Decomposition of 1,3-Dialkyltriazenes in Aqueous Buffers: Kinetic and Mechanistic Studies

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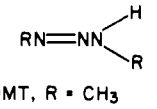
Received September 23, 1985. Revised Manuscript Received February 14, 1986

Abstract: 1,3-Dialkyltriazenes, prepared by the reaction of alkyl azides with alkyllithiums, are stable as pure liquids or in aprotic solutions. The kinetics of decomposition of 1,3-dimethyltriazene (DMT) were investigated in buffered, aqueous solutions over the pH range of 9–12. The reaction is acid-catalyzed since the rate is inversely proportional to pH. The invariance of the rate with (cyclohexylamino)propanesulfonic acid (CAPS) buffer concentration at pH 9.5 and the finding of an inverse solvent isotope effect of 0.35 suggest that the reaction follows simple specific acid catalysis in that buffer. Decomposition of DMT in phosphate and carbonate buffers, however, indicated dependence of rate on buffer concentration, although the solvent isotope effects were still less than 1. These data suggested that the reaction in those buffers is catalyzed by specific acid, followed by general base. The kinetics of decomposition of 1,3-diethyltriazene (DET) and 1,3-diisopropyltriazene (DIT) were also studied. DET decomposed slightly more rapidly than DMT in phosphate and carbonate buffers but showed a similar dependence of the rate on the buffer concentration. This triazene also exhibited an inverse solvent isotope effect. DIT, on the other hand, showed a rate that was invariant with phosphate buffer concentration and exhibited a biphasic profile of rate vs. carbonate buffer concentration. The rate of decomposition of DIT was also invariant with the pK_a of various buffers and showed an inverse solvent isotope effect. Decomposition of DMT in buffered deuterium oxide resulted in incorporation of deuterium into the product methanol, which indicated that an intermediate product of the reaction was the methyldiazonium ion. The dependence of the rate of decomposition on buffer concentration of DMT and DET is explained in terms of nucleophilic attack of the buffer anions on N-2 of the protonated triazenes. The protonated DIT, on the other hand, is seen as dissociating directly to the isopropyl carbonium ion in phosphate buffer and in low concentrations of carbonate buffer.

Until recently, the study of the chemistry of triazenes was restricted almost exclusively to 1-aryl-3,3-dialkyltriazenes. The development of general synthetic methods in our laboratory[1] has made 1,3-dialkyl- and 1,3,3-trialkyltriazenes available. Previously, we reported on the decomposition of trialkyltriazenes in aqueous buffers.[2] The mechanism in that case involves fast, reversible protonation of the triazene followed by rate-determining heterolysis of the protonated species to alkyldiazonium ions and dialkylamines, a specific acid-catalyzed process.

$$RN{=}NNR_2' \overset{H_3O^+}{\rightleftharpoons} RN{=}NN^+HR_2' \rightarrow RN_2^+ + R_2'NH$$

The present work describes the decomposition of triazenes DMT, DET, and DIT in aqueous buffers.



DMT, R = CH_3
DET, R = CH_3CH_2
DIT, R = $(CH_3)_2CH$

Experimental Section

Materials. The preparation of 1,3-dimethyltriazene (DMT) and 1,3-diethyltriazene (DET) was described earlier.[1b] 1,3-Diisopropyltriazene (DIT), bp 52 °C (20 mmHg), was prepared in an analogous manner in 12% yield by the reaction of isopropylmagnesium bromide and isopropylazide. Buffer components of reagent grade purity were dried in an Abderhalden apparatus for at least 24 h by using either refluxing acetone or *p*-xylene. Buffers were prepared according to the method previously described[2] by using water distilled from $KMnO_4$. D_2O (Aldrich) was >99.8% isotopic purity. The pH measurements were made with an Orion Model 710 digital pH meter using a Fisher (13-639270) high ionic strength combination electrode with a calomel reference. Mass spectra were obtained on a VG Micromass ZAB-2F high-resolution spectrometer equipped with VG-2035 data system.

Determination of Kinetics. The rates were followed spectrophotometrically by using a Cary Model 17 UV-vis spectrophotometer or a Hewlett-Packard Model 8450A diode array spectrophotometer. The reaction solutions were contained in thermostated 1-cm cells. The temperature was held constant at 25 ± 0.2 °C in all experiments. Decomposition of DMT was followed by monitoring the decrease in its absorbance at its λ_{max} (230 nm, ϵ 7900). The reaction cuvette was charged with the appropriate prethermostated buffer (1.49 mL), and the reaction was initiated by addition of 10 μL of 0.003 M triazene in acetonitrile, giving a final concentration of 2.0×10^{-5} M. The reference blank contained the same buffer (1.49 mL) and 10 μL of acetonitrile. The absorbance vs. time data were recorded on a strip chart recorder for a period of 3–4 half-lives. At the end of the run, 30 points were measured from the chart, and the data were analyzed by a computer program employing the Guggenheim approximation least-squares method for first-order rate constant determination.[3] The rate plots were linear for at least 3 half-lives. Each rate constant reported in this paper represents the average of three determinations, except that the rate measurements of DET and DIT as a function of buffer concentration were carried out in duplicate.

In the case of the experiments carried out on the diode array spectrophotometer, between 300 and 400 data points were obtained per run, and the output was transferred directly to an IBM CS 9000 computer. The mathematical treatment of the data was identical with both modes of acquisition.

Deuterium Incorporation Experiments. Decomposition of DMT in pH 9.7 deuterium oxide buffered with phosphate (1 M, μ = 4 M ($NaClO_4$)) was carried out as described previously.[4] The product methanol was distilled out of the reaction mixture and was analyzed by high-resolution mass spectrometry. The amounts of the variously deuterated methanols (CH_3OD, CH_2DOD, CHD_2OD, and CD_3OD) were calculated from the specific ion traces obtained at a resolution of at least 35 000. The distribution of the deuterated methanols was virtually the same as that obtained from several other sources of the methyldiazonium ion.[4]

Safety Note. The di- and trialkyltriazenes are relatively stable in absence of hydroxylic solvents. These compounds are, however, potent bacterial mutagens and vesicants (as judged from experiments on mouse skin). They must be considered to be potential carcinogens and hence should be handled accordingly.

The precursors to dialkyltriazenes are alkyl azides. In spite of precautions, we have had three explosions (two with methylazide and one

(1) (a) Sieh, D. H.; Wilbur, D. J.; Michejda, C. J. *J. Am. Chem. Soc.* **1980**, *102*, 3883–3887. (b) Smith, R. H., Jr.; Michejda, C. J. *Synthesis* **1983**, 476–477.

(2) Smith, R. H.; Denlinger, C. L.; Kupper, R.; Koepke, S. R.; Michejda, C. J. *J. Am. Chem. Soc.* **1984**, *106*, 1056–1059.

(3) Guggenheim, E. A. *Phil. Magazine* **1926**, *2*, 538–543. The program was written in Applesoft BASIC and IBM BASIC; the latter for an IBM CS 9000 computer.

(4) Smith, R. H., Jr.; Koepke, S. R.; Tondeur, Y.; Denlinger, C. L.; Michejda, C. J. *J. Chem. Soc., Chem. Commun.* **1985**, 936–937.

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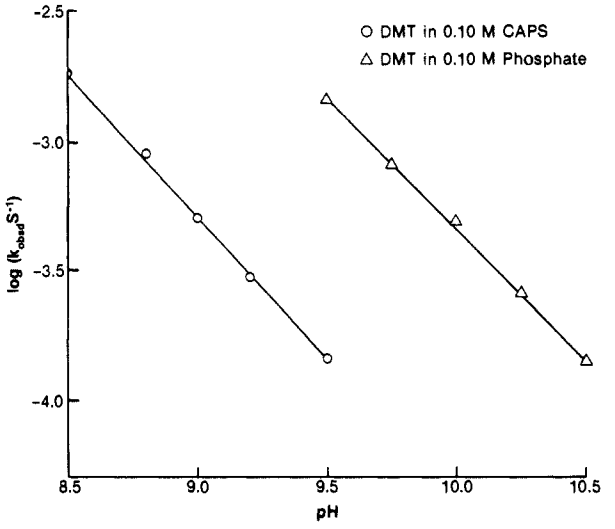


Figure 1. Plots of the logarithms of the observed pseudo-first-order rate constants vs. pH for the decomposition of DMT in CAPS and phosphate buffers. The concentration of both buffers was 0.10 M with the ionic strength held constant at 0.5 M with $NaClO_4$. The initial concentration of the triazene was 2.0×10^{-5} M.

Table I. pH Profile for the Rate of Decomposition of 1,3-Dimethyltriazene in 0.10 M CAPS and Phosphate Buffers

buffer[a]	pH	$k_{obsd} \times 10^4$ s^{-1} (SD $\times 10^4$)[b]
CAPS	8.50	18.1 (0.40)
	8.80	8.87 (0.23)
	9.00	5.05 (0.21)
	9.20	2.95 (0.25)
	9.50	1.44 (0.177)
phosphate	9.50	14.6 (0.22)
	9.75	8.17 (0.088)
	10.00	4.94 (0.03)
	10.25	2.60 (0.047)
	10.50	1.42 (0.032)

[a] The ionic strength was held constant at 0.50 M with $NaClO_4$. [b] Average of three independent determinations. All rate determinations, were carried out at 25.0 ± 0.2[6] at a substrate concentration of 2.0×10^{-5} M.

with ethyl azide). Low molecular weight alkyl azides are treacherous substances which should never be prepared in large quantities. The reactions should be carried out in a well-protected hood, and the laboratory personnel should be made aware of the potential danger. The preparation of methyl and ethyl azides should be treated in the same way as the preparation of diazomethane, i.e., no ground glass joints, protection from strong light, and dilution of the product with solvent.

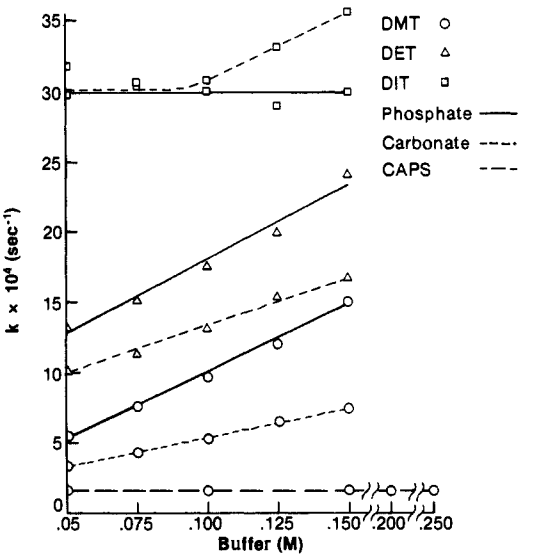


Figure 2. Dependence of the pseudo-first order rate constants of the decomposition of triazenes DMT, DET, and DIT as a function of buffer concentrations at pH 9.5. The ionic strength of the solutions was 0.50 M ($NaClO_4$) and the initial concentration of the triazenes was 2.0×10^{-5} M.

Results

pH Dependence of the Rate of Decomposition of DMT. The rate of decomposition of DMT was determined over the pH range of 8.5–9.5 in (cyclohexylamino)propanesulfonic acid (CAPS) buffer and over the pH range of 9.5–10.5 in phosphate buffer. The observed rate constants are listed in Table I. The rates were cleanly first-order and a plot of log k_{obsd} vs. pH, Figure 1, revealed that the reaction rate was inversely proportional to pH in both buffers. The slopes of the plots in CAPS and phosphate are −1.12 and −1.01, respectively. The dependence of the rate constant on pH was also determined in lysine buffer over the pH range of 7.5–11.5. The linear dependence was found to have a slope of −0.90.

Dependence of the Rate of Decomposition of the Dialkyltriazenes on Buffer Concentration. The dependence of the rate of decomposition of DMT on buffer concentration was studied at pH 9.5 in CAPS buffers ranging in concentration from 0.05 to 0.25 M. The ionic strength was held constant at 0.50 M with sodium perchlorate. The rate constants are listed in Table II and displayed graphically in Figure 2. The data indicated no significant variation of the rate with change in CAPS buffer concentration.

A similar study of rate dependence of decomposition of DMT was carried out in phosphate and carbonate buffers at pH 9.5.

Table II. Rates of Triazene Decomposition as a Function of Buffer Concentration[a]

		$k_{obsd} \times 10^4$ s^{-1} (SD $\times 10^4$)[b]			
buffer	[buffer] M	DMT	DET	DIT	TMT
CAPS	0.05	1.63 (0.06)			
	0.10	1.57 (0.09)			
	0.15	1.60 (0.04)			
	0.20	1.49 (0.03)			
	0.25	1.65 (0.06)			
phosphate	0.05	5.52 (0.01)	13.1 (0.16)	31.8 (0.42)	
	0.075	7.63 (0.08)	15.1 (0.11)	30.6 (0.28)	
	0.10	9.66 (0.02)	17.5 (0.03)	30.1 (0.03)	
	0.125	12.0 (0.01)	19.9 (0.21)	29.0 (0.12)	
	0.15	15.0 (0.12)	24.1 (0.90)	30.0[c]	
carbonate	0.05	3.35 (0.03)	10.1 (0.13)	29.8 (0.17)	16.4 (0.14)
	0.075	4.26 (0.04)	11.3 (0.22)	30.2 (0.36)	16.3 (0.13)
	0.10	5.22 (0.07)	13.2 (0.35)	30.8 (0.11)	15.6 (0.04)
	0.125	6.52 (0.07)	15.4 (0.09)	33.1 (0.17)	15.5 (0.02)
	0.15	7.42 (0.04)	16.5 (0.01)	35.6 (0.20)	15.5[c]

[a] All rate determinations were carried out at 25.0 ± 0.2 °C, at a substrate concentration of 2.0×10^{-5} M, at pH 9.5, and the ionic strength of 0.50 ($NaClO_4$). [b] The rate constants are an average of three independent runs for DMT and two independent runs for DET and DIT. [c] Only one run was obtained at this buffer concentration.

Table III. Rates[a] of Dialkyltriazene Decomposition as a Function of Buffer pK_a

buffer[b]	pK_a	DMT	DIT
borate	9.14	2.02 ± 0.01	
glycine	9.6	2.14 ± 0.08	29.4 ± 0.2
sarcosine	10.01	2.12 ± 0.08	
CAPS	10.4	1.57 ± 0.09	29.4 ± 0.8
triethylamine	10.76	1.76 ± 0.03	
carbonate	10.25	5.70 ± 0.11	30.6 ± 0.2
arsenate	11.53	8.77 ± 0.16	
phosphate	12.32	10.9 ± 0.3	30.6 ± 0.1

[a] The rate constants ($k_{obsd} \times 10^4$ s^{-1} ± SD × 10^4) are an average of three independent runs. [b] 0.10 M buffer with ionic strength of 0.50 M held constant by using $NaClO_4$. The initial triazene concentration was 2.0×10^{-5} M.

The buffers ranged in concentration from 0.05 to 0.15 M, with the ionic strength being maintained at 0.50 M ($NaClO_4$). These data are also given in Table II and displayed graphically in Figure 2. The rates were directly proportional to the concentration of these buffers. The slope of the linear least-squares line for the phosphate buffer was 9.30×10^{-3} mol^{-1} s^{-1}, which corresponds to the catalytic rate constant, and an intercept of 0.63×10^{-4} s^{-1}. The linear least-squares treatment of the data obtained in carbonate buffer yielded a slope of 4.16×10^{-3} mol^{-1} s^{-1} and an intercept of 1.19×10^{-4} s^{-1}. Ideally, the phosphate and carbonate intercepts should be identical with the CAPS intercept. They are not identical, even when experimental error is taken into account. A reason for this anomaly si suggested in the Discussion section.

Table II also lists the rate constants for 1,3,3-trimethyltriazene (TMT) in carbonate buffers of various concentration. There is no significant variation in these constants. These data demonstrate that anomalous salt effects, due to the inadequacy of the Debye–Hückel approximation, are not responsible for the rate constant variation for the decomposition of DMT and DET in phosphate and carbonate buffers.

The effect of phosphate and carbonate buffer concentration on the decomposition rates of DET and DIT was studied under the same conditions as were utilized for DMT. The data are tabulated in Table II and displayed in Figure 2. The rate of decomposition of DET was linearly dependent on the concentration of both of these buffers. The slope of the phosphate buffer line was 1.07×10^{-2} mol^{-1} s^{-1}, and the intercept was 7.23×10^{-4} s^{-1}. The corresponding values in carbonate buffer were 6.79×10^{-3} mol^{-1} s^{-1} and 6.50×10^{-4} s^{-1}. The decomposition of DIT was found to be essentially invariant with changes in phosphate buffer concentration. The apparent scatter of the data is almost certainly due to difficulties of pH measurements in phosphate buffers containing relatively large amounts of added salt.[5] The decomposition of DIT in carbonate buffer showed a biphasic profile.

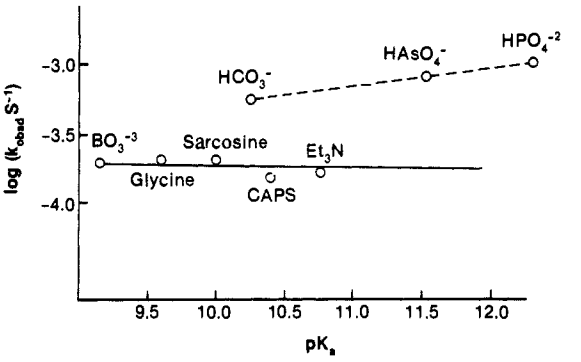


Figure 3. Brønsted plot for the decomposition of DMT in buffers of various pK_a. The concentrations of the buffers were 0.10 M at a constant ionic strength of 0.50 M ($NaClO_4$). The initial concentration of DMT was 2.0×10^{-5} M.

There was no variation in the rate constant at low carbonate concentration (0.05 and 0.075 M), but a linear dependence was observed at higher carbonate concentrations (see Figure 2). These data suggest that the carbonate at high concentration is able to catalyze the decomposition of the protonated DIT, in contrast to phosphate.

Rate of Decomposition as a Function of Buffer pK_a. The rate of decomposition of DMT was measured at pH 9.5 in eight different buffers ranging in pKa from 9.14 to 12.32. The rate constants are shown graphically in Table III and in Figure 3. Considered as a whole, no obvious trend is visible. However, when the buffers are grouped according to the nature of the proton-bearing heteroatom, a pattern does emerge. The rate of decomposition shows no significant correlation with the pK_a of amino acid or amine buffers. In the case of buffers derived from oxyacids there is a small, direct dependence of decomposition rate on buffer pK_a (slope = 0.221, excluding borate). The data are consistent with specific acid catalysis in nitrogen acid buffers which, in oxyacid buffers, is followed by general base catalysis.

The decomposition of DIT was studied at pH 9.5 in four buffers: glycine, carbonate, CAPS, and phosphate, all at a concentration of 0.10 M (μ = 0.50 M). The data, shown in Table III, indicated that there was no variation in the rate decomposition of DIT with change in buffer pK_a from 9.6 to 12.32, at least at the lower buffer concentrations.

Solvent Deuterium Isotope Effects on the Decomposition of DMT, DET, and DIT. The solvent isotope effects were determined by carrying out parallel reactions in aqueous buffers and deuterium oxide buffers at the same pH, ionic strength, and temperature. The pH of the deuterium oxide buffer was corrected according to the relationship, $pD = pH_{nominal} + 0.4$.[6] Thus, a 0.10 M, pD 9.5 CAPS deuterium oxide buffer gave a nominal pH meter reading of 9.1. All of the buffers were prepared at a constant ionic strength of 0.50 M by using sodium perchlorate. The decomposition of DMT was examined by using both the CAPS buffer and the phosphate buffer. DET and DIT isotope effects were determined in phosphate buffers only. The results are presented in Table IV. It is clear from these data that all of the reactions are more rapid in D_2O than in H_2O.

Deuterium Incorporation into Product Alcohols Derived from the Decomposition of DMT in Deuterated Buffer. The decomposition of DMT was carried out in a 1.0 M phosphate buffer prepared in D_2O at a total ionic strength of 3.0 ($NaClO_4$) at various pH values. The methanol was distilled out of the reaction mixture and was analyzed by high-resolution mass spectrometry, as described previously.[4] The distribution of the methanols (in percent) is presented in Table V. It is clear from these data that the methyldiazonium ion formed during the decomposition of DMT undergoes considerable pH-dependent exchange. We had previously postulated that, in absence of exchange in the starting material, the exchange of protons in the product methanols is a criterion for the presence of intermediate methyldiazonium ions.[4]

(5) The problems with high ionic strength buffers containing relatively large amounts of sodium perchlorate make comparisons among various sets of buffers difficult, especially in the case of phosphate buffers. The data reported in Table II were obtained with carbonate and phosphate buffers prepared at the same time under identical conditions. All three compounds were studied in these two sets of buffers, and all of the kinetics were determined within a short span of time. Under these conditions, the kinetic constants are internally consistent and direct comparisons can be made. It should be noted, however, that the absolute values of the rate constants in various batches of phosphate buffer which were prepared under nominally identical conditions, but several weeks apart, varied considerably more than the variations observed between kinetic runs in which the same batch of buffer was used. Consequently, all of the arguments in this paper which are based on rate comparisons utilize data which were obtained with the same batches of buffer. The CAPS and other buffers used in this study were much more reproducible, batch to batch. The phosphate–perchlorate buffers, particularly at high ionic strengths, appear to be hard to reproduce. We suspect that this is due to somewhat random variation in the response of the pH electrode caused by effects of the high ionic strength on the glass membrane. In an earlier kinetic study using phosphate buffer, where the added salt was potassium chloride, we observed even more erratic behavior, which led to the abandonment of those data. It should be pointed out that most reported quantitative values for phosphate solutions refer to either very dilute solutions or to solutions in which the ionic strength is not maintained constant. We have observed that, in the absence of sodium perchlorate, the behavior of phosphate solutions is much more consistent.

(6) Glasoe, P. K.; Long, F. A. *J. Phys. Chem.* **1960**, *102*, 188–190.

Table IV. Solvent Isotope Effects on the Rates of Decomposition of Dialkyltriazenes

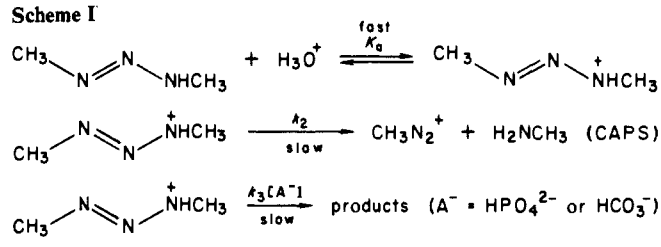
substrate	buffer (pH)[a]	$k_{obsd}^{H_2O} \times 10^4$,[b] s^{-1}	$k_{obsd}^{D_2O} \times 10^4$,[b] s^{-1}	k_{H_2O}/k_{D_2O}
1,3-dimethyltriazene	CAPS (9.5)	1.57 ± 0.09	4.50 ± 0.11	0.35
	phosphate (10.0)	4.94 ± 0.03	12.8 ± 0.3	0.39
1,3-diethyltriazene	phosphate (9.5)	18.4 ± 0.22	52.1 ± 0.16	0.35[c]
1,3-diisopropyltriazene	phosphate (9.5)	33.2 ± 0.37	107.5 ± 2.0	0.31

[a] Buffer concentrations were 0.1 M in each case, with the ionic strength held constant at 0.50 with $NaClO_4$. [b] Average of three independent determinations. [c] The solvent isotope effect for diethyltriazene determined in pH 10.5 phosphate buffer was $k_{H_2O}/k_{D_2O} = 0.37$.

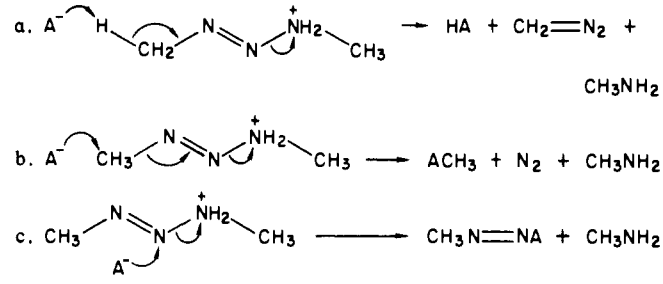
Discussion

It was shown in a previous study[2] that 1,3,3-trialkyltriazenes decompose in aqueous buffers by a simple, specific acid-catalyzed reaction to form alkyldiazonium ions and secondary amines. It would have been reasonable to assume that 1,3-dialkyltriazenes might follow a similar path. The present data, however, indicate that the mechanistic course of this reaction is considerably more complex. Our initial efforts were focused on the simplest member of the series, 1,3-dimethyltriazene (DMT). This compound is slightly more stable to aqueous decomposition than its trimethyl analogue (e.g., $t_{1/2}$ (DMT) = 12.0 min, as compared with $t_{1/2}$ = 7.4 min for trimethyltriazene at pH 9.5, 0.10 M phosphate). Nevertheless, it decomposes by an acid-catalyzed mechanism, as indicated by the data in Table I and in Figure 1. It is interesting to note that the reaction in the zwitterionic CAPS buffer at a given pH is significantly slower than that in phosphate buffer. In spite of the differences in rates, the slopes of the lines of the log k_{obsd} vs. pH graphs are both close to unity, which suggests (but does not prove) that the protonating species is the hydronium ion.[7] The faster rate in phosphate buffer, however, suggests that some buffer-derived species are involved in a step which follows the initial protonation. This supposition was strengthened further by consideration of the data shown in Table II. The kinetics of decomposition of DMT in varying concentrations of CAPS buffer showed that the rate constant did not vary significantly over a five-fold change in concentration of the buffer. These data should be compared with the decomposition of DMT in phosphate and carbonate buffers. Here, a three-fold variation in buffer concentration produced an almost three-fold variation in the rate constant in phosphate buffer and over a two-fold variation in the carbonate buffer. These data would lead to a conclusion that the decomposition of DMT was catalyzed by specific acid in CAPS buffer in analogy to trimethyltriazene[2] and by general acid in the phosphate and carbonate buffers. There is, however, an added complication. The decomposition of DMT in various buffers, covering the pK_a range from 9.14 to 12.32 (Figure 3), indicated that the rate of decomposition in buffers derived from zwitterionic substances, where the proton of the acid component resides on a nitrogen, did not vary with the pK_a. There was, however, a small variation of the rate with pK_a of oxy acid buffers. A similar dichotomy was observed by Sinnott and co-workers[8] in the general acid-catalyzed decomposition 1-aryl-3-alkyltriazenes. A catalytic effect of phosphate on the decomposition of triazene, N_3H_3, was observed by Sutherland.[9] In the present instance, however, a general acid-catalyzed reaction would demand a positive solvent deuterium isotope effect. Thus, if the reaction were catalyzed by acid HA, and assuming a rapid equilibration of HA with deuterium in the solvent, a decomposition in D_2O buffer should proceed more slowly than an analogous reaction in H_2O at the same pH. Conversely, a specific acid-catalyzed reaction, which depends only on the concentration of H_3O^+ (or D_3O^+), would proceed more rapidly in the deuterated solvent, since D_3O^+ is a stronger acid than H_3O^+.[10] The data in Table IV indicate without doubt that the decomposition of DMT in CAPS and phosphate buffers is faster in D_2O than in H_2O. Therefore, the reaction appears to be catalyzed by specific acid. The conclusion of this study suggests strongly that, in CAPS buffer, the decomposition of DMT follows a simple, specific acid catalysis mechanism. In phosphate and carbonate buffers, however, the specific acid catalysis step is followed by a rate-limiting general base-catalyzed reaction. The mechanistic distinction is best seen by considering Scheme I.

Scheme I



Scheme II



There are three reasonable mechanisms which might explain the involvement of the oxybuffer components in the rate-determining step. It is clear from the foregoing data that all must follow the initial protonation to form the conjugate acid of the triazene.[11] These possibilities are depicted in Scheme II.

The kinetics of the decomposition of the higher homologues of DMT, namely 1,3-diethyltriazene (DET) and 1,3-diisopropyltriazene (DIT), were examined to provide further insight into the mechansim of the general base dependence. Both DET and DIT decompose by an acid-catalyzed reaction, with the protonated triazene being the key intermediate. This reaction also appears to be specific acid-catalyzed since the solvent isotope effect is less than unity, as indicated by the data in Table IV. The dependence of the rate of decomposition of DET and DIT on

(7) Reference 2 and arguments made therein.

(8) Jones, C. C.; Kelly, M. A.; Sinnott, M. L.; Smith, P. J.; Tzotzos, G. T. *J. Chem. Soc., Perkin Trans. 2* **1982**, 1655–1664.

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(11) A referee correctly questioned our use of a glass electrode for pH measurements in solutions which contained a high concentration of sodium ions (see ref 5). He suggested that we ought to obtain independent data on hydrogen ion concentrations by using an indicator method. We carried out these measurements. Phenolphthalein (P) was used as the indicator. The absorbance of 2.1×10^{-5} M P was determined at λ_{max} 552 nm in a series of standard buffers ranging in pH from 9.24 to 9.92 in approximately 0.1 pH unit increments. The standard curve derived from these data allowed us to calculate the pK_a of P to be 9.55. A series of phosphate buffers, ranging in concentration from 0.05 to 0.15 M (μ = 0.5 maintained with $NaClO_4$), were prepared in such a manner that the absorbance of P, at the same concentration as in the standard curve, was equivalent to pH 9.52. All of the buffers were within 0.017 pH units. The rates of DMT, DIT, and TMT decompositions were determined in these buffers. The qualitative results are in accord with the data presented in the body of the paper. The rates for DIT and TMT were essentially invarient with changes in buffer concentrations. The rate for the DMT decomposition increased with buffer concentration. The slope of the DMT line was within experimental error of that shown in Figure 2. It is entirely possible that part of the increase in the rate of DMT decomposition as a function of buffer concentration is due to small changes in hydrogen ion concentration, but if this is the case, the two independent methods of pH measurement were not capable of detecting that contribution to the rate increase. Thus, our conclusion that the decompositions of DMT and DET are catalyzed by phosphate and carbonate appears to be correct.

Table V. Deuterium Incorporation into Methanol Derived from the Decomposition of 1,3-Dimethyltriazene in Phosphate[a]-Buffered Deuterium Oxide

pH	CH_3OD[b]	CH_2DOD	CHD_2OD	CD_3OD
5.5	74.2 ± 1.7	22.0 ± 1.3	3.6 ± 0.3	0.3 ± 0.1
6.5	70.3 ± 2.3	24.9 ± 0.9	4.5 ± 1.2	0.4 ± 0.2
7.4	57.7 ± 2.5	29.6 ± 2.4	10.7 ± 0.1	2.0 ± 0.1
8.5	43.0 ± 1.9	31.9 ± 0.1	18.3 ± 0.9	6.9 ± 1.2
9.5	22.3 ± 2.8	22.4 ± 0.5	25.6 ± 0.9	29.8 ± 2.4

[a] 1.0 M Buffer (3.0 M ionic strength), 99.8 D_2O. The solution was 40 mM in triazene. [b] The values are expressed as percent of total methanol and each entry is the average of two independent runs which, in turn, were an average of at least five separate scans.

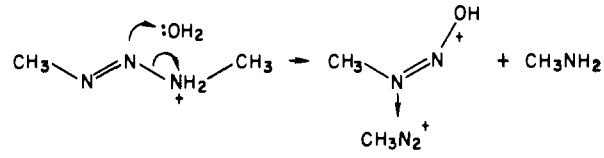
phosphate and carbonate buffer concentration at pH 9.5, shown in Table II and Figure 2, indicates that DET decomposes faster than DMT and that DIT is faster still, at least at the buffer concentrations studied. It is reasonable to assume that DET and DIT are somewhat more basic than DMT, and hence the concentration of the triazene conjugate acids at a given pH will be somewhat higher.[12] The slopes of the DET curves are very similar to the DMT curves for both phosphate and carbonate, which implies that the influence of the general base is very similar for both of these triazenes. If the nucleophilic displacement mechanism (reaction b in Scheme II) were important, we would have predicted that the slope of the buffer dependence curves, which corresponds to the general base-catalyzed rate constants, would have been greater for DMT than for DET. This would have reflected the differences between methyl and ethyl in the steric requirements of the S_N2 transition states. Since the slopes are virtually the same, it would seem unlikely that reaction b of Scheme II would account for the observed general base affect. Additionally, we found (data not shown) that at least 60% of the theoretical amount of methanol can be recovered from the DMT decomposition in phosphate buffer and 75% of ethanol from the DET reaction. If reaction b were obtained, the initial products would have been the respective phosphate esters, which are stable under those conditions.[13]

DIT decomposes by a different mechanism. The rate of decomposition is independent of phosphate buffer concentration and is also independent of carbonate concentration at low buffer concentrations. We postulate that protonated DIT decomposes directly to the isopropyl carbocation, bypassing the diazonium ion intermediate, as shown in the following reaction.

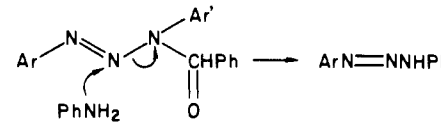
$$(CH_3)_2CH\ N{=}NN^+H_2CH(CH_3)_2 \rightarrow (CH_3)_2CH^+ + N_2 + (CH_3)_2CHNH_2$$

This result suggests that the isopropyldiazonium ion is less stable than the carbocation and nitrogen under these conditions and may further suggest that reactions which result in the formal formation of secondary alkyldiazonium ions proceed directly to the carbocation,[14,15] initially in contact with a nitrogen molecule.[16] Additional experiments on this problem will seek to resolve this issue. The carbonate buffer was found to catalyze the decomposition of DIT at higher buffer concentrations (Figure 2). Why the carbonate buffer does this while the phosphate does not is not clear at the present time, particularly since both phosphate and carbonate appear to have similar nucleophilicity.[17]

The remaining problem is how to distinguish between reactions a and c of Scheme II. We postulate that reaction c is more likely than reaction a. This conclusion is based on two lines of reasoning. First, we have examined the exchange of the C-protons of the methyldiazonium ion generated from a variety of sources in deuterium oxide buffers.[4] Decomposition of DMT in phosphate buffered deuterium oxide solutions exhibits exchange patterns which are very similar to those observed for the methyldiazonium ion generated, inter alia, from *N*-nitroso-*N*-methylcarbamate, *N*-nitroso-*N*-(acetoxymethyl)-*N*-methylamine, and *N*-nitroso-*N*-methylurea. The data for DMT are presented in Table V. For the present argument, suffice it to say that the pH dependent pattern of deuteration in the methanol derived from the decomposition of DMT in phosphate buffered deuterium oxide is consistent with the methyldiazonium ion being formed as the initial intermediate, rather than diazomethane. Incidentally, these data also provide additional evidence against reaction b. The second argument in favor of reaction c in Scheme II is the nature of the specific acid-catalyzed reaction which is observed in, for example, CAPS buffer. In considering the diazonium ion forming step, it would be reasonable to assume that water acts as the nucleophile to displace the diazonium ion from the methylamine, as indicated in the following reaction. Naturally, it is possible that this reaction



involves the initial formation of diazotic acid ($CH_3N{=}NOH$), which then collapses to the diazonium ion. Thus, reaction c could be viewed as a substitution of a more nucleophilic monohydrogen phosphate anion or the bicarbonate anion (these are the predominant species at pH 9.5) for water. A somewhat analogous reaction was postulated for the aniline-catalyzed decomposition of 1,3-diaryl-3-acyltriazenes in acetonitrile solutions.[18] In this



example, acylation of N-3 would be equivalent to protonation, rendering N-2 susceptible to nucleophilic attack. The result of the nucleophilic attack of N-2 on the protonated DMT would be the formation of the mixed anhydrides of methyldiazotic acid with phosphoric acid and methyldiazotic acid with carbonic acid. These substances would be expected to dissociate to the methyldiazonium ion and the respective anions.

Acknowledgment. Research sponsored by the National Cancer Institute, DHHS, under contract No. N01-CO-23909 with Litton Bionetics, Inc. The contents of this publication do not necessarily reflect the views or policies of the Department of Health and Human Services, nor do mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government. R. H.S., Jr., was supported by an NIH-NRSA Senior Fellowship from the National Cancer Institute (F33-CA-0-7613-01). Permanent address: Department of Chemistry, Western Maryland College, Westminster, MD 21157. We are grateful to Dr. Y. Tondeur and to John Roman for the mass spectrometry data. We are also grateful to Beth Rudrow for her efforts in the preparation of the indicator-standardized buffers.

Registry No. DMT, 3585-32-8; DET, 63980-20-1; DIT, 84713-95-1; D_2, 7782-39-0.

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