Usually, 8–12 spectra were taken for each log K determination. The original cryptand concentrations were about 0.04 M, and the variation of metal cation concentrations were from 0.00 to 0.08 M for each of the experiments. In such an experiment, an accurately weighed quantity of the cryptand was dissolved in a known volume of solvent. The concentrations of metal ions and cryptands were calculated according to the volume in the tube and the original concentration of each material. The log K values were obtained from the variation of the observed chemical shift with the metal cation/ligand mole ratio. It should be noted that the method becomes unreliable for very stable complexes (log K > 5.0).[51,52]

Determination of log K and ΔH Values by the Titration Calorimetric Method. Calorimetric titrations were carried out in a Tronac Model 450 isoperibol calorimeter using the reported method.[45]

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Chemoselective Ring Construction from Unsymmetrical 1,6-Dienes via Radical Addition of Sulfonyl Halides

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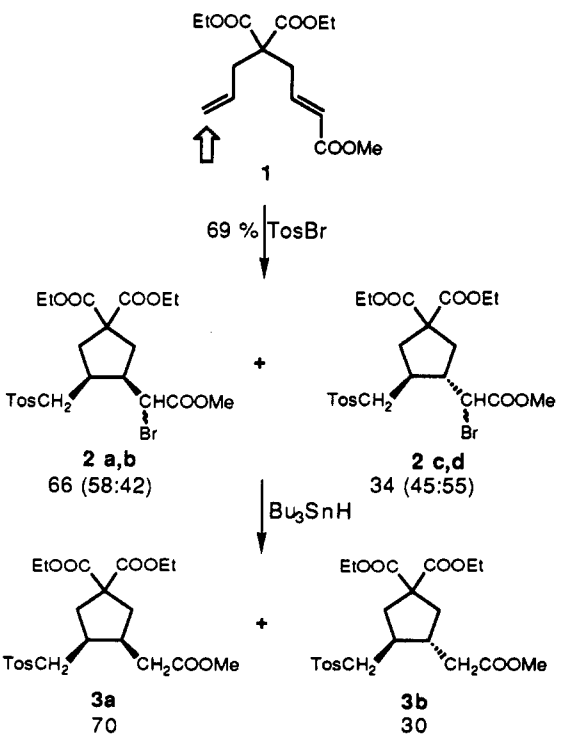
Received December 30, 1991 (Revised Manuscript Received July 30, 1992)

The sulfonyl radical-promoted cyclizations of 1,6-unsymmetrical dienes can be totally chemoselective. The addition of tosyl halides to various 1,6-dienes bearing both a nucleophilic and an electrophilic double bond clearly indicates that this attractive property is not related to the generally accepted electrophilic nature of tosyl radical. The chemoselectivity is likely to originate from the reversibility of the first step, i.e. tosyl radical addition to the double bond, which favors the formation of the adducts resulting from the one intermediate radical that cyclizes faster.

Sulfonyl radicals are generally recognized as useful intermediates in the synthesis of sulfones.[1] In previous papers,[2,3] we described the ability of the radical addition of sulfonyl halides to functionalize regio- and stereoselectively 1,6-dienes. Concurrently, other research groups have become interested in this strategy to prepare sulfonylated cyclic compounds from tosyl chloride,[4] tosyl iodide,[5] and allyl sulfones.[6,7]

From all these results it has appeared that the reaction with unsymmetrical 1,6-dienes could be highly stereoselective and moreover totally chemo- and regioselective. The synthetic aspects of the reaction have been illustrated by our experiments and those, previously mentioned, conducted simultaneously by other groups, whereas little attention has been paid to mechanistic aspects until very recently.[8] In order to investigate more thoroughly the reasons for such a high chemoselectivity, which we primarily ascribed to the reversibility of the initial addition of sulfonyl radical,[3] we studied the addition of TsBr to various 1,6-dienes bearing both a nucleophilic and an electrophilic double bond, thus trying to check the possibility of an influence of polar effects. The dienes 1 and 4 selected for this study contain both a monosubstituted

Scheme I



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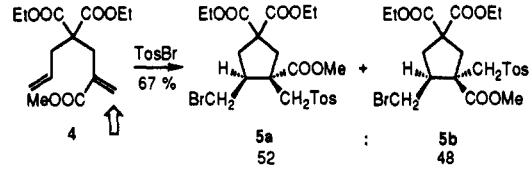
Scheme II



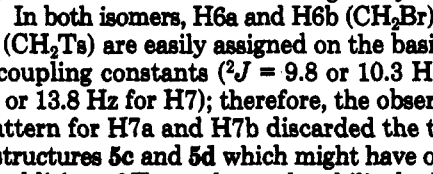
olefin and a α,β-unsaturated ester moiety. At the same time, we studied the addition of TsX to *N*-alkyl-*N*-allylacrylamides (**6a–d**).

Results

The reactions were carried out under the standard experimental conditions already described for other substrates.[1-3] In typical experiments, 0.035 M solutions of tosyl halide along with 1 equiv of diene in acetonitrile were irradiated at 18 °C (unless otherwise stated) until the reactants disappeared (the reactions were monitored by TLC). All the results are summed up in Schemes I–III and Table II.

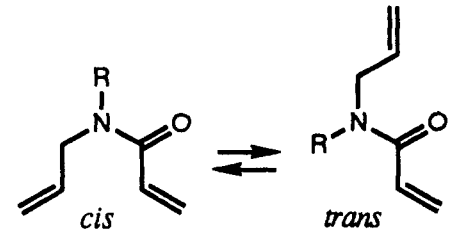
The addition of TsBr to **1** afforded a mixture of four diastereomers, resulting from the addition of Ts• to the monosubstituted double bond, in 69% yield. The cis stereochemistry was assigned to **2a** and **2b**, and conversely, **2c** and **2d** were identified as the trans adducts. HPLC analysis indicated a 66:34 ratio of **2a,b** versus **2c,d**. Only **2a** and **2b** could be, at least partially, isolated as pure samples. The stereochemistry of **2a** and **2d** was determined by ^{13}C NMR on the basis of the readily assigned chemical shift of C7 (CH_2Ts). C7 is significantly more shielded in **2a** than in **2d** (55.20 versus 60.25 ppm). The assignment of the cis configuration to **2b** and consequently of the trans configuration to **2c** was deduced from the reduction of a mixture of **2a** and **2b** by Bu_3SnH which led to **3a** as the only product, whereas the reduction of the four adducts mixture, under the same experimental conditions, led to **3a** and **3b** in a 70:30 ratio (this ratio confirmed, within the limits of experimental errors, the cis:trans proportion determined by HPLC on the unreduced products). The relative proportions of **2a:2b** and **2c:2d** witness to the low diastereoselectivity of the transfer of bromine atom from both isomers of the cyclic intermediate radical. The overall cis:trans stereoselectivity is lower than that previously observed for the addition of TsBr to the diethyl ester of diallylmalonic acid (93:7).[3]

The addition of TsBr to **4** was also totally chemoselective and led to two diastereomers, **5a** and **5b**, as a 52:48 mixture. The two diastereomers, isolated in 67% yield, resulted this time from the addition of the electrophilic tosyl radical to the electrophilic double bond. As could be reasonably expected, the reaction exhibited a low stereoselectivity. The structures were unambiguously established by NMR. In both isomers, H6a and H6b (CH_2Br) and H7a and H7b (CH_2Ts) are easily assigned on the basis of their geminal coupling constants (^2J = 9.8 or 10.3 Hz for H6; ^2J = 13.7 or 13.8 Hz for H7); therefore, the observation of an AB pattern for H7a and H7b discarded the two other possible structures **5c** and **5d** which might have originated from the addition of Ts• to the nucleophilic double bond.



Stereochemical assignments followed from ^{13}C NMR. The γ gauche effect contributes to shield C7 in **5a** more than in **5b** (57.39 versus 63.30 ppm). These results corroborate those reported by Chuang[7] for the addition of allyl sulfones to **4**.

Table I. Isomers Ratios in Amides 6



Amide	R	*cis*	*trans*
6a	CH_2Ph	40	60
6b	CH_2-CH=CH_2	50	50
6c	*t*Bu	100	0
6d	Ph	0	100

Acrylamides **6a–d** present a different structural feature. The carbonyl group is included in the linking chain. Owing to the restricted rotation around the C–N bond, the amides **6a–d** exist as two rotamers in equilibrium.[9] Table I summarizes their equilibrium ratios, measured by ^1H NMR, at room temperature.[10]

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(10) The rotational barrier in amide **6a** was estimated 16.9 kcal/mol from NMR. Coalescence temperature is 333 K for the benzylic protons and 343 K for the allylic protons.

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(17) (a) Mansuy, D.; Julia, M. *C. R. Acad. Sci. C* **1972**, *274*, 408. For related examples, see ref 14a and references therein. (b) Gottschalk, P.; Neckers, D. C. *J. Org. Chem.* **1985**, *50*, 3498. The addition of the nucleophilic acyl radical to methyl octa-2,7-dienoate (analogous to **1**), gives exclusively the six-membered-ring products resulting from the intermediate radical analogous to R'_2.

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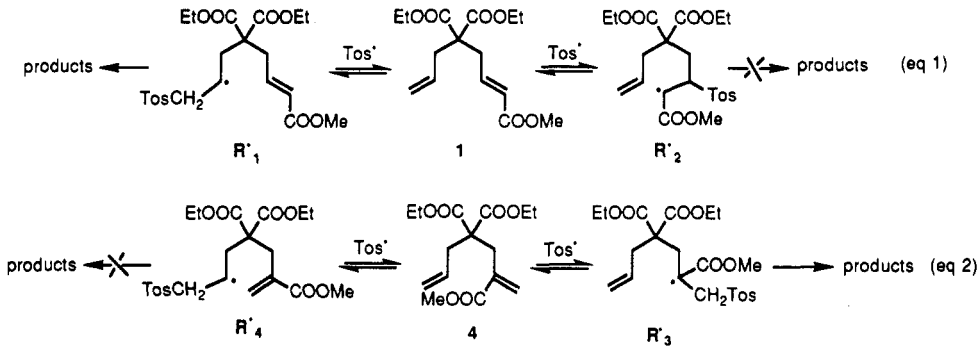
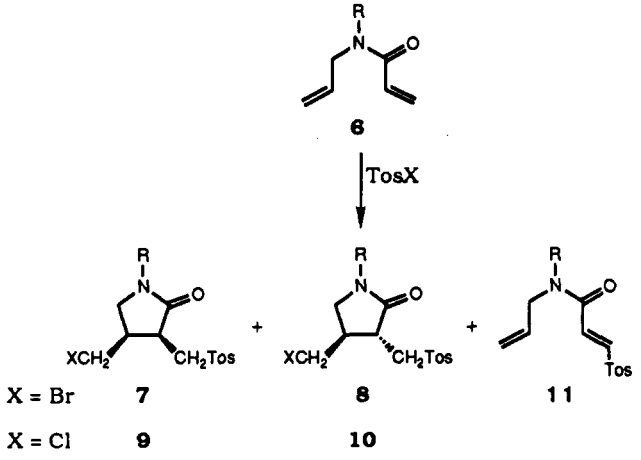


Scheme III



The addition of tosyl bromide and tosyl chloride to **6** led mainly to diastereomeric pyrrolidones (**7**:**8** or **9**:**10**) by chemoselective addition to the electron-poor double bond. A small amount of **11a** was isolated from the reaction of TsBr with **6a**. The addition of TsI to **6d** resulted in **11d** as the single product.[22] ^{1}H NMR spectra (400 MHz) were carefully analyzed with the help of COSY experiments in order to establish whether the tosylmethyl group was bound to C3 or C4 in pyrrolidones **7**–**10**. The splitting patterns clearly demonstrate that H3 is coupled to CH_2Ts whereas H4 interacts with CH_2Br (cf. Experimental Section). Stereochemical assignments were deduced from ^{13}C NMR spectra. HETCORR experiments allowed the assignment of CH_2X(C6) and CH_2Ts(C7) which are both more shielded in the cis isomers (**7**, **9**) than in the trans ones (**8**, **10**).

The addition of TsCl to **6a** was reported[4] to give **9a** and **10a** in a 80:20 ratio, in a 64% overall yield, when conducted at 100 °C on 0.1 M solutions of diene in the presence of 10 equiv of TsCl. Upon investigating the comparative behavior of TsBr toward **6a**–**c**, we found that the addition to **6a** led to **7a** and **8a** in the approximately reverse 24:76 ratio, when the reaction was conducted with stoichiometric amounts of both reactants, at 18 °C. Therefore, we decided to reinvestigate the addition of TsCl under various conditions. All the results are reported on Scheme III and Table II.

Table II. Tosyl Halide Addition[a] to Amides 6a–d

Substrate	TosX	Yield (%)	Products (%) and relative ratios	
6a	TosBr (i)	65	**7a** : **8a** (94%) 24 : 76	**11a** (6%)
6a	TosCl (i) (6 equiv.)	60	**9a** : **10a** (100%) 10 : 90	-
6a	TosCl (ii) (10 equiv.)	65	**9a** : **10a** (100%) 26 : 74	-
6b	TosBr (i)	66	**7b** : **8b** (100%) 20 : 80	-
6c	TosBr (i)	53	**7c** : **8c** (100%) 5 : 95	-
6d	TosI (iii)	64	-	**11d** (100%)

[a] (i) *hν* (high-pressure mercury lamp), at 18 °C in acetonitrile; 1 equiv of halide was used unless otherwise stated. (ii) Thermal initiation at 110 °C in toluene. (iii) *hν* (300-W sunlamp) at 40 °C in acetonitrile.

Discussion

It must be underlined for the following discussion that the overall yields in isolated products (60–70%, whatever the substrate) are very similar to those previously obtained with other dienes. The reaction proceeds through addition of the tosyl radical to one of the double bonds and subsequent ring formation. Two different routes are offered to the tosyl radical, and the individual rates of addition are likely to reflect either the electron demand of each partner or the relative stabilities of the resulting radicals. Diene **1** is the only substrate in the series where sulfur binds to the terminal carbon of the nucleophilic double bond. Although this observation is in apparent agreement with the electrophilic character of sulfonyl radicals,[11,12] this explanation does not hold for substrates **4** and **6** which give exclusively the adducts resulting from the addition to the electron-deficient double bond. The stabilization of the intermediate radicals does not provide a satisfying rationalization either. Sulfonyl radicals are generally recognized as electrophilic; however, a detailed examination of the few available kinetic results.[8,11] indicates that alkyl acrylates would be nearly as reactive as terminal olefins and that methyl methacrylate would be 4 times more reactive than 1-hexene. Therefore the addition of tosyl halides to unsymmetrical dienes should not be expected

(19) The rate constant for chlorine abstraction from $PhSO_2Cl$ by a primary alkyl radical was estimated 1.5×10^5 M^{-1} s^{-1} at 25 °C (see ref 12c and references therein). According to ref 24a, iodine transfer is 600 times faster than chlorine transfer; therefore, iodine abstraction can be estimated 9×10^7 M^{-1} s^{-1}. In the presence of 0.7 M [TsI], the approximate pseudo-first-order constant for iodine transfer would be 6×10^7 s^{-1}.

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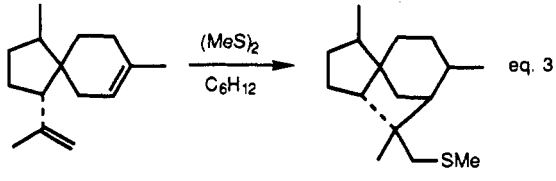
(21) (a) Snieckus, V.; Cuevas, J.-C.; Sloan, C. P.; Liu, H.; Curran, D. P. *J. Am. Chem. Soc.* **1990**, *112*, 896. (b) Curran, D. P.; Abraham, A. C.; Liu, H. *J. Org. Chem.* **1991**, *56*, 4335. (c) Clark, A. J.; Jones, K.; Mc Carthy, C.; Storey, J. M. D. *Tetrahedron Lett.* **1991**, *32*, 2829.

(22) **11d** was also formed from TsBr and **6d**. However the overall yield is only 40% and analytical difficulties do not allow the separation of the products. **11d**:(**7d** + **8d**) was estimated to be 15:85 from NMR. Only telomeric materials were isolated from the addition of TsCl to **6d**.

to be so selective. The results reported here are rather in favor of our opinion that the well-known reversibility of sulfonyl radical addition to double bonds[12c,6,13] plays a crucial role in determining product composition.

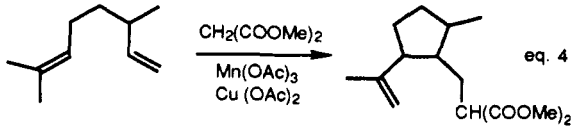
The rate constant for the fragmentation of β-benzenesulfonyl radicals was estimated superior to 10^7 s^{-1} at 0 °C, from refs 11b and 13e. The reverse step—even though it could be slowed by substituents able to stabilize the radical—is therefore faster than the known radical cyclizations of 5-hexenyl or 6-heptenyl radicals (the fastest rate constants for related processes being close to 10^7 s^{-1}).[14] The chemoselectivities reported herein, in the case of dienes 1 and 4, are in fairly good agreement with the equilibration of the radical pairs, ($\mathbf{R}^{\bullet}_1$, $\mathbf{R}^{\bullet}_2$) and ($\mathbf{R}^{\bullet}_3$, $\mathbf{R}^{\bullet}_4$) (eqs 1 and 2). Neither constant has ever been measured, but there is no doubt that the rate constant for the 5-*exo* cyclization of the nucleophilic radical $\mathbf{R}^{\bullet}_1$, involving an activated double bond, would be higher than that of the 6-*exo* rearrangement of radical $\mathbf{R}^{\bullet}_2$.[14] Similarly, a qualitative approach would lead to the prediction that radical $\mathbf{R}^{\bullet}_3$, although made rather nucleophilic by its two alkyl-like substituents,[15] should cyclize faster, according to the 5-*exo* mode, than radical $\mathbf{R}^{\bullet}_4$. The last one, owing to substitution of the double bond in the 5-position—moreover by an electron-withdrawing group—would probably lead to six-membered ring products. This typical situation is known to slow down the 5-*exo* cyclization process and therefore to favor the 6-*endo* mode.[14] We already encountered such a context for the addition of TsBr to the diethyl ester of allyl methallyl malonic acid.[3]

Steric[16a] or polar effects[16b] and more generally stabilization effects[16c] are now well known to affect the selectivity of both inter- and intramolecular free-radical reactions. Chemoselective radical-induced cyclizations taking advantage of the irreversible addition of either an electrophilic radical[17a] or a nucleophilic radical[17b] to unsymmetrical dienes have been exploited. To our knowledge, there are very few reports that illustrate a similar result from radicals, adding reversibly to double bonds. Some of them involve thiyl radicals,[18a,b] although these results were not discussed in these terms. The nearly quantitative yield of a single 1:1 tricyclic adduct of methane thiol[18a] to α-acoradiene is well rationalized in that way (eq 3).



eq. 3

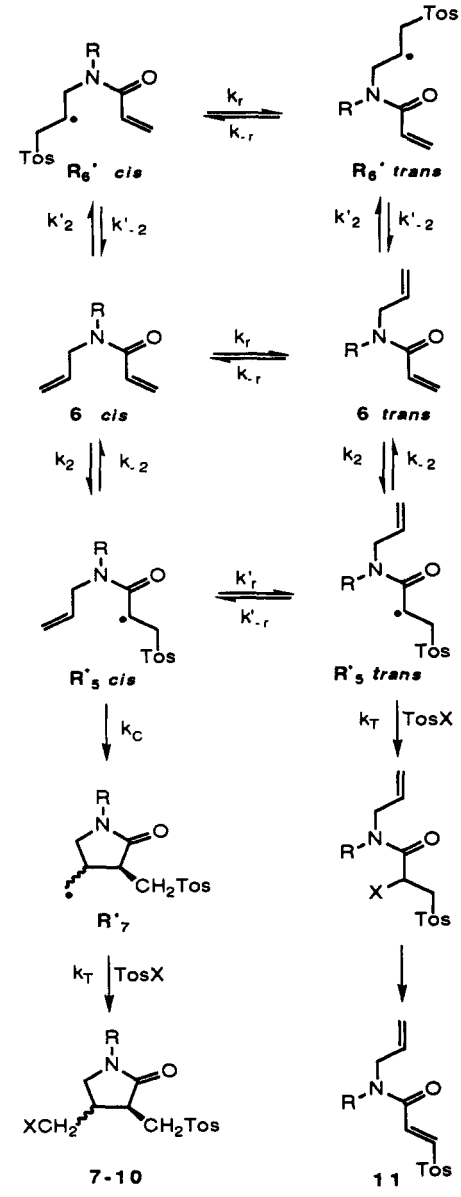
McQuillin and Wood were the first to suggest that a reversible addition, followed by the fastest of the several possible ensuing steps, could explain the highly chemoselective Mn(III)-induced reaction of dimethyl malonate to 3,7-dimethyl-1,6-octadiene[18c-e] (eq 4). In the presence of Cu(II), the only product originated from the addition of malonyl radical to the less substituted double bond. Stork rationalized in the same way the chemoselective stannyl radical induced cyclization of enynes.[18f]



eq. 4

The addition of tosyl halides to acrylamides 6 deserves three separate comments (Scheme IV represents the different steps that might be involved). First, it must be pointed out that, once again, polar factors—referring to

Scheme IV



an electrophilic radical—cannot explain the chemoselectivity. Two kinds of adducts were isolated, both kinds resulting from the addition of Ts• to the acrylic double bond. According to the above discussion, these results could indicate that radical $\mathbf{R}_5^{\bullet}$ cyclizes much faster than radical $\mathbf{R}_6^{\bullet}$, even in the case of amide **6b** which offers the possibility of a fast intramolecular addition to the second allylic chain. We have studied the addition of TsI to **6d** in order to estimate the intrinsic reactivity of each double bond (because of its conformation, **6d** has no propensity to cyclization in the presence of a fast halogen atom transfer agent such as tosyl iodide). The dehydrohalogenated adduct **11d** was the sole isolated product, even in the presence of 20 times greater concentrations of reactants.[19] Thus, substrates **6a–d** behave as if the acrylic double bond was the only reactive center. These experiments, and especially the very last one, may question the actual efficiency of the addition step leading to $\mathbf{R}_6^{\bullet}$, which in turn may raise the question of the stabilization of α-carbamoyl radicals as the determining factor of the chemoselectivity. According to Occam's razor, the simplest rationalization implies that tosyl radical adds much faster to the acrylamide than to the other double bond and that this fast addition step is followed either by a fast cycli-

Table III. Calculated Differences in Strain Energy between 7 and 8

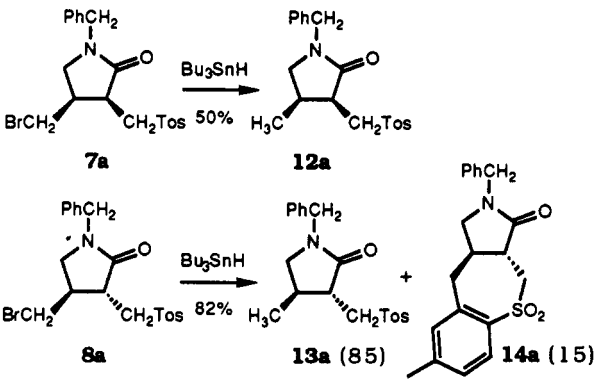
R	CH_2Ph	$CH_2CH{=}CH_2$	*tert*-Bu
ΔE (kcal)	3,5	4,5	5,5
cis:*trans*	24:76	20:80	5:95

zation or by a fast iodine transfer. These results are somewhat puzzling. They underline that too few kinetic data are available for the radical additions to acrylamides.

Secondly, amides **6a** and **6d** are the only two members in the series leading to 1,2-dehydrohalogenated adducts **11**. The conformational equilibrium strongly influences the chemoselectivity of radical reactions involving amides.[20,21] Contrary to the tin hydride promoted cyclizations of *N*-allyl α-halo amides[20] which are known to give pyrrolidones to reduced products ratios that are very sensitive to the conformational equilibrium of the amide, the proportion of cyclized adducts versus 1,2-adducts reported herein do not strictly reflect the amide conformation except in the case of the previously discussed addition of TsI to **6d**. Amide **6a**, which displays 60% of trans rotamer, unfavorably disposed to cyclization, affords only 6% of 1,2-adduct **11a**.[22] The formation of **11a** was completely inhibited when TsBr was replaced by TsCl. This implies that, under these typical experimental conditions, even the rate of the bimolecular bromine atom transfer is low compared to the rate of isomerization of radical $\mathbf{R_5}^{\bullet}{}_{trans}$ into $\mathbf{R_5}^{\bullet}{}_{cis}$ via rotation around the C–N bond (this rate should not be very different for the radical and for the amide).

The third point we were interested in is stereoselectivity. The cyclization is highly stereoselective and exhibits a strong preference for the trans diastereomer. This observation is rather unusual in the field of 5-*exo* radical cyclization but the classical stereoelectronic model of "chair-like" and "boat-like" transition states may not apply to α-carbamoyl radicals involving a rather rigid amide moiety.[23a] Tin hydride promoted cyclization of α-chloro- and α-(phenylthio)-*N*-allylamides has been also reported to afford predominantly trans isomers.[23b] Several observations suggest that this selectivity might result from a thermodynamic control, involving a reversible cyclization step. The diastereoselectivity is influenced by the nature of the halide. Replacement of tosyl bromide by tosyl chloride enhanced the diastereoselectivity by slowing down the final step of halogen atom transfer (the rate constant for the transfer of bromine to phenyl radical is 192 times that of chlorine transfer).[24] Similarly slowing down the rate of bromine transfer by adding TsBr with a syringe pump over 8 h increases the ratio of **8a** from 76 to 87%. The diastereomeric ratio is sensitive to the substituent on nitrogen. Molecular mechanics calculations[25] confirm that the cis isomers are less stable than the trans ones. Though obviously overestimated, if refered to experimental results,

Scheme V



the calculated differences in total strain energy fit in with the variation of the cis:trans ratio in the series (cf. Table III). However, we could not get any evidence of this reversibility from the reduction of **7a** and **8a** by Bu_3SnH under highly diluted conditions. The reduction of **8a** led to a mixture of **13a** and **14a** in 82% overall yield. Owing to the low concentration of tin hydride, intramolecular aromatic substitution is competitive with the hydrogen transfer. The reduction of **7a** was less efficient; **12a** was isolated in 50% yield. Heavier unidentified side products were also formed, but from the NMR analysis of the crude reaction mixture, no ethylenic protons which could have arisen from ring-opening products were detected. Furthermore MM force field calculations recently performed on other α-carbamoyl-5-hexenyl radicals conclude that the most stable transition state leads to the trans cyclized product, which therefore, must be the kinetic product.[23]

Conclusion

The chemoselective addition of sulfonyl radicals to unsymmetrical 1,6-dienes offers attractive routes to radical cyclization that we are currently investigating in the field of carbohydrates derivatives. The results described therein lead to the conclusion that the observed chemoselectivity can neither be ascribed to polar effects nor to stabilization effects. The reversibility of the addition of sulfonyl radical to double bonds can play a crucial part in favoring the formation of the adducts which result from the one intermediate radical that cyclizes faster.

Experimental Section

Melting points are uncorrected. NMR spectra were recorded in $CDCl_3$ solution (unless otherwise stated). Column chromatographies were performed on silica gel 60 (Merck 7734). HPLC analysis were conducted on Waters Nova-Pak silica (4 μm) column (3.9-mm i.d. × 15 cm) coupled to a UV detector (254 nm) or a refractometer, using EtOAc–isooctane mixtures as eluent. Sulfonyl bromide was prepared according to a procedure adapted from a previously described synthesis of sulfonyl iodide[26] and was dried under vacuum before use. Dienic starting materials (**1**, **4**) were obtained by alkylation of monoallylmalonic acid esters according to classical procedures.[27]

Preparation of Methyl 5,5-Bis(ethoxycarbonyl)-2,7-octadienoate (1). Ethyl 2-propenyl-2-propanedioate (5.55 g, 28 mmol) was added dropwise to a suspension of sodium hydride (0.67 g, 28 mmol) in DMF at 0 °C. The reaction was allowed to warm up to room temperature and then stirred for half an hour. After cooling again at 0 °C, methyl 4-bromo-2-butenoate (5 g, 28 mmol) was added. After 24 h at room temperature, the reaction mixture

(23) (a) α-Carbamoyl radicals also exhibit a peculiar behavior with regard to disfavored 4-*exo* and 5-*endo* cyclization modes, see: Ishibashi, H.; Nakamura, N.; Tatsunori, S.; Takeuchi, M.; Ikeda, M. *Tetrahedron Lett.* **1991**, *32*, 1725 and Fremont, S.; Belletire, J. L.; Ho, D. M. *Tetrahedron Lett.* **1991**, *32*, 2335. (b) Sato, T.; Wada, Y.; Nishimoto, M.; Ishibashi, H.; Ikeda, M. *J. Chem. Soc., Perkin Trans. 1* **1989**, 879. (c) Gennari, C.; Poli, G.; Scolastico, C.; Vassalo, M. *Tetrahedron Asym.* **1991**, *2*, 793.

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was diluted with water, extracted with ether, and dried on Na_2SO_4. Chromatography on silica gel (EtOAc–pentane, 10:90), gave 4.6 g of **1** (55%): IR (neat) 1731, 1660, 984, 925, 859 cm^{-1}; ^1H NMR (200 MHz) 1.26 (t, J = 7.2, 6 H), 2.65 (d, J = 7.3, 2 H), 2.77 (d, J = 7.8, 2 H), 3.72 (s, 3 H), 4.21 (q, J = 7.2, 4 H), 5.10–5.18 (m, 2 H), 5.55–5.75 (m, 1 H), 5.88 (d, J = 15.6, 1 H), 6.81 (dt, J = 15.6, 7.8, 1 H). Anal. Calcd for $C_{15}H_{22}O_6$: C, 60.39; H, 7.43. Found: C, 60.51; H, 7.37.

Addition of TsBr to 1. Irradiation of a 1:1 mixture of **1** (1.3 g, 4.36 mmol) and TsBr (1.03 g, 1 equiv) dissolved in 140 mL of acetonitrile at 18 °C during 30 h led, after chromatography on silica gel using EtOAc–petroleum ether mixtures of gradually increased polarity (10:90 to 40:60), to 1.6 g of adducts **2a–d** (69%), in that order of elution. Only the first and last ones could be isolated as pure samples. The relative ratios were determined by analytical HPLC (two identical coupled columns; EtOAc–isooctane, 20:80; 2.5 mL/min). Anal. Calcd for $C_{22}H_{29}O_8SBr$ (mixture): C, 49.54; H, 5.48; S, 6.01. Found: C, 49.52; H, 5.60; S, 5.90.

Diethyl 3-(Bromo(methoxycarbonyl)methyl)-4-(tosylmethyl)cyclopentane-1,1-dicarboxylate (2). 2a: ^1H NMR (200 MHz) 1.25 (t, J = 7.1, 3 H), 1.26 (t, J = 7.1, 3 H), 2.21 (dd, J = 13.4, 9.5, 1 H), 2.46 (s, 3 H), 2.51–2.85 (m, 5 H), 3.11 (d, J = 6.6, H7a,b), 3.73 (s, 3 H), 4.20 (q, J = 7.1, 4 H), 4.25 (d, J = 8.5, H6), 7.37 (d, J = 8.0, 2 H), 7.75 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz) 14.07 (2 CH_3), 21.68 (CH_3), 36.01 (C4), 37.73 (C2*), 39.16 (C5*) (* these assignments may be reversed), 45.59 (C3), 46.29 (C6), 53.21 (CH_3O), 55.20 (C7), 58.14 (C1), 61.92 (CH_2O), 62.02 (CH_2O), 128.18 (=CH), 130.12 (=CH), 136.81 (=C), 144.98 (=C), 168.32 (C=O), 169.13 (C=O), 171.69 (C=O). **2b:** the following signals, assigned to **2b** followed from the spectral data of a **2a:2b** mixture; ^1H NMR (200 MHz) 2.05 (dd, J = 13.7, 12.2, 1 H), 2.26 (dd, J = 13.5, 7.1, 1 H), 3.76 (s, 3 H), 3.84 (d, J = 11.2, 1 H), 4.18 (q, J = 7.1, 2 H), 7.77 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz): 35.70 (C2*), 36.42 (C4), 36.42 (C5*), 44.14 (C3), 46.41 (C6), 53.73 (C7), 61.95 (CH_2O), 127.95 (=CH), 136.15 (=C), 144.80 (=C), 171.26 (C=O). **2d:** ^1H NMR (400 MHz) 1.23 (t, J = 7.1, 3 H), 1.24 (t, J = 7.1, 3 H), 2.18 (dd, J = 14.0, 7.0, H2a*), 2.25 (dd, J = 14.0, 8.7, H5a*), 2.32–2.45 (m, H4, H3), 2.46 (superimposed s, 3 H), 2.56 (dd, J = 14.0, 7.3, H2b*), 2.69 (dd, J = 14.0, 8.1, H5b*), 3.13 (dd, J = 14.0, 9.0, H7a), 3.25 (dd, J = 14.0, 3.0 H7b), 3.74 (s, 3 H), 4.17 (q, J = 7.1, CH_2O), 4.18 (q, J = 7.1, CH_2O), 4.38 (d, J = 5.9, H6), 7.37 (d, J = 8.0, 2 H), 7.78 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz) 13.91 (2 CH_3), 21.55 (CH_3), 36.93 (C4), 37.03 (C2*), 39.75 (C5*), 47.14 (C3), 48.90 (C6), 53.17 (CH_3O), 58.80 (C1), 60.25 (C7), 61.75 (CH_2O), 61.84 (CH_2O), 127.99 (=CH), 130.00 (=CH), 136.24 (=C), 144.90 (=C), 169.30 (C=O), 171.10 (C=O), 171.66 (C=O).

Diethyl 3-((Methoxycarbonyl)methyl)-4-(tosylmethyl)-cyclopentane-1,1-dicarboxylate (3). The reduction of a mixture of **2a–d** (1.54 g, 2.9 mmol) by Bu_3SnH (900 mg, 3.1 mmol) at reflux in toluene (10 mL), using AIBN as initiator, afforded after purification by column chromatography on silica gel (EtOAc–petroleum ether, 20:80 to 40:60) 530 mg (40%) of a 70:30 mixture of **3a** and **3b** (the ratio was measured by HPLC, AcOEt–isooctane, 25:75, 1 mL/min). Conversely the reduction of a mixture of **2a** and **2b** (340 mg, 0.64 mmol) under the same conditions led to 170 mg (59%) of **3a** as the only product. **3a:** ^1H NMR (400 MHz) 1.22 (2 t, $\Delta\nu$ = 1.76 Hz, J = 7.1, 6 H), 2.06 (dd, J = 14.1, 6.3, H2a), 2.20 (dd, J = 15.6, 8.7, H5a), 2.26 (dd, J = 14.1, 6.0, H2b), 2.29 (dd, J = 15.6, 6.2, H5b), 2.41 (dd, J = 13.6, 6.9, H6a), 2.44 (superimposed s, 3 H), 2.50–2.65 (m, H6b, H3, H4), 3.02 (dd, J = 14.0, 8.5, H7a), 3.11 (dd, J = 14.0, 4.3, H7b), 3.62 (s, 3 H), 4.15 (q, J = 7.1, CH_2O), 4.17 (q, J = 7.1, CH_2O), 7.36 (d, J = 8.0, 2 H), 7.78 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz) 14.00 (2 CH_3), 21.50 (CH_3), 34.25 (C6), 36.57 (C4), 38.25 (C2*), 38.80 (C3), 38.92 (C5*), 51.70 (CH_3), 56.35 (C7), 58.51 (C1), 61.68 (OCH_2), 61.80 (OCH_2), 128.10 (=CH), 130.01 (=CH), 136.82 (=C), 144.79 (=C), 171.92 (C=O), 172.31 (C=O), 172.34 (C=O). **3b:** the following signals specifically assigned to **3b**, were deduced from the spectra of a **3a:3b** mixture, ^1H NMR (400 MHz) 1.95 (dd, J = 13.5, 9.5, 1 H), 2.13 (dd, J = 12.6, 8.7, 1 H), 3.25 (dd, J = 13.9, 2.0, 1 H), 3.63 (s, 3 H); ^{13}C NMR (100 MHz) 37.70 (C6*), 38.94 (C4), 39.38 (C2*), 39.76 (C3), 41.14 (C5*), 51.63 (OCH_3), 59.03 (C1), 60.32 (C7), 61.62 (OCH_2), 129.98 (=CH), 144.75 (=C), 172.34 (C=O).

Preparation of Methyl 4,4-Bis(ethoxycarbonyl)-2-methylene-6-heptenoate (4). According to the protocol previously described for the preparation of **1**, the alkylation of ethyl 2-propenyl-2-propanedioate (4.8 g, 24 mmol) with methyl 2-(bromomethyl)-2-propenoate led after purification by liquid chromatography (LC) to 3 g (42%) of **4**: IR (neat) 1727, 1630, 955, 926, 860 cm^{-1}; ^1H NMR 1.23 (t, J = 7.1, 6 H), 2.60 (d, J = 7.2, 2 H), 2.98 (s, 2 H), 3.72 (s, 3 H), 4.15 and 4.17 (2 q, J = 7.1, 4 H), 5.07–5.14 (m, 2 H), 5.67–5.77 (m, 2 H), 6.27 (d, J = 1.3, 1 H).

Addition of TsBr to 4. After irradiation of a solution of **4** (1.5 g, 5 mmol) along with TsBr (1.18 g, 5 mmol) in 140 mL of CH_3CN during 24 h, purification on silica gel, using AcOEt–petroleum ether (15:85 to 40:60), gave 1.79 g (comprising 200 mg of a pure sample of **5a**) of **5a** and **5b** (67%) in that order of elution. A pure sample of **5b** was isolated by a second chromatography. The 52:48 ratio of **5a:5b** was determined by analytical HPLC (EtOAc–isooctane, 25:75; 2 mL/min). Anal. Calcd for $C_{22}H_{29}BrO_2S$ (mixture): C, 49.54; H, 5.48; S, 6.01. Found: C, 49.49; H, 5.50; S, 5.90.

Diethyl 4-(Bromomethyl)-3-(methoxycarbonyl)-3-(tosylmethyl)cyclopentane-1,1-dicarboxylate (5). 5a: ^1H NMR (200 MHz) 1.27 (t, J = 7.1, 6 H), 2.39–2.48 (m, H5a), 2.45 (superimposed s, 3 H), 2.60–2.73 (m, H5b, H4), 3.04 (d, J = 15.2, H2a), 3.11 (t, J = 9.8, H6a), 3.35 (d, J = 13.7, H7a), 3.38 (d, J = 15.2, H2b), 3.57 (dd, J = 9.8, 3.6, H6b), 3.60 (d, J = 13.7, H7b), 3.73 (s, 3 H), 4.14–4.30 (m, 4 H), 7.36 (d, J = 8.0, 2 H), 7.75 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz) 13.73 (2 CH_3), 21.36 (CH_3), 31.00 (C6), 37.53 (C5), 39.55 (C2), 49.77 (C4), 52.80 (CH_3O), 53.35 (C3), 56.77 (C1), 57.39 (C7), 61.74 (CH_2O), 62.08 (CH_2O), 127.66 (=CH), 129.79 (=CH), 137.58 (=C), 144.83 (=C), 171.04 (C=O), 171.70 (C=O), 172.57 (C=O). **5b:** ^1H NMR (200 MHz) 1.25 (t, J = 7.1, 3 H), 1.29 (t, J = 7.1, 3 H), 2.24 (t, J = 11.3, H5a), 2.39–2.60 (m, H5b, H4), 2.45 (superimposed s, 3 H), 2.89 (d, J = 14.9, H2a), 3.03 (t, J = 9.4, 10.3, H6a), 3.29 (d, J = 13.8, H7a), 3.34 (d, J = 14.9, H2b), 3.40 (dd, J = 10.3, 4.0, H6b), 3.68 (s, 3 H), 4.06 (d, J = 13.8, H7b), 4.14–4.31 (m, 4 H), 7.36 (d, J = 8.0, 2 H), 7.77 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz), 13.98 (CH_3), 14.09 (CH_3), 21.66 (CH_3), 30.92 (C6), 37.90 (C5), 40.85 (C2), 51.75 (C4), 52.59 (CH_3O), 53.84 (C3), 57.51 (C1), 61.74 (CH_2O), 62.17 (CH_2O), 63.30 (C7), 127.82 (=CH), 129.97 (=CH), 137.85 (=C), 144.94 (=C), 170.85 (C=O), 171.66 (C=O), 172.60 (C=O).

Preparation of *N*-Benzyl-*N*-(2-propenyl)acrylamide (6a). 2-Propenylbenzylamine (5.6 g, 38 mmol), prepared by alkylation of 2-propenylamine with benzyl chloride, was stirred at room temperature in the presence of 2-propenoyl chloride (4.14 g, 1.2 equiv) and NEt_3 (3.85 g, 38 mmol) in CH_2Cl_2 (25 mL) during 24 h. After being washed with water and dried over Na_2SO_4, the crude product was purified by LC (EtOAc–petroleum ether, 10:90 to 30:70). **6a** (5.72 g) was isolated in 75% yield: IR (neat) 1652, 1615, 979, 926, 735, 700 cm^{-1}; ^1H NMR (200 MHz) (the product is a mixture of two rotational isomers) 3.90 (d, J = 4.3, 1.2 H), 4.06 (d, J = 5.7, 0.8 H), 4.57 (s, 0.8 H), 4.65 (s, 1.2 H), 5.09–5.24 (m, 2 H), 5.66–5.80 (m, 2 H), 6.39 (dd, J = 16.7, 2.8, 1 H), 6.54 (dd, J = 16.7, 9.5, 1 H), 7.16–7.35 (m, 5 H). Anal. Calcd for $C_{13}H_{15}NO$: C, 77.58; H, 7.51; N, 6.96. Found: C, 77.40; H, 7.55; N, 6.93.

Addition of TsBr to 6a. Irradiation of a solution of **6** (1 g, 4.98 mmol) and TsBr (1.17 g, 4.98 mmol) in CH_3CN (140 mL) during 18 h at 18 °C afforded after purification by LC (EtOAc–petroleum ether, 30:70 to 50:50) 50 mg of **11a**, 80 mg of a mixture of **11a** and **7a**, 400 mg of a mixture of **7a** and **8a**, and 880 mg of **8a**. HPLC analysis (AcOEt–isooctane, 30:70; 1 mL/min) indicated a 6:22.5:71.5 ratio of **11a:7a:8a**. A second chromatography allowed the separation of a pure sample of **7a**. A second experiment carried out on 0.39 g (1.94 mmol) of **6a** in 140 mL of acetonitrile, introducing TsBr (0.45 g, 1 equiv) diluted in 8 mL of solvent over 8 h with a syringe pump, led to 25 mg of unreacted **6a**, 20 mg of **11a**, and 400 mg of a 13:87 mixture of **7a** and **8a** (overall yield, 62%).

***N*-Benzyl-*N*-(2-propenyl)-3-tosylacrylamide (11a)** (the product is a 60:40 mixture of two rational isomers): ^1H NMR (200 MHz) 2.45 (s, 3 H), 3.93 (d, J = 4.8, 1.2 H), 4.04 (d, J = 6.0, 0.8 H), 4.60 (s, 0.8 H), 4.63 (s, 1.2 H), 5.13–5.30 (m, 2 H), 5.60–5.90 (m, 1 H), 7.13–7.40 (m, 9 H), 7.67 (d, J = 8.1, 0.8 H), 7.76 (d, J = 8.1, 1.2 H); ^{13}C NMR (25 MHz) 21.62 (2 CH_3), 48.68 (CH_2), 49.22 (CH_2), 49.40 (CH_2), 50.47 (CH_2), 117.75 (=CH_2), 118.57 (=CH_2), 126.27 (=CH), 126.50 (=CH), 127.74 (=CH), 128.13 (=CH),

128.26 (=CH), 128.68 (=CH), 129.03 (=CH), 130.10 (=CH), 130.55 (=CH), 131.78 (=CH), 132.07 (=CH), 135.80 (=C), 136.32 (=C), 141.66 (=C), 141.83 (=C), 145.28 (2 × =C), 163.13 (C=O), 163.38 (C=O). Anal. Calcd for $C_{20}H_{22}BrNO_3S$: C, 67.58; H, 5.96; N, 3.94; S, 9.02. Found: C, 67.48; H, 6.05; N, 3.90; S, 9.00.

***N*-Benzyl-4-(bromomethyl)-3-(tosylmethyl)-2-pyrrolidone (7a, 8a).** **7a**: mp (EtOH) 115 °C; ^{1}H NMR (400 MHz) 2.48 (s, 3 H), 3.03 (qd, J = 7.3, 3.4, H4), 3.17 (ddd, J = 12.3, 8.0, 1.8, H3), 3.23 (d, J = 10.5, H5a), 3.29 (dd, J = 14.5, 12.3, H7a), 3.41 (dd, J = 10.5, 6.4 H5b), 3.43 (dd, J = 10.5, 7.3, H6a), 3.66 (dd, J = 10.5, 3.4, H6b), 3.72 (dd, J = 14.5, 1.8, H7b), 4.27 (d, J = 14.8, NCHa), 4.58 (d, J = 14.8, NCHb), 7.17–7.33 (m, 5 H), 7.36 (d, J = 8.3, 2 H), 7.79 (d, J = 8.3, 2 H); ^{13}C NMR (100 MHz) 21.63 (CH_3), 33.09 (C6) 35.39 (C4), 40.30 (C3), 47.14 (C9), 49.39 (C5), 52.50 (C7), 127.88 (=CH), 128.35 (=CH), 128.76 (=CH), 130.13 (=CH), 135.49 (=C), 135.87 (=C), 145.25 (=C), 170.77 (C2). Anal. Calcd for $C_{20}H_{22}BrNO_3S$: C, 55.05; H, 5.08; N, 3.21; S, 7.35. Found: C, 55.06; H, 5.14; N, 3.23; S, 7.50. **8a**: ^{1}H NMR (400 MHz) 2.45 (s, 3 H), 2.81 (quint of d, J = 7.4, 3.5, H4), 2.91 (ddd, J = 10.2, 8.2, 2.4, H3), 3.12 (dd, J = 14.3, 10.2, H7a), 3.14 (dd, J = 10.1, 7.4, H5a), 3.39 (dd, J = 10.1, 8.5, H5b), 3.67 (dd, J = 10.4, 7.4, H6a), 3.80 (dd, J = 14.3, 2.4, H7b), 3.88 (dd, J = 10.4, 3.5, H6b), 4.38 (d, J = 14.6, NCHa), 4.56 (d, J = 14.6, NCHb), 7.15–7.34 (m, 5 H), 7.36 (d, J = 8.2, 2 H), 7.80 (d, J = 8.2, 2 H); ^{13}C NMR (100 MHz) 21.52 (CH_3), 35.52 (C6), 39.25 (C4), 41.36 (C3), 46.91 (C9), 49.66 (C5), 57.39 (C7), 127.74 (=CH), 127.84 (=CH), 127.97 (=CH), 128.68 (=CH), 129.98 (=CH), 135.34 (=C), 135.91 (=C), 145.05 (=C), 171.52 (C2). Anal. Calcd for $C_{20}H_{22}BrNO_3S$: C, 55.05; H, 5.08; N, 3.21; S, 7.35. Found: C, 54.87; H, 5.15; N, 3.12; S, 7.30.

Addition of TsCl to 6a. Reaction of **6a** (1.5 g, 7.46 mmol) and TosCl (9.03 g, 6.3 equiv) dissolved in toluene (75 mL), at room temperature, under irradiation in the presence of benzoyl peroxide, gave 1.74 g (100 mg of **9a**, 350 mg of a **9a**:**10a** mixture, and 1290 mg of **10a**, 60% overall yield) of a 10:90 mixture of **9a**:**10a** isolated from LC (AcOEt–petroleum ether, 10:90 to 40:60). In another experiment, **6a** (0.115 g, 0.57 mmol) and TsCl (1.15 g, 5.97 mmol, 10.4 equiv) were refluxed for 8 h in toluene (5 mL), in the presence of benzoyl peroxide. After evaporation of the solvent and LC of the crude mixture (EtOAc–petroleum ether, 65:35), 135 mg (60%) of **9a** and **10a** were isolated, in a 26:74 ratio (HPLC, AcOEt–isooctane, 30:70, 1 mL/min). Anal. Calcd for $C_{20}H_{22}ClNO_3S$ (mixture): C, 61.29; H, 5.66; N, 3.57; Cl, 9.05; S, 8.18. Found: C, 61.12; H, 5.57; N, 3.56; Cl, 9.20; S, 8.20.

***N*-Benzyl-4-(chloromethyl)-3-(tosylmethyl)-2-pyrrolidone (9a, 10a).** **9a**: ^{1}H NMR (200 MHz) 2.47 (s, 3 H), 2.83–3.16 (m, H4, H3), 3.15 (dd, J = 14.2, 10.0, H7a), 3.21 (dd, J = 10.3, 7.4, H5a), 3.42 (dd, J = 10.3, 8.5, H5b), 3.82 (dd, J = 14.2, 2.0, H7b), 3.83 (dd, J = 11.2, 6.7, H6a), 3.99 (dd, J = 11.2, 3.4, H6b), 4.45 (AB type spectrum, J_{AB} = 14.6, $\Delta\nu$ = 46.7 Hz, NCH_2), 7.39 (d, J = 8.1, 2 H), 7.83 (d, J = 8.1, 2 H); ^{13}C NMR (25 MHz) 21.66 (CH_3), 35.45 (C4), 39.54 (C3), 44.60 (C6), 47.12 (NCH_2), 48.40 (C5), 52.63 (C7), 127.92 (=CH), 128.35 (=CH), 128.74 (=CH), 130.15 (=CH), 135.54 (=C), 135.86 (=C), 145.24 (=C), 170.94 (C2). **10a**: ^{1}H NMR (200 MHz) 2.46 (s, 3 H), 2.82–3.01 (m, H3, H4), 3.15 (dd, J = 14.1, 10.0, H7a), 3.21 (dd, J = 10.0, 7.4, H5a), 3.42 (dd, J = 10.0, 8.5, H5b), 3.82 (dd, J = 14.1, 2.1, H7b), 3.86 (dd, J = 11.2, 6.7, H6a), 3.99 (dd, J = 11.2, 3.4, H6b), 4.51 (AB type spectrum, J_{AB} = 14.7, $\Delta\nu$ = 15.4 Hz, NCH_2), 7.17–7.35 (m, 5 H), 7.37 (d, J = 8.0, 2 H), 7.82 (d, J = 8.0, 2 H); ^{13}C NMR (25 MHz) 21.54 (CH_3), 39.40 (C4*), 40.03 (C3*), 46.08 (C6), 46.91 (C8), 48.40 (C5), 57.44 (C7), 127.75 (=CH), 127.85 (=CH), 127.98 (=CH), 128.69 (=CH), 129.98 (=CH), 135.41 (=C), 135.93 (=C), 145.07 (=C), 171.52 (C2).

Preparation of *N*,*N*-Di(2-propenyl)acrylamide (6b) (Registry No. 3085-68-5). According to the protocol already described or **6a**, **6b** (5.37 g) was prepared in 71% yield from the reaction of *N*,*N*-diallylamine (4.85 g, 50 mmol) with 2-propenoyl chloride (6.79 g, 75 mmol): ^{1}H NMR (400 MHz) 3.95 (d, J = 4.2, 2 H), 4.05 (d, J = 5.7, 2 H), 5.19 (m, 4 H), 5.69 (dd, J = 10.2, 2.1, 1 H), 5.80 (m, 2 H), 6.37 (dd, J = 16.7, 2.1, 1 H), 6.50 (dd, J = 16.7, 10.2, 1 H).

Addition of TsBr to 6b. One gram (6.6 mmol) of **6b** along with 1.55 g (1 equiv) of TsBr in 140 mL of acetonitrile was irradiated during 8.5 h at 18 °C. Purification by LC (AcOEt–petroleum ether, 10:90 to 80:20) gave 190 mg of **7b**, 400 mg of a mixture of **7b** and **8b**, and 1010 mg of **8b** (overall yield, 66%). HPLC analysis (AcOEt–isooctane, 25:75) indicated an overall 20:80 ratio of **7b** to **8b**.

***N*-Allyl-4-(bromomethyl)-3-(tosylmethyl)-2-pyrrolidone (7b, 8b).** **7b**: mp 108 °C (CH_2Cl_2–pentane): ^{1}H NMR (400 MHz) 2.43 (s, 3 H), 3.09 (qd, J = 7.1, 3.1, H4), 3.14 (m, H3), 3.27 (dd, J = 14.6, 12.0, H7a), 3.33 (d, J = 10.5, H5a), 3.50 (dd, J = 10.5, 7.1, H6a), 3.52 (dd, J = 10.5, 6.4, NCHa), 3.69 (dd, J = 14.6, 1.7, H7b), 3.70 (dd, J = 10.5, 3.1, H6b), 3.88 (d, J = 6.4, NCHb), 5.14–5.21 (m, 2 H), 5.70 (ddt, J = 17.2, 10.1, 6.1, 1 H), 7.40 (d, J = 8.3, 2 H), 7.78 (d, J = 8.3, 2 H); ^{13}C NMR (25 MHz) 21.64 (CH_3), 33.32 (C6), 35.42 (C4), 40.33 (C3), 45.67 (NCH_2), 49.41 (C5), 52.50 (C7), 118.91 (=CH_2), 127.94 (=CH), 130.11 (=CH), 131.75 (=CH), 135.91 (=C), 145.25 (=C), 170.54 (C2). Anal. Calcd for $C_{16}H_{20}BrNO_3S$: C, 49.75; H, 5.32; N, 3.63; S, 8.30. Found: C, 49.70; H, 5.43; N, 3.54; S, 8.20. **8b**: ^{1}H NMR (400 MHz) 2.42 (s, 3 H), 2.78–2.90 (m, H3, H4), 3.10 (dd, J = 14.3, 10.3, H7a), 3.22 (dd, J = 10.1, 7.1, H5a), 3.48 (dd, J = 10.1, 8.5, H5b), 3.75 (dd, J = 14.3, 2.0, H7b), 3.72 (dd, J = 10.4, 6.9, H6a), 3.85 (d, J = 6.3, NCH_2), 3.91 (dd, J = 10.3, 3.1, H6b), 5.14–5.21 (m, 2 H), 5.66 (ddt, J = 17.2, 10.1, 6.1, 1 H), 7.35 (d, J = 8.3, 2 H), 7.79 (d, J = 8.3, 2 H); ^{13}C NMR (100 MHz) 21.58 (CH_3), 35.83 (C6), 39.36 (C4), 41.45 (C3), 45.52 (C8), 49.81 (C5), 57.42 (C7), 118.50 (=CH_2), 127.90 (=CH), 130.00 (=CH), 131.51 (=CH), 136.05 (=C), 145.07 (=C), 171.29 (C2). Anal. Calcd for $C_{16}H_{20}BrNO_3S$: C, 49.75; H, 5.32; N, 3.63; S, 8.30. Found: C, 50.10; H, 5.47; N, 3.72; S, 8.60.

Preparation of *N*-(2-Propenyl)-*N*-*tert*-butylacrylamide (6c). The acylation of *N*-allyl-*N*-*tert*-butylamine (4.24 g, 37.5 mmol) with 4.25 g of 2-propenoyl chloride gave 4.53 g (71%) of **6c**: IR (neat) 1655, 1616, 982, 920, 799 cm^{-1}; ^{1}H NMR (200 MHz) 1.33 (s, 9 H), 3.84 (dd, J = 3.9, 2.0, 1 H), 5.05–5.14 (m, 2 H), 5.41 (dd, J = 10.1, 2.2, 1 H), 5.65–5.83 (m, 1 H), 6.10 (dd, J = 16.7, 2.3, 1 H), 6.32 (dd, J = 16.7, 10.2, 1 H).

Addition of TsBr to 6c. According to standard conditions, 0.8 g (4.7 mmol) of **6c** and 1.11 g (4.7 mmol) of TosBr were irradiated during 14 h in 140 mL of acetonitrile. LC (AcOEt–petroleum ether, 15:85 to 55:45) led to 53 mg of **7c** and 950 mg of **8c** (overall yield 53%).

***N*-*tert*-Butyl-4-(bromomethyl)-3-(tosylmethyl)-2-pyrrolidone (7c, 8c).** **7c**: ^{1}H NMR (400 MHz) 1.40 (s, 9 H), 2.45 (s, 3 H), 2.90–3.00 (m, H3, H4), 3.19 (dd, J = 14.0, 8.9, H7a), 3.38 (dd, J = 14.0, 4.5, H7b), 3.48 (dd, J = 11.0, 6.8, H5a), 3.53 (dd, J = 10.2, 7.0, H6a), 3.60 (dd, J = 11.1, 3.1 H5b), 3.65 (dd, J = 10.2, 5.7, H6b), 7.37 (d, J = 8.2, 2 H), 7.80 (d, J = 8.2, 2 H); ^{13}C NMR (100 MHz) 21.70 (CH_3), 27.73 (3 CH_3), 29.61 (C4), 29.84 (C6), 47.59 (C3), 48.76 (C5), 54.01 (C7), 54.93 (C), 128.03 (=CH), 130.40 (=CH), 136.18 (=C), 145.34 (=C), 171.89 (C2). **8c**: mp 104 °C (CH_2Cl_2–pentane); ^{1}H NMR (400 MHz) 1.40 (s, 9 H), 2.69 (qd, J = 8.1, 3.5, H4), 2.75 (ddd, J = 10.1, 8.8, 2.3, H3), 3.05 (dd, J = 14.3, 10.1, H7a), 3.24 (dd, J = 10.1, 7.4, H5a), 3.62 (dd, J = 10.1, 8.1, H5b), 3.64 (dd, J = 10.3, 7.7, H6a), 3.72 (dd, J = 14.3, 2.3, H7b), 3.93 (dd, J = 10.3, 3.5, H6b), 7.37 (d, J = 8.3, 2 H), 7.80 (d, J = 8.3, 2 H); ^{13}C NMR (100 MHz) 21.69 (CH_3), 27.69 (3 CH_3), 35.73 (C6), 39.29 (C4), 42.89 (C3), 48.89 (C5), 57.83 (C7), 128.01 (=CH), 130.10 (=CH), 136.30 (=C), 145.10 (=C), 171.58 (C2). Anal. Calcd for $C_{17}H_{24}BrNO_3S$: C, 50.75; H, 6.01; N, 3.48; S, 7.97. Found: C, 50.71; H, 6.00; N, 3.42; S, 8.00.

Preparation of *N*-(2-Propenyl)-*N*-phenylacrylamide (6d). Acylation of *N*-(2-propenyl)aniline (5 g, 38 mmol) with 2-propenoyl chloride (4.16 g, 46 mmol) gave 5.57 g (77%) of **6d** after purification by LC: IR (neat) 1659, 1614, 1595, 983, 924, 702 cm^{-1}; ^{1}H NMR (400 MHz) 4.39 (d, J = 6.2, 2 H), 5.08–5.17 (m, 2 H), 5.57 (dd, J = 10.2, 1.7, 1 H), 5.90 (ddt, J = 16.9, 10.4, 6.2, 1 H), 6.03 (dd, J = 16.8, 10.2, 1 H), 6.39 (dd, J = 16.8, 2.0, 1 H), 7.14–7.18 (m, 2 H), 7.31–7.43 (m, 3 H).

Addition of TsI to 6d. A solution of 1 g (5 mmol) of **1d** and 1.41 g (5 mmol) of TosI was irradiated at room temperature, under argon atmosphere, with a 300-W sun lamp. Purification by LC (AcOEt–petroleum ether, 15:85 to 50:50) gave 1070 mg (64%) of **11d**.

***N*-(2-Propenyl)-*N*-phenyl-3-tosylacrylamide (11d)**: mp (CH_2Cl_2–pentane) 71 °C; ^{1}H NMR (400 MHz) 2.41 (s, 3 H), 4.36 (dt, J = 6.3, 1.0, NCH_2), 5.08–5.18 (m, 2 H), 5.81 (ddt, J = 16.5, 10.2, 6.2, 1 H), 6.75 (d, J = 14.7, H2), 7.05 (m, 2 H), 7.29 (d, J = 14.7, H3), 7.31 (d, J = 8.3, 2 H), 7.35–7.45 (m, 3 H), 7.67 (d, J = 8.3, 2 H); ^{13}C NMR (100 MHz) 21.63 (CH_3), 52.74 (CH_2),

118.67 (=CH_2), 127.74 (=CH), 128.10 (=CH), 128.64 (=CH), 129.90 (=CH), 130.05 =(CH), 131.36 (=CH), 131.93 (=CH), 135.92 (=C), 140.62 (=C), 141.02 (=CH), 145.17 (=C), 162.01 (C1). Anal. Calcd for $C_{19}H_{19}NO_3S$: C, 66.84; H, 5.61; N, 4.10; S, 9.39. Found: C, 66.76; H, 5.69; N, 3.97; S, 9.50.

Reduction of 7a and 8a by Bu_3SnH. A solution containing 85 μL of freshly distilled Bu_3SnH and 15 mg of AIBN in 5 mL of benzene was added over 8 h to a solution of 110 mg (0.25 mmol) of **8a** in 10 mL of benzene irradiated at room temperature with a mercury lamp. After completion, the solvent was evaporated and the residue, dissolved in acetonitrile, was washed twice with pentane. Flash chromatography (CH_2Cl_2–Et_2O; 100:0 to 80:20) afforded 74 mg of a mixture of **13a** and **14a** in a 85:15 ratio (82% overall yield). Coversely the reduction of 20 mg of **7a** under identical conditions afforded 8 mg of **12a** (50%).

***N*-Benzyl-4-methyl-3-(tosylmethyl)-2-pyrrolidone (12a, 13a). 12a:** ^{1}H NMR (400 MHz) 0.99 (d, J = 7.0, 3 H), 2.46 (s, 3 H), 2.74 (sext., J = 7, H4), 2.80 (d, J = 9.9, H5a), 3.07 (ddd, J = 12, 7, 1.7, H3), 3.21 (dd, J = 14.3, 12.1, H7a), 3.41 (dd, J = 9.9, 6.0, H5b), 3.70 (dd, J = 14.3, 1.7, H7b), 4.43 (AB type spectrum, J_{AB} = 14.7, $\Delta\nu$ = 53.5 Hz, NCH_2), 7.15–7.20 (m, 2 H), 7.28–7.39 (m, 5 H), 7.81 (d, J = 8.3, 2 H); ^{13}C NMR 15.41 (CH_3, C6), 21.67 (CH_3), 29.51 (C4), 41.60 (C3), 47.08 (CH_2Ph), 52.42 (C5*), 52.51 (C7*) (these assignments may be reversed), 127.78 (=CH), 127.97 (=CH), 128.15 (=CH), 128.75 (=CH), 130.03 (=CH), 135.96 (=C), 136.39 (=C), 144.95 (=C), 171.87 (C=O); MS 357 (16), 293 (2), 202 (5), 201 (5), 188 (7), 186 (5), 174 (34), 145 (5), 110 (8), 92 (8), 91 (100), 85 (16), 71 (15), 70 (7), 69 (9), 65 (10), 57 (27), 55 (15), 43 (20), 42 (5), 41 (28), 39 (8), 29 (6), 28 (15), 27 (5), 18 (7); HRMS calcd for $C_{20}H_{23}NO_3S$ 357.1398, found 357.1411. **13a:** ^{1}H NMR (400 MHz), 1.28 (d, J = 6.7, 3 H), 2.46 (s, 3 H), 2.42–2.51 (superimposed m, H4), 2.64 (ddd, J = 9.7, 8.3, 2.7, H3), 2.84 (dd, J = 9.8, 7.3, H5a), 3.11 (dd, J = 14.3, 9.7, H7a), 3.35 (dd, J = 9.8, 8.1, H5b), 3.76 (dd, J = 14.3, 2.7, H7b), 4.41 (AB type spectrum, J_{AB} = 14.8, $\Delta\nu$ = 18.6 Hz, NCH_2), 7.18–7.21 (m, 2 H), 7.26–7.40 (m, 5 H), 7.82 (d, J = 8.2, 2 H); ^{13}C NMR (100 MHz) 18.71 (CH_3, C6), 21.65 (CH_3), 33.19 (C4), 44.84 (C3), 46.99 (CH_2Ph), 52.30 (C5), 57.50 (C7), 127.77 (=CH), 128.00 (=CH), 128.11 (=CH), 128.78 (=CH), 129.97 (=CH), 135.94 (=C), 136.73 (=C), 144.86 (=C), 172.96 (C=O); MS 357 (23), 293 (1), 202 (6), 188 (10), 186 (6), 175 (6), 174 (62), 145 (11), 110 (11), 92 (11), 91 (100), 85 (4), 71 (7), 69 (9), 65 (11), 57 (14), 55 (11), 43 (10), 42 (5), 41 (14), 39 (5), 28 (23), 18 (9); HRMS calcd for $C_{20}H_{23}NO_3S$ 357.1398, found 357.1411.

Data for 14a: ^{1}H NMR (400 MHz) 2.03 (qd, J = 11.1, 7.5, H4), 2.74 (d, J = 14.4, H6a), 3.03 (dd, J = 14.4, 12.5, H7a), 3.08 (dd, J = 11.1, 9.5, H5a), 3.17 (td, J = 12.5, 2.5, H3), 3.30 (dd, J = 9.5, 7.5, H5b), 3.48 (dd, J = 14.4, 11.1, H6b), 3.90 (dd, J = 14.4, 2.5, H7b), 4.48 (AB type spectrum, J_{AB} = 14.7, $\Delta\nu$ = 34.5 Hz, NCH_2), 7.05 (s, 1 H), 7.17–7.24 (m, 3 H), 7.28–7.36 (m, 3 H), 8.01 (d, J = 8, 1 H); ^{13}C NMR (100 MHz) 21.34 (CH_3), 37.08 (C6), 41.43 (C4), 46.41 (C3), 46.72 (CH_2Ph), 49.58 (C5), 54.48 (C7), 127.82 (=CH), 127.85 (=CH), 128.11 (=CH), 128.85 (=CH), 129.14 (=CH), 132.24 (=CH), 135.95 (=C), 137.27 (=C), 138.87 (=C), 144.97 (=C), 171.99 (C=O); the assignments followed from COSY and HETCOR experiments. NOE experiments led to no enhancement of H3 when irradiating H4 and vice versa; MS 357 (2), 356 (8), 355 (40), 337 (11), 320 (17), 187 (5), 186 (16), 185 (6), 119 (6), 118 (5), 106 (12), 105 (6), 92 (8), 91 (100), 77 (5), 65 (12), 55 (5), 43 (5), 28 (21), 27 (5), 18 (14); HRMS calcd for $C_{20}H_{21}NO_3S$ 357.1242, found 357.1252.

Acknowledgment. We are grateful to Professor Dennis Curran (Pittsburgh University) for fruitful suggestions.

Supplementary Material Available: NMR spectra for compounds **3a**, **3b**, **4**, **6c**, **7c**, **6d**, **12a**, **13a**, and **14a** and MS data of compounds **12a**, **13a**, and **14a** (33 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

The Kinetic Acidity of 1,1,1-Triphenylethane[1]

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Received June 10, 1992

Hydrogen isotope exchange studies were carried out on the methyl group of 1,1,1-triphenylethane, **1**, with cesium cyclohexylamide (CsCHA) in cyclohexylamine (CHA). Mixtures of labeled compounds were used, Ph_3C-$^{14}CH_3$ (**1**-^{14}**C**), Ph_3CCH_2T (**1-t**), Ph_3CCH_2D (**1-*d***), and Ph_3CCD_3 (**1-*d*$_3$**). The second-order rate constant for tritium exchange, 3.6×10^{-5} M^{-1} s^{-1}, is 9.0×10^{-6} the rate of benzene and 8.5×10^3 times the rate of exchange of cyclohexane. The primary isotope effect, k_D/k_T = 1.8, and corresponds to k_H/k_D = 3.8, a moderate value that is comparable to that of cyclohexane and indicates an unsymmetrical transition state. The α-secondary isotope effect, k_H/k_D = 1.2, indicates that C–H bonds at the carbanion center have significantly lower bending frequency at the transition state.

Introduction

A substantial body of experimental data has appeared from this laboratory concerning the kinetic acidities of unconjugated hydrocarbons with cesium cyclohexylamide (CsCHA) in cyclohexylamine.[2] This work is significant as a measure of relative carbanion stability in solution because the low acidities of these compounds make meaningful equilibrium studies exceptionally difficult. The kinetic acidities of alkanes and other unconjugated hydrocarbons is of further recent interest because of their possible relevance in "hydrocarbon activation" by transition-metal organometallic compounds.[3] Although our past studies have provided relative reactivities of some unconjugated tetrahedral C–H bonds, further details of transition-state structure, such as those obtainable from isotope effects, is made difficult by their exceptional unreactivity: half-lives for tritium exchange of alkanes and cycloalkanes even with CsCHA range from decades to centuries. For this reason, the methyl group of 1,1,1-triphenylethane, **1**, was of especial interest. It is an unconjugated group but preliminary studies indicated a reactivity of about 10^4 that

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