ g|}{8.09 g}$ = 48.9 %

Theoretical yield: ***Part B***

- Cyclopentanone:

(0.90 ml) x (0.949 g/ml) = 0.854 g

(1.898 g) / (84.1 g/mol) = 0.0102 mol **(limiting)**

- Furfural:

(2.0 ml) x (1.159 g/ml) = 2.318 g

(2.318 g) / (96.1 g/mol)= 0.0241 mol **(excess)**

- Therefore the theoretical yield (product A) is:

(0.0102 mol) x (84.1 g/mol) = **0.858 g**

- Experimental yield (product A):

(**0.759 g**) / (240.3 g/mol)= **0.00316 mol**

% Yield = $\frac{Experimental\ Yield}{Theoretical\ Yield} = \frac{0.759\ g}{0.858 g}$ = 88.5%

% Error= $\frac{|Experimental - Theoretical\ Yield|}{Theoretical\ Yield} = \frac{|0.759\ g - 0.858\ g|}{0.858\ g}$ = 11.5%

Reaction Mechanism:

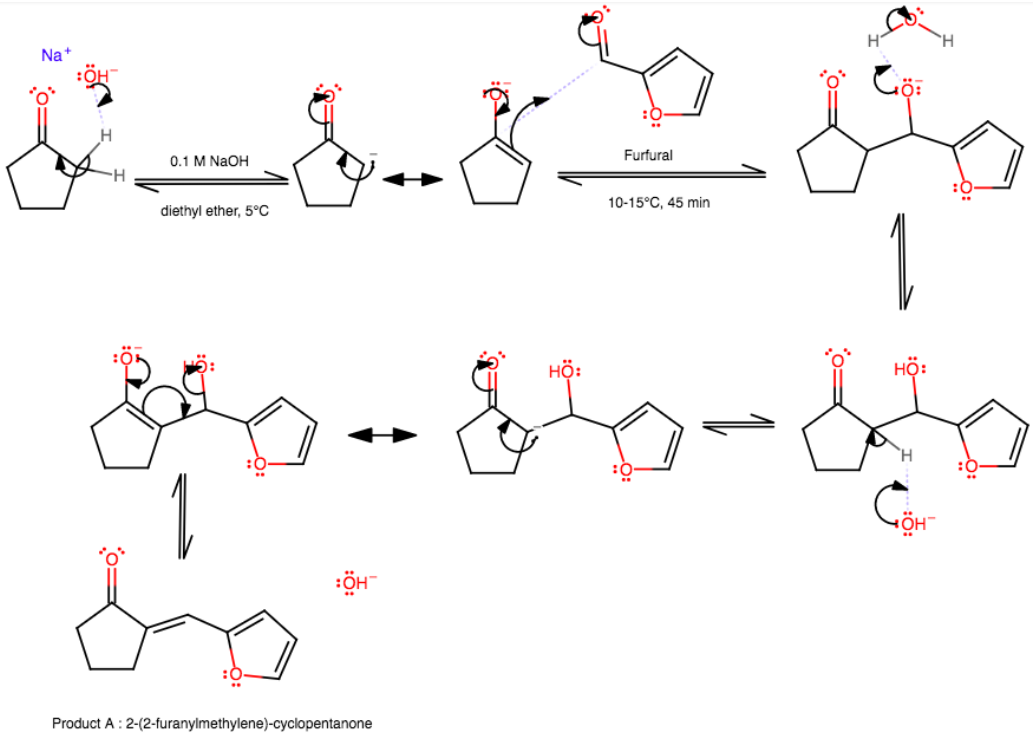

Figure 4. Reaction mechanism for the Claisen-Schmidt reaction forming product A which is 2-(2-furanyl methylene)-cyclopentanone. Drawn using Marvin JS.

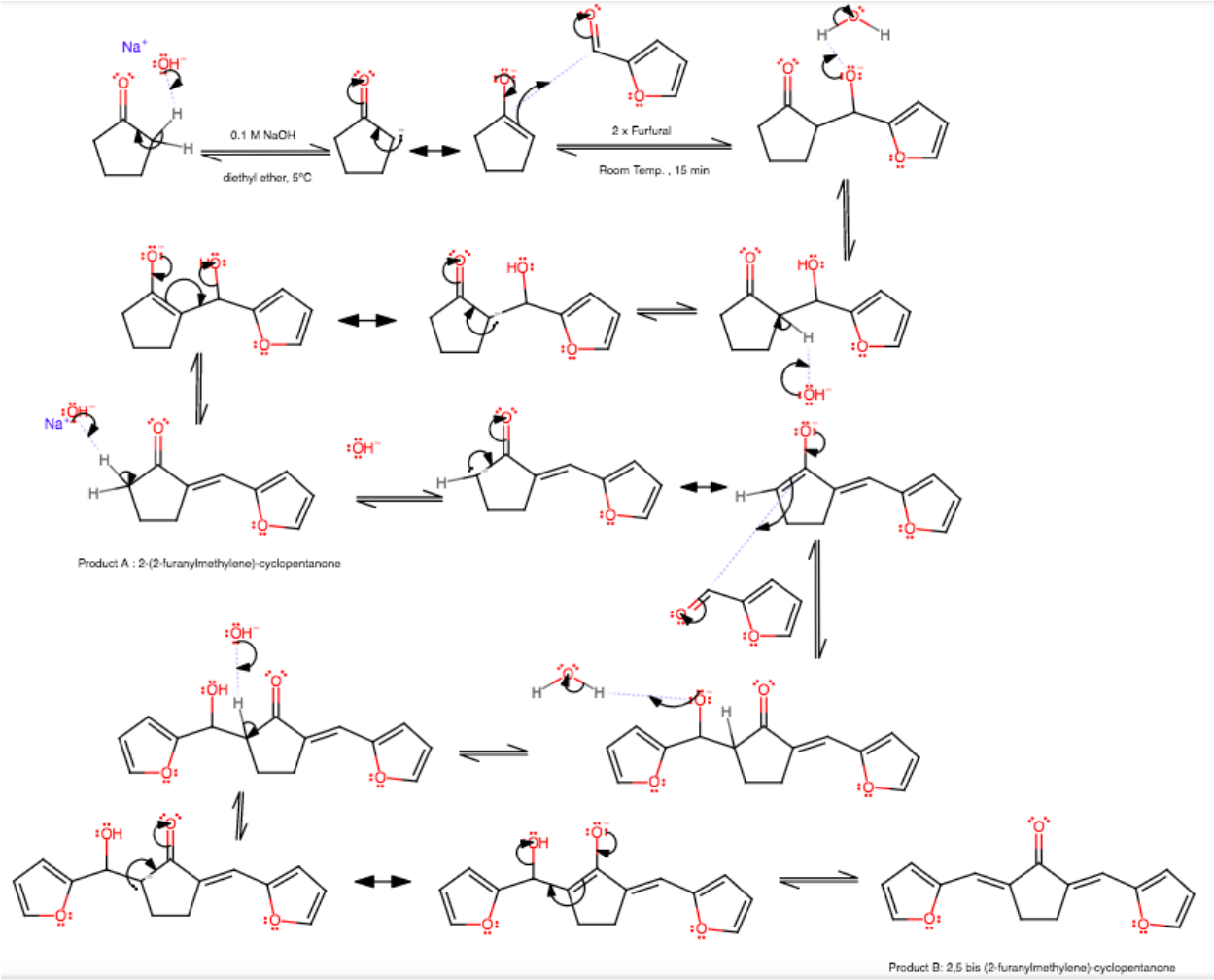

Figure 5. Reaction mechanism for the Claisen-Schmidt reaction forming product B which is 2,5 bis (2-furanyl methylene)-cyclopentanone, using two times the amount of furfural. Drawn using Marvin JS.

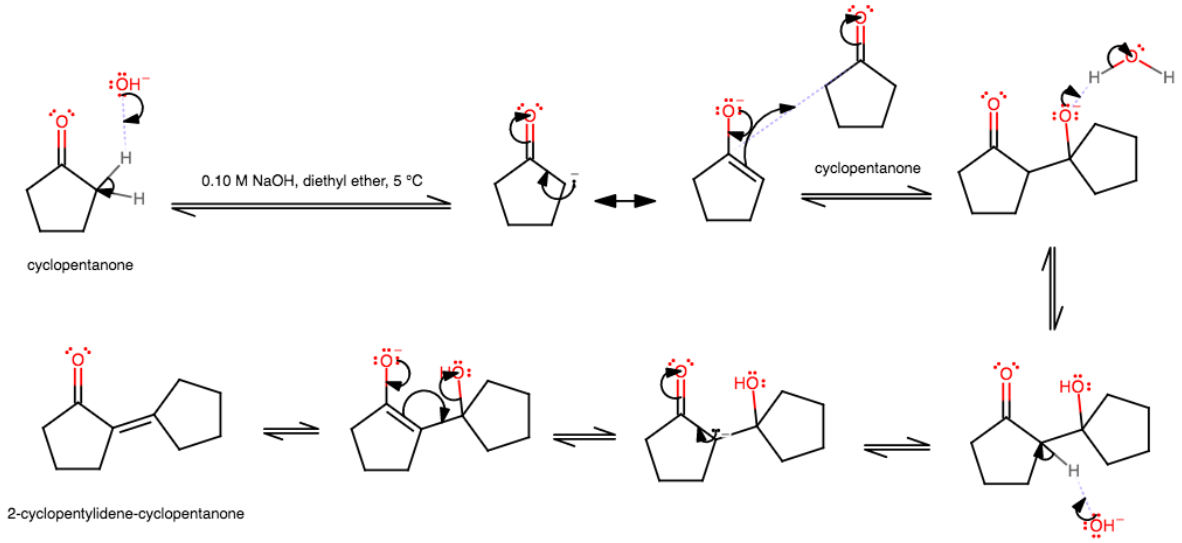

Figure 6. Reaction mechanism for Self condensation of cyclopentanone yielding 2-cyclopentylidene-cyclopentanone via a Perkins reaction. Drawn using Marvin JS.

Discussion:

The purpose of this experiment was to perform two Claisen-Schmidt reactions between cyclopentanone and furfural used different conditions which will yield two different products. The Claisen-Schmidt reaction is similar to an aldol condensation reaction because they both create water as a side product, and the aldol condensation reaction occurs between two aldehydes whereas the Claisen-Schmidt reaction occurs between an aldehyde (furfural) and a ketone (cyclopentanone). Reaction A was performed with a phase transfer catalyst (PTC) and reaction B was performed with a PTC.

When looking at the reaction mechanism for both reactions in figures 4 and 5, we notice that the mechanism for both reaction are quite similar. We begin by deprotonating the alpha hydrogen on the carbonyl carbon of cyclopentanone forming the enolate ion with 0.1 M NaOH. This compound can then resonate to stabilize, and then act as a nucleophile for attack on the carbonyl carbon of furfural. This forms the deprotonated form of the beta-hydroxy carbonyl

compound, this intermediate then gets protonated by water forming the protonated form of the beta-hydroxy carbonyl compound. A hydroxide ion will then deprotonate the hydrogen located in the middle of the beta-hydroxy carbonyl compound forming another enolate compound that can resonate and this enolate compound undergoes E1cb[1] elimination reaction, the mechanism is shown in figure 4. Finally the E1cb reaction yields the alpha-beta unsaturated ketone a.k.a. 2-(2-furanyl methylene)-cyclopentanone. In reaction B the second alpha hydrogen is removed forming the enolate, and with aid of the PTC, furfural can react with the enolate forming the product shown in figure 5 which is 2,5 bis (2-furanyl methylene)-cyclopentanone. The reaction mechanism is that same as explained above. A side reaction that can occur is that of self aldolization shown in figure 6. This is a unwanted side product and occurs minimally because furfural, the aldehyde is much more electrophilic than ketone and is much less sterically hindered than the ketone (cyclopentanone) therefore the nucleophile will most likely react with furfural than cyclopentanone. But in the synthesized compounds, there might be some traces of the self adolized product.

In reaction A we reacted 4.43 ml of cyclopentanone, 25 ml of diethyl ether and 45 ml of 0.1 M NaOH in a 125 ml Erlenmeyer flask. The reaction was cooled down to 5℃ using an ice/water bath to reduce the evaporation of the ether. The NaOH was used to deprotonated the alpha hydrogen on cyclopentanone. Once the reaction mixture reached 5 ℃, 4.15ml (0.05 mol) of furfural was added to the reaction mixture making the solution turn bright yellow. The reaction mixture was left stirring for 45 mins at 10-15℃, using parafilm to minimize the loss of solvent. The solution was kept on an ice/water bath due to the reaction being exothermic upon the addition of the furfural, this is due to the fumes formed. Next, the reaction mixture was vacuum filtrated to remove any unwanted solids such as unreacted enolate ions or the product of the self aldol condensation reaction. Only the filtrate was kept, and this solution was extracted using

liquid liquid extraction. The solution was added to a separatory addition funnel and washed two separate 15 ml portions of diethyl ether, time saving the organic layer which contains the product. The combined organic layers were this extracted with two separate 15 ml portions of NaCl again keeping the organic layer each time. During each extraction the funnel was shaken vigorously and the stop cock was opened to release pressure. The final organic layer obtained was then dried over anhydrous sodium sulfate. This solution was then covered with a kimwipe, para filmed with poked holes and stored for 1 week. This solution was the purified using column chromatography, where the stationary phase is composed of alumina and the mobile was composed of ether. A ~20 ml portion of product a was obtained and submitted to rotary evaporation, finally obtaining 4.173 g of product. The melting point of the solution was not measured because the final product was in solution and already liquid.

Reaction A and B are similar expect that in reaction ,B a PTC was used to aid the formation of 2,5 bis (2-furanyl methylene)-cyclopentanone. The reaction began by mixing 0.90 ml of cyclopentanone, 10 ml ml of diethyl ether, 12 ml of 0.1 M NaOH and 6 drops of TMAC (tricaprylmethylammonium chloride). The reaction again was cooled down to 5℃ using an ice/water bath to reduce the evaporation of the ether. The NaOH produces OH^- ions which are used was used to deprotonated the alpha hydrogen on cyclopentanone. Once the reaction mixture reached 5 ℃, 2 ml of furfural was added to the reaction flask and was left to react for 15 minutes at room temperature. We add two equivalent of furfural to ensure that it adds twice to the cyclopentanone. In part A the reaction was left to react for 45 minutes whereas for part b the reaction is only left to react for 15 minutes. This is because of the PTC which lets OH^- ions to travel from the aqueous phase to the phase transfer boundary and allowing the hydroxide ions to react with the cyclopentanone along with its intermediates to form 2,5 bis (2-furanyl methylene)-cyclopentanone. The same precautions were taken in part B to ensure the ether

does not evaporate. The product was the obtained using vacuum filtration giving a yellow/orange crude product, 1.016 g of this product was obtained and recrystallized using 2-butanone to yield a neon orange solid, with a mass of 0.759 g. The average melting point for product B was 166.5 ℃ and the theoretical melting point for product B is 162 ℃, giving a % error of 2.8, meaning our product did contain some impurities but due to the low error on the melting point analysis we can say that the product is relatively pure. The structure of product A and B are similar due to the symmetry in product B. Thereofor by looking at table 6. We can identify the product to be 2-(2-furanyl methylene)-cyclopentanone. And by analyzing the melting point we can can identify product B as being n2,5 bis (2-furanyl methylene)-cyclopentanone.

Conclusion:

The goal of the experiment was attained, synthesis of product A which was 2-(2-furanyl methylene)-cyclopentanone and synthesis of product B which was 2,5 bis (2-furanyl methylene)-cyclopentanone.

References

1. de Bellefeuille, D.; Muchall, H.; Robidoux, S. *CHEM 324 Organic III: Organic Reactions*; Concordia University: Montreal, Qc.
2. Aldehydes and Ketones http://www.mendelset.com/articles/695/aldehydes_and_ketones (accessed Apr 2, 2018).
3. Reusch, W. Nuclear Magnetic Resonance Spectroscopy https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/nmr/nmr1.htm (accessed Apr 2, 2018).
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