cation gave 17.3 g. (66.3%) of 2,3,3,4,4,4-hexafluorobutyltriethylsilane, b.p. 173.1°.

The methyl Grignard reactions were run with a 33% excess of Grignard reagent over the theoretically required amount, while a larger excess was used in ethyl Grignard reactions in order to ensure finding any reaction of the β-halogen substituent.

All the tetraalkyl compounds derived from trifluoropropyltrichlorosilane and hexafluorobutyltrichlorosilane were found to be stable toward concentrated hydrochloric acid and 40% aqueous potassium hydroxide at reflux for 14 hr.

Trifluorotetrachloropropyltrichlorosilane.—A Carius tube was charged with 12.1 g. (0.17 mole) of dry chlorine and 27.8 g. (0.093 mole) of trifluorodichloropropenyltrichlorosilane, sealed under a purified nitrogen atmosphere, and irradiated with light from an AH-1 bulb (Gartner Scientific Co.) for 3 days. After removal of the excess chlorine *in vacuo* the white solid residue was distilled to give 31.7 g. (94.9%) of trifluorotetrachloropropyltrichlorosilane, b.p. 118–120° (8.5 mm.). This compound hydrolyzed only slowly in dilute acid.

Anal. Calcd. for $C_3Cl_7F_3Si$: C, 9.74; Cl, 67.28; F, 15.42. Found: C, 10.02; Cl, 67.01; F, 14.79.

Trifluorodichloropropenyltriethylsilane from Trifluorotetrachloropropyltrichlorosilane.—A solution of 30.5 g. (0.075 mole) of trifluorotetrachloropropyltrichlorosilane in 50 ml. of anhydrous ether was added at 0° to a Grignard solution prepared from 12.81 g. (0.54 g.-atom) of magnesium turnings in 300 ml. of anhydrous ether and 57.7 g. (0.54 mole) of ethyl bromide in 100 ml. of anhydrous ether. The resulting suspension was stirred at reflux temperature for 12 hr., the ether distilled, the residue heated on a steam-bath for 5 hr., the ether added again, the mixture decomposed with ice and hydrochloric acid, the aqueous layer extracted with ether and the combined ether layers dried over Drierite. Rectification gave 11.8 g. (56.2%) of trifluorodichloropropenyltriethylsilane, b.p. 112.5–113.5° (23 mm.), $n^{20}\text{D}$ 1.4534–1.4535, d^{20}_4 1.189.

The infrared spectrum of this compound was identical with the one of trifluorodichloropropenyltriethylsilane prepared from trifluorodichloropropenyltrichlorosilane.

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WEST LAFAYETTE, INDIANA

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, NORTHWESTERN UNIVERSITY]

The Cleavage of Ethers by Hydrogen Bromide

BY ROBERT L. BURWELL, JR., AND MILTON E. FULLER

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The relative reactivities of several alkyl groups have been determined in the internal competitive reaction RR'O + HBr = (RBr, R'Br) + (R'OH + ROH). With initial mole fraction hydrogen bromide of about 0.65, relative reactivities at 26° are: methyl 11.1, ethyl 1.00, propyl 1.00, butyl 0.93, *i*-butyl 0.053, *i*-propyl 0.87, 3-pentyl 4.2 and cyclopentyl 3.8. The first five groups are cleaved apparently by an SN2 reaction, the last three by a reaction to which there is considerable SN1 contribution. The relative reactivities of secondary alkyl groups in ethers decrease with decreasing mole fraction of hydrogen bromide. In the competitive reaction of butyl ether and propyl alcohol with hydrogen bromide, the ether reacts about 7.5 times faster at an initial mole fraction of hydrogen bromide of 0.63; about 1.4 times faster at an initial mole fraction of 0.32. At the higher initial mole fraction, butyl ether reacts about 12 times faster than isopropyl alcohol.

Despite the importance of the alkyl–oxygen bond in organic chemistry, relatively little mechanistic attention has been given to its cleavage in simple ethers and alcohols. Although both ethers and alcohols involve similar factors, the investigation of ethers offers advantages which will appear in the discussion.

The alkyl–oxygen bond cannot be cleaved by displacement reactions in alkyl ethers and alcohols as such but only in complexes in which considerable positive charge is transferred to the oxygen atom, *e.g.*, in such species as R_2OH^+ and $R_2O{:}BCl_3$.[1] In the present work, hydrogen bromide is employed as the cleaving agent. Cleavage by hydrogen bromide of primary alkyl–oxygen and of tertiary alkyl–oxygen bonds seems to occur by typical SN2 and SN1 reactions, respectively.[1] The nature of the cleavage of secondary alkyl–oxygen bonds is in doubt.

The stoichiometry of the reaction is

$$R'RO + HBr = (R'Br, RBr) + (ROH, R'OH) \quad (1)$$

Determination of the ratio R'Br/RBr in the product gives the relative rates of cleavage of the two alkyl–oxygen bonds in the unsymmetrical ether, R'RO. The relative rates of displacement of two groups attached to the same center is an unusually favorable case of competitive reactions.[2] The present paper reports the results of the cleavage of a number of unsymmetric ethers and of the relative rates of cleavage of butyl ether *vs.* propyl and isopropyl alcohols in conventional competitive reactions.

Experimental Procedure

Materials.—The following ethers were prepared by the Williamson synthesis: methyl butyl, b.p. 69.2°; ethyl butyl, 91.9°; propyl butyl, 116.2°; isobutyl butyl, 138.8°; cyclopentyl butyl, 168°; isopropyl propyl, 80°; isobutyl propyl, 107°; 1-ethylpropyl propyl, 128.5°; and diisobutyl, 120–121°. Since unreacted alcohol usually would form an azeotrope with the ether, gross quantities of alcohol were removed by formation of borate esters[3] followed by distillation. Certain ethers were next chromatographed on silica gel with elution by methanol. The ethers were then fractionated from sodium in a 50-plate Stedman column. Butyl ether (Eastman Kodak Co., White Label) was given the last treatment. The infrared absorption spectra of these and the other compounds employed in this research are presented in the doctoral thesis of Milton E. Fuller, Northwestern University, 1956.

The following alkyl halides were either commercial materials subjected to purification or compounds prepared from the corresponding alcohols by standard methods: butyl bromide and isobutyl bromide, Eastman Kodak Co., White

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[1] R. L. Burwell, Jr., *Chem. Revs.*, **54**, 615 (1954).

[2] Such cleavage of ethers resembles the cleavage of unsymmetric dialkylmercury, RR'Hg + HCl = (RH, R'H) + (RHgCl, R'HgCl); M. S. Kharasch and A. L. Flenner, THIS JOURNAL, **54**, 674 (1932).

[3] C. Weygand, "Organic Preparations," Interscience Publishers, Inc., New York, N. Y., 1945, p. 163.

Label; cyclopentyl bromide, Arapahoe Chemicals, Inc.; ethyl bromide, Fisher Scientific Co., certified reagent; methyl bromide, Matheson; propyl bromide and isopropyl bromide. 2-Pentanol was prepared from acetaldehyde and propylmagnesium bromide, 3-pentanol by the hydrogenation of ethyl ketone on nickel–kieselguhr (Harshaw) at 110°, 100 atm. Both pentanols were converted to the corresponding bromides *via* treatment of the tosylates with sodium bromide.[4] Infrared spectra demonstrated the absence of each bromide in the other.

Ether Cleavage.—About 5 cc. of ether was placed in a tube in the form of the Ostwald–Sprengel pycnometer. Anhydrous hydrogen bromide was passed into the tube leading to the bottom of the bulb while the tube was cooled in ice. At the desired weight increase, the inlet and outlet tubes were sealed off. Saturation of an ether gives a mole fraction of hydrogen bromide close to $^2/_3$.

Analytical Procedures.—The reaction mixture contained unreacted ether and hydrogen bromide, both alcohols and both bromides. The analytical scheme involved the removal of everything except the bromides and then analysis of the bromide mixture for the ratio of the two bromides. The reaction tube was opened and its contents blown into a scrubbing tube containing 85% phosphoric acid. Continued passage of dry air carried the bromides and some of the hydrogen bromide and ether forward. The hydrogen bromide was removed by a tube containing sodium hydroxide. The vapor stream then passed through two scrubbing units containing 96% sulfuric acid to remove ether and any residual alcohols. The sulfuric acid traps were kept at 0° to minimize conjunct polymerization. Bromides were then condensed from the vapor stream in a Dry Ice trap. When methyl and ethyl bromides were present, liquid nitrogen was used as the condensing agent and the sweep gas was purified nitrogen. The procedure was carefully checked with known mixtures. Bromide recoveries of over 90% were obtained. Since there were transfer losses in introducing these mixtures into the purification line and in removing the bromides from the trap, recovery in the purification system was substantially quantitative. We estimate that preferential volatilization leads to changes in the bromide composition of less than 0.5 percentage unit.

Samples of liquid bromide mixtures were analyzed by infrared spectroscopy with the Baird double beam instrument.[5] For example, for cleavage of propyl butyl ether, mixtures containing 48.8, 58.5 and 64.6 mole % propyl bromide and the rest butyl bromide were prepared. With the 58.5 mole % sample in cell A, runs were made in succession with each of the three synthetic samples and the product of an actual ether cleavage in cell B. Plots of the logarithm of the % transmission of the synthetic samples against mole % propyl bromide were prepared for a number of wave lengths. The mole % propyl bromide was then determined at the four most favorable wave lengths and averaged. A number of "known" unknowns of isopropyl and propyl bromides and of butyl and propyl bromides were analyzed by this method. The average deviation of the average from the known value was 0.3 percentage unit. The average maximum deviation of the results at any one wave length from the average of all wave lengths was 1.1 percentage units. We estimate that the reported percentage compositions may involve errors amounting over-all to about 1 percentage unit.

The accuracy of these analyses was checked a number of times by preparing a mixture whose composition was that of the analysis of a reaction product. The infrared spectra of the experimental and synthetic samples were compared by the techniques described above. Agreement was satisfactory.

The infrared technique could not be used with the volatile methyl and ethyl bromides. In these cases analysis was by density determination. A series of about five capillary tubes suspended vertically from a larger tube was provided. The volumes of the bulbs were chosen so that in at least one case the sample of mixed bromides would fill the bulb and part of the capillary. The purified sample of bromides was then totally transferred into the appropriate bulb by vacuum distillation, sealed off and the level of the mixture in the capillary at 0° determined. The density was determined by calibration with butyl bromide. The over-all possible errors are about the same as in the infrared method.

At the very end of this research, vapor phase chromatography became available to us. Results of the density analysis of ethyl butyl ether were checked on the Podbielniak Chromacon using tricresyl phosphate on Celite as the stationary phase and hydrogen as the sweep. Actually, all of our reaction products probably could have been analyzed by this means and without the necessity of isolating the bromide mixture. In the one case which we report, the bromide mixture was isolated before analysis.

Experimental Results

Alcohol–Ether Mixtures.—If the analytical determinations just described are to represent relative rates of cleavage of alkyl–oxygen bonds in ethers, reaction 1 must not be subject to interference with the possible subsequent reaction

$$\mathrm{ROH + HBr = RBr + H_2O} \qquad (2)$$

To check this, the bromide ratio in the product of reaction of a mixture of symmetrical ether and alcohol was determined and, in most detail, with butyl ether and propyl alcohol. If the reactions of both species with hydrogen bromide have the same kinetics and if both rates are first order in alcohol or ether, the ratio of the rate constants of the two reactions are

$$k_{\text{ether}}/k_{\text{alc}} = \log(X^0_{\text{ether}}/X_{\text{ether}})/\log(X^0_{\text{alc}}/X_{\text{alc}}) \qquad (3)$$

The assumptions cannot be exactly valid and the reaction also suffers interference from reaction 2. However, equation 3 becomes increasingly valid as total conversions decrease. Results of a series of runs are given in Table I. Times of reaction varied from 2 to 26 hr. at ambient temperatures. At $X^0_{\text{HBr}} = {}^1/_3$, the ether reacts about 1.4 times as fast as the alcohol. This value increases to 7.5 as X^0_{HBr} increases to $^2/_3$. Higher conversions at low values of X^0_{HBr} result in heterogeneous mixtures. Such runs were discarded since the hydrogen bromide rich layer may preferentially extract alcohol from the other phase. Because of the low concentration of propyl bromide in the product in the last 5 runs of Table I, about 4%, the relative reactivity is subject to an error of about ±1. The probable error for the first 5 runs (about 14% propyl bromide) is ±0.2.

TABLE I

RELATIVE RATES OF REACTION OF BUTYL ETHER AND PROPYL ALCOHOL

Mole fraction Ether	Mole fraction Alc.	HBr	Reacted, % Ether	Reacted, % Alc.	$\dfrac{\log(X^0_{\text{ether}}/X_{\text{ether}})}{\log(X^0_{\text{alc}}/X_{\text{alc}})}$
0.56	0.12	0.32	11.4	8.0	1.5
.55	.12	.33	15.3	11.4	1.4
.50	.11	.39	26.0	19.2	1.4
.42	.17	.41	38.6	19.3	2.3
.40	.14	.45	51.1	22.4	2.8
.41	.11	.48	60.1	23.8	3.4
.42	.09	.49	48.2	13.0	4.7
.05	.45	.50	21.9	5.5	4.3
.37	.09	.54	49.6	9.1	7.2
.37	.09	.54	39.0	7.0	6.8
.31	.07	.62	35.6	5.7	7.6
.30	.07	.63	40.5	7.5	6.7
.29	.07	.64	48.5	7.6	8.3

At $X^0_{\text{HBr}} = 0.62$, the ratio of the rates of reaction of butyl ether and isopropyl alcohol is about 12.

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[4] H. Pines, A. Rudin and V. N. Ipatieff, THIS JOURNAL, **74**, 4063 (1952).

[5] R. L. Burwell, Jr., and A. D. Shields, *ibid.*, **77**, 2766 (1955).

The relative rate of reaction of alcohols is substantial but, since in cleavage of unsymmetric ethers the ether starts at a finite mole fraction and the alcohol at zero, the effect of reaction 2 can be made negligible by confining the cleavage reaction to low conversions. The data in the next section appear free of interference from reaction 2 to within the estimated experimental error.

Ether Cleavage by Hydrogen Bromide.—The results of ether cleavages are shown in Tables II–V. Reaction temperatures were the ambient, about 26°.

Isomerization During Cleavage.—As shown in Table V, substantial amounts of 2-pentyl bromide appeared in the cleavage of propyl 3-pentyl ether. However, much or all of this isomerization could have occurred during isolation of the bromides. Reaction of hydrogen bromide with a mixture of propyl ether and 3-pentyl bromide yielded a bromide fraction in which about 8% isomerization of the 3-pentyl to 2-pentyl bromide had occurred. Also, on merely carrying a sample of 3-pentyl bromide through the isolation apparatus, 10.7% isomerization occurred.[6] Vapor phase chromatography of the total reaction mixture might yield analyses devoid of accompanying isomerization.

Table II

Ether Cleavage with Analysis by Density Determination

X^0_{HBr}	Reacn. time, min.	Conversion,[a] %	Mole % C_4H_9Br	Average mole % C_4H_9Br
Methyl butyl ether				
0.61	12	39	7.5	
0.62	9	34	7.8	7.7
Ethyl butyl ether				
0.62[b]	70	19	48.3	
.63	60	20	48.0	
.65[b]	60	15	46.1	
.68	60	19	49.1	
.69	60	21	48.1	
.70	65	23	46.8	47.7

[a] In terms of total yield of bromide assuming equation 1. [b] Analyzed by vapor phase chromatography.

Table III

Cleavage of Butyl Ethers with Analysis by Infrared Absorption

X^0_{HBr}	Reacn. time, min.	Conversion, %	Mole % C_4H_9Br	Average mole % C_4H_9Br
Propyl butyl ether				
0.27	1340	11	48.5	
.27	2680	26	48.5	
.35	2680	40	47.8	
.66	90	33	47.9	
.67	120	38	48.4	
.67	100	39	47.9	48.2
Isobutyl butyl ether				
0.62	135	23	94.8	
.65	120	23	94.3	
.67	60	11	94.2	
.69	60	10	94.7	94.5
Cyclopentyl butyl ether[a]				
0.44	150	14	32.8[b]	
.59	90	19	35.8[b]	
.65	30	33	20.1	
.66	90	46	21.1	
.67	55	38	15.5	
.69	90	42	23.7	20.1

[a] The vapor pressure of cyclopentyl bromide is so low that the isolation procedure becomes difficult. The analyses here are probably of lower accuracy than in the other runs. In addition, the conversions are too large. [b] Excluded from the average. The average applies to X^0_{HBr} about 0.67.

Table IV

Ether Cleavage with Analysis by Infrared Absorption

X^0_{HBr}	Reacn. time, min.	Conversion, %	Mole % n-C_3H_7Br	Average mole % C_3H_7Br
Isobutyl propyl ether				
0.61	90	7	94.7	
.64	120	24	94.3	
.64	80	14	94.5	
.65	80	19	93.9	
.65	90	13	94.1	
.66	120	27	93.3	
.66	90	21	94.2	
.69	60	12	93.2	94.0
Isopropyl propyl ether				
0.35	210	9	65.7	
.37[a]	2×10^4	30	66.4	
.50	120	18	62.3	
.65	60	22	55.3	
.67	30	12	53.3	

[a] Temperature of reaction, 5°.

Table V

Cleavage of Propyl 1-Ethylpropyl Ether, Infrared Analysis

X^0_{HBr}	Reacn. time, min.	Conversion, %	Product composition, mole % PrBr	2-Pentyl Br	3-Pentyl Br
0.60	25	16	20.0	20.3	59.7
.68	20	15	19.2	25.3	55.5
.71	60	46	19.2	11.5	69.3

Isobutyl bromide passed through the isolation apparatus without detectable change. No detectable content of t-butyl bromide appeared in the products of cleavage of propyl isobutyl and butyl isobutyl ethers (Tables III and IV); however, with the low concentration of isobutyl bromide, this test of isomerization was not sensitive. Accordingly, isobutyl ether was cleaved with hydrogen bromide. About 0.4% t-butyl bromide was found in the product.

Discussion

The reaction mixtures of most of our experiments (initial mole fraction of hydrogen bromide about $^2/_3$, of ether about $^1/_3$) are undoubtedly rather complicated mixtures of various species. The relatively high electrical conductivity[7] and the Raman spectra[8] of ether–hydrogen chloride solutions indicate the presence of dialkylhydronium ions, $RR'HO^+$.

The saturation ratio of about two moles of hydrogen bromide to one of ether suggests that the negative ion $BrHBr^-$ is important.[9] Most of the

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(6) See also ref. 4.

(7) O. Maass and D. McIntosh, This Journal, **35**, 535 (1913).

(8) G. L. Vidale and R. C. Taylor, *ibid.*, **78**, 294 (1956).

(9) There is evidence for the corresponding chloride ion; H. F. Herbrandson, R. T. Dickerson, Jr., and J. Weinstein, *ibid.*, **76**, 4046 (1954). Also, the low temperature crystalline phase of hydrogen bro-

ionized species must be involved in ion pairs or in higher aggregates.

Presumably, there will also be substantial concentrations of hydrogen bonded species, RR'O·H-Br, particularly at lower concentrations of hydrogen bromide. In any case, the drastically reduced partial pressure of hydrogen bromide from ether solutions (the vapor pressure of pure hydrogen bromide is 12.3 atm. at 0°) indicates strong interaction between ether and hydrogen bromide.

The reactive form of the ether must be the dialkylhydronium ion[1] and the displacing species is presumably an anion such as Br^- or $BrHBr^-$, although, particularly at lower concentrations of hydrogen bromide, RR'O·HBr may be involved.

Bennett and Reynolds[10] investigated the cleavage of the R–O bond by measurement of the rate of reaction between alcohols and hydrogen bromide in aqueous phenol. Variation in basicities of the alcohols must have influenced rates. Such an effect may be small, but it represents an uncontrolled variable. The problem of relative basicities does not enter into an analysis based on equation 1. However, a new uncertainty does; each reaction occurs in a slightly different medium because of the change of ether. In addition, the possibility of steric hindrance of one alkyl group by the other must be considered, but models indicate that such effect is negligible in the ethers under consideration.

TABLE VI

RELATIVE RATES OF REACTION

Methyl	Ethyl	Propyl	Butyl	*i*-Butyl	*i*-Propyl	*s*-Butyl	3-Pentyl	Cyclopentyl
ROR' + HBr at 26°, X^0_{HBr} *Ca.* 0.65								
11.1	1.00	1.00	0.93	0.053	0.87		4.2	3.8
ROH + HBr in aqueous phenol, 83° (ref. 10)								
5.6	1.00	0.87	0.90	0.11	2.30	5.5		
$ROSO_3^-$ + H_2O, first order, 138° (ref. 14)								
1.79	1.00	0.65		0.15	16	19.5		
Br^- + RBr in acetone, 25° (ref. 13)								
76	1.00	0.65		0.033	0.011			

The first line of Table VI presents the relative rate of cleavage compared with ethyl for various alkyl groups at a mole fraction of hydrogen bromide of about 0.65. These are derived from the data on competitive cleavage of unsymmetrical ethers presented in Tables II–V. We did not plan to obtain absolute kinetics, but the data of these tables indicate that the time in minutes required for 20% cleavage of the various ethers at $X_{HBr} = 0.65$ was: ethyl butyl, propyl butyl and isopropyl propyl, 55; methyl butyl, 5 to 6; isobutyl propyl, 90; isobutyl butyl, 110; cyclopentyl butyl and 3-pentyl propyl, 30. These times are in good agreement with the relative rate data of Table VI. The agreement suggests that the change in medium consequent to the change in ether for each competitive cleavage is not too serious, although the variation in medium remains, to some extent, as an uncontrolled variable.

There is some disagreement in the older literature as to the products of the cleavage of propyl isopropyl ether.[1] With the mole fraction of hydrogen bromide about 0.65, both bromides are formed with propyl bromide in slightly the greater quantity. On the basis of Ingold's kinetic criterion[11] then, the isopropyl group is cleaved by a mechanism differing from that of the propyl group. The secondary alkyl groups apparently are cleaved by a reaction to which the form R^+ OHR makes considerable contribution. Similar considerations apply to the reaction between alcohols and hydrogen bromide in aqueous phenol[10] (Table VI, second series).

Relative rates of cleavage of propyl–oxygen *vs.* isopropyl–oxygen bonds are influenced by the initial mole fraction of hydrogen bromide. As shown in Table IV, the reactivity of isopropyl *vs.* propyl decreases from 0.8 at $X^0_{HBr} = 0.66$ to 0.52 at $X^0_{HBr} = 0.35$. A similar effect is observed in the cleavage of butyl cyclopentyl ether (Table III). The decreasing relative rate of cleavage of the *sec*-alkyl–oxygen bond presumably results from the declining polarity of the medium.

To the extent that the three ethers with secondary alkyl groups are cleaved by the same mechanism, the relative figures for the three groups represent relative rate constants. However, in view of the probable change of mechanism, the relative reactivities are not ratios of rate constants in comparisons between primary and secondary groups.

The relative rates in the primary ether sequence, particularly the large value of methyl and the low value of isobutyl, are typical of SN2 reactions[12] such as the exchange reaction between bromide ion and alkyl bromides[13] (Table VI, fourth series). One would not expect the relative reactivities of the primary groups to change substantially with the mole fraction of hydrogen bromide. As shown in Table III, we could detect no difference in the bromide ratio in the cleavage of propyl butyl ether in varying the mole fraction from 0.27 to 0.67. Unlike such reactions as the first-order solvolysis of the alkyl sulfate ion,[14] there is probably no large amount of SN1 character in the sequence of primary alkyl ether cleavages. The near absence of isomerization of isobutyl to *t*-butyl during cleavage of isobutyl ether is consistent with this.

Our data do not establish the exact nature of the cleavage of *sec*-alkyl–oxygen bonds. We attempted to determine the degree of isomerization consequent to the cleavage of the 3-pentyl group but were prevented by the isomerization which accompanied the isolation process. Isomerization during cleavage, if any, stops well short of equilibrium so that the reaction does not involve an extreme form of carbonium ion reaction, but this would hardly be expected. Successful determination of the degree of isomerization of the 3-pentyl group and of the exact stereochemistry in cleavage of the optically active *sec*-butyl group would be of value.

Olefin formation probably does not accompany the cleavage of primary groups since, if it had, the olefin would have reacted with hydrogen bromide

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mide appears to contain hydrogen bonded chains; D. F. Hornig and W. E. Osberg, *J. Chem. Phys.*, **23**, 662 (1955).

(10) G. M. Bennett and F. M. Reynolds, *J. Chem. Soc.*, 131 (1935).

(11) "Structure and Mechanism in Organic Chemistry," C. K. Ingold, Cornell University Press, Ithaca, N. Y., 1953, p. 316.

(12) Reference 11, Chapter VII, contains numerical data on a number of examples; see also "Physical Organic Chemistry," L. P. Hammett, McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p. 154.

(13) P. B. D de la Mare, L. Fowden, E. D. Hughes, C. K. Ingold and J. D. H. Mackie, *J. Chem. Soc.*, 3200 (1955).

(14) G. M. Calhoun and R. L. Burwell, Jr., THIS JOURNAL, **77**, 6441 (1955).

to form secondary alkyl halides. In particular, none was detected in cleavage of propyl butyl ether carried to extensive conversions.

The reactivity in ether cleavage of propyl relative to ethyl, 1.00 (Table VI), is large. The value 0.65 (Table VI) is about the average for a group of halide exchange reactions.[13] In general, the value for propyl is distinctly less than 1.0.[12] Our value depends primarily upon the cleavage of ethyl butyl ether, the analyses for which were performed both by density and by vapor phase chromatography (Table II). The reactivity of propyl in a reaction which also involves a positively charged species, that of alcohols with hydrogen bromide in aqueous phenol,[9] is also large, 0.87. In fact, and not surprisingly, this reaction parallels the ether cleavage rather closely. It has been proposed that the relative reactivity of propyl in general should be about $^2/_3$ on the basis that rotation about the central carbon–carbon bond in propyl compounds would lead the terminal methyl group to obstruct the entering groups in $^1/_3$ of the possible configurations.[15] The effect would appear in the pre-exponential frequency factor.[15,16]

Relative Rates of Reaction of Ethers and Alcohols with Hydrogen Bromide.—Table I presents the first direct data on the relative rates of cleavage of the alkyl–oxygen bond in ethers and in alcohols. Ethers appear to be less basic than alcohols.[17] At concentrations of hydrogen bromide high enough to protonate both ether and alcohol completely, the relative reactivity would be that of the hydronium ions. With decreasing acidity, the ratios of hydronium ions would involve the relative basicities, and the alcohol would become relatively more reactive. The observed data fit this scheme. At a total mole fraction of hydrogen bromide of 0.63, butyl ether reacts 7.5 times as fast as propyl alcohol; at a mole fraction of 0.33, 1.4 times faster. At the higher mole fraction, butyl ether reacts about 12 times faster than isopropyl alcohol. To within the rather low precision of the data, the computed relative reactivities of propyl and isopropyl alcohols are the same as those of propyl and isopropyl groups in propyl isopropyl ether, 0.8 (Table VI). The ether–HBr medium is somewhat more favorable to nucleophilic displacement than hydrogen bromide in aqueous phenol in which isopropyl alcohol reacts 2.6 times faster than propyl alcohol (second series in Table VI).

Acknowledgment.—This research was supported by a grant from the National Science Foundation.

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[15] N. Ivanoff and M. Magat, *J. chim. phys.*, **47**, 914 (1950).

[16] See also ref. 13, section (C) and (D).

[17] J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, p. 80; J. Hine and M. Hine, THIS JOURNAL, **74**, 5266 (1952); E. F. Pratt and K. Matsuda, *ibid.*, **75**, 3739 (1953).

EVANSTON, ILLINOIS

COMMUNICATIONS TO THE EDITOR

THE POLYMERIZATION OF α-BENZYL-L-GLUTAMATE N-CARBOXY ANHYDRIDE

Sir:

In a recent communication[1] Doty and Lundberg have claimed that during the primary-amine-initiated polymerization of γ-benzyl-L-glutamate N-carboxy anhydride in dioxane solution at 25° two successive stages may be recognized. Using *n*-hexylamine as initiator these authors concluded that the initial part of the polymerization (up to a degree of polymerization of approximately 8) is comparatively slow, with a rate constant of $5\text{–}7 \times 10^{-3}$ mole^{-1} l. sec.$^{-1}$. Following this stage in the growth of the polymer an acceleration was reported, the final rate constant being approximately 3×10^{-2} mole^{-1} l. sec.$^{-1}$. The acceleration was correlated with the adoption by the growing polymer chain of an α-helical configuration at a degree of polymerization of about 8. A similar effect, rather smaller in magnitude, was obtained with the DL-anhydride.

We have previously reported[2] that under certain conditions the polymerization of DL-leucine and DL-phenylalanine N-carboxy anhydrides show auto-acceleration. This is in no way connected with the size of the growing polymer, but results from the presence of impurities in the anhydrides. It can be eliminated in these cases by the use of dry-box techniques and purification of the anhydrides by sublimation. In view of these results it appeared desirable to repeat the experiments of Doty and Lundberg, particularly since γ-benzyl-L-glutamate N-carboxy anhydride cannot be purified by sublimation.

We have studied chloride and acid-free samples of the anhydride prepared by phosgenation of the amino acid (the technique apparently used[3] for the anhydrides of Doty and Lundberg) and also from the carbobenzoxy derivative of the amino acid by treatment with phosphorus pentachloride.[4] The materials were crystallized from chloroform in both cases and stored *in vacuo* until required. Dry-box techniques were used throughout, and the rates of reaction were measured in constant-volume and

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[1] P. Doty and R. D. Lundberg, THIS JOURNAL, **78**, 4810 (1956).

[2] D. G. H. Ballard and C. H. Bamford, *Proc. Roy. Soc.* (*London*), **A223**, 495 (1954).

[3] E. R. Blunt and R. H. Karlson, THIS JOURNAL, **78**, 941 (1956).

[4] W. E. Hanby, S. G. Waley and J. Watson, *J. Chem. Soc.*, 3009 (1950).