Tetrahedron, 1965, Vol. 21, pp. 2799 to 2812. Pergamon Press Ltd. Printed in Northern Ireland

LEAD TETRAACETATE OXIDATION OF SATURATED ALIPHATIC ALCOHOLS[1].—III[2]

UNBRANCHED PRIMARY AND SECONDARY ALCOHOLS

M. Lj. Mihailović,[3] Ž. Čeković, Z. Maksimović, D. Jeremić, Lj. Lorenc
and R. I. Mamuzić
Department of Chemistry, Faculty of Sciences and Institute of Chemistry, Technology and Metallurgy, Belgrade, Yugoslavia

(*Received* 10 *March* 1965)

Abstract—The action of lead tetraacetate, in benzene solution, on various unbranched primary and secondary aliphatic alcohols containing 4 to 12 carbon atoms has been investigated and the ratio of carbonyl compounds, cyclic ethers and fragmentation products determined. The results obtained are discussed with regard to the number and length of the n-alkyl rests attached to the carbinol carbon atom of the starting alcohol.

INTRODUCTION

It was recently reported[4] that the oxidation of 1-heptanol and 1-octanol with lead tetraacetate in benzene solution (I, Scheme 1) yields as major products (in 36–37% yield) the corresponding 2-alkyl tetrahydrofurans (IV), accompanied by a small amount (about 3%) of the isomeric tetrahydropyran derivatives (V), and that secondary aliphatic alcohols, 2-octanol and 5-nonanol (I), are converted to a mixture of *cis*- and *trans*-2,5-dialkyl tetrahydrofurans (IV), in 20–30% yield. The corresponding aldehydes and ketones (III) are formed in only low yields (2–5%).

We have now investigated the action of lead tetraacetate on various saturated, unbranched primary and secondary aliphatic alcohols (I), with the purpose of determining the effect of structure on the reaction times and on the yields of products formed by oxidation (a), cyclization (b) and fragmentation (c), processes which all may take place when alcohols are treated with lead tetraacetate in non-polar solvents.[2,4,5]

RESULTS AND DISCUSSION

The results of the lead tetraacetate oxidation of unbranched primary and secondary aliphatic alcohols, using a 1:1 molar ratio of reactants in boiling benzene, are given in Tables 1 and 2, respectively. In addition to the carbonyl compound (III) and its derivatives, cyclic ethers (IV and V) and fragmentation products (stabilization products of VI and aldehydes VII), the acetate of the starting alcohol (9–31%), unchanged alcohol (9–20%), formaldehyde (traces), the formate ester of the starting

---

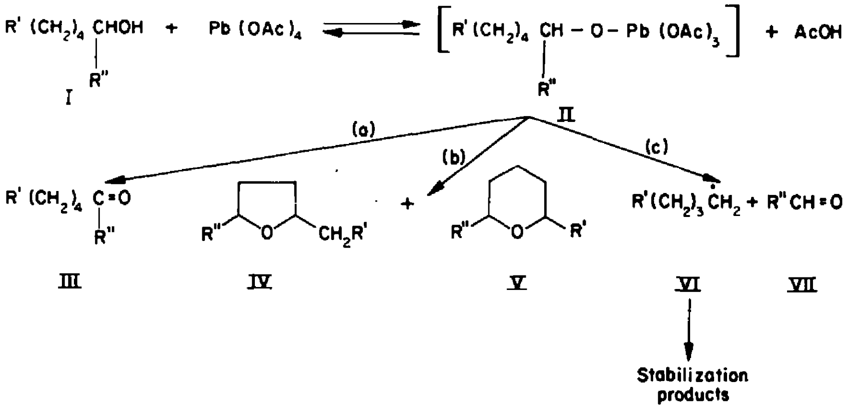
[1] Paper VI in the series *Reactions with lead tetraacetate*. Paper V: M. Lj. Mihailović, A. Stojiljković and V. Andrejević, *Tetrahedron Letters* No. 8, 461 (1965).

[2] For paper IV, part II see M. Lj. Mihailović, Z. Maksimović, D. Jeremić, Ž. Čeković, A. Milovanović and Lj. Lorenc, *Tetrahedron* **21**, 1395 (1965).

[3] To whom enquiries should be made. Full address: Department of Chemistry, Faculty of Sciences, Studentski trg 16, P.O. Box 550, Belgrade, Yugoslavia.

[4] V. M. Mićović, R. I. Mamuzić and M. Lj. Mihailović, *Tetrahedron* **20**, 2279 (1964).

[5] See K. Heusler and J. Kalvoda, *Angew. Chem.* **76**, 518 (1964); *Ibid.* (Intern. English Ed.) **3**, 525 (1964), and Refs therein.



Scheme 1

alcohol (0·5–3%) and, upon oxidation of primary alcohols, the acid derived from the starting alcohol (traces–1%) and the corresponding ester (1–3%) were isolated in almost every case investigated.[6] The formation of these by-products are discussed in our previous paper.[2]

Reaction products were isolated by fractional distillation followed by preparative gas-chromatographic separation, and were identified on the basis of analytical data and by comparison of their physical and chemical properties with those of authentic reference compounds.[7]

TABLE 1. PRODUCT DISTRIBUTION IN THE REACTION OF LEAD TETRAACETATE WITH UNBRANCHED PRIMARY ALIPHATIC ALCOHOLS IN BENZENE SOLUTION

Alcohol[a]	Reaction time[b] (in hr)	Products (yields in %)[c,d]				
		Oxidation	Cyclization			
		Aldehyde + acetal[e]	THF[f]	THP[g]	Acetate[h]	Unreacted alcohol
1-Butanol	12⅛	0 + 5[i]	20	—	15	16
1-Pentanol	2¼	3 + 1	43	0	9·5	10
1-Hexanol	1¼	2	49·5	3	9	9
1-Heptanol	¾	2	49·5	3·5	9	10·5
1-Octanol	1⅛	1·5	48	4	9	10
1-Dodecanol	2¼	2	49	3	*j*	*j*

[a] A 1:1 molar ratio of alcohol to lead tetraacetate was used. [b] In refluxing benzene until disappearance of tetravalent lead. [c] In all runs formaldehyde (traces), the formate ester of the starting alcohol (0·5–2%), acid derived from starting alcohol (traces–1%) and the corresponding ester (1–3%) were isolated. [d] The structures of high-boiling products, such as acetates and hydroxy-acetates, which were usually present in the reaction mixture, were not investigated. [e] Acetal of starting alcohol and corresponding aldehyde. [f] Corresponding tetrahydrofuran. [g] Corresponding tetrahydropyran. [h] Acetate of starting alcohol. [i] In addition, about 4% of α-acetoxybutyraldehyde was also isolated. [j] Not determined.

---

[6] High-boiling products, most of which contained acetate groups, were also present in the reaction mixtures, but have not yet been investigated.

[7] By a slight modification of the oxidation procedure and by simplifying the working up of the reaction mixture (Experimental), the yields of cyclic ethers were improved by about 10% (Tables 1 and 2), in comparison to previously reported results 1·4.

TABLE 2. PRODUCT DISTRIBUTION IN THE REACTION OF LEAD TETRAACETATE WITH UNBRANCHED SECONDARY ALIPHATIC ALCOHOLS IN BENZENE SOLUTION

Alcohol[a]	Reaction time[b] (in hr)	Products (yields in %)[c,d]						
		Oxidation	Cyclization			Fragmentation		
			Tetrahydrofurans					
				2,5-Dialkyl		1-Alkyl acetate + 2-Alkyl acetate		Acetate[g]
		Ketone[e]	2-Alkyl	*cis* + *trans*	Ratio *cis*/*trans*[f]			
2-Pentanol	26	*h*	9·5	—	—	*h*		*h*
2-Hexanol	6	3	—	41	40:60	1-butyl	0·4	12
						2-butyl	0·7	
2-Heptanol	4	3·5	—	44	40:60	1-pentyl	0·4	11
						2-pentyl	0·6	
3-Heptanol	8½	5	—	41	43:57	*h*		12
4-Heptanol	32	7·5[i]	15·5 .	—	—	*h*		31
2-Octanol	2½	3	—	40[j]	40:60	1-hexyl	0·5	9
						2-hexyl	0·9	
3-Octanol	8	3	—	41[j]	41:59	1-pentyl	0·5[k]	12
						2-pentyl	0·8	
4-Octanol	14	5	2	39	45:55	*h*		17
3-Nonanol	7	3·5	—	38	43:57	*h*		*h*
4-Nonanol	13	4·5	2	38	45:55	*h*		16
5-Nonanol	2	4	—	33	43:57	1-butyl	0·5[l]	9
						2-butyl	0·7	
2-Decanol	3	3·5	—	38	39:61	1-octyl	0·7	10
						2-octyl	0·9	

[a,b,d] See the corresponding remarks in Table 1. [c] Formaldehyde (traces), unchanged alcohol (10–20%) and the formate ester of the starting alcohol (1–3%) were isolated in almost every run. [e] Corresponding to the starting alcohol. [f] Tentatively assumed configurations of geometrical isomers, designated in the text by "A" and "B", respectively.[4,10] [g] Of starting alcohol. [h] Not determined. [i] In addition, 7–8% of the corresponding α-acetoxy ketone was present in the reaction mixture.[8] [j] In addition, the isomeric *cis*- and *trans*-2-ethyl-6-methyltetrahydropyrans were isolated in about 1% yield. [k] Propionaldehyde (0·8%) was also isolated. [l] Valeraldehyde (0·4%) was also isolated.

(a) *Oxidation reaction*

The yields of carbonyl compounds (III, Scheme 1) and their derivatives (i.e. acetals, acids, esters of acids and starting alcohols, α-acetoxylated carbonyl compounds[8]) are in general low, and even when the formation of cyclic ethers (IV and V) is very slow (1-butanol, Table 1; 4-heptanol, Table 2) the yields of III and derivatives, although somewhat higher, are not in accordance with the diminished yields of the cyclization products (IV and V). These observations are in agreement with results previously reported,[2,9] i.e. the conversion of alcohols to carbonyl compounds (Scheme 1, reaction a) by means of lead tetraacetate is not favoured in non-polar solvents, and confirms the suggestion that this oxidation reaction (a) proceeds by heterolytic

---

[8] Except in the case of α-acetoxybutyraldehyde (from 1-butanol), α-acetoxylated carbonyl compounds were not fully characterized, but their structures were inferred from IR spectra.[2]

[9] K. Heusler, *Tetrahedron Letters* No. 52, 3975 (1964).

cleavage of the O–Pb bond in the intermediate alkoxy lead triacetate (II) with elimination of an α-proton.[2]

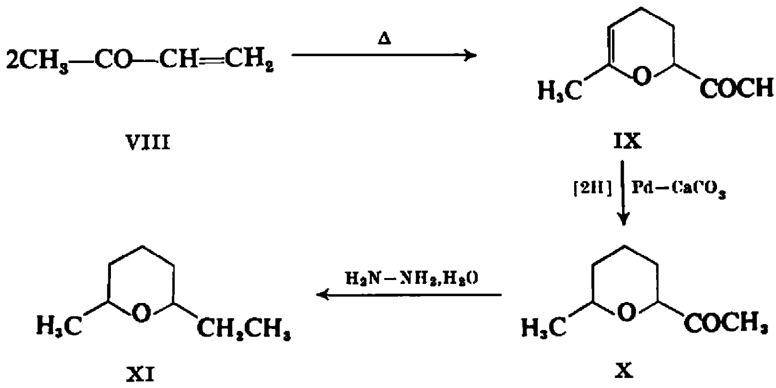
(b) *Cyclization reaction*

2-Alkyl tetrahydrofurans (IV, Scheme 1) are obtained from primary alcohols in yields amounting to about 50%, with the exception of 1-butanol, which gives tetrahydrofuran in only 20% yield (Table 1). In addition, starting from 1-hexanol, small amounts of 2-alkyltetrahydropyrans (V) may also be isolated, the ratios of tetrahydrofurans to tetrahydropyrans being 94:6, 93:7, 92:8 and 94:6 for 1-hexanol, 1-heptanol, 1-octanol and 1-dodecanol, respectively.

When a δ-methylene group is involved in cyclization, secondary alcohols afford 2,5-dialkyl tetrahydrofurans (IV) in yields ranging from 38 to 44% (5-nonanol gives a somewhat lower yield; Table 2). These 2,5-dialkyl tetrahydrofurans (IV) consist of a mixture of *cis*- and *trans*-isomers,[10] the ratio *cis*/*trans* varying only slightly from 40:60 (for 2-alkanols) to 45:55 (for 4-alkanols). Therefore, the formation of five-membered cyclic ethers from unbranched secondary aliphatic alcohols by means of lead tetraacetate is not stereoselective, although the presumed *trans*-isomers ("B" stereoisomers)[10] are always formed in somewhat higher yields.

Similarly to 1-butanol (Table 1), in secondary alcohols (2-pentanol, 4-heptanol) which can undergo 1,5-cyclization only between the hydroxyl oxygen and a δ-methyl group, and particularly in alcohols (such as 4-octanol and 4-nonanol) where both a δ-methyl and δ-methylene group can participate in competing intramolecular 1,5-cyclizations, five-membered cyclic ether formation involving the δ-methyl group is slow and the yields of the corresponding 2-alkyl-tetrahydrofurans are either unsatisfactory (9·5–15·5% in the first case) or very low (2% in the second case; see Table 2).[11]

Careful gas-chromatographic separation of the oxide fractions obtained from 2-octanol and 3-octanol afford, in addition to the corresponding *cis*- and *trans*-2,5-dialkyltetrahydrofurans (IV), the two other cyclic ethers ("A" and "B"), in about 1%



---

[10] The configurations of the cyclic geometrical isomers were not determined. However, for reasons mentioned previously,[4] it is assumed that the isomers with shorter gas-chromatographic retention times ("A" stereoisomers) have the *cis*-configuration and those with longer retention times ("B" stereoisomers) have the *trans*-configuration.

[11] The higher yield of tetrahydrofuran formation from 4-heptanol (15·5%), as compared to 2-pentanol (9·5%), is the result of increased probability for 1,5-cyclization, since the former alcohol contains *two* symmetrical δ-methyl groups, capable of participating in the reaction.

yield, which, because of similar IR spectra and close retention times, appear to be the geometrical isomers of the same structure. The retention time and IR spectrum of the "A" ether (with shorter retention time) are identical with those of authentic 2-ethyl-6-methyltetrahydropyran (XI), which was synthesized from methyl vinyl ketone (VIII) as illustrated above.[12]

According to gas-chromatographic analysis, 2-acetyl-6-methyltetrahydropyran (X) and its reduction product, 2-ethyl-6-methyltetrahydropyran (XI), consist mainly of one stereoisomer (which was isolated). Since unsaturated IX and saturated X ketones have an easily enolizable tertiary hydrogen atom, it is assumed that the slow catalytic hydrogenation of 2-acetyl-6-methyl-2,3-dihydro-4*H*-pyran (IX), in the presence of Pd-$CaCO_3$ in ethanol, affords the product of thermodynamic control, i.e. the more stable diequatorial *cis*-ketone (X).[13] Therefore, the "A" stereoisomer of 2-ethyl-6-methyltetrahydropyran (XI) obtained from IX and by lead tetraacetate oxidation of 2-octanol or 3-octanol has most probably the *cis*-configuration, the "B" cyclic ether of XI, in that case, representing the *trans*-isomer.[14]

The ratio of 2,6-dialkyltetrahydropyran (V, Scheme 1) to 2,5-dialkyltetrahydrofuran (IV) is in both cases about 2:98 (see Table 2).[15] As in the case of 1-pentanol, six-membered cyclic ethers are not present or only in amounts undetectable among the reaction products of 2-hexanol, 3-heptanol, 4-octanol and 5-nonanol. This is as expected, since the formation of tetrahydropyrans from these alcohol would involve a terminal methyl group, which, as described above for 1,5-cyclization, is considerably less reactive than a methylene group.[16]

If the conversion of aliphatic alcohols (XII) to cyclic ethers (XIX) by means of lead tetraacetate proceeds, as shown on Scheme 2, *via* the initial formation of the lead alkoxide (XIII) which subsequently decomposes to the alkoxy radical (XIV),[5] the fact that 1,5-hydrogen transfer (leading to tetrahydrofurans XIXa) is preferred over 1,6-hydrogen abstraction (leading to tetrahydropyrans XIXb) in the alkoxy radical

---

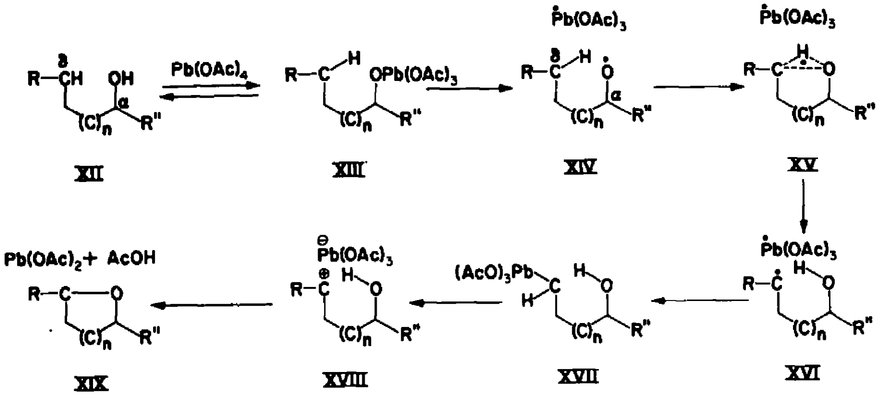
[12] K. Alder, H. Offermanns and E. Rüden, *Ber. Dtsch. Chem. Ges.* **74B**, 905 (1941).

[13] According to molecular models, approach to the catalyst surface of the dihydropyran IX in the quasi-chair conformation and with the acetyl group in the more stable equatorial position does not appear to be appreciably more hindered from one side than from the other side, and therefore, in the absence of equilibration by tautomeric isomerization, both geometrical isomers of X might be formed, in a ratio depending on kinetic control (under defined reaction conditions). See, for example, S. Siegel and G. V. Smith, *J. Amer Chem. Soc.* **82**, 6082, 6087 (1960); J.-F. Sauvage, R. H. Baker and A. S. Hussey, *Ibid.* **82**, 6090 (1960); **83**, 3874 (1961); S. Siegel and B. Dmuchovsky, *Ibid.* **84**, 3132 (1962); S. Siegel, G. V. Smith, B. Dmuchovsky, D. Dubbell and W. Halpern, *Ibid.* **84**, 3136 (1962).

[14] Because of small amounts and very close retention times to those of their five-membered cyclic isomers, the stereoisomers of 2-ethyl-6-methyltetrahydropyran were not detected in the first lead tetraacetate oxidations of 2-octanol.[4]

[15] The lead tetraacetate oxidation of other secondary alcohols, such as 2-heptanol, 3-nonanol, 4-nonanol and 2-decanol, probably also afforded small amounts of the corresponding 2,6-dialkyl tetrahydropyrans, the presence of which, however, was not investigated.

[16] The results of the lead tetraacetate oxidation of a 3α-hydroxy-5β-steroid have shown that the yields of six-membered cyclic ethers are low even when a teriary hydrogen from a methine group is involved in the 1,6-hydrogen transfer. However, the yield of tetrahydropyran formation could be increased by introducing functions which activated the reacting tertiary hydrogen atom. H. Immer, M. Lj. Mihailović, K. Schaffner, D. Arigoni and O. Jeger, *Experientia* **16**, 530 (1960); *Helv. Chim. Acta*. **45**, 753 (1962).



(a) n = 1; (b) n = 2

Scheme 2

XIV,[17] may be explained by assuming that the conformation which can be adopted by the six-membered transition state (XVa) is more favourable than that of a seven-membered cyclic structure (XVb) necessary for 1,6-hydrogen transfer.[20–22]

As already stated, in the formation of five-membered cyclic ethers (XIXa, Scheme 2) secondary hydrogen atoms on δ-methylene carbons are considerably more reactive than primary hydrogen atoms on δ-methyl carbons[23,24] (compare in Tables 1 and 2 the

---

[17] Similar results have been reported for the intramolecular chlorinations with hypoclhorites[18] and for the Hofmann-Löffler-Freitag reaction.[19]

[18] C. Walling and A. Padwa, *J. Amer. Chem. Soc.* **85**, 1597 (1963).

[19] E. J. Corey and W. R. Hertler, *J. Amer. Chem. Soc.* **82**, 1657 (1960).

[20] From previous studies on lead tetraacetate cyclization of steroid alcohols[5] it appears that a linear conformation of C, H and O in the transition state XV is not indispensable for hydrogen transfer. However, if the linearity factor is of importance for aliphatic alcohols,[18,19] both ring transition states (XVa and XVb) should be of similar energy, but tetrahydrofuran formation would again be preferred over tetrahydropyran formation, since the probability of attaining an approximate linear conformation of C, H and O in the transition state is higher in a quasi-six-membered ring (corresponding to XVa) than in a quasi-seven-membered ring (corresponding to XVb).

[21] The unfavourable steric factor (or/and linearity factor if operative) seems to be responsible for the absence of smaller cyclic ethers, the formation of which would involve 1,3- or 1,4-hydrogen shifts. This was confirmed in our previous work involving the lead tetraacetate oxidation of low-mol. wt. alcohols with structures which did not permit 1,5-cyclization to tetrahydrofuran derivatives.[3] However, the formation of some (non-cyclic) reaction products was interpreted (alternatively) in terms of a 1,3-hydrogen abstraction in the intermediate alkoxy radicals, and reactions involving smaller cyclic transition states have also been reported in other cases. cf. H. E. De La Mare and F. F. Rust, *J. Amer Chem. Soc.* **81**, 2691 (1959); O. A. Reutov in *Congress Lectures Presented at the XIXth International Congress of Pure and Applied Chemistry* pp. 205–211. Butterworths, London (1963).

[22] The non-formation of larger cyclic ethers resulting from 1,7- and higher order hydrogen shifts is probably also due to the unfavourable free energy change associated with the formation of the corresponding eight- and higher membered cyclic transition states.

[23] That a methylene group is involved in 1,5-oxide ring closure rather than a methyl group was also shown in the case of the lead tetraacetate oxidation of (+)-citronellol and its dibromide (primary acyclic alcohols). See C. F. Seidel, D. Felix, A. Eschenmoser, K. Biemann, E. Palluy and M. Stoll, *Helv. Chim. Acta* **44**, 598 (1961).

[24] This order of reactivity was also observed in the formation of six-membered cyclic ethers (see discussion above).

reaction times and cyclizations[25] of 1-butanol with those of other primary alcohols, of 2-pentanol and 4-heptanol with those of other secondary alcohols, and the competing 1,5-cyclizations in 4-octanol and 4-nonanol). This order of ease of 1,5-hydrogen transfer (i.e. secondary hydrogen > primary hydrogen) in the alkoxy radical XIVa (Scheme 2) is in accordance with previous observations,[5,11,18] and is consistent with the order of stability of alkyl radicals and simple carbonium ions.[26,27] In the mechanism proposed for ether formation[5] (Scheme 2), the intermediate secondary hydroxy alkyl carbon radicals (XVIa, R = alkyl), formed by 1,5-hydrogen abstraction from the alkoxy radicals (XIVa, R = alkyl), and the corresponding secondary carbonium ions (XVIIIa, R = alkyl)[5,28,29] are stabilized by additional hyperconjugation and positive inductive effects (due to the alkyl group R), while in the analogous primary intermediate species (XVIa and XVIIIa, R = H), derived from 1-butanol, 2-pentanol, 4-heptanol, etc., these stabilization factors are absent.[30,33] In addition the +I inductive effect of the alkyl group R will increase electron density on the δ-carbon atom in the alkoxy radical (XIVa, R = alkyl) and thus facilitate hydrogen abstraction by the "electrophilic" oxygen radical.[26,27]

---

[25] The fact that, in spite of the low yields of tetrahydrofurans (XIX), lead tetraacetate was completely consumed upon prolonged heating with alcohols in which primary hydrogen atoms are involved in the cyclization process (1-butanol, 2-pentanol, 4-heptanol; see reaction times in Tables 1 and 2), indicates that the tetravalent lead compound can react with the starting alcohol in other ways (principally to give the corresponding acetate) and can further attack products present in the reaction mixture, and also that the intermediate alkoxy radical (XIV) may undergo reactions other than intramolecular 1,5 (and 1,6) hydrogen abstraction.[2] Moreover, the slowness of reaction in these cases (up to 32 hr) corresponds to the reaction times (until disappearance of tetravalent lead) observed in the lead tetraacetate oxidation of alcohols having structures which did not permit intermolecular formation of five-membered cyclic ethers.[3]

[26] C. Walling, *Free Radicals in Solution* Chap 8. J. Wiley, New York (1957).

[27] See, for example, E. S. Gould, *Mechanism and Structure in Organic Chemistry* Chap. 8 and 16. H. Holt, New York (1959).

[28] D. Hauser, K. Schaffner and O. Jeger, *Helv. Chim. Acta* **47**, 1883 (1964).

[29] D. Hauser, K. Heusler, J. Kalvoda, K. Schaffner and O. Jeger, *Helv. Chim. Acta* **47**, 1961 (1964).

[30] The same factors should also facilitate the oxidation of the secondary (as compared to primary) hydroxyalkyl carbon radical XVIa (R = alkyl) to the corresponding secondary carbonium ion XVIIIa (R = alkyl), probably in the form of radical and ion pairs, either by direct electron transfer or *via* the organo-lead compound XVII.[5] (Compare the oxidation of primary, secondary and tertiary radicals by metal salts[31] and the ease of oxidation, expressed in ionization potentials, of primary secondary and tertiary radicals to the corresponding carbonium ions.)[32]

[31] H. E. De La Mare, J. K. Kochi and F. F. Rust, *J. Amer Chem. Soc.* **85**, 1437 (1963).

[32] R. W. Kiser, *Table of Ionization Potentials.* U.S. Atomic Energy Commission, TID-6142 (1960).

[33] When the methyl group and the hydroxyl function are in sterically favourable positions, without the possibility of large changes in conformation, as in the case of the 18-methyl group in 20-hydroxy steroids[34] or the 19-methyl group in 6β-hydroxy steroids,[5] the methyl group participates in ring formation to give five-membered cyclic ethers in good to excellent yields. Such an angular methyl group being attached to a quaternary carbon atom, the corresponding primary hydroxyalkyl carbon radical (XVIa, R = H) is somewhat more stable as compared to the analogous species derived, for example, from 1-butanol. However, for these cases it was postulated[5] that ether formation might occur by direct oxidation of the transition state (XVa), without passing through the carbonium ion XVIII.

[34] G. Cainelli, M. Lj. Mihailović, D. Arigoni and O. Jeger, *Helv. Chim. Acta* **42**, 1124 (1959); G. Cainelli, B. Kamber, J. Keller, M. Lj. Mihailović, D. Arigoni and O. Jeger, *Ibid.* **44**, 518 (1961).

If one compares the order of reaction times (Tables 1 and 2) in the series of alcohols (XII) with R = variable and R″ = constant, for R″ = H: 1-pentanol (R = CH_3) > 1-hexanol (R = C_2H_5) > 1-heptanol (R = n-C_3H_7) < 1-octanol (R = n-C_4H_9) < 1-dodecanol (R = n-C_8H_{17}); for R″ = CH_3: 2-hexanol (R = CH_3) > 2-heptanol (R = C_2H_5) > 2-octanol (R = n-C_3H_7) < 2-decanol (R = n-C_5H_{11}); for R″ = C_2H_5: 3-heptanol (R = CH_3) > 3-octanol (R = C_2H_5) > 3-nonanol (R = n-C_3H_7); for R″ = n-C_3H_7: 4-octanol (R = CH_3) > 4-nonanol (R = C_2H_5), it is evident that all the δ-methylene groups are not equivalent and that the reaction times decrease when the length of the alkyl group R attached to the δ-carbon atom increases up to R = n-C_3H_7; further lengthening of R again slightly increases the reaction time. Up to R = n-C_3H_7 the positive (+I) inductive effect of R will enhance the reactivity of the δ-carbon atom in the alkoxy radical (XIVa, Scheme 2) and increase the stability of the carbonium ion XVIIIa, in the same way as discussed above (for explaining the difference in reactivity of secondary and primary hydrogens on the δ-carbon atom). However, beginning with R = n-C_4H_9, the alkyl rest R is long enough to hinder, when in a coiled conformation, the abstraction of hydrogen from the δ-carbon atom in the alkoxy radical XIVa, and therefore the duration of the reaction will again increase.

On the other hand, the orders of reaction times (Tables 1 and 2) in the series of alcohols (XII) with R = constant and R″ = variable, for R = H: 1-butanol (R″ = H) < 2-pentanol (R″ = CH_3); for R = CH_3: 1-pentanol (R″ = H) < 2-hexanol (R″ = CH_3) < 3-heptanol (R″ = C_2H_5) < 4-octanol (R″ = n-C_3H_7) > 5-nonanol (R″ = n-C_4H_9); for R = C_2H_5: 1-hexanol (R″ = H) < 2-heptanol (R″ = CH_3) < 3-octanol (R″ = C_2H_5) < 4-nonanol (R″ = n-C_3H_7); for R = n-C_3H_7: 1-heptanol (R″ = H) < 2-octanol (R″ = CH_3) < 3-nonanol (R″ = C_2H_5), show that by increasing the alkyl rest R″ attached to the carbinol carbon atom the reaction times increase. It appears that the important factor in this case is the positive (+I) inductive effect of the electron releasing alkyl group R″, which by increasing electron density on the radical oxygen in the alkoxy radical XIVa will diminish its "electrophilic" properties as hydrogen abstracting agent (in the order corresponding to the length of R″, i.e. methyl < ethyl < n-propyl) and thus slow down the reaction. This effect is nonexistent when R″ = H and therefore the reaction of primary alcohols with lead tetraacetate to produce five-membered cyclic ethers is relatively fast.

The steric effect of the rest R″ is probably only of minor importance, since alkyl groups from methyl to n-propyl are not large enough to hinder appreciably the formation of the alkoxy lead triacetate (XIII, Scheme 2) and the attack of oxygen on the δ-hydrogens in the alkoxy radical XIVa. When R″ = n-C_4H_9, as in the symmetrical secondary alcohol 5-nonanol, the reaction is again fast (and comparable to the rate of the primary alcohol 1-pentanol; see Tables 1 and 2), because R″ having also a δ-methylene group and being identical to the other alkyl rest attached to the carbinol carbon atom, the probability for secondary hydrogen 1,5-abstraction was doubled.[35] The fact that in this case the reaction was relatively fast indicates also that even when

---

[35] When in secondary alcohols R″ = n-C_3H_7, 1,5-cyclization with the participation of this alkyl rest is also possible but would involve a primary δ-hydrogen atom. Since this reaction is very slow (see above) it can be disregarded when discussing the effect of R″ on the rate of the competing 1,5-cyclization involving secondary δ-hydrogen atoms, in alcohols such as 4-octanol and 4-nonanol (Table 2).

R″ = n-butyl the alcoholysis of lead tetraacetate to give the alkoxide XIII (Scheme 2) is not markedly retarded.

According to these qualitative findings on the rates of the lead tetraacetate reaction with primary and secondary aliphatic alcohols, one can roughly predict the ease of tetrahydrofuran formation, i.e. that when moving the hydroxyl group along an unbranched carbon chain the reaction times will increase in the order: 1-alkanol < 2-alkanol < 3-alkanol < 4-alkanol, because (in XII, Scheme 2) R decreases and R″ increases in the same order (Tables 1 and 2). This is particularly useful when one wants to prepare a five-membered cyclic ether which can be obtained from two alcohols; the alcohol with a larger group R and a shorter group R″ will be preferred as substrate for the reaction (e.g. 1-heptanol over 4-heptanol for preparing 2-n-propyltetrahydrofuran; 2-heptanol over 3-heptanol for obtaining 2-ethyl-5-methyltetrahydrofuran; 2-octanol over 4-octanol for the synthesis of 2-methyl-5-*n*-propyltetrahydrofuran).

(c) *Fragmentation reaction*

The lead tetraacetate oxidation of monohydroxylic alcohols in non-polar solvents can afford (Scheme 1), beside the corresponding carbonyl compounds (III, reaction a) and cyclic ethers (IV and V, reaction b), also fragmentation products (stabilization products of VI and carbonyl compounds XII, reaction c),[5,29,34b,36–38] the relative rates of these processes (a, b, c) depending on the structure of the substrate and the nature of the solvent. The rate of the fragmentation reaction (c) is mainly dependent on the stability of the primarily formed carbon radicals (XXII, Scheme 3),[5,39] but other factors are also of importance, such as the stability of the carbonyl fragmentation compound (XXIII), decrease in steric strain, polar effects in the transition state and the entropy effect. Since the lead tetraacetate fragmentation of alcohols is similar to the fragmentation process of alkoxy radicals,[39] but may also show specific features,[5] it is postulated[5] that the lead tetraacetate fragmentation, which involves the scission of the bond between the carbinol carbon atom and the β-carbon atom in the alkoxy lead triacetate (XX, Scheme 3), is a homolytic process proceeding through a transition state with alkoxy radical character (XXI),[40] but differing somewhat in the geometry of its basic skeleton from "free" alkoxy radicals generated from other sources.[39]

Evidence has been advanced[5,29,34b,36,41] that, beside the carbonyl fragmentation compound (XXIII), the primary decomposition product of the alkoxide XX is an alkyl

---

[36] M. Amorosa, L. Caglioti, G. Cainelli, H. Immer, J. Keller, H. Wehrli, M. Lj. Mihailović, K. Schaffner, D. Arigoni and O. Jeger, *Helv. Chim. Acta* **45**, 2674 (1962).

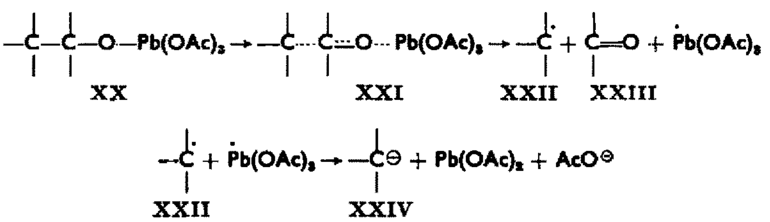
[37] M. Lj. Mihailović, M. Stefanović, Lj. Lorenc and M. Gašić, *Tetrahedron Letters* No. 28, 1876 (1964).

[38] M. Stefanović, M. Gašić, Lj. Lorenc and M. Lj. Mihailović, *Tetrahedron* **20**, 2289 (1964).

[39] J. K. Kochi, *J. Amer. Chem. Soc.* **84**, 1193 (1962); F. D. Greene, M. L. Savitz, F. D. Osterholtz, H. H. Lau, W. N. Smith and P. M. Zanet, *J. Org. Chem.* **28**, 55 (1963); C. Walling and A. Padwa, *J. Amer. Chem. Soc.* **85**, 1593 (1963).

[40] Since, as shown on hydroxy steroids,[9] the ratio of cyclic ether formation to fragmentation is practically independent on reaction conditions, the transition state (or a similar intermediate) of type XXI (Scheme 3) may be considered as the common precursor to both processes. In the case of cyclic ether formation, XXI would generate a more or less fully developed alkoxy radical (XIV, see Scheme 2).

[41] K. Heusler, J. Kalvoda, G. Anner and A. Wettstein, *Helv. Chim. Acta* **46**, 352 (1963); K. Heusler and J. Kalvoda, *Ibid.* **46**, 2732 (1963).



$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-O-Pb(OAc)_3 \rightarrow -\overset{|}{\underset{|}{C}}\cdots\overset{|}{\underset{|}{C}}\cdots O\cdots Pb(OAc)_3 \rightarrow -\overset{|}{\underset{|}{\dot{C}}} + \overset{|}{\underset{|}{C}}{=}O + \dot{P}b(OAc)_3$$

XX XXI XXII XXIII

$$-\overset{|}{\underset{|}{\dot{C}}} + \dot{P}b(OAc)_3 \rightarrow -\overset{|}{\underset{|}{C}}^{\oplus} + Pb(OAc)_2 + AcO^{\ominus}$$

XXII XXIV

Scheme 3

radical (XXII), and not a carbonium ion which would be formed by a heterolytic process.[42] However, the distribution of olefinic fragmentation products in the lead tetraacetate oxidation of a 19-hydroxy-5β-steroid[29] suggests that the alkyl radical (XXII) may be subsequently oxidized (by lead containing species) to the corresponding carbonium ion (XXIV).[43]

We have now obtained convincing evidence that such an oxidation step (i.e. alkyl radical → carbonium ion) occurs in the fragmentation reaction, by isolating, upon lead tetraacetate oxidation of secondary aliphatic alcohols (I, Scheme 4), as final fragmentation products both the unrearranged (XXVI) and rearranged acetates (XXVIII), the latter in somewhat higher yields (Table 2). Since it appears that radicals do not rearrange *via* 1,2-shifts of hydrogen (or alkyl groups),[27,44] the formation of 2-alkyl acetates (XXVIII, Scheme 4) must have occurred by oxidation of the 1-alkyl radical (VI, Scheme 4) to the corresponding primary carbonium ion (XXV), followed by rearrangement involving a 1,2-hydride shift to the more stable secondary carbonium ion (XXVII)[45] and subsequent addition of an acetate anion.[46]

As expected, because of the instability of primary alkyl radicals (VI), the yields of fragmentation products (1-alkyl acetate XXVI + 2-alkyl acetate XXVIII) from secondary alcohols are low (1–1·6%). In a few cases the other fragmentation component, i.e. the aldehyde (VII), also may be isolated (Table 2). As can be seen, the rate of the fragmentation reaction of secondary aliphatic alcohols having a β- and δ-methylene group is very low and does not compete successfully with the rate of 1,5-hydrogen abstraction leading to cyclic ether formation.

---

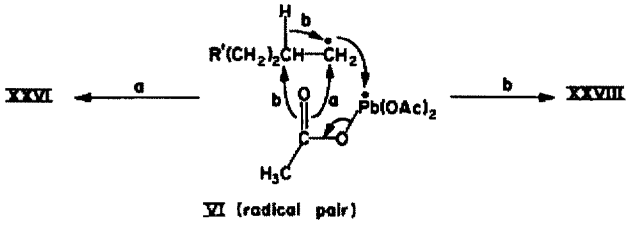
[42] As proposed by W. A. Mosher, C. L. Kehr and L. W. Wright, *J. Org. Chem.* **26**, 1044 (1961), for the fragmentation in acetic acid.

[43] Similarly to the oxidation of carbon radicals by cupric salts.[31] See also J. K. Kochi, *J. Amer. Chem. Soc.* **85**, 1958 (1963).

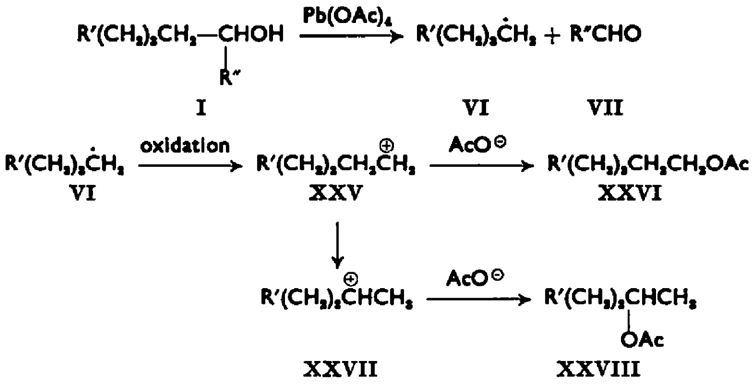
[44] C. Walling, *Free Radical Rearrangements* in *Molecular Rearrangements* (Edited by P. de Mayo) Part I; pp. 416–423. Interscience, New York (1963).

[45] *Cf.* J. H. Ridd, *Quart. Rev.* **15**, 418 (1961).

[46] It is possible that in fact "free" carbonium ions are not generated, and that oxidation of the 1-alkyl radical (VI) and acetoxylation, with or without rearrangement, take place in a simultaneous, multicenter reaction step:



VI (radical pair)



Scheme 4

The lead tetraacetate oxidation of primary aliphatic alcohols does not afford fragmentation products (or only in undetectable amounts), although in these cases the same primary alkyl radicals (VI) as formed from secondary alcohols would be expected. However, some of the other factors influencing the fragmentation process are less favourable in the case of primary alcohols, particularly the stability of the carbonyl fragmentation compound (VII; formaldehyde, which would arise from primary alcohols, being less stable than the higher aldehydes obtained from secondary alcohols),[47] and possibly, but only to a minor extent, release of steric strain resulting from the cleavage of the bond between the carbinol carbon atom and the β-carbon atom.

EXPERIMENTAL[48]

B.ps and m.ps are uncorrected. Gas chromatography was run on a Perkin Elmer instrument, Model 116-E, equipped with a thermistor detector; the columns (2 m × 4 mm, 4 m × 6 mm, 6 m × 8 mm) consisted of polyethylene glycol (1500) or Apiezon L adsorbed on Celite or Chromosorb (25–30%); the temp. of the columns, the sensitivity of the detector and the press. and flow rate of the carrier gas (dry H_2) were adjusted according to the fractions which were analysed. IR spectra were recorded on a Perkin Elmer Infracord, Model 137. For fractional distillations well-isolated, modified semimicro Vigreux and Widmer columns were used.

Starting products

Lead tetraacetate[49,50] was dried *in vacuo* at 20 mm over P_2O_5 and KOH, and its purity was determined iodometrically.[51] Calcium carbonate was dried *in vacuo* over P_2O_5. Thiophene-free benzene, dried over Na, was used as solvent.

---

[47] Traces of formaldehyde (and formate esters) detected among the reaction products of primary aliphatic alcohols (Table 1) might, *a priori*, result from the fragmentation process. However, since the same products were also found upon lead tetraacetate oxidation of secondary alcohols (Table 2), which could not afford formaldehyde by fragmentation (e.g. 3-octanol, 4-nonanol, etc.), it seems much more probable that the source of formaldehyde were methyl radicals produced by the decomposition of lead tetraacetate, the corresponding alkoxide (II, Scheme 1) or other lead containing intermediate species, *via* the acetoxy radicals, as discussed in our previous paper.[2]

[48] We thank Mrs. R. Tasovac and Miss R. Dimitrijević from the Microanalytical Laboratory of our Department, for the elemental microanalysis they carried out.

[49] J. C. Bailar, Jr., *Inorganic Syntheses* **1**, 47 (1939); see also R. E. Oesper and C. L. Deasy, *J. Amer. Chem. Soc.* **61**, 972 (1939).

[50] The reagent without lead chloride was used in most reactions, although lead tetraacetate contaminated with the chloride[49] gave similar yields of reaction products.

[51] R. Criegge, *Ber. Dtsch. Chem. Ges.* **64**, 260 (1931); see also M. S. Kharasch, H. N. Friedlander and W. H. Urry, *J. Org. Chem.* **16**, 533 (1951).

Alcohols were commercial products, with the exception of 4-octanol, 3-nonanol and 4-nonanol, which were obtained by reduction of the corresponding ketones with sodium borohydride. A solution of 4 g $NaBH_4$ in 30 ml water and 40 ml EtOH was added, with stirring, to 0·2 mole ketone in 30 ml EtOH, at such a rate as to maintain the temp. in the flask below 40° (40 to 60 min). After the addition was complete the mixture was refluxed for 1 hr, cooled and treated with 20% H_2SO_4. The upper layer was separated, the aqueous solution extracted with ether, the combined organic layers washed with $NaHCO_3$ aq and dried (K_2CO_3). Distillation *in vacuo* afforded the pure alcohol in 70–80% yield. Immediately before use all the alcohols were again dried and fractionated. The purity of each alcohol was checked by means of gas chromatography.

Lead tetraacetate oxidations

General procedure. In a 500 ml round-bottomed flask, equipped with a sealed stirrer and water separator,[52] containing anh. K_2CO_3 and connected to a reflux condenser, were placed 100–120 ml benzene, 0·1 mole starting alcohol, 0·1 mole (+2–5% excess) lead tetraacetate (based on the pure product) and 0·1 mole (+10–20% excess) $CaCO_3$. The mixture was stirred and heated to boiling; if at that point the reaction became vigorous, heating was interrupted as long as the mixture continued to boil (a few min) and was resumed after the exothermic reaction had subsided. When the tetravalent lead had been completely consumed (negative starch-iodide test or non-formation of dark-brown lead dioxide upon addition of water to one or two drops of the reaction mixture) and converted to insoluble lead diacetate (in the form of an almost white precipitate), refluxing was stopped and the flask cooled to room temp.

The reaction mixture was treated with dry ether (100–200 ml) and allowed to stand for 2–3 hr at 5°. The solution was decanted, the solid residue in the flask treated with 30–50 ml ether or benzene and the mixture heated under reflux for 5 min. After cooling to 10°, the mixture was filtered, the precipitate of lead diacetate returned to the flask and the extraction with warm ether or hot benzene repeated. The combined organic filtrates were successively washed with 5% $NaHCO_3$ aq and sat. NaCl aq (until neutral). After drying (K_2CO_3), the solvents and low-boiling products were separated by fractional distillation at atm. press., while the products boiling over 130° at 760 mm were fractionated under red. press. The acid components were isolated from the $NaHCO_3$-washings, upon acidification with mineral acid, extraction with ether and drying ($CaSO_4$). Each fraction obtained by distillation was further separated, if necessary, into pure compounds by means of gas chromatography.

Identification of products. (Distribution and yields given in Tables 1 and 2). Carbonyl compounds were identified by comparing their IR spectra and retention times with those of authentic products and by mixed m.p. determination of their solid derivatives (2,4-dinitrophenylhydrazones and/or semicarbazones). Aldehydes and ketones, required for comparison purposes, were all known compounds, either commercially available or prepared by CrO_3–H_2SO_4 oxidation of the corresponding alcohols. α-Acetoxybutyraldehyde, n_D^{20} 1·4115 (Found: C, 55·4; H, 7·9. Calc. for $C_6H_{10}O_3$: C, 55·4; H, 7·7%), obtained in 4% yield from the lead tetraacetate oxidation of 1-butanol, was identical with an authentic product (b.p. 61–63° at 10 mm, n_D^{20} 1·4110) prepared by acetoxylation of butyraldehyde with lead tetraacetate in acetic acid at 80°.[53]

Acetates and formates of the starting alcohols were characterized on the basis of their IR spectra and particularly of the position of the C—O stretching vibrations,[54] and in most cases their structures were confirmed by comparing their physical properties (b.ps, refractive indices, retention times, spectral data) with those of reference compounds, which were prepared by the usual esterification procedures.

1-Butyl butyrate (3% yield), 1-pentyl valerate (2% yield) and 1-heptyl heptanoate (1% yield), isolated as by-products in the oxidations of 1-butanol, 1-pentanol and 1-heptanol, respectively, have IR spectra and retention times which agree with those of the authentic esters, prepared by treating the corresponding alcohol with N-bromosuccinimide in CCl_4 in the presence of pyridine.[55] 1-Butyl

---

[52] K. B. Wiberg, *Laboratory Technique in Organic Chemistry* pp. 215–216, McGraw-Hill, New York (1960).

[53] J.-J. Riehl, *C.R. Acad. Sci. Paris* **250**, 4174 (1960).

[54] *cf.* L. J. Bellamy, *The Infra-red Spectra of Complex Molecules* (Second Ed.) pp. 178–192. Methuen, London (1960).

[55] V. M. Mićović, R. I. Mamuzić and M. Lj. Mihailović, *Glasnik hem. društva, Beograd* **22**, 443 (1957).

butyrate, b.p. 61–63° at 18 mm, n_D^{20} 1·4060 (lit.[56] b.p. 165°, n_D^{20} 1·4064); 1-pentyl valerate, b.p. 97–98° at 18 mm, n_D^{20} 1·4160 (lit.[56] b.p. 202°, n_D^{20} 1·4164); 1-heptyl heptanoate, b.p. 134–136° at 13 mm, n_D^{20} 1·4321. (Found: C, 73·4; H, 12·5. Calc. for $C_{14}H_{28}O_2$: C, 73·6; H, 12·4%) (lit.[57] b.p. 96–97° at 1 mm, n_D^{20} 1·4310–1·4327.)

n-Butyric, n-valeric and heptanoic acid, which were formed in the oxidation of 1-butanol, 1-pentanol and 1-heptanol, respectively, and isolated in 0·2–1% yield, were identified by comparing their IR spectra and retention times with those of authentic samples.

The acetals, 1,1-dibutoxybutane, n_D^{20} 1·4168, obtained in 5% yield from 1-butanol, and 1,1-dipentoxypentane, n_D^{20} 1·4258, obtained in 1·3% yield from 1-pentanol, were characterized by identity of their IR spectra, retention times and refractive indices with those of authentic products. These acetals were prepared from the corresponding alcohol (2 moles) and aldehyde (1 mole) in the presence of anh. $CaCl_2$. After standing overnight in a separatory funnel, the aqueous layer was separated and the organic layer was repeatedly dried over $CaCl_2$ (until no more water was formed) and finally fractionated. The first fraction (unreacted alcohol and aldehyde) was discarded and the second fraction was redistilled to afford the pure acetal. 1,1-Dibutoxybutane, b.p. 100–101° at 12 mm, n_D^{20} 1·4165 (lit.[58] b.p. 97–98° at 10 mm, n_D^{20} 1·4161); 1,1-*dipentoxypentane*, b.p. 91·5° at 0·6 mm, n_D^{20} 1·4265, n_D^{25} 1·4245. (Found: C, 73·8; H, 13·1. $C_{15}H_{32}O_2$ requires: C, 73·7; H, 13·2%.)

Five- and six-membered cyclic ethers, obtained, usually as major products, upon lead tetraacetate oxidation of primary and secondary alcohols (yields given in Tables 1 and 2), were characterized as follows:

Tetrahydrofuran (from 1-butanol), b.p. 64–67°,[59] was identical[60] with a redistilled (over KOH, Na and LAH_4) commercial product, b.p. 66–67°. 2-Methyltetrahydrofuran (from 1-pentanol), b.p. 78–80°.[59] (Found: C, 69·6; H, 11·8. Calc. for $C_5H_{10}O$: C, 69·7; H, 11·7%), was identical with 2-methyltetrahydrofuran isolated upon oxidation of 2-pentanol and with a redistilled commercial product, b.p. 77–79°. 2-Ethyltetrahydrofuran (from 1-hexanol), b.p. 107–111° at 752 mm, n_D^{20} 1·4155. (Found: 71·8; H, 11·9. Calc. for $C_6H_{12}O$: C, 72·0; H, 12·1%), was identical with authentic 2-ethyltetrahydrofuran, b.p. 108–110° at 763 mm, n_D^{20} 1·4156 (lit.[61] b.p. 107–108°, n_D^{20} 1·4160), prepared from furfuryl alcohol, through the corresponding bromide and 2-ethylfuran.[62-64] 2-Methyltetrahydropyran (from 1-hexanol), n_D^{20} 1·4180, was identical with an authentic product, b.p. 102–104° at 760 mm, n_D^{20} 1·4182 (lit.[65,66] b.p. 101–103°, n_D^{20} 1·4181), synthesized from 2-bromotetrahydropyran and methylmagnesium bromide.[67,64] 2-n-Octyltetrahydrofuran (from 1-dodecanol), b.p. 115–116° at 15 mm, n_D^{20} 1·4422, n_D^{22} 1·4415. (Found: C, 78·0; H, 13·3. Calc. for $C_{12}H_{24}O$: C, 78·2; H, 13·1%) (lit.[68] b.p. 85–87° at 3 mm, n_D^{20} 1·4412). 2-n-Heptyltetrahydropyran (from 1-dodecanol), b.p. 112–113° at 15 mm, n_D^{20} 1·4450 (lit.[69] b.p. 112° at 12 mm).

2,5-Dimethyltetrahydrofuran, *cis* + *trans*,[10,70] ratio 40:60[71] (from 2-hexanol), b.p. 90–93° at

---

[56] A. I. Vogel, *J. Chem. Soc.* 624 (1948).

[57] J. C. Craig and E. C. Horning, *J. Org. Chem.* **25**, 2098 (1960).

[58] R. H. Hall, A. R. Philpotts, E. S. Stern and W. Thain, *J. Chem. Soc.* 3341 (1951).

[59] B.p. micro-determination was carried out according to the modified (capillary) Emich method. See N. D. Cheronis, *Micro- and Semimicro Methods, Technique of Organic Chemistry* (A. Weissberger, Editor-in-chief) Vol. VI; pp. 190–192. Interscience, New York (1954).

[60] Identity in this and other cases was established by comparison of infra-red spectra and gas-chromatographic retention times.

[61] N. I. Shuikin, B. V. Lopatin and B. L. Lebedev, *Zh. Anal. Khim.* **16**, 639 (1961).

[62] R. Paul, *Bull. Soc. Chim. Fr.* [5] **2**, 2227 (1935).

[63] R. Paul, *Bull. Soc. Chim. Fr.* [5] **5**, 1053 (1938).

[64] R. Paul, *C.R. Acad. Sci., Paris* **206**, 1028 (1938); *Bull. Soc. Chim. Fr.* [5] **6**, 331 (1939).

[65] E. Hanschke, *Chem. Ber.* **88**, 1053 (1955).

[66] H. P. Richards and A. N. Bourns, *Canad. J. Chem.* **33**, 1433 (1955).

[67] R. Paul, *C.R. Acad. Sci., Paris* **198**, 1246 (1934); *Bull. Soc. Chim. Fr.* [5] **2**, 311 (1935).

[68] G. I. Nikishin and V. D. Vorobev, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk* 892 (1962).

[69] A. Gaumeton and C. Glacet, *Bull. Soc. Chim. Fr.* 1501 (1959).

[70] The separation of the geometrical isomers, their physical properties and assignment of configuration will be the subject of a forthcoming publication.

[71] According to gas-chromatographic analysis.

755 mm, n_D^{23} 1·4040 (lit. b.p. 90–94°,[72–76] n_D^{20} 1·4033–1·4050,[74–76] n_D^{23} 1·4045[73]). (Found: C, 71·9; H, 12·2. Calc. for $C_6H_{12}O$: C, 72·0; H, 12·1%); its identity was confirmed by comparing its IR spectrum and retention time with that of authentic 2,5-dimethyltetrahydrofuran (*cis* + *trans*), b.p. 90–93°, n_D^{23} 1·4038, prepared by cyclization of 2,5-hexanediol by means of benzenesulphonyl chloride in pyridine.[72] 2-Ethyl-5-methyltetrahydrofuran, *cis* + *trans*,[10] ratio 40:60[71] (from 2-heptanol), b.p. 116–117° at 760 mm, n_D^{20} 1·4162, n_D^{23} 1·4153 (lit.[75] b.p. 116–117°, n_D^{20} 1·4147). (Found: C, 73·3; H, 12·5. Calc. for $C_7H_{14}O$: C, 73·6; H, 12·4%); the same product (ratio *cis* to *trans* 43:57) was also obtained from 3-heptanol. 2-Ethyl-6-methyltetrahydropyran "A" (presumably the *cis*-form). (Found: C, 75·0; H, 12·5. Calc. for $C_8H_{16}O$: C, 74·9; H, 12·6%), obtained from 2-octanol, was identical[60] with an authentic XI prepared from VIII *via* IX and X;[18] the synthetic six-membered cyclic ether (XI), b.p. 39·5–40° at 21 mm, n_D^{20} 1·4250 (lit. b.p. 34–35° at 15 mm[18] and 133–136° at 748 mm,[77] n_D^{20} 1·4300[77]). (Found: C, 74·8; H, 12·6. Calc. for $C_8H_{16}O$: C, 74·9; H, 12·6%), consisted, according to gas chromatography, of only one geometrical isomer ("A", presumably *cis*-form). 2-Ethyl-6-methyltetrahydropyran "A" was also obtained from 3-octanol. 2,5-Diethyltetrahydrofuran, *cis* + *trans*,[10,70] ratio 41:59[71] (from 3-octanol), b.p. 141–142° at 757 mm, n_D^{20} 1·4206 (lit.[78] b.p. 142–143°, n_D^{20} 1·4215). (Found: C, 74·9; H, 12·8. Calc. for $C_8H_{16}O$: C, 74·9; H, 12·6%); its identity was confirmed by comparing its IR spectrum and gas-chromatographic retention time with that of authentic 2,5-diethyltetrahydrofuran (*cis* + *trans*), b.p. 141–143° at 760 mm, n_D^{20} 1·4210, prepared by cyclization of 3,6-octanediol[78] by means of benzenesulphonyl chloride in pyridine.[72] 2-Ethyl-5-*n*-propyltetrahydrofuran, *cis* + *trans*,[10] ratio 43·57[71] (from 3-nonanol), b.p. 73–74° at 35 mm, n_D^{20} 1·4270, n_D^{23} 1·4259 (lit. b.p. 60–61° at 22 mm,[79] 157–159° at 760 mm,[75] n_D^{20} 1·4297,[79] n_D^{20} 1·4301[75]). (Found: C, 76·1; H, 12·7. Calc. for $C_9H_{18}O$: C, 76·0; H, 12·8%); the same cyclic ether (*cis* + *trans*,[10] ratio 45:55[71]) was obtained from 4-nonanol. 2-n-Pentyltetrahydrofuran (from 4-nonanol), n_D^{20} 1·4321 (Found: C, 75·7; H, 12·9. Calc. for $C_9H_{18}O$; C, 76·0; H, 12·8%) was identical[60] with an authentic product, b.p. 179–181° at 760 mm, n_D^{20} 1·4323 (lit. b.p. 181–182°,[80] 178–180,[68] n_D^{20} 1·4323,[80] n_D^{20} 1·4325[68]), prepared from furfuryl alcohol through the corresponding bromide and 2-n-pentylfuran.[62–64] 2-*Methyl-5-n-pentyltetrahydrofuran*, *cis* + *trans*,[10] ratio 39:61[71] (from 2-decanol), b.p. 71–73° at 12 mm, n_D^{23} 1·4290. (Found: C, 76·7; H, 13·0. $C_{10}H_{20}O$ requires: C, 76·9; H, 12·9%.)

All cyclic ethers have IR spectra with characteristic C—O stretching vibrations in the region 1030–1100 cm^{-1}.

The other tetrahydrofuran and tetrahydropyran derivatives, namely 2-n-propyltetrahydrofuran (from 1-heptanol and 4-heptanol), 2-n-butyltetrahydrofuran (from 1-octanol and 4-octanol), the stereoisomeric 2-methyl-5-n-propyltetrahydrofurans (from 2-octanol and 4-octanol), the stereoisomeric 2-n-butyl-5-methyltetrahydrofurans (from 5-nonanol), 2-ethyltetrahydropyran (from 1-heptanol) and 2-n-propyltetrahydropyran (from 1-octanol), are described in one of our previous papers.[4]

[72] D. D. Reynolds and W. O. Kenyon, *J. Amer. Chem. Soc.* **72**, 1593 (1950).

[73] J. Colonge and A. Lagier, *Bull. Soc. Chim. Fr.* 17 (1949).

[74] E. V. Whitehead, R. A. Dean and F. A. Fidler, *J. Amer. Chem. Soc.* **73**, 3632 (1951).

[75] I. F. Belskiĭ, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 142 (1962).

[76] E. A. Youngmann, F. F. Rust, G. M. Coppinger and H. E. De La Mare, *J. Org. Chem.* **28**, 144 (1963).

[77] N. I. Shuikin, I. F. Belskiĭ and G. K. Vasilevskaya, *Z. Chem.* **2**, 359 (1962); *Chem. Abstr.* **59**, 2750 (1963).

[78] Yu. K. Yurev. G. Ya. Kondrateva, P. A. Akishin and A. A. Derbeneva, *Zh. Obshch. Khim.* **22**, 339 (1952).

[79] I. F. Belskiĭ and N. I. Shuikin, *Dokl. Akad. Nauk SSSR* **128**, 945 (1959).

[80] N. I. Shuikin and I. F. Belskiĭ, *Zh. Obshch Khim.* **27**, 402 (1957).