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Rhodium(II)-Catalyzed Aziridination of Allyl-Substituted Sulfonamides and Carbamates

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Several unsaturated sulfonamides underwent intramolecular aziridination when treated with PhI(OAc)$_2$, MgO, and catalytic $Rh_2(OAc)_4$ to give bicyclic aziridines in excellent yield. Treatment of the resulting azabicyclic sulfonamides in methanol in the presence of *p*-TsOH resulted in exclusive opening of the aziridine ring at the most substituted position affording six- and seven-membered ring products in high yield. In contrast, the intramolecular aziridination of several cycloalkenyl-substituted carbamates did not require a Rh(II) catalyst and proceeded via an iminoiodinane intermediate. The resulting tricyclic aziridines underwent ring opening when treated with various nucleophiles to give *anti*-derived products as expected for nucleophilic attack at the three-membered ring. The iodine(III)-mediated reaction of a 3-indolyl-substituted carbamate, however, required a Rh(II) catalyst. The expected aziridine was not observed, but rather simultaneous spirocyclization of C_3 and stereoselective *syn*-acylation at C_2 occurred to give compound **41**, whose structure was unequivocally established by an X-ray crystallographic study. The reaction proceeds in a stepwise manner via a metal-free zwitterionic intermediate which is attacked by a nucleophilic reagent on the same side of the amide anion. Related reactions occurred with both a 2-indolyl- and 3-benzofuranyl-substituted carbamate but with lower stereoselectivity.

The chemistry of metal carbene complexes has provided chemists with exceptionally fertile ground for the design and development of new stereoselective bond formation processes for application to organic synthesis.[1−7] Metallocarbenoid reactions involving X−H insertion (X = C, O, N),[8] cyclopropanation,[1] or ylide generation[2] have been extensively used to prepare complex synthetic targets. The development of chiral catalysts for asymmetric reaction of metal carbenoids has also been widely studied[9] since the first report by Nozaki and co-workers that decomposition of ethyl diazoacetate in the presence of copper(II) complex with a chiral Schifff base ligand resulted in enantioselective cyclopropanation of styrene.[10] In recent years, chiral rhodium catalysts have been investigated with considerable success for generating enantiomerically enriched products in many important transformations of diazo compounds, such as cyclopropanations and C−H insertions.[1]

While the transition-metal-catalyzed carbon transfer[11,12] to olefins is a highly developed process, significantly fewer reagents and procedures are available for the analogous nitrogen atom transfer.[13] Addition of a metallo nitrene to an olefin followed by aziridine ring opening represents an attractive approach to a variety of medicinally important compounds (Scheme 1).[14] Vicinal amino alcohols are found in a substantial number of bioactive compounds[15] and are also utilized for asym-

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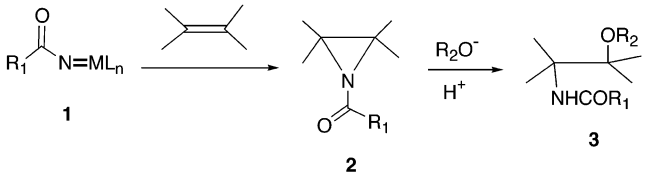
SCHEME 1



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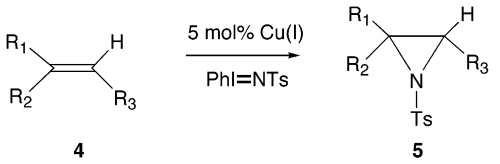

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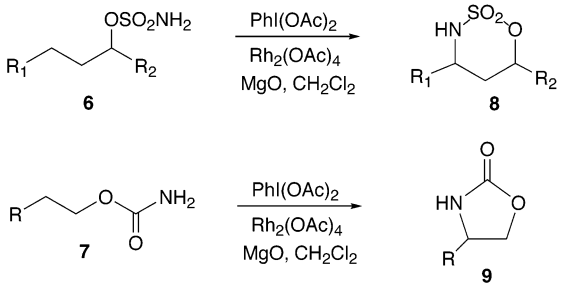

metric synthesis[16] and as ligands for transition-metal-catalyzed processes.[17] This functionality is not only of importance in the chemistry of aminosugars, carbohydrates, and nucleosides[18] but also has varied applications in organic synthesis.[19] Considering the enormous potential of the β-amino alcohol moiety for chemistry, it is not surprising that numerous synthetic routes have been reported.[20] Based on our long-standing involvement with metallocarbenoids derived from α-diazocarbonyl compounds,[2] we naturally became interested in the chemistry of the corresponding acyl nitrenoid with the intention of using this reactive species for the preparation of various β-amino alcohols via aziridine intermediates.

Pioneered by the groups of Breslow[21] and Mansuy[22] in the early 1980s, transition-metal-catalyzed nitrene transfer reactions with (arene-sulfonylimino)phenyliodinanes have become recognized in recent years as a potentially powerful method for the synthesis of various nitrogen-containing substrates.[23] Aziridination using TsN═IPh- and Cu(I)-based catalysts was subsequently developed and optimized to become an efficient synthetic method by the Evans group (Scheme 2).[24] A crucial feature of the copper(II)-catalyzed reaction is the exclusive formation of the three-membered aziridine ring.[25] Rhodium(II) catalysts were also found to mediate aziridinations but with a higher propensity to generate C−H insertion products.[26] The first metal-catalyzed inter- and intramolecular insertions into C−H bonds by iminophenyliodinanes in the presence of a Rh(II) catalyst was reported by Breslow and Gellman.[21] More recently, Du Bois and co-workers demonstrated that it was possible to perform stereospecific intramolecular C−H insertions starting from either sulfamate (**6**) or carbamate esters (**7**) when used in combination with a Rh(II) catalyst, $PhI(OAc)_2$, and MgO, thereby greatly enhancing the use of iminoiodanes for organic synthesis (Scheme 3).[27] The method was elegantly highlighted as a unique strategy in a recent synthesis of (−)-tetrodotoxin.[28]

Inspired by the work of both Breslow[21] and Du Bois[27] as well as our ongoing interest in the chemistry of rhodium carbenoids,[2] we wondered whether this reaction could also be applied to the catalytic intramolecular aziridination of C═C bonds. When we started our studies in this area, the transition-metal-catalyzed delivery of nitrogen from a carbamoyl nitrene to an olefin had not been described in the literature.[29] Our plan was to utilize an intramolecular primary carbamate cyclization to provide for the directed aziridination reaction shown in Scheme 4.

Nucleophilic ring opening would generate oxazolidinone **12**, which we intended to use for the stereospecific preparation of a variety of 1,2-amino alcohol derivatives (**12** → **13**). In an earlier report, we described some preliminary results in this area,[30] and in this paper we expand on our initial findings.

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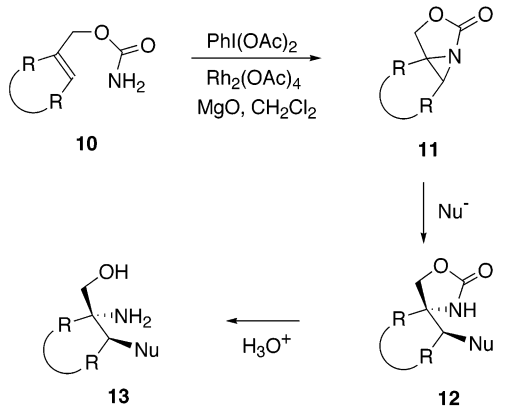
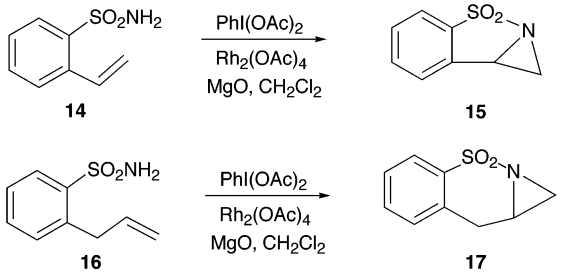
SCHEME 4



SCHEME 5

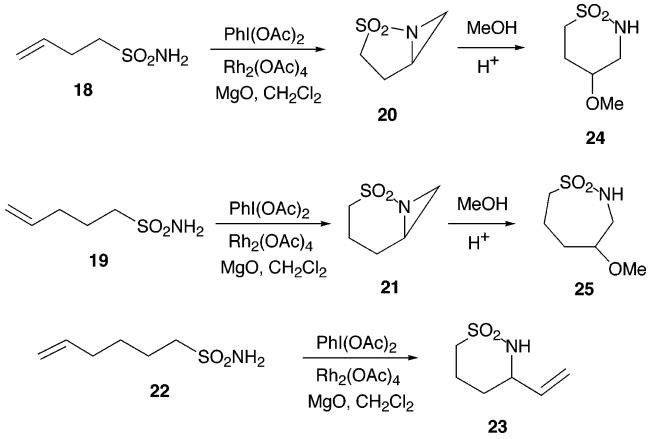


Results and Discussion

The intramolecular aziridination reaction of several easily available unsaturated sulfonamides was chosen as our initial test for establishing the necessary reaction conditions since it had previously been demonstrated that iminoiodanes can be readily prepared from sulfonamides.[23] Following the standard protocol developed by Du Bois,[27] which consisted of treating the appropriate sulfonamide with $PhI(OAc)_2$, MgO, and catalytic $Rh_2(OAc)_4$, we found that it was possible to convert vinylphenylsulfonamide **14** into the bicycic aziridine **15** in 80% isolated yield. A similar reaction occurred with the related allyl-substituted system **16** affording **17** in 91% yield (Scheme 5). A variety of solvents and different Rh(II) carboxylate catalysts were examined to determine the effect of the reaction conditions on the yield and conversion. The results of this study showed CH_2Cl_2 to be the solvent of choice. Reactions conducted in THF, benzene, or acetonitrile gave lower yields of the product. The nature of the ligand in the rhodium metal did not appear to influence the outcome of the reaction.[31]

We next examined a series of unsaturated acyclic sulfonamides to establish the generality and scope of the aziridination process. The readily available substrates **18** and **19** underwent smooth intramolecular aziridination to give the bicyclic aziridines **20** and **21** in 85% and 91% yield, respectively (Scheme 6). Interestingly, reaction of the related 5-hexenyl-substituted sulfonamide **22** furnished only the product derived from allylic insertion (i.e., **23**) in 70% isolated yield. Related work by Dauban and Dodd had previously been reported which made use of a

SCHEME 6



copper-catalyzed aziridination reaction using iminoiodinane intermediates.[32] The present set of conditions, however, led to product yields significantly higher than those reported by these workers.[33] Treatment of azabicyclic sulfonamides **20** and **21** in methanol in the presence of *p*-TsOH resulted in exclusive opening of the aziridine ring at the more substituted position affording the six- and seven-membered ring products **24** and **25** in 60% and 86% yield, respectively. It should be noted that the ring-opening reaction required the presence of a protic acid or a Lewis acid such as boron trifluoride etherate. In the absence of these additives, no ring-opening reaction occurred.

Cyclic carbamates, readily available from cyclocarbamation of allylic or homoallylic amines and alcohols, have often been used as crucial intermediates for highly stereoselective construction of both 1,2- and 1,3-amino alcohol structures.[34] With the intention of exploring the scope, generality, and synthetic opportunities of the above metal-mediated nitrenoid cyclization reaction, we extended our initial studies to include several carbocyclic systems containing an allylic carbamate subunit. Carbamic acid cycloalk-1-enylmethyl esters **26** and **27** were obtained upon treatment of the corresponding alcohols with $CCl_3C(O)NCO$ followed by K_2CO_3/MeOH.[35] Application of the Du Bois conditions to carbamates **26** and **27** afforded tricyclic aziridines **28** and **29** in 71% and 75% yield, respectively, as the exclusive products (Scheme 7). Interestingly, when the reactions were carried out using iodosobenzene (PhI═O) rather than $PhI(OAc)_2$ as the oxidant[36] in the presence of 5 equiv of an added alcohol, the same two tricyclic aziridines (**28** and **29**) were obtained in essentially identical yield. Although both aziridines were stable to silica gel chromatography, they did undergo reaction with various nucleophiles at room

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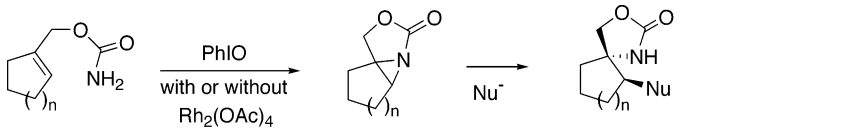
SCHEME 7

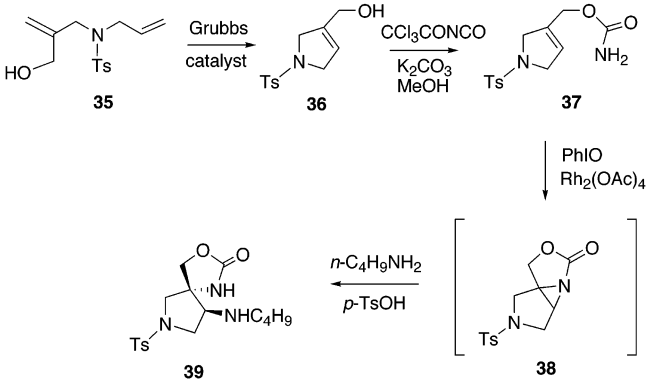


26; n = 1
27; n = 2

28; n = 1
29; n = 2

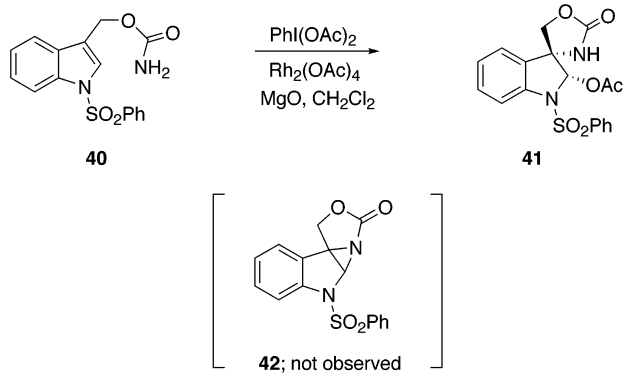
30; n = 1; Nu = OMe; 80%
31; n = 1; Nu = Br; 78%
32; n = 2; Nu = OMe; 83%
33; n = 2; Nu = NHC_4H_9; 82%
34; n = 2; Nu = *p*-$(OMe)C_6H_4NH$; 82%

SCHEME 8



35 **36** **37** **38** **39**

SCHEME 9



40 **41** **42**; not observed

temperature in the presence of either *p*-TsOH or $LiClO_4$. In most cases, the addition of 1−5 equiv of the nucleophile was used. The stereochemical assignment of **30** was unequivocally established by X-ray crystallography. The smooth and efficient reaction with aliphatic and aromatic amines is potentially very useful since 1,2-diamines represent an important subunit in many biological compounds.[37] Notably, the ring-opened products (i.e., **30**−**34**) were completely *anti*-stereoselective; only the *trans*-isomers were formed (ca. 80% yield) as expected for nucleophilic attack at the three-membered ring.[38]

To further highlight the synthetic utility of the spirocyclization reaction, the intramolecular aziridination of carbamate **37** was examined. A Grubb's catalyzed ring-closing metathesis reaction of *N*-allyl-*N*-(2-hydroxymethyl)-allyl-4-methylbenzenesulfonamide (**35**) afforded the expected 2,5-dihydropyrrole[39] **36** (63%) which was readily transformed into carbamate **37** in 80% yield (Scheme 8). In the presence of PhIO and $Rh_2(OAc)_4$, compound **37** was converted to **38**. Azabicycle **38**, however, decomposed on silica gel chromatography, and consequently, the crude product produced from the aziridination reaction was immediately treated with *n*-butylamine in the presence of a catalytic amount of *p*-toluenesulfonic acid. After the mixture was stirred for 1 h, standard workup afforded 3-oxa-1,7-diazaspiro[4.4]-nonan-2-one **39** in 73% yield. Compound **39** is the result of attack of *n*-butylamine at the less hindered terminal carbon of the aziridine ring. The ring opening of activated aziridines with various amines is a well-studied process and represents an efficient route to variously substituted diamines.[40] In all cases reported, the resulting products possess *trans*-stereochemistry of the ensuing amino groups.[41] This is the consequence of backside attack of the nucleophile on the aziridine ring.

The next system we investigated corresponded to the protected 3-indolyl carbamate **40** which was synthesized in three steps [tosylation (82%), reduction (77%), and carbamoylation (71%) starting from indole-3-carboxaldehyde. Application of the Du Bois/Espino conditions[27] to indole **40** provided oxazolidinone **41** as a single diastereomer in 85% yield (Scheme 9). The expected aziridine **42** was not observed. Rather, simultaneous spirocyclization of C_3 and stereoselective acetylation at C_2 occurred leading to compound **41**. The stereochemical assignment of **41** was unequivocally established by an X-ray crystallographic study. The stereochemical outcome of the reaction was totally unexpected and certainly incompatible with an S_N2 opening of a transient aziridine intermediate (i.e., **42**), since nucleophilic attack of an acetate on the three-membered ring would have led to an *anti*-configuration of the substituent groups[38] as was encountered with tricyclic aziridines **28** and **29**. The experimental observations suggest a close interaction of the acetate moiety with the metal fragment, thereby favoring formation of the oxazolidinone with the *syn*-configuration of substituents. Without the addition of the Rh(II) catalyst, only recovered starting material was obtained. When the above reaction was carried out using iodosobenzene (PhIO) rather than $PhI(OAc)_2$ as the oxidant in the presence of 5 equiv of an added alcohol, indolines **47**−**49**

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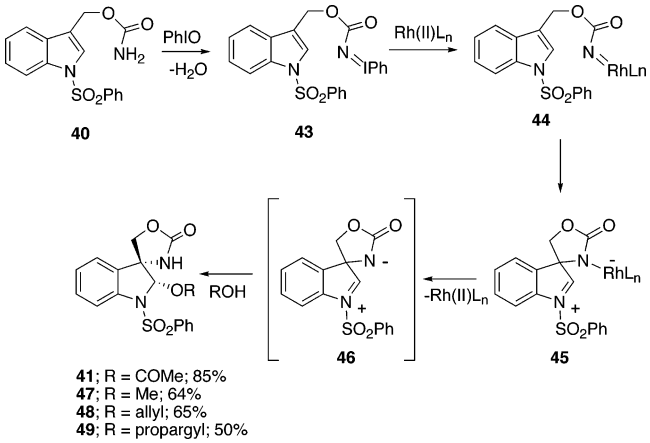
SCHEME 10

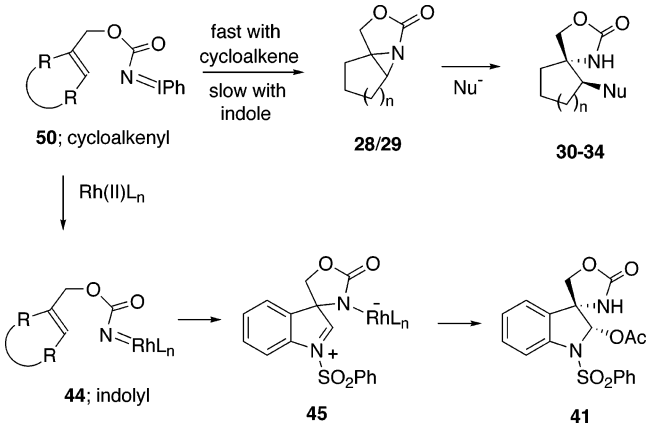


were formed in 64%, 65%, and 50% isolated yield. The stereochemical assignment of **49** was unequivocally established by X-ray crystallography. Again, without the addition of the Rh(II) catalyst, only recovered starting material was obtained. A reasonable mechanism which accounts for the experimental findings involves initial formation of an iminoiodinane intermediate (i.e., **43**) followed by catalyst (Rh(II))-promoted loss of iodobenzene to give the metallonitrene **44** (Scheme 10). Stepwise addition across the indole π-bond to give **45** followed by Rh(II) detachment generates the metal-free zwitterionic intermediate **46**. Attack of the neutral nucleophile will then occur on the side of the amide anion because deprotonation of the nucleophile and nucleophilic attack on the *N*-sulfonyliminium ion can occur simultaneously to deliver indolines **47**−**49**.[31] Another possible explanation is that the nucleophile attacks iminium ion **46** from the less congested α-face.[42]

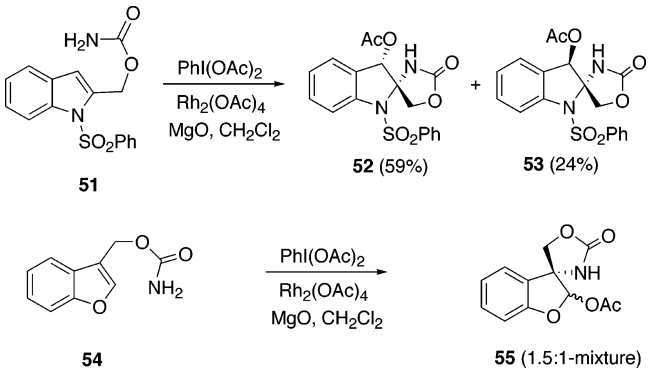
The observed stereochemistry encountered with indolyl-substituted carbamate **40** stands in marked contrast with the results obtained with cycloalkenyl carbamates **26** and **27** where the ring-opening reaction of the tricyclic aziridine proceeded with complete *anti*-selectivity. A clue to the differing behavior of these systems was gleaned when it was noted that the reactions of **26** and **27** proceeded smoothly in the absence of the Rh(II) catalyst. This would suggest that the initially formed iminoiodinane **50** readily reacts with the electron-rich π-bond present in the cycloalkene ring (Scheme 11). In the case of the indole system, however, addition of iminoiodinane **43** to the π-bond is much slower, presumably as a result of its heteroaromatic character. It is only when **43** reacts with the Rh(II) catalyst that stepwise addition to the indole π-bond occurs, eventually producing acetate **41**.

We have also studied the behavior of the closely related 2-indolyl carbamate **51** in order to determine the stereoselectivity of its reaction. Application of the standard Du Bois/Espino conditions to **51** provided a 5:2 mixture of diastereomers **52** (59%) and **53** (24%) (Scheme 12). The

SCHEME 11

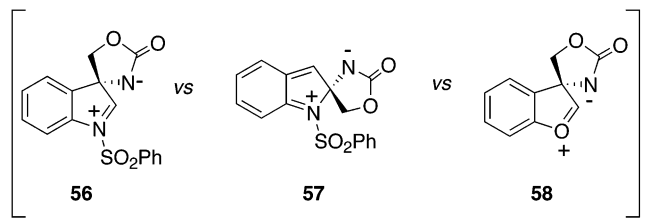


SCHEME 12



stereochemistry of the major diastereomer **52** was established by NOE measurements and corresponds to the *syn*-selective isomer. To further expand the scope of the intramolecular aziridination reaction using other heteroaromatic ring systems, we also prepared 3-benzofuranyl carbamate **54** and examined its reaction with PhI(OAc)$_2$ in the presence of $Rh_2(OAc)_4$ under the same conditions used for the indolyl-substituted systems. In contrast to the reaction that occurred with **40** which proceeded with exclusive *syn*-selectivity, the amination of **54** produced a 1.5:1-mixture of the diastereomers of **55**.

What is the origin of the much higher degree of stereocontrol encountered with 3-indolyl carbamate **40** relative to carbamates **51** and **54**? We hypothesize that the stepwise addition of the metallonitrenoid derived from **40** across the indole π-bond will lead to a much more stable zwitterionic intermediate (i.e., **56**) than that resulting from carbamate **51** (i.e., **57**). The higher reac-



tivity of iminium ion **57** is undoubtedly related to the disruption of aromaticity of the benzenoid portion of the molecule. The stereochemical controlling step in the process involves nucleophilic addition of the acetate group

(42) One of the reviewers has suggested an alternative mechanism involving addition of the nucleophile from the coordination sphere of the metal in **45** to give **41**, **47**, **48**, and **49** directly, without the intermediacy of the dipolar species **46**. Although this pathway is consistent with the observed *syn*-selectivity of addition, we believe that it can be discounted because one would expect acetate transfer in all cases, independent of other nucleophiles present.

onto the carbon atom of the *N*-sulfonyliminium ion. When diastereomeric transition states involving different iminium ion precursors are considered, the shorter lived and less stable iminium ion **57** does not easily allow for facial discrimination by the attacking acetic acid. In contrast, the more stable and longer lived cation **56** does permit the nucleophile to preferentially react on the same side as the amide anion due to an electrostatic attraction.[43] Although this hypothesis remains to be critically evaluated, the model can also be used to understand the lack of selectivity observed with the benzofuranyl analogue **54**. With this system, the resulting oxonium ion **58** is simply too reactive to exhibit any significant facial discrimination as a consequence of electrostatic factors.[44]

In summary, the iodine(III)-mediated intramolecular aziridination reaction of unsaturated sulfonamides occurs readily in the presence of $Rh_2(OAc)_4$ and gives bicyclic sultams. Several indolyl- and benzofuranyl-substituted carbamates were also studied. The amination reaction requires a Rh(II) catalyst and proceeds in a stepwise manner via a metal-free zwitterionic intermediate. In contrast, the intramolecular aziridination of several cycloalkenyl carbamates does not require a Rh(II) catalyst and takes place via an iminoiodinane intermediate. Further mechanistic investigations and application of acyl nitrenoid methodology to natural product synthesis are underway in our laboratories and will be reported in due course.

Experimental Section

1,1a-Dihydro-6-thia-6a-azacycloprop[*a*]indene 6,6-Dioxide (15). To a 0.1 g sample of 2-vinylphenylsulfonamide (**14**)[45] in 10 mL of CH_2Cl_2 was added 0.25 g of $PhI(OAc)_2$, 0.1 g of MgO, and 10 mg of $Rh_2(OAc)_4$. The mixture was stirred at 40 °C under an argon atmosphere for 8 h. The solution was filtered through a short pad of Celite, and the solvent was removed under reduced pressure. The residue was subjected to flash silica gel chromatography to give **15** (80%) as a clear oil: IR ($CHCl_3$) 2930, 1600, 1550, 1470, 1340, and 1050 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.35 (dd, 1H, J = 4.0, 0.9 Hz), 2.92 (dd, 1H, J = 5.0, 0.9 Hz), 4.15 (m, 1H), 7.55−7.80 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 43.2, 44.5, 123.8, 125.5, 130.5, 133.3, 137.2. Anal. Calcd for $C_8H_7NSO_2$: C, 53.03; H, 3.89; N, 7.73. Found: C, 52.89; H, 3.71; N, 7.66.

1a,2-Dihydro-1*H*-7-thia-7a-azacyclopropa[*b*]naphthalene 7,7-Dioxide (17). To a solution of *N*-*tert*-butylbenzenesulfonamide (2 g) in 25 mL of hexane was added 1.6 M *n*-butyllithium solution in hexane. After stirring for 3 h at −60 °C, the solution was warmed to −30 °C and 1 equiv of allyl bromide was added in THF. After being stirred for 3 h, the mixture was allowed to warm to 25 °C and was treated with 10% hydrochloric acid. The THF layer was removed, dried, and concentrated under reduced pressure. The resulting residue was subjected to silica gel chromatography to give 2-allylbenzenesulfonamide (**16**) (70%) as a white solid: mp 121−123 °C; ^1H NMR (300 MHz, $CDCl_3$) δ 3.91 (d, 2H, J = 6.0 Hz), 5.02 (brs, 2H), 5.15 (m, 2H), 6.10 (m, 1H), 7.35 (m, 2H), 7.5 (dt, 1H, J = 7.5, 1.4 Hz), 8.05 (dd, 1H, J = 8.0, 1.0 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 37.2, 117.4, 127.1, 128.5, 132.2, 133.3, 136.9, 138.3, 140.2. Anal. Calcd for $C_9H_{11}NSO_2$: C, 54.80; H, 5.62; N, 7.10. Found: C, 54.64; H, 5.55; N, 7.08.

To a 0.24 g sample of the above sulfonamide in 8 mL of CH_2Cl_2 was added 0.5 g of $PhI(OAc)_2$, 0.2 g of MgO, and 10 mg of $Rh_2(OAc)_4$. The mixture was stirred at 40 °C under an argon atmosphere for 8 h. The solution was filtered through a short pad of Celite, and the solvent was removed under reduced pressure. The residue was subjected to flash silica gel chromatography to give **17** as a clear oil in 91% yield: ^1H NMR (300 MHz, $CDCl_3$) δ 1.95 (dd, 1H, J = 4.0, 2.0 Hz), 2.52 (dd, 1H, J = 5.0, 1.4 Hz), 3.25 (m, 2H), 3.60 (dd, 1H, J = 17.0, 4.0 Hz), 7.31 (d, 1H, J = 7.0 Hz), 7.50 (t, 1H, J = 7.0 Hz), 7.65 (dt, 1H, J = 7.5, 1.5 Hz), 7.85 (dd, 1H, J = 7.5, 1.0 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) $\delta\delta$ 26.1, 30.2, 49.4, 36.9, 126.3, 129.2, 129.5, 134.2. Anal. Calcd for $C_9H_9NSO_2$: C, 55.37; H, 4.65; N, 7.17. Found: C, 55.24; H, 4.50; N, 7.03.

2-Thia-1-azabicyclo[3.1.0]hexane 2,2-Dioxide (20). A sample of but-3-ene-1-sulfonamide (**18**) was prepared in 45% yield by heating a solution of 4-bromo-but-1-ene (2 mL) and sodium sulfite (3.0 g) in 15 mL of water at reflux for 12 h. The resulting solid was then treated with phosphorus oxychloride for 6 h at 125 °C. The mixture was concentrated, and the residue was taken up in acetonitrile and treated with an aqueous ammonia solution. Standard workup afforded **18** as a white solid in 65% yield: mp 44−45 °C; ^1H NMR (300 MHz, $CDCl_3$) δ 2.62 (q, 2H, J = 7.5 Hz), 3.29 (t, 2H, J = 7.5 Hz), 5.1−5.25 (m, 2H), 5.45 (brs, 2H), 5.90 (m, 1H); ^{13}C NMR (CDCl3, 100 MHz) δ 28.0, 54.2, 117.3, 134.2. Anal. Calcd for $C_4H_9NSO_2$: C, 35.55; H, 6.72; N, 10.37. Found: C, 35.28; H, 6.57; N, 10.21.

To a 0.1 g sample of the above sulfonamide in 8 mL of CH_2Cl_2 was added 0.2 g of $PhI(OAc)_2$, 0.08 g of Al_2O_3, and 8 mg of $Rh_2(OAc)_4$. The mixture was stirred at 40 °C under an argon atmosphere for 4 h. Filtration through a short pad of Celite was followed by removal of the solvent under reduced pressure. The residue was subjected to silica gel chromatography to give azabicyclic sulfonamide **20** (85%) as a white solid: mp 75−77 °C; ^1H NMR (300 MHz, $CDCl_3$) δ 2.34 (dd, 1H, J = 4.3, 3.0 Hz), 2.52 (dd, 1H, J = 5.4, 3.0 Hz), 2.60−2.75 (m, 2H), 2.90 (ddd, 1H, J = 13.0, 12.0, 8.0 Hz), 3.20 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz), $\delta\delta$ 2.3, 30.1, 39.4, 40.6. Anal. Calcd for $C_4H_7NSO_2$: C, 36.08; H, 5.30; N, 10.53. Found: C, 35.84; H, 5.17; N, 10.46.

2-Thia-1-azabicyclo[4.1.0]heptane 2,2-Dioxide (21). A sample of pent-4-ene-1-sulfonamide (**19**) was prepared in 39% yield by heating a solution of 5-bromopent-1-ene (1.0 g) and sodium sulfite (3.0 g) in 15 mL of water at reflux for 12 h. The resulting solid was then treated with phosphorus oxychloride for 6 h at 125 °C. The mixture was concentrated, and the residue was taken up in acetonitrile and treated with an aqueous ammonia solution. Standard workup afforded **19** as a clear oil: ^1H NMR (300 MHz, $CDCl_3$) δ 1.97 (q, 2H, J-7.5 Hz), 2.24 (q, 2H, J = 7.5 Hz), 3.18 (t, 2H, J = 7.5 Hz), 5.05−5.15 (m, 2H), 5.24 (brs, 2H), 5.81 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 23.1, 32.2, 54.7, 116.3, 136.7. Anal. Calcd for $C_5H_{11}NSO_2$: C, 40.25; H, 7.43; N, 9.39. Found: C, 40.03; H, 7.19; N, 9.46.

To a 0.1 g sample of the above sulfonamide in 8 mL of CH_2Cl_2 was added 0.25 g of $PhI(OAc)_2$, 0.08 g of Al_2O_3, and 10 mg of $Rh_2(OAc)_4$. The mixture was stirred at 40 °C under argon atmosphere for 6 h. The solution was filtered through a short pad of Celite, and the solvent was removed under reduced pressure. The residue was subjected to flash silica gel chromatography to give azabicyclic sulfonamide **21** (91%) as a white solid: mp 68−70 °C; ^1H NMR (300 MHz, $CDCl_3$) δ 1.85−2.05 (m, 1H), 2.10 (q, 1H, J = 5.0 Hz), 2.25 (m, 2H), 2.60 (d, 1H, J = 5.0 Hz), 2.72 (dd, 1H, J = 5.0, 0.8 Hz), 3.10 (ddd, 1H, J = 14, 12, 4.0 Hz), and 3.20 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 17.0, 18.9, 32.5, 42.7, 47.0. Anal. Calcd for $C_5H_9NSO_2$: C, 40.80; H, 6.16; N, 9.52. Found: C, 40.66; H, 6.03; N, 9.61.

(43) Another reasonable possibility suggested by one of the reviewers is that the dipolar structures **56**−**58** might adopt different conformations, due to a buttressing effect of the tosyl group, and this may change the steric requirements around the carbon atom that is attacked by the nucleophile.

(44) For structures **57** and **58**, there is the possibility that the intermediate exists as a mixture of dipolar and aziridine structures, the dipolar one being responsible for the *syn*-addition product and the highly strained aziridine for the *anti*-addition product.

(45) Müller, P.; Baud, C.; Jacquier, Y. *Can. J. Chem.* **1998**, *76*, 738.

3-Vinyl[1,2]thiazinane 1,1-Dioxide (23). A sample of hex-5-ene-1-sulfonamide (**22**) was prepared in 65% yield by heating a solution of 6-bromohex-1-ene (1.0 g) and sodium sulfite (3.0 g) in 15 mL of water at reflux for 12 h. The resulting solid was treated with phosphorus oxychloride for 6 h at 125 °C. The mixture was concentrated, and the residue was taken up in acetonitrile and treated with an aqueous ammonia solution. Standard workup afforded **22** in 62% yield as a white solid: mp 50−51 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.55 (q, 2H, J = 7.5 Hz), 1.85−1.90 (m, 2H), 2.15 (q, 2H, J = 7.5 Hz), 3.15 (m, 2H), 5.0−5.1 (m, 4H), 5.80 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 23.6, 27.7, 33.4, 55.4, 115.7, 137.9. Anal. Calcd for $C_6H_{13}NSO_2$: C, 44.15; H, 8.03; N, 8.58. Found: C, 44.06; H, 7.95; N, 8.44.

To a 0.1 g sample of the above sulfonamide in 10 mL of CH_2Cl_2 was added 0.25 g of $PhI(OAc)_2$, 0.1 g of Al_2O_3, and 10 mg of $Rh_2(OAc)_4$. The mixture was stirred at 40 °C under an argon atmosphere for 8 h. The solution was filtered through a short pad of Celite, and the solvent was removed under reduced pressure. The residue was subjected to flash silica gel chromatography to give **23** (70%) as a white solid: mp 95−97 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.35−1.50 (m, 1H), 1.90 (qd, 1H, J = 14, 3.0 Hz), 2.25 (m, 2H), 2.85−3.0 (m, 1H), 3.20 (dt, 1H, J = 13, 3.5 Hz), 4.10 (m, 1H), 4.20 (brd, 1H, J = 8.0 Hz), 5.20 (d, 1H, J = 11 Hz), 5.30 (d, 1H, J = 17 Hz), 5.80 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 2.31, 29,0.8, 49.4, 58.2, 116.5, 136.7. Anal. Calcd for $C_6H_{11}NSO_2$: C, 44.70; H, 6.88; N, 8.69. Found: C, 44.62; H, 6.87; N, 8.53.

4-Methoxy[2,1]thiazinane 1,1-Dioxide (24). A 0.07 g (0.5 mmol) sample of azabicyclosulfonamide **20** in 5 mL of methanol was stirred at room temperature in the presence of *p*-TsOH for 24 h. Removal of the solvent followed by silica gel chromatography of the residue afforded the titled compound as a clear oil in 60% yield: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.30−2.45 (m, 2H), 3.09 (dt, 1H, J = 13, 4.0 Hz), 3.2−3.40 (m, 2H), 3.42 (s, 3H), 3.50 (m, 2H), 4.61 (brs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 27.2, 45.3, 48.1, 56.4, 70.1. Anal. Calcd for $C_5H_{11}NSO_3$: C, 36.35; H, 6.71; N, 8.48. Found: C, 36.27; H, 6.58; N, 8.30.

4-Methoxy[1,2]thiazepane 1,1-Dioxide (25). A 0.1 g (0.7 mmol) sample of azabicyclosulfonamide **21** in 5 mL of methanol was stirred at room temperature in the presence of *p*-TsOH for 24 h. Removal of the solvent followed by silica gel chromatography of the residue afforded the titled compound in 86% yield as a clear oil: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.90 (m, 2H), 2.10 (m, 2H), 3.30−3.50 (m, 7H), 3.60 (m, 1H), 5.15 (brs, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 18.1, 31.9, 44.7, 56.8, 57.0, 78.4. Anal. Calcd for $C_6H_{13}NSO_3$: C, 40.21; H, 7.31; N, 7.81. Found: C, 40.17; H, 7.05; N, 7.79.

Tetrahydro-2-oxa-3a-azacyclopropadicyclopenten-3-one (28). In a sealed tube was placed 0.27 g (1.9 mmol) of carbamic acid cyclopent-1-enylmethyl ester (**26**)[46] in 16 mL of anhydrous CH_2Cl_2. To this solution were added 0.76 g (3.4 mmol) of PhIO and 3 g of molecular sieves, and the mixture was stirred for 12 h at 40 °C. The reaction mixture was filtered through a short pad of Celite. The solvent was removed under reduced pressure and the residue subjected to flash silica gel chromatography to give 0.19 g (71%) of aziridine **28** as a colorless oil: IR (film) 1769, 1386, 1240, 1156, 1132, 1086, 1037 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.39−1.53 (m, 1H), 1.65−1.85 (m, 3H), 2.02 (dd, 1H, J = 8.1 Hz), 2.13 (dd, 1H, J = 8.1 Hz), 2.98 (d, 1H, J = 2.5 Hz), 4.39 (d, 1H, J = 9.4 Hz), 4.57 (d, 1H, J = 9.4 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 19.9, 27.2, 27.8, 52.96, 56.9, 66.8, 167.3. Anal. Calcd for $C_7H_9NO_2$: C, 60.40; H, 6.52; N, 10.07. Found: C, 60.25; H, 6.49; N, 9.92.

Tetrahydro-2-oxa-3a-azacyclopenta[1,3]cyclopropa-[1,2]benzen-3-one (29). In a sealed tube was placed 0.12 g (0.77 mmol) of carbamic acid cyclohex-1-enylmethyl ester (**27**)[47] in 7 mL of anhydrous CH_2Cl_2. To this solution were added 0.3 g (1.4 mmol) of PhIO and 1.5 g of molecular sieves, and the mixture was stirred for 12 h at 40 °C. The reaction mixture was filtered through a short pad of Celite. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.09 g (75%) of aziridine **29** as a white solid: mp 34−35 °C; IR (film) 1778, 1219, 1133, 1076, 1038 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.21−1.49 (m, 4H), 1.73−1.84 (m, 2H), 1.92−2.06 (m, 2H), 2.65 (m, 1H), 4.01 (d, 1H, J = 9.4 Hz), 4.37 (d, 1H, J = 9.4 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 19.4, 20.6, 24.3, 24.9, 48.9, 49.2, 70.6, 168.4. Anal. Calcd for $C_8H_{11}NO_2$: C, 62.73; H, 7.24; N, 9.14. Found: C, 62.54; H, 7.32; N, 9.22.

6-Methoxy-1-azaspiro[4.4]nonan-2-one (30). A 0.05 g (0.38 mmol) sample of tetrahydro-2-oxa-3a-azacyclopropadicyclopenten-3-one (**28**) was dissolved in 2 mL of anhydrous methanol. A catalytic amount of *p*-TsOH was added. The solution was stirred for 4 h at room temperature. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to afford 0.05 g (80%) of oxazolidinone **30** as a white solid: mp 114−115 °C; IR (film) 1751, 1716, 1401, 1198, 1151, 1112, 1044, 1007 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.62−1.71 (m, 3H), 1.80−1.91 (m, 3H), 3.31 (s, 3H), 3.51 (m, 1H), 4.04 (d, 1H, J = 8.9 Hz), 4.64 (d, 1H, J = 8.9 Hz), 7.16 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 19.2, 27.6, 35.4, 57.3, 57.4, 67.4, 70.6, 86.2, 160.4. Anal. Calcd for $C_8H_{13}NO_3$: C, 56.11; H, 7.66; N, 8.18. Found: C, 56.07; H, 7.53; N, 8.01.

6-Bromo-1-azaspiro[4.4]nonan-2-one (31). A 0.05 g (0.33 mmol) sample of tetrahydro-2-oxa-3a-azacyclopropadicyclopenten-3-one (**28**) was dissolved in 3 mL of anhydrous acetone. A 0.12 g (1.3 mmol) sample of lithium bromide and a catalytic amount of $LiClO_4$ were added. The solution was stirred for 4 h at room temperature. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to afford 0.06 g (78%) of oxazolidinone **31** as a white solid: mp 98−100 °C; IR (film) 1751, 1474, 1396, 1330, 1253, 1044 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.70−1.99 (m, 3H), 2.07−2.19 (m, 2H), 2.32−2.41 (m, 1H), 4.19−4.21 (m, 1H), 4.25 (d, 1H, J = 9.2 Hz), 4.68 (d, 1H, J = 9.2 Hz), 7.35 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 19.8, 33.8, 34.5, 58.4, 68.8, 73.2, 159.8. Anal. Calcd for $C_7H_{10}BrNO_2$: C, 38.36; H, 4.60; N, 6.39. Found: C, 38.19; H, 4.55; N, 6.26.

6-Methoxy-3-oxa-1-azaspiro[4.5]decan-2-one (32). A 0.05 g (0.29 mmol) sample of tetrahydro-2-oxa-3a-azacyclopenta-[1,3]cyclopropa[1,2]benzen-3-one (**29**) was dissolved in 2 mL of anhydrous methanol. A catalytic amount of *p*-TsOH was added. The solution was stirred for 4 h at room temperature. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.05 g (83%) of oxazolidinone **32** as a colorless oil: IR (film) 1747, 1397, 1249, 1099, 1044, 983 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.29−1.84 (m, 8H), 3.14 (dd, 1H, J = 7.3 Hz), 3.35 (s, 3H), 3.93 (d, 1H, J = 8.6 Hz), 4.39 (d, 1H, J = 8.6 Hz), 7.25 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.1, 22.1, 26.0, 34.8, 57.6, 60.9, 72.6, 81.5, 160.4. Anal. Calcd for $C_9H_{15}NO_3$: C, 58.35; H, 8.17; N, 7.56. Found: C, 58.24; H, 7.97; N, 7.50.

6-Butylamino-3-oxa-1-azaspiro[4.5]decan-2-one (33). A 0.06 g (0.38 mmol) sample of tetrahydro-2-oxa-3a-azacyclopenta-[1,3]cyclopropa[1,2]-benzen-3-one (**29**) was dissolved in 3 mL of anhydrous CH_2Cl_2. A 0.08 g (1.1 mmol) sample of *n*-butylamine and a catalytic amount of *p*-TsOH were added. The solution was stirred for 4 h at room temperature. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.07 g (82%) of the oxazolidinone **33** as a white solid: mp 82−83 °C; IR (film) 1744, 1647, 1542, 1284, 1036 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.91 (t, 3H, J = 7.3 Hz), 1.23−1.51 (m, 8H), 1.68−1.89 (m, 3H), 2.10−2.17 (m, 1H), 2.40 (d, 1H, J = 3.2 Hz), 3.17−3.23 (m, 2H), 3.31 (dd, 1H, J = 12.2, 3.7 Hz), 3.76 (dd, 1H, J = 10.0, 3.7 Hz), 3.94 (dd, 1H, J = 12.2, 10 Hz), 5.01 (s, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) dδ 14.0, 20.0, 20.2, 20.4, 24.1, 27.0, 32.2, 40.5, 40.6, 46.0, 68.4, 165.2. Anal. Calcd for $C_{12}H_{22}N_2O_2$: C, 63.68; H, 9.80; N, 12.38. Found: C, 63.78; H, 9.87; N, 12.30.

6-(4-Methoxyphenylamino)-3-oxa-1-azaspiro[4.5]decan-2-one (34). A 0.06 g (0.4 mmol) sample of tetrahydro-2-oxa-3a-azacyclopenta[1,3]cyclopropa[1,2]benzen-3-one (**29**) was dissolved in 2 mL of anhydrous acetonitrile. A 0.05 g (0.4 mmol) sample of *p*-anisidine and a catalytic amount of $LiClO_4$ was added. The solution was stirred for 4 h at room temperature. The solvent was removed under reduced pressure and the residue subjected to flash silica gel chromatography to afford 0.09 g (82%) of oxazolidinone **34** as a white solid: mp 193−194 °C; IR (film) 1754, 1509, 1289, 1239, 1169, 1033 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.38−1.81 (m, 8H), 3.29 (m, 1H), 3.72 (s, 3 H), 4.02 (d, 1H, J = 9.0 Hz), 4.42 (d, 1H, J = 9.0 Hz), 6.62 (m, 2H), 6.74 (m, 3H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 22.2, 22.4, 28.5, 35.6, 55.9, 58.5, 61.6, 72.1, 115.1, 116, 4, 141.3, 153.1, 160.2. Anal. Calcd for $C_{15}H_{20}N_2O_3$: C, 65.20; H, 7.30; N, 10.14. Found: C, 65.36; H, 7.25; N, 10.18.

2-[[Allyl(toluene-4-sulfonyl)amino]methyl]acrylic Acid Ethyl Ester. A 1.5 g (7.1 mmol) sample of *N*-allyl-4-methylbenzenesulfonamide[48] was dissolved in DMF, and the solution was stirred at 0 °C for 30 min. To this solution was added 0.37 g (9.3 mmol) of NaH (60% dispersion in mineral oil), and the mixture was stirred for 0.5 h at 25 °C. To the resulting solution was added 3.0 g (15.3 mmol) of 2-bromomethylacrylic acid ethyl ester.[49] After the reaction mixture was stirred for 12 h at 25 °C, water was added and the mixture was extracted with ether. The organic phase was washed with brine and dried over $MgSO_4$. After the solvent was removed under reduced pressure, the residue was subjected to flash silica gel chromatography to give 1.95 g (85%) of the titled compound as a colorless oil: IR (film) 1712, 1343, 1159, 1092 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 1.27 (t, 3H, J = 7.2 Hz), 2.42 (s, 3H), 3.75 (d, 2H, J = 6.5 Hz), 3.99 (m, 2H), 4.17 (q, 2H, J = 7.0 Hz), 5.06 (m, 1H), 5.11 (m, 1H), 5.48−5.62 (m, 1H), 5.89 (q, 1H, J = 1.6, 1.2 Hz), 6.34 (d, 1H, J = 1.2 Hz), 7.29 (d, 2H, J = 8.9 Hz), 7.70 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.4, 21.7, 47.2, 51.3, 61.1, 119.7, 127.2, 127.4, 129.9, 132.6, 136.0, 137.2, 143.6, 166.1. Anal. Calcd for $C_{16}H_{21}NO_4S$: C, 59.42; H, 6.54; N, 4.33. Found: C, 59.48; H, 6.47; N, 4.40.

***N*-Allyl-*N*-(2-hydroxymethylallyl)-4-methylbenzenesulfonamide (35).** To a solution containing 0.1 g (0.7 mmol) of neat DIBAL-H in 8 mL of ether was added a solution of 0.2 g (0.63 mmol) of the above ethyl ester at −78 °C. After the mixture was stirred for 10 min, the cooling bath was removed and the mixture was stirred for 10 h at 25 °C. The solution was extracted with ether, and the organic phase was dried over $MgSO_4$. Removal of the solvent under reduced pressure left a clear oil which was subjected to flash silica gel chromatography to give 0.13 g (74%) of **35** as a colorless oil: IR (film) 1340, 1157, 1092 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 2.41 (s, 3H), 2.55 (t, 1H, J = 6.6 Hz), 3.70 (m, 4H), 4.12 (d, 2H, J = 6.7 Hz), 4.98 (s, 1H), 5.07 (m, 2H), 5.16 (d, 1H, J = 0.6 Hz), 5.48 (m, 1H), 7.29 (d, 2H, J = 8.0 Hz), 7.69 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.8, 49.2, 49.9, 63.6, 115.5, 119.9, 127.3, 130.0, 132.2, 137.1, 143.6, 143.8. Anal. Calcd for $C_{14}H_{19}NO_3S$: C, 59.76; H, 6.81; N, 4.98. Found: C, 59.79; H, 6.81; N, 4.93.

[1-(Toluene-4-sulfonyl)-2,5-dihydro-1*H*-pyrrol-3-yl]methanol (36). A 0.11 g (0.13 mmol) sample of Grubbs' catalyst[50] was dissolved in 240 mL of degassed CH_2Cl_2, and 0.8 g (2.85 mmol) of alcohol **35** was added. The solution was stirred at 40 °C for 24 h, and then an additional 0.07 g (0.079 mmol) of Grubbs' catalyst was added. The reaction mixture was stirred for an additional 10 h at 40 °C in order to complete the reaction. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.45 g (63%) of **36** as a white solid: mp 94−95 °C; IR (film) 3510, 2856, 1338, 1161 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 1.96 (t, 1H, J = 4.8 Hz), 2.40 (s, 3H), 4.08 (m, 6H), 5.51 (m, 1H), 7.30 (d, 2H, J = 7.9 Hz), 7.68 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.8, 54.8, 55.1, 59.7, 120.1, 127.6, 130.1, 134.1, 139.5, 143.9. Anal. Calcd for $C_{12}H_{15}NO_3S$: C, 56.90; H, 5.97; N, 5.53. Found: C, 56.48; H, 5.84; N, 5.46.

Carbamic Acid 1-(Toluene-4-sulfonyl)-2,5-dihydro-1*H*-pyrrol-3-ylmethyl Ester (37). To a solution containing 0.07 g (0.26 mmol) of dihydropyrrole **36** in 2 mL of anhydrous CH_2Cl_2 was slowly added a solution containing 0.05 g (0.27 mmol) of trichloroacetyl isocyanate in 0.5 mL of CH_2Cl_2 at 0 °C. The solution was stirred for 3 h at room temperature. The solvent was removed under reduced pressure, and the residue was taken up in 2 mL of methanol. To this solution was added 0.004 g (0.03 mmol) of K_2CO_3, and the mixture was stirred at 25 °C for 2 h. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.06 g (80%) of **37** as a white solid: mp 142−143 °C; IR (film) 3424, 1689, 1158 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 2.45 (s, 3H), 4.15−4.30 (m, 6H), 4.65 (s, 2H), 5.55 (m, 1H), 7.35 (d, 2H, J = 8.0 Hz), 7.70 (m, 2H). Anal. Calcd for $C_{13}H_{16}N_2O_4S$: C, 52.69; H, 5.44; N, 9.45. Found: C, 52.71; H, 5.56; N, 9.48.

9-Butylamino-7-(toluene-4-sulfonyl)-3-oxa-1,7-diazaspiro[4.4]nonan-2-one (39). In a sealed tube was placed 0.17 g (0.6 mmol) of carbamate **37** in 7 mL of anhydrous CH_2Cl_2. To this solution was added 0.23 g (1.0 mmol) of PhIO, 7 mg (0.016 mmol) of $Rh_2(OAc)_4$, and 1 g of molecular sieves, and the mixture was stirred for 6 h at 40 °C. The reaction mixture was filtered through a short pad of Celite, and the solvent was removed under reduced pressure. The residue was subjected to flash silica gel chromatography, and the resulting bicyclic aziridine **38** was immediately taken up in 4 mL of anhydrous CH_2Cl_2, and 0.06 g (0.82 mmol) of *n*-butylamine together with a catalytic amount of *p*-TsOH was added. The solution was stirred for 1 h at room temperature. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.06 g (73%) of **39** as a clear oil: IR (film) 1655, 1534, 1343, 1163 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.91 (t, 3H, J = 7.3 Hz), 1.27−1.47 (m, 4H), 2.41 (s, 3H), 2.88 (m, 1H), 2.97 (d, 1H, J = 2.0 Hz), 3.10−3.22 (m, 4H), 3.63 (dd, 1H, J = 4.8 Hz), 3.80 (d, 1H, J = 11.1 Hz), 3.90 (d, 1H, J = 11.1 Hz), 3.99 (dd, 1H, J = 7.3 Hz), 5.02 (s, 1H), 7.29 (m, 2H), 7.67 (d, 2H, J = 9.2 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.0, 20.2, 21.8, 32.0, 40.6, 42.9, 48.0, 49.6, 52.7, 61.6, 127.8, 129.9, 134.2, 144.0, 161.1. Anal. Calcd for $C_{17}H_{25}N_3O_4S$: C, 55.57; H, 6.86; N, 11.44. Found: C, 55.73; H, 6.91; N, 11.29.

Carbamic Acid 1-Benzenesulfonyl-1*H*-indol-3-yl Methyl Ester (40). To a solution containing 1.8 g (6.4 mmol) of (1-benzenesulfonyl-1*H*-indol-3-yl)methanol[51] in 10 mL of anhydrous CH_2Cl_2 was slowly added a 1.3 g (6.7 mmol) solution of trichloroacetyl isocyanate[35] in 3 mL of CH_2Cl_2 at 0 °C. The solution was stirred for 3 h at room temperature. The solvent was removed under reduced pressure, and the residue was dissolved in 10 mL of methanol. To this solution was added 0.1 g (0.7 mmol) of K_2CO_3, and the mixture was stirred for 2 h at 25 °C. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 1.5 g (71%) of **40** as a white solid: mp 142−143

(46) Carbamate **26** was synthesized starting from commercially available cyclopent-1-enecarboxylic acid ethyl ester in two steps. (1) Reduction to cyclopent-1-enyl-methanol with $LiAlH_2/AlCl_3$ (54% yield), see: Hager, D. C.; Bentrude, W. G. *J. Org. Chem.* **2000**, *65*, 2786. (2) Conversion of the alcohol to carbamate **26** was carried out using trichloroacetyl isocyanate/K_2CO_3, MeOH (70% yield) according to the procedure described in ref 35.

(47) Carbamate **27** was synthesized starting from commercially available cyclohex-1-enecarbaldehyde in two steps. (1) Reduction to cyclohex-1-enyl-methanol with $LiAlH_4$ (84% yield), see: Julia, S.; Julia, M.; Linares, H.; Blondel, J.-C. *Bull. Soc. Chim. Fr.* **1962**, 1947. (2) Conversion of the alcohol to carbamate **27** was carried out using trichloroacetyl isocyanate/K_2CO_3, MeOH (65% yield) according to the procedure described in ref 35.

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°C; IR (film) 1717, 1447, 1366, 1175, 1121, 1046 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 4.63 (s, 2H), 5.23 (d, 2H, J = 1.0 Hz), 7.24−7.62 (m, 6H), 7.89 (m, 2H), 7.98 (d, 1H, J = 8.3 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 58.7, 113.9, 118.0, 120.0, 123.8, 125.4, 125.7, 127.1, 129.6, 129.7, 134.2, 135.4, 138.3, 156.7. Anal. Calcd for $C_{16}H_{14}N_2O_4S$: C, 58.17; H, 4.27; N, 8.48. Found: C, 58.12; H, 4.21; N, 8.36.

***N*-Phenylsulfonyl-2-(methylcarbonyloxy)spiro[3*H*-indole-3,2′-oxazolidin]-5′-one (41).** In a sealed tube was placed 0.11 g (0.3 mmol) of carbamate **40** in 10 mL of CH_2Cl_2. To this mixture was added 0.17 g (0.5 mmol) of $PhI(OAc)_2$, 0.04 g (0.9 mmol) of MgO, and 0.008 g (0.017 mmol) of $Rh_2(OAc)_4$, and the mixture was stirred for 12 h at 40 °C. The mixture was filtered through a short pad of Celite, the solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.11 g (85%) of indoline **41** as the exclusive product: mp 189−190 °C; IR (film) 1766, 1366, 1220, 1171, 1109, 1036 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 2.00 (s, 3H), 3.91 (s, 3 H), 4.08 (d, 1H, J = 9.2 Hz), 6.27 (s, 1H), 6.63 (s, 1H), 7.12−7.64 (m, 7H), 7.85−7.87 (m, 2H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 20.6, 67.2, 74.7, 87.4, 114.9, 124.3, 125.7, 127.2, 129.1, 129.7, 131.5, 134.2, 138.8, 140.3, 159.4, 169.8. Anal. Calcd for $C_{18}H_{16}N_2O_6S$: C, 55.66; H, 4.15; N, 7.21. Found: C, 55.38; H, 4.00; N, 7.27.

***N*-Phenylsulfonyl-2-methoxyspiro[3*H*-indole-3,2′oxazolidin]-5′-one (47).** The reaction of 0.07 g (0.2 mmol) of carbamate **40**, 0.17 g (0.8 mmol) of PhIO, 0.07 g (2.0 mmol) of methanol, 0.006 g (0.014 mmol) of $Rh_2(OAc)_4$, and 2 g of molecular sieves in 6 mL of CH_2Cl_2 was stirred in a sealed tube at 40 °C for 6 h. The reaction mixture was filtered through a short pad of Celite, the solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to afford 0.05 g (64%) of **47** as a white solid: mp 228−229 °C; IR (film) 1772, 1356, 1206, 1172, 1036 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 3.17 (d, 1H, J = 9.2 Hz), 3.42 (d, 1H, J = 9.2 Hz), 3.61 (s, 3H), 5.02 (s, 1H), 5.44 (s, 1H), 7.20−7.26 (m, 2H), 7.38−7.48 (m, 3H), 7.58−7.71 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.2, 67.9, 73.6, 95.7, 117.9, 124.1, 126.6, 126.9, 129.8, 131.3, 131.9, 134.3, 138.5, 139.7, 158.4. Anal. Calcd for $C_{17}H_{16}N_2O_5S$: C, 56.65; H, 4.48; N, 7.78. Found: C, 56.53; H, 4.41; N, 7.69.

***N*-Phenylsulfonyl-2-(2-propenyloxy)spiro[3*H*-indole-3,2′oxazolidin]-5′-one (48).** The reaction of 0.07 g (0.2 mmol) of carbamate **40**, 0.18 g (0.8 mmol) of PhIO, 0.12 g (2.0 mmol) of 2-propen-1-ol, 0.007 g (0.015 mmol) of $Rh_2(OAc)_4$, and 2 g of molecular sieves in 6 mL of CH_2Cl_2 was stirred in a sealed tube at 40 °C for 6 h. The reaction mixture was filtered through a short pad of Celite, the solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.05 g (65%) of **48** as a white solid: mp 94−95 °C; IR (film) 1766, 1447, 1360, 1171, 1090, 1038 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 3.41 (d, 1H, J = 9.2 Hz), 4.28−4.33 (ddt, 1H, J = 12.5, 6.4, 1.3 Hz), 4.42−4.47 (ddt, 1H, J = 12.5, 5.3, 1.4 Hz), 5.17 (s, 1H), 5.23−5.36 (m, 2H), 5.52 (s, 1H), 5.82−5.92 (m, 1H), 7.17−7.27 (m, 2H), 7.38−7.48 (m, 3H), 7.57−7.62 (m, 1H), 7.65−7.70 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 67.8, 70.3, 73.7, 93.7, 117.8, 119.3, 124.0, 126.5, 126.9, 129.8, 131.3, 131.9, 133.0, 134.3, 138.4, 139.7, 158.3. Anal. Calcd for $C_{19}H_{18}N_2O_5S$: C, 59.05; H, 4.70; N, 7.25. Found: C, 58.87; H, 4.68; N, 7.19.

***N*-Phenylsulfonyl-2-ethynyloxyspiro[3*H*-indole-3,2′-oxazolidin]-5′-one (49).** The reaction of 0.07 g (0.2 mmol) of carbamate **40**, 0.18 g (0.8 mmol) of PhIO, 0.11 g (1.96 mmol) of 2-propyn-1-ol, 0.007 g (0.015 mmol) of $Rh_2(OAc)_4$, and 2 g of molecular sieves in 6 mL of CH_2Cl_2 was stirred in a sealed tube at 40 °C for 6 h. The reaction mixture was filtered through a short pad of Celite, the solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.03 g (50%) of **49** as a white solid: mp 159−161 °C; IR (film) 1767, 1604, 1361, 1171, 1103, 1040 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 2.54 (t, 1H, J = 2.4 Hz), 3.21 (d, 1H, J = 9.2 Hz), 3.46 (d, 1H, J = 9.5 Hz), 4.48 (dd, 1H, J = 15.9, 2.4 Hz), 4.58 (dd, 1H, J = 15.9, 2.4 Hz), 5.29 (s, 1H), 5.49 (s, 1H), 7.19−7.23 (m, 2H), 7.25−7.42 (m, 3H), 7.46−7.73 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.0, 67.7, 73.8, 76.1, 78.3, 93.1, 117.6, 124.1, 126.6, 126.9, 127.1, 129.9, 131.4, 131.6, 134.4, 138.3, 139.6, 158.1. Anal. Calcd for $C_{19}H_{16}N_2O_5S$: C, 59.37; H, 4.20; N, 7.29. Found: C, 59.13; H, 4.17; N, 7.28.

Carbamic Acid 1-Benzenesulfonyl-1*H*-indol-2-yl Methyl Ester (51). To a solution containing 0.56 g (2.0 mmol) of (1-benzenesulfonyl-1*H*-indol-3-yl)methanol[51] in 7 mL of anhydrous CH_2Cl_2 was slowly added a solution of 0.4 g (2.1 mmol) of trichloroacetyl isocyanate in 1 mL of CH_2Cl_2 at 0 °C. The solution was stirred for 2 h at room temperature, and the solvent was removed under reduced pressure. The residue was taken up in 5 mL of methanol, and 0.03 g (0.22 mmol) of K_2CO_3 was added. The mixture was stirred for 2 h, and the solvent was evaporated. The residue was subjected to flash silica gel chromatography to give 0.36 g (56%) of **51** as a white solid; mp 147−148 °C; IR (film) 1721, 1449, 1368, 1355, 1175, 1090 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 4.67 (s, 2H), 5.50 (d, 2H, J = 0.6 Hz), 6.73 (d, 1H, J = 0.6 Hz), 7.23−7.54 (m, 6H), 7.83 (m, 2H), 8.12 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.2, 112.7, 114.8, 121.5, 124.0, 125.5, 126.7, 129.1, 129.4, 134.1, 135.6, 137.4, 139.1, 156.2. Anal. Calcd for $C_{16}H_{14}N_2O_4S$: C, 58.17; H, 4.27; N, 8.48. Found: C, 57.93; H, 4.19; N, 8.36.

***N*-Phenylsulfonyl-3-(methylcarbonyloxy)spiro[2*H*-indole-3,2′oxazolidin]-5′-one (52).** In a sealed tube was placed 0.07 g (0.21 mmol) of the above carbamate in 5 mL of degassed CH_2Cl_2. To this solution were added 0.11 g (0.33 mmol) $PhI(OAc)_2$, 0.03 g (0.6 mmol) of MgO, and 5 mg (0.01 mmol) of $Rh_2(OAc)_4$. The mixture was heated for 14 h at 80 °C, filtered through a short pad of Celite, and concentrated under reduced pressure. The resulting residue contained 0.06 g (83%) of a 2.5:1 mixture of indoline diastereomers. Flash silica gel chromatography of the crude solid afforded 0.045 g (59%) of the *syn*-diastereomer **52** as a white solid: mp 191−193 °C; IR (film) 1759, 1353, 1222, 1164, 1088, 1027, 754 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 2.11 (s, 3H), 4.76 (d, 1H, J = 9.4 Hz), 5.02 (d, 1H, J = 9.4 Hz), 5.94 (s, 1H), 7.04 (brs, 1H), 7.11 (t, 1H, J = 7.8 Hz), 7.32 (d, 1H, J = 7.8 Hz), 7.40 (t, 1H, J = 7.8 Hz), 7.54 (t, 2H, J = 7.8 Hz), 7.61 (t, 1H, J = 7.8 Hz), 7.66 (d, 1H, J = 7.8 Hz), 7.93 (d, 2H, J = 7.8 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.7, 29.9, 77.5, 84.5, 114.1, 123.2, 124.4, 126.7, 127.2, 129.8, 131.9, 134.0, 139.9, 141.0, 157.9, 170.6.; Anal. Calcd for $C_{18}H_{16}N_2O_6S$: C, 55.66; H, 4.15; N, 7.21. Found: C, 55.30; H, 3.89; N, 6.90.

NOE experiments performed on **52** showed that irradiation of the singlet at δ 5.94 produced enhancements for the methylene set of hydrogens at δ 4.76 and 5.02. The minor indoline diastereomer **53** could not be fully separated from the major isomer but showed characteristic peaks in the NMR at δ 2.16 (s, 3H), 4.78 (d, 1H, J = 9.4 Hz), 5.15 (d, 1H, J = 9.4 Hz), 6.05 (s, 1H).

Carbamic Acid Benzofuran-3-ylmethyl Ester (54). To a solution of 0.5 g (3.4 mmol) of benzofuran-3-ylmethanol[52] in 8 mL of anhydrous CH_2Cl_2 was slowly added a solution of 0.7 g (3.6 mmol) of trichloroacetyl isocyanate in 1 mL of CH_2Cl_2 at 0 °C. The solution was stirred for 1.5 h at room temperature. The solvent was removed under reduced pressure, and the residue was taken up in 6 mL of methanol. To this solution was added 0.07 g (0.5 mmol) of K_2CO_3, and the mixture was stirred at 25 °C for 2 h. The solvent was removed under reduced pressure, and the residue was subjected to flash silica gel chromatography to give 0.5 g (82%) of **54** as a white solid: mp 115−116 °C; IR (film) 1679, 1598, 1451, 1338, 1190, 1104, 742 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 4.64 (brs, 2 H), 5.27 (s, 2H), 7.28−7.35 (m, 2H), 7.50 (d, 1H, J = 8.4 Hz), 7.66−

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7.69 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.6, 111.9, 116.3, 120.1, 123.2, 125.0, 126.9, 144.3, 155.7, 156.7. Anal. Calcd for $C_{10}H_9NO_3$: C, 62.82; H, 4.74; N, 7.33. Found: C, 62.73; H, 4.80; N, 7.28.

2-(Methylcarbonyloxy)spiro[3*H*-benzofuranyl-3,2′-oxazolidin]-5′-one (55). In a sealed tube was placed 0.12 g (0.21 mmol) of the above carbamate in 8 mL of degassed α,α,α-trifluorotoluene. To this solution were added 0.3 g (0.95 mmol) of $PhI(OAc)_2$, 0.07 g (1.6 mmol) of MgO, and 14 mg (0.03 mmol) of $Rh_2(OAc)_4$. The mixture was heated for 3 h at 90 °C, filtered through a short pad of Celite, and concentrated under reduced pressure. The resulting solid residue contained 0.06 g of a 1.5:1 mixture of the dihydrobenzofuran diastereomers. Fractional crystallization of the crude solid afforded the major diastereomer as a white solid: mp 162−163 °C; IR (film) 1751, 1215, 1052, 990, 759 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.17 (s, 3H), 4.35 (d, 1H, J = 9.2 Hz), 4.64 (d, 1H, J = 9.2 Hz), 5.83 (brs, 1H), 6.55 (s, 1H), 6.93 (d, 1H, J = 7.6 Hz), 7.12 (t, 1H, J = 7.6 Hz), 7.33−7.40 (m, 2 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.1, 67.5, 74.7, 99.9, 111.6, 123.7, 123.9, 124.9, 131.9, 157.6, 158.2, 169.4. Anal. Calcd for $C_{12}H_{11}NO_5$: C, 57.83; H, 4.45; N, 5.62. Found: C, 57.38; H, 4.45; N, 5.34.

The minor diastereomer could not be fully separated from the major isomer but showed characteristic peaks in the NMR at δ 2.16 (s, 3H), 4.55 (d, 1H, J = 9.6 Hz), 4.89 (d, 1H, J = 9.6 Hz), 5.62 (brs, 1H), 6.59 (s, 1H), 6.94 (d, 1H, J = 7.6 Hz), 7.12 (t, 1H, J = 7.6 Hz), 7.35−7.41 (m,2 H).

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Supporting Information Available: ORTEP drawings for structures **30**, **41**, and **48**. The authors have deposited atomic coordinates for these structures with the Cambridge Crystallographic Data Centre. This material is available free of charge via the Internet at http://pubs.acs.org.

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