the MD results (cf. Figure 5). The harmonic calculations do allow an estimate of quantum effects, and these appear to be nonnegligible for ^{13}C and ^{15}N relaxation: the order parameters arising from vibrations are about 0.05 lower when zero-point motion is considered than in a classical calculation. The behavior has been noted before[52] and will be important for precise comparisons of simulation with experiment. The vibrations responsible for this change appear to be mostly bending vibrations with frequencies in the 1000–1500-cm^{-1} range. Both solvated and vacuum dynamics indicate that the initial decay of $C(\tau)$ is oscillatory; in this respect the white-noise Langevin treatment appears to overstate the effects of viscous damping. It should be remembered, however, that NMR relaxation is insensitive to the details of atomic correlations on this timescale.

All the correlation functions show a rapid, vibrational contribution, followed by slower decay to a plateau value (cf. Figures 3 and 7). This has implications for the interepretation of internal correlation times determined from a model-free analysis of experimental data. Consider a reasonable but hypothetical case of $^{13}C\alpha$ relaxation in which the model-free analysis yields $S^2 = 0.85$ and $\tau_e = 50$ ps. About half the difference of S^2 from 1 is likely to arise from vibrational effects, with a very short time constant; the effective timescale for the remaining, slower motion (which is probably of greater physical interest) would then be 100 ps, since the model-free τ_e is essentially a weighted average of the vibrational and slower motion time constants (eq 8). Note that for side chain carbons, the initial fast decay can reduce S^2 to 0.8 or even less (cf. Figure 3). Detailed comparisons of τ_e values from experiment and simulation are made difficult at present by the limited precision with which they can be determined experimentally[7] and by the relatively short timescale of the present simulations, which precludes study of the nature of correlation functions in the 50–100-ps range (and longer).

The simulations reported here also are germane to the interpretation of proton NOESY cross-peaks in terms of distances for use in NMR structural refinements. Overall, the results are encouraging: the ratios of relaxation rate constants estimated from the full simulations to those that would be appropriate for a rigid molecule with the same average distance are distributed with a mean near 1 and a standard deviation of about 0.2–0.4 (Table VII, Figure 8); in addition, the fraction of proton NOESY peaks for which the internal motion corrections are substantial is small, so a conservative application of distance constraints is appropriate. Hence, aside from methyl groups, neglect of the effects of internal motion should lead to relatively small errors in the derived distances. We and others have shown that relatively simple models for methyl motion that capture most of the essential physics can be incorporated into estimates of relaxation rate constants.[45,46]

Several limitations of this analysis of predicted proton NOESY intensities must be noted. First, the conclusions are based on relatively short simulations and may not include important contributions from longer processes. Second, the present results also apply directly only to a zinc-finger peptide, although the results are in general accord with simulations on larger proteins.[50,53,54] Third, complications arising from anisotropic rotational tumbling, which can systematically affect relaxation behavior, have not been considered.[55,56] Finally, correction factors given by eq 13 apply only to individual relaxation matrix *rate constants*; under many circumstances, multispin effects can make important contributions to observed cross-peak *intensities*, and systematic errors can arise from neglect of such multispin effects. This point has been extensively discussed in the recent literature, and a variety of methods are available to account for multispin effects.[57] The results presented here suggest that once the multispin complications are taken into account, the resulting distance estimates should be acceptably accurate for most structural studies.

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Dynamic Behavior and Reactivity of (1,1,3,3-Tetramethylallyl)lithium

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Abstract: (1,1,3,3-Tetramethylallyl)lithium (**1**), prepared by cleaving the corresponding phenyl sulfide **2** at −92 °C with lithium 1-(dimethylamino)naphthalenide or by reacting the trimethyltin derivative **3** with CH_3Li in THF/diethyl ether/TMEDA at −78 °C, adds rapidly to naphthalene and 1-(dimethylamino)naphthalene at −78 °C to give mixtures of the corresponding 1-substituted 1,2- and 1,4-dihydronaphthalenes. Carbon-13 NMR studies show **1**·TMEDA to be a contact ion-pair with Li^+-coordinated TMEDA disymmetrically sited with respect to the delocalized allyl counterion. Carbon-13 NMR line-shape analysis shows the barrier to allyl rotation $C_1C_2(C_2C_3)$ to be $\Delta H_r^{\ddagger} = 14$ kcal/mol with $\Delta S^{\ddagger} = 13$ eu. Analysis of the N–CH_3 ^{13}C NMR of contained TMEDA shows two dynamic processes take place, one a reorientation of coordinated Li^+ within the ion-pair (m) with $\Delta H_m^{\ddagger} = 7.9$ kcal/mol and $\Delta S_m^{\ddagger} = -5.3$ eu and the other the exhcange of TMEDA between its free and complexed states (bi) with $\Delta H_{bi}^{\ddagger} = 4.9$ kcal/mol and $\Delta S_{bi}^{\ddagger} = -29$ eu.

The influence of alkyl substituents on stability of π conjugated carbanions[1] is not well understood in part because few highly alkylated carbanions have been prepared, let alone investigated.[2]

We recently described a convenient synthesis of (1,1,3,3-

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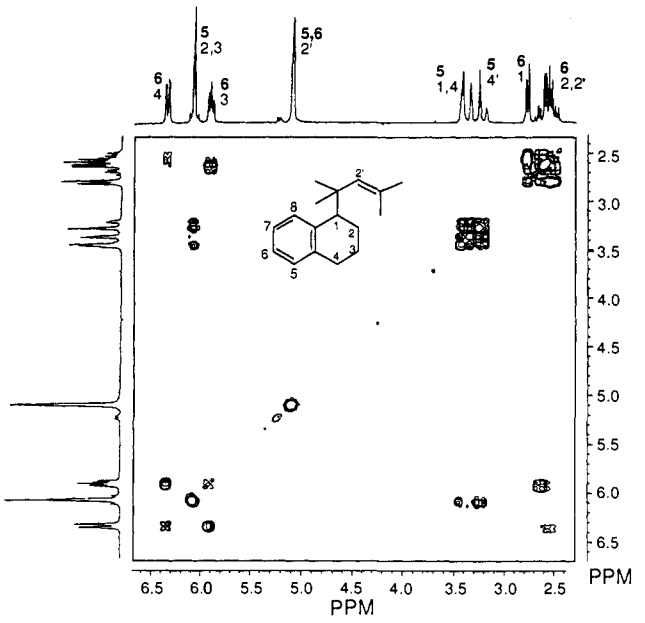
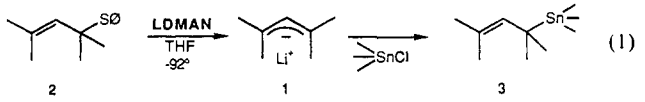


Figure 1. Proton–proton COSY, 300 MHz, of **5** and **6** in $CDCl_3$.

tetramethylallyl)lithium (**1**) based on reductive cleavage of 4-(phenylthio)-2,4-dimethyl-2-pentene using lithium 1-(dimethylamino)naphthalenide (LDMAN) (eq 1).[3] Compound **1** gave



(1)

expected products with standard electrophiles such as triphenyltin chloride and benzaldehyde. In addition, it showed surprising reactivity with anthracene, adding rapidly to the 9-position even at −90 °C. Thus, **1** turns out to be far more reactive toward aromatic compounds than any other organolithium reported so far.

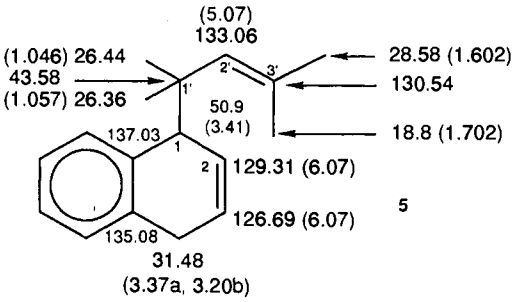
In this paper, we describe similar reactivity to that described above of **1** with naphthalenes and, in addition, report studies of its structure and dynamic behavior.

Results and Discussion

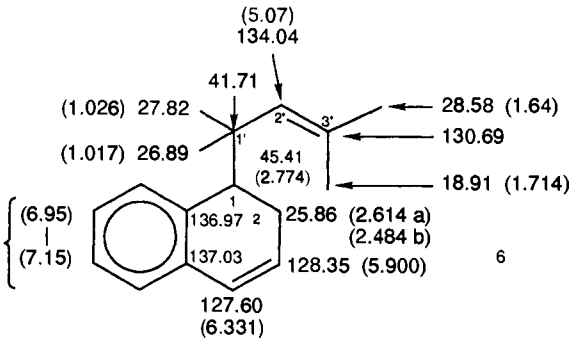
(1,1,3,3-Tetramethylallyl)lithium (**1**) was first generated by cleavage of the sulfide **2** with lithium 1-(dimethylamino)-naphthalenide (LDMAN) and then converted to the trimethyltin compound **3**.[3] Cleavage of **3** with CH_3Li in diethyl ether/THF with *N,N,N',N'*-tetramethylethylenediamine (TMEDA) afforded the purified reagent **1**·TMEDA. The reactivity of both preparations of **1** was investigated.

$$3 \xrightarrow[\text{diethyl ether}\\ \text{THF -78 °C}]{\text{CH}_3\text{Li}\\ \text{TMEDA}} \mathbf{1}\cdot\text{TMEDA} \qquad (2)$$

Encouraged by the surprisingly high reactivity of **1**·TMEDA with anthracene, we treated this reagent with benzene in diethyl ether/THF (10%) at −78 °C. Neither addition of **1** nor deprotonation could be detected even on warming the mixture to 0 °C. In contrast, **1** was found to react rapidly with both naphthalene and 1-(dimethylamino)naphthalene at −78 °C under two different sets of conditions. In method I, lithium naphthalenide or LDMAN was allowed to react with sulfide **2** in THF, while, in II, **1**·TMEDA, prepared from tin compound **3**, was reacted directly with the naphthalene under investigation. Both methods gave



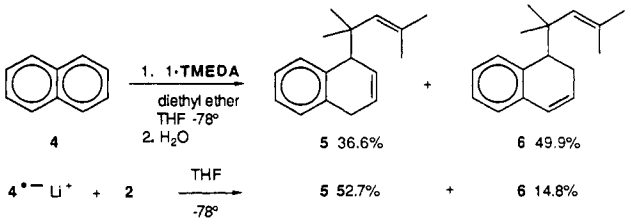
$^3J(H_1, H_2)$	3.20	$^4J(H_2, H_{4b})$	<0.3
$^3J(H_1, H_3)$	1.25	$^3J(H_3, H_{4a})$	<0.3
$^5J(H_1, H_{4a})$	1.25	$^3J(H_3, H_{4b})$	3.32
$^5J(H_1, H_{4b})$	0.30	$^2J(H_{4a}, H_{4b})$	-22.7
$^4J(H_2, H_{4a})$	1.35	$^4J(H_2, H_{3'Z})$	1.36



$^3J(H_1, H_{2a})$	1.76	$^4J(H_{2a}, H_4)$	0.9
$^3J(H_1, H_{2b})$	8.11	$^3J(H_3, H_4)$	9.52
$^2J(H_{2a}, H_{2b})$	-18.09	$^3J(H_7, H_8)$	6.9
$^3J(H_{2a}, H_3)$	5.87	$^4J(H_{2'}, H_{3'CH3Z})$	1.39
$^3J(H_{2b}, H_3)$	2.6	$^4J(H_{2'}, H_{3'CH3E})$	1.39
$^4J(H_{2b}, H_4)$	2.6		

Figure 2. ^{13}C and (^1H) shifts, δ, and proton–proton coupling constants, Hz, for compounds **5** (top) and **6** (bottom) in $CDCl_3$.

mixtures of 1,2- and 1,4-dihydronaphthalenes in total yields, based on sulfide **2**, of 68% to 87%, as shown below.



For example, within 15 min of mixing **1**·TMEDA and naphthalene at −78 °C, the color of the mixture changed from orange-red, due to **1**, to deep red, typical of dihydroaromatic anions. Hydrolysis yielded a mixture of the monosubstituted 1,2- and 1,4-dihydronaphthalenes, as identified by NMR. Proton NMR of this hydrolyzed reaction mixture showed two sets of 1,1,3,3-tetramethylallyl resonances. Comparison of the spectra with published NMR data[4] for dihydronaphthalenes shows this product to be a mixture of **5** and **6**. A proton–proton COSY experiment established the coupling connectivities and thus identified the individual

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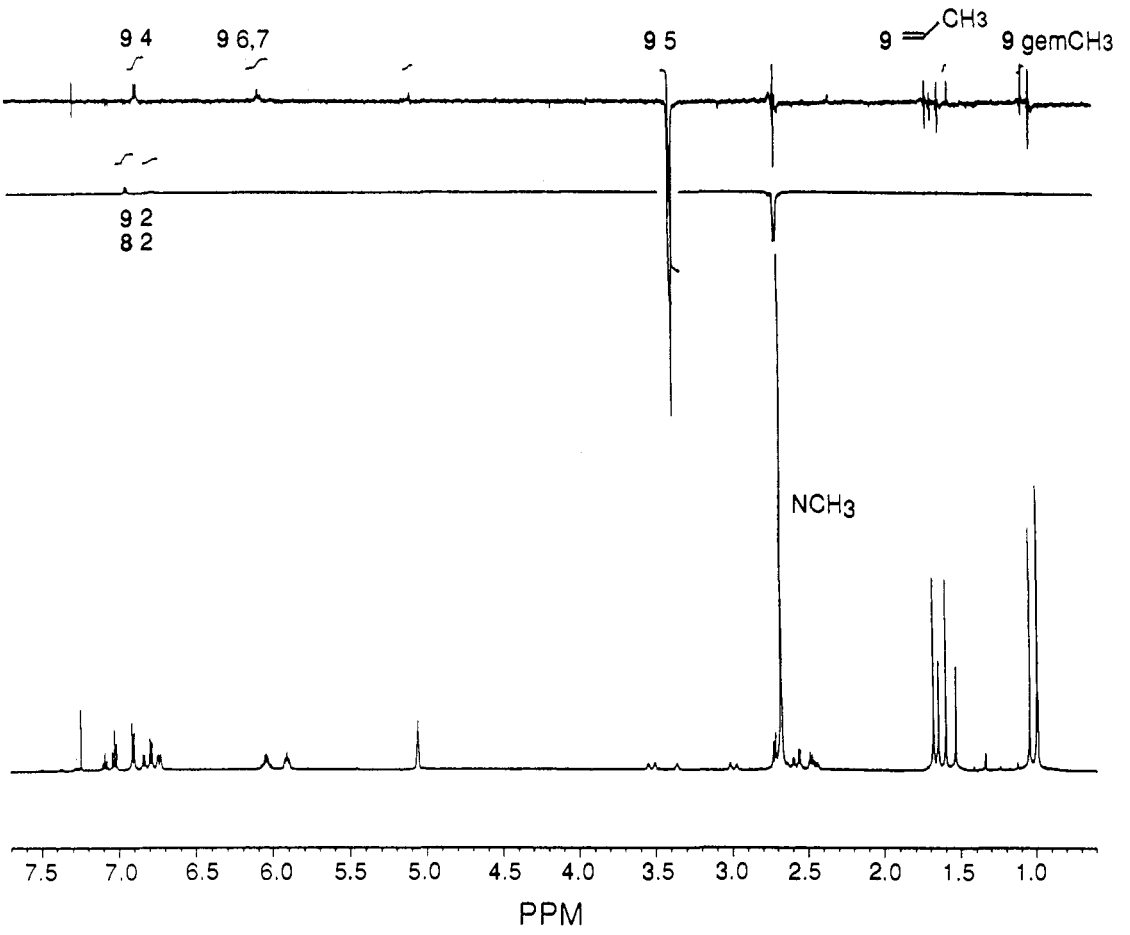
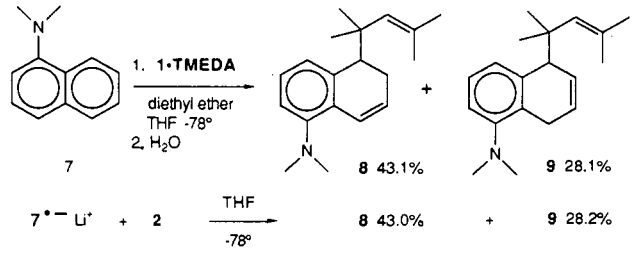


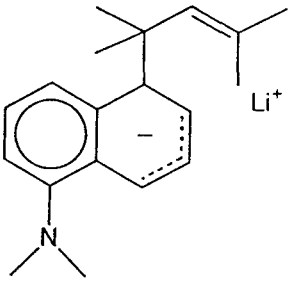
Figure 3. Proton–proton NOE experiments on a mixture of **8** and **9**, in $CDCl_3$: bottom, normal spectrum; middle, response to irradiating N–CH_3 in **8** and **9**; top, response to irradiating H_5 in **9**.

spectra (Figure 1). Then selective decoupling of protons on the reduced rings elucidated the coupling constants listed together with proton and ^{13}C shifts in Figure 2. These results alone do not establish the conformation of the reduced rings. However, Rabideau has already shown that 1-(2-propanol)-1,4-dihydronaphthalene assumes the boat structure with the 1-substituent axial.[5] This is consistent with the two vicinal proton–proton coupling constants in **5**, $J(H_1,H_{2a})$ and $J(H_1,H_{2b})$ of 1.76 and 8.11 Hz, respectively. According to the modified Karplus equation,[6] this corresponds to dihedral angles C_1H to C_2H_a and C_2H_b of 84° and 34°, respectively. Interestingly, a molecular mechanics[7] calculation of **5** results in a structure with the 1,1,3,3-tetramethylallyl substituent axial and with dihedral angles C_1H to C_2H_a and C_2H_b, respectively, 73° and 43°. In this treatment, **5** is assumed to be a single conformer.

The reaction products of **1** with 1-(dimethylamino)naphthalene via methods I and II were identified, without separation, to be mixtures of **8** and **9** in a fashion similar to that used to identify



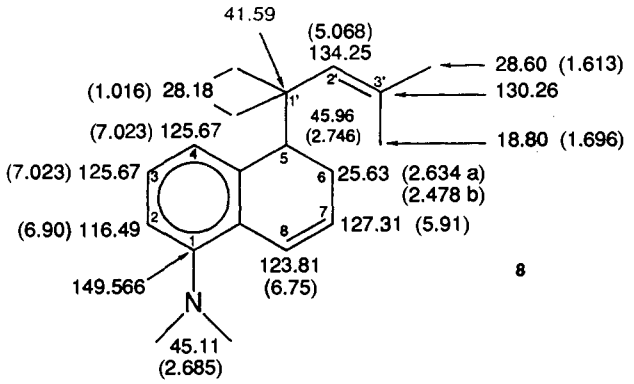
products **5** and **6**, described above. Although the gross features of these two dihydronapthalenes (**8** and **9**) were readily distinguished, the relative site of dimethylamino to the allyl substituent had yet to be determined. This was accomplished via the proton–proton NOE experiment illustrated in Figure 3. Thus, irradiating H_5 of **9** enhances the resonances of H_4 (6.787 δ), H_6 and H_7 (6.075 δ), $H_{2'}$ (allyl) (5.068 δ), and the *gem* methyls on allyl $C_{1'}$ (1.050 δ). Since the shifts on the aromatic ring were already assigned from a 300-MHz proton spectrum of pure **9**, see below, these results establish the sites of dimethylamino and tetramethylallyl in **8** and **9**, assuming both compounds arise from the same dihydro aromatic anion **10**.



10

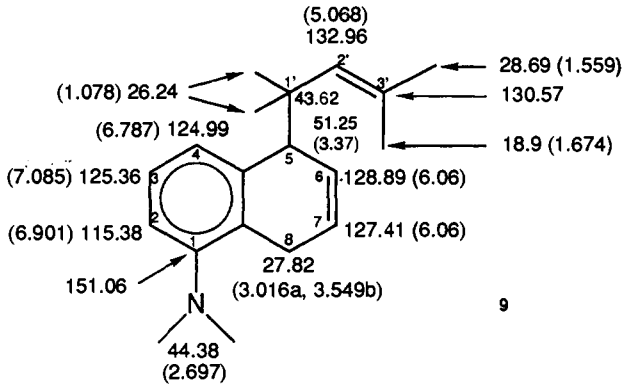
The *N*-methyl protons in **8** and **9** have the same proton shift. Irradiating these protons enhances only H_2 in **8** (6.901 δ) by 3.62% and H_8 by 1.2%. Evidently, the *N*-methyls in **8** and **9** lie out of the aromatic plane and hence point away from the proton(s) at C_8 in both compounds. All NMR data for **8** and **9** are listed in Figure 4. So far, these NMR data were obtained from mixtures of **5** and **6** and of **8** and **9**. Due to their tendency to aromatize, we were not able to separate these mixtures. However, a pure sample of **9** was serendipitously obtained in a separate experiment.

(5) (a) Rabideau, P. W.; Burkholder, E. G.; Yates, M. J.; Paschal, J. W. *J. Am. Chem. Soc.* **1977**, *99*, 3596. (b) Rabideau, P. W. *Acc. Chem. Res.* **1978**, *11*, 141.
(6) Bothner-By, A. *Adv. Magn. Reson.* **1965**, *1*, 195.
(7) PCMODEL, Version 2, Serena Software, Box 3076, Bloomington, IN 47402.



$^3J(H_2, H_3)$	7.8	$^3J(H_{6b}, H_7)$	2.93
$^3J(H_3, H_4)$	7.8	$^4J(H_{6a}, H_8)$	6.79
$^3J(H_5, H_{6a})$	1.48	$^4J(H_{6b}, H_8)$	2.91
$^3J(H_5, H_{6b})$	8.32	$^3J(H_7, H_8)$	9.41
$^2J(H_{6a}, H_{6b})$	-18.28	$^4J(H_2, H_3^a \cdot_E)$	1.11
$^3J(H_{6a}, H_7)$	5.35	$^4J(H_2, H_3^b \cdot_Z)$	1.10

[a]Methyl E at C_3, [b]Methyl Z at C_3,



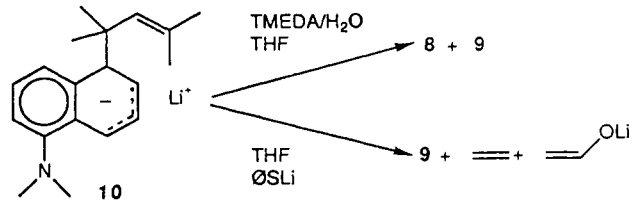
$^3J(H_2, H_3)$	7.77	$^3J(H_7, H_{8a})$	4.57
$^3J(H_3, H_4)$	7.77	$^3J(H_7, H_{8b})$	1.36
$^4J(H_6, H_{8a})$	1.4	$^2J(H_{8a}, H_{8b})$	-20.65
$^4J(H_6, H_{8b})$	0.64	$^4J(H_2,, H_3^a \cdot_E)$	0.75

[a]methyl E, C_3,

Figure 4. ^{13}C and (^1H) shifts and proton–proton coupling constants for compounds **8** (top) and **9** (bottom) in $CDCl_3$.

The reaction (1) used to prepare the tin compound **3** also yielded small quantities of a dihydronaphthalene whose NMR spectra are identical to those previously assigned to **9**. The proton NMR of pure **9**, shown in Figure 5, clarified some previously ambiguous aspects of its coupling constants. Thus, we see spin coupling of H_6 with H_7 and H_7 with H_8 but not H_6 with H_8. However, in addition to $J(H_7,H_8)$ (-18.12 Hz), the H_{8ab} proton resonance is further broadened clearly due to $^5J(H_5,H_8)$.

That **9** appears among the products of seemingly different reaction conditions implies a common dihydro aromatic anion precursor to its formation (**10**). The difference in the distribution



of products must lie in the mode of proton transfer to **10**. In methods I and II, anion **10** was quenched with H_2O at -78 °C within 2 h of mixing the reactants. In contrast to the case in sequence 1 for the preparation of tin compound **3**, the reaction mixture was allowed instead to warm up to room temperature overnight, with the proton quench most likely coming from THF.

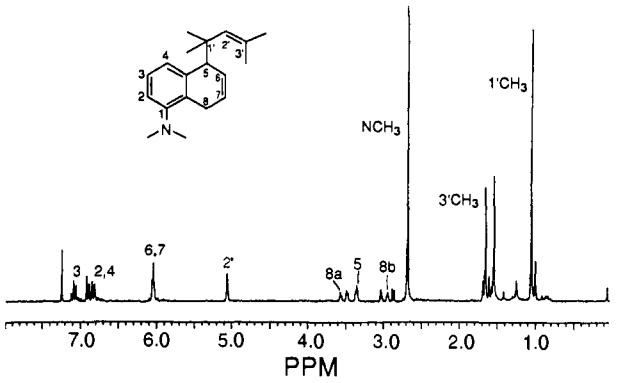


Figure 5. Proton NMR, 300 MHz, of **9** in $CDCl_3$.

Questions were raised previously as to why **1** is so reactive with aromatic molecules.[3] To date, very little has been reported on addition reactions of allyllithiums to aromatic compounds. In a preliminary study, we find that allyllithium with 1 equiv of TMEDA in THF at -78 °C slowly adds to anthracene, giving the 9-allyl-9,10-dihydroanthracenyl anion in 42% yield, based on anthracene. In contrast, allyllithium (1 equiv of TMEDA, diethyl ether) is unreactive to naphthalene up to 22 °C. Hence, the allyl skeleton of **1** is not alone responsible for its reactivity, which must arise instead from the four methyl substituents.

Samples of **1** for NMR studies were generated by first cleaving the tin compound **3** with CH_3Li in diethyl ether/THF (10%) containing 1 equiv of TMEDA at -92 °C. This preparation of **1** is not stable. At -78 °C, **1** is almost entirely hydrolyzed, most likely by deprotonating THF. However, removal of diethyl ether and THF under vacuum at -92 °C and then dissolving the residue in diethyl ether-d_{10} afforded pure samples of **1**·TMEDA, which survived NMR investigation. The carbon-13 NMR of this sample at room temperature is shown in Figure 6. At lower temperature, 180 K, both proton and ^{13}C NMR of a second sample of similar composition showed equal doublets for the *C*-methyls, implying a symmetric allylic moiety in which rotation about the C_1C_2 or C_2C_3 bonds is slow relative to the NMR time scale. Further, by 180 K, free TMEDA ($^{13}CH_3$ at 46.2 δ) is well resolved from complexed TMEDA, the latter exhibiting two broad ^{13}C *N*-methyl resonances at 46.19 and 43.17 δ, of equal intensity. However, in the proton NMR spectrum, only a single narrow peak was seen for N–CH_3 down to 180 K. Thus, at 180 K, the exchange rate of TMEDA between the complex and its free state in solution must be slow relative to the NMR time scale. Carbon and proton NMR shifts varied little over the temperature range 180–295 K; where signal averaging was observed, see below, doublets averaged to single lines at their respective centers. Hence, one can assume that the nature of the prevailing species does not change over the temperature range observed.

Above 180 K with increasing temperature, the two *C*-methyl ^{13}C signals, as well as the corresponding proton resonances, progressively signal average to single lines at their respective centers (Figure 7), most reasonably the result of rotation about the C_1C_2 or C_2C_3 bonds. Comparison of experimental spectra with the calculated line shapes,[8] (Figure 7) afforded the rates of allyl rotation in **1**·TMEDA, and in turn, $\Delta H_r^{\ddagger}$ is found to be 14 kcal/mol with $\Delta S_r^{\ddagger} = +13$ eu, as obtained from the Eyring plot (Figure 8). These values are not necessarily due to rotation within the 1,1,3,3-tetramethylallyl anion. Barriers to rotation for other allylic lithium species vary with potential ligand and solvent.[9]

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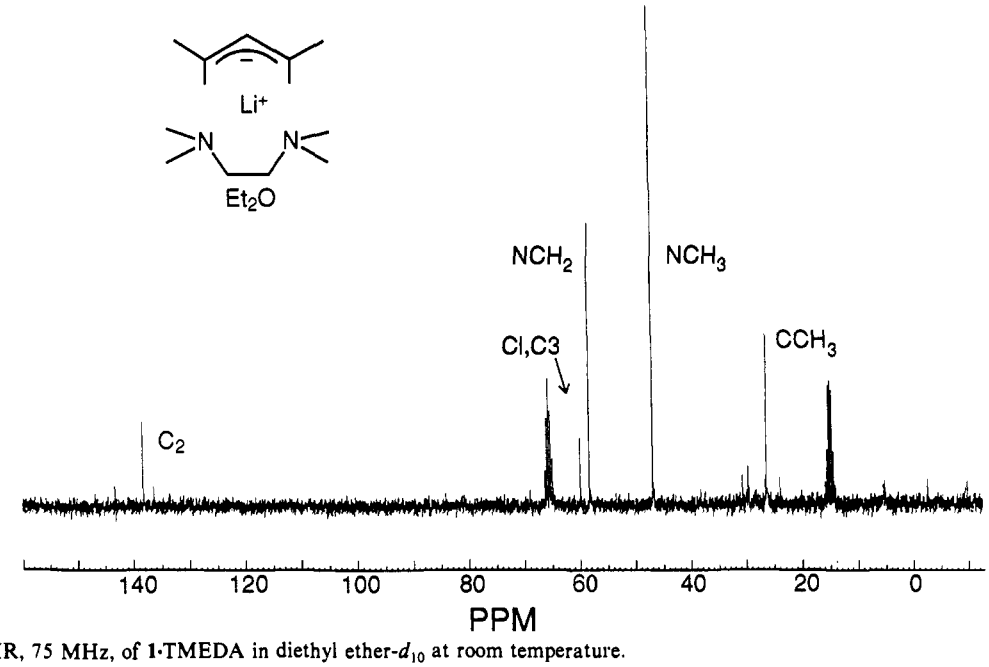


Figure 6. ^{13}C NMR, 75 MHz, of 1·TMEDA in diethyl ether-d_{10} at room temperature.

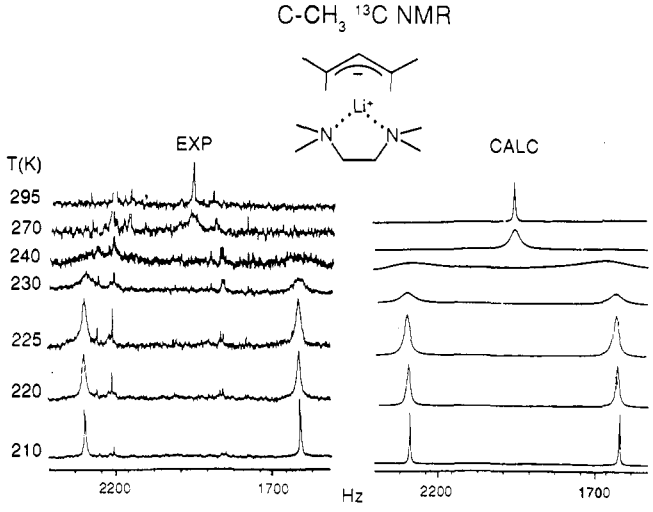
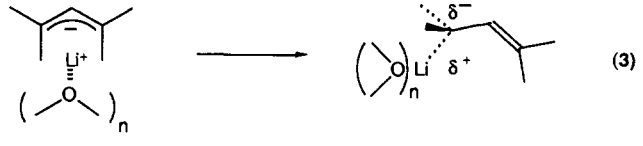


Figure 7. ^{13}C NMR line shapes of the *C*-methyls of 1·TMEDA in diethyl ether-d_{10}: left, experimental, different temperatures; right, calculated.

That has been ascribed to some increase in covalency between Li^+ and one terminal carbon of the allyl group as the system proceeds from ground to transition state for the rotation (see eq 3). Nevertheless, it is interesting that Deno et al. reported the



(3)

barrier to allyl rotation (C_1C_2 or C_2C_3) in the 1,1,3,3-tetramethylallyl cation (fluorosulfonate salt) in FSO_3H solution to be E_a = 15.7 kcal/mol with log A = 11.3 (equivalent to $\Delta H^{\ddagger}$ = 15·1 kcal/mol with $\Delta S^{\ddagger}$ = 8.9 eu).[10] The barrier was insensitive to the concentration of added $(CH_3)_4NCl$, which rules out a partly covalent transition state to rotation. The 1,1,3,3-tetramethylallyl system is the only one to our knowledge for which barriers to rotation have been measured for the cation and the anion, to the extent that the latter resembles the lithium compound 1·TMEDA. The similarity of the two barriers is consistent with simplified

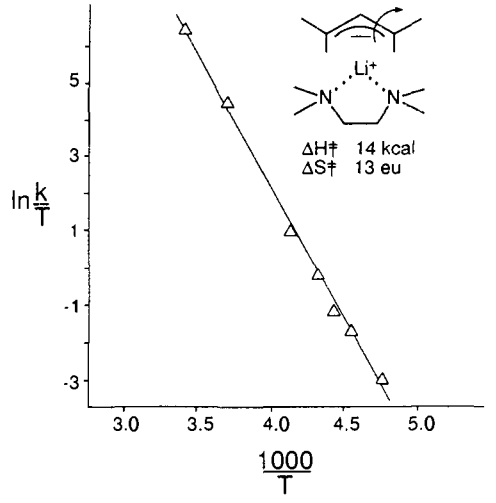


Figure 8. Eyring plot for internal rotation about C_1C_2 (C_2C_3) in 1·TMEDA in diethyl ether-d_{10}.

Huckel treatments. However, using ab initio calculations, Wiberg, Breneman, and LePage predicted barriers to rotation in allyl cation and anion to be 36 and 19 kcal/mol, respectively, in the *gas phase*;[11] experimental measurements for these gas-phase barriers are not currently available.

The *N*-methyl ^{13}C NMR due to TMEDA in the sample of 1·TMEDA under discussion also exhibited signal averaging (Figure 9). There are three lines, two of equal intensity which come from the complex, a and c, and one due to free TMEDA, b. All three lines signal average by 270 K. These spectra were simulated most successfully as coming from a three $^1/_2$ spin uncoupled exchanging system. Fast rearrangement within complexed TMEDA averages the two methyl resonances a and c of the ligand, and a slower intermolecular exchange of TMEDA between its bound and free state (b) in solution finally averages all the *N*-methyl resonances in both states.

$$k_{ac} = k_{ca} \quad (4)$$

Thus, we have the relationships (5) and (6)

$$k_{ab} = k_{cb} \quad (5)$$

$$k_{ba} = k_{bc} \quad (6)$$

(10) Haddon, R. C.; Nowak, E. N.; Deno, N. C. *J. Am. Chem. Soc.* **1970**, *92*, 6691.

(11) Wiberg, K. B.; Breneman, C. M.; LePage, T. J. *J. Am. Chem. Soc.* **1990**, *112*, 61.

and (7)

$$\frac{k_{bc}}{k_{cb}} = \frac{(c)}{(b)} \tag{7}$$

where the k's are pseudo-first-order rate constants and concentrations are in g mol ^{13}C/unit volume. Comparing the $(c)/(b)$ ratio at low temperature with the shift of the averaged a, b, and c resonances, it appears that the ratio of free to complexed TMEDA does not vary enough to detect with NMR over the entire temperature range studied, 160–300 K.

Given the measured concentration ratio $(c)/(b)$ and eqs 4–6, the dynamics are described by just two rate constants, k_{ab} and k_{ac}. The density matrix for this system in matrix form is written as (8), wherein ν_i's are shifts, $1/T$'s are intrinsic line widths, and

$$\begin{bmatrix} i2\Pi(\nu-\nu_a) - \frac{1}{T_a} - k_{ab} - k_{ac} & k_{ab} & k_{ac} \\ k_{ba} & i2\Pi(\nu-\nu_b) - \frac{1}{T_b} - k_{ba} - k_{bc} & k_{bc} \\ k_{ca} & k_{cb} & i2\Pi(\nu-\nu_c) - \frac{1}{T_c} - k_{cb} - k_{ca} \end{bmatrix} \begin{bmatrix} \rho^a \\ \rho^b \\ \rho^c \end{bmatrix} = iC \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \tag{8}$$

ρ^i's are the abbreviated elements of the density matrix for species a, b, and c, actually $\langle\alpha|\rho_i|\beta\rangle$, for ^{13}C in different N–CH_3 environments. Then the absorption is given by the weighted sum (9).

$$\mathrm{Abs}(\nu) = -\mathrm{Im}((a)\rho^a + (b)\rho^b + (c)\rho^c) \tag{9}$$

This treatment satisfactorily reproduced the experimental spectra as seen in Figure 9. The Eyring plot, Figure 10, for the derived rate constants yields for internal N–CH_3 exchange, m, $\Delta H_m^{\ddagger}$ = 7.8 kcal/mol with $\Delta S_m^{\ddagger}$ = −5.3 eu and for intermolecular exchange, bi, of TMEDA between its free and complexed states $\Delta H_{bi}^{\ddagger}$ = 4.9 kcal/mol and $\Delta S_{bi}^{\ddagger}$ = −29 eu. The latter $\Delta S_{bi}^{\ddagger}$ value is quite consistent for a bimolecular process.

To discuss the NMR behavior of complexed TMEDA requires some assumption about the structure of **1**·TMEDA. X-ray crystallography of several allylic lithium compounds shows lithium (complexed) to be on one side of the allyl plane.[12] Such is the case for polymeric allyllithium TMEDA,[12a] as well as monomeric allyllithium complexed to one molecule of pentamethyldiethylenetriamine.[12b] The nonequivalence for the *N*-methyls implies the coordinated ligand exists mainly in one conformation and is disymmetrically sited with respect to the allyl moiety. At 150 K, the coordinated lithium moves slowly with respect to the allyl counterion, the time scale being the shift between the N–$^{13}CH_3$ carbons. Such a structure would be expected to show four nonequivalent *N*-methyls. That two broad lines are observed just before the sample crystallizes may imply that some fast conformational motion at this temperature already averaged shifts within two doublets to two broad lines. A similar proposal was made for (1,3-bis(trimethylsilyl)allyl)lithium complexed to TMEDA, on the basis of NMR data.[13]

Effects similar to those which we ascribe to the motion of coordinated Li^+ with respect to the counterion within the ion-pair of **1**·TMEDA have been observed also in the ^{13}C NMR data for (1,3-bis(trimethylsilyl)allyl)lithium–TMEDA,[13] and (trimethylsilyl)lithium complexed to pentamethyldiethylenetriamine[9d] and in a recent study of a (1-silylallyl)lithium with attached ligand.[14]

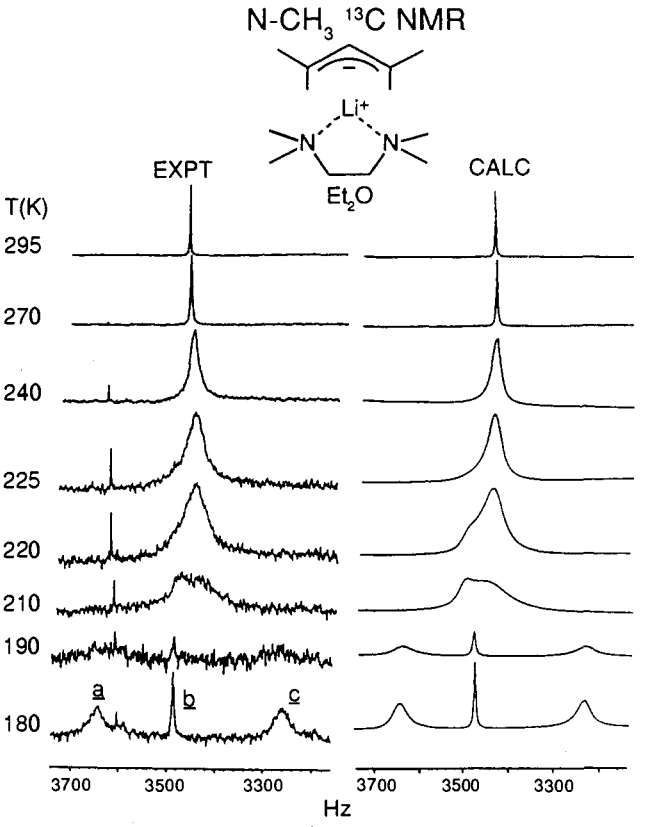


Figure 9. ^{13}C NMR line shapes of N–CH_3 of **1**·TMEDA, diethyl ether-d_{10}: left, experimental, different temperatures; right, calculated. Peaks a and c are due to the complex; peak b is from the free diamine.

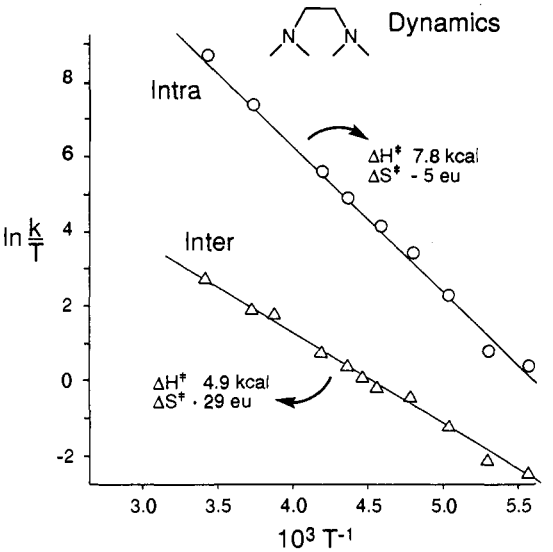


Figure 10. Eyring plot for reorientation of TMEDA within **1**·TMEDA, upper line; for exchange of TMEDA between its free and complexed states, lower line.

In all these cases, the $\Delta H^{\ddagger}$ assigned to reorientation of coordinated lithium with respect to the anion is 7 to 8 kcal/mol. This implies that the nature of the reorientation processes in all these cases must be very similar. Only a rotation of coordinated lithium with respect to the anion would be consistent with all these data.

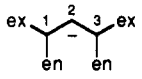
Finally, there is the question as to why **1** is so much more reactive to aromatic molecules than all other organolithium compounds studied so far. Simple unsolvated (but polymeric) alkyllithiums add to aromatic compounds at higher temperature, 160 °C.[15] Photochemical addition has been reported of RLi to

(12) (a) Köster, H.; Weiss, E. *Chem. Ber.* **1982**, *115*, 3422. (b) Schumann, U.; Weiss, E.; Dietrich, H.; Mahdi, W. *J. Organomet. Chem.* **1987**, *322*, 299. (c) Sebastian, J. F.; Grunwell, J. R.; Hsu, B. *J. Organomet. Chem.* **1974**, *78*, C1. (d) Boche, G.; Etzrodt, H.; Marsch, M.; Massa, W.; Baum, G.; Dietrich, H.; Mahdi, W. *Angew. Chem.* **1986**, *98*, 84.

(13) Fraenkel, G.; Chow, A.; Winchester, W. R. *J. Am. Chem. Soc.* **1990**, *112*, 1382.

(14) (1-(((bis(2-methoxyethyl)amino)methyl)dimethylsilyl)allyl)lithium: recent results, Dr. Jose Cabral, The Ohio State University, **1992**.

Table I. Energy Minimized Structures of Allyl Anions by MNDO Calculation



anion	dihedral angle, deg		bond length, Å (order) C_1C_2	C_2C_3
	$H_{1ex}C_1C_2C_3$	179.70	1.3709	1.3709
	$H_{1ex}C_1C_2H_2$	−0.28	(0.6305)	(0.6304)
	$C_{1ex}C_1C_2C_3$	180.02	1.4004	1.3590
	$C_1C_2C_3H_{3ex}$	180.03	(0.5486)	(0.6983)
	$C_{1en}C_1C_2C_3$	0.02	1.4006	1.3587
	$H_{1ex}C_1C_2C_3$	180.00	(0.5431)	(0.6999)
	$C_{1en}C_1C_2C_3$	0.42	1.4305	1.3518
	$C_{1ex}C_1C_2C_3$	−179.48	(0.4688)	(0.7413)
	$C_1C_2C_3H_{3ex}$	−179.85		
	$C_{1ex}C_1C_2C_3$	180.06	1.3868	1.3868
	$C_1C_2C_3C_{3ex}$	179.91	(0.6129)	(0.6129)
	$H_{1en}C_1C_2C_3$	0.01	1.3865	1.3870
	$C_1C_2C_3H_{3ex}$	180.05	(0.6142)	(0.6144)
	$C_{1en}C_1C_2C_3$	−0.07	1.3856	1.3871
	$C_1C_2C_3C_{3en}$	−0.26	(0.6174)	(0.6123)
	$C_1C_2C_3C_{3ex}$	179.95	1.3857	1.3718
	$C_{1en}C_1C_2C_3$	0.0	(0.5308)	(0.6682)
	$C_{1en}C_1C_2C_3$	−0.38	1.4183	1.3766
	$C_1C_2C_3C_{3en}$	.18	(0.5311)	(0.6716)
	$C_{1en}C_1C_2C_3$	−1.252	1.4064	1.4062
	$C_{1ex}C_1C_2C_3$	177.48	(0.5876)	(0.5849)
	$C_1C_2C_3C_{3en}$	−1.49		
	$C_1C_2C_3C_{3ex}$	177.65		

arenes at room temperature.[16] Simple alkyllithiums in the presence of tertiary amines or ethers (THF) add to anthracene at measurable rates at temperatures as low as −30 °C.[17] *n*-Butyllithium adds to naphthalene at 148 °C in the presence of TMEDA. As noted above, allyllithium adds to anthracene at −78 °C. No products could be detected when naphthalene was treated with alkyllithiums or allyllithium in donor solvents at −78 °C. Only **1** adds to naphthalene at −78 °C.

For simplicity, we modeled allyllithiums as allyl anions and obtained their energy minimized structures, with MNDO[19] calculations, varying the number of methyls at the termini from 1 to 4, in all reasonable arrangements. Inspection of the results in Table I shows that methyl substitution at a terminus, C_t, increases the C_t–C_2 bond length and decreases its bond order, consistent with the traditional view that alkyl substituents destabilize carbanions. Further, the only species which significantly deviates from coplanarity of substituents with the allyl framework is the 1,1,3,3-tetramethylallyl anion. Tentatively, that may be the origin of the reactivity of **1** to aromatic compounds.

Conclusion

Compared to all other organolithium compounds investigated so far, (1,1,3,3-tetramethylallyl)lithium is by far the most reactive to aromatic compounds, adding rapidly to naphthalenes at −78 °C. The purified complex **1**·TMEDA exhibits a barrier to rotation of 14 kcal/mol, similar to that for the corresponding cation. In the species **1**·TMEDA, TMEDA is disymmetrically sited with respect to the allyl anion. The barrier to reorientation of coordinated Li^+ within the ion-pair is 7.9 kcal/mol.

Some MNDO calculations show that among several substituted allyl anions, only the 1,1,3,3-tetramethyl species show significant deviation from coplanarity.

Experimental Section

(1,1,3,3-Tetramethylallyl)lithium–TMEDA (1·TMEDA). A 50-mL Schlenk flask containing a glass-coated stir bar was flamed and cooled under vacuum. The flask was transported into a glovebox where it was charged with 0.050 g (0.192 mmol) of **3** and 0.022 g (0.189 mmol) of *N,N,N',N'*-tetramethylethylenediamine (TMEDA). The flask was removed from the box and placed in a dry ice bath at −92 °C. Under a flow of argon, the flask was then opened and 1.85 mL of diethyl ether and 0.15 mL of tetrahydrofuran (ca. 10 mol equiv of THF per mole of **3**) were added for solvation. Methyllithium (0.1 mL, 1.6 M, diethyl ether) was then added dropwise and slowly from a syringe to the reaction flask. The reaction was allowed to proceed for 0.5 h at −92 °C. At this point the glass stopper was replaced with a high-vacuum stopcock adaptor and the flask was connected to a high-vacuum line. Evaporation of THF, diethyl ether, and $(CH_3)_4Sn$ at −92 °C was realized over 8 h. The reddish color of the allylic complex became faintly yellow when the solvents were fully evaporated. The powdery residue was then taken-up in 2 mL of vacuum-transferred *n*-pentane. The reaction apparatus was transferred back into a glovebox, where unreacted MeLi was filtered off by passing the solution through a Pasteur pipet stoppered with tightly packed glass wool. The yield of **1**·TMEDA is estimated at 85%. Aliquots of **1**·TMEDA in NMR tubes can then be used for spectroscopic studies following evaporation of *n*-pentane and vacuum transfer of deuterated solvent. NMR (ppm, diethyl ether-d_{10}, 296 K): ^{13}C C1 and C3 59.72, C2 138.28, allylic CH_3's 25.85, NCH_3 46.27, NCH_2 58.12; ^1H CH_3's 1.76 (s), allylic CH 5.386 (s), NCH_3 2.219 (s), NCH_2 2.373 (s). Line-shape analysis was conducted on **1**·TMEDA at 0.24 M in diethyl ether-d_{10}.

2,4-Dimethyl-4-(phenylthio)-2-pentene (2). A 1-L, three-necked flask fitted with an addition funnel and an argon inlet adaptor was charged by cannulation with 81.0 g of CH_3MgI (0.49 mol) in 400 mL of diethyl ether. The solution was cooled to an ice bath temperature, and 14.7 g of mesityl oxide (0.15 mol) in 35 mL of diethyl ether was added dropwise over 2 h. After a total time of 3 h, bubbling of HCl gas directly into the solution with a syringe needle and dropwise addition of 16.5 g of thiophenol (0.15 mol) in 35 mL of diethyl ether were initiated simultaneously. The HCl gas was then removed halfway through the addition, about 0.5 h, and the solution was stirred 1 h more upon completion of the addition. The reaction was then quenched with 50 mL of 5% NaOH solution. The organic phase was extracted, washed 5 times with 50 mL of the hydroxide solution and once with brine, and then dried over $MgSO_4$. Concentrating under vacuum followed by distillation yielded 25.13 g (0.1218 mol, 95%) of 2,4-dimethyl-4-(phenylthio)-2-pentene (**2**), bp 67 °C, 0.15 Torr. NMR ($CDCl_3$, ppm): ^1H Ar 7.42–7.39 and 7.23–7.20 (m, 5 H), $(CH_3)_2C{=}CH$ 5.13 (m, 1 H), $=CHC(CH_3)_2-$ 1.44 (s, 6 H), *exo*-CH_3 1.711 (d, 3 H, $^4J(CH_3{-}CH)$ = 1.72 Hz), *endo*-CH_3 1.718 (d, 3 H, $^4J(CH_3{-}CH)$ = 1.55 Hz); ^{13}C *exo*-CH_3 27.77, *endo*-CH_3 18.97, $(CH_3)_2C$ = 134.62, $(CH_3)_2C{=}CH-$ 133.53, $=CHC(CH_3)_2-$ 49.09, $=CHC(CH_3)_2$ 30.75, Ar 136.90, 128.22, 130.52, 128.09. MS: *m/e* M^+ 206 ($C_{13}H_{18}S$, 2%), 109 (C_6H_5S, 12%), 97 (C_7H_{13} and C_5H_5S, 100%), 55 (C_4H_7, 55%).

4-(Trimethylstannyl)-2,4-dimethyl-2-pentene (3). A 250-mL Schlenk flask with a glass-coated stir bar was flamed and cooled under vacuum. Under a flow of argon, the flask was charged with 4.52 g (0.026 mol) of *N,N*-dimethyl-1-naphthalenamine and 25 mL of tetrahydrofuran. Some lithium silvers were then added to the solution at room temperature. Once formation of the radical anion ensued, as indicated by the dark green color, the reaction flask was immersed in an external bath at −45 to −55 °C. Lower temperatures suppressed formation of the radical anion. The remaining slivers of lithium were then added to bring the total to 0.026 moles, 1.05 mol equiv, and the reaction was allowed to proceed. After 5 h, the reaction flask was placed in a bath at −92 °C. A three-fourths fraction of 2.72 g (0.0132 mol) of **2** in 10 mL of tetrahydrofuran was then added dropwise from an addition funnel over a period of 40 min. The remaining one-fourth portion of **2** was mixed with 2.63 g (0.0132 mol) of trimethyltin chloride in 10 mL of tetrahydrofuran, and the addition was continued dropwise at the same rate. The duration of the reaction was extended by 1 h upon addition of all reagents, after which it was quenched with 30 mL of 0.1 N NaOH. The aqueous phase was

(15) (a) Dixon, J.; Fishman, D. *J. Am. Chem. Soc.* **1963**, *85*, 1356. (b) Dixon, J.; Fishman, D.; Dudinyak, R. S. *Tetrahedron Lett.* **1964**, 613.
(16) Winkler, H.; Bollinger, R.; Winkler, H. *J. Org. Chem.* **1967**, *32*, 1700.
(17) (a) Zieger, H.; Rosenkranz, J. *J. Org. Chem.* **1964**, *29*, 2469. (b) Zieger, H.; Laski, E. *Tetrahedron Lett.* **1966**, 3801. (c) Zieger, H.; Schaeffer, D. *J. Org. Chem.* **1969**, *34*, 3958. (d) Panek, E. J. *J. Am. Chem. Soc.* **1973**, *95*, 8460. (e) Harvey, R. G.; Davis, C. C. *J. Org. Chem.* **1969**, *34*, 3607. (f) Panek, E. J.; Rodger, T. J. *J. Am. Chem. Soc.* **1974**, *96*, 6921. (g) Fu, P. P.; Harvey, R. G.; Paschal, J. W.; Rabideau, P. W. *J. Am. Chem. Soc.* **1975**, *97*, 1145.
(18) Halasa, A. F. *J. Organomet. Chem.* **1971**, *31*, 369.
(19) (a) Bingham, R. C.; Dewar, M. J. S.; Lo, D. H. *J. Am. Chem. Soc.* **1975**, *97*, 1302. (b) Dewar, M. J. S.; Thiel, W. *J. Am. Chem. Soc.* **1977**, *99*, 4899.

saturated with NaCl, and the organic phase was extracted, washed three times with hydroxide solution, dried over $MgSO_4$, and then concentrated under low vacuum. The yield of **3**, determined by gas chromatographic analysis of the crude reaction product, was nearly quantitative, 95%. Compound **3** (3.05 g) was distilled directly from the crude mixture, bp 78 °C at 2 Torr, in 88% yield. NMR ($CDCl_3$, ppm): ^1H $(CH_3)_2C=CH-$ 5.205 (m, 1 H, ^3J(Sn–H) = 30.37 Hz), $=CHC(CH_3)_2-$ 1.279 (6 H, ^3J(Sn–CH_3) = 67.60 and 64.7 Hz), *exo*-CH_3 1.646 (d, 3 H, ^4J-(CH_3–CH) = 1.17 Hz), *endo*-CH_3 1.691 (d, 3 H, ^4J(CH_3–CH) = 1.14 Hz), $-Sn(CH_3)_3$ 0.019 (9 H, m, ^2J(Sn–H) = 47.62 and 49.63 Hz); ^{13}C *exo*-CH_3 27.65, $(CH_3)_2C=$ 135.37, *endo*-CH_3 19.43, $(CH_3)_2C=CH-$ 127.16, $=CHC(CH_3)_2$ 27.50, $=CHC(CH_3)_2$ 28.76, $-Sn(CH_3)_3$ −10.05. MS: *m/e* M^+ 260 ($C_{10}H_{22}Sn$, 3%), 165 (C_3H_9Sn, 100%), 135 (CH_3Sn, 24%), 97 (C_7H_{13}, 34%), 55 (C_4H_7, 26%).

Procedure I. A. Dihydronaphthalenes 5 and 6. A dry 50-mL Schlenk flask with a glass-coated stir bar was charged with 1.8 mL of diethyl ether and 0.2 mL of tetrahydrofuran. Samplings of 0.20 mmol each of *N,N,N′,N′*-tetramethylethylenediamine (23 mg) and trimethyl(1,1,3,3-tetramethylallyl)tin (52 mg) were added to the solution, and the flask was then brought to −78 °C with an external bath. Methyllithium (0.14 mL, 1.4 M, diethyl ether) was then added dropwise from a syringe to generate **1**·TMEDA. After 2 h, 1 equiv of naphthalene, 25.6 mg, was then added neat to the anion. Within minutes, the bright orange color of the anion began to change to red, indicating the presence of alkenylated naphthalene anion. The reaction was allowed to proceed for 2 h when it was then quenched with 5 mL of 0.1 M hydrochloric acid at −78 °C. The reaction flask was then allowed to come to room temperature, and the organic phase was extracted, dried over $MgSO_4$, and concentrated under vacuum. The oily organic phase was analyzed by NMR for the presence of vinylic C=C*H*– resonances whose integration indicated yields of 86.5% of **5** (36.6%) and **6** (49.9%) and 13.5% of **2**. The oil residue was then purified (38.5 mg) by column chromatography, silica gel, 200–400 mesh, 60 Å. 1,4-Dihydro-1-(1′,1′,3′-trimethyl-2′-butenyl)naphthalene (**5**) NMR ($CDCl_3$, ppm): ^{13}C C1 50.09, C2 129.31, C3 126.69, C4 31.48, C9 137.03, C10 135.08, $-C(CH_3)_2$ 43.58, $-C(CH_3)_2$ 26.44 and 26.36, $CH=C(CH_3)_2$ 133.31, $CH=C(CH_3)_2$ 130.54, *exo*-CH_3 28.58, *endo*-CH_3 18.80; ^1H H1 3.31 (m, 1 H), H2 and H3 6.07 (m, 2 H), H4a 3.37 (m, 1 H), H4b 3.20 (m, 1 H), Ar 7.19 (m, 4 H), $C(CH_3)_2$ 1.046 and 1.057 (s, 6 H), $CH=C(CH_3)_2$ 5.07 (m, 1 H), *endo*-CH_3 1.702 (d, 3 H), *exo*-CH_3 1.602 (d, 3 H); $^4J(CH=C(CH_3)_2)$ = 1.257 and 1.359 Hz, ^3J(H4b–H3) = 3.32 Hz, ^2J(H4a–H4b) = −22.7 Hz, ^3J(H1–H2) = 3.2 Hz, ^5J(H1–H4a) = 1.25 Hz, ^4J(H1–H3) = 1.25 Hz, ^4J(H2–H4a) = 1.35 Hz. 1,2-Dihydro-1-(1′,1′,3′-trimethyl-2′-butenyl)naphthalene (**6**) NMR ($CDCl_3$, ppm): ^{13}C C1 45.40, C2 25.86, C3 128.35, C4 127.60, C8 125.75, C9 136.97, C10 137.03, $C(CH_3)_2$ 41.71, $C(CH_3)_2$ 27.82 and 26.89, $CH=C(CH_3)_2$ 134.04, $CH=C(CH_3)_2$ 133.69, *exo*-CH_2 28.58, *endo*-CH_3 18.91; ^1H H1 2.774 (dd, 1 H), H2a 2.614 (dddd, 1 H), H2b 2.484 (dddd, 1 H), H3 5.90 (dddd, 1 H), H4 6.331 (dddd, 1 H), Ar 6.95–7.19, $C(CH_3)_2$ 1.026 and 1.107 (s, 6 H), $CH=C(CH_3)_2$ 5.07 (m, 1 H), *endo*-CH_3 1.714 (d, 3 H), *exo*-CH_3 1.614 (d, 3 H), $^4J(CH=C(CH_3)_2)$ = 1.393 Hz, ^3J(H1–H2a) = 1.76 Hz, ^3J(H1–H2b) = 8.11 Hz, ^2J(H2a–H2b) = −18.09 Hz, ^3J(H2a–H3) = 5.87 Hz, ^3J(H2b–H3) = 2.60 Hz, ^4J(H4–H2a) = 0.9 Hz, ^4J(H4–H2b) = 2.60 Hz, ^3J(H4–H3) = 9.52 Hz, ^3J(H8–H7) = 6.94 Hz. Other eight unassigned aromatic resonances (**5** and **6**): 125.57, 125.62, 125.75, 126.57, 130.26, 131.16, 124.7, and 127.84.

B. Dihydronaphthalenamines 8 and 9. A dry 50-mL Schlenk tube with a glass-coated stir bar was charged with 1.8 mL of diethyl ether and 0.2 mL of tetrahydrofuran. Samplings of 0.20 mmol each of *N,N,N′,N′*-tetramethylethylenediamine (23 mg) and trimethyl(1,1,3,3-tetramethylallyl)tin (52 mg) were added to the solution, and the flask was then brought to −78 °C with an external bath. Methyllithium (0.14 mL, 1.4 M, diethyl ether) was then added dropwise from a syringe to generate **1**·TMEDA. After 2 h, 1 equiv of *N,N*-dimethyl-1-naphthalenamine, 34.2 mg, was then added neat to the anion. Within minutes, the bright orange color of the anion began to change to dark red, indicating the presence of alkenylated naphthalene anion. The reaction was allowed to proceed for 2 h when it was then quenched with 5 mL of 2% aqueous sodium hydroxide at −78 °C. The reaction flask was then allowed to come to room temperature, and the organic phase was extracted, dried over $MgSO_4$, and concentrated under vacuum. The organic phase was analyzed by NMR for the presence of vinylic C=C*H*– resonances whose integration indicated yields of 71.2% of **8** (43.1%) and **9** (28.1%) and 28.8% of **2**. The mixture of these compounds was then taken up in diethyl ether, and the amines were extracted with 0.5 M HCl. The aqueous phase was then rendered alkaline with NaOH, and the amines were taken-up in diethyl ether. MS *m/e* **8** and **9**: M^+ 270 (44.5%), 97 (100%, C_7H_{13}), 173 (24.8%, $C_{12}H_{14}N$). 5,6-Dihydro-*N,N*-dimethyl-5-(1′,1′,3′-trimethyl-2′-butenyl)-1-naphthalenamine (**8**) NMR ($CDCl_3$, ppm): ^{13}C: C1 149.56, C2 116.49, C3 125.67, C4 125.08, C5 45.96, C6 25.63, C7 127.31, C8 123.81, C9 131.60, C10 136.63, $N(CH_3)_2$ 45.11, $C(CH_3)_2$ 41.49, $C(CH_3)_2$ 28.18, $CH=C(CH_3)_2$ 134.25, $CH=C(CH_3)_2$ 130.26, *endo*-CH_3 18.80, *exo*-CH_3 28.60; ^1H H2 6.901 (d, 1 H), H3 7.023 (t, 1 H), H4 6.786 (d, 1 H), H5 2.746 (dddd, 1 H), H6a 2.634 (dddd, 1 H), H6b 2.478 (dddd, 1 H), H7 6.591 (ddd, 1 H), H8 6.75 (dd, 1 H), $N(CH_3)_2$ 2.685 (s, 6 H), $C(CH_3)_2$ 1.016 (s, 6 H), $CH=C(CH_3)_2$ 5.068 (m, 1 H), *endo*-CH_3 1.696 (d, 3 H), *exo*-CH_3 1.613 (d, 3 H), ^3J(H4–H3 and H2–H3) = 7.78 Hz, $^4J(CH=C(CH_3)_2)$ 1.06 Hz, ^3J-(H5–H6a) = 1.48 Hz, ^3J(H5–H6b) = 8.32 Hz, ^2J(H6a–H6b) = −18.28 Hz, ^3J(H6a–H7) = 5.35 Hz, ^3J(H6b–H7) = 2.93 Hz, ^4J(H8–H6b) = 2.91 Hz, ^4J(H8–H6a) = 0.79 Hz, ^3J(H8–H7) = 9.41 Hz. 5,8-Dihydro-*N,N*-dimethyl-5-(1′,1′,3′-trimethyl-2′-butenyl)-1-naphthalenamine (**9**) NMR ($CDCl_3$, ppm): ^{13}C: C1 151.67, C2 115.38, C3 125.56, C4 124.99, C5 45.25, C6 128.89, C7 127.41, C8 27.82, C9 132.96, C10 138.34, $N(CH_3)_2$ 44.38, $C(CH_3)_2$ 43.62, $C(CH_3)_2$ 26.64, $CH=C(CH_3)_2$ 132.96, $CH=C(CH_3)_2$ 130.57, *endo*-CH_3 18.80, *exo*-CH_3 28.69; ^1H H2 6.901 (d, 1 H), H3 7.085 (t, 1 H), H4 6.787 (d, 1 H), H5 3.503 (m, 1 H), H6 and H7 6.06 (m, 2 H) H8a 3.549 (m, 1 H), H8b 3.016 (m, 1 H), $N(CH_3)_2$ 2.696 (s, 6 H), $C(CH_3)_2$ 1.079 (s, 6 H), $CH=C(CH_3)_2$ 5.068 (m, 1 H), *endo*-CH_3 1.674 (d, 3 H), *exo*-CH_3 1.559 (d, 3 H), ^3J(H2–H3 and H3–H4) = 7.77 Hz, ^2J(H8a–H8b) = −18.12 Hz, ^4J-(H6–H8a) = 1.40 Hz, ^4J(H6–H8b) = 0.63 Hz, ^3J(H7–H8a) = 4.57 Hz, ^3J(H7–H8b) = 1.360 Hz.

Procedure II. A. Dihydronaphthalenes 5 and 6. A 250-mL round-bottom Schlenk flask with a glass-coated stir bar was flamed and cooled under vacuum. Under a flow of argon, the flask was then charged with 50 mL of dry tetrahydrofuran and 3.048 g of naphthalene (0.0238 mol). The mixture was cooled to −78 °C, and 0.166 g of Li (0.0238 mol) finely cut into shavings was added to the reaction mixture. The solution slowly turned green, and formation of the naphthyl radical anion was allowed to continue. After 6 h, 2.45 g of **2**, 2,4-dimethyl-4-(phenylthio)-2-pentene (0.019 mol), at room temperature and neat was added dropwise from a syringe to the reaction mixture at −78 °C. The reaction was allowed to proceed for 1 h and was then quenched with 5 mL of 2% sodium hydroxide solution. The reaction flask was allowed to come to room temperature, and the organic phase was taken-up in 50 mL of petroleum ether and extracted. This phase was then dried over $MgSO_4$ and concentrated under vacuum. Proton NMR analysis of the crude reaction mixture indicated the presence of 23.3% 2,4-dimethyl-4-(phenylthio)-2-pentene (**2**) and 77.8% of vinylic C2′H of dihydronaphthalenes **5** and **6**. This latter fraction was resolved into 14.8% 1,2-dihydro-1-(1′,1′,3′-trimethyl-2′-butenyl)naphthalene (**6**), 52.7% 1,4-dihydro-1-(1′,1′,3′-trimethyl-2′-butenyl)naphthalene (**5**), and 10.3% 1,2-dihydro-2-(1′,1′,3′-trimethyl-2′-butenyl)naphthalene.

B. Dihydronaphthalenamines 8 and 9. A 250-mL Schlenk flask with a glass-coated stir bar was flamed and cooled under vacuum. Under a flow of argon, the flask was then charged with 2.47 g of *N,N*-dimethyl-1-naphthalenamine (0.014 mol) and 30 mL of tetrahydrofuran. The mixture was cooled to −65 °C, and 0.101 g of Li (0.014 mol) finely cut into shavings was added to the reaction mixture. The radical anion of the naphthalenamine was allowed to form over a period of 5 h, and the reaction was then cooled to −78 °C. A sample of 1.488 g of neat **2**, 2,4-dimethyl-4-(phenylthio)-2-pentene (0.0072 mol), was added dropwise from a syringe. After 2 h at −78 °C, the reaction mixture was quenched with 5 mL of 5% sodium hydroxide solution and allowed to come to room temperature, and the organic phase was extracted with 50 mL of petroleum ether. The products were dried over $MgSO_4$ and concentrated under vacuum. Proton NMR analysis of the crude reaction products revealed 10% **2**, 2,4-dimethyl-4-(phenylthio)-2-pentene, and 90% dihydronaphthalenamines **8** and **9**. The crude product mixture was then taken-up in 0.5 M aqueous hydrochloric acid, and 2,4-dimethyl-4-(phenylthio)-2-pentene was extracted with petroleum ether. The aqueous phase was rendered basic with 10% NaOH solution, and the neutral amines were extracted with petroleum ether. The substituted dihydronaphthalenamines were then separated from *N,N*-dimethyl-1-naphthalenamine by silica gel chromatography (2:1 silica gel G/thin layer silica gel and 4% THF in petroleum ether, by volume). The mixture of dihydronaphthalenamine reaction products was resolved by proton NMR as 43% **8**, 5,6-dihydro-*N,N*-dimethyl-5-(1′,1′,3′-trimethyl-2′-butenyl)-1-naphthalenamine, and 28.2% **9**, 5,8-dihydro-*N,N*-dimethyl-5-(1′,1′,3′-trimethyl-2′-butenyl)-1-naphthalenamine.

Attempted Preparation of 1-Allyldihydronaphthalenes. A 50-mL Schlenk flask with a glass-coated stir bar was flamed and cooled under vacuum. Under a flow of argon, the flask was then charged with 0.05 g of *N,N,N′,N′*-tetramethylethylenediamine (0.43 mmol), 0.03 g of tetraallyltin (0.11 mmol), and 2 mL of diethyl ether. The temperature of the solution was then brought to −5 °C with an external bath, and *n*-butyllithium (0.27 mL, 1.6 M, hexane) was then added to the reaction mixture. The solution was then brought to room temperature and the reaction allowed to proceed for 1.5 h. A sample of 0.055 g of naphthalene

(0.43 mmol) was then added and the reaction allowed continue for 1.5 h. The reaction was then quenched with 5 mL of 0.1 M hydrochloric acid with noticeable evolution of gas, and the organic phase was extracted, dried over $MgSO_4$, and concentrated under vacuum. An NMR analysis of the solid organic residue revealed unreacted naphthalene and minor impurities of tin-coupled vinylic C=C*H*– resonances (<2%).

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Atomic Charges for Variable Molecular Conformations

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Abstract: The problem of generating high-quality atomic charges valid over a range of conformations has been addressed using two related methods which both employ a constrained minimization of the difference between the quantum mechanical and classical MEP (molecular electrostatic potential) with respect to the atomic charges. The first method involves determining the MEP and constraining the charges to reproduce the dipole at an alternative geometry. The second method involves determining the MEP for each conformation of interest and weighting the MEP for each conformation according to the appropriate Boltzmann factor. These methods offer considerable improvement over averaging the charges obtained at each conformation. The improvement in the performance of these multiple conformation MEP derived charges is illustrated by studying the variation of the classical dipole with conformation and comparing the results with those from ab initio calculations. It is proposed that the main use of these multiple conformation MEP derived charges and dipole constrained charges is likely to be in computer simulations where the ability to search conformational space is matched by the ability of the charges to yield the correct electrostatic properties at the conformations of interest. The errors arising from ignoring these effects have been assessed by evaluating the hydration free energy using a continuum method and are found to be significant. The extension of these methods to protein simulations is discussed.

Point charges on atoms are vital for many applications. A difficulty arises when the atomic point monopole charges change with molecular conformation. In particular, this is important in molecular dynamics. The ability to sample correctly alternative conformational regions is in some cases severely limited by the monopole model where the atomic charges are calculated at a single geometry but they are assumed to be valid for all geometries. Here we show that charges derived from the MEP (molecular electrostatic potential) determined for a range of conformations, with the MEP appropriately weighted according to the Boltzmann factor of the conformation, give a greatly improved description of the electrostatics of the molecule. These multiple conformation MEP derived charges yield superior free energy results when compared to standard single MEP charges in computer simulations of normal alcohols in water and carbon tetrachloride.[1,2]

The determination of reliable and theoretically justifiable atomic charges has long been a perplexing task for theoretical chemists since the description of atomic charges is shrouded in uncertainty, and yet at the same time the use of atomic charges in empirical potential energy functions provides an extremely powerful tool. Perhaps this usefulness is seen most strikingly in the recent application of free energy calculations to biological problems where calculated enzyme ligand binding energies in good agreement with experiment have been reported.[3] To date, many of these calculations have successfully used single MEP derived charges; but as techniques and computer power enable more extensive regions of conformational space to be sampled, the need will arise for charges valid over a wider range of conformations: a need which current methods cannot be guaranteed to meet.

Quantum mechanics offers the most general method of determining atomic charges, since other approaches such as fitting to experiment[4–6] are limited by the availability of experimental data. Moreover, different experimental properties may yield different values, particularly if the charges represent one part of a restricted force field. Thus if the force field does not treat polarization or if it treats repulsion inadequately, the charges are likely to be contaminated by polarization or repulsion effects. Moreover, if the experimental molecules have restricted mobility, as in a crystal, the resulting charges may only be valid for those restricted geometries.

Quantum mechanics does not provide a useful definition of an atom in a molecule. Bader partitioning[7] offers an elegant approach to the problem, but it is not a practical solution due to the computational expense. The Mulliken[8] and related population schemes are computationally inexpensive but do not yield reliable results. Extensions to the Mulliken scheme such as those developed by Huzinaga[9] and Stone[10] may offer more accurate results but are less useful in simulations because they introduce additional centers or higher order multipoles. Recently Hagler[11] has reported charges

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