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SELECTIVITY OF TETRAHYDROFURAN FORMATION FROM UNACTIVATED ALIPHATIC ALCOHOLS BY THE BROMINE-SILVER-SALT REACTION

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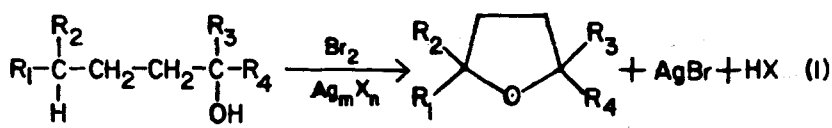
A B S T R A C T

Studies of the bromine-silver carbonate reaction with aliphatic alcohols in which intramolecular δ-H competition is possible are generally quite specific. Loss of a tertiary δ- hydrogen occurs preferentially from both tertiary and secondary aliphatic alcohols to yield the most highly substituted cyclic ether. For example, 2,5-dimethyl-2-octanol yields only 2,2,5-trimethyl-5-propyltetrahydrofuran as the cyclic ether product; 2-methyl-2-isopentyltetrahydrofuran is not detected.

Treatment of aliphatic alcohols with bromine and silver salt affords tetrahydrofurans as a major product (2-5) with the yield depending on the reaction conditions (6-10). The reaction involves a 1,5-hydrogen abstraction from the unactivated δ-position (equation 1).

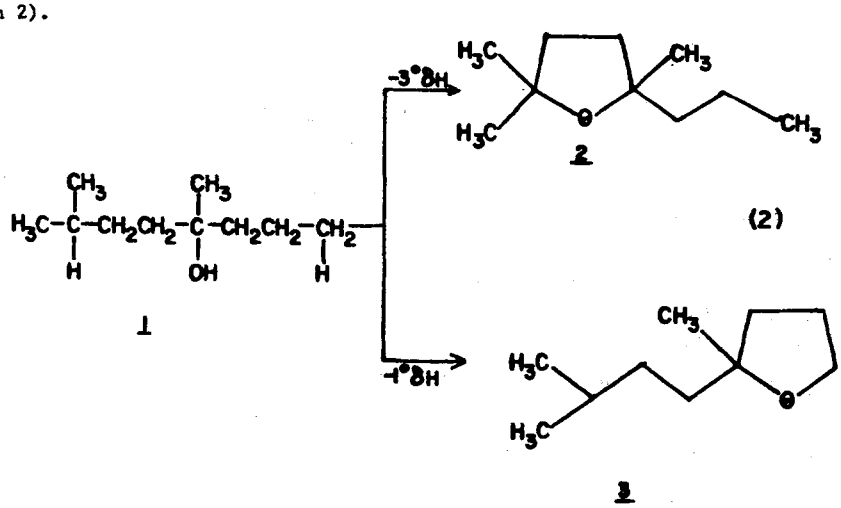


R = H and/or alkyl chains

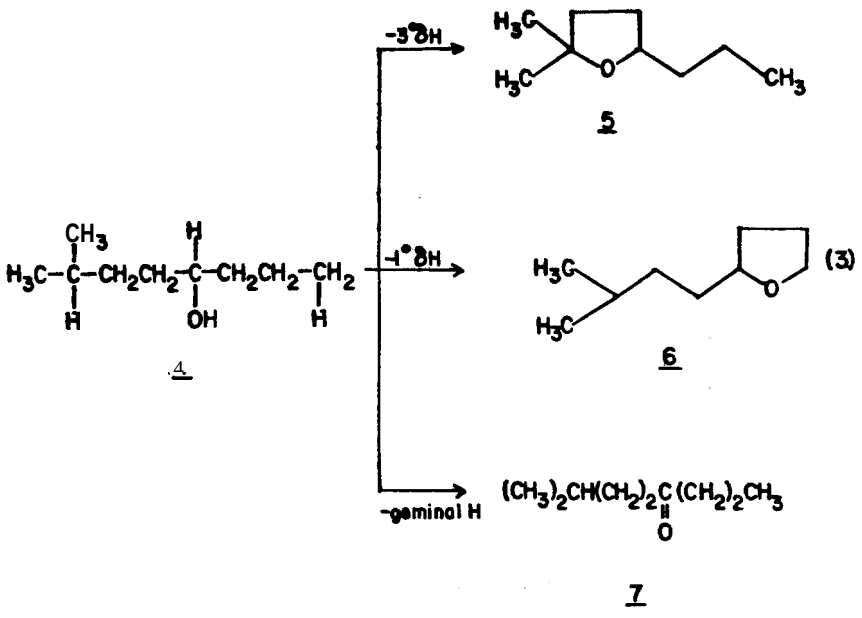
X = CO_3, SO_4, O (m = 2, n ≠ 1)

OAc, NO_3 (m = n = 1)

Until now, an investigation relating reactivity and molecular geometry of the substrate has not been reported. Data describing the reactivities of the various abstractable hydrogens has been obtained in a system which allows for competitive intramolecular δ-H within the appropriate starting alcohols. Thus, the tertiary alcohol, 2,5-dimethyl-5-octanol, 1, can lose either a tertiary or primary δ-H to yield the corresponding tetrahydrofurans 2 and 3 (equation 2).



In a similar manner, secondary alcohols can cyclize to form tetrahydrofurans, according to the ease of abstraction of their respective δ-hydrogens. With these alcohols, a second major oxidation product is generated, the ketone. For example, 2-methyl-5-octanol, 4, can lose either its tertiary or primary &hydrogen leading to cyclic ethers 5 and 6 or its geminal hydrogen (leading to carbonyl formation, 2-methyl-5-octanone 7). See equation 3.



Methods for the selective preparation of these ketones or tetrahydrofurans have previously been described (6-9).

We have conducted these studies both to demonstrate the synthetic utility of the bromine-silver salt reaction as a route to α,α'-substituted tetrahydrofurans and, further, to report the specificities of 6-H abstraction. In addition, the mass spectra of the ethers obtained in each case illustrate that a-cleavage is the major fragmentation process.

Results and Discussion

δ-H Reactivity Orders

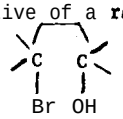
The results shown in Tables I and II demonstrate the specificity of &hydrogen abstraction within aliphatic alcohols when they are treated with bromine and silver carbonate, effecting cyclization to a,a'-substituted tetrahydrofurans. Loss of the unactivated hydrogen occurs preferentially from the most highly substituted 6-C in alcohol systems where 6-H competition is available.

With tertiary alcohols, the formation of α,α'-substituted ethers 2, 9, and 12 occurred to the exclusion of the least substituted isomers 3, 10, and 13, respectively. Likewise, the di- and trialkyl α,α'-substituted tetrahydrofurans 5, 15, and 18 were produced predominantly (65-95%) over the respective ethers 6, 16, and 19, from the corresponding secondary alcohol systems. Thus, the general order of reactivity for cyclization is $3^0 > 2^0 > 1^0$ in the loss of δ-hydrogens from tertiary and secondary aliphatic alcohols.

Structural and Mechanistic Considerations

The fact that α,α'-tetrasubstituted 2 and 12 are formed at all is interesting. Although optically inactive 2,2,5-trimethyl-5-ethyltetrahydrofuran has been reported from the bromine-silver oxide reaction with (+)- (S)-2,5-dimethyl-2-heptanol (5), Walling and Padwa obtained only the 1- and 2-nonenes from the light induced-base catalyzed decomposition of the hypochlorite of 11 (10). Ethers 2, 9, 12, 5, 15, 18, and 19 would be expected to exhibit 1,3-diaxial type interactions with the cis isomer. However with 4-octanol, 14, the ratio of the cis to the trans form was 55:45, as compared to the lead tetraacetate oxidation, which was 45:55 (11).

While δ-bromohydrin species indicative of a radical type process, have



been isolated in both light and dark bromine-silver salt reactions (11, 16), catalytic effects of polar solvents (8), and the gegen-ion of rhe silver salt (6,7) oupport an Ionic type mechanism. However, the formation of the hypobromite is well established, as well as its silver Ion-catalyzed decomposition to tetrahydrofurans (1, 16. 17, 18). The observed H-abstraction results are comparable to those obtained by Walling and Padwa for the intramolecular light-induced chlorination of long chain hypochlorites (10) equivalent to the formation of δ-bromohydrins. Irradiation of tertiary hypochlorites, causing rearrangement to the corresponding δ-chloroalcohols, yielded the same $3^0 > 2^0 > 1^0$ order for 6-H reactivity *in a* 47:9:1 ratio, paralleling intramolecular reactions of alkoxy radicals.

These results, in agreement with the common stabflity order for cerbonium and radical species, support a mechanism, beginning with the formation of hypobromite and culminating with a nucleophilic attack of oxygen on the *6-C.*

Table II Tetrahydrofuran Products from Secondary Alcohols

Starting Alcohol	6-H Competition	α,α'-Substituted Tetrahydrofuran Products	Relative Yields(a)	δ (ppm)(b)	m/e
$(CH_3)_2CH(CH_2)_2\underset{\displaystyle OH}{\underset{|}{C}}H(CH_2)_2CH_3$	3"	5 α = Me, Me a' = Pr, H	80%	3.95 (m, 1H) 1.82 (m, 4H) 1.36 (m, 4H) 1.22 (s, 6H) 0.94 (t, 3H)	99 (M-Pr) 43 (Pr)(c)
4	1°	6 a = isopentyl. H α' = H, H	20%	4.00 (m, 1H) 3.56 (m, 2H) 1.50 (m, 4H) 1.40 (m, 5H) 0.89 (d, 6H)	85 (M-Bu) 71 (M-iPent) 43 (i-Pr)(c)
$CH_3CH_2(CH_2)_2\underset{\displaystyle OH}{\underset{|}{C}}H(CH_2)_2CH_3$	2°	15 a = Me, H a'= Pr, H	90-95X	3.67 (m, 2H) 1.86 (m, 4H) 1.41 (m, 4H) 1.18 (d, 3H) 0.94 (m, 3H)	113 (M-Me) 85 (M-iPent)(c) 43 (Pr)
14	1'	16 a = Bu, H a' = H, H	5-10%		71 (m-Bu)(c) 57 (Bu)
$(CH_3)_2CH(CH_2)_2\underset{\displaystyle OH}{\underset{|}{C}}H(CH_2)_2CH_2CH_3$	3'	18 α = Me, Me a' = Bu, H	65%	3.92 (m, 1H) 1.39 (m, 6H) 1.21 (s, 6H) 0.93 (t, 3H)	141 (M-Me) 99 (M-Bu)(c)
17	2'	19 a = isopentyl. H α' = Me, H	35%	3.94 (m, 2H) 2.00 (m, 4H) 1.42 (m, 5H) 1.18 (d, 3H) 0.90 (d, 6H)	65 (M-iPr)(c)

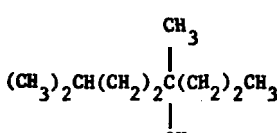
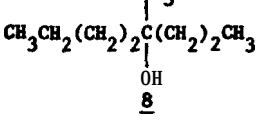
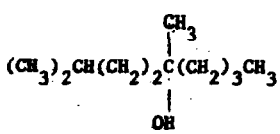
(a) Gas chromatographic yield - thermal conductivity- or flame ionization detection.
(b) Downfield from TMS internal standard; samples in $CDCl_3$ or CCl_4.
(c) m/c of 100% relative abundance.

The observation that S-membered rings are formed almost exclusively in oxygen insertion reactions is a general phenomenon. Mihailovic and coworkers identified only small quantities (3-4X) of tetrahydropyran compounds in addition to the tetrahydrofuran products (61-73%) upon oxidation of primary and secondary alcohols by the bromine-silver salt method (4). Similarly, with long chain hypochlorites, intramolecular chlorination involving 1,6-H shifts occurs about 1/15 as readily as the 1.5 process, while reactivity increases to 1/9 when activated benzylic hydrogene are available (10).

A similar propensity for 1.5 ring closure (vs. 1,6 or 1,4) is found with lead tetraacetste-catalyzed reactions (12). Activation of the adjacent C-H bond by a phenyl group is insufficient to favor formation of the 6-membered ether (13). Likewise, even the absence of an abstractable 6-E in 4,4-dimethyl-n-pentanol did not prevent the formation of 1% of the rearranged product, 2-methyl-2-ethyltetrahydrofuran, in addition to 4-6X of the tetrahydropyran (2,2-dimethyltetrahydropyran) (14). In this case, there is evidence for the intermediacy of a carbonium ion.

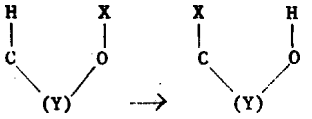
Treatment of 14 with lead tetraacetate in benzene afforded 15 in 39% yield along with only 2% of 16 a ratio of 20:1, after refluxing for 14 hours (12). We have reported the same ethereal preference in an average ratio of 14:1 after a 40 minute reaction period. Mechanistically for the lead tetraacetate system, a free radical process to form a δ-lead tetraacetate alcohol intermediate, followed by nucleophilic attack of oxygen on the Incipient δ-carbonium ion. is considered reasonable (12). Nearly identical kinetic and stereochemical similarities (11, 15) suggest that the bromine-silver salt reaction involves an analogous process.

Table I Tctrahydrofuran Products from Tertiary Alcohols

Starting Alcohol	δ-H Competition	α,α'-Substituted Tetrahydrofuran Products	Relative Yields(a)	δ (ppm) (b)	m/e
 1	3°	2 α = Me, Me a' = Me, Pr	100%	1.41 (m,4H) 1.25 (s,3H) 1.21 (s,3H) 1.18 (s,3H) 0.92 (t,3H)	141 (M-Me) 113 (M-Pr)(c)
	1°	3 α = Me, Isopentyl a' = H, H	(ND)		
 8	2°	9 α = Me, Pr a' = Me, H	100%	4.07 (sextet,1H) 1.46 (m,4H) 1.20 (d,3H) 1.15 (s,3H) 0.91 (m,3H)	127 (M-Me) 99 (M-Pr)(c)
	1°	10 α = Me, Bu a' = H, H	(ND)		
 11	3°	12 α = Me, Me a' = Me, Bu	100%	1.34 (m,6H) 1.24 (s,3H) 1.20 (s,3H) 1.17 (s,3H) 0.91 (m,3H)	155 (M-Me) 113 (M-Pr)(c)
	2°	13 α = We. ibopentyl a' = Me, H	(ND)		

(a) Gas chromatographic yields, flame ionization detection; ND signifies not detected.
(b) Downfield from TMS internal standard; samples in $CDCl_3$ or CCl_4.
(c) m/e of 100% relative abundance.

Thus, by demonstrating the tendency for alcohols to cyclize to the most highly substituted tetrahydrofurans, the bromine-silver salt reaction may help to characterize the versatile Barton reaction (Equation 4). in which an exchange of various groups. X, for hydrogen is photochemically induced.



(4)

For the former intramolecular process, the electronic nature of the oxygen and hydrogen species, as well as the extent to which oxygen acts as a nucleophile (S_N2 displacement of Br or "pseudo" nuclaophilic attack on a carbonium ion) remain as topics for future investigation.

Identification of Tetrahydrofuran Isomers

Qualitative and quantitative assignments are based on NMR and mass spectral analysis of the ethereal compounds isolated by gas chromatography. For confirmatory identification, in each case one of the two possible isomeric tetrahydrofurans vas synthesized via a separate route and analyzed. While several of the ethers have been reported previously, generally NMR and mass spectral data were not reported.

The tetrasubstituted product of a tertiary g-hydrogen abstraction from 2,5-dimethyl-5-octanol. 1, i.e.. 2,2,5-trimethyl-5-propyltetrahydrofuran, 2, was identified by the appearance of a-methyl singlets at 1.25, 1.21, and 1.18 ppm and the terminal methyl peak at 0.92 ppm in the mixture of ethereal products isolated. The detection of only a trace of a-hydrogen absorbance (3.68 ppm) and absence of a doublet near 0.90 ppm (terminal methyl groups of an isopentyl side chain) suggested that a negligible amount of the 2-methyl-2-isopentyl isomer, 3, was formed. Mass spectral fragments of m/e 141 (M - 15) and m/e 113 (M - 43, 100X). representing the loss of methyl and propyl side chains, respectively,. and the absence of a m/e 85 (M - 71, loss of isopentyl) fragment confirmed the predominance of 2 (95%). The NMR and mass spectra of 2 and the ethereal isomer synthesized separately (from the bromine-silver salt reaction with 2,5-dimethyl-2-octanol, 20) were identical.

Treatment of 4-methyl-4-octanol, 8, with bromine and silver carbonate yielded predominantly 2,5-dimethyl-2-propyltetrahydrofuran, 9, in the collected ethereal mixture, identified by u-hydrogen (4.07, sextet, 1H) and a-methyl (1.20,d and 1.15 ppm, s - both 3H) peaks, while the absence of absorbance at 3.50 - 3.70 ppm (unsubstituted tetrahydrofuran αH region) indicated that no 2-methyl-2-butyl isomer, 10, vas formed. Fragments representing the loss of methyl (m/e 127) and propyl (m/e 99, 100%) groups vere produced upon ionization of the ethereal product, while a m/e 85 (M - butyl) ion was not detected. A preparation of 9 from the dark reaction of 5-methyl-2-octanol, 21, with bromine and silver carbonate displayed identical absorbance (4.09 ppm, sextet, 1H) and ionization (m/e 127, 99, etc.) spectra to confirm the identification of the trisubstituted tetrahydrofuran, 9.

The tetrasubstituted ether 2,2,5-trimethyl-5-butyltetrahydrofuran 12 vas identified as the isomer produced from the bromine-silver carbonate catalyzed cyclization of 2,5-dimethyl-5-nonanol, 11, on the basis of three NMR singlets (1.24. 1.20, and 1.17 ppm, 3H each - a-methyl groups) and the absence of any α-H (3.5 - 4.0 ppm) absorbance, while ionization of the ethereal product yielded m/e 155 (M - CH_3) and 113 (M - butyl, 100%) fragments. but no m/e 85 peak (M - isopentyl, expected from 13). The other possible isomer, 2,5-dimethyl-2-isopentyl tetrahydrofuran, 13, vas not observed (19).

Two separate ethereal products were collected by GC and analyzed from the dark reaction of 2-methyl-5-octanol, 4. The first ether, comprising > 80% of the original isomeric mixture, vas identified as the trisubstituted tetrahydrofuran, 5, due to proton resonance at 3.95 (m, 1 a-H). 1.22 (s, 6 a-methyl hydrogens), and 0.94 ppm (m, 3 terminal methyl hydrogens), which corresponded to the NMR spectrum of 5 produced upon cyclization of

P-methyl-2-octanol, 22, with bromine and silver carbonate. The formation of strong M - propyl (m/e 99) and M - methyl (m/e 127) fragments upon Ionization confirmed the identification of 5. The second chromatographic peak (> 20% relative yield) which contained one tertiary a-hydrogen (4.00 ppm), two unaubstituted α-hydrogens (3.56 ppm), and six terminal methyl hydrogens on an iaopentyl aide chain (d, 0.89 ppm), was characterized as the 2-iaopentyl isomer, 6. This isomer yielded a major m/e 71 fragment corresponding to iaopentyl and M - iaopentyl molecular ions.

The mixture of ethereal products obtained from the bromine-silver carbonate catalyzed cyclisation of 4-octanol, 14, contained a sharp doublet centered at 1.18 ppm (3H) as evidence for the 2-methyl-5-propyltetrahydrofuran Isomer. 15. The relative ratio of α-hydrogens (2H, 3.87 ppm) and methylene protons (4H, 1.41 ppm) as well as Ionization fragments of 85 (M - Pr, 100%) and 43 (Pr) confirmed the predominance of 15 over 16 (m/e 71, M - Bu) by more than 9:1 according to GC peak area ratios. The bromine-silver carbonate reaction of 2-octanol, 23, confirmed the structural assignment of 15.

The ethereal products analyzed upon treatment of 2-methyl-5-nonanol, 17, with bromine and the silver salt consisted of two isomers. The first, displaying NMR absorbance at 63.92 (m, 1H), 1.21 (a, 6H) and 0.93 ppm (t, 3H) was formed in 65% relative yield and identified as 2,2-dimethyl-5-butyltetrahydrofuran, 18. The assignment of 18 was confirmed by comparison with the same ether produced from the dark reaction with 2-methyl-2-nonanol, 24, both of which formed mass spectral fragments of m/e 99 (M - Bu, 100%) and 141 (M - Me). The 2-isopentyl-5-methyl isomer 19, containing two α-hydrogens (3.94, m) as well as three a-methyl (1.18, d) and six terminal chain methyl (0.90 ppm, d) hydrogens and forming a stable m/e 85 (M - iPent, 100%) fragment, comprised 35% of the tetrahydrofuran mixture.

EXPERIMENTAL SECTION

General. Boiling points are uncorrected. All preparative GC was carried out using a Varian Aerograph Model A-90-P instrument equipped with a thermal conductivity detector. Two columns, packed with Carbowax 20M [10% on Chromoaorb W (AW) 60/80 mesh, 10 ft. x 0.25 in.] and OV-17 [11% on Chromoaorb W (BP) 60/80 mesh, 10 ft. x 0.25 in.] were employed. Analytical GC data were obtained using an Aerograph Model 600 equipped with a flame ionization detector, on a column of Carbowax 20M [15X on Chromoaorb W (AW) 60/80 mesh, 10 ft. x 0.125 in.]. HPLC was carried out using dual columns packed with Porasil B (2 ft. x 0.375" each, 37/75 mesh) with a Waters Associates M600A pump and U6K injector, an LCD 1107L differential refractometer, and a Bausch and Lomb Model 33-01-06 recorder.

IR spectra were recorded as neat films on a Perkin-Elmer Model 747 Spectrometer using sodium chloride plates. NMR spectra were obtained on a Varian Associates A-60 instrument and on a Varian M-100 FT System. The NMR samples were run in carbon tetrachloride or deuterated chloroform containing 1% TMS as an internal standard, and chemical shifts are reported in parts per million downfield from this standard (TMS = 0 ppm). Mass spectra were obtained on a Hewlett-Packard 5930A Gas-liquid Chromatograph-Mass Spectrometer unit coupled with a 2100T computer, and employing an OV-17 column [11% on Chromosorb W (HP) 60/80 mesh, 6 ft. x 0.125 in.] for chromatography. Only fragments present above 5% relative abundance are reported. Refractive indices were read on an Abbe refractometer with a sodium D light source. Micro boiling points were obtained by a standard capillary'technique.

Solvent. Commercial pentane was first shaken with concentrated sulfuric acid (60 parts pentane/1 part acid, v/v), then separated, followed by distillation and collection at 35-37°C, before use as a solvent.

Chromatography Methods

1. Gas-liquid, Carbowax 20M and OV-17 columns: as described, Temperature: 60-140°C. Sample size: 2 to 50 μl. Flow rate (He or air/N_2): 20 - 40 psi.
2. Column. Alumina (neutral), 80/200 mesh; packed in hexane. Elution with hexane (200 to 500 ml), then diethyl ether (250 ml). Sample size: 1 to 3 ml. Also employed for purification of atartfng alcohols.
3. Liquid. Dual Porasil B columns, as described. Solvent: hexane (400 to 800 ml). Sample site: 5 to 100 μl. Pump speed: 2.8 ml/min. Pressure: 3000 psi. Temperature: 25°C.
4. GC-MS. OV-17 column, as described. Sample size: 2 μl of hexane solution (1 mg/ml). Column temperature: 70°C.

Preparation of 2-methyl-5-octanol, 4. The 2-methyl-5-octanol was prepared by a standard Grignard reaction of one mole of 1-bromo-3-methylbutane with n-butyraldehyde.

IR (neat): 3360 (a), 3000 (a). 2960 (a), 1470 (m), 1380 cm^{-1} (m)

^1H NMR (CC14, 60 MHz): 63.48 (m, 1H), 3.45 (a. 1H), 1.39 (m, 9H), 0.91 ppm (m, 9H)

Preparation of 2-methyl-5-nonanol, 17. The 2-methyl-5-nonanol was prepared by a Grignard reaction of 1-bromo-3-methylbutane with n-valeraldehyde.

IR (neat): 3380 (s), 2975 (s), 2890 (s), 1470 (m), 1380 (m), 1030 cm-1 (m)

^{1}H NMR (CCl_4, 60 MHz): 3.79 (s, 1H), 3.47 (m, 1H), 1.36 (m, 118). 0.91 ppm (m, 9H)

Preparation of 2,5,dimethyl-5-nonanol, 11. The 2,5-dimethyl-5-nonanol was prepared by the Grignard reaction of methyl Iodide with 2-methyl-5-nonanone.

IR (neat): 3400 (s), 2975 (s), 2900 (s), 1470 (m), 1380 (m). 1150 (m), 910 cm-1 (m)

^{1}H NMR (CC14, 60 MHz): 3.04 (s, 1H), 1.37 (m, 9H), 1.18 (s, 6H), 0.92 ppm (m, 6H)

Preparation of 5-methyl-2-octanol, 21. The 5-methyl-2-octanol was prepared by a classic lithium aluminum hydride reduction of 5-methyl-2-octanone.

IR (neat): 3400 (s), 2975 (s), 2900 (s), 1465 (m), 1380 (m), 1120 (w), 945 cm^{-1} (w)

^{1}H NMR (CCl_4, 60 MHz): 3.72 (s-broad, 1H), 3.58 (m, 1H), 1.33 (m, 9H), 1.12 (d, 3H), 0.90 ppm (m, 6H)

All other starting alcohols used [2,5-dimethyl-5-octanol, (sold commercially as 4,7-dimethyl-4-octanol), 4-methyl-4-octanol, 2-methyl-2-octanol, 2-methyl-2-nonanol, 4-octanol and 2-octanol], as well as the 5-methyl-2-octanone and the 2-methyl-5-nonanone, were commercial preparations. Gas chromatographic retention times, IR spectra and ^{1}H NMR spectra were obtained for each alcohol prior to its use in the bromine-silver salt reaction.

Standard Dark Reaction of Alcohols with Bromine and Silver Carbonate. Bromine (0.51 ml, 0.01 mol) was added dropwise to the stirred suspension of starting alcohol (0.01 mol). silver carbonate (2.76 g, 0.01 mol), and pentane (100 ml) in a 250 ml Erlenmeyer flask-covered with aluminum foil, to eliminate stray light. Following the bromine addition, the mixture was allowed to react for forty minutes, at which time anhyd. sodium carbonate (0.5 g) was added, with continued stirring. After 10 min., sodium thiosulfate (0.25 g) was added to the flask, and the reaction mixture was stirred for an additional 5 min. The solution was then filtered, and the pentane removed from the filtrate on a rotary vacuum evaporator. The residue (1 to 3 ml) was immediately analyzed by either gas-liquid, column, or high pressure. liquid chromatography.

Analysis of Products from the Alcohol-Bromine-Silver Salt Reaction. Reaction products were mediately analyzed by either gas-liquid, column, or high pressure liquid chromatography systems, as described. With all systems, separation of three or four major products was accomplished. The order of elution was, consistently, as follows: alkenes, cyclic ethers, ketones (from secondary alcohols only), and recovered starting alcohols. Products were identified by infrared, mass, and nuclear magnetic resonance spectrometry and comparison with known samples. Isomeric mixtures of both olefinic and cyclic ether products were collected.

Cyclic Ether Products. The second major chromatographic peak(s) were collected. All samples exhibited infrared absorption in the 1050 - 1140 (m - s) and 2850 - 3000 cm^{-1}(vs) regions. Additional peaks were present at 1470 (m), 1380 (m), and 1310 -20 cm^{-1} (m - w). Recorded physical and spectral properties are listed for the tetrahydrofuran Products obtained from each alcohol system. Relative intensities of the mass spectral fragments are included with the peak messes.

Cyclizatlon of 2,5-dimethyl-5-octanol, 1. One ethereal product was detected and identified as 2,2,5-trimethyl-5-propyltetrahydrofuran, 2: bp 145 - 6^{0}C; n_D^{20} 1.4220;

^{1}H NMR (CC14, 100 MHz) δ 1.82 (m, 4H), 141 (m, 4H), 1.25 (s, 3H), 1.21 (s, 3H), 1.18 (s, 3H), and 0.92 ppm (m, 3H); MS (70 ev) m/e 141 (12), 123 (8), 113 (100), 98 (11). 95 (28), 87 (16), 83 (10). 81 (6), 71 (40), 70 (67), 69 (40), 67 (8), 59 (18), 57 (30), 56 (36), 55 (60), 53 (10). and 45 (19).

Cyclizatlon of 2,5-dimethyl-2-octanol, 20. One ethereal product was detected and identified as 2,2,5-trimethyl-5-propyltetrahydrofuran, 2. Spectral and physical properties were Identical to the tetrahydrofuran product obtained from the reaction of 1.

Cyclizatlon of 4-methyl-4-octanol, 8. One ethereal product was detected and identified as 2,5-dimethyl-2-propyltetrahydrofuran, 9.

^{1}H NMR (CCl_4, 60 MHz) δ 4.07 (sextet, 1H), 1.82 (m, 4H), 1.46 (m, 4H), 1.20 (d. 3H), 1.15 (s, 3H), and 0.91 (m, 3H): MS (70 ev) m/e 127 (6), 100 (7), 99 (100), 87 (17), 86 (7), 71 (34), 70 (11). 69 (17). 67 (6), 58 (7), 57 (34). 56 (47), 55 (29). 53 (7), 51 (7), and 45 (22).

Cyclization of 5-methyl-2-octanol, 21. One ethereal product was detected and identified as 2,5-dimethyl-2-propyltetrahydrofuran, 9. Spectral and physical properties were Identical to the tetrahydrofuran product obtained from the reaction of 8.

Cyclization of 2,5-dimethyl-5-nonanol, 11. One ethereal product was detected and Identified as 2,2,5-trimethyl-5-butyltetrahydrofuran 12:

^{1}H NMR (CCl_4, 100 MHz) δ 1.81 (m, 4H), 1.34 (m, 6H), 1.24 (s, 3H), 1.20 (s, 3H), 1.17 (s, 3H), and 0.91 (m, 3H); MS (70 ev) m/e 155 (9), 120 (6), 114 (9), 113 (100). 104 (17). 101 (11). 97 (6). 95 (29). 85 (15). 83 (10), 81 (7). 79 (5), 71 (13), 70 (55). 69 (10), 67 (8). 59 (14), 58 (8), 57 (23). 56 (10), 55 (46), 53 (8), 51 (5), and 45 (8).

Cyclization of 2-methyl-5-octanol, 4. Two ethereal products were detected and identified 2,2-dimethyl-5-propyltetrahydrofuran, 5: 80% by GC;

^{1}H NMR (CCl_4, 60 MHz) δ 3.95 (m, 1H), 1.82 (m, 4H), 1.36 (m, 4H), 1.22 (s, 6H), and 0.94 ppm (t, 3H); MS (70 ev) m/e 142 (1), 141 (3), 140 (6), 128 (8), 127 (95), 125 (5), 109 (43), 100 (15), 99 (100), 97 (14), 84 (19), 83 (17), 82 (21), 81 (100), 79 (11), 71 (54), 70 (loo), 69 (61). 67 (17), 60 (5). 59 (100). 57 (20), 56 (48). 55 (100), 53 (18), 44 (10), 43 (100), 42 (36), 41 (93), and 39 (43).

2-isopentyltetrahydrofuran, 6: 20% by GC;

^{1}H NMR (CCl_4, 60 MHz) δ 4.00 (m, 1H), 3.56 (t, 2H), 1.93 (m, 4H), 1.40 (m, 5H), and 0.89 ppm (d, 6H); MS (70 ev) m/e 127 (3), 99 (4), 85 (1), 83 (8), 81 (5), 72 (11), 71 (100). 70 (17), 69 (7), 57 (5), 56 (5), 55 (59), 53 (7), 44 (5), 43 (100), 42 (21), 41 (61), 40 (6), and 39 (35).

Cyclization of 2-methyl-2-octanol, 22. One ethereal product was detected and identified as 2,2-dimethyl-5-propyltetrahydrofuran, 5: Spectral and physical properties were identical to the major tetrahydrofuran, 5, obtained from the reaction of 4.

Cyclisation of 4-octanol, 14. Two ethereal products were detected and identified, (12). 2-methyl-5-propyltetrahydrofuran, 15: 90–95% by GC;

^{1}H NMR (CC14, 60 MHz) δ 3.87 (m, 2H), 1.86 (m. 2H), 1.41 (m, 4H), 1.18 (d-cis/trans, 3H), and 0.94 ppm (t, 3H); MS (70 ev) m/e 128(2),113(2),95(5),86(6),85(100),84(7), 69(8), 67 (20), 57 (20), 56 (25), 55 (21), 45 (8), 43 (48), 42 (9), 41 (51), 39 (21), 29 (37). and 27 (28).

2-butyltetrahydrofuran. 16: 5-10% by GC;

MS (70 ev) m/e 128 (2), 85 (2), 72 (5), 71 (100), 70 (7), 57 (7), 55 (7), 43 (47), 42 (10), 41 (30). 39 (14), 29 (21). and 27 (19).

Cyclization of 2-octanol, 23. One ethereal product was detected and identified as 2-methyl-5-propyltetrahydrofuran, 15 (12). Spectral and physical properties were identical to the major tetrahydrofuran obtained from the reaction of 14.

Cyclization of 2-methyl-5-nonanol, 17. Two ethereal products were detected and identified. 2,2-dimethyl-5-butyltetrahydrofuran, 18: 65% by GC;

^{1}H NMR (CCl_4, 60 MHz) δ 3.92 (m, 1H), 1.77 (m, 4H), 1.39 (m, 6H), 1.21 (s, 6H), and 0.93 ppm (t, 3H); MS (70 ev) m/e 156 (15), 155 (14), 141 (16). 126 (6). 123 (7), 115 (lo), 112 (lo), 101 (12). 100 (8). 99 (100), 97 (12), 85 (7), 83 (11). 82 (6), 81 (66), 71 (13). 70 (31), 69 (16). 67 (5), 59 (21). 57 (14), 56 (17), 55 (36), and 53 (6).

2-methyl-5-isopentyltetrahydrofuran. 19: 35% by GC;

^{1}H NMR (CCl_4, 60 MHz) δ 3.94 (m, 2H), 2.00 (m, 4H), 1.42 (m, 5H), 1.18 (d, 3H), and 0.90 ppm (d, 6H); MS (70 ev) m/e 156 (5), 155 (10), 86 (9), 85 (100), 84 (5), 83 (5), 81 (7), 69 (6), 67 (12). 57 (15), 56 (12), 55 (12), and 53 (3).

Cyclization of 2-methyl-2-nonanol, 24. One ethereal product was detected and identified as 2,2-dimethyl-5-butyltetrahydrofuran. 18: Spectral and physical properties were identical to the major tetrahydrofuran, 18, obtained from the reaction of 17.

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