The Preparation of Allyl Phenyl Ether and 2-Allylphenol Using the Williamson Ether Synthesis and Claisen Rearrangement

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The coordination of lecture and laboratory topics while simultaneously covering necessary laboratory techniques is always a challenge. It was our desire to develop a new laboratory experiment that uses ether chemistry during a portion of our laboratory course that also concentrates on ^{1}H NMR interpretation and works to build students' synthetic skills for multistep synthesis. It was natural to turn to the Williamson ether synthesis as an option because it is such a workhorse of synthetic organic chemistry *(1)*. The preparation of allyl phenyl ether also offers the opportunity to perform a Claisen rearrangement to give 2-allylphenol, another reaction of ethers typically covered in organic chemistry lecture *(1)*.

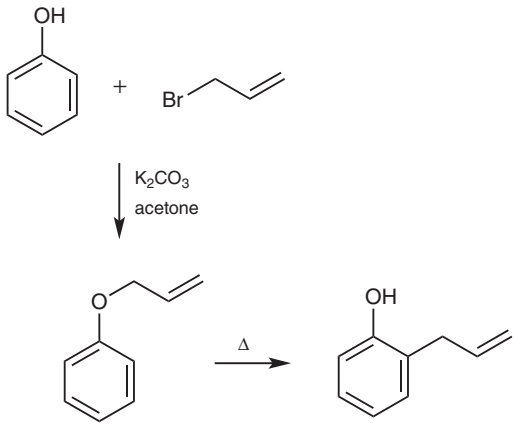
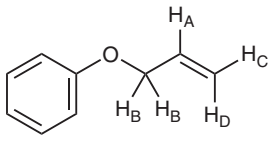


Figure 1. Williamson preparation of allyl phenyl ether from phenol and allyl bromide and the subsequent Claisen rearrangement to form 2-allylphenol.

Table 1. ^{1}H NMR Coupling Constants of Allyl Phenyl Ether



Coupling	*J*/Hz	Interaction
H_A–H_B	5.3	vicinal
H_A–H_C	10.6	cis-vicinal
H_A–H_D	17.3	trans-vicinal
H_B–H_C	1.8	allylic
H_B–H_D	1.8	allylic
H_C–H_D	1.8	geminal

Ether functionality, because of its ease of formation and the stability of the resulting ether bond, is ubiquitous in organic synthesis. Williamson ether syntheses, however, often have prolonged reaction times that are not convenient for the undergraduate lab. For example, a literature preparation of allyl phenyl ether from phenol and allyl bromide in acetone with potassium carbonate as a base gives a reaction time of eight hours *(2)*. In the Williamson preparation of allyl phenyl ether the separation of the product from the starting materials is achievable via base extraction of residual phenol and allyl bromide. We surmised that we could dramatically reduce reaction time and still obtain pure product using base extraction. The reaction time was reduced to one hour with only a slightly diminished yield and excellent purity. Furthermore, the purification could be easily followed by thin-layer chromatography (TLC). The subsequent Claisen rearrangement can also be accomplished in reduced reaction times compared to the known preparation, again taking advantage of the fact that the product can be purified by extraction *(2)*. Completing the Claisen rearrangement in the laboratory also allows a more in-depth study of pericyclic reactions and augments coverage of this class of reactions.

This reaction sequence (Figure 1) covers two important reactions while reinforcing skills in acid–base extraction and TLC. ^{1}H NMR and IR are used to identify the compounds spectroscopically. The ^{1}H NMR of allyl phenyl ether and 2-allyl phenol can both be interpreted using chemical shift and integration. The ^{1}H NMR of allyl phenyl ether is also conducive to the introduction of the use of coupling constants for structure determination.

Experimental Overview

The Williamson ether synthesis of allyl phenyl ether was completed in 70–75% yields after refluxing phenol, allyl bromide, and potassium carbonate in acetone for one hour. Before workup, a TLC of the reaction mixture is run showing the presence of both allyl phenyl ether and phenol. After base extraction, a second TLC is run to show that phenol was removed from the reaction mixture. TLC plates were visualized under UV light. Remaining allyl bromide was not visualized on the TLC. Allyl bromide is hydrolyzed to allyl alcohol and removed during the base extraction. The IR of allyl phenyl ether is clearly different from both starting materials and shows a sp^2 C−C stretch at 1650 cm^{-1}. The ^{1}H NMR spectrum of allyl phenyl ether can be assigned from chemical shift and integration values. In addition, the coupling constants for splitting among the vinyl and allylic protons can be extracted from the complex multiplets to confirm the assignment as shown in Table 1.

The Claisen rearrangement to form 2-allylphenol can be completed in a 50% yield after heating the liquid allyl phenyl ether to reflux for 3 hours. After heating, the residue is parti-

tioned between hexane and aqueous base. The hexane removes unreacted starting materials while the base deprotonates the 2-allylphenol and partitions it into the aqueous layer. The aqueous fraction is then acidified to protonate the 2-allylphenoxide. The resulting 2-allylphenol is extracted into ether. Removal of ether gives the desired product in excellent purity.

The IR clearly shows the reappearance of an OH stretch and a sp^2 C−C stretch at 1638 cm^{-1}. The ^1H NMR of this product is easily assigned based on chemical shift and integration. Because of the overlapping of resonances, in-depth analysis of the vinyl and allylic resonances is not recommended for most undergraduate laboratories.

Hazards

All transformations were completed in fume hoods. Students wore standard protective eyewear and gloves. Acetone, allyl bromide, diethyl ether, hexane, and ethyl acetate are flammable. Allyl bromide is toxic and a lachrymator. Phenol is highly toxic and a vesicant. Phenol and 2-allylphenol are corrosive. Acetone, ethyl acetate, 2-allylphenol, and allyl phenyl ether are irritants. Allyl bromide, potassium carbonate, diethyl ether, and hexane are harmful and dangerous to the environment. All of the compounds used should be handled in a manner consistent with the appropriate safety data.

Conclusion

A two-step synthesis using a Williamson ether synthesis to prepare allyl phenyl ether and the rearrangement to 2-allylphenol through a Claisen rearrangement has been described. Ether chemistry is important in organic synthesis and the Williamson ether synthesis provides the synthetic experience of ether formation and a chance to review fundamental S_N2 chemistry. The ^1H NMR spectra of the product allyl phenyl ether gives well-resolved aromatic, allylic, and vinyl resonances. The splitting of the allylic and vinyl peaks can be used to demonstrate the interpretation of complex splitting patterns. The Claisen rearrangement provides an example of the use of ethers as starting materials and introduces a pericyclic reaction to the undergraduate laboratory. The reactions can be used together or separately. The reaction times have been shortened to allow undergraduate students to complete the experiments in an undergraduate laboratory timeframe.

Acknowledgments

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Abstract and keywords

Full text (PDF)

Supplement

Student handouts for both experiments

Instructor notes including spectra