Standard iodination of the malonates provided **29a** and **29b** in 79 and 71% overall yield, respectively. The reaction of **29a** with 1-hexene was conducted under the usual conditions, and the crude product[32] was treated with tributyltin hydride in situ. Purification gave **30a** as mixture of α and β isomers[33] (89/11) in 73% yield. A similar annulation with **29b** gave **30b** (α/β, 78/22)[33] in 68% yield. Reaction of iodomalonate **29a** with allyl alcohol gave tricyclic tetrahydrofuran **31a** as the direct product of the reaction (tin hydride was not added) in 75% isolated yield. Homologue **31b** was formed from **29b** in 66% isolated yield. In these two reactions, tetrahydrofuran products can only be formed if the cyclization gives an α-oriented hydroxymethyl group. It is likely that small amounts of the β-oriented products were formed, as in the case of 1-hexene, but we did not isolate these products.

The work described herein illustrates the basic principles that one must consider when planning an annulation reaction of an electrophilic radical with an alkyl-substituted alkene. Compared to annulation reactions of nucleophilic radicals with electron-deficient alkenes, additional complications are present. However, given appropriate consideration, these complications do not limit the method. We believe that the relatively simple reactions that we have studied so far represent only a beginning. It is likely that other types of iodide and alkene partners could be used to generate different types of carbo- and heterocyclic rings.

Experimental Section

Dimethyl Iodomalonate (1-H). A mixture of 4-Å molecular sieves (1.06 g), molecular iodine (506 mg, 2.0 mmol), pyridinium chlorochromate (863 mg, 4.0 mmol), and methylene chloride (20 mL) was stirred under nitrogen for 30 min at 25 °C.[15] To this was added dimethyl malonate (0.23 mL, 2.0 mmol) in methylene chloride (5 mL). After being stirred for 13 h at 25 °C, the mixture was filtered through silica gel, eluting with ether. After concentration, the residue was dissolved in ether (50 mL) and washed with saturated sodium bisulfite (2 × 25 mL). Concentration gave the crude product as a yellow oil that darkened and decomposed over a period of 2 or 3 days at 25 °C in the dark. This crude product, containing ~80% 1-H, was used for the addition reactions: ^{1}H NMR (C_6D_6) δ 4.72 (1 H, s), 3.17 (6 H, s); MS m/z 258 (M^+).

Dimethyl Methyliodomalonate (1-Me). A detailed procedure for the preparation of **14**[4a] and other substituted iodomalonates[4b] has recently appeared.

Dimethyl Propargyliodomalonate (14).[4] To a solution of propargylsodiomalonate [prepared from propargyl malonate (250 mg, 1.46 mmol) and sodium hydride (77 mg, 3.2 mmol)] in THF (15 mL) was added N-iodosuccinimide (335 mg, 1.0 mmol) in THF (2 mL) in the dark at room temperature. The mixture was stirred for 10 min and then filtered through silica gel, eluting with ether. Concentration gave **14** as a pale yellow oil in 73% yield (317 mg): ^{1}H NMR ($CDCl_3$) δ 3.83 (6 H, s), 3.25 (2 H, d, J = 3 Hz), 2.21 (1 H, t, J = 3 Hz); MS m/z 296, 237, 169, 137, 69, 59; HRMS calcd for $C_8H_9O_4I$, 295.9546, found, 295.9545.

Dimethyl Allyliodomalonate (23). This was prepared following the above procedure[4] with dimethyl allylmalonate (346 mg, 2.0 mmol), sodium hydride (156 mg, 6.5 mmol), and N-iodosuccinimide (472 mg, 2.1 mmol) in THF (20 mL). A pale yellow oil of **23** was obtained in 91% yield (540 mg) after filtration through silica gel: ^{1}H NMR ($CDCl_3$) δ 5.76 (1 H, m), 5.17 (2 H, m), 3.80 (6 H, s), 2.99 (2 H, d, J = 7 Hz); MS m/z 298, 171, 139, 71, 59; HRMS calcd for $C_8H_{11}O_4I$, 297.9702, found, 297.9702.

Standard Procedure for Addition and Annulation Reactions. A solution of iodomalonate (1 equiv), alkene (2 equiv), and hexabutylditin (0.1 equiv) in benzene (0.3 M in iodide, under argon atmosphere) was irradiated with a GE 275-W sunlamp for 10–120 min. A standard NMR tube (5 or 10 mm) was typically used as the reaction vessel and the sunlamp was kept at a distance of ~8 cm from the tube. At this distance, the reaction was warmed by the light (estimated temperature 65–85 °C) but did not reflux. After cooling, the reaction was either directly chromatographed, or treated with tin hydride (1.1 equiv, 12 h, 85 °C) or DBU, or heated. These standard procedures are described in the supplementary material.

Acknowledgment. We thank the National Institutes of Health (GM 33372) for funding of this work and we also thank Hoffman-La Roche for support.

Supplementary Material Available: Contains a detailed general experimental section, procedures for preparation of all the annulation products reported in Tables II and III and eq 5 with accompanying spectral and physical characterizations and 300-MHz ^{1}H NMR spectra for representative products, and a summary of the X-ray crystal structure determination of **16j** (23 pages). Ordering information is given on any current masthead page.

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(32) Although four stereoisomeric iodides are possible, only two were detected at this stage in a ratio of 89/11. These are probably the two isomers epimeric at the butyl-bearing carbon that have abstracted iodine from the less hindered exo face.

(33) We assign the stereochemistry of these products by analogy to the major products resulting from the reactions with allyl alcohol.

Carbanion-Accelerated Claisen Rearrangements. 6. Preparative and Stereochemical Studies with Sulfonyl-Stabilized Anions†

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Contribution from the Roger Adams Laboratory, Department of Chemistry, University of Illinois, Urbana, Illinois 61801. *Received April 20, 1989*

Abstract: The aliphatic Claisen rearrangement is markedly accelerated by an arylsulfonylmethide substituent at position 2. The generality of this anion variant has been extensively examined (31 allyl vinyl ethers) with regard to substitution, stereochemistry, and anion-stabilizing groups. The reactions generally proceed in good yield and with high regio- and stereoselectivities. The regiochemical course of the reaction is independent of the structure of the anionic precursor (α,β- or β,γ-unsaturated). The anionic rearrangement is highly diastereoselective producing either syn or anti products with 90–96% de. Vicinal quaternary centers are constructed easily. Other sulfur-based, anion-stabilizing groups were found to be inferior (sulfide, sulfoxide, and sulfilimine).

The Claisen rearrangement in its manifold variations (Scheme I) is without doubt the most synthetically useful [3,3]-sigmatropic rearrangement.[2] The widespread application in organic synthesis can be ascribed to several characteristics: (1) the γ,δ-unsaturated carbonyl compounds produced are versatile, differentially functionalized intermediates, (2) the wide range of carbonyl derivatives,

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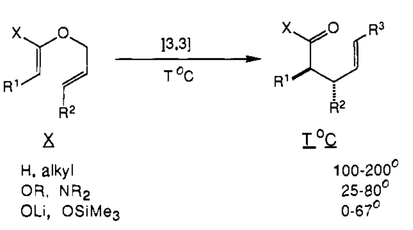
† Dedicated to the late Roger Adams on the occasion of the 100th anniversary of his birth, January 1889.

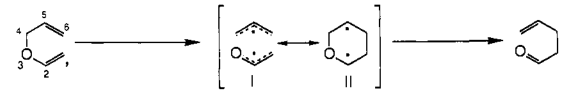
(1) (a) Taken in part from Harmata, M. A. Ph.D. Thesis, University of Illinois, Urbana, 1985. (b) Present address: Department of Chemistry, University of Missouri-Columbia, Columbia, MO 65211. (c) Taken in part from White, K. S. M.S. Thesis, University of Illinois, Urbana, IL, 1986.

0002-7863/89/1511-8878$01.50/0

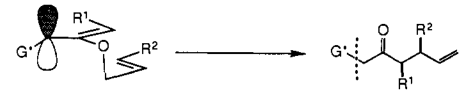
Scheme I



Scheme II



Scheme III



X, which are available (aldehydes,[3a] ketones,[3b,c] acids,[3d] esters,[3e] lactones,[3f] thioesters,[3g] amides,[3h-k] and acid fluorides,[3l] (3) the generally mild conditions, operational ease, and high yields associated with the reaction; (4) the accessibility of the allylic alcohol precursors, and (5) the high stereoselectivity in the formation of double bonds[4] and stereocenters.[5] The great number of synthetic efforts on record which employ a Claisen rearrangement in a key carbon–carbon bond-forming step attest to the power of the reaction. In recent years the Claisen rearrangement has taken on special significance in the construction of more complex systems with a great measure of stereocontrol.[2d] Accordingly, considerable efforts have been directed toward methods for internal,[3j,6] relative,[7] and auxiliary based[8] stereogenesis.[9]

Scheme IV

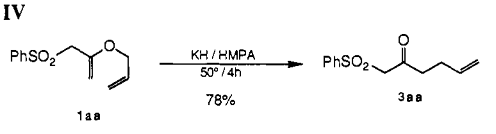


Chart I. General Structures for Starting Materials (1 and 2), Products (3), and R^1, R^2, and R^3 Substituent Patterns

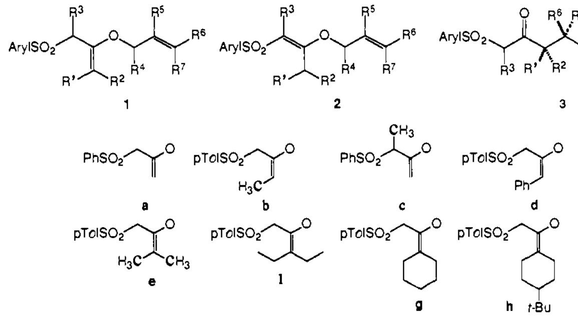
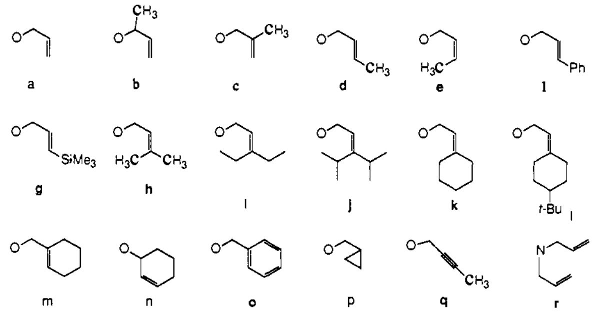


Chart II. R^4, R^5, R^6, and R^7 Substitution Patterns for 1 and 2



No less impressive is the continued interest in understanding the reaction in mechanistic detail through application of experimental[10] and modern theoretical methods.[11] Primarily these studies have addressed the following: (1) the structure of the transition state, (2) the relative extent of bond breaking and bond mixing, and (3) substituent effects on the rate of rearrangement. The crux of the issue is which of the two limiting alternatives, the oxallyl radical/allyl radical pair (i) or the 2-oxacyclohexane-1,4-diyl (ii) (Scheme II), more accurately represents or contributes to the transition-state structure. While there is still some disagreement[11e] the generally accepted picture is an early, reactant-like transition state with considerably more bond breaking than bond making (radical pair i).[10i] Furthermore, the nature of the transition state is dependent on substituents present.[10h] The effects of substituents have been studied in detail[12-14] stimulated

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Table I. Rearrangements of Allyl Vinyl Ethers **1** and **2** Mono- or Unsubstituted at C(1) or C(3)[a]

entry	substrate	aryl	R^1	R^3	R^4	R^5	R^6	temp, °C	time, h	product	yield,[b] %
1	**1ba**	*p*-Tol	CH_3	H	H	H	H	20	1.5	**3ba**	85
2	**1ca**	Ph	H	CH_3	H	H	H	50	1.5	**3ca**	67
3	**1ab**	Ph	H	H	CH_3	H	H	50	0.5	**3ab**	89[c]
4	**1ac**	Ph	H	H	H	CH_3	H	50 (62)	4.5 (2.25)	**3ac**	71
5	**1ad**	Ph	H	H	H	H	CH_3	50	4.5	**3ad**	64[d]
6	**2ad**	Ph	H	H	H	H	CH_3	50	5	**3ad**	54[d]
7	**1da**	*p*-Tol	Ph	H	H	H	H	20	3	**3da**	79
8	**1cb**	Ph	H	CH_3	CH_3	H	H	20	2	**3cb**	52[e]

[a] All reactions of K^+ salts in HMPA/THF (3:1) at 0.1 M. [b] Yield after chromatography. [c] 8% of **4ab** was isolated. [d] Phenylsulfonylacetone was isolated in this run: entry 5, 16%; entry 6, 22%. [e] 7% of **5** was isolated.

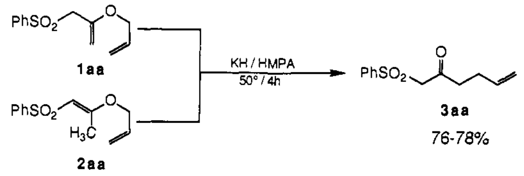
in great measure by the early predictions of Carpenter.[11a] At positions 1, 2, and 4 both donor and acceptor substituents accelerate the reaction with respect to hydrogen. At positions 5 and 6 the effects are complementary. Accelerated rates are found with donors at 6 and acceptors at 5, while decelerated rates are observed when the positions are interchanged. The decelerating effect of a methoxy group has been taken as evidence against significant 1,4-diyl character (ii) in the transition state.

Our interest in the Claisen rearrangement had its genesis in the amalgamation of synthetic and mechanistic considerations. The synthetic versatility of the Claisen rearrangement primarily resides in the variety of the substituents X which determine the carbonyl derivative produced. In addition the nature of this group also influences the rate of rearrangement. Further, in agreement with the notion that a donor group at position 2 should accelerate the reaction, there appeared to be an empirical correlation between π-electron donor ability of X and rate. Thus, our objectives could be formulated in the following question: *what are the preparative, stereochemical, and mechanistic consequences of a carbanionic p-donor at position 2 in the Claisen rearrangement*? Our approach to this enterprise was to first establish what kind of anion stabilizing group G* (Scheme III) would give rise to an anionic rearrangement and then address the three questions posed above for that substituent. The second stage of the study involves the search for and development of other heteroatom assemblies G* with a particular focus on chiral auxiliary-based, anion-stabilizing groups.[15]

The incorporation on an anion would add several new dimensions to the Claisen rearrangement such as insights into the structure and reactivity of heteroatom-stabilized allyl anions[16] and the charge perturbation of pericyclic reactions.[17]

In 1982 we reported the carbanion-accelerated Claisen rearrangement (CACR) of the sulfone **1aa**, Scheme IV.[18] Since then other carbanionic Claisen rearrangements have been reported.[19,20]

Scheme V



We now describe the details of these rearrangements with arylsulfonyl anion-stabilizing groups with respect to (1) the rearrangement conditions, (2) scope and limitations, and (3) stereochemical course of the rearrangement. The following papers in this series will deal with the mechanism of the rearrangement.[21]

Results

1. Anionic Rearrangements. The allyl vinyl ether substrates used in this study were all prepared as described in a recent paper.[22] We have examined a large number of compounds and employed a simplified numbering system to catalog the permutations. The structure of the allyl vinyl ethers and corresponding β-ketosulfone products are uniquely specified by Nxy where N = 1 for β,γ-unsaturated sulfones, N = 2 for α,β-unsaturated sulfones, and N = 3 for β-ketosulfones. The substitution pattern is specified by x = a–h for substituents R^1, R^2, and R^3 (Chart I) and y = a–r for substituents R^4, R^5, R^6, and R^7 (Chart II).

1.1. Allyl Vinyl Ethers 1aa and 2aa (Unsubstituted). As delineated in our preliminary report, treatment of **1aa** with 1.5 equiv of potassium hydride and 1.5 equiv of 18-crown-6 in refluxing THF for 1.5 h afforded the rearrangement product **3aa** in 40% yield along with phenylsulfonylacetone (11%). By changing the solvent to HMPA/THF (3:1) the temperature could be lowered (50 °C) and the yield correspondingly improved (78%). Control experiments (no KH) resulted in a 97% recovery of **1aa** unchanged, proving that anions were responsible for the observed rearrangements. Reaction homogeneity excluded the possibility of surface-catalyzed processes.

The tautomeric α,β-unsaturated sulfone **2aa** reacted under the same conditions as **1aa** to produce **3aa** in 76% yield, Scheme V. The position of the double bond had no effect on the yield or regiochemical outcome of the reaction. This lends further support to the intermediacy of allylic anions as the rearranging species. The facility of γ deprotonation in this system is noteworthy.[23]

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(20) Cooper, D.; Trippett, S. *J. Chem. Soc., Perkin Trans. 1* **1981**, 2127. We have found this report of an anionic Claisen rearrangement to be misinterpreted. Denmark, S. E.; Marlin, J. E.; Dorow, R. L. *Abstracts of Papers*; 191st American Chemical Society Meeting, New York, NY; American Chemical Society: Washington, DC, 1986; ORGN 273.

(21) Denmark, S. E.; Harmata, M. A.; Leung, A. T. K.; Sear, N. L., manuscript in preparation.

(22) Denmark, S. E.; Harmata, M. A.; White, K. S. *J. Org. Chem.* **1987**, *52*, 4031.

(23) γ deprotonation of vinylic sulfones is known, but the method has not been widely used, ref 16.

Table II. Rearrangements of Allyl Vinyl Ethers **1** Disubstituted at C(3)[a]

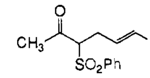
entry	substrate	R^1	R^2	R^4	R^5	R^6	R^7	temp, °C	time, h	product	yield,[b] %
1	**1ea**	Me	Me	H	H	H	H	20[c]	0.25	**3ea**	91
2	**1fa**	Et	Et	H	H	H	H	20 (50)	1 (0.25)	**3fa**	83
3	**1ga**	$(CH_2)_5$		H	H	H	H	20	1.75	**3ga**	85
4	**1eb**	Me	Me	Me	H	H	H	*d*		**3ab**	87
5	**1em**	Me	Me	H	$(CH_2)_4$		H	50	1.25	**3em**	74
6	**1eh**	Me	Me	H	H	Me	Me	50	0.25	**3eh**	98
7	**1ei**	Me	Me	H	H	Et	Et	50	1.5	**3ei**	69
8	**1ek**	Me	Me	H	H	$(CH_2)_5$		50	0.5	**3ek**	82[e]
9	**1ej**	Me	Me	H	H	*i*-Pr	*i*-Pr	50	24	**3ej**	0
10	**1fh**	Et	Et	H	H	Me	Me	50	1.75	**3fk**	64
11	**1fi**	Et	Et	H	H	Et	Et	50	29[f]	**3fi**	38
12	**1gh**	$(CH_2)_5$		H	H	Me	Me	50	0.75	**3gh**	77
13	**1gk**	$(CH_2)_5$		H	H	$(CH_2)_5$		50	1.25	**3gk**	87

[a] All reactions performed with KH (2.5–3.5 equiv) in DMSO at 0.1 M unless otherwise noted. Reactions in entries 5–13 employed the KH/LiCl system. [b] Yield after column chromatography. [c] Reaction in HMPA. [d] **3eb** was formed in the preparation of **1eb**.[18] [e] Only decomposition occurred at higher temperatures. [f] Reaction was not complete.

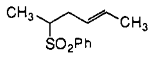
1.2. Monosubstituted Allyl Vinyl Ethers. A large part of this investigation involved a qualitative study of substituent effects on the CACR with respect to rate and yield. Degree of substitution is based on the parent allyl vinyl ethers **1aa** and **2aa**. The results for monosubstituted allyl vinyl ethers are shown in Table I. In general, the reactions were performed with an excess of KH (1.5–2 equiv) in HMPA/THF (3:1) as solvent.

The first five entries in Table I survey the effect of methyl substitution at positions 1–6 on the allyl vinyl ether (see Chart I). The effects of methyl substitution on the rates of reaction were qualitatively similar to those effects observed by Ireland in the ester enolate Claisen rearrangement.[12a] In addition, if one considered methyl groups to be π donors or radical-stabilizing substituents, there is agreement with the predictions made by Carpenter and Gajewski.[13b]

Substrates **1ba** and **1ca** rearranged more rapidly than **1aa** to give good yields of regiohomogeneous products (Table I, entries 1 and 2). Allyl vinyl ether **1ab** with a methyl group at C(4) provided some interesting rearrangement data. As expected, rearrangement was faster than in the unsubstituted case, requiring only 0.5 h at 50 °C (Table I, entry 3). However, in addition to **3ab**, an ca. 3% yield of the "abnormal" regioisomer **4ab** was isolated.



4ab



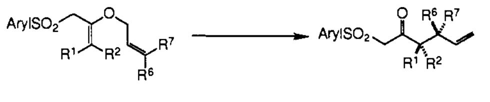
5

This first case of divergence from the normal regiochemical course of the reaction was subsequently shown to be artifactual and the result of thermal rearrangement of starting materials. A discussion of this will appear elsewhere.[21]

Substrates **1ac**, **1ad**, and **2ad**, with methyl substitution at C(5) and C(6) rearranged more slowly than **1aa**. Good yields and regioselectivity were observed throughout. The yield for **3ab** was corrected for the appearance of phenylsulfonylacetone. The appearance of this side product was unique to **1ad** and **2ad** and may derive from a base-promoted E2′ elimination. Substrate **1cb** gave a fair yield of rearrangement product. This may have been due to the presence of α,β-unsaturated isomer in the starting material. In addition an ca. 7% yield of **5** was isolated. This derives from the "anomalous product" already present in the starting material.[21] Finally, **1da**, bearing a phenyl substituent at C(1) (Table I, entry 7) rearranged significantly more rapidly than **1aa**.

1.3. Allyl Vinyl Ethers Disubstituted at C(1). The results for disubstituted allyl vinyl ethers are collected in Table II. These reactions were carried out with potassium dimsylate as base in DMSO. We have discovered the salutary effect of added LiCl when R^6 and/or $R^7 \neq$ H and have used it in these cases. The reasons for the effect will be discussed later. Substrates disubstituted at C(1) rearranged much faster than the unsubstituted **1aa** under similar conditions, again in agreement with Ireland's observations. Entries 1–3 illustrate the generality and extent of the rate enhancement compared to **1aa** as well as a steric deceleration as the bulk of R^1/R^2 increased. Once again high yields of *single regioisomers* were generally obtained. Remarkably, the same regioisomer was formed in all of these reactions despite the creation of quaternary and vicinal quaternary centers (vide infra). Entry 4 illustrates the combined accelerating effect of substitution at C(1) and C(4). In this case, which has been discussed previously,[18] **1eb** was not isolated, but rearrangement occurred during the preparation of **4eb**. With increasing substitution on the allyl unit, entry 5, the rate decreased, but the reaction still proceeded cleanly at 50 °C to give a single regioisomer.

Scheme VI



The ultimate test of substitution compatibility and regiochemical control is illustrated by the rearrangements in entries 6–13. By using the C(1)/C(6) tetrasubstituted allyl vinyl ethers we sought to probe the possibility of using the carbanion-accelerated Claisen rearrangement to create vicinal quaternary centers, Scheme VI.[24] We expected that the anionic charge should not only provide accelerating potential but should also contribute to the exothermicity of the reaction. The result would be a reduction in both the kinetic and thermodynamic barriers to rearrangement. In addition there might exist cases in which thermal rearrangement failed, while that in the carbanionic mode succeeded. The results of this study demonstrated that the aliphatic Claisen rearrangement in both anionic and thermal modes has significant potential for creating vicinal quaternary centers. In all cases, the Claisen products were formed as *single regioisomers* and in very good yield. A moderate rate retardation was noted in changing from methyl to pentamethylene substituents (entries 6–8). This trend continued with ethyl substitution as reaction times increased and yields decreased with increasing ethyl substitution at C(1) and C(6). Unfortunately, isopropyl groups at C(6) (entry 9) proved too bulky for either anionic or thermal (vide infra) rearrangements to proceed. Thermal rearrangements of the neutral allyl vinyl ethers were examined in certain cases for comparison purposes,

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(24) Preliminary studies: (a) Denmark, S. E.; Harmata, M. A. *Tetrahedron Lett.* **1984**, *25*, 1543. For other examples of Claisen rearrangements to vicinal quaternary centers, see: (b) Gilbert, J. C.; Kelly, T. A. *Tetrahedron* **1988**, *44*, 7587. (c) Ziegler, F. E.; Nangia, A.; Schulte, G. *J. Am. Chem. Soc.* **1987**, *109*, 3987. (d) Van Middlesworth, F. L. *J. Org. Chem.* **1986**, *51*, 5019. (e) Kraus, G. A.; Thomas, P. J. *Ibid.* **1986**, *51*, 503. (f) Ponaras, A. A. *Ibid.* **1983**, *48*, 3866. (g) Nakamura, E.; Fukuzaki, K.; Kuwajima, I. *J. Chem. Soc., Chem. Commun.* **1983**, 499. (h) Suda, M. *Tetrahedron Lett.* **1982**, *23*, 427.

Table III. Comparison of Thermal and Anionic Rearrangements of Selected Tetrasubstituted Allyl Vinyl Ethers[a]

entry	substrate	R^1	R^2	R^6	R^7	conditions[b]	temp, °C	time, h	product	yield,[c] %
1	**1ei**	Me	Me	Et	Et	A	50	1.5	**3ei**	68
2	**1ei**	Me	Me	Et	Et	T	135	1.5	**3ei**	56
3	**1fh**	Et	Et	Me	Me	A	50	1.75	**3fh**	64
4	**1fh**	Et	Et	Me	Me	T	135	1.5	**3fh**	77
5	**1fi**	Et	Et	Et	Et	A	50	29	**3fi**	38
6	**1fi**	Et	Et	Et	Et	T	135	6	**3fi**	0
7	**1gk**	$(CH_2)_5$		$(CH_2)_5$		A	50	1.25	**3gk**	87
8	**1gk**	$(CH_2)_5$		$(CH_2)_5$		T	135	1.5	**3gk**	100

[a] All reactions in DMSO at ca. 0.1 M. [b] A = anionic reactions using KH (2.5–3.3 equiv) and LiCl (12–16 equiv); T = thermal reaction. [c] Yield after chromatography.

Scheme VII

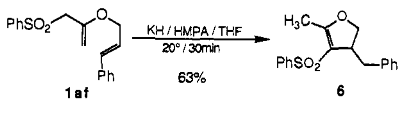


Chart III. Unsuccessful Rearrangement Precursors

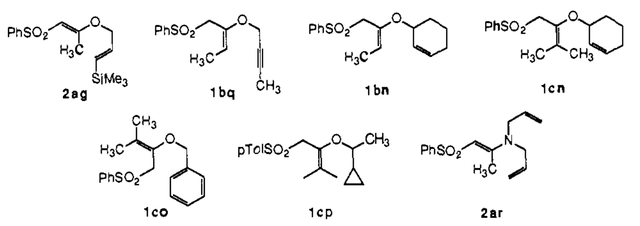
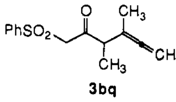


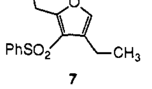
Table III. In all cases the anionic rearrangement proceeded at considerably lower temperature. The case of **1fi** (entries 5 and 6) is the most interesting since it illustrates the advantage of the anionic rearrangement. Thermolysis of **1fi** led only to decomposition.

1.4. Unsuccessful Rearrangements. As part of our survey of the scope of this reaction we discovered a number of structural limitations to the CACR. Upon treatment with KH in HMPA/THF, allyl vinyl ether **1af** gave only the dihydrofuran **6** (Scheme VII). The structure of this compound was easily established by ^{1}H NMR. Each of the ring protons as well as the benzylic protons occurred as five distinct multiplets; four of which were sharp and easy to analyze when benzene-d_6 was used as solvent. This product clearly arose from anionic cyclization at the β-terminus of the styryl unit.

The remaining rearrangements were unsuccessful due to low conversions or lack of reactivity. Those substrates are collected in Chart III. The C(6) silylated substrate **2ag** gave only decomposition upon exposure to KH in HMPA. The reasons for this are not clear but may be related to the formation of **6** from **1af**. Propargylic vinyl ether **1bq** also gave poor results on attempted rearrangement. Only a very low yield of Claisen rearrangement product **3bq** could be isolated along with a furan **7**. The latter product probably arose via a mechanism similar to that leading to **6**.



3bq



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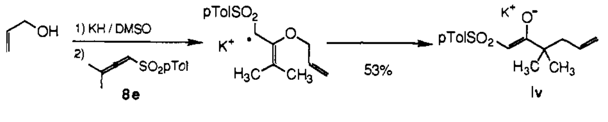
Structures **1bn** and **1cn** represent our attempts to study allyl vinyl ethers derived from cyclohexenol. It was our intention to use **1bn** to examine the boat-chair stereochemical question which arises when cyclic allyl alcohols are used in the Claisen rearrangement. However, only small amounts of rearrangement products were observed. Similarly, **1cn** gave no rearrangement product at all. Apparently, the energy required to attain the proper geometry for the Claisen rearrangement was so high as to preclude rearrangement under conditions in which the allylic anion was stable. The barrier associated with the anionic aromatic Claisen rearrangement of **1co** was apparently of sufficient energy to prevent rearrangement under usual reaction conditions. An attempt to perform a carbanion accelerated homo-Claisen rearrangement[25] using substrate **1cp** resulted only in the recovery of starting material. Finally, it was known from the work of Stirling that secondary amines reacted with allenic sulfones to produce enamines.[26] We thought that carbanion acceleration of an amino-Claisen rearrangement would be an interesting and useful process, since they are known to be more difficult than their oxygen analogues. Upon exposure to base (KH/HMPA) **2ar** tautomerized from a diallyl amine to a bis 1-propenyl amine.

Scheme VIII



1.5. One-Pot Addition Rearrangements. From the outset of our studies we realized the potential for streamlining the procedure for the CACR to increase its synthetic utility. In particular, we sought to bypass the formation and isolation of the allyl vinyl ethers by carrying out the rearrangement in a one-pot procedure. Combination of a sulfonylallene with a metal allyloxide should give the same allyl anion intermediate capable of rearrangement, Scheme VIII.

Experiments performed in pursuit of this goal were not promising. The reactions were conducted by the slow addition of a solution of allene **8c** to a solution of metal allyloxide in THF, HMPA, or DMSO. Allene **8c** was chosen because of the facility with which **1ca** underwent the CACR. None of the reactions in this study were clean either macroscopically or by TLC, with many unidentified side products being formed. Counterion and solvent changes did not seem to have any dramatic effect on the outcome of the reaction. Higher temperatures (ca. 50 °C) were detrimental, and temperatures below 25 °C were not investigated. In the best possible case (DMSO, KH, 25 °C) a 53% yield of the rearrangement product **3ca** could be isolated after chromatography. However, on scaling up this reaction the yield dropped to 38%.

The problems with this protocol most probably arose from competition between allyloxide and other anionic species (formed from allyloxide and allene) for added allene. The result was a plethora of products from which only fair to poor yields of the desired adduct could be isolated. The success of similar efforts by Blechert is probably due to the facility of cleavage of the N–O bond.[19e]

2. Stereochemistry. 2.1. Internal Asymmetric Induction. The thermal rearrangement of allyl vinyl ethers monosubstituted at both C(1) and C(6) is highly diastereoselective.[3j,6] This feature is a hallmark of all [3,3]-sigmatropic rearrangements and is

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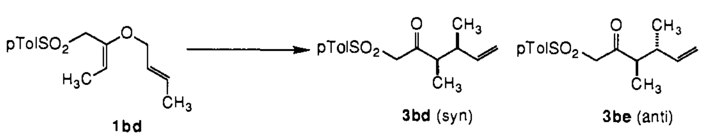
(25) Replacement of a double bond with a cyclopropyl ring is known in the Diels–Alder reaction but not in sigmatropic rearrangements. Herges, R.; Ugi, I. *Chem. Ber.* **1986**, *119*, 829.

(26) Stirling, C. J. M. *J. Chem. Soc.* **1964**, 5863.

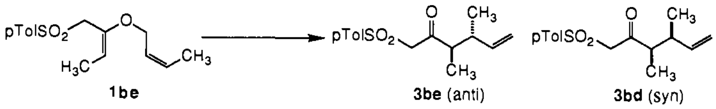
Table IV. Carbanionic Claisen Rearrangement of **1bd**[a]



entry	base (equiv)[b]	solvent	temp, °C	time, h	**3bd**/**3be**[c]	**9bd**/**9be**[d]	yield,[e] %
1	none	DMSO	100	4	96:4	92:8	97
2	KH (2.2)	DMSO	20[f]	4	93:7	91:9	79[g]
3	KH (2.2)	THF	20	24	89:11	88:12	78
4	KH (2.2)	HMPA	20	2	64:36	64:36	83
5	NaH (2.2)	DMSO	20[f]	4	98:2		85
6	NaH (2.2)	DMSO	50	0.25	98:2	97:3	93
7	NaHMDSi (1.0)	DMSO	20	5	78:22	76:24	29
8	*n*-BuLi (2.5)	DMSO	20[f]	4	89:11	89:11	87
9	KH (2.2)/LiCl (4.2)	DMSO	20[f]	4	97:3		73

[a] Reactions were run at 0.09–0.12 M. [b] Dimsylate solutions were prepared by literature procedures.[29] [c] HPLC analysis. [d] Capillary GC analysis. [e] Yield after chromatography. [f] Reaction was warmed to 50 °C for 2–5 min to assure complete conversion. [g] 13% of **10** was isolated.

Table V. Carbanionic Claisen Rearrangement of **1be**[a]



entry	base (equiv)[b]	solvent	temp, °C	time, h	**3be**/**3bd**[c]	yield,[d] %
1	none	DMSO	100	8	96:4	89
2	KH (2.1)	DMSO	20	6.75	86:14	7[e]
3	KH (1.9)	THF	20	23	93:7[f]	31[e]
4	NaH (2.2)	DMSO	50	3	94:6	64[e]
5	NaHMDSi (1.0)	DMSO	20	5	84:16	6
6	KH (2.6)/LiCl (15)	DMSO	50	1.5	95:5	85

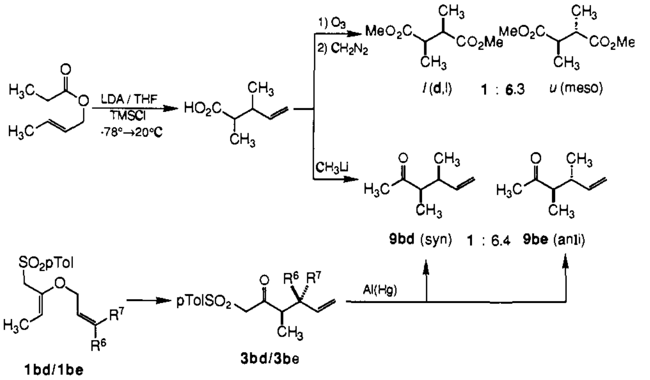
[a–c] See footnotes Table V. [d] Yield after column chromatography. [e] **10** was isolated in this run: entry 2, 65%; entry 3, 28%; entry 4, 24%. [f] Ratio of **9be**/**9bd** after desulfonylation 91:9 (GC).

characteristic of the variants of the Claisen rearrangement. If the CACR is to be of synthetic value it also must be highly diastereoselective. We therefore investigated the rearrangement of compounds **1bd** and **1be** and studied their stereochemical outcome with regard to solvent, counterion, and temperature variation.[27]

The configuration of the products was established as shown in Scheme IX. Rearrangement of crotyl propionate according to the method of Ireland[12a] produced the 2,3-dimethyl-4-pentenoic acids which were ozonized and converted to a mixture of dimethyl 2,3-dimethylsuccinates with diazomethane. This mixture was compared by GC analysis with commercially available samples of *meso*- and *d*,*l*-dimethyl-2,3-dimethylsuccinates. The ratio of meso (anti) to *d*,*l* (syn) was 6.3:1. Reaction of the acids with methyllithium produced the diastereomeric 3,4-dimethyl-5-hexen-2-ones (**9bd**/**9bc**) in a ratio of 6.4:1, as determined by capillary GC analysis. Assuming no change in the configurations of the stereocenters during the course of both reactions, the configurations of the ketones could be assigned: anti for the major component (**9be**) and syn for the minor (**9bd**). The CACR rearrangement products **3bd**/**3be** were desulfonylated by treatment with Al(Hg) in THF/HOAc/H_2O.[28] Spectroscopic and gas chromatographic comparison of these methyl ketones with the ketones prepared in Scheme VIII allowed stereochemical assignment of the rearrangement products. Further, comparison of the GC ratios obtained after desulfonylation, with HPLC ratios of the product ketosulfones **3bd** and **3be** allowed assignment of the diastereomeric ratios directly by HPLC analysis, making desulfonylation and GC analysis unnecessary.

The allyl vinyl ether derived from *trans*-crotyl alcohol (>99% *E*) **1bd** was examined first, Table IV. Thermal rearrangement showed diastereoselection that was comparable to Claisen rearrangements. The carbanionic version, while decidedly faster, also was slightly more stereoselective than the thermal version (compare entries 1 and 6). Counterion effects were not dramatic, although under comparable conditions the trend in selectivity $Li^+ \sim Na^+ > K^+$ was discernable (compare entries 2, 5, and 9). Only with the latter cation in DMSO was an appreciable amount of 1-(*p*-tolylsulfonyl)-2-butanone (**10**) (entry 3) isolated. Use of divalent cations (Mg^{2+}, Zn^{2+}) essentially suppressed the rearrangement. The effects of solvent and temperature on stereoselectivity were briefly examined. Neither THF nor HMPA improved the selectivity in rearrangement of K^+ **1bd**$^-$ (entries 2–4). For optimal yield and diastereoselectivity we found that short reaction times at slightly elevated temperatures gave the best results (entry 6). We were pleased to find that HMPA could be replaced by DMSO.

Scheme IX



The allyl vinyl ether derived from *cis*-crotyl alcohol (>99% *Z*) **1be** was more problematic, Table V. Thermal rearrangement proceeded cleanly at about half the rate of **1bd** but with comparable selectivity, in this case favoring the anti isomer, **3be**. In contrast to **1bd** the success of anionic rearrangement of **1be** was highly dependent upon counterion. Reactions with either po-

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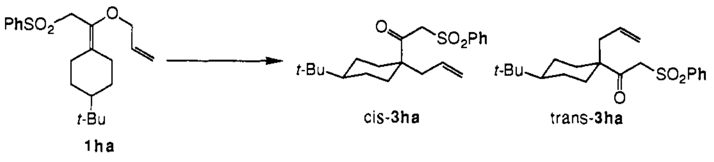
(27) Preliminary report: Denmark, S. E.; Harmata, M. A. *J. Org. Chem.* **1983**, *48*, 3369.

(28) Johnson, C. R.; Kirchoff, R. A. *J. Am. Chem. Soc.* **1979**, *101*, 3602.

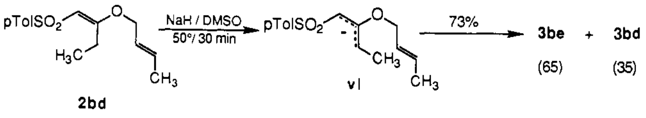
Table VI. Carbanionic Claisen Rearrangement of **1ha**[a]



entry	base (equiv)	solvent	temp, °C	time, h	*cis*/*trans*-**3ha**	yield,[b] %
1	none	DMSO	100	3	66:34	93
2	KH (2.9)	DMSO	25 (50)	2.5 (0.5)	36:64	66
3	KH (3.5)	DMSO	50	0.5	41:59	80
4	KH (4.2)	THF	25	24	37:63	82
5	NaH (3.3)	DMSO	50	0.75	39:61	66
6	KH (4.4)/LiCl (16)	DMSO	50	0.5	45:55	86

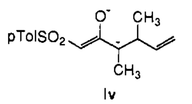
[a] Reactions runs at 0.1 M. [b] Yield after chromatography.

Scheme X

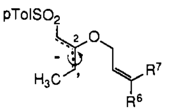


tassium or sodium dimsylate were plagued by the production of 1-(*p*-tolylsulfonyl)-2-butanone (**10**) in significant quantities. This side reaction could be completely suppressed by adding excess LiCl to the K$^+$DMSO$^-$ solution. This recipe gave cleaner reactions than the use of *n*-BuLi to generate Li$^+$DMSO$^-$.[29c] Under optimal conditions this rearrangement proceeded ca. 12-fold more slowly than **1bd**.

The highly selective and complementary thermal rearrangements of **1bd** and **1be** were to be expected based on a wealth of literature precedent. However, the anionic process offers other opportunities for erosion of stereoselectivity. We anticipated two pitfalls: (1) a trivial, ex post facto epimerization of the product via dianion **iv** and (2) rotational isomeration about the C(1)–C(2) bond in the allyl anion **v**. The production of both **3bd** and **3be** with high selectivity imply that species **iv** is not accessible in DMSO even in the presence of excess base.[30] The low selectivity observed with KH/HMPA (entry 4, Table IV) may well be due to the existence of **iv** in this solvent. Furthermore, the high selectivities also imply that either (1) the barrier to C(1)–C(2) bond rotation is very high or (2) the *E* geometry as shown is thermodynamically preferred.



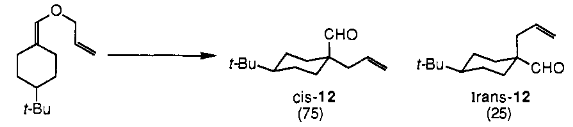
iv



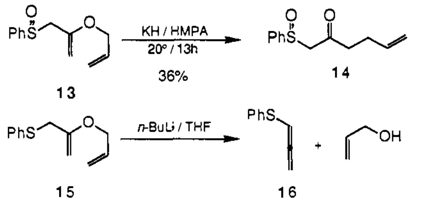
v

The relative rate of rearrangement versus C(1)–C(2) bond rotation in the anion was probed experimentally. We have previously shown that for the CACR the allyl anions may be generated from either β,γ-**1** or α,β-**2** unsaturated sulfones with no impact on regiochemistry (Scheme IV). However, we anticipated that the *geometrical composition* of a substituted anion would depend on the structure of the enol ether. Thus deprotonation of **2bd**,[31] prepared by base-catalyzed isomerization of **1bd**, should lead to the (*Z*)-allyl anion **vi** to avoid van der Waals interactions between the ethyl and the *p*-toluenesulfonyl groups, Scheme X. Rearrangement via **vi** should then lead to **3be**. In fact the product mixture indeed favored **3be** (anti) (65:35), strongly suggesting the conformational stability of the allylic anions **v** and **vi** about the C(1)–C(2) bond.[32] This behavior is also seen in CACR's with phosphonates[33] and phosphonamidates.[15b]

Scheme XI



Scheme XII



2.2. Axial–Equatorial Preference. As part of our studies in the use of the CACR to create quaternary centers a stereochemical issue arose with regard to axial versus equatorial preference in sterically unbiased cyclohexylidenes. This question has been examined previously in other variants of the Claisen rearrangement, and the results range from moderate to striking in selectivity.[34] The original study by House[34a] employed allyl vinyl ether **11** (Scheme XI). Thermal rearrangement resulted in a 3:1 mixture of aldehydes in which the major component arose from equatorial attack of the allyl side chain. Thermolysis of **1ha** produced a 2:1 mixture of rearrangement products, Table VI. The major product was assigned by analogy to the results of House, i.e., with equatorially disposed allyl group. The anionic rearrangements of **1ha** were at best only weakly selective (ca. 2:1) but interestingly in the opposite sense, i.e., the trans product derived from axial attachment of the allyl group was favored.

3. Other Stabilizing Groups. In an effort to broaden the scope of the reaction and to determine if a relationship exists between anion pK_a and reaction rate, an investigation of several other carbanion stabilizing groups was undertaken. This study served to set limits on the types of structures which could be successfully employed in the carbanion-accelerated Claisen rearrangement.

3.1. Sulfoxide and Sulfide. This portion of our studies focused on sulfur-based anion stabilizing groups in various oxidation states and with various substituents. The phenylsulfinyl (**13**) and phenylsulfenyl (**14**) groups were examined first, Scheme XII. Since these groups are less effective at stabilizing an adjacent anion,[35] we anticipated rearrangements faster than **1aa**. This was

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(29) (a) Corey, E. J.; Chaykovsky, M. *J. Am. Chem. Soc.* **1965**, *87*, 1345. (b) Brown, C. A. *Ibid.* **1973**, *95*, 982. (c) Chaykovsky, M. *J. Org. Chem.* **1975**, *40*, 145.

(30) Control experiments with the related ketophosphonates showed that no epimerization of the α-stereocenter occurred with excess Li$^+$DMSO$^-$, ref 15b.

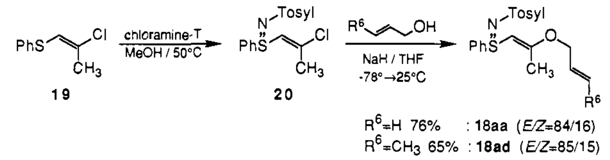
(31) The *E* configuration of **2bd** is based on the ^{1}H NMR chemical shift of H–C(1) and by analogy to a phosphonate which has been established by X-ray crystallography, ref 15b.

(32) The barrier to rotation about this bond in lithio phenyl allyl sulfone has been estimated to be >19.5 kcal/mol. Gais, H.-J.; Volhardt, J.; Lindner, H. J. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 932.

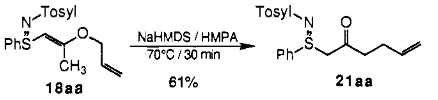
(33) Marlin, J. E. Ph.D. Thesis, University of Illinois, Urbana, IL, 1987.

(34) (a) House, H. O.; Lubinkowski, J.; Good, J. J. *J. Org. Chem.* **1975**, *40*, 86. (b) Ireland, R. E.; Varney, M. D. *Ibid.* **1983**, *48*, 1829. (c) Fraser-Reid, B.; Tulshian, D. B.; Lowe, D.; Tsang, R.; Box, V. G. B. *Tetrahedron Lett.* **1984**, *25*, 4579.

Scheme XIII

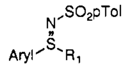


Scheme XIV



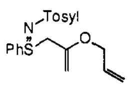
indeed the case with sulfoxide **13** which rearranged at 20 °C with KH/HMPA, albeit in low yield. The allyl sulfide **15** underwent a β-elimination to allene **16** upon treatment with *n*-BuLi. KH/HMPA only isomerized **15** to its α,β-unsaturated tautomer. Attempts at reductive cleavage of the allyl sulfide moiety to generate an allyl anion[36] were also unsuccessful. Thus it was clear that we needed to examine a group with a pK_a closer to that of sulfones.

3.2. Sulfilimines. The sulfilimine functional group is the nitrogen analogue of the sulfoxide. The rich chemistry of this group has been thoroughly reviewed.[37] For our purposes in this investigation, the *N*-tosyl aryl sulfilimine was pursued for two

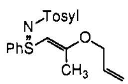


reasons: (1) ease of synthesis and (2) pK_a similarity to analogous sulfones. The synthesis of *N*-tosyl sulfilimines generally involves the treatment of a sulfide with Chloramine-T (Mann–Pope reaction) in methanol or under phase-transfer conditions.[38] The pK_a of sulfilimines with protons adjacent to the sulfilimine function is highly dependent on the nature of the nitrogen ligand. The pK_a of *S*-phenyl-*S*-methyl-*N*-tosyl sulfilimine (27.7) is only 1.3 units lower than that of phenyl methyl sulfone.[39] In addition to the ease of synthesis and acidifying effects of the sulfilimine function, we recognized the chirality of the sulfur atom as a potential stereocontrolling element in the CACR.

3.2.1. Synthesis of Sulfilimines. From literature sources it was clear that allylic sulfilimine **17aa** would undergo a [2,3]-sigmatropic rearrangement with the equilibrium strongly favoring the formation of the sulfenamide.[37] Thus, **18aa** became the target



17aa

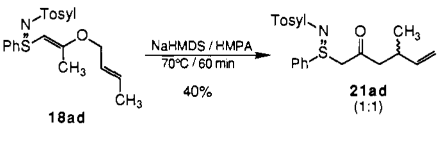


18aa

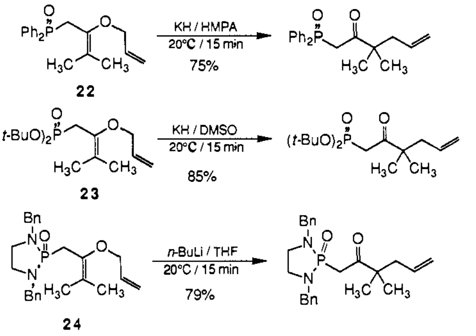
based on the assumption that, as with α,β-unsaturated sulfones, γ deprotonation would be facile. Treatment of sulfide **19** with Chloramine-T in methanol[38a] at 50 °C for 2 h afforded sulfilimine **20** as a thick oil in, at best, 35% yield, Scheme XIII.

Reaction of **20** with solutions of metal allyloxides produced the desired allyl vinyl ethers **18** in good yields as separable mixtures of *E* and *Z* isomers. A small amount of optimization indicated that very low temperature, THF as solvent, and NaH as base produced the highest yield of product. In these cases the *Z* isomer **18** was not isolated. By using the optimal conditions the allyl vinyl ethers derived from allyl alcohol (*E*/*Z*-**18aa**) and *trans*-crotyl alcohol (*E*/*Z*-**18ad**) were prepared.

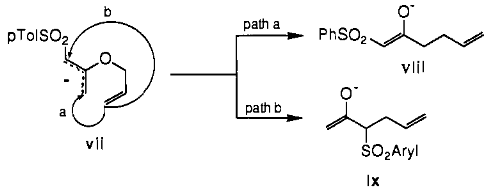
Scheme XV



Scheme XVI



Scheme XVII



3.2.2. Rearrangement of 18aa and 18ad. A study of the rearrangement of **18aa** indicated that the reaction was feasible but not nearly as straightforward as for the sulfone **2aa**. In each case the rearrangement was highly regioselective, supporting the intermediacy of allyl anions in the reaction. Yields varied dramatically with reaction conditions. Lower temperatures and longer reaction times resulted in decreased yields of product, and DMSO was clearly inferior to HMPA. The best conditions for rearrangement were treatment of **18aa** with excess NaHMDS in HMPA followed by heating at 70 °C for 30 min, Scheme XIV. This gave rearrangement product **21aa** in 61% yield.

Substrate **18ad** represented a case in which diastereoselection between C(5) and the chiral-stabilizing group is possible. In the event, treatment of (*E*)- or (*Z*)-**18ad** with excess NaHMDS in HMPA at 70 °C for 1 h resulted in the formation of a regiohomogeneous inseparable mixture of diastereomers in 42% and 36% yield, respectively, in a 1:1 ratio (^{1}H NMR[40]), Scheme XV.

The next logical member of this series is the well-known sulfoximine function.[41] Unfortunately, despite extensive efforts, the requisite allyl vinyl ether precursors could never be prepared.

At this point our search for alternative, chiral sulfur-based anion-stabilizing groups for the CACR was curtailed when concurrent investigations revealed exciting potential for phosphorus-based anion-stabilizing groups. We have now extensively examined phosphine oxides[33] (**22**), phosphonates[33] (**23**), and phosphondiamides (**24**)[42] as well as optically active phosphonamidates,[15a] Scheme XVI. These studies will be elaborated in forthcoming reports.

Discussion

The demonstration that an arylsulfonylmethide unit at position 2 in an allyl vinyl ether accelerates the Claisen rearrangement supports the predictions by Carpenter[11a] and validates our more empirical expectations based on heteroatom donor groups. The extent of acceleration (ca. 300-fold)[21] is somewhat less than anticipated and may be related to the significant stabilizing effect of the sulfone. Indeed, Büchi has shown that carboxylate dianions

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(35) Bordwell, F. G. *Acc. Chem. Res.* **1988**, *21*, 456.

(36) (a) Cohen, T.; Daniewski, W. M.; Weisenfeld, R. B. *Tetrahedron Lett.* **1978**, 4665. (b) Ager, D. J. *Ibid.* **1981**, 2923.

(37) (a) Gilchrist, T. L.; Moody, C. J. *Chem. Rev.* **1977**, *77*, 409. (b) Johnson, C. R. In *Comprehensive Organic Chemistry*; Jones, N. D., Ed.; Pergamon: Oxford, 1979; Vol. 3, Chapter 11.10.

(38) (a) Tsujihara, K.; Furukawa, N.; Oae, K.; Oae, S. *Bull. Soc. Chem. Jpn.* **1969**, *42*, 2631. (b) Johnson, C. R.; Mori, K.; Nakanishi, A. *J. Org. Chem.* **1979**, *44*, 2065.

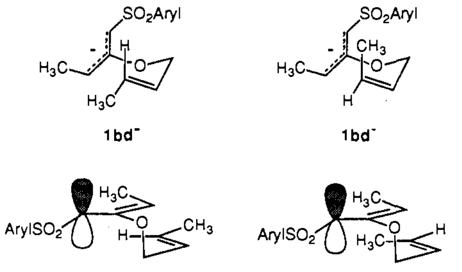
(39) Reference 37b, p 224.

(40) The methyl doublets for each diastereomer were of equal intensity.

(41) (a) Johnson, C. R. *Acc. Chem. Res.* **1973**, *6*, 341. (b) Johnson, C. R. *Aldrich. Acta* **1985**, *18*, 3.

(42) Denmark, S. E.; Stadler, H., manuscript in preparation.

Scheme XVIII



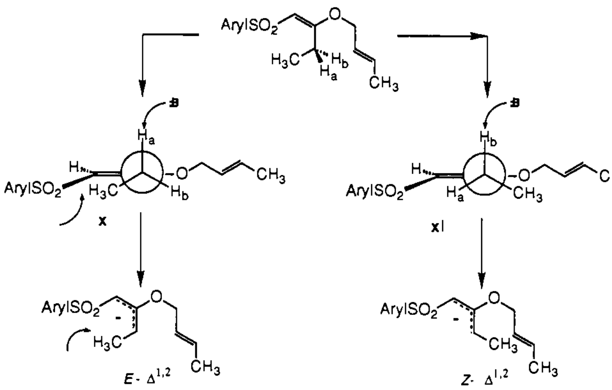
at position 2 require 120 °C for rearrangement. Our own studies with carboethoxy-, cyano-, and cyanohydrin-stabilizing groups were not successful.

One of the most striking aspects of the CACR is the regioselectivity. Because of the ambident nature of the allyl anion and unlike the thermal rearrangement two regioisomers are a priori possible. In none of the cases studied with any pattern of substitution (where we were certain that anionic rearrangements were occurring) did we detect any of the anomalous regioisomer, Scheme XVII. We can understand this behavior by comparison of the relative stabilities of the primary products of rearrangement, anions viii (path a) and ix (path b). By comparison of the pK_a values (in DMSO)[35] for acetone (26.5) and phenylsulfonylacetone (12.5) there is a 21 kcal/mol advantage (50 °C) for rearrangement to a β-ketosulfone anion compared to a ketone enolate. Given the current view that Claisen rearrangements, in particular accelerated variants, have early transition states with advanced bond breaking[10i] this "product-side" argument seems inappropriate. Nevertheless, only a small fraction (ca. 15%) of stability difference in the products need be present in the transition state to produce the regioselectivity observed. The persistently high regioselectivity in case of extreme steric hindrance (Table III) suggests that a more significant fraction of the stability difference is present in the transition state. An alternative explanation is based on cation complexation at the α-carbon which provides a hindrance to approach. This is unlikely in view of the recent demonstration that even lithium is not within bonding distance of the "carbanion" in the solid state.[16b] It would appear less likely for potassium in HMPA or DMSO. The isolation of **4ab** has been shown to be an artifact of the precursor synthesis and does not arise from anionic rearrangement.[20,21]

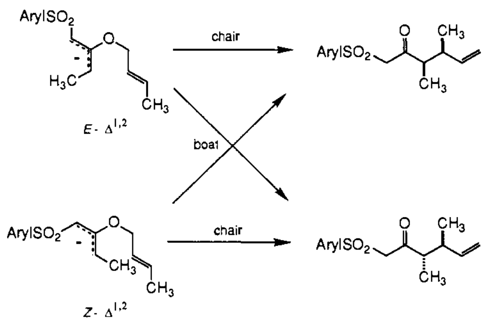
The effects of substitution on rate are noteworthy. Alkyl groups at positions 1 (**1ba**, **1ea**), 1′ (**1ca**), and 4 (**1ab**) accelerate, and the effects are cumulative. These results are in agreement with the conclusions of Coates and Curran[13a] assuming alkyl groups are donors compared to hydrogen.[43] Moreover, the CACR has an additional feature which may amplify the donor effects at C(1) and C(1′). Donor groups will destabilize the starting anion,[43] vii, but will have no effect on the stability of the product anion viii. Thus, this excess energy translates to a faster reaction because the transition state is not as destabilized. This hypothesis also finds support in the effect of a phenyl group at position 1 (**1cb**). This substrate rearranged faster than **1aa** ($R^1 = H$) but slower than **1ba** ($R^1 = CH_3$). A conjugating substituent at C(1) should accelerate the reaction, but, now in the anion, the phenyl stabilizes the ground state. These effects partially cancel resulting in an intermediate effect. Alkyl substituents at positions 5 (**1ac**, **1em**) and 6 (**1ad**, **1eh**) decelerate the rearrangement. While the former agrees, the latter results are at variance with the Coates/Curran study. However, the acceleration they observed due to a methoxy group at C(6) has been ascribed to a "vinylogous anomeric effect"[44] due to the nonbonding electron pairs on oxygen. While a highly attenuated version of this effect may be operative in our substrates, the steric effects of the alkyls surely dominate.

The limitations on this method are for the most part related to incompatibilities with the presence of anionic intermediates. Styryl double bonds, allenes, and vinylsilanes either as precursors or products undergo secondary reactions with the educt or product anions.

Scheme XIX



Scheme XX



The high diastereoselectivity observed in CACR of **1bd** and **1be** is of both preparative and mechanistic significance. The high selectivity of the thermal processes was expected,[5] but there was no precedent for a stereocontrolled anionic rearrangement.[45] The similarity of stereochemical outcomes suggests that the reactive conformations are not too dissimilar in the anionic and thermal modes. Thus we consider the classic chair-like transition states for **1bd**$^-$ and **1ba**$^-$, Scheme XVIII. The lack of a significant counterion effect on stereoselectivity or rate supports our notion of solvent-separated ion pairs as the reactive species. Further information about the transition state is forthcoming from comparison of the relative rates of rearrangement of **1bd** and **1be**. Thermally, **1bd** rearranged twice as fast as **1be** as expected due to the syn–diaxial interactions of the C(6) methyl group with the sulfonylmethylene substituent. Anionically the rearrangement proceeded 12 times faster (Na^+ salt) suggesting that the sulfonylmethyl is effectively larger due to the association with cation and solvent.

Mechanistically, the highly selective anionic rearrangements implied a high barrier to alkyl anion stereomutation relative to rearrangement. A lower limit of 20 kcal/mol on the barrier to rotation about the C(2)/C(3) bond in lithio allyl phenyl sulfone[32] has been reported by Gais by using VT ^{1}H NMR methods. By virtue of the highly selective synthesis of (*E*)-**1bd** the configuration of the resulting anion is assured. The corresponding *Z* isomer is not directly accessible by addition to allenes.[22] However, we were able to generate some of the *Z* anion by deprotonation of **2bd**. Scheme XIX shows Newman projections for the deprotonation transition states. Deprotonation of H_a via conformation x engenders nonbonding interactions as the allylic carbon rehybridizes to form the *E* $\Delta^{1,2}$ anion. However, deprotonation of H_b via conformation xi experiences no such interaction and should lead preferentially to the *Z* $\Delta^{1,2}$ anion. The observed preponderance in the anti product **3be** (65:35) supports this hypothesis

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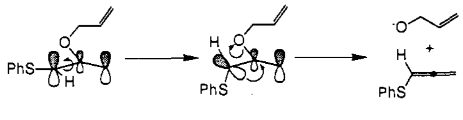
[43] Bordwell, F. G.; Bartmess, J. E.; Hautula, J. A. *J. Org. Chem.* **1978**, *43*, 3095.

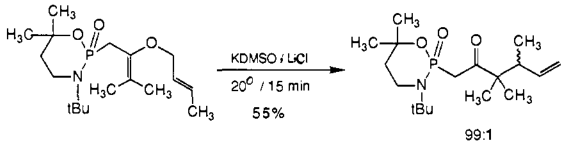
[44] Denmark, S. E.; Dappen, M. S. *J. Org. Chem.* **1984**, *49*, 798.

[45] In Evans' anionic oxy-Cope rearrangements the anion is not an integral part of the rearrangement network: Evans, D. E.; Golob, A. M. *J. Am. Chem. Soc.* **1975**, *97*, 4765.

Scheme XXI



Scheme XXII



as well as the contention that rotation about the alkyl anion bond is slow, Scheme XX. We believe that the reduced selectivity derives from imperfect control in deprotonation followed by highly selective rearrangements of the anions in the mixture.[46] In CACR's with phosphorus-stabilized anions we have observed similar inversions in selectivity with different groups under different conditions.

The change in axial/equatorial preference for **1al** in thermal and anionic rearrangements is interesting but unfortunately of too small a magnitude to be of synthetic value. A possible explanation for this reversal could be the preference of the metal ion for the more accessible equatorial face of the allyl anion with rearrangement then occurring to the axial side (anti S_E2').[15a]

The success and generality of the CACR with sulfones (pK_a ca. 23) was unfortunately not shared by other sulfur-based anion-stabilizing groups. On the basis of pK_a considerations[35] we expected and observed a faster rearrangement with sulfoxide **13** (pK_a ca. 27) although the poor yield (36%) suggested competing, elimination pathways. In the sulfide **15** (pK_a ca. 31) isolation of allene **16** verified the preference for elimination versus rearrangement. Although this outcome is understandable, it is surprising as well. As the allyl anion decreases in stability (i.e., with poorer anion-stabilizing groups), the thermodynamic advantage of elimination increases. For elimination to occur the allyl anion must rotate 90° to align the orbitals for allene formation, Scheme XXI. This is obviously the orthogonal minimum for allyl anion stabilization. In this regard, the recently reported X-ray crystal structure of lithio 2-butenyl *tert*-butyl sulfide is informative.[47] The lithium is clearly η^3 bonded, but the double bond is of normal length acting only as a ligand for lithium. Thus, conjugation appears to be absent, and the rotational barrier about the C(1)–C(2) bond may be low.

The failure of these substrates defined a narrow window of pK_a's for successful rearrangements in the range 22–27. The pK_a of an allyl *N*-tosyl sulfilimine is estimated to be ca. 22.[48] It was thus not surprising that **18aa** required heating to 70 °C as its sodium salt to rearrange. The slower rate of rearrangement of **18ad** was also expected based on substituent effects. However, we were more concerned about the complete lack of diastereoinduction in the creation of the new center based on the stereogenic sulfur group. Whether this was due to a lack of intrinsic face selectivity in the transition state or facile inversion of the sulfur atom is not known.[49] In contrast the high diastereoinduction observed with oxazaphosphorinanes, Scheme XXII, discouraged further efforts with sulfur.[33]

It should be stressed that pK_a alone cannot be the basis for predicting the success of a given anion-stabilizing group in the CACR. For example, in DMSO, ethyl phenylacetate (22.6) and benzyl phenyl sulfone (22.3) have nearly identical pK_a's, but the sulfonylmethide rearranges readily (~50 °C) while the ester enolate does not (>135 °C). Furthermore, benzyl phenyl sulfoxide (27.2) and diethylbenzylphosphonate (27.6) have very similar pK_a's, yet under similar conditions a 2-phosphonylmethyl allyl vinyl ether rearranges much faster and more cleanly than **13** (cf. Schemes XII and XVI). Clearly the structure and charge distribution in the heteroatom-stabilized allyl anion is playing a significant role in rate acceleration as well as stereoselectivity.

Conclusions. This study has established the feasibility and laid the groundwork for carbanionic-accelerated Claisen rearrangements. The arylsulfonylmethylene substituent is well suited for this role based on ease of incorporation, accelerating potential, and synthetic opportunities available to the products. By using this substituent we have demonstrated the scope and limitations of the reaction. The reaction is conveniently performed in DMSO with KH or NaH as the base. The salutary effect of added LiCl was demonstrated in some cases. A broad range of substitution patterns is tolerated including tetrasubstituted reaction termini. The rearrangement is completely regioselective and highly stereoselective. The arylsulfonyl group was found to be unique among sulfur-based groups examined in the ability to promote rearrangement. Our current efforts are focused on the elucidation of allyl anion structure and the application of the charge acceleration concept to other pericyclic processes.

Experimental Section

1. General Methods. See Supplementary Material. Alkyllithiums were titrated by the method of Gilman.[50] Dry solvents were distilled freshly prior to use: THF, Et_2O, DME (sodium/benzophenone), benzene, acetonitrile, TMEDA, CH_2Cl_2 (CaH_2). DMSO, HMPA, and pyridine was distilled from CaH_2 and stored over activated 4 Å sieves. All other reagents were distilled or recrystallized as necessary. All air- and moisture-sensitive reactions were performed in oven (140 °C) or flame-dried glassware under an inert atmosphere of N_2 or Ar. All of the allyl vinyl ethers were prepared as previously described.[22] 2,3-Dimethyl-4-pentenoic acid was prepared according to Ireland.[12a]

2. Preparative Studies. 2.1. General Procedure for the Carbanion-Accelerated Claisen Rearrangement (CACR) in HMPA/THF. The scale was not necessarily the same in all experiments. An oven-dried, three-necked, 15-mL, round-bottomed flask equipped with a stirring bar, septa, and a vacuum/N_2 inlet was charged with 105 mg (0.65 mmol) of a 24.6% dispersion of KH in mineral oil. The KH was rinsed free of mineral oil with dry hexane (3 × 0.5 mL). The flask was successively evacuated and filled with dry N_2 (12×) and left over an atm of N_2 (balloon). HMPA (2.5 mL) was then added. The allyl vinyl ether (0.42 mmol) in 500 μL of THF was then added followed by a 500 μL rinse of the allyl vinyl ether's container. This gave a yellow-to-golden solution. The flask was placed in a 50 °C bath or left at room temperature, and the progress of the reaction was monitored by TLC at 15-min intervals. After completion, the reaction was quenched with 10 mL of 1 N HCl, pH 7 buffer, or saturated NH_4Cl. The result was extracted with ether (3 × 15 mL). Each ether extract was washed with H_2O (4 × 5 mL) and brine (1 × 5 mL). The ether layers were then combined and dried ($MgSO_4$), and the solvent was removed. The crude product was purified by column chromatography. If necessary, distillation or recrystallization was performed to obtain an analytical sample.

General Procedure for the CACR with KDMSO/LiCl. A 15-mL, three-necked, round-bottomed flask equipped with a stirring bar, nitrogen inlet, and septum was charged with KH dispersion (92 mg, 0.8 mmol). The dispersion was rinsed with three 0.5-mL portions of dry hexane. DMSO (2.0 mL) was added to the flask. Lithium chloride (176 mg, 41.0 mmol) was added to the suspension, and the flask was placed in a 50 °C oil bath to dissolve the salt. A solution of sulfone (0.3 mmol) in 1.0 mL of DMSO was added to the reaction flask via syringe at room temperature. The reaction was again heated to 50 °C in an oil bath. The reaction was monitored by TLC and upon completion was quenched with 4% ammonium chloride solution. The organic layer was extracted with ether (3 × 30 mL) and washed with water (4 × 10 mL) and brine (1 × 10 mL). The organic layer was dried over magnesium sulfate, and the solvent was removed.

General Procedure for the CACR with Other Base and Solvent Systems. An oven-dried, 15-mL, three-necked, round-bottomed flask equipped with two septa, an N_2 or Ar/vacuum/balloon three-way stopcock, and a stirring bar was charged with the necessary base. Rinsing (hexane) was

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[46] This hypothesis is testable by kinetic α-protonation of the anion and analysis of the *E*/*Z* mixture of **1aa**.

[47] Seebach, D.; Maetzke, T.; Haynes, R. K.; Paddon-Row, M. N.; Wong, S. S. *Helv. Chim. Acta* **1988**, *71*, 299.

[48] Based on a pK_a of the methyl derivative of 27.7[37b] and subtracting ca. 6 pK_a units for allyl conjugation cf.: Bordwell, F. G.; Bares, J. E.; Bartmess, J. E.; McCollum, G. J.; VanDerPuy, M.; Vanier, N.; Matthews, W. S. *J. Org. Chem.* **1977**, *42*, 321.

[49] (a) Furukawa, N.; Harada, K.; Oae, S. *Tetrahedron Lett.* **1972**, 1377. (b) Annunziata, R.; Cinquini, M.; Colonna, S.; Cozzi, F. *J. Chem. Soc., Chem. Commun.* **1981**, 1005.

[50] Gilman, H.; Haubein, R. H. *J. Am. Chem. Soc.* **1944**, *66*, 1515.

performed if required, and the system was alternately evacuated and flushed with inert gas (6×). The system was purged with inert gas for 10 min, and the balloon was filled and opened to the system. Two thirds of the solvent (total solvent gives ca. 0.1 N solution) was added. With NaH in DMSO, the mixture was heated for 45 min at 65 °C to effect the formation of the dimethyl sulfoxylate. The allyl vinyl ether was added in half of the remaining solvent followed by a rinse of its container. With ethereal solvents, freeze-degas-thaw cycles were performed, and the reaction was not monitored. Otherwise, the procedure continued as described above.

General Procedure for the Thermal Rearrangement of Allyl Vinyl Ethers. A 15-mL, three-necked, round-bottomed flask equipped with stirring bar and nitrogen inlet was charged with 0.24 mmol of the appropriate allyl vinyl ether and 2.4 mL of DMSO. The mixture was placed in a 135 °C oil bath and monitored by TLC. Upon completion, the reaction was quenched with water, extracted into ether, and washed with water and brine. The organic layer was dried over magnesium sulfate, and the solvent was removed.

1-(Phenylsulfonyl)-5-hexen-2-one (3aa). Chromatography solvent: hexane/EtOAc, 2/1. Yields from **1aa** and **2aa**: 78% and 76%, respectively. Rearrangement product was identical with **3aa** obtained from thermolysis by TLC and NMR (vide supra). Control experiments with **1aa** and **2aa** (HMPA, 50 °C, 4 h) resulted in a near quantitative recovery of starting materials with no evidence of rearrangement.

Thermolysis of 1aa. Crude **1aa** (680 mg, 2.86 mmol) was distilled in a Kugelrohr apparatus (bath 150–160 °C, 0.06 mmHg) for 4 h. Very little material reached the outside of the oven. This gave 620 mg of crude product. Column chromatographic purification of 557 mg of this mixture (hexane/EtOAc, 2/1) gave 334 mg (54%) of **3aa**. Data on **3aa**: ^{1}H NMR (90 MHz) 7.97–7.73 (m, 2 H, aromatic H ortho to SO$_2$), 7.73–7.43 (m, 3 H, aromatic H), 5.90–5.48 (m, 1 H, C*H*=CH$_2$), 5.13–4.86 (m, 2 H, CH=C*H*$_2$), 4.16 (s, 2 H, -SO$_2$C*H*$_2$–), 2.79 (t, 2 H, *J* = 7, COCH$_2$–), 2.27 (br q, 2 H, *J* = 7, CH$_2$CH=); IR (neat) 3090 w, 3000 w, 2925 m, 1720 s, 1650 m, 1600 w, 1480 w, 1445 s, 1400 m, 1365 m, 1310 s, 1295 s, 1240 m, 1185 s, 1152 s, 1090 s, 1020 m, 1030 m, 1010 m, 923 m, 890 w, 847 w, 800 w, 763 m, 738 s; MS (70 eV) *m/z* 238 (M$^+$, 0.63), 141 (37), 97 (38), 96 (100), 95 (18), 83 (10), 79 (17), 78 (13), 77 (91), 56 (53), 51 (30), 43 (30), 41 (23), 39 (19). Anal. Calcd for $C_{12}H_{14}O_3S$: C, 60.50; H, 5.88; S, 13.45. Found: C, 60.19; H, 5.93; S, 13.46.

3-Methyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3ba). Chromatography solvent: cyclohexane/EtOAc, 4/1; yield 85%. Kugelrohr distillation gave an analytical sample of **3ba**: bp 150–160 °C, 0.025 mmHg; ^{1}H NMR (220 MHz) 7.76 (d, 2 H, *J* = 8.2, aromatic H ortho to SO$_2$), 7.36 (d, 2 H, *J* = 8.1, aromatic H), 5.78–5.58 (m, 1 H, C*H*=CH$_2$), 5.07–5.00 (m, 2 H, CH=C*H*$_2$), 4.19 (s, 2 H, SO$_2$C*H*$_2$–), 2.95 (sextet, 1 H, 1 H, *J* = 6.8, -C*H*CH$_3$), 2.46 (s, 3 H, C*H*$_3$), 2.45–2.31 (m, 1 H, -C*H*$_a$H$_b$), 2.17–2.04 (m, 1 H, CH$_a$*H*$_b$), 1.09 (d, 3 H, *J* = 6.8, -C*H*$_3$); IR (neat) 3010 w, 2940 m, 2880 m, 1710 s, 1640 m, 1599 m, 1490 m, 1439 m, 1400 m, 1380 m, 1710 s, 1640 m, 1599 m, 1490 w, 1450 m, 1439 m, 1400 m, 1380 m, 1320 s, 1300 s, 1290 s, 1225 m, 1188 m, 1155 s, 1120 m, 1090 s, 1039 s, 1021 s, 999 m, 923 m, 825 w, 819 m; MS (10 eV) *m/z* 266 (M$^+$, 2.4), 155 (33), 111 (33), 110 (100), 95 (13), 93 (17), 91 (14), 69 (37), 43 (17). Anal. Calcd for $C_{14}H_{18}O_3S$: C, 63.16; H, 6.77; S, 12.03. Found: C, 62.95; H, 6.56; S, 11.84.

1-Methyl-1-(phenylsulfonyl)-5-hexen-2-one (3ca). Chromatography solvent: hexane/EtOAc, 3/1; yield 67%. Kugelrohr distillation gave an analytical sample of **3ca**: bp 140–150 °C, 0.05 mmHg; ^{1}H NMR (200 MHz) 7.81–7.48 (m, 5 H, aromatic H), 5.89–5.70 (m, 1 H, C*H*=CH$_2$), 5.10–4.99 (m, 2 H, CH=C*H*$_2$), 4.18 (q, 1 H, *J* = 7, -SO$_2$C*H*CH$_3$), 3.04 (dt, 1 H, *J* = 7, 18.3, COC*H*$_a$H$_b$), 2.74 (dt, 1 H, *J* = 7, 18.3, COCH$_a$*H*$_b$), 2.34 (br q, 2 H, *J* = 7, -C*H*$_2$), 1.40 (d, 3 H, *J* = 7, -C*H*$_3$); IR (CHCl$_3$) 3070 w, 3025 m, 2985 w, 2943 w, 2930 w, 1724 s, 1645 w, 1589 w, 1480 w, 1451 s, 1405 w, 1380 m, 1360 w, 1322 s, 1312 s, 1148 s, 1083 s, 1024 w, 998 m, 922 m; MS (70 eV) *m/z* 197 (M$^+$ − 55, 1.03), 110 (21), 83 (21), 77 (28), 58 (26), 55 (56), 51 (12), 43 (100), 41 (19), 39 (12). Anal. Calcd for $C_{13}H_{16}O_3S$: C, 61.90; H, 6.35; S, 12.70. Found: C, 61.67; H, 6.17; S, 12.84.

(*E*)-1-(Phenylsulfonyl)-5-hepten-2-one (3ab). Chromatography solvent: hexane/EtOAc, 2/1; yield 89% or 82%, see Table IX. Yields refer to mixtures of **3ab** and **4ab**. In the reaction run at 50 °C **4ab** was isolated in 3% yield and identified by NMR. In the other reaction **4ab** was present to the extent of 8% by HPLC (silica column, H:MC:A, 50:10:1.5; t_R **3ab**, 5.94 min; t_R **4ab**, 3.50 min; at 2 mL/min). Kugelrohr distillation afforded an analytical sample of **3ab**: bp 140 °C, 0.025 mmHg; ^{1}H NMR (220 MHz) 7.88 (d, 2 H, *J* = 7.5, aromatic H ortho to SO$_2$), 7.73–7.54 (m, 3 H, aromatic H), 5.52–5.31 (m, 2 H, olefinic H), 4.15 (s, 2 H, SO$_2$C*H*$_2$–), 2.77 (t, 2 H, *J* = 7.2, COC*H*$_2$–), 2.24 (br q, 2 H, *J* = 6.8, -C*H*$_2$–), 1.62 (dd, 3 H, *J* = 5.6, 9.6, -C*H*$_3$); irradiation of the signal at 2.24 ppm (360 MHz) caused collapse of a portion of the olefinic region to a doublet, *J* = 15.2; IR (CHCl$_3$) 3065 w, 3020 s, 2970 w, 2935 w, 2919 w, 2885 w, 2855 w, 1721 m, 1585 w, 1520 w, 1480 w, 1449 m, 1440 w, 1393 w, 1378 w, 1365 w, 1325 s, 1310 m, 1295 w, 1223 s, 1220 s, 1210 s, 1181 w, 1157 s, 1086 w, 1061 w, 1047 w, 1022 w, 999 w, 967 w, 928 w, 880 w, 850 w; MS (70 eV) *m/z* 198 (M$^+$ − 54, 1.1), 141 (17), 125 (13), 111 (24), 110 (100), 95 (55), 93 (33), 91 (16), 77 (72), 69 (14), 68 (13), 67 (13), 55 (33), 53 (11), 51 (23), 43 (38), 41 (40), 39 (21). Anal. Calcd for $C_{13}H_{16}O_3S$: C, 61.90; H, 6.35; S, 12.70. Found: C, 62.12; H, 6.26; S, 12.83. Data on **4abb**: ^{1}H NMR (220 MHz) 7.80 (d, 2 H, *J* = 7.3, aromatic H ortho to SO$_2$), 7.70 (t, distorted, 1 H, *J* = 7.5, para H), 7.57 (t, distorted, 2 H, *J* = 7.8, meta H), 5.54–5.41 (m, 1 H, olefinic H), 5.23–5.09 (m, 1 H, olefinic H), 4.10 (dd, 1 H, *J* = 4.9, 10.2, SO$_2$C*H*–), 2.61–2.57 (br m, 2 H, -C*H*$_2$), 2.38 (s, 3 H, COC*H*$_3$), 1.57 (d, 3 H, *J* = 6.2, -C*H*$_3$).

5-Methyl-1-(phenylsulfonyl)-5-hexen-2-one (3ac). Chromatography solvent: hexane/EtOAc, 2/1; yield 71%. Kugelrohr distillation gave an analytical sample of **3ac**: bp 150–160 °C (bath), 0.75 mmHg; ^{1}H NMR (220 MHz) 7.89 (d, 2 H, *J* = 7.2, aromatic H ortho to SO$_2$), 7.69 (t, distorted, 1 H, *J* = 7.2, para H), 7.56 (t, distorted, 2 H, *J* = 7.2, meta H), 4.75 (s, 1 H, C=C*H*H), 4.66 (s, 1 H, C=CH*H*), 4.17 (s, 2 H, SO$_2$C*H*$_2$–), 2.86 (t, 2 H, *J* = 7.3, COC*H*$_2$–), 2.27 (t, 2 H, *J* = 7.3, COCH$_2$C*H*$_2$–), 1.72 (s, 3 H, –CH$_3$); IR (CHCl$_3$) 3068 w, 3030 m, 3021 m, 2964 w, 1719 m, 1651 w, 1597 w, 1580 w, 1450 s, 1392 w, 1378 w, 1326 s, 1312 s, 1222 s, 1209 s, 1181 m, 1155 s, 1133 m, 1078 m, 1069 m, 1038 w, 1028 w, 1000 w, 928 w, 900 w, 850 w; MS (70 eV) *m/z* 252 (M$^+$, 3.2), 141 (24), 111 (100), 110 (26), 95 (29), 93 (32), 91 (11), 77 (61), 69 (42), 67 (11), 58 (11), 51 (17), 43 (46), 41 (40), 39 (15). Anal. Calcd for $C_{13}H_{16}O_3S$: C, 61.90; H, 6.35; S, 12.70. Found: C, 61.75; H, 6.20; S, 12.88.

4-Methyl-1-(phenylsulfonyl)-5-hexen-2-one (3ad). Chromatography solvent: hexane/EtOAc, 2/1; yield 64%. A 16% yield of phenylsulfonylacetone was obtained. Corrected yield for **3ad**, 71%. Kugelrohr gave an analytical sample of **3ad**: bp 140–150 °C (bath), 0.025 mmHg; ^{1}H NMR (220 MHz) 7.90–7.86 (m, 2 H, aromatic H ortho to SO$_2$), 7.73–7.55 (m, 3 H, aromatic H), 5.80–5.65 (m, 1 H, C*H*-CH$_2$), 5.00 (d, 1 H, *J* = 17.1, CH=C*H*$_t$H$_c$), 4.96 (d, 1 H, *J* = 10.6, CH=CH$_t$*H*$_c$), 4.14 (s, 2 H, SO$_2$CH$_2$–), 2.81–2.65 (m, 3 H), 1.02 (d, 3 H, *J* = 6.4, –C*H*$_3$); IR (CHCl$_3$) 3080 w, 3030 m, 3018 m, 2970 w, 2930 w, 2890 w, 1721 s, 1640 w, 1587 w, 1520 w, 1480 w, 1450 m, 1421 w, 1395 w, 1375 w, 1362 w, 1326 s, 1312 s, 1296 m, 1285 w, 1270 w, 1230 m, 1225 m, 1209 m, 1181 m, 1157 s, 1086 m, 1071 w, 1038 w, 1025 w, 1000 w, 922 m; MS (70 eV) *m/z* 183 (M$^+$ − 69, 2.1), 141 (42), 125 (11), 111 (81), 110 (50), 97 (27), 93 (42), 91 (13), 78 (11), 77 (100), 69 (37), 67 (11), 55 (49), 53 (12), 51 (33), 43 (25), 39 (24). Anal. Calcd for $C_{13}H_{16}O_3S$: C, 61.90; H, 6.35; S, 12.70. Found: C, 61.98; H, 6.39; S, 12.50.

CACR of 2ad. Chromatography solvent: hexane/EtOAc, 4/1; yield 64%. Rearrangement product was identical with **3ad** obtained from the above experiment (TLC and NMR). A 22% yield of phenylsulfonylacetone was obtained. Corrected yield for **3ad**, 69%.

1-((4-Methylphenyl)sulfonyl)-3-phenyl-5-hexen-2-one (3da). Chromatography solvent: hexane/EtOAc, 4/1; yield 79%. An analytical sample of **3da** was obtained after three recrystallizations from isopropyl ether: mp 75–76 °C; ^{1}H NMR (200 MHz) 7.71 (d, 2 H, *J* = 8.2, aromatic H ortho to SO$_2$), 7.36–7.26 (m, 5 H, aromatic H), 7.15–7.10 (m, 2 H, tolyl H), 5.72–5.52 (m, 1 H, C*H*=CH$_2$), 5.06–4.94 (m, 2 H, CH=C*H*$_2$), 4.22 (d, 1 H, *J* = 13.3, –SO$_2$C*H*$_a$H$_b$–), 4.09 (t, 1 H, *J* = 7.6, PhC*H*), 3.82 (d, 1 H, *J* = 13.3, –SO$_2$CH$_a$*H*$_b$–), 2.77–2.70 (m, 1 H, CHC*H*$_a$H$_b$), 2.46 (s, 3 H, aryl C*H*$_3$), 2.46–2.36 (m, 1 H, CHCH$_a$*H*$_b$); IR (CHCl$_3$) 3078 w, 3056 w, 3021 w, 2980 w, 2921 w, 1719 s, 1641 w, 1599 m, 1492 m, 1452 m, 1425 w, 1393 w, 1324 s, 1305 s, 1293 m, 1151 s, 1119 m, 1086 m, 1063 m, 1030 m, 1016 m, 992 m, 920 m; MS (70 eV) *m/z* 173 (M$^+$ − 155.22), 172 (35), 155 (22), 132 (12), 131 (100), 130 (10), 129 (13), 116 (12), 91 (70), 65 (13). Anal. Calcd for $C_{19}H_{20}O_3S$: C, 69.51; H, 6.10; S, 9.76. Found: C, 69.51; H, 6.27; S, 9.74.

3,3-Dimethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3ea). Chromatography solvent: hexane/EtOAc, 4/1; yield 91%. Recrystallization from isopropyl ether/hexane gave an analytically pure sample as colorless needles: mp 44–46 °C; ^{1}H NMR (220 MHz) 7.82 (d, 2 H, *J* = 8.5, aromatic H ortho to SO$_2$), 7.36 (d, 2 H, *J* = 8.2, aromatic H), 5.68–5.49 (m, 1 H, C*H*=CH$_2$), 5.05–4.96 (m, 2 H, CH=C*H*$_2$), 4.28 (s, 2 H, SO$_2$C*H*$_2$–), 2.45 (s, 3 H, aryl C*H*$_3$), 2.21 (d, 2 H, *J* = 7.2, –C*H*$_2$–), 1.11 (s, 6 H, 2× –C*H*$_3$); IR (CHCl$_3$) 3080 w, 3070 w, 3030 s, 3020 m, 2979 m, 2932 m, 2877 w, 1717 s, 1640 w, 1597 m, 1492 w, 1469 m, 1450 w, 1440 w, 1418 w, 1400 w, 1390 m, 1370 m, 1327 s, 1306 s, 1292 m, 1261 m, 1230 s, 1188 m, 1154 s, 1120 w, 1089 m, 1037 s, 1020 m, 1003 m, 983 w, 975 m, 926 m; MS (70 eV) 280 (M$^+$, 1.6), 155 (26), 125 (15), 124 (22), 107 (18), 105 (12), 91 (56), 83 (100), 82 (31), 67 (12), 65 (24), 55 (93), 43 (16), 41 (54), 39 (22). Anal. Calcd for $C_{15}H_{20}O_3S$: C, 64.29; H, 7.36; S, 11.43. Found: C, 64.45; H, 7.36; S, 11.42.

3,3-Diethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3fa). This reaction was conducted in DMSO. Column chromatography: hexane/EtOAc, 4/1; yield 83%. Recrystallization from hexane/EtOAc gave an analytical sample of **3fa** as colorless needles: mp 79–80 °C; ^{1}H NMR (200 MHz) 7.85 (d, 2 H, *J* = 8.3, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8.6, aromatic H), 5.63–5.42 (m, 1 H, $C\mathit{H}{=}CH_2$), 5.08–4.96 (m, 2 H, $CH{=}C\mathit{H}_2$), 4.26 (s, 2 H, $-SO_2C\mathit{H}_2-$), 2.45 (s, 3 H, $C\mathit{H}_3$), 2.25 (dt, 2 H, *J* = 1.1, 7.2, allylic $-C\mathit{H}_2-$), 1.61–1.49 (m, 4 H, 2× $-C\mathit{H}_2CH_3$), 0.71 (t, 6 H, *J* = 7.5, 2× $-CH_2C\mathit{H}_3$); IR ($CHCl_3$) 3070 w, 3022 m, 2985 s, 2942 m, 2930 m, 2893 m, 1712 s, 1640 w, 1599 m, 1494 w, 1460 m, 1383 m, 1324 s, 1305 s, 1290 m, 1265 m, 1150 s, 1086 m, 1063 w, 1025 m, 995 w, 923 m, 889 w, 872; MS (70 eV) *m/z* 111 (M^+ – 197, 30.3), 110 (13), 105 (11), 91 (27), 69 (100), 67 (10), 55 (45), 41 (50), 39 (12). Anal. Calcd for $C_{17}H_{24}O_3S$: C, 66.23; H, 7.79; S, 10.39. Found: C, 66.14; H, 7.83; S, 10.22.

1-[2-((4-Methylphenyl)sulfonyl)-1-oxoethyl]-1-(2-propen-1-yl)cyclohexane (3ga). This reaction was conducted in DMSO. Chromatography solvent: cyclohexane/EtOAc, 4/1; yield 85%. Kugelrohr distillation gave an analytical sample of **3ga**: bp 175 °C, 0.020 mmHg, which solidified; mp 66–68 °C; ^{1}H NMR (220 MHz) 7.85 (d, 2 H, *J* = 8.4, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8.2, aromatic H), 5.55–5.36 (m, 1 H, $C\mathit{H}{=}CH_2$), 4.99–4.90 (m, 2 H, $CH{=}C\mathit{H}_2$), 4.27 (s, 2 H, $SO_2C\mathit{H}_2-$), 2.45 (s, 3 H, aryl $C\mathit{H}_3$), 2.20 (d, 2 H, *J* = 7.3, $-C\mathit{H}_2-$), 1.91–1.85 (m, 2 H), 1.53–1.26 (m, 8 H); IR ($CHCl_3$) 3030 w, 2900 s, 2840 m, 1710 s, 1649 w, 1495 w, 1450 m, 1400 w, 1379 w, 1320 s, 1300 m, 1280 w, 1152 s, 1089 m, 1040 m, 1024 m, 999 m, 970 w, 950 w, 923 m, 907 w, 880 w, 815 w; MS (70 eV) 320 (M^+, 0.43), 170 (11), 164 (17), 155 (12), 147 (10), 123 (69), 122 (25), 105 (13), 91 (48), 81 (100), 79 (15), 69 (17), 67 (43), 65 (17), 55 (28), 53 (28), 44 (10), 43 (15), 41 (47), 39 (13). Anal. Calcd for $C_{18}H_{24}O_3S$: C, 67.50; H, 7.50; S, 10.00. Found: C, 67.78; H, 7.73; S, 9.87.

(*E*)-1-Methyl-1-(phenylsulfonyl)-5-hepten-2-one (3cb). Chromatography solvent: hexane/EtOAc, 4/1; yield 52%. In addition, a 7% yield of (*E*)-2-(phenylsulfonyl)-4-pentene **5** was isolated. An analytical sample of **3cb** was obtained by Kugelrohr distillation: bp 150 °C, 0.04 mmHg. Data on **3cb**: ^{1}H NMR (200 MHz) 7.84–7.53 (m, 5 H, aromatic H), 5.55–5.31 (m, 2 H, olefinic H), 4.18 (q, 1 H, *J* = 7, $-SO_2C\mathit{H}CH_3$), 2.98 (dt, 1 H, *J* = 7.5, 18, $-COC\mathit{H}_aH_b$), 2.70 (dt, 1 H, *J* = 7.5, 18, $COCH_a\mathit{H}_b$), 2.31–2.21 (m, 2 H, $-C\mathit{H}_2-$), 1.65 (d, 3 H, *J* = 4.7, allylic $C\mathit{H}_3$), 1.39 (d, 3 H, *J* = 7, $-C\mathit{H}_3$); IR ($CHCl_3$) 3065 w, 3030 m, 2970 w, 2945 m, 2923 m, 2888 w, 2860 w, 1723 s, 1588 w, 1480 w, 1451 s, 1404 m, 1380 m, 1362 w, 1321 s, 1311 s, 1148 s, 1083 s, 1023 m, 999 m, 982 m; MS (70 eV) *m/z* 141 (M^+ – 125, 13.9), 125 (23), 124 (97), 109 (13), 107 (21), 105 (10), 97 (15), 81 (25), 79 (12), 78 (17), 77 (83), 71 (10), 69 (62), 68 (25), 67 (17), 57 (11), 55 (100), 53 (21), 51 (33), 43 (73), 41 (77). Anal. Calcd for $C_{14}H_{18}O_3S$: C, 63.16; H, 6.77; S, 12.03. Found: C, 63.41; H, 7.11; S, 11.70. Data on **5**: ^{1}H NMR (200 MHz) 7.88–7.25 (m, 5 H, aromatic H), 5.52–5.44 (m, 1 H, $=C\mathit{H}CH_3$), 5.30–5.22 (m, 1 H, $-CH_2C\mathit{H}{=}$), 3.05–2.97 (m, 1 H, $-SO_2C\mathit{H}CH_3$), 2.70–2.64 (m, 1 H, $-C\mathit{H}_aH_b$), 2.08–1.99 (m, 1 H, $-CH_a\mathit{H}_b$), 1.63 (d, 3 H, *J* = 6.2, allylic $-CH_3$). Decoupling (360 MHz) gave the following results. Irradiation at 3.05–2.97 resulted in the following: (1) dd, *J* = 13.4 at 2.66, (2) dd, *J* = 13.4, 7.9 at 2.04, and (3) s at 1.23; irradiation at 1.63 gave a d, *J* = 15 at 1.23; irradiation at 1.23 gave dd, *J* = 3.5, 10.4 at 2.90; IR ($CHCl_3$) 3055 w, 3018 w, 2979 w, 2939 m, 2921 m, 2883 w, 2860 w, 1703 w, 1449 s, 1381 s, 1310 s, 1270 m, 1155 s, 1095 s, 1082 m, 1036 w, 1024 w, 1010 w, 974 s; MS (70 eV) *m/z* 170 (M^+ – 54, 2.03), 85 (35), 82 (78), 77 (25), 67 (29), 55 (100), 51 (17), 43 (13), 41 (39); high-resolution MS calcd for $C_{12}H_{16}O_2S$ + H 225.0949, found 225.0930.

2-[1,1-Dimethyl-3-((4-methylphenyl)sulfonyl)-2-oxopropyl]-methylidenecyclohexane (3em). Chromatography solvent: hexane/EtOAc, 5/1; yield 74%. Recrystallization from hexane/EtOAc afforded an analytical sample of **3em** as colorless flakes: mp 109.7–112 °C; ^{1}H NMR (200 MHz) 7.82 (d, 2 H, *J* = 8.3, aromatic H ortho to SO_2), 7.34 (d, 2 H, *J* = 8.3, aromatic H), 4.61 (d, 1 H, $=C\mathit{H}H$), 4.43 (d, 1 H, *J* = 1.59, $-SO_2C\mathit{H}_aH_b$), 4.21 (s, 1 H, $=CH\mathit{H}$), 4.14 (d, 1 H, *J* = 15.9, $-SO_2CH_aH_b$), 2.44 (s, 3 H, aryl $C\mathit{H}_3$), 2.25–2.17 (m, 2 H), 2.05–1.70 (m, 4 H), 1.46–1.15 (m, 3 H), 1.13 (s, 3 H, $C\mathit{H}_3$), 1.12 (s, 3 H, $-C\mathit{H}_3$); IR ($CHCl_3$) 3020 w, 2980 m, 2860 m, 1714 s, 1643 w, 1599 m, 1492 w, 1467 m, 1448 m, 1389 m, 1370 w, 1325 s, 1306 s, 1291 m, 1155 s, 1142 s, 1090 m, 1077 w, 1028 s, 999 m, 910 m, 894 w, 871 w; MS (10 eV) *m/z* 334 (M^+, 0.42), 240 (41), 222 (32), 179 (16), 178 (12), 161 (71), 157 (12), 140 (17), 137 (100), 95 (57), 94 (12), 85 (61), 81 (19). Anal. Calcd for $C_{19}H_{26}O_3S$: C, 68.26; H, 7.78; S, 9.58. Found: C, 67.99; H, 7.58; S, 9.47.

1-((4-Methylphenyl)sulfonyl)-3,3,4,4-tetramethyl-5-hexen-2-one (3eh). Distillation gave an analytical sample of **3eh** (91%): bp 150–170 °C, 0.025 mmHg; mp 59.5–62 °C; ^{1}H NMR (200 MHz) 7.80 (d, 2 H, *J* = 8.2, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8.2, aromatic H), 5.80 (dd, 1 H, *J* = 10.5, 17.2, $C\mathit{H}{=}CH_2$), 5.04 (d, 1 H, *J* = 10.5, $CH{=}CH_tC\mathit{H}_c$), 4.92 (d, 1 H, *J* = 17.2, $CH{=}C\mathit{H}_tH_c$), 4.26 (s, 2 H, $-SO_2C\mathit{H}_2-$), 2.46 (s, 3 H, CH_3), 1.15 (s, 6 H, 2× $-C\mathit{H}_3$), 0.93 (s, 6 H, 2× CH_3); IR ($CHCl_3$) 3098 w, 3030 m, 3019 m, 2990 s, 2935 m, 2890 w, 1710 s, 1640 w, 1601 m, 1496 w, 1460 m, 1452 w, 1419 w, 1446 m, 1433 m, 1420 m, 1325 s, 1306 s, 1291 m, 1266 m, 1185 w, 1155 s, 1121 m, 1090 m, 1032 s, 1020 m, 1004 m, 937 m, 895 w, 875 w; MS (70 eV) *m/z* 240 (M^+ – 68, 16.8), 222 (18), 140 (11), 111 (25), 91 (36), 85 (67), 69 (100), 67 (28), 65 (15), 57 (17), 55 (28), 43 (14), 41 (63), 39 (13). Anal. Calcd for $C_{117}H_{24}O_3S$: C, 66.23; H, 7.79; S, 10.40. Found: C, 66.32; H, 7.79; S, 10.18.

3,3-Dimethyl-4,4-diethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3ei). Chromatography solvent hexane/EtOAc, 8/1; yield (thermal) 56%, (anionic) 68%. An analytical sample was prepared by recrystallization from hexane/EtOAc: mp 54–56 °C; ^{1}H NMR (200 MHz), $CDCl_3$) 7.74 (d, 2 H, *J* = 8, aromatic H ortho to SO_2), 7.30 (d, 2 H, *J* = 8, aromatic H), 5.46 (dd, 1 H, *J* = 11, 2, $C\mathit{H}{=}CH_2$), 5.17 (d, 1 H, *J* = 11, $CH{=}C\mathit{H}_2$ (cis)), 4.93 (d, 1 H, *J* = 18, $CH{=}C\mathit{H}_2$ (trans)), 4.21 (s, 2 H, SO_2CH_2), 2.39 (s, 3 H, CH_3), 1.58–1.35 (m, 4 H, $C\mathit{H}_2CH_3$), 1.12 (2 s, 6 H, $C(CH_3)_2$), 0.69 (t, 6 H, *J* = 7, $CH_2C\mathit{H}_3$); IR ($CHCl_3$) 2980 s, 2940 s, 2880 m, 1700 s, 1600 w, 1460 m, 1390 m, 1380 w, 1365 m, 1320 s, 1305 m, 1290 m, 1085 m, 1030 s, 1000 s, 1000 w, 920 m, 890 w, 870 w; MS (70 eV) *m/z* 240 (21), 222 (23), 157 (12), 155 (12), 140 (14), 139 (12), 97 (29), 91 (35), 85 (74), 83 (29), 69 (16), 67 (30), 65 (13), 55 (100), 43 (13), 41 (39). Anal. Calcd for $C_{19}H_{28}O_3S$: C, 67.82; H, 9.39; S, 9.53. Found: C, 67.73; H, 8.36; S, 9.49.

1-Ethenyl-1-[1,1-dimethyl-3-((4-methylphenyl)sulfonyl)-2-oxopropyl]-cyclohexane (3ek). Chromatography solvent: hexane/EtOAc, 8/1; yield 82%. Recrystallization from isopropyl ether gave **3ek** as colorless flakes: mp 88–89 °C; ^{1}H NMR (360 MHz) 7.80 (d, 2 H, *J* = 8.2, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8.2, aromatic H), 5.42–5.33 (m, 2 H, $CH{=}C\mathit{H}_2$), 5.06–4.92 (m, 1 H, $C\mathit{H}{=}CH_2$), 4.25 (s, 2 H, $-SO_2C\mathit{H}_2-$), 2.45 (s, 3 H, aryl $C\mathit{H}_3$), 1.63–0.92 (m, 16 H, $-(C\mathit{H}_2)_5-$ and 2× $-CH_3$, singlet at 1.13); IR ($CHCl_3$) 3079 w, 3018 w, 2983 m, 2947 s, 2868 m, 1703 s, 1637 w, 1601 m, 1495 w, 1476 w, 1450 m, 1412 w, 1392 m, 1373 m, 1325 s, 1291 m, 1155 s, 1088 m, 1039 m, 1020 s, 998 m, 926 m, 895 w, 873 w, 844 w; MS (10 eV) *m/z* 240 (M^+ – 108, 63.6), 222 (50), 157 (18), 140 (21), 139 (12), 109 (44), 85 (100), 68 (19), 67 (35). Anal. Calcd for $C_{20}H_{28}O_3S$: C, 68.97; H, 8.05; S, 9.20. Found: C, 68.55; H, 7.91; S, 8.81.

3,3-Diethyl-4,4-dimethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3fh). Chromatography solvent hexane/EtOAc, 3/1; yield (thermal) 75%, (anionic) 64%. An analytical sample was obtained by recrystallization from hexane/EtOAc: mp 77–78 °C; ^{1}H NMR (200 MHz, $CDCl_3$) 7.81 (d, 2 H, *J* = 8, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8, aromatic H), 5.88 (dd, 1 H, *J* = 17, 10, $C\mathit{H}{=}CH_2$), 5.02 (dd, 1 H, *J* = 11, $CH{=}C\mathit{H}_2$ (cis)), 4.92 (dd, 1 H, *J* = 11, $CH{=}C\mathit{H}_2$ (trans), 4.21 (s, 2 H, SO_2CH_2), 2.45 (s, 3 H, aryl $C\mathit{H}_3$), 1.90 (m, 2 H, $2CH\mathit{H}CH_3$), 1.70 (m, 2 H, $2CH\mathit{H}CH_3$), 0.93 (s, 6 H, $C(CH_3)_2$), 0.87 (t, 6 H, *J* = 7, $CH_2C\mathit{H}_3$); IR ($CHCl_3$) 2980 s, 2920 m, 2880 w, 1700 s, 1600 w, 1450 w, 1380 w, 1340 s, 1305 m, 1150 s, 1080 m, 1070 w, 1040 m, 1020 m, 920 m, 880 w; MS (70 eV) *m/z* 268 (10), 155 (16), 113 (21), 112 (70), 111 (19), 97 (22), 95 (42), 91 (44), 83 (62), 69 (100), 67 (14), 65 (14), 55 (51), 43 (49), 41 (66). Anal. Calcd for $C_{19}H_{28}O_3S$: C, 67.82; H, 8.39; S, 9.53. Found: C, 67.43; H, 8.28; S, 10.01.

3,3-Diethyl-4,4-diethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3fi). Chromatography solvent hexane/EtOAc, 3/1; yield (anionic) 38%. ^{1}H NMR (200 MHz, $CDCl_3$) 7.83 (d, 2 H, *J* = 8, aromatic H ortho to SO_2), 7.40 (d, 2 H, *J* = 8, aromatic H), 5.62 (dd, 1 H, *J* = 18, 11, $C\mathit{H}{=}CH_2$), 5.23 (dd, *J* = 11, 1, $CH{=}C\mathit{H}_2$ (cis)), 4.96 (dd, *J* = 18, 1, $CH{=}C\mathit{H}_2$ (trans)), 4.3 (s, 2 H, $SO_2C\mathit{H}_2$), 2.45 (s, 3 H, aryl $C\mathit{H}_3$), 1.2–2.0 (m, 8 H, $4C\mathit{H}_2CH_3$), 0.87 (t, 6 H, *J* = 8, $CH_2C\mathit{H}_3$), 0.72 (t, 6 H, *J* = 8, $CH_2C\mathit{H}_3$); IR ($CHCl_3$) 2980 s, 2950 s, 2900 m, 1700 s, 1630 w, 1600 m, 1460 m, 1380 m, 1320 s, 1305 s, 1290 m, 1150 s, 1090 s, 1070 m, 1030 s, 1020 m, 1005 w, 925 m, 880 w; MS (70 eV) *m/z* 113 (14), 112 (42), 111 (13), 97 (30), 95 (26), 91 (26), 69 (24), 67 (13), 65 (10), 57 (16), 55 (100), 43 (40), 39 (11); high-resolution MS (FAB) calcd for $C_{21}H_{32}O_3S$ 365.2150, found 365.2158.

1-(1,1-Dimethyl-2-propenyl)-1-[2-((4-methylphenyl)sulfonyl)-1-oxoethyl]cyclohexane (3gh). Chromatography solvent: hexane/EtOAc, 5/1; yield 77%. Recrystallization from isopropyl ether gave **3gh** as colorless flakes: mp 82–82.5 °C; ^{1}H NMR (200 MHz) 7.89 (d, 2 H, *J* = 8.2, aromatic H ortho to SO_2), 7.36 (d, 2 H, *J* = 8.2, aromatic H), 5.88 (dd, 1 H, *J* = 10.8, 17.5, $C\mathit{H}{=}CH_2$), 5.07 (dd, 1 H, *J* = 1.3, 10.8, $CH{=}C\mathit{H}_cH_t$), 4.90 (dd, 1 H, *J* = 1.3, 17.5, $CH{=}CH_cC\mathit{H}_t$), 4.36 (s, 2 H, $-SO_2C\mathit{H}_2-$), 2.45 (s, 3 H, aryl $C\mathit{H}_3$), 2.17–2.07 (m, 2 H), 1.67–1.47 (m, 4 H), 1.40–1.21 (m, 2 H), 1.12–0.94 (m, 2 H), 0.89 (s, 6 H, 2× $-C\mathit{H}_3$); IR ($CHCl_3$) 3090 w, 3030 w, 2980 m, 2950 s, 2870 m, 1708 s, 1638 w, 1600 m, 1495 w, 1460 m, 1451 m, 1418 w, 1388 m, 1373 m, 1324 s, 1305 s, 1267 m, 1156 s, 1088 m, 1074 m, 1050 m, 1020 s, 925 m; MS (70 eV) *m/z* 280 (M^+ – 68, 8.1), 124 (100), 123 (13), 107 (13), 95 (21), 81 (23), 79 (19), 69 (66), 67 (32), 55 (17), 43 (26), 41 (43). Anal. Calcd for $C_{20}H_{28}O_3S$: C, 68.97; H, 8.05; S, 9.20. Found: C, 69.09; H, 7.95; S, 9.18.

1-(1-Ethenylcyclohexyl)-1-[2-((4-methylphenyl)sulfonyl)-1-oxoethyl]-cyclohexane (3gk). Chromatography solvent: cyclohexane/EtOAc, 4/1; yield 87%. Recrystallization from isopropyl ether gave an analytical sample of **3gk**: mp 123–124 °C; ^{1}H NMR (220 MHz) 7.90 (d, 2 H, J = 8.2, aromatic H ortho to SO_2), 7.26 (d, 2 H, J = 8.2, aromatic H), 5.44–5.30 (m, 2 H, $\mathrm{CH{=}C}\mathit{H}_2$), 5.01–4.90 (m, 1 H, $\mathrm{C}\mathit{H}\mathrm{{=}CH_2}$), 4.38 (s, 2 H, $-\mathrm{SO_2C}\mathit{H}_2-$), 2.45 (s, 3 H, aryl $\mathrm{C}\mathit{H}_3$), 2.12–2.06 (m, 2 H), 1.61–0.88 (m, 18 H); IR ($CHCl_3$) 3085 w, 3027 w, 2945 s, 2868 s, 1703 s, 1632 w, 1601 m, 1494 w, 1458 m, 1450 m, 1410 w, 1377 w, 1352 w, 1323 s, 1305 s, 1292 m, 1266 m, 1183 w, 1157 s, 1132 s, 1102 w, 1089 m, 1072 m, 1037 m, 1019 s, 927 m, 898 w, 888 w, 871; MS (70 eV) m/z 280 (M^+ – 108, 6.4), 125 (28), 124 (100), 109 (26), 107 (12), 91 (25), 81 (23), 79 (22), 67 (63), 55 (19), 43 (25), 41 (21). Anal. Calcd for $C_{23}H_{32}O_3S$: C, 71.13; H, 8.25; S, 8.25. Found: C, 71.27; H, 8.24; S, 8.25.

Thermal Rearrangement of 1gk. A solution of 52 mg (1.34 mmol) of **1gk** in 1.5 mL of DMSO was heated at 135 °C for 1.5 h under N_2. Usual workup and column chromatography purification (cyclohexane/EtOAc, 4/1) afforded 52 mg (100%) of **3gk**, identical (TLC and NMR) with an authentic sample.

2-Methyl-4-(phenylmethyl)-3-(phenylsulfonyl)-3,4-dihydrofuran (6). Chromatography solvent hexane/EtOAc, 6/1; yield 63%. The structure was based on the following data: ^{1}H NMR (220 MHz, C_6D_6) 7.94–7.90 (m, 2 H, aromatic H ortho to SO_2), 7.11–6.91 (m, 8 H, aromatic H), 3.77 (dd, 1 H, J = 9.4, 5, $\mathrm{OC}\mathit{H}_a\mathrm{H}_b$), 3.47 (t, 1 H, J = 9.4, $\mathrm{OCH}_a\mathit{H}_b$), 3.32 (dd, 1 H, J = 13.5, 3.2, $\mathrm{OC}\mathit{H}_a\mathrm{H}_b$), 3.20–3.11 (m, 1 H, $\mathrm{OCH_2C}\mathit{H}$), 2.46 (dd, 1 H, J = 10.1, 13.6, $\mathrm{OCH}_a\mathit{H}_b$), 2.10 (d, 3 H, J = 0.94, furan $\mathrm{C}\mathit{H}_3$). Irradiation of the signal at 3.20–3.11 ppm (360 MHz) causes the signal at 2.10 ppm to collapse to a singlet. IR ($CHCl_3$) 3010 w, 2900 w, 1735 w, 1623 s, 1492 w, 1445 m, 1380 m, 1370 w, 1300 s, 1230 m, 1155 s, 1130 s, 1092 m, 1070 m, 1028 w, 989 w, 918 w; MS (70 eV) m/z 314 (M^+, 1.1), 224 (13), 223 (100), 141 (32), 125 (15), 91 (17), 77 (72), 43 (14); high-resolution MS calcd for $C_{18}H_{18}O_3S$ 314.0978, found 314.0965.

CACR of 1bq. Preparation of 3,4-Dimethyl-1-((4-methylphenyl)-sulfonyl)-4,5-hexadien-2-one (3ba) and 2,4-Diethyl-3-((4-methylphenyl)sulfonyl)furan (7). Chromatography solvent cyclohexane/EtOAc, 4/1; yields 9% for both **3bq** and **7**. Data for **3bq**: ^{1}H NMR (220 MHz) 7.77 (d, 2 H, J = 8.4, aromatic H ortho to SO_2), 7.36 (d, 2 H, J = 8.2, aromatic H), 4.71 (br s, 2 H, allenic H), 4.41 (d, 1 H, J = 13.7, $-\mathrm{SO_2C}\mathit{H}_a\mathrm{H}_b$), 3.38 (q, 1 H, J = 6.7, $-\mathrm{C}\mathit{H}\mathrm{CH_3}$), 2.45 (s, 3 H, aryl $\mathrm{C}\mathit{H}_3$), 1.62 (t, 3 H, J = 3.2, allenic $-\mathrm{C}\mathit{H}_3$), 1.17 (d, 3 H, J = 6.7, $\mathrm{CHC}\mathit{H}_3$); IR ($CHCl_3$) 3000 w, 2960 w, 2910 m, 2840 w, 1950 w, (allene), 1925 w, 1717 s, 1600 m, 1540 w, 1495 w, 1448 m, 1392 w, 1385 m, 1321 s, 1301 s, 1152 s, 1086 m, 1038 m, 1020 m, 1005 br w, 908 br w, 941 w, 910 m, 883 w, 860 m; MS (70 eV) m/z 278 (M^+, 5.8), 123 (18), 122 (100), 91 (31), 81 (13), 79 (18), 65 (17), 57 (10), 53 (15), 43 (15), 41 (20), 39 (13). Data for **7**: ^{1}H NMR (220 MHz) 7.77 (d, 2 H, J = 8.4, aromatic H ortho to SO_2), 7.30 (d, 2 H, J = 8.1, aromatic H), 7.03 (s, 1 H, furan H), 3.08 (q, 2 H, J = 7.4, $-\mathrm{C}\mathit{H}_2$), 2.47 (q, 2 H, J = 7.3, $-\mathrm{C}\mathit{H}_2-$), 2.42 (s, 3 H, aryl $\mathrm{C}\mathit{H}_3$), 1.27 (t, 3 H, J = 7.4, $-\mathrm{C}\mathit{H}_3$), 1.11 (t, 3 H, J = 7.4, $-\mathrm{C}\mathit{H}_3$); IR ($CHCl_3$) 2920 m, 2840 w, 1720 w, 1670 s, 1599 m, 1485 w, 1455 m, 1370 m, 1320 s, 1300 s, 1285 m, 1230 m, 1159 s, 1125 s, 1081 m, 1070 m, 1040 m, 1020 m, 999 m, 945 w, 933 w, 912 s; MS (70 eV) m/z 279 (M^+ + 1, 14.5), 278 (M^+, 81.3), 261 (12), 243 (24), 140 (42), 139 (56), 123 (26), 122 (27), 109 (14), 107 (20), 105 (11), 98 (15), 95 (13), 93 (26), 91 (72), 86 (15), 85 (27), 84 (22), 83 (41), 81 (22), 80 (12), 79 (100), 78 (14), 77 (59), 68 (25), 66 (12), 65 (55), 63 (13), 57 (15), 55 (32), 54 (12), 53 (49), 52 (12), 51 (26), 49 (35), 48 (10), 47 (22), 43 (38), 41 (56), 39 (60).

3. Stereochemical Studies. 3.1. Internal Asymmetric Induction. Thermolysis of 1bd and 1be. General Procedure. A 0.1 N DMSO solution of **1bd** or **1be** was heated under N_2 until all starting material was gone (TLC). The reaction mixture was cooled, diluted with H_2O, and extracted with ether. The ether extracts were washed thoroughly with water and brine. Drying and removal of solvent gave fairly high quality product which could be purified by chromatography and/or distillation. The solvent for column chromatography for all stereochemical experiments was cyclohexane/EtOAc, 4/1 or hexane/EtOAc, 4/1.

Thermolysis of 1bd. Preparation of (3*R,4*S**)-3,4-Dimethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3bd).** Yield 97%. An analytical sample of **3bd** was obtained by Kugelrohr distillation: bp 160 °C, 0.075 mmHg; ^{1}H NMR (220 MHz, C_6D_6) 7.75 (d, 2 H, J = 8.2, aromatic H ortho to SO_2), 6.73 (d, 2 H, J = 8.1, aromatic H), 5.58–5.43 (m, 1 H, $\mathrm{C}\mathit{H}\mathrm{{=}CH_2}$), 4.84–4.78 (m, 2 H, $\mathrm{CH{=}C}\mathit{H}_2$), 3.86 (d, 1 H, A of AB, J = 13.4, $\mathrm{SO_2C}\mathit{H}_a\mathrm{H}_b-$), 3.72 (d, 1 H, B of AB, J = 13.7, $\mathrm{SO_2CH}_a\mathit{H}_b-$), 2.67 (quintet, 1 H, J = 6.8, $\mathrm{COC}\mathit{H}-$), 2.23 (sextet, 1 H, J = 6.8, $\mathrm{mC}\mathit{H}\mathrm{CH{=}}$), 1.81 (s, 3 H, $\mathrm{C_6H_4C}\mathit{H}_3$), 0.88 (d, 3 H, J = 7.2, $-\mathrm{C}\mathit{H}_3$), 0.72 (d, 3 H, J = 6.7, $-\mathrm{C}\mathit{H}_3$); IR ($CHCl_3$) 2940 w, 2900 w, 1715 s, 1645 w, 1600 w, 1492 w, 1450 m, 1380 w, 1320 s, 1300 m, 1180 w, 1155 s, 1088 m, 1020 m, 923 w, 900 w; MS (70 eV) m/z 280 (M^+, 1.4), 157 (14), 155 (46), 139 (29), 125 (28), 124 (50), 109 (15), 107 (45), 105 (10), 92 (15), 91 (100), 83 (67), 81 (12), 71 (19), 67 (15), 65 (33), 57 (11), 55 (99), 53 (17), 44 (29), 41 (48), 39 (25). Anal. Calcd for $C_{15}H_{20}O_3S$: C, 64.29; H, 7.14; S, 11.37. Found: C, 64.18; H, 7.10; S, 11.37. **3be** was present to the extent of 4% by LC (aminopropyl column, hexane/isopropyl alcohol, 4/1; t_R **3bd**, 4.28 min; t_R **3be**, 6.10; at 2 mL/min.

Thermolysis of 1be. Preparation of (3*R,4*R**)-3,4-Dimethyl-1-((4-methylphenyl)sulfonyl)-5-hexen-2-one (3be).** Yield 89%: ^{1}H NMR (220 MHz, C_6D_6) 7.75 (d, 2 H, J = 8.4, aromatic H ortho to SO_2), 6.72 (d, 2 H, J = 8.4, aromatic H), 5.48–5.32 (m, 1 H, $\mathrm{C}\mathit{H}\mathrm{{=}CH_2}$), 4.84 (d, 1 H, J = 8.6, $\mathrm{CH{=}C}\mathit{H}_c\mathrm{H}_t$), 4.79 (d, 1 H, J = 15.8, $\mathrm{CH{=}CH}_c\mathit{H}_t$), 3.85 (d, J = 13.6, A of AB, $\mathrm{SO_2C}\mathit{H}_a\mathrm{H}_b-$), 3.73 (d, 1 H, B of AB, $\mathrm{SO_2CH}_a\mathit{H}_b$), 2.61 (quintet, 1 H, J = 6.8, $\mathrm{COC}\mathit{H}-$), 2.29 (sextet, 1 H, J = 7.4, $-\mathrm{C}\mathit{H}-$), 1.81 (s, 3 H, $\mathrm{C_6H_4C}\mathit{H}_3$), 0.85 (s, 3 H, J = 7.1, $-\mathrm{C}\mathit{H}_3$), 0.84 (d, 3 H, J = 6.6, $-\mathrm{C}\mathit{H}_3$); IR (neat) 3080 w, 3040 w, 2985 s, 2940 s, 2888 m, 1716 s, 1643 m, 1600 s, 1497 m, 1457 s, 1420 m, 1404 m, 1381 s, 1322 s, 1307 s, 1292 s, 1221 m, 1188 s, 1152 s, 1121 m, 1089 s, 1030 s, 1020 s, 1008 s, 923 s, 899 m, 882 m, 820 s, 778 m, 760 m, 725 s; MS (70 eV) m/z 280 (M^+, 1.7), 208 (10), 157 (23), 155 (60), 139 (37), 129 (13), 125 (40), 124 (71), 109 (24), 108 (72), 105 (15), 92 (20), 91 (100), 83 (96), 82 (10), 81 (18), 79 (13), 77 (14), 71 (25), 69 (10), 67 (21), 65 (53), 55 (100), 53 (26), 43 (51), 41 (72). Anal. Calcd for $C_{15}H_{20}O_3S$: C, 64.29; H, 7.14; S, 11.43. Found: C, 63.90; H, 7.11; S, 11.35. **3bd** was present to the extent of 6% by LC (aminopropyl column, hexane/isopropyl alcohol, 4/1), t_R **3bd**, 4.62 min; t_R **3be**, 5.81 min; at 2 mL/min.

CACR of 1bd and 1be. The general procedures given earlier were followed. See Tables V and VI for the results.

Preparation of a Mixture of *syn*- and *anti*-3,4-Dimethyl-5-hexen-2-ones. A flame-dried, 50-mL, three-necked, round-bottomed flask equipped with a thermometer, N_2 inlet, septum, and stirring bar was charged with 553 mg (5.3 mmol) of (*syn*/*anti*)-2,3-dimethyl-4-pentenoic acid and 25 mL of dry ether. The flask was cooled to −5 °C in an ice/salt bath and 4.9 mL (1.6 equiv) of a 1.75 M solution of CH_3Li in ether was added via syringe (syringe pump) over 45 min. The bath was removed, and the reaction mixture was stirred for 1.5 h. The reaction mixture was poured into 75 mL of cold 0.1 N HCl. The organic layer was washed with 10% $NaHCO_3$ (1 × 40 mL), H_2O (1 × 25 mL), and brine (1 × 25 mL). Drying ($MgSO_4$) and removal of solvent by distillation gave a residue which was purified by column chromatography (pentane/ether, 5/1). Removal of solvent and distillation of the residue gave 222 mg (41%) of product, bp 120 °C (bath). GC analysis indicated an anti/syn ratio of 6.4/1 (capillary, 50 °C for 12 min to 150 °C at 15°/min; t_R anti, 13.03 min; t_R syn, 14.23 min). The stereochemical assignments were based on the next experiment. Data for the mixture: ^{1}H NMR (220 MHz) 5.70–5.54 (m, 1 H, $\mathrm{C}\mathit{H}\mathrm{{=}CH_2}$), 5.07–4.96 (m, 2 H, $\mathrm{CH{=}C}\mathit{H}_2$), 2.52–2.33 (m, 2 H, 2× $-\mathrm{C}\mathit{H}-$), 2.15 (s, 3 H, $\mathrm{C}\mathit{H}_3\mathrm{CO}$), 2.13 (s, 3 H, $-\mathrm{C}\mathit{H}_3$, syn isomer), 1.01 (t, 6 H, J = 6.7, 2× $-\mathrm{C}\mathit{H}_3$); IR ($CHCl_3$) 3050 w, 2920 s, 1701 s, 1645 w, 1450 m, 1350 s, 1290 w, 1219 m, 1182 m, 1145 w, 1073 m, 1000 m, 955 w, 916 s; MS (70 eV) m/z 126 (M^+, 2), 111 (21), 83 (35), 72 (23), 55 (91), 43 (100), 41 (30), 39 (17). Anal. Calcd for $C_8H_{14}O$: C, 76.19; H, 11.11. Found: C, 76.04; H, 11.18.

Ozonolysis of *syn*–*anti*-2,3-Dimethyl-4-pentenoic Acid. This was performed according to the method of Ireland[12a] to give a quantitative yield of crude product. The crude product was dissolved in 3% NaOH and extracted with ether. Acidification and continuous extraction with ether (36 h) gave a mixture of dimethyl succinic acids. A portion of this was esterified with diazomethane to give dimethyl 2,3-dimethylsuccinates. GC analysis showed a ratio of anti/syn of 6.3/1 (capillary, 50 °C for 3 min to 150 °C at 15°/min; t_R anti, 12.19 min; t_R syn, 12.85 min). The stereochemical assignments were made on the basis of coinjection with dimethyl 2,3-dimethylsuccinates obtained from authentic samples of the acids (Aldrich).

General Procedure for the Reductive Desulfonylation of 3bd and 3be.[28] To a stirred 0.075 N solution of **3bd** or **3be** (or mixture) in THF/H_2O/AcOH, 2/1/1 was added 20–30 equiv of Al(Hg) prepared from foil. The reaction was stirred about 12 h and then worked up. Filtration through a pad of $MgSO_4$ with ether followed by washing with H_2O and 15% $NaHCO_3$, drying ($MgSO_4$), and removal of solvent by distillation gave a residue that was examined by capillary GC. Comparison was made to authentic ketones prepared as described earlier. This allowed unambiguous stereochemical assignment. The results are given in Tables IV and V as GC product ratios.

(*E*)-2-Ethyl-1-((4-methylphenyl)sulfonyl)-2-[(*E*)-2-butenyloxy]-1-butene (2bd). An oven-dried 25-mL, three-necked, round-bottomed flask equipped with two septa, an N_2 inlet, and a stirring bar was charged with 450 mg (1.6 mmol) of **1bd** and 10 mL of THF and cooled in an ice bath. A solution of potassium *tert*-amyloxide in benzene was added (10 mol%), and the yellow reaction mixture was stirred for 1 h at 0 °C and 24 h at 25 °C. Aqueous workup as usual gave 430 mg of crude product as a yellow liquid. This was combined with other material obtained similarly to give 591 mg of material. Purification by medium pressure liquid chromatography (*R*-phenylglycine dinitrobenzoate bonded to aminopropyl silica (1 mmol/g); column 1 in. ×36 in., hexane/EtOAc, 99/1.5 mL/min) and column chromatography (hexane/EtOAc, 4/1) gave 170 mg (29%) of **2bd** with only a trace of **1bd** by NMR. Data on **2bd**: ^{1}H NMR (200 MHz) 7.78 (d, 2 H, $J = 8.2$, aromatic H ortho to SO_2), 7.30 (d, 2 H, $J = 8.2$, aromatic H), 5.87–5.70 (m, 1 H, $=CHCH_3$), 5.64–5.49 (m, 1 H, $-CH_2CH=$), 5.49 (s, 1 H, $-SO_2CH=$), 4.17 (d, 2 H, $J = 6$, $-CH_2O-$), 2.64 (q, 2 H, $J = 7.3$, $-CH_2CH_3$), 2.42 (s, 3 H, $C_6H_4CH_3$), 1.72 (d, 3 H, $J = 6.4$, $-CHCH_3$), 1.05 (t, 3 H, $J = 7.3$, $-CH_2CH_3$); IR ($CHCl_3$) 3025 m, 2985 m, 2952 m, 2933 m, 2890 w, 1671 w, 1599 s, 1499 w, 1465 m, 1455 m, 1404 w, 1382 m, 1348 m, 1315 s, 1305 s, 1293 s, 1150 s, 1082 s, 1016 m, 991 w, 975 w, 943 w, 908 m; MS (10 eV) *m*/*z* 280 (M^+, 1.2), 226 (37), 126 (10), 125 (100), 124 (35), 97 (32); high-resolution MS calcd for $C_{15}H_{20}O_3S$ 280.1133, found 280.1132.

CACR of 2bd. Treatment of **2bd** with 2.7 equiv of sodium dimsylate at 50 °C for 30 min under usual conditions for the CACR gave a 73% yield of a mixture of **3bd** and **3be** in a ratio of 35/65 by HPLC.

3.2. Axial–Equatorial Preference. Thermolysis of 1ha. Preparation of *cis*- and *trans*-4-(1,1-Dimethylethyl)-1-[2-((4-methylphenyl)sulfonyl)-1-oxoethyl]-1-(2-propen-1-yl)cyclohexane (3ha and 3ah′). A solution of 150 mg (0.4 mmol) of **1al** in 4 mL of DMSO was heated at 100 °C for 3.25 h under N_2. Usual workup and column chromatography (hexane/EtOAc, 6/1) afforded 140 mg (93%) of a mixture of **3ha** and **3ha′** in a ratio of 66/34 by analysis of the intensities of the sulfonylmethylene ($-SO_2CH_2-$) signal of each isomer. The isomers could not be separated, and HPLC gave inconsistent results. Recrystallization from hexane/EtOAc gave an analytical mixture of **3ha** and **3ha′**: mp 118.5–128 °C; ^{1}H NMR (200 MHz) 7.87–7.80 (m, 2 H, aromatic H ortho to SO_2), 7.35 (d, 2 H, $J = 7.9$, aromatic H), 5.60–5.39 (m, 1 H, $CH=CH_2$), 5.07–4.89 (m, 2 H, $CH=CH_2$), 4.28 (s, 2 H, $-SO_2CH_2-$, **3ha**), 4.25 (s, 2 H, $-SO_2CH_2-$, **3ha′**), 2.44 (s, 3 H, aryl CH_3), 2.35–2.08 (m, 4 H), 1.63–1.55 (m, 2 H), 1.25–0.74 (m, 5 H), 0.74 (s, 9 H, *t*-butyl); IR ($CHCl_3$) 3075 w, 3060 w, 3025 m, 3009 w, 2950 s, 2865 m, 1712 s, 1639 w, 1597 m, 1491 w, 1478 w, 1467 w, 1454 m, 1438 w, 1393 w, 1366 m, 1324 s, 1305 s, 1290 m, 1265 w, 1239 m, 1231 m, 1183 w, 1154 s, 1087 m, 1035 m, 1018 w, 1002 m, 980 w, 921 m, 871 w, 814 m; MS (70 eV) *m*/*z* 376 (M^+, 0.39), 221 (11), 220 (19), 203 (16), 179 (30), 178 (17), 155 (12), 137 (16), 123 (39), 109 (31), 107 (11), 95 (21), 91 (43), 83 (14), 81 (33), 79 (19), 69 (16), 67 (26), 65 (11), 57 (100), 55 (21), 43 (13), 41 (37). Anal. Calcd for $C_{22}H_{32}O_3S$: C, 70.21; H, 8.51; S, 8.51. Found: C, 70.25; H, 8.57; S, 8.44.

CACR of 1ha. The general procedures were followed. The diastereomeric ratios were based on NMR analysis of chromatographically homogeneous materials. See Table VII.

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Registry No. 1aa, 109787-35-1; **1ab**, 109787-39-5; **1ac**, 109889-21-6; **1ad**, 109787-38-4; **1af**, 109787-43-1; **1ba**, 109787-47-5; **1bd**, 87039-98-3; **1be**, 87039-99-4; **1bg**, 123209-39-2; **1ca**, 123209-23-4; **1cb**, 123209-26-7; **1da**, 123209-25-6; **1ea**, 109787-55-5; **1eb**, 123209-27-8; **1eh**, 91873-76-6; **1ei**, 109787-57-7; **1ej**, 109787-58-8; **1ek**, 91873-77-7; **1em**, 109787-59-9; **1fa**, 109787-63-5; **1fh**, 109787-64-6; **1fi**, 109787-65-7; **1ga**, 109787-67-9; **1gh**, 91873-78-8; **1gk**, 91873-79-9; **1ha**, 123209-45-0; **2aa**, 109787-36-2; **2ad**, 123209-24-5; **2bd**, 123209-44-9; **3aa**, 80945-31-9; **3ab**, 82352-35-0; **3ac**, 82352-34-9; **3ad**, 82352-33-8; **3ba**, 123209-28-9; **3bd**, 87040-00-4; **3be**, 87040-01-5; **3bg**, 123209-41-6; **3ca**, 80945-33-1; **3cb**, 123209-30-3; **3da**, 123209-29-0; **3ea**, 82352-36-1; **3eb**, 109787-56-6; **3eh**, 91873-80-2; **3i**, 123209-34-7; **3ek**, 91873-81-3; **3em**, 123209-33-6; **3fa**, 123209-31-4; **3fh**, 123209-35-8; **3fi**, 123209-36-9; **3ga**, 123209-32-5; **3gh**, 91873-82-4; **3gk**, 9173-83-5; *cis*-**3ha**, 123209-46-1; *trans*-**3ha**, 123209-47-2; **4ab**, 123209-37-0; **5**, 123209-38-1; **6**, 82352-37-2; **7**, 123209-40-5; **9bd**, 123209-42-7; **9be**, 123209-43-8; **10**, 66947-20-4; **13**, 123209-62-1; **14**, 51620-81-6; **15**, 123209-61-0; **16**, 123209-48-3; (*E*)-**18aa**, 123209-51-8; (*Z*)-**18aa**, 123209-52-9; (*E*)-**18ad**, 123209-53-0; (*Z*)-**18ad**, 123209-54-1; **19**, 123209-49-4; **20**, 123209-49-4; **21aa**, 123209-55-2; **21ad**, 123209-56-3; $MeCH=CH_2OH$, 6117-91-5; *syn*-2,3-dimethyl-4-pentenoic acid, 58367-54-7; *anti*-2,3-dimethyl-4-pentenoic acid, 58367-53-6; 2-(2-propenyloxy)propenal, 70265-44-0; 2-(2-propenyloxy)propenal diethyl acetal, 123209-57-4; 2-(2-propenyloxy)propenal oxime, 123209-58-5; 2-(2-propenyloxy)-2-propenyl methanesulfonate, 123209-59-6; 2-(2-propenyloxy)-2-propenol, 123209-60-9; thiophenol, 108-98-5; 1-phenylsulfenyl-2-propyne, 5651-88-7; 1-phenylsulfenyl-1,2-propadiene, 1595-38-6; 2-chloro-3-phenylsulfenyl-1-propene, 4834-59-7; chloramine-T, 127-65-1; allyl alcohol, 107-18-6; phenylsulfonylacetone, 5000-44-2.

Supplementary Material Available: A description of the general experimental methods and the preparations, full characterizations, and reactions of compounds containing other stabilizing groups (**13**, **14**, **15**, **17aa**, **18aa**, **18ad**, **19**, **20**, **21aa**, and **21ad**) (9 pages). Ordering information is given on any current masthead page.

Model Studies for the Mechanism of Inactivation of Monoamine Oxidase by 5-(Aminomethyl)-3-aryl-2-oxazolidinones

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Abstract: 3-[4-[(3-Chlorophenyl)methoxy]phenyl]-5-[(methylamino)methyl]-2-oxazolidinone (MD 780236) has been reported to be an irreversible inactivator of monoamine oxidase (MAO), but the mechanism of inactivation is not known. A mechanism is now proposed that involves one-electron transfer to give the corresponding amine radical cation, removal of an α-proton, and decomposition of the oxazolidinone ring with loss of CO_2 to another radical which attaches to an enzyme active site radical. Chemical model studies for the proposed inactivation mechanisms are reported. Treatment of 3-(4-methoxyphenyl)-5-(chloromethyl)-2-oxazolidinone with tributylstannane and AIBN at 190 °C gave *N*-allylanisidine (6%) and CO_2 in addition to the hydrogen atom rebound product 3-(4-methoxyphenyl)-5-methyl-2-oxazolidinone. A high yield of *N*-allylanisidine was obtained by treatment of the corresponding bromo analogue with zinc, magnesium, or *n*-butyllithium. These studies support a radical inactivation mechanism that may proceed through additional carbon radical or carbanion intermediates. MD 780236 labeled with ^{14}C at the carbonyl of the oxazolidinone ring inactivates MAO with loss of $^{14}CO_2$, consistent with the model study results.

Monoamine oxidase (MAO; EC 1.4.3.4) is a flavoenzyme that catalyzes the oxidation of various biogenic amines; inactivation of this enzyme can result in an antidepressant effect.[1,2] Our mechanistic studies over the last several years[3-15] with mecha-