Functionalization of Poly(methyl acrylate). 2. The Kinetics of the Amination of Small-Molecule Analogs†

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ABSTRACT: The kinetics of amination of dimethyl glutarate (DMG) and dimethyl 2,4-dimethylglutarate (DMDMG), considered to be small-molecule analogs of poly(methyl acrylate) (PMA), by reactions with ethanolamine (EA), *n*-hexylamine (HAN), benzylamine (BZA), and cyclohexanemethylamine (CN) have been studied by means of solution ^{13}C NMR. For the amines considered, it is found that under similar conditions the rate constant for the replacement of the first ester group (k_0) of DMG is always larger than that for the replacement of the ester groups of PMA that have no reacted neighbors. This is in keeping with less steric hindrance. As was observed for the functionalization of PMA, K (defined as k_1/k_0) is sensitive to the reaction medium but not to the reaction temperature. Comparison of the values of K for the reactions of the analogs to those for the reactions of PMA reveals that the polymer chain plays an important part in determining the kinetic parameters. The value of K is also found to be dependent on the size and hydrophobicity of the amines. Although the rates of reaction of *meso* and *racemic* forms of DMDMG with ethanolamine are virtually the same, those with HAN and CN show substantial differences. A model of intramolecular assisting effects that involves the formation of an eight-membered ring is proposed and discussed.

Introduction

The reactions of small-molecule analogs of polymers have been used with considerable success to probe the reaction mechanisms of macromolecules and thus to develop some important fundamental concepts.[1-3] As early as 1939, Flory[1] used the observation that the reactivity of functional groups is independent of the size of the molecules to which they are attached to develop the kinetic theory for condensation polymerization. A comparison of the rates of quaternization, by alkyl halides, of 4-picoline and 1,2-di-4-pyridylethane with those of poly(4-vinylpyridine)[2] led to the suggestion that an autoretardation effect exists because electrostatic repulsion plays an important role in these reactions. This result was used as supporting evidence for the now well-known neighboring-group effect model for the reactions of macromolecules. By comparative studies of the kinetic behavior of polymers and their small-molecule analogs, Morawetz and co-workers[3] found that the rates of aminolysis of *p*-nitrophenyl ester residues attached to various polymer backbones are insensitive to the nature of the amine but are strongly dependent on the nature of the backbone. This was attributed to a concentration inhomogeneity that resulted from the preferential absorption of the amines from the bulk solution into the macromolecule coils which form microphases within the polymer solutions.

The study of the relative reactivities of functional groups in different tactic environments has been made possible by the quantitative aspects offered by modern high-resolution NMR.[4] For example, by means of ^{13}C NMR, Jameison et al.[5] studied the kinetics of the dehydrochlorination of oligo(ethylene chlorides), the analogs of poly(vinyl chloride) (PVC). Through a statistical approach, they demonstrated that the kinetic parameters obtained for the dehydrochlorination of the analogs can be applied remarkably well to the degradation of PVC, suggesting that the reactivities of Cl in different configurations of the analogs are the same as those in PVC. Our recent *in situ* NMR studies on the kinetics of the functionalization of poly(methyl acrylate) (PMA) by reactions with amines have revealed that the rate of reaction of an ester group can be affected by the neighboring groups.[6,7] However, certain important aspects of these reactions remain unexplained: First of all, the relative importance of effects due to neighboring groups compared with those due to nonneighboring groups is not clear. Second, the deviations of reacted monomer triad sequence distributions from theoretical predictions, for example, as reported in the previous paper,[7] are not completely understood. Due in large measure to limitations in the experimental methods of analysis, the effects of different configurational environments on the kinetic behavior of the functional groups are relatively unexplored.[8] Certainly, a preliminary report by Robertson and Harwood[9] suggests that differences in tacticity can cause large differences in reactivities of triads. It was these considerations that motivated this study.

This paper describes an NMR study of the kinetics of the amination of dimethyl glutarate (DMG) and dimethyl 2,4-dimethylglutarate (DMDMG), which are considered to be small-molecule analogs of PMA. The experimental results are compared to those obtained previously[6,7] in studies of the analogous reactions of PMA.

Experimental Section

(1) **Materials.** Dimethyl glutarate and dimethyl 2,4-dimethylglutarate were used as received from Aldrich. The amines, *n*-hexylamine (HAN; Eastman Kodak), ethanolamine (EA; BDH), cyclohexanemethylamine (CN; Aldrich), and benzylamine (BZA; Aldrich), were dried over a molecular sieve (4 Å) for at least 24 h prior to use. The deuterated solvents were purchased from MSD Isotopes.

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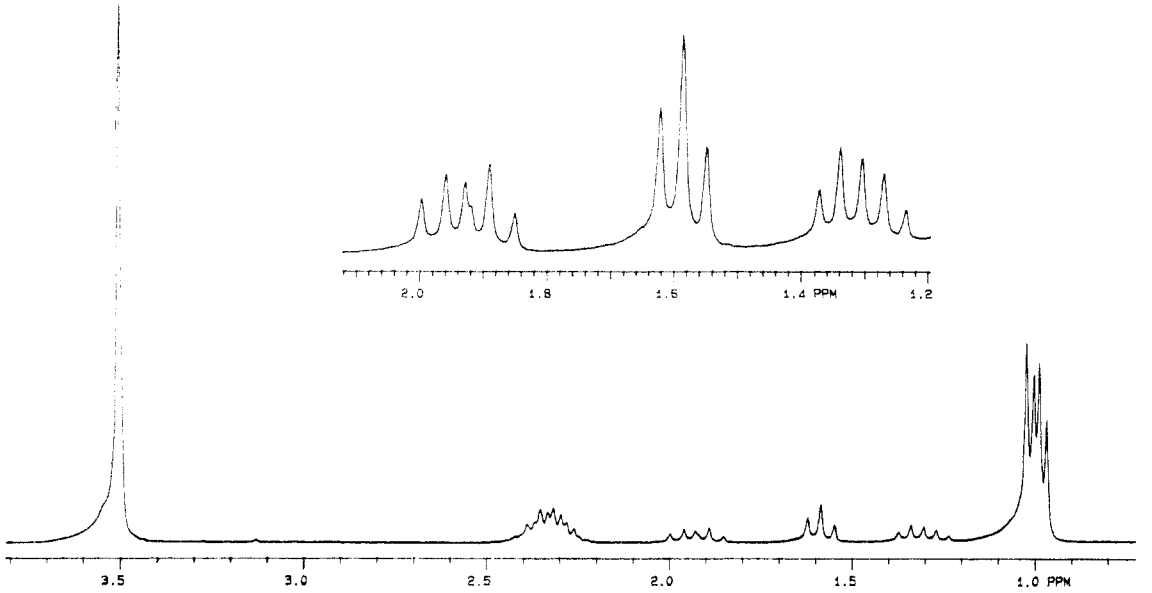
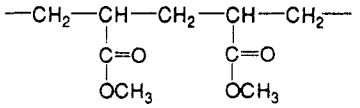
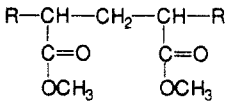


Figure 1. ^{1}H NMR spectrum of dimethyl 2,4-dimethylglutarate obtained with a Varian XL-200 NMR spectrometer in $CDCl_3$. The inset shows *meso* and *racemic* structures of this mixture (see the text).

The structures of PMA and its small-molecule analogs, DMG and DMDMG, are illustrated in **I**. The ^{1}H NMR spectrum of



PMA



R = H, dimethyl glutarate, DMG
R = CH_3, dimethyl 2,4-dimethylglutarate, DMDMG

I

dimethyl 2,4-dimethylglutarate, shown in Figure 1, confirms that it is a mixture of the *meso* and *racemic* forms. The triplet at a chemical shift of *ca.* 1.59 ppm in the inset is assigned to the two protons attached to the β-methylene group of the *racemic* DMDMG. Because this molecule has a 2-fold axis of symmetry, the protons attached to the β-methylene groups are magnetically equivalent and exhibit a single chemical shift.[4] However, the protons attached to the β-methylene carbon of the *meso*-DMDMG are magnetically nonequivalent and hence show two chemical shifts, seen as two multiplets at 1.30 and 1.92 ppm, respectively.

(2) Sample Preparation. In a 10-mm NMR tube, 0.5–1 g of DMG or DMDMG was mixed with 1.5–2.0 g of a dimethyl sulfoxide (DMSO-d_6) *o*-dichlorobenzene (*o*-DCB-d_4) solvent. After it was degassed by purging with dry N_2 gas for *ca.* 20 min, this solution was heated to the desired reaction temperature and 0.3–0.7 mL of the amine was added and thoroughly mixed. The molar ratio of amine/DMG or DMDMG was kept in the range of 1.5–2.0. The initial reaction time was taken as the moment at which the amine was added.

(3) NMR Spectroscopy. Unless otherwise indicated, all of the NMR spectra were recorded with a Varian XL-300 NMR spectrometer operating at a frequency of 75.43 MHz for carbon-13. The reaction temperature was controlled to within ±0.2 °C. A 90° pulse and a pulse delay of 30 s were employed between each scan. To obtain spectra with an acceptable S/N ratio, 20 scans were recorded at each sampling point.

To verify that the NMR spectra yielded quantitative data, measurements were made of the T_1(^{13}C) and nuclear Overhauser enhancement factors (NOE) for the starting materials, intermediates, and products using the standard inverse-recovery and gated decoupling methods.[10] No apparent differences in NOE were detected for the carbon species used in the kinetic calculations. The results of T_1 measurements, presented in Table 1, show that the delay time of 30 s represents at least 5T_1 intervals for all of the carbon moieties that were used in the kinetic calculations, except for the carbonyl groups. In the case where the intensities of these carbonyl resonances were used in the kinetic calculations, eq 1[11,12] was used to convert the raw data to the final intensities where θ is the flip angle, $E = \exp(-\tau/T_1)$, and

$$\frac{M_{(Z)}}{M^0_{(Z)}} = \frac{(1-E)\sin\theta}{1-E\cos\theta} \qquad (1)$$

τ is the pulse delay.

Table 1. Chemical Shifts (δ) and Spin–Lattice Relaxation Time (T_1) of the Carbon Moieties for the Reactions of DMG with Ethanolamine and *n*-Hexylamine[a]

R	carbon	assignment	δ (ppm)	T_1 (s)
$-CH_2CH_2OH$	C=O	G	172.4	8.3
		M_e		
		M_a	172.7	7.1
		D	173.0	5.4
	α-CH_2	G	32.1	3.1
		M_e	32.5	1.1
		M_a	34.3	0.63
		D	34.6	0.53
	β-CH_2	G	19.7	2.9
		M_{e+a}	20.4	0.91
		D	21.3	0.55
$-(CH_2)_5CH_3$	C=O	G	171.9	37.8
		M_e	172.1	27.8
		M_a	170.6	12.5
		D	171.0	8.47
	α-CH_2	G	31.7	3.55
		M_e	32.0	1.91
		M_a	33.8	1.36
		D	34.3	0.80
	β-CH_2	G	19.2	3.61
		M_{e+a}	20.0	1.68
		D	21.0	1.03

[a] The subscripts e and a represent the carbon species in an ester or an amide group, respectively.

Results and Discussion

As illustrated in eq 2, DMG (G) is sequentially transformed into monoamide (M) and then to diamide (D)

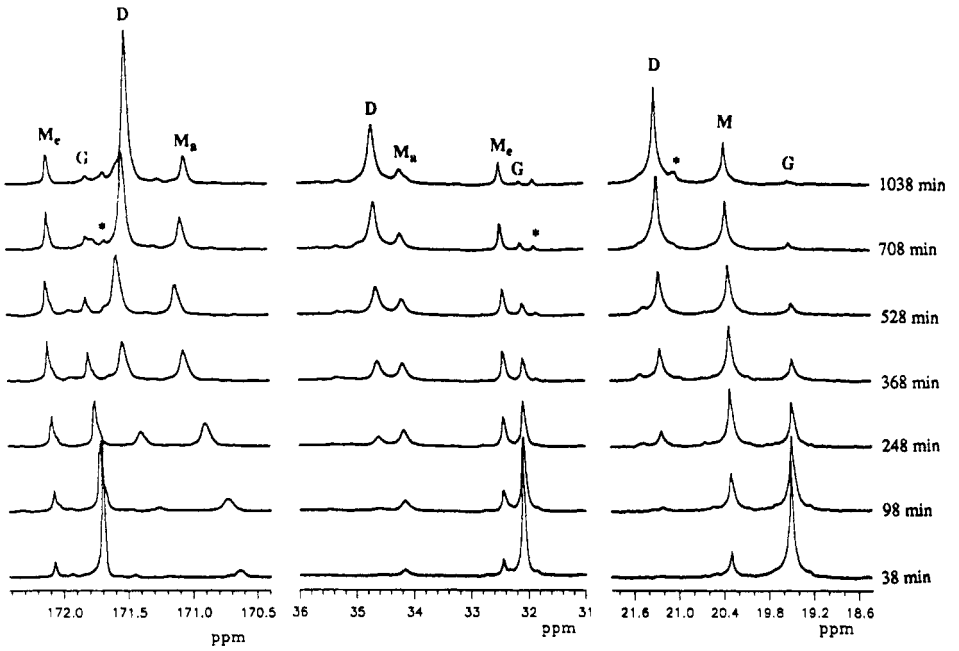
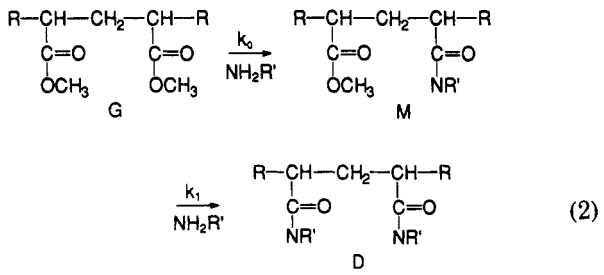


Figure 2. Stack plots of selected NMR spectra of DMG reacted with CN in DMSO at 120 °C for various times. The subscripts a and e represent the resonances of carbons in an amide and an ester group, respectively. The peaks marked with the asterisk (*) indicate the formation of imide. (G represents DMG, M, the monosubstituted DMG, and D, the disubstituted DMG.)

during its reaction with an amine ($R'NH_2$).



(2)

The rate expressions for these irreversible, bimolecular and competitive–consecutive second-order reactions are given by

$$d[G]/dt = -k_0[G][N]$$

$$d[M]/dt = k_0[G][N] - k_1[M][N] \quad (3)$$

$$d[D]/dt = k_1[M][N]$$

where [N] represents the concentration of amines. It can be shown[13] that, by eliminating time as an independent variable and substituting K, defined as k_1/k_0, the progress of the reaction is described by

$$\frac{[M]_\xi}{[G]_0} = \frac{1}{1-K}\left[\left(\frac{[G]_\xi}{[G]_0}\right)^K - \left(\frac{[G]_\xi}{[G]_0}\right)\right] \qquad K \neq 1 \quad (4)$$

$$\frac{[M]_\xi}{[G]_0} = \left(\frac{[G]_\xi}{[G]_0}\right)\left(-\ln\frac{[G]_\xi}{[G]_0}\right) \qquad K = 1$$

where the subscripts 0 and ξ denote the initial time and the time at which the extent of reaction is ξ, respectively. The ratio of rate constants, K, can be obtained accurately from values of [G] and [M] measured at various times of reaction.

For reaction schemes such as that described by eq 2, the primary rate constant, k_0, is given by[14]

$$k_0 = \frac{1}{[N]_0 t}\int_\xi^1 \frac{d\xi}{\xi\left\{1 + \frac{[G]_0}{[N]_0}\left[\frac{1-\xi^{K-1}}{K-1}\xi\right]\right\}} \quad (5)$$

where $[N]_0$ and $[G]_0$ are the initial concentrations of the amine and DMG, respectively, and ξ is the extent of reaction. Numerical integration of eq 5, using the derived value of K, yields k_0. Similarly, the relative rates of the amination of *meso* (m) and *racemic* (r) forms of DMDMG, denoted as K' ($=k_m/k_r$), can be determined[4,15] by plotting the logarithm of the intensity of the m-isomer against that of the r-isomer, based on eq 6, i.e.,

$$K' = \frac{\ln [G_m] - \ln [G_m]_0}{\ln [G_r] - \ln [G_r]_0} \quad (6)$$

where $[G_m]$ and $[G_m]_0$ are the concentrations of the m-isomer of DMDMG at the sampling time and the initial state, respectively, and $[G_r]$ and $[G_r]_0$ are the corresponding concentrations of the r-isomer.

Portions of typical 75.4-MHz NMR spectra showing the resonances for the C=O and the α-methylene and β-methylene carbon species of DMG and the products of amination at various reaction times are presented in Figure 2. The resonance intensities for each of the carbon moieties (G, M, D) were converted into concentrations according to the method described in the Experimental Section. For the reactions with EA, CN, and BZA the intensities of β-CH_2 carbon species were used for the kinetic calculations, but for the reaction with HAN those of α-CH_2 carbon were used because the resonance of β-CH_2 carbon in the disubstituted molecule overlaps with those of the *n*-hexyl groups.

In Figure 3 the percentages of G, M, and D species observed during the functionalization of DMG by reaction with EA are plotted as a function of the extent of reaction. As expected, it shows the kinetic features of a typical serial

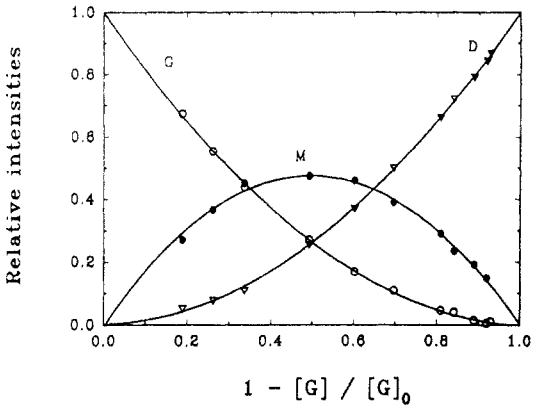


Figure 3. Distributions of reactants and products observed in the functionalization of DMG with HAN in DMSO at 130 °C.

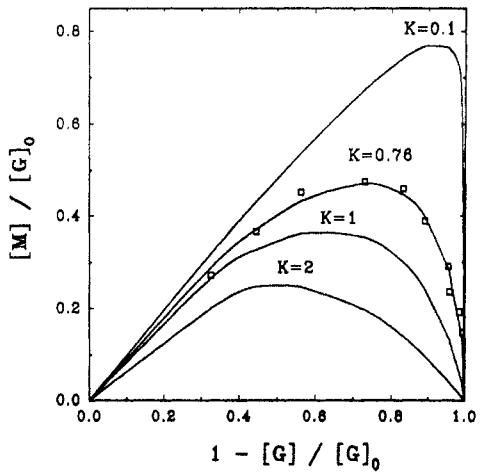


Figure 4. Distributions of M in the reaction system of DMG functionalized with HAN in DMSO at 130 °C, which illustrate the method of obtaining K: (—) theoretical results calculated with given values of K (eq 4), (□) the experimental values.

Table 2. Kinetic Results for the Amination of DMG by Reactions with Various Amines (k_0 in L mol^{-1} min^{-1})

amine	temp (°C)	solv	[Am] (mol L^{-1})	[DMG] (mol L^{-1})	10^3k_0	K	E_a (kJ mol^{-1})
EA	72	DMSO	4.73	2.37	3.00	1.3	45
	85	DMSO	4.73	2.37	5.76	1.3	
	100	DMSO	4.51	2.42	9.66	1.3	
	100	1:1[a]	4.73	2.37	2.50	1.8	
HAN	100	DMSO	2.87	1.59	0.66	0.80	88
	120	DMSO	2.87	1.59	1.89	0.80	
	130	DMSO	1.47	0.77	6.13	0.76	
	130	1:1[a]	2.64	1.59	3.28	0.55	
CN	110	DMSO	3.13	1.95	1.83	0.49	78
	120	DMSO	2.72	1.72	2.70	0.48	
	130	DMSO	2.72	1.72	6.10	0.50	
	120	1:1[a]	2.72	1.72	2.21	0.42	
BZA	100	DMSO	3.85	1.92	0.39	0.50	

[a] 1:1 DMSO/DCB (w/w).

consecutive reaction. Similar patterns were observed for the reactions of DMG with HAN, CN, and BZA.

A graphical method[13] based on eq 4 was used to obtain the value of K, as illustrated in Figure 4. The best values of K, obtained by superimposing the experimental data on the calculated values, are given in Table 2. These values of K were then used in the numerical integration of eq 5 to obtain the values of k_0.

Due to the overlap of the methylene with the methine resonances, for the reactions of DMDMG the intensities of the carbonyl resonances were used for the kinetic calculations. A stack plot of the portions of typical NMR spectra that show the *meso* (m) and *racemic* (r) carbonyl resonances as a function of reaction time is given in Figure

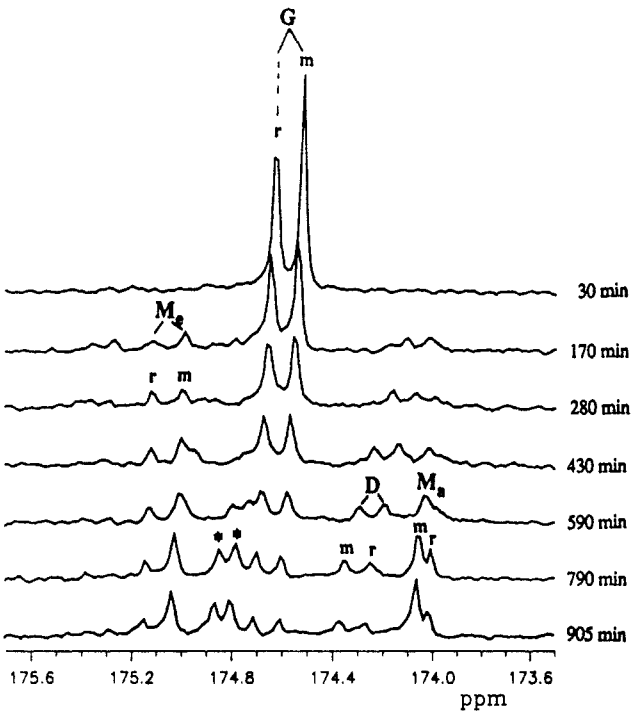


Figure 5. Stack plots of the carbonyl region of a typical set of NMR spectra, plotted as a function of reaction time, for DMDMG functionalized with HAN in DMSO at 130 °C. The subscripts a and e represent the resonance of a carbon in an amide group and an ester group, respectively. The peaks marked with the asterisk (*) indicate the formation of imide. *m* and *r* represent the resonances for the m- and r-isomers of DMDMG and substituted DMDMG. (G represents DMDMG, M, the monosubstituted DMDMG, and D, the disubstituted DMDMG.)

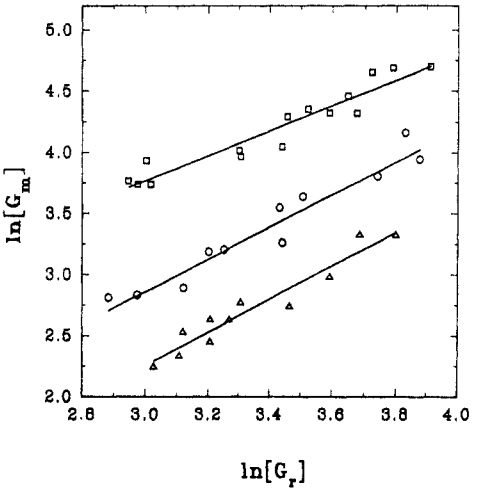


Figure 6. Logarithmic plots of the intensities of r-DMDMG against those of m-DMDMG remaining in the reaction of DMDMG with EA (□ + 0.6), HAN (○), and CN (△ - 0.7). The values of K' were obtained from the slopes of these lines.

5. The plot of the natural logarithm of the intensity of the m-isomer, ln G_m, as a function of the natural logarithm of the intensity of the r-isomer, ln G_r, exhibits good linearity (Figure 6). The values of K' ($=k_m/k_r$) obtained from slopes of these lines (eq 6) are given in Table 3.

The value of K ($=k_1/k_0$) is a measure of the relative reactivity of ester groups neighbored by an amide to those flanked by an ester group. The results shown in Table 2 indicate that, although the replacement of the second ester group of DMG by reaction with EA in DMSO is more than 30% faster than that of the first, the corresponding replacement by HAN is 20% slower, and by CN and BZA *ca.* 50% slower, than the replacement of the first ester

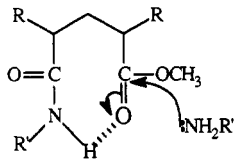
Table 3. Kinetic Results for the Amination of DMDMG (G) by Reactions with Various Amines in DMSO

amine	temp (°C)	[G] [mol L^{-1}]	[Am] (mol L^{-1})	K	K'	10^4k_0 (L mol^{-1} min^{-1})	10^4k_1 (L mol^{-1} min^{-1})
EA	120	1.18	2.36	0.50	1.00	8.14	4.1
HAN	130	1.17	2.34	0.70	1.37	1.44	1.0
CN	130	0.96	1.92	0.10	1.35	4.61	0.46

group. Interestingly, although independent of the reaction temperature, K is found to be sensitive to changes in the reaction medium (Table 2): For the reaction of DMG with EA the value of K increases from 1.3 to 1.8 with a change of solvent from 1:1 DMSO/DCB (w/w) to pure DMSO; By comparison, for the reactions with HAN and CN, the values of K decrease from 0.76 to 0.55 and from 0.49 to 0.42, respectively, with the corresponding solvent change.

A detailed analysis of the values of K for the amination of DMG and comparison to those reported previously for the analogous reactions of PMA[6,7] leads to the following observations:

(i) Amide groups tend to accelerate the amination at neighboring ester groups: In the 1:1 DMSO/DCB (w/w) solvent, the amination of DMG by the reaction with EA shows an autoacceleration effect, with K = 1.8 (Table 2), i.e., the same as that for the amination of PMA in the same solvent.[6] This autoacceleration can originate from (a) the formation of intramolecular hydrogen bonds within the monosubstituted DMG, as shown in **II** (DMG, R = H;



II

DMDMG, R = CH_3), which could result in a neighboring group assisting effect and (b) polar and/or hydrogen-bonding interactions of the monosubstituted DMG with the amine, which increases the effective concentration near the reacting site compared to the bulk.

The formation of intramolecular hydrogen bonding, as shown in **II**, would cause the reacting acyl carbon to become more electron deficient, thus benefiting the nucleophilic attack on the ester acyl group by the amine. As a result, the rate of substitution of the second ester group is accelerated. It has been demonstrated that this type of intramolecular assisting effect could enhance the reaction rate, by as much as several orders of magnitude under optimal conditions.[8,16,17] However, in the present case model **II** requires the formation of an eight-membered ring which involves a relatively higher energy, so that the net acceleration effect is accordingly smaller. As will be shown later, an increase in the size of R and/or R′ retards the substitution at the second ester group, obviously due to steric effects that hinder the formation of the intramolecular hydrogen bonds.

An increase in the DMSO content in the solvent is expected to increase the solvation of the monosubstituted DMG, hence diminishing the hydrogen-bonding interaction shown in **II** and thus reducing K. This is indeed the case for the amination of DMG by reaction with EA: In 1:1 DMSO/DCB, the value of K is 1.8, but in pure DMSO the amination shows a lesser extent of autoacceleration with K = 1.3. This effect was even more pronounced in the amination of PMA by EA.[5]

(ii) Steric hindrance can overwhelm the neighboring group autoacceleration: This is clearly shown in the amination of DMG by reaction with CN which, like the corresponding reaction with PMA,[7] shows an autoretardation (Table 2). This seems to reflect the strong steric hindrance arising from the presence of the cyclohexyl ring that undergoes rapid chair–boat conformational transformations.[18] The bulky cyclohexyl group in the monosubstituted DMG not only restricts the approach of CN to the neighboring ester groups but also causes an increased strain in formation of the ring shown in **II**, so that the intramolecular hydrogen bonding, if any, is diminished.

The fact that the values of K for the reactions of DMG with the amines are independent of reaction temperature (Table 2), as was also observed for the amination of PMA,[6] suggests that the value of K be determined by the ratio of the preexponential factors, A_1/A_0, i.e., the steric factors, and implies that the observed differences in K reflect differences in the number of effective collisions between the reacting groups either because of conformational effects or steric hindrance. It also indicates that the activated states for the reactions leading to the substitutions of the first and second ester groups either remain unchanged or change in parallel fashion with the change in temperature.

(iii) The importance of the so-called "global" effect arising from the coiled structure of the macromolecule is clearly seen in a comparison of the value of K for the reaction of CN with DMG (0.42; Table 2) to that for PMA (0.82) in the same solvent.[7] The effects of steric hindrance, which are a dominant factor for the reaction with DMG, remain strong for the reaction with PMA, but they are partially offset by the preferential partitioning of CN from the bulk into the polymer coils, which results in an increase in the effective concentration of CN near reaction sites.[8]

Similarly, while the amination of DMG by reaction with HAN in DMSO shows an autoretardation with K = 0.80, that of PMA with HAN in the same solvent shows an autoacceleration with K = 1.3.[7] This suggests, once again, that the steric hindrance caused by the *n*-hexyl group plays an important role in diminishing the rate of substitution of the second ester group in DMG, but the increased effective concentration of HAN that results from the partitioning of HAN apparently is sufficient to more than compensate for the steric effect, causing a net effect of autoacceleration.

It is of interest that an autoretardation effect (K = 0.50) was also observed for the amination of DMG by reaction with BZA, which is much smaller than both K (0.9) and L (3.0)[6,7] for the amination of PMA. This supports the proposal that the autoacceleration at the later stages of the amination of PMA by reaction with BZA results from the global effect; i.e., as the reaction proceeds, the polymer chain becomes increasingly nonpolar which favors absorption of BZA from the bulk solution into the polymer coils.

(iv) For the amination reactions of DMDMG the values of K are all smaller than unity (Table 3), showing autoretardation. Although the values of K for the aminations of DMG (Table 2) and DMDMG (Table 3) with HAN are virtually identical, for the other systems they differ dramatically: The value of K for the reaction of DMG with EA in DMSO is 1.3 as compared to ~0.5 for the reaction of DMDMG in the same solvent; similarly, it is reduced from ~0.5 to 0.1 for the reactions of DMG and DMDMG with CN, respectively. This indicates that there is a major difference in the relative reactivities of the two ester groups in DMG and DMDMG. Structurally,

Table 4. Ratios of the Initial Rate Constants, k_0, for the Amination of DMG to Those for PMA

solvent	EA[a]	HAN[b]	CN[c]	BZA[d]
DMSO	5.6	2.8	2.8	2.6
1:1[e]	3.3	2.7	2.7	3.7

[a] 100 °C. [b] 130 °C. [c] 120 °C. [d] 100 °C. [e] 1:1 DMSO/DCB (w/w).

DMDMG differs from DMG in the presence of the methyl groups at the 2- and 4-positions (**I**), and these additional methyl groups increase the steric hindrance to the attack of DMDMG by the amines. The larger the amine, the greater the steric hindrance, and hence the slower the reaction rate. Methyl groups at the 2- and 4-positions of DMDMG undoubtedly have a conformational effect by introducing extra strain in the eight-membered ring shown in **II**, thus further diminishing the intramolecular hydrogen-bonding. Consequently, these methyl groups tend to retard the attack at the second acyl group, in keeping with the experimental results.

As shown in Table 4, the primary rate constants, k_0, for reactions with DMG are several times greater than those for analogous reactions with PMA, indicating that steric hindrance arising from the polymer chains plays an important part. Since the ester groups of DMG have only one nearest neighbor, their attack by an amine involves relatively less steric hindrance than for reaction of those in a polymer chain, which have two nearest neighbor and numerous nonneighboring groups. Similarly, the smaller values of k_0 for the aminations of DMDMG compared to those for reactions with DMG apparently reflect the structural differences between these analogs, in keeping with the importance of the steric effects. On the other hand, the exceptionally large value of the ratio of k_0 for the reactions of EA with DMG and that with PMA in DMSO (Table 4) seems to result from not only its small size, hence a lower susceptibility to steric effects, but also the strong polar and/or hydrogen-bonding interactions between the polar amine and the polar substituents.

Although there is virtually no difference in rates of reaction of the m and r enantiomers of DMDMG with EA, for reactions with HAN and CN the m-enantiomer was found to react more rapidly than the r-enantiomer (Table 4); i.e., in reactions with the larger amines, the reactivities of the ester groups in m-DMDMG are different from those in r-DMDMG. This is in accord with the intramolecular assistance effect, proposed above. Furthermore, molecular modeling with energy minimization by the use of Alchemy II[19,20] shows that in the most stable conformation the distance between the methoxy groups of m-DMDMG is longer than that in the r-enantiomer. Hence, less steric hindrance would be experienced by an amine molecule when approaching a methoxy group of the m-enantiomer than that of the r-enantiomer. The differences in steric hindrance experienced by EA approaching m- or r-DMDMG apparently are too small to significantly influence the overall reaction rates, yielding $K' = 1.00$; however, the larger amines such as HAN and CN experience more steric hindrance, yielding an overall difference in K'. It is of interest that the magnitude of the stereoisomerism effect indicated by reactions with DMDMG is much smaller than that for the acid-catalyzed solvolysis of PMA, as reported by Robertson and Harwood.[9]

Conclusions

It has been shown that under similar conditions the rate constant (k_0) for the replacement of the first ester group of DMG is always larger than that for the replacement of the ester groups of PMA that have no reacted neighbors, in keeping with less steric hindrance. Similar to what was seen for the functionalization of PMA, the value of K is sensitive to changes in the reaction medium but not to the reaction temperature. Comparison of the values of K for reactions of the analogs with those for the corresponding amination of PMA reveals that the polymer coil plays an important part in determining the kinetic parameters. The value of K was also found to be dependent on the size and hydrophobicity of the amines. Although the reactivities of the *meso* (m) and *racemic* (r) enantiomers of DMDMG toward EA are virtually the same, they are found to be different in the reactions with HAN and CN. It seems clear that, in general, the kinetic features of the reactions of neither DMG nor DMDMG exactly resemble those of the analogous reactions of PMA: For the reactions of DMG the steric effects seem to be of lesser importance than for the corresponding reactions with PMA, but they are greater for the reactions of DMDMG.

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