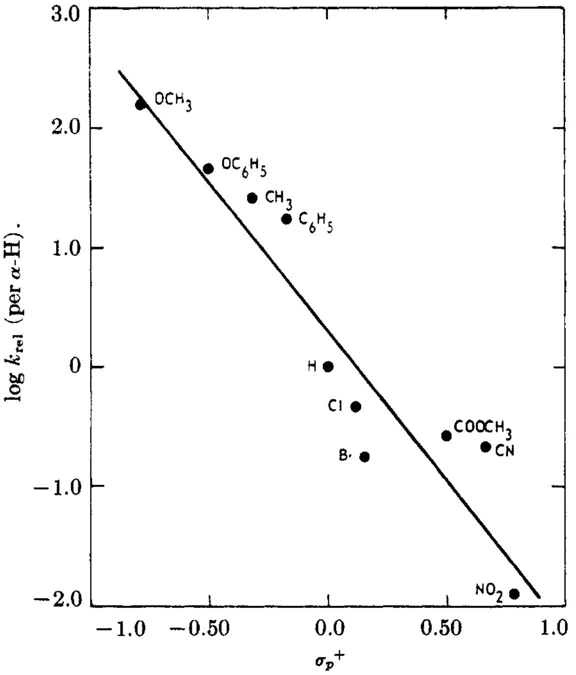

Figure 2.—Logarithms of rates, relative to that for toluene, for the reactions of $C_6H_5CH_2X$ with N-bromosuccinimide (CCl_4, 77°) *vs.* σ_p^+ values for the substituents X.

$$[C_6H_5CH{=}\overset{+}{O}CH_3\ \dot{H}\ Br{:}^-]$$

III

to structure at the transition state when the α substituent, *e.g.*, methoxyl, is electron releasing through resonance. Inasmuch as the points of Figure 2 conform to the least-squares line as well as they do, it appears that the changes in reactivity with changes in X are not to a significant degree associated with corresponding changes in steric barrier to attainment of the transition state. Since the medium in this case (CCl_4) cannot contribute significantly to the polarization process accompanying activation, this is not entirely surprising.

The relative reactivities of α-substituted toluenes with peroxy radicals fall into a pattern which is neither that to be expected of a reaction in which the structure at the transition state is radicallike nor of a reaction in which that structure is significantly polar in nature.[19a] Substituent effects characteristic of both types of reactions have been observed (*e.g.*, the reactivities of α-substituted toluenes, $C_6H_5CH_2X$, change with X in the order CH_3 > Cl > H > CN). In their reactions with peroxy radicals the ring-substituted toluenes respond to changes in X more or less as predicted by σ^+ values, but the ρ value for the reaction[17] is significantly less than that observed when bromine is the attacking radical. Presumably the difference in substituent effects on the course of the reactions involving the two radicals Br· and RO_2· can be traced to differences in electronegativities of the radicals[22] and in the extent of bond breaking at the transition states. An extended discussion of the matter must await a further elaboration of the influence of other factors, *e.g.*, solvent and temperature, on the rates of radical abstraction processes.[17]

Registry No.—N-Bromosuccinimide, 128-08-5.

Acknowledgments.—This research was supported by a grant from the National Science Foundation. The authors are indebted to Dr. Ian Horman for his help with certain of the measurements and for his interest in the progress of the work. Discussions between L. J. A. and Dr. John Shorter have been very helpful in connection with the preparation of the manuscript.

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[22] R. van Helden and E. C. Kooyman, *Rec. Trav. Chim.*, **73**, 269 (1954).

Benzylic Bromination in the Reactions of Benzyl Methyl Ether and Related Compounds with N-Bromosuccinimide

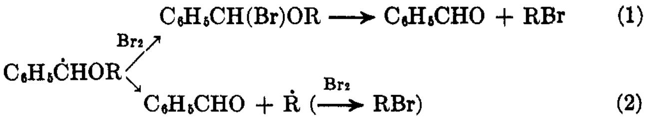
IAN HORMAN, SEVGI S. FRIEDRICH, R. M. KEEFER, AND L. J. ANDREWS

Department of Chemistry, University of California, Davis, California 95616

Received August 26, 1968

Through application of nmr analysis of reaction products it has been established conclusively, as is strongly suggested by earlier work of Huang and Lee, that the benzaldehyde formed in the reaction of benzyl methyl ether and N-bromosuccinimide in carbon tetrachloride is derived mainly, if not exclusively, by breakdown of α-bromobenzyl methyl ether, the primary reaction product. The alternate reaction path in which the aldehyde is formed by direct breakdown of a radical intermediate ($C_6H_5\dot{C}HOCH_3 \rightarrow C_6H_5CHO + \dot{C}H_3$) is unimportant. When dibenzyl ether is substituted for benzyl methyl ether, the aldehyde is generated, in a similar fashion. No bromo ether is found in the products of reactions of benzyl *t*-butyl ether, but the path by which benzaldehyde forms is thought to involve the bromo ether as an intermediate. Benzyl *p*-chlorophenyl ether reacts to form a thermally stable α-bromo derivative and no aldehyde. Benzyl acetate is converted in part by N-bromosuccinimide into α-bromobenzyl acetate, but benzaldehyde and acetyl bromide are also formed in quantity by a process in which the bromo acetate is not an intermediate. α-Bromobenzyl methyl ether is readily hydrolyzed, but treatment of its carbon tetrachloride solution with a small amount of water results in its decomposition to benzaldehyde and methyl bromide rather than its hydrolysis. Evidence has been obtained that $C_6H_5CH(NC_4H_4O_2)OR$ formed during the reaction of benzyl ethers ($C_6H_5CH_2OR$) and N-bromosuccinimide is produced from $C_6H_5CH(Br)OR$ and the brominating agent by a process which is reversible.

Benzyl alkyl ethers have been found to react with N-bromosuccinimide and other halogenating agents to produce benzaldehyde.[1-5] Formation of the aldehyde in the reaction with N-bromosuccinimide is presumed to occur by one of two pathways (reactions 1 and 2) in which $C_6H_5\dot{C}HOR$ is a common precursor.



$$C_6H_5\dot{C}HOR \xrightarrow{Br_2} C_6H_5CH(Br)OR \longrightarrow C_6H_5CHO + RBr \quad (1)$$

$$C_6H_5\dot{C}HOR \longrightarrow C_6H_5CHO + \dot{R}\ (\xrightarrow{Br_2} RBr) \quad (2)$$

Convincing chemical evidence for the generation of m-$ClC_6H_4CH(Br)OCH_3$ in the reaction of m-chlorobenzyl methyl ether has been reported previously.[2a] It has been concluded, therefore, that in the reaction of benzyl methyl ether itself α-bromobenzyl methyl ether is formed as a highly unstable intermediate which undergoes decomposition to the major isolable products, benzaldehyde and methyl bromide. Very good, though indirect, evidence that this is the case has been reported by Huang and Lee.[2a]

The formation of the α-halo ether in good yield as an immediate product of the benzyl methyl ether reaction with N-bromosuccinimide has now been confirmed by the application of nmr techniques to analysis of the product mixtures. The ready conversion of the bromo ether to aldehyde by thermal processes as well as by hydrolysis has been demonstrated. Similar studies of the course of bromination of certain other benzyl ethers and of benzyl acetate have been conducted in an attempt to determine whether aldehyde products are generated exclusively from α-halo ether intermediates, or whether they may also be formed in certain cases by path 2. The source of α-N-succinimidyl derivatives in these reactions has also been investigated.

TABLE I

NMR ABSORPTIONS (τ) FOR BENZYL ETHERS AND THEIR PRODUCTS OF REACTIONS WITH NBS (CCl_4 SOLUTION)[a]

Compound	Registry no.	Type of proton		
		$\gtrdot CH$	$>CH_2$	$-CH_3$
$C_6H_5CH_2OCH_3$	538-86-3		5.60	6.69
$C_6H_5CH(Br)OCH_3$	18963-53-6	3.33		6.47
$C_6H_5CH(NC_4H_4O_2)OCH_3$[b]	3378-26-5	3.90		6.59
C_6H_5CHO		0.00		
CH_3Br	74-83-9			7.40
$C_6H_5CH_2OCH_2C_6H_5$	103-50-4		5.56	
$C_6H_5CH(Br)OCH_2C_6H_5$	18963-55-8	3.11	5.09	
$C_6H_5CH(NC_4H_4O_2)OCH_2C_6H_5$[c]	3395-59-3	3.66	5.47	
$C_6H_5CH_2Br$	100-39-0		5.46	
$C_6H_5CH_2OH$	100-51-6		5.39	
$C_6H_5CH_2OC(CH_3)_3$	3459-80-1		5.66	8.75
$C_6H_5CH(NC_4H_4O_2)OC(CH_3)_3$[d]	18963-57-0	3.59		8.75
$(CH_3)_3CBr$	507-19-7			8.24
$C_6H_5CH_2OC_6H_4Cl$-*p*	7700-27-8		4.93	
$C_6H_5CH(Br)OC_6H_4Cl$-*p*		*e*		
$C_6H_5CH(NC_4H_4O_2)OC_6H_4Cl$-*p*[f]		*e*		

[a] Tetramethylsilane was used as an internal reference. [b] The succinimidyl group proton signal is at τ 7.47. [c] The succinimidyl group proton signal is at τ 7.75. [d] The succinimidyl group proton signal is at τ 7.50. [e] The tertiary hydrogen peak is masked by the aromatic multiplet. [f] The succinimidyl group proton signal is at τ 7.60

Experimental Section

Materials.—Except as indicated, the organic substances used were obtained from Eastman Organic Chemicals and were not subjected to purification procedures. The N-bromosuccinimide (Arapahoe Chemicals, Inc.), carbon tetrachloride and methanol (Mallinckrodt spectrophotometric grade), hydrogen bromide and methyl bromide (Matheson Co., Inc.), and ethylene glycol (J. T. Baker Chemical Co.) were also used without further purification. The D_2O (99.9 mol %) was obtained from Bio Rad Laboratories. Benzyl *p*-chlorophenyl ether, mp 69–70° (lit.[6] mp 70–71°), was prepared from benzyl chloride by reaction with sodium *p*-chlorophenoxide in methanol, and benzyl *t*-butyl ether, bp 62° (3 mm) [lit.[7] bp 82–83° (8 mm)], was obtained by a similar procedure.[8] Benzaldehyde dimethyl acetal was prepared as described by Huang and Lee.[2a]

The Reaction of Benzyl Methyl Ether and Other Benzyl Ethers with N-Bromosuccinimide (NBS/Ether Mole Ratio of 1.0).—Mixtures of 1.22 g (10.0 mmol) of the benzyl ether, 1.78 g (10.0 mmol) of N-bromosuccinimide, 0.05 g of benzoyl peroxide, and 20 ml of carbon tetrachloride were brought to reflux temperature in a system protected by a drying tube. In a short time the mixtures became reddish brown and rapid reaction occurred over a period of a few minutes without further external heating. When refluxing subsided, cooled samples of the liquid phases of the reaction mixtures were subjected to product analysis by nmr spectrometry using a Varian A-60A spectrometer. Samples of these product mixtures were subjected to further treatment as described in the tabulation of the results, and the analyses reported for the carbon tetrachloride phases of the resulting product mixtures were again established through application of nmr techniques.

In most cases the positions of the absorptions characteristic of the various substances contributing to the nmr spectra of the products were established through the addition of authentic samples of the materials in question to reaction mixtures (see Table I).

The identification of nmr absorptions for $C_6H_5CH(Br)OCH_2C_6H_5$ and for the N-succinimidyl derivatives of the various ethers (except for N-α-methoxybenzylsuccinimide) was made by inference as based on the absorptions of structurally related compounds. Also of significance in the identification of the absorptions for the α-bromo ethers was the fact that these compounds hydrolyze rapidly when exposed to water.

The compositions of the product mixtures cited in Table II and elsewhere were calculated on the assumption that the total area in the nmr spectrum corresponding to aromatic protons was directly related to the quantity of benzyl ether used as starting material. The reported percentages were obtained by comparison of the integrated peak areas per H of selected ab-

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(1) D. G. Markees, *J. Org. Chem.*, **23**, 1490 (1958).

(2) (a) R. L. Huang and K. H. Lee, *J. Chem. Soc.*, 5957 (1964); (b) R. L. Huang, H. H. Lee, and M. S. Malhotra, *ibid.*, 5947 (1964); (c) R. L. Huang and K. H. Lee, *ibid.*, *C*, 932 (1966).

(3) M. Okawara, H. Sato, and E. Imoto, *J. Chem. Soc. Jap., Ind. Chem. Sect.*, **58**, 924 (1955).

(4) R. E. Lovins, L. J. Andrews, and R. M. Keefer, *J. Org. Chem.*, **28**, 2847 (1963); **30**, 1577 (1965).

(5) G. A. Russell and Y. R. Vinson, *ibid.*, **31**, 1994 (1966).

(6) R. C. Huston, R. L. Guile, P. S. Chen, W. N. Headley, G. W. Warren, L. S. Baur, and B. O. Mate, *J. Amer. Chem. Soc.*, **55**, 4639 (1933).

(7) T. W. Evans and K. R. Edlund, *Ind. Eng. Chem.*, **28**, 1186 (1936).

(8) N. A. Milas, *J. Amer. Chem. Soc.*, **53**, 230 (1931).

TABLE II

PRODUCTS OF REACTION OF 1:1 MIXTURES OF BENZYL ETHERS ($PhCH_2OR$) AND NBS IN CCl_4

R	Reaction mixture	Additional treatment after initial reaction	Product composition, %[b]				
			PhCH(Br)OR	$PhCH(NC_4H_4O_2)OR$	$PhCH_2OR$	PhCHO	RBr
CH_3	1[a]	None (liquid phase analyzed directly)	50	14	17	15	1
	1A	Refluxed mixture 1 (77°) 2 hr	36	19		37	8
	1B	Refluxed mixture 1 (77°) 4 hr	19	19		53	8
	2[a]	None	43	16	25	8	4
	2A	Sample of liquid phase of 2 heated (65°) 2 hr in sealed nmr tube	27	12	22	28	21
$C_6H_5CH_2$	3	None	54	11	18	16	8
	3A[c]	Sample of liquid phase of 3 shaken with equal volume of water	7	13	17	59	16
	3B	Sample of liquid phase of 3 heated at reflux (77°) 90 min	6	6	6	80	70
$(CH_3)_3C$	4	None			50	42	21
	5	None[d]		8	26	59	41
	5A	Sample of liquid phase of 5 shaken with equal volume of water		7	25	62	41
	5B	Refluxed mixture 5 (77°) 1 hr.			8	84	64
p-ClC_6H_4	6	None	70[e]	10	20		
	6A	Sample of liquid phase of 6 shaken with equal volume of water	15[e]	10	20	55	
	6B	Sample of liquid phase of 6 heated (65°) 2 hr in sealed nmr tube	70[e]	10	20		

[a] The commercial N-bromosuccinimide is in the form of soft lumps which were powdered for use in these reaction mixtures. [b] As established by analysis of the carbon tetrachloride phase. Reported percentages refer to the molar quantities of individual products relative to the total moles of aromatic material in the product solution. In the case of the dibenzyl ether reaction a reported yield of $x\%$ signifies that $x/100$ moles of the product were formed per mole of starting $(C_6H_5CH_2)_2O$. [c] The product mixture also contained benzyl alcohol (40% yield). [d] Reaction carried out at 0° using uv light as an initiator. [e] This was estimated from the amounts of starting material remaining and N-α-(p-chlorophenoxy)benzylsuccinimide and benzaldehyde formed since its characteristic tertiary H peak is hidden by the aromatic multiplet.

sorptions either for $>$CH, $>CH_2$, or $-CH_3$ for each product with the total aromatic peak area divided by the number of aromatic protons in the starting ether. In those cases in which figures for benzoyl bromide are presented, the reported values were obtained on the assumption that all aromatic absorption in the product spectrum not otherwise accounted for was produced by the aroyl halide.

The Low-Temperature Reaction of Benzyl *t*-Butyl Ether with N-Bromosuccinimide.—A mixture (5 in Table II) of 1.64 g (10 mmol) of benzyl *t*-butyl ether, 1.78 g (10 mmol) of NBS, and 20 ml of carbon tetrachloride was irradiated with uv light and stirred over a period of 15 min. While the bromination progressed, the solvent was prevented from refluxing by cooling the reaction flask in an ice bath. Samples of the liquid phase of this mixture were treated as described in Table II and were subjected to product analysis as described above.

The Reaction of α-Bromobenzyl Methyl Ether with D_2O.—Solutions of the bromo ether in carbon tetrachloride were generated as described above. To the cooled product mixtures, weighed samples of diphenylmethane were added to serve as internal standards in nmr analysis of the carbon tetrachloride phases subsequent to their treatment with D_2O solution as later described in Table III. The nmr absorption characteristic of methylene protons (τ 6.25) in the diphenylmethane spectrum did not interfere with any of the significant product absorptions. All of the D_2O solutions contained ethylene glycol (0.40 M) to serve as an internal standard in the nmr analyses of the aqueous phases. In addition to proton absorptions characteristic of CH_3OD (τ 6.60) and $DOCH_2CH_2OD$ (τ 6.34) the D_2O layers also displayed an absorption in the region τ 5.16 due to the hydroxylic protons (H_2O, CH_3OH, $HOCH_2CH_2OH$).

The Reaction of Benzyl Methyl Ether with N-Bromosuccinimide (NBS/Ether Mole Ratios of >1).—A mixture of 1.22 g (10.0 mmol) of benzyl methyl ether, 3.56 g (20.0 mmol) of N-bromosuccinimide, 0.05 g of benzoyl peroxide, and 20 ml of carbon tetrachloride was brought to reflux temperature to initiate reaction. When vigorous self-sustained refluxing subsided, a sample of the liquid phase was subjected to analysis by nmr spectrometry. The mixture contained α-bromobenzyl methyl ether (41% yield) and N-α-methoxybenzylsuccinimide (35% yield). The remaining aromatic product was presumed to be largely benzoyl bromide. The spectrum contained an absorption of significant proportions characteristic of methyl bromide.

The product mixture was refluxed for an additional 90 min, at which time nmr analysis of the liquid phase indicated that it contained only N-α-methoxybenzylsuccinimide (20% yield), benzoyl bromide (80% yield), and methyl bromide. A 0.4-g sample of the aroyl bromide was isolated through distillation of the carbon tetrachloride solution of products, bp 57° (2 mm). A 0.2-g sample of benzoic acid, mp 118–119°, was obtained by warming this material with water.

The reaction of N-bromosuccinimide and benzyl methyl ether in a 2:1 mole ratio was repeated as described above with the exception that in the second instance the bromine produced was distilled from the mixture, along with carbon tetrachloride, as it formed. Carbon tetrachloride was added to maintain a relatively constant volume during the course of the distillation. The liquid phase of the cooled product mixture was found to contain only N-α-methoxybenzylsuccinimide (80% yield) and benzoyl bromide. A 1.0-g sample of the N-α-methoxybenzylsuccinimide was recovered as a colorless oil by distillation of

TABLE III

THE REACTION OF $C_6H_5CH(Br)OCH_3$ (BME) AND D_2O

		Analyses					
			Composition, mmol[a]				
Reaction mixture	Source	Phase	$PhCH(Br)OCH_3$	$PhCH(NC_4H_4O_2)OCH_3$	PhCHO	CH_3Br	CH_3OD[b]
I	Reaction of 10.0 mmol each of NBS and BME in CCl_4 (20 ml volume)	CCl_4[c]	6.0	0.9	1.1	0.7	
IA	2 ml of I shaken with 2 ml of D_2O	CCl_4[c]		0.9	6.6	Trace	
		D_2O					4.5
IB	2 ml of I shaken with 2 ml of 1 *M* NaOH in D_2O	CCl_4[c]			7.5	Trace	
		D_2O					5.9
II	Reactions of 10 mmol each of NBS and BME in CCl_4 (20 ml volume)	CCl_4[e]	4.2	1.4	0.8	0.5	
IIA[d]	0.5 ml of II + 1 drop of D_2O sealed in an nmr tube and shaken	CCl_4[e]	3.1	1.4	1.9	1.1	
IIB[d]	IIA after standing at 45° for 0.5 hr	CCl_4	0.2	1.1	5.0	4.3	
IIC[d]	IIB shaken with an equal volume of D_2O	CCl_4[e]		1.1	5.3	4.4	
		D_2O					0.3
IID[d]	II shaken with an equal volume of D_2O	CCl_4[e]		1.4	5.1	Trace	
		D_2O					4.1

[a] Quantities of products which would have been obtained had the entire 20-ml sample of solution I or II been treated as indicated. In all cases the shaking time was 1 min. [b] Peaks for the CH_3OH and $HOCH_2CH_2OH$ hydroxyl protons appeared in the nmr spectra of the D_2O layers as part of the common $-OH/H_2O$ absorption at τ 5.2. [c] These solutions also contained 2.1 mmol of unreacted $PhCH_2OCH_3$. [d] Similar product distributions (CH_3Br *vs.* CH_3OD) were observed when samples of CCl_4 solutions of $C_6H_5CH(Br)$-OCH_3 prepared from $C_6H_5CH(OCH_3)_2$ and HBr were treated with D_2O by procedures like those applied here (IIA–IID). [e] These solutions also contained 3.3 mmol of unreacted $PhCH_2OCH_3$.

the reaction mixture, bp 182–184° (3 mm) [lit.[2a] bp 125° (1 mm)].

Anal. Calcd for $C_{12}H_{13}NO_3$: C, 65.78; H, 5.94; N, 6.39. Found: C, 65.69; H, 5.72; N, 6.36.

By means of iodometric titrations, the distillate was found to contain 7.2 mmol of bromine (as compared to an 8-mmol yield of the succinimidyl derivative of benzyl methyl ether).

Similar experiments were conducted in which bromine was removed by distillation as 10.0-mmol samples of benzyl methyl ether in carbon tetrachloride were subjected to reaction with varying quantities of N-bromosuccinimide. As the NBS/ether mole ratio changed in the order 1.25, 1.5, 1.75, and 2, the quantities in millimoles of bromine distilled and of N-α-methoxybenzylsuccinimide produced (the latter in parentheses) varied in the order 2.5 (3.0), 4.0 (4.6), 5.0 (6.2), and 7.2 (8.0), respectively.

The Reaction of α-Bromobenzyl Methyl Ether with N-Bromosuccinimide.—A sample of α-bromobenzyl methyl ether in 20 ml of carbon tetrachloride was prepared by gassing a solution of 1.52 g (10.0 mmol) of benzaldehyde dimethyl acetal with dry hydrogen bromide.[9] Passage of the gas was stopped when the mixture began to fume. The methanol formed was salted out by the HBr, leaving a carbon tetrachloride solution which displayed no nmr peaks characteristic either of the alcohol or the hydrogen halide. A trial preparation was made in which a weighed sample of diphenylmethane was present to serve as an internal standard. By comparison of the area of the methylene absorption for diphenylmethane with that for the absorption corresponding to the tertiary hydrogen of the bromo ether it was ascertained that reaction to form α-bromobenzyl methyl ether was almost quantitative (9.8 mmol yield).

The solution of the bromo ether was treated with 1.78 g (10.0 mmol) of N-bromosuccinimide, and the mixture was distilled to remove bromine. When halogen was no longer evolved, the nmr spectrum of the carbon tetrachloride solution of products contained no absorption typical of the bromo ether. N-α-Methoxybenzylsuccinimide was produced in 30% yield. The other aromatic product, which showed no absorption characteristic of nonaromatic protons, was presumed to be benzoyl bromide.

A mixture of α-bromobenzyl methyl ether and N-bromosuccinimide was prepared as described immediately above and treated with 1.64 g (20 mmol) of cyclohexene. After the mixture stood for 2 hr at room temperature, it contained N-α-methoxybenzylsuccinimide in 70% yield (established by nmr analysis of the liquid phase). Absorptions due to cyclohexene and brominated cyclohexane derivatives were also observed. When a solution of the bromo ether was treated with succinimide in a similar manner, no N-α-methoxybenzylsuccinimide was formed.

The Reaction of N-α-Methoxybenzylsuccinimide with Bromine.—A solution of 1.09 g (5.0 mmol) of N-α-methoxybenzylsuccinimide and 0.8 g (5 mmol) of bromine in 10 ml of carbon tetrachloride was refluxed for 1 hr. The nmr spectrum of the solution of the products indicated that the aromatic material present was 37% α-bromobenzyl methyl ether, 5% benzaldehyde, and 21% of the starting succinimide derivative. The remaining aromatic material in the product was presumed to be benzoyl bromide. A solid formed during the reaction and collected at the bottom of the vessel. This material was obtained in 0.31-g yield, mp 120–127°, and was probably a mixture of succinimide and N-bromosuccinimide.

The Relative Rates of Reaction of Benzaldehyde and Ethylbenzene.—For each determination a carbon tetrachloride solution (total volume ~20 ml) containing weighed quantities of benzaldehyde and ethylbenzene was prepared. A limited quantity of N-bromosuccinimide and 0.05 g of benzoyl peroxide were added and the mixture was heated under reflux for about 10 min. The product mixture was analyzed by the application of nmr spectroscopy.[10] A mixture which initially contained 9.92 mmol of the aldehyde, 10.03 mmol of ethylbenzene, and 8.38 mmol of N-bromosuccinimide contained 7.43 mmol of aldehyde and 5.14 mmol of the alkylbenzene at completion of reaction. A second mixture in which the reactants were present in 11.39-, 9.60-, and 9.10-mmol quantities, respectively, contained 7.92 mmol of aldehyde and 4.21 mmol of ethylbenzene when reaction was over. From the two sets of results the reactivity of benzaldehyde relative to ethylbenzene has been calculated as 0.426 and 0.440, respectively.

The Reaction of Benzyl Acetate with N-Bromosuccinimide.—A solution containing weighed samples of benzyl acetate and N-bromosuccinimide in a total volume of 25 ml in carbon tetra-

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[9] The preparation of α-bromobenzyl methyl ether from benzaldehyde dimethyl acetal through reaction with acetyl bromide has been reported by F. Straus and H. J. Weber, *Ann.*, **498**, 101 (1932).

[10] S. S. Friedrich, E. C. Friedrich, L. J. Andrews, and R. M. Keefer *J. Org. Chem.*, **34**, 900 (1969).

TABLE IV

PRODUCTS OF REACTIONS OF BENZYL ACETATE AND NBS IN CCl_4[a]

Treatment	Amt of $C_6H_5CH_2OAc$ reacted, mmol	Products formed, mmol: $C_6H_5CHBrOAc$	CH_3COBr	C_6H_5CHO	C_6H_5COBr[b]
Reaction mixture refluxed (77°) 15 min	8.8	3.4	5.3	0.8	(4.5)
Reaction mixture refluxed (77°) 2 hr more	8.8	3.2	5.6	0.8	(4.8)
Mixture then shaken with D_2O[c]	8.9	0	0	3.9	?

[a] From 16.2 mmol of benzyl acetate and 15.2 mmol of NBS in 25-ml volume in CCl_4. [b] The figures reported in parentheses are the differences between the figures in the two preceding columns. [c] The figures reported are for the CCl_4 layer. The CCl_4 layer also contains CH_3COOD (estimated as ~1.6 mmol); the CH_3 absorption (nmr) for the deuterated acid is partially obscured in CCl_4 solution by the methyl absorption of benzyl acetate. The D_2O layer was found to contain 7.5 mmol of CH_3COOD.

chloride was treated with 0.1 g of benzoyl peroxide, and the mixture was heated at reflux until the NBS was consumed. A weighed sample of diphenylmethane was added to the cooled reaction mixture to serve as an internal standard in nmr analyses. After sampling for analysis, the mixture was refluxed for a longer period, cooled, and then resampled. A 10-ml portion of the liquid phase of the product mixture was then shaken with 8 ml of D_2O and a weighed sample of ethylene glycol was added to serve as an internal standard in nmr analysis of the D_2O layer. In the analyses, methyl group proton absorptions for benzyl acetate, $C_6H_5CH(Br)OCOCH_3$, and acetyl bromide in carbon tetrachloride were located at τ 7.92, 7.82, and 7.18, respectively, and the methylene absorption for benzyl acetate appeared at τ 4.76. In the aqueous layer the methyl absorption for CH_3COOD was located at τ 7.95. Further details are given later in Table IV.

Results

Reaction of Equimolar Quantities of Benzyl Ethers and N-Bromosuccinimide.—α-Bromobenzyl methyl ether is thermally unstable[9] and has not been isolated in pure form from the mixture of products of reaction of benzyl methyl ether and N-bromosuccinimide. Absorptions characteristic of the bromo ether (Table I) are, however, readily apparent in the nmr spectrum of the mixture generated from equimolar quantities of the reactants in carbon tetrachloride. The chemical shifts associated with the benzyl and methyl protons of the α-halo ether formed in this reaction are identical with those of α-bromobenzyl methyl ether prepared by treating benzaldehyde dimethyl acetal with hydrogen bromide. As is indicated in Table II (reaction mixtures 1 and 2), the typical mixture of products formed in the short period of initial reactions of equimolar quantities of benzyl methyl ether and N-bromosuccinimide contains relatively little benzaldehyde. The bromo ether is produced in substantial yield along with a moderate quantity of N-α-methoxybenzylsuccinimide. As is to be expected, the nmr absorptions characteristic of the bromo ether disappear from the product mixture when its carbon tetrachloride solution is shaken with water, and benzaldehyde is generated virtually quantitatively (see entries I and IA, Table III).

Some starting ether and brominating agent remain after the initial fast reaction. Further heating of the product mixture (*cf.*, 1, 1A, and 1B, and 2 and 2A) results in the gradual decomposition of the bromo ether which it contains to form benzaldehyde and methyl bromide. When unreacted N-bromosuccinimide is first removed and the additional heating is conducted in a closed system, the decrease in molar quantity of bromo ether is matched by roughly equal increases in benzaldehyde and methyl bromide.

It has been reported previously[2b] that the reaction of dibenzyl ether and N-bromosuccinimide leads to the formation of benzaldehyde and benzyl bromide. On the basis of the present results (*cf.* reaction mixtures 3, 3A, and 3B of Table II), it can be stated that as in the benzyl methyl ether reaction the aldehyde is derived largely, if not exclusively, by decomposition of bromo ether [$C_6H_5CH(Br)OCH_2C_6H_5$] formed as the initial product (eq 1). Possibly some of the aldehyde may be generated by the alternate process (eq 2). Some succinimidyl derivative of the starting ether is also formed as a by-product of the major reaction. For reasons that are not known the observed yield of benzyl bromide is somewhat less than that of benzaldehyde in mixture 3B.

Benzaldehyde, *t*-butyl bromide, and a substantial quantity of unreacted ether are found in the products of reaction of benzyl *t*-butyl ether and N-bromosuccinimide (mixture 4, Table II). When the reaction is conducted at low temperature (mixture 5, Table II), it proceeds smoothly to give in addition to benzaldehyde and *t*-butyl bromide, a significant quantity of $C_6H_5CH(NC_4H_4O_2)$-$OC(CH_3)_3$. The formation of this compound probably takes place by a reaction analogous to that later described by eq 6. That is, the appearance of the succinimide derivative in the product mixture suggests that some α-bromo ether is initially produced from the ether and the brominating agent. It seems likely that the major pathway for benzaldehyde formation during the course of the reaction is that shown in eq 1 rather than eq 2 in view of the evidence obtained concerning the mode of the production of aldehyde from benzyl methyl and dibenzyl ethers. Presumably C_6H_5CH-$(Br)OC(CH_3)_3$ is highly unstable.

The bromo ether produced in the reaction of benzyl *p*-chlorophenyl ether and N-bromosuccinimide is easily hydrolyzed but is not readily subject to heat-induced decomposition (*cf.* mixtures 6, 6A, and 6B of Table II). This is to be expected of an α-halo ether, $C_6H_5CHBrOR$, in which R is aromatic.

The Hydrolysis of α-Bromobenzyl Methyl Ether.—The results of experiments to determine the effects of D_2O on carbon tetrachloride solutions of the products of reaction of benzyl methyl ether and N-bromosuccinimide are summarized in Table III. The interpretation of the nmr spectra of the mixtures of hydrolysis products has proved to be considerably simplified through substitution of D_2O for H_2O as the solvolyzing agent. When a relatively large volume of heavy water is used, methanol-*d* and benzaldehyde are produced (eq 3) in quantities comparable to that of bromo ether which is solvolyzed along with traces of methyl bromide (*cf.* reaction mixtures I and IA and II and IID of Table III). When the D_2O used to hydrolyze the bromo ether contains base (*cf.* mixtures I and IB), the by-product, N-α-methoxybenzylsuccinimide, is also hydrolyzed (eq 4).

$$C_6H_5CH(Br)OCH_3 + D_2O \longrightarrow C_6H_5CHO + CH_3OD + DBr \qquad (3)$$

$$C_6H_5CH(NC_4H_4O_2)OCH_3 \xrightarrow[D_2O]{OD^-} C_6H_5CHO + C_4H_4O_2ND + CH_3OD \qquad (4)$$

If the volume of D_2O relative to that of the carbon tetrachloride solution of the bromo ether is small, little CH_3OD is formed (*cf.* IIA, IIB, and IIC). Under these conditions the water appears to induce decomposition of the bromo ether to form benzaldehyde and methyl bromide, a process which presumably is polar in character (eq 5). Conceivably this reaction is subject to catalysis by traces of HBr in the reaction mixture.

$$\underset{Br}{C_6H_5CHOCH_3} \longrightarrow \underset{Br^-}{[C_6H_5\overset{+}{C}HOCH_3]} \longrightarrow C_6H_5CHO + CH_3Br \qquad (5)$$

It is regarded as unlikely that significant amounts of methyl bromide are produced (in mixtures IIA and IIB) by the reaction of methanol and hydrogen (deuterium) bromide formed as initial bromo ether hydrolysis products. Experimental difficulties have been encountered in attempting to investigate the rate of reaction of the alcohol and hydrogen bromide in carbon tetrachloride because the two reactants tend to separate as a second phase. It has been estimated, using an nmr method of analysis, that the half-life for formation of methyl bromide from the reaction of hydrogen bromide in pure methanol at 45° is of the order of 5 hr, which is much greater than that for the reactions summarized in Table III in which the alkyl halide is produced by water-induced decomposition of α-bromobenzyl methyl ether in carbon tetrachloride.

The Source of N-α-Methoxybenzylsuccinimide.—It has been reported by Huang and Lee[2a] that the α-succinimidyl derivative of a benzyl alkyl ether formed as a by-product of reaction of the ether and N-bromosuccinimide (Table II) is not produced by the reaction of the α-bromo ether with either succinimide or N-bromosuccinimide. During the course of this investigation it has, in fact, been confirmed that no buildup of N-α-methoxybenzylsuccinimide occurs when α-bromobenzyl methyl ether is subjected to decomposition by heating in the presence of succinimide. However, several bits of evidence have been obtained which suggest that $C_6H_5CH(NC_4H_4O_2)OCH_3$ is indeed formed from the bromo ether and N-bromosuccinimide and that, in fact, reaction 6 is reversible.

$$C_6H_5CH(Br)OCH_3 + BrNC_4H_4O_2 \rightleftharpoons C_6H_5CH(NC_4H_4O_2)OCH_3 + Br_2 \qquad (6)$$

For example, if the ratio of brominating agent to benzyl methyl ether is increased stepwise from 1 to 2 and bromine is removed by distillation during the course of reaction in carbon tetrachloride, the molar quantities of $C_6H_5CH(NC_4H_4O_2)OCH_3$ produced and of bromine recovered increase in a more or less parallel fashion.[11] Under these conditions and with a 2:1 initial ratio of N-bromosuccinimide to ether an 80% yield of the succinimidyl derivative has been obtained.

When α-bromobenzyl methyl ether, prepared in carbon tetrachloride by the reaction of benzaldehyde dimethyl acetal and hydrogen bromide, is treated with an equimolar quantity of N-bromosuccinimide and the mixture is distilled to remove bromine, N-α-methoxybenzylsuccinimide is produced in 30% yield. If the reaction is conducted at room temperature and cyclohexene is added to absorb bromine and shift the equilibrium, this yield is more than doubled.

As is to be anticipated if the reaction to form the succinimidyl derivative is reversible, α-bromobenzyl methyl ether is produced in significant quantity when equimolar amounts of N-α-methoxybenzylsuccinimide and bromine are heated in carbon tetrachloride solution. Some benzaldehyde, formed from breakdown of the bromo ether, is detected along with unreacted N-α-methoxybenzylsuccinimide in the resulting product mixture, and there is evidence that some benzoyl bromide (from benzaldehyde and N-bromosuccinimide) is also present.

The reaction of α-bromobenzyl methyl ether and N-bromosuccinimide to form the succinimidyl derivative (eq 6) has been accomplished without the addition of a radical initiator, and it is possible that it is polar in character. The bromination of cycloheptatriene with N-bromosuccinimide leads to the formation of a significant quantity of N-(cyclohepta-2,4,6-trienyl)succinimide which is presumed to be produced from tropylium bromide and the brominating agent.[12] It is conceivable that bromides which give rise to relatively stable carbonium ions, *e.g.*, tropylium bromide and $C_6H_5CH(Br)OR$, are disposed to react in this fashion. In this connection it is pertinent that the formation of N-tritylsuccinimide from trityl phenyl sulfide and N-bromosuccinimide is postulated to proceed by way of triphenylmethyl cation.[13]

The Reaction of Benzyl Acetate with N-Bromosuccinimide.—This matter has been explored in connection with a separate investigation.[10] Certain of the results are pertinent to the subject of this report (see Table IV). In contrast to what is observed for the corresponding reaction of benzyl methyl ether, benzaldehyde is apparently generated in quantity during the bromination of benzyl acetate by N-bromosuccinimide, even when the period of heating of the reaction mixture is short. Also, the aldehyde produced in the benzyl acetate reaction is substantially converted into benzoyl bromide even if the initial ratio of brominating agent to acetate is relatively low (~1:1). The acyl bromide can be detected in the mixture of products through observation of its characteristic *ortho*-hydrogen absorption at τ 2.19. Since this absorption is rather close to the *ortho*-hydrogen absorption of benzaldehyde (τ 2.44), it is of significance in a qualitative but not a

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[11] The distillation technique has been applied by L. L. Braun and J. H. Looker in improving the yield of N-α-(p-bromophenoxy)benzylsuccinimide from p-bromophenyl benzyl ether and N-bromosuccinimide [*cf. J. Org. Chem.*, **26,** 574 (1961)]. Their explanation of the manner of formation of this product is somewhat different from that presented here.

[12] H. L. Dryden, Jr., and B. E. Burgert, *J. Amer. Chem. Soc.*, **77,** 5633 (1955).

[13] K. C. Schreiber and V. P. Fernandez, *J. Org. Chem.*, **26,** 2478 (1961).

quantitative sense. The stoichiometry of the reaction leading to aldehyde production is given by eq 7, but benzaldehyde is present in the products in much smaller amount than acetyl bromide because of its further reaction with N-bromosuccinimide. This is not surprising.

$$C_6H_5CH_2OCOCH_3 \xrightarrow{NBS} CH_3COBr + C_6H_5CHO \qquad (7)$$

Using the relative reactivities of benzaldehyde and ethylbenzene as determined in this investigation and those for ethylbenzene and benzyl acetate which are reported elsewhere,[10] it can be shown that the relative reactivities of benzaldehyde and benzyl acetate with respect to N-bromosuccinimide in carbon tetrachloride (77°) are in the ratio 8:1. The corresponding ratio for benzaldehyde and benzyl methyl ether is 0.07:1. The acetyl bromide in the product mixture is, incidentally, easily identified through its characteristic nmr absorption and through its ready conversion to CH_3COOD on exposure to D_2O (see Table IV). The α-bromobenzyl acetate is also easily recognized through its conversion to benzaldehyde on hydrolysis.

The mixture of products obtained through brief heating at reflux of benzyl acetate and N-bromosuccinimide in carbon tetrachloride contains appreciably more acetyl bromide than α-bromobenzyl acetate. Prolonged further heating of this mixture results in little change in the quantities of these products. Therefore breakdown of the bromo acetate (eq 1) does not occur readily. It appears that this bromide is significantly more stable thermally than α-bromobenzyl methyl ether, and this may be a reflection of the relative stabilities of the ion pairs, $C_6H_5C^+HOCOCH_3\ Br^-$ and $C_6H_5C^+HOCH_3\ Br^-$ (*cf.* eq 5). The pathway of eq 2 is important—even dominant—in the reaction of benzyl acetate with N-bromosuccinimide, although this is not the case for the reaction of benzyl methyl ether. A possible explanation for this difference can be made by considering the relative reactivities of the acetate and the ether with N-bromosuccinimide (1/116 at 77° in carbon tetrachloride[10]). It is reasonable to conclude, on the basis of this large reactivity difference, that of the two radical intermediates, $C_6H_5\dot{C}HOCOCH_3$ and $C_6H_5\dot{C}HOCH_3$, the former is much less stable and should be more susceptible to direct breakdown to benzaldehyde (eq 2) than the latter.

Registry No.—N-Bromosuccinimide, 128-08-5.

Acknowledgments.—The authors are indebted to the National Science Foundation for a grant in support of this research, and to Dr. Edwin C. Friedrich for his many helpful discussions and suggestions. Some of the work on the manuscript was done at the Chemistry Department, University of Hull, England, which served as a kind host to L. J. A. during his stay there as a Fulbright-Hays Research Scholar.

Chemistry of N-Halamines. XII. Amination of Alkyl Halides with Trichloramine–Aluminum Chloride[1]

PETER KOVACIC[2] AND MICHAEL K. LOWERY[3,4]

Department of Chemistry, Case Western Reserve University, Cleveland, Ohio 44106

Received August 26, 1968

Treatment of alkyl halides with trichloramine–aluminum chloride provided various types of amine products. With *t*-butyl chloride or bromide, high yields of *t*-butylamine were obtained. A minor product, 2,2-dimethylaziridine, was also formed. Other *t*-halides similarly produced the corresponding *t*-carbinamines. Skeletal rearrangement was noted with isobutyl chloride which afforded *t*-butylamine, *sec*-butylamine, and 2,2-dimethylaziridine. Primary and secondary amines, as well as N-alkylaziridines, were generated from *sec*-halides. *meso*-2,3-Dibromobutane gave *trans*-2,3-dimethylaziridine. Rationalizations of the results are provided.

Recent reports from this laboratory have revealed that the direct amination of aromatic compounds with N-halamines under Friedel–Crafts conditions leads to products of unusual orientation. When monoalkylbenzenes were treated with trichloramine and aluminum chloride or aluminum bromide, the corresponding *m*-alkylanilines were formed.[5–8] The proposed mechanism, σ substitution, accounts for the selective *meta* orientation. Further work showed that dialkylbenzenes,[9] biphenyl,[10] and napthalene[10] behaved similarly. With halobenzenes and anisole,[11] *o*- and *p*-chloroanilines were detected in addition to the *meta*-substituted aniline derivatives. The substitution of N-halo- or N,N-dihaloalkylamines for trichloramine in the amination of toluene resulted in the formation of the corresponding N-alkyl- or N,N-dialkylanilines.[12] Although *meta* orientation generally predominated, the *ortho* and *para* isomers were observed in appreciable quantities in certain cases.

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[1] For a preliminary report see P. Kovacic and M. K. Lowery, *Chem. Commun.*, 651 (1966); presented at the 155th National Meeting of the American Chemical Society, San Francisco, Calif., April 1968.

[2] To whom correspondence should be addressed at the Department of Chemistry, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201.

[3] National Science Foundation Graduate Trainee, 1965–1967.

[4] From the Ph.D. Thesis (1969) of M. K. L.

[5] P. Kovacic, R. M. Lange, J. L. Foote, C. T. Goralski, J. J. Hiller, Jr., and J. A. Levisky, *J. Amer. Chem. Soc.*, **86**, 1650 (1964).

[6] P. Kovacic, C. T. Goralski, J. J. Hiller, Jr., J. A. Levisky, and R. M. Lange, *ibid.*, **87**, 1262 (1964).

[7] P. Kovacic, J. A. Levisky, and C. T. Goralski, *ibid.*, **88**, 100 (1966).

[8] P. Kovacic and J. A. Levisky, *ibid.*, **88**, 1000 (1966).

[9] P. Kovacic, K. W. Field, P. D. Roskos, and F. V. Scalzi, *J. Org. Chem.*, **32**, 585 (1967).

[10] P. Kovacic and A. K. Harrison, *ibid.*, **32**, 207 (1967).

[11] P. Kovacic, J. J. Hiller, Jr., J. F. Gormish, and J. A. Levisky, *Chem. Commun.*, 580 (1965).

[12] V. L. Heasley, P. Kovacic, and R. M. Lange, *J. Org. Chem.*, **31**, 3050 (1966).