

# A Highly Versatile One-Pot Aqueous Wittig Reaction

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**Abstract** The implementation of green chemistry experiments in the sophomore organic teaching lab is essential in order to increase student awareness of issues that pertain to sustainability and reducing waste that impacts the environment. Aspects of green chemistry that draw attention to these important issues include, but are not limited to, the use of safer solvents, the development of energy efficient reactions, the use of less hazardous chemicals, and the prevention of waste. To demonstrate the ease of introducing green chemistry principles into the organic chemistry teaching lab a Wittig reaction was chosen to be “greened.” The green Wittig reaction described within this report was performed at ambient temperature and in an aqueous medium; in addition, the reaction was complete within one hour, and the transformation was accomplished in “one-pot.” Finally, students analyzed the Wittig products using <sup>1</sup>H NMR spectroscopy to confirm structure and to determine the *E:Z* ratio.

**Keywords:** *second-year undergraduate, organic chemistry, inquiry-based, problem solving, Wittig reaction, green chemistry*

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## 1. Introduction

The development of environmentally responsible experiments for the sophomore organic chemistry teaching laboratory, which clearly demonstrate the principles of green chemistry is an exciting area to explore. Multiple reports have been published that demonstrate the feasibility of “greening” classical organic reactions that have traditionally generated an unreasonable amount of waste, used halogenated and other environmentally deleterious solvents, and required a significant amount of time and energy to perform. [1-7] The chemical literature was scanned to compile a list of organic reactions that possessed the potential to be “greened” and it was concluded that the Wittig reaction would be an excellent candidate for such a process.

In 2004, Leung and Angel [6] reported the solvent-free Wittig reaction for implementation in the sophomore organic chemistry teaching laboratory. The reaction was carried out within a 3 hour period, and was performed in the absence of a solvent. However, the yield was poor to moderate (mixture of *E* and *Z* isomers was approximately 70 %; yield of *E* isomer was between 20 and 26 %), and the benzyltriphenylphosphonium chloride must be synthesized prior to utilization in the solvent-free Wittig reaction. A scan of synthetic protocols that described the preparation of benzyltriphenylphosphonium chloride in yields greater than 90 % revealed that elevated temperatures were required to afford the transformation, and organic solvents such as chloroform, acetonitrile, or toluene must be utilized. [8-14] Therefore, any efficiencies gained by not employing an organic solvent during the solvent-free Wittig reaction were somewhat negated by the solvent required to generate the benzyltriphenylphosphonium chloride.

In 2007, Weizman [4] reported another solvent-free Wittig reaction. The reaction described the stereoselective synthesis of ethyl *trans*-cinnamate and *trans*-3-(9-anthryl)-2-propenoic acid ethyl ester through the use of a stabilized ylide in the absence of a solvent. The reaction was accomplished in 15 minutes, and the products were synthesized in high yield and with a high level of stereoselectivity. Although the report published by Weizman improved upon the reaction conditions described by Thamattoor [15] in that the use of methylene chloride as the reaction solvent was avoided, the requisite ylide that Weizman employed had to be synthesized prior to its use in the Wittig reaction. A cursory review of synthetic protocols that describe the synthesis of this ylide revealed that harmful solvents such as benzene and toluene are commonly used, and the reactions can take up to 24 hours to complete. [16,17]

Recently, Bergdahl and coworkers [18] reported an aqueous Wittig reaction that could be performed in the sophomore organic chemistry laboratory. The reaction was amenable to a variety of aldehydes, and the products were synthesized in poor to excellent yields. In addition, the reaction could be completed within 30 minutes. However, the conditions for this reaction did not adhere to the principles of green chemistry; the aqueous solution had to be refluxed to afford the desired products, the reaction was performed on a multi-gram scale that resulted in a copious amount of waste, and two equivalents of ethyl bromoacetate was required to access the products.

It would be ideal to implement a “greened” Wittig reaction in the sophomore organic laboratory that is a one-pot process, can be performed either solventless or in a green solvent, and completed within the time constraints of a standard 3–4 hour laboratory period. A scan of the chemical literature for a Wittig reaction that could be performed under green chemistry conditions and could be

adapted to suit the level of a sophomore organic laboratory provided a paper by Bergdahl, et al. published in the *Journal of Organic Chemistry*. [19] Within this paper Bergdahl and his co-workers described a Wittig reaction that could be performed within 1–3 hours in one-pot simply by adding an aldehyde, an  $\alpha$ -bromoester ( $R_2 = CO_2R$ ), and triphenylphosphine to a reaction vessel that contained an aqueous, saturated solution of sodium bicarbonate (Figure 1). The expected alkene products were isolated in high yields and determined to be synthesized under a high degree of stereocontrol. Within the present report, the reaction published by Bergdahl and co-workers [19] has been tailored to the sophomore organic chemistry laboratory so that it could be completed over the course of two 4 hour laboratory periods; this allowed the students to perform the reaction, work-up and purify the reaction mixture, and analyze the products of the reaction using IR and  $^1H$  NMR spectroscopy.

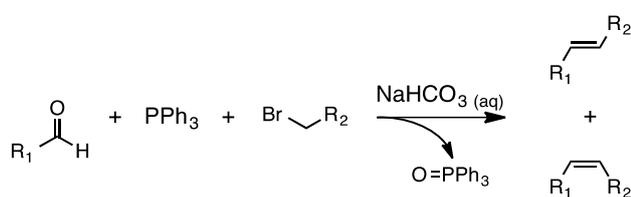


Figure 1. Bergdahl's green, one-pot Wittig reaction

## 2. Experimental Section

The development of the green, one-pot Wittig reaction presented here was accomplished in two phases. The first phase focused on the versatility of the reaction when different aldehydes were explored. The second phase investigated whether the reaction was amenable to varying the alkyl halide. In addition, once the experimental protocol had been optimized, all subsequent experiments were performed by undergraduate students; all of the data that these students gathered is presented within this report (Table 1).

Triphenylphosphine was weighed, powdered, and then added to a 13 x 100 mm test tube that contained a magnetic stir bar. To the 13 x 100 mm test tube was added 5 mL of an aqueous, saturated solution of sodium bicarbonate; stir the suspension that is formed for 1 minute. To the suspension of triphenylphosphine was added the alkyl halide followed by the aldehyde. The reaction mixture was vigorously stirred for 1 hour. After aging the reaction for 1 hour, the reaction mixture was quenched with 40 drops of 1.0 M  $H_2SO_4$  (aq), extracted using diethyl ether, dried with magnesium sulfate, and concentrated *in vacuo*. A TLC plate of the crude reaction mixture is run using 80:20 hexanes:ethyl acetate as the mobile phase and all observations are recorded. The crude reaction mixture is purified using column chromatography.

## 3. Hazards

Hexanes, ethyl acetate, and diethyl ether are flammable liquids. Methyl bromoacetate is a potent lachrymator. Handle silica gel in the fume hood to prevent dust inhalation.

## 4. Results and Discussion

The implementation of the green, one-pot Wittig reaction into the sophomore organic chemistry laboratory was a profitable endeavor because the students were able to observe first-hand the “greening” of a seminal organic reaction and understand the benefit of reducing the amount of organic waste that is generated in the organic chemistry laboratory. In addition, the students were able to perform column chromatography under conditions that more closely resembled a research laboratory environment; the clear and colorless appearance of the crude reaction mixture necessitated that the students utilize TLC (which was previously added to their synthetic toolbox) in order to successfully locate and isolate the Wittig products from the collected fractions. The reaction was simple to execute, and the reaction conditions were amenable to variation in both the aldehyde component and the alkyl halide component (Table 1).

Table 1. Data for the Green, One-Pot Wittig Reaction

Entry	R <sub>1</sub>	R <sub>2</sub>	% Yield <sup>a</sup>	E:Z Ratio <sup>b</sup>
1		CO <sub>2</sub> Me	46.5(87.0) <sup>c</sup>	95.5:4.5
2		CO <sub>2</sub> Me	54.9(87.0) <sup>c</sup>	99.8:0.2
3		CO <sub>2</sub> Me	55.8(90.5) <sup>c</sup>	93.1:6.9
4		CN	56.9(86.1) <sup>c</sup>	58.8:41.2

<sup>a</sup>Average yields. <sup>b</sup>Average E:Z ratios. <sup>c</sup>Highest yields reported by students. Note: See Figure 1 for positions of R<sub>1</sub> and R<sub>2</sub>.

As previously mentioned, the ability to perform the one-pot Wittig reaction in an aqueous solution has been reported independently by both Bergdahl and Wu. [19,20] The justification for how the Wittig reaction is able to proceed in an aqueous medium is two-fold. First, the generation of the phosphonium salt is favorable in an aqueous medium due to an increase in hydrophilicity, which then allows the deprotonation step to occur readily; second, the hydrophobic effect promotes the reaction in an aqueous medium by causing the reactants to agglomerate and thereby react.

The data presented within this paper was collected by 45 sophomore-level, undergraduate students over a two year period. The students were able to successfully synthesize the expected Wittig products in mediocre to excellent yields and were able to analyze the Wittig products using  $^1H$  NMR and IR spectroscopy. In addition, the students used  $^1H$  NMR spectroscopy to determine the stereoselectivity of the Wittig reaction, which revealed that excellent E:Z ratios were realized for all but one of the substrate combinations.

The average yields of methyl cinnamate (Table 1, entry 1), methyl 4-methoxycinnamate (Table 1, entry 2), and methyl 3-(2-thienyl)propenoate (Table 1, entry 3) were decent, but the most significant aspect of the % yield data in Table 1 is that some students were able to synthesize these three Wittig products at levels that nearly matched the yields reported by Bergdahl. [19] This data highlights the ability of sophomore-level students to realize high yields when proper care and technique are employed. The  $^1H$  NMRs of methyl cinnamate (Table 1, entry 1), methyl

4-methoxycinnamate (Table 1, entry 2), and methyl 3-(2-thienyl)propenoate (Table 1, entry 3) were thoroughly analyzed and it was revealed that the average *E*:*Z* ratios for these three Wittig products surpassed the *E*:*Z* ratios reported by Bergdahl. [19]

The  $^1\text{H}$  NMR data collected for all of these experiments confirmed that the expected products had been isolated and that the products were very pure. A representative  $^1\text{H}$  NMR spectrum for each Wittig product can be found in the Supplemental Information. Furthermore, having the students analyze the  $^1\text{H}$  NMR of the product to determine the stereoselectivity of the reaction and the % composition of each isomer within the mixture gave the students a deeper appreciation for the utility of  $^1\text{H}$  NMR spectroscopy. The high *E*:*Z* ratios for each of the Wittig products mentioned above can be attributed to the *in situ* generation of a stabilized ylide. It is well established that stabilized ylides react with aldehydes to selectively form the (*E*)-alkene product. Structural assignment of the signals within the  $^1\text{H}$  NMR spectrum of the Wittig products were made and this exercise clearly demonstrated how resonance affects the electronic environment of nuclei within a molecule. For example, the students were able to calculate the coupling constants of the signals that corresponded to the vinylic protons within each Wittig product mixture to determine whether those signals came from the (*E*)-alkene or the (*Z*)-alkene. For all of the Wittig products mentioned above the coupling constants were well within the accepted ranges, which allowed the students to readily assign the signals to one of the two stereoisomers. For instance, the coupling constants for the vinylic protons within (*E*)-methyl cinnamate and (*Z*)-methyl cinnamate were 16.0 Hz and 12.6 Hz, respectively. In addition, the vinylic proton that was  $\beta$  to the ester group in each of the three (*E*)-Wittig products mentioned above was consistently located between 7.6 ppm and 7.8 ppm while the corresponding vinylic proton that was  $\alpha$  to the ester group was located between 6.2 ppm and 6.4 ppm. The drastic difference in the chemical shifts of the two vinylic protons is a result of resonance and diamagnetic anisotropy (Figure 2,  $R_1 = \text{Aryl}$ ).

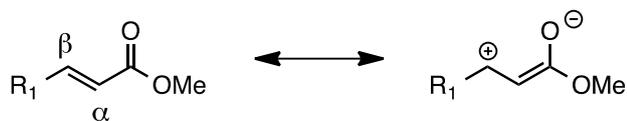


Figure 2. Resonance structures of the (*E*)-Wittig product

The  $\beta$  proton is more downfield than the  $\alpha$  proton because it is being deshielded by the aromatic ring through diamagnetic anisotropy. Furthermore, a significant resonance contributor of the Wittig product places a full positive charge on the carbon attached to the  $\beta$  proton. Students were also asked to acquire and fully analyze the IR spectrum of the Wittig products to confirm that the expected bonds were, in fact, present in that sample. For example, the students were required to identify the signals that were a result of C—H ( $\text{sp}^2$  hybridized), C—H ( $\text{sp}^3$  hybridized), C=C (aromatic), C=C (conjugated), and C=O bonds and to then tabulate this information.

In an effort to determine the versatility of this experimental protocol when other alkyl halides were employed, bromoacetonitrile was substituted for methyl bromoacetate and then reacted with benzaldehyde. The

students synthesized cinnamionitrile and the average yield was calculated to be 56.9 %; the highest yield that was reported for the synthesis of cinnamionitrile was 86.1 %. Cinnamionitrile was synthesized in a stereoselective manner, but the *E*:*Z* ratio was severely eroded; Wu [20] observed similar results and suggested that the erosion in stereoselectivity for the Wittig reaction that employed bromoacetonitrile was a result of the less bulky nitrile group. The students then analyzed the IR and  $^1\text{H}$  NMR spectra of cinnamionitrile. The IR spectrum clearly showed the diagnostic nitrile peak at  $2215.73\text{ cm}^{-1}$ . The  $^1\text{H}$  NMR spectrum displayed the expected signals for the vinylic protons of (*E*)-cinnamionitrile at 5.89 ppm and 7.37 ppm, and the vinylic protons of (*Z*)-cinnamionitrile at 5.46 ppm and 7.14 ppm. The coupling constants for the vinylic protons within (*E*)-cinnamionitrile and (*Z*)-cinnamionitrile were 16.7 Hz and 12.1 Hz, respectively. Although the stereoselectivity of this specific example was poor it was an excellent opportunity for the students to observe the effects of varying just one component of a stereoselective Wittig reaction.

## 5. Conclusion

The Wittig reaction described within this report is an excellent example of how traditional organic chemistry experiments can be modified to ensure that green principles are being discussed and promoted within a traditionally non-green discipline. The reaction is performed in one-pot, which circumvents the need to perform the phosphonium salts or ylides in a separate reaction that requires the use of copious amounts of deleterious solvents; this report is an improvement upon the “green” Wittig reactions that have thus far been published in the literature. In addition, the reaction was performed in a saturated, aqueous solution of sodium bicarbonate, which is an environmentally benign and green solvent thus reducing the amount of organic waste that is generated within the organic chemistry laboratory. The analysis of the  $^1\text{H}$  NMR and IR spectra of the Wittig products is a great opportunity to improve the critical thinking and analytical skills of the students. In closing, the Wittig reaction described in this report was a great introduction to advanced synthetic transformations that reinforced techniques learned over the course of the two semesters of organic chemistry.

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I would like to thank all of the organic chemistry students who contributed to this work, and WCSU for its financial support.

## Statement of Competing Interests

The author has no competing interests.

## Supporting Information

List of chemicals, student handouts, instructor notes,  $^1\text{H}$  NMR spectra, and IR spectra are available.

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## Supplemental Information

### 1. List of Chemicals (CAS Numbers):

Anisaldehyde (123-11-5)  
 Benzaldehyde (100-52-7)  
 Bromoacetonitrile (590-17-0)  
 Diethyl ether (60-29-7)  
 Ethyl acetate (141-78-6)  
 Hexanes (110-54-3)  
 Magnesium Sulfate (7487-88-9)  
 Methyl Bromoacetate (96-32-2)  
 Sodium Bicarbonate (144-55-8)  
 Sulfuric Acid (7664-93-9)  
 2-Thiophenecarboxaldehyde (98-03-3)  
 Triphenylphosphine (603-35-0)

### 2. Instructor Notes

**Aldehyde Scope:** Triphenylphosphine (0.367 g, 1.4 mmol, 1.4 equiv.) was weighed out onto weigh paper, powdered (**Note 1**), and then added to a 13 x 100 mm test tube that contained a magnetic stir bar (**Note 2**). To the 13 x 100 mm test tube was added 5 mL of an aqueous, saturated solution of sodium bicarbonate; stir the suspension that is formed for 1 minute. To the suspension of triphenylphosphine was added 17 drops of methyl bromoacetate (0.245 g, 0.151 mL, 1.6 mmol, 1.6 equiv.) followed by the aldehyde (benzaldehyde: 7 drops, 0.106 g, 0.102 mL, 1.0 mmol, 1.0 equiv.; 2-thiophenecarboxaldehyde: 6 drops, 0.112 g, 0.093 mL, 1.0 mmol, 1.0 equiv.; anisaldehyde: 8 drops, 0.136 g, 0.122 mL, 1.0 mmol, 1.0 equiv.). The reaction mixture was vigorously stirred for 1 hour (**Note 3**). Once the reaction aged for 1 hour, the reaction mixture was quenched with 40 drops of 1.0 M H<sub>2</sub>SO<sub>4</sub> (**Note 4**). Pour the quenched reaction mixture into a 60 mL separatory funnel and wash the 13 x 100 mm test tube with 5 mL of diethyl ether; add the diethyl ether rinse to the separatory funnel to perform an extraction. Extract the aqueous layer two more times with 5 mL portions of diethyl ether per extraction (**Note 5**). Combine the organic extracts and dry with anhydrous magnesium sulfate. Decant the dried extracts to a 50 mL Erlenmeyer flask. Rinse the magnesium sulfate with 5 mL diethyl ether and transfer this volume to the 50 mL Erlenmeyer flask. Run a TLC plate of your crude reaction mixture using 80:20::hexanes:EtOAc and record all observations (**Note 6**). Using a rotary-evaporator concentrate the crude reaction mixture. Purify the crude reaction

mixture using column chromatography (**Note 7**). Analysis of the data collected during this experiment includes calculating the  $R_f$  value of each spot on the TLC plate that was run before purification, calculating the % yield of the reaction, interpreting the IR spectrum of the Wittig products, interpreting the  $^1\text{H}$  NMR spectrum of the Wittig products, and calculating the  $E/Z$  ratio of the Wittig products (**Note 8**).

**Alternate Alkyl Halide:** Triphenylphosphine (0.367 g, 1.4 mmol, 1.4 equiv.) was weighed out onto weigh paper, powdered (**Note 1**), and then added to a 13 x 100 mm test tube that contained a magnetic stir bar (**Note 2**). To the 13 x 100 mm test tube was added 5 mL of an aqueous, saturated solution of sodium bicarbonate; stir the suspension that is formed for 1 minute. To the suspension of triphenylphosphine was added bromoacetonitrile (12 drops, 0.192 g, 0.111 mL, 1.6 mmol, 1.6 equiv.) followed by benzaldehyde (7 drops, 0.106 g, 0.102 mL, 1.0 mmol, 1.0 equiv.). The reaction mixture was vigorously stirred for 1 hour (**Note 3**). After the reaction has aged for 1 hour, work up the reaction as described in the "Aldehyde Scope" protocol (*vide supra*) (**Notes 4,5,6**). Purify the crude reaction mixture using column chromatography (**Note 7**). Analyze the data as described in the "Aldehyde Scope" protocol (*vide supra*).

**Note 1:** Sandwich the massed triphenylphosphine between the piece of weigh paper and then crush the triphenylphosphine to a fine powder using a glass stirring rod or spatula.

**Note 2:** Perform the following before adding the powdered triphenylphosphine to the 13 x 100 mm test tube. Place a 5 x 10 mm PTFE-coated magnetic stir bar in the 13 x 100 mm test tube and then secure the test tube above a stir plate. Ensure that the magnetic stir bar is able to freely rotate within the empty test tube. If this step is not performed there is a possibility that the 13 x 100 mm test tube will be too small, which will prevent the magnetic stir bar from properly rotating in the 13 x 100 test tube.

**Note 3:** The evolution of carbon dioxide will begin almost immediately and will be quite pronounced. If solids begin to collect at the top of the mixture, carefully shake the test tube by hand to incorporate the solids back into the reaction mixture.

**Note 4:** While stirring the reaction mixture, the addition of acid should be performed slowly to ensure that the reaction mixture does not discharge from the test tube.

**Note 5:** Wash the test tube with the 5 mL portions of fresh diethyl ether used for each extraction to ensure quantitative mass transfer.

**Note 6:** A sample of the aldehyde should be made available so that the students can co-spot it against the crude reaction mixture.

**Note 7:** Conditions for preparing and running the column can be found in the student handout.

**Note 8:** The  $E/Z$  ratio can be calculated by comparing the integration values for the vinylic protons located on the carbons  $\alpha$  to the ester group of the two Wittig products.

### 3. Student Handouts

#### Aldehyde Scope:

#### **The Wittig Reaction** **Conversion of Carbonyls to Alkenes**

#### Background

The development of "Green Chemistry" experiments for the sophomore organic lab is extremely important due to the ever-increasing push to reduce the amount of organic waste that is generated in the lab. In an effort to reduce the amount of organic solvent that is utilized during a single organic laboratory experiment two routes exist so that this goal can be achieved. These approaches include 1) performing solventless reactions and 2) performing organic reactions in water which is a "green" solvent because it is a "safer solvent and auxiliary" as defined by Paul Anastasia and John Warner in *Green Chemistry: Theory and Practice*. A scan of recent chemical literature that specifically described organic reactions that were performed in water and could be adapted to suit the level of a sophomore organic laboratory provided a paper by Bergdahl, et al. that was published in the *Journal of Organic Chemistry*. Within this paper Bergdahl and his co-workers described a Wittig reaction that could be performed in water using stabilized ylides and aldehydes. Furthermore, the most appealing aspect of this paper is that the reaction could be performed *in situ* simply by adding all of the reagents to the reaction vessel that contained a saturated solution of sodium bicarbonate. The reaction provided a high level of stereocontrol in the products in addition to high yields.

#### Procedure

Place a magnetic stir bar in a 13 x 100 mm test tube (supplied by the Instructor) and then clamp this test tube to a ring stand above a stir plate. Ensure that the test tube is clamped directly above the center of the stir plate, and that the stir bar can freely rotate in the test tube before adding any reagents.

**Wittig Reaction.** To the 13 x 100 mm test tube add freshly ground triphenylphosphine (0.367 g, 1.4 mmol, 1.4 equiv.) and 5 mL of a saturated solution of sodium bicarbonate. Stir this suspension for 1 minute. To the suspension of triphenylphosphine in sodium bicarbonate add 17 drops of methyl bromoacetate (0.245 g, 0.151 mL, 1.6 mmol, 1.6 equiv.) followed by the aldehyde (benzaldehyde: 7 drops, 0.106 g, 0.102 mL, 1.0 mmol, 1.0 equiv.; 2-thiophenecarboxaldehyde: 6 drops, 0.112 g, 0.093 mL, 1.0 mmol, 1.0 equiv.; anisaldehyde: 8 drops, 0.136 g, 0.122 mL, 1.0 mmol, 1.0 equiv.). Vigorously stir the reaction mixture for 1 hour (**Note:** The evolution of carbon dioxide will begin almost immediately and will be quite pronounced. If solids begin to collect at the top of the mixture, carefully shake the test tube by hand to incorporate the solids back into the reaction mixture).

**Work-up.** After 1 hour has elapsed, quench the reaction mixture with 40 drops of 1.0 M H<sub>2</sub>SO<sub>4</sub> (**Note:** The addition of acid should be performed slowly to ensure that the reaction mixture does not discharge from the test tube). Once the reaction has been quenched add the reaction mixture to a 60 mL separatory funnel. Rinse the test tube with 5 mL of diethyl ether and add this volume to the separatory funnel to perform an extraction. Extract the aqueous layer two more times with 5 mL portions of diethyl ether per extraction (**Note:** Wash the test tube with the 5 mL diethyl ether used for each extraction to ensure quantitative mass transfer). Combine the organic extracts and dry with anhydrous magnesium sulfate. Decant the dried extracts to a 50 mL Erlenmeyer flask. Rinse the magnesium sulfate with 5 mL diethyl ether and transfer this volume to the 50 mL Erlenmeyer flask. Run a TLC plate of your crude reaction mixture using 80:20::hexanes:EtOAc and record your observations (**Note:** A sample of the aldehyde will be available to co-spot against the crude reaction mixture). Using a rotary-evaporator concentrate the crude reaction mixture. This material contains your Wittig product and triphenylphosphine oxide. A column must be performed to purify the Wittig product.

**Purification.** Add 5.5 g of silica gel to a 12" x 0.5" glass column. Prepare 50 mL of an 80:20::hexanes:EtOAc solution to be utilized as the mobile phase for this purification. Flash 10-20 mL of the mobile phase through the silica gel using pressurized air to expedite this process. Make sure that there are no cracks before loading your sample onto the column. Carefully add a layer of sand on top of the prepared silica gel column to protect the silica gel from being disturbed. Add a few drops of ethyl acetate to the impure solid material/viscous oil so that it dissolves and then load this solution onto the column. Rinse the flask with the 80:20::hexanes:EtOAc solution and then load this volume onto the column. Rinse the inside of the column with the 80:20::hexanes:EtOAc solution and then begin flashing your column to elute your Wittig product. You will collect each fraction in a 13 x 100 mm test tube. To determine which fraction(s) contain(s) your product you will need to perform a TLC analysis. Once the product has been located transfer the fraction(s) to a **pre-weighed** 50 mL round bottom flask and evaporate the solvent using a rotary-evaporator. A clear and colorless oil will remain in the flask (**Note:** The product isolated from using anisaldehyde is a white solid). Once you are certain that no more solvent remains obtain the mass of your product and then transfer a small portion of the product to an NMR tube. Label the cap of the NMR tube with your name and place the capped NMR tube in the NMR rack at the front of the lab. Obtain an IR of your sample.

**Analysis.** Calculate the R<sub>f</sub> value of each spot on the TLC plate that you ran before purification, and make sure to discuss your observations. Calculate the % yield of your reaction, analyze your IR spectrum, analyze your <sup>1</sup>H NMR spectrum, and tabulate all data. Calculate the E/Z ratio of your product.

### Clean-Up

Dispose of organic solvents in the organic waste container. Dispose of the aqueous waste in the aqueous waste container. Magnesium sulfate can be disposed of in the solid waste container. All glassware should be washed with soap and water only and then rinsed with a minimal amount of acetone.

### Post-Lab Questions

1. Upon treatment of bromonitromethane with PPh<sub>3</sub> and benzaldehyde, under basic conditions, a new product is formed. Would you expect that this is going to be a stereoselective reaction? If so, which stereoisomer would be formed in excess? Please provide the structure.
2. Based on the results that you obtained for your Wittig reaction, what type of ylide did you generate? Please provide evidence that supports your choice of ylide.
3. What would be the major product from the reaction between the ylide generated in Problem #1 and methyl 4-oxobutanoate?

### References

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3. El-Batta, A.; Jiang, C.; Zhao, W.; Anness, R.; Cooksy, A.; Bergdahl, M. *J. Org. Chem.* 2007, 72, 5244-5259.