with absorption maxima, in benzene solution, at 5230, 2830, and 3450 Å., and at 5270 and 3750 Å. in carbon disulfide solution.

In another run, 1 g. of the triiodophenol in 170 ml. of benzene gave 99% of the calculated iodine release after 11 hr. of irradiation. Intermittent gas chromatographic analysis at 2, 3, 5, 7, and 9 hr. showed several major peaks, which diminished progressively with continued irradiation. None of the original triiodophenol was present after only 2 hr. of irradiation. The iodine in the photolysate was discharged with 5% sodium bisulfite solution, the benzene was evaporated, and the residue was recrystallized from glacial acetic acid, giving 76 mg. (19%) of colorless 2,4,6-triphenylphenol, m.p. 147–149.5°, lit.[30] m.p. 149–150°. A small amount of white solid, melting above 200°, was also noted.

Photolysis of 4-Iodobiphenyl in Cyclohexane.—Photolysis of 1 g. of 4-iodobiphenyl in 250 ml. of cyclohexane (reagent grade) gave rapid iodine release. After 24 hr., the reaction mixture was decolorized by treatment with aqueous sodium thiosulfate solution. The cyclohexane solution was filtered and dried over magnesium sulfate, and the reaction mixture was chromatographed on alumina, using hexane–benzene for elution, giving 494 mg. (90%) of biphenyl, m.p. 69°, not depressed on admixture with authentic biphenyl.

Photolysis of Pure Benzene and of a Dilute Solution of Iodine in Benzene. A.—Irradiation of reagent grade benzene with the lamp of Figure 1 causes formation of a yellow color.[37] When 150 ml. of pure benzene was photolyzed for 72 hr., the biphenyl was scarcely detectable with the flame-ionization detector of the Aerograph instrument. The gas chromatographic sample was prepared by evaporating the benzene from the reaction mixture at room temperature and diluting the "residue" with carbon disulfide. Using the 12 ft × $^1/_8$ in. column (0.2% Apiezon L on glass beads) as little as 1 mg. of biphenyl/l. can be detected. After 287 hr. of irradiation, only 640 γ (0.64 mg.) of biphenyl was found in the entire sample. This corresponds to only 5 × 10^{-4}% conversion. The reagent grade benzene, without irradiation, does not reveal any appreciable biphenyl in the chromatographic analysis.

B.—A solution containing 784 mg. of iodine in 200 ml. of reagent grade benzene was irradiated for 200 hr. No high-boiling products were detectable in the reaction mixture, using gas chromatography. Analysis, as above, showed only 20 mg. of biphenyl in the total mixture, representing only 0.01% conversion.

Photolysis of 1-Iodopropane in Benzene.—1-Iodopropane (3.14 g, 0.018 mole) in 200 ml. of benzene was irradiated 23 hr. Gas chromatography of the photolysate showed some starting material. A minute peak for iodobenzene and *ca.* 0.5% biphenyl were also noted. Iodine was also released in 68% yield. Some *n*-propylbenzene and isopropylbenzene were also observed.

Attempt to Detect Molecular Hydrogen.—4-Iodobiphenyl (5.6 g.) in 200 ml. of benzene (0.1 *M* solution) was photolyzed to 30% of the expected iodine release in an upright lamp which was connected with a gas-tight seal to a gas buret. The lamp was kept at 45 ± 0.5° in a constant-temperature bath. No gas evolution was detected; in fact, a slight decrease in volume was noted.[38]

Quantum Yield for Photolysis of 4-Iodobiphenyl in Benzene.—The quantum yield for release of iodine in the photolysis of 4-iodobiphenyl, 0.01 *M* in benzene, was found to be 0.08 and 0.09 in two separate runs. The value for Φ_{I_2} is based on the known value[30,32a] for photolysis of ethyl iodide. The latter was photolyzed for comparison under identical conditions; *cf.* also ref. 29.

Acknowledgment.—We are indebted to Mrs. Heidi B. Lewis for assistance in checking several of the synthetic runs and with chromatographic analyses, also with the help of Mr. Robert P. Brady. Mr. Laszlo Tokes carried out the photolyses of the iodotoluenes and Dr. John R. Holmes helped us in the design of the 2537-Å. light sources used in this study. The preparation of 3,5-diphenyl-4-hydroxybenzaldehyde was first carried out by Mr. Tom Erpelding, and Mr. Paul Dallons constructed the various lamps used in this study. Messrs. David Parker and Martin D. Cooper assisted in confirming data on the rates of release of iodine and for the quantum yield in photolysis of 4-iodobiphenyl. The formation of biphenyl as one of the products in the photolysis of 4-iodobiphenyl in benzene was first ascertained in this laboratory by Drs. T. G. Alston and L. Göthlich.

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[37] *Cf.* H. J. Angus, J. M. Blair, and D. Bryce-Smith, *J. Chem. Soc.*, 2003 (1964), who ascribed the color to formation of fulvene.

[38] Details of construction for the upright immersion-type lamp may be obtained from the authors.

The Reaction of Lead Tetraacetate with Aliphatic Alcohols[1]

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The oxidation of the primary alcohols 1-propanol through 1-hexanol, under various conditions, has been accomplished. The results indicate that lead tetraacetate effects the production of cyclic ethers even when the intramolecular functional groups are not spacially fixed. A discussion on the mechanism of oxidation is presented.

In 1959, Cainelli, *et al.*, introduced the reaction of lead tetraacetate with steroidal secondary alcohols to yield ethereal products.[2] Since that time the oxidative powers of lead tetraacetate have been extensively exploited and several recent papers have indicated the versatility of this reagent in organic synthesis.[3–6] This paper is of particular interest when taken in conjunction with that of Mihailovic, *et al.*, on the oxidation of the series, heptanol through nonanol.[1] Mihailovic has shown that oxidation produces primarily tetrahydrofuran ethers and that the process is nonstereospecific. The present work substantiates these results, using not only benzene as solvent, but also heptane, acetic acid, and chloroform. However, ether formation does not occur when pyridine is used as solvent. Further, photolysis and pyrolysis experiments, in the absence of solvent, suggest that a free-

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[1] Compare V. M. Micovic, R. I. Mamucic, D. Jeremic, and M. L. Mihailovic, *Tetrahedron*, **20**, 2279 (1964); C. Walling and A. Padwa, *J. Am. Chem. Soc.*, **85**, 1597 (1963); K. Heusler, *Tetrahedron Letters*, **No. 52**, 3975 (1964).

[2] G. Cainelli, M. L. Mihailovic, D. Arigoni, and O. Jeger, *Helv. Chim. Acta*, **42**, 1124 (1959).

[3] K. Heusler and J. Kalvoda, *Angew. Chem., Intern. Ed. Engl.*, **3**, 525 (1964).

[4] E. Corey and J. Casanova, Jr., *J. Am. Chem. Soc.*, **85**, 165 (1963).

[5] E. Van Tamelen and S. Pappas, *ibid.*, **85**, 3297 (1963).

[6] C. Djerassi, "Steroid Reactions," Holden-Day, Inc., San Francisco, Calif., 1963, p. 327.

radical process operates in all these reactions (except when pyridine is the solvent).

Experimental

Infrared spectra were determined using a Beckman IR-9 spectrophotometer. The gas chromatographic separations were achieved on Beckman GC-2 and Aerograph A-90-P2 instruments. All column materials were obtained from Wilkens Instrument and Research, Inc., Walnut Creek, Calif. All boiling and melting points are uncorrected.

Starting Alcohols.—The starting alcohols were obtained from commercial sources and purified by drying over potassium carbonate and fractionating through a Todd distillation assembly. Gas chromatography of the purified alcohols on Reoplex 400 and Silicone SF-96 columns revealed them to be free of impurities. The infrared spectra were comparable with those in the Sadtler Catalog.[7]

Product Sources.—Tetrahydrofuran, 2-methyltetrahydrofuran, propanal, and butanal were obtained from Eastman Kodak Co. Tetrahydropyran was obtained from Aldrich Co. Pentanal and hexanal were prepared by the method in Vogel,[8a] as were all alcohol acetates.[8b] Oxetan was prepared from 3-chloro-1-propanol.[9] Lithium aluminum hydride reduction of 2-chloromethyltetrahydropyran (in refluxing THF) produced a low yield of 2-methyltetrahydropyran. Except for the sample of pentanal and hexanal, gas chromatography showed these materials to be free of major impurities. The infrared spectra were comparable with those in the Sadtler Catalog.[7]

Alcohol Oxidation in Heptane.—A mixture of 200 ml. of purified heptane, 35.5 g. (0.08 mole) of freshly prepared lead tetraacetate,[10] and 15 g. of anhydrous calcium carbonate was placed in a dry flask equipped with stirrer and condenser. After heating to 70°, the alcohol (0.05 mole) in 50 ml. of heptane was added in one batch. Refluxing and stirring for 18 hr. yielded a chocolate brown mixture which was filtered, and the solid was washed with heptane. The combined liquids were fractionated through a helices-packed column. Each fraction was analyzed by g.l.p.c. on Reoplex 400, Carbowax 1540, and Silicone SF-96 columns.[11] Positive identification of individual products was achieved by infrared analysis of collected samples. Table I shows the products of oxidation for each alcohol. No lead tetraacetate was found in the solid reaction residue, as determined by the addition of water. Individual experiments, using the same reaction materials as above, revealed the following facts. (1) Addition of the alcohol over a period of 1 hr. did not alter the product distribution. (2) A shorter reflux period of 2 hr. was just as effective as the 18-hr. period. (3) Oxidation at room temperature for 18 hr. greatly reduced the amounts of ether and ester products. The main products were aldehyde and alcohol. Also, as in the high temperature reactions, all of the lead tetraacetate had been reduced.

TABLE I

PRODUCTS OF OXIDATION IN REFLUXING HEPTANE

	% yield[a]			
	Starting alcohol			
Product	Propanol	Butanol	Pentanol	Hexanol
Oxetan	0	..	..	..
THF ether	..	18	25	15
THP ether	..	..	1	1
Aldehyde	10	16	20	15
Acetate ester	2	25	30	30
Alcohol	80	40	25	40

[a] Total per cent compositions on g.l.p.c. standardized areas. THF refers to tetrahydrofuran; THP refers to tetrahydropyran.

Alcohol Oxidation in Benzene.—The procedure for heptane was followed except that lower reflux temperature of benzene gave rise to different product distributions in the distilled fractions. Table II shows the products of oxidation identified by g.l.p.c.[11] and infrared comparisons with authentic samples. As in the heptane solvent, no lead tetraacetate was found in the solid reaction products of either the reflux or room temperature reactions.

TABLE II

PRODUCTS OF PENTANOL OXIDATION IN DIFFERENT SOLVENTS[a]

	Production, %				
Solvent	THF ether	THP ether	Aldehyde	Acetate	Alcohol
Heptane	25	1	20	30	25
Heptane–acetic acid[b]	31	0	15	41	13
Acetic acid	27	0	20	53	0
Benzene	25	0	20	30	25
Benzene–acetic acid[b]	30	0	10	50	10
Chloroform	25	0	15	30	30
Pyridine	0	0	75	10	15

[a] Total per cent compositions based on g.l.p.c. standardized areas. [b] Mixtures (50:50) on a volume basis.

Alcohol Oxidation in Acetic Acid.—The procedure for heptane was followed except that no calcium carbonate was added to the reaction mixture. The reaction mixture became homogeneous during the 18-hr. reflux period. Table II shows the products of oxidation as identified by g.l.p.c. and infrared analysis. Room temperature reaction conditions almost completely prevented the formation of cyclic product. No lead tetraacetate was found in the product solution.

Alcohol Oxidation in Chloroform.[12]—The procedure for heptane was followed. The clear mixture of chloroform, lead tetraacetate, and calcium carbonate turned black when the alcohol was added. The boiling point of the solvent required most of the oxidation products to remain in the residue from distillation. Table II shows the products of oxidation identified by g.l.p.c. and infrared analysis. In the absence of alcohol, lead tetraacetate did not seem to react with refluxing chloroform.

Alcohol Oxidation. A. In Heptane–Acetic Acid.—The heptane procedure was followed except for the replacement of 100 ml. of heptane by 100 ml. of acetic acid, and deletion of the calcium carbonate. After the mixture was heated to reflux with stirring, it became homogeneous. At the end of the 18-hr. oxidation period, the solution was cooled to yield three layers. The top liquid layer was fractionated to yield heptane and a residue containing most of the expected products as identified by g.l.p.c. and infrared methods (see Table II). The bottom liquid layer proved to be mostly acetic acid containing small amounts of ether, acetate, and alcohol products. The third layer, a white solid, was found to be lead diacetate from qualitative analysis procedures. No lead tetraacetate could be detected in the product mixture.

B. In Benzene–Acetic Acid.—The procedure for heptane was followed except that the solvent was composed of 100 ml. each of benzene and acetic acid, and calcium carbonate was not added to the reaction mixture. After the 18-hr. reflux period, the mixture was filtered and the pale yellow liquid was distilled. G.l.p.c.[11] and infrared analysis indicated the products to be those shown in Table II.

C. In Pyridine.[13]—The procedure for heptane was followed except that the solvent was pyridine and no calcium carbonate was added to the reaction mixture. It was observed that lead tetraacetate and pyridine react to give a deep red solution. G.l.p.c. analysis of this mixture, however, showed that no volatile materials were formed. Furthermore, the lead tetraacetate could be recovered in crude form by evaporation of the solvent. After alcohol addition, the pyridine–lead tetraacetate solution turned pale yellow and remained homogeneous. Cooling produced a precipitate which was collected by filtration. Qualitative tests revealed this to be crude lead diacetate. The colored liquid was distilled; g.l.p.c. analysis of each fraction showed that oxida-

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[7] "Sadtler Catalog," Sadtler Research Laboratories, Philadelphia, Pa.

[8] A. Vogel, "Practical Organic Chemistry," Longmans, Green and Co., London, 1959: (a) p. 320; (b) p. 382.

[9] C. R. Noller, *Org. Syn.*, **29**, 92 (1949).

[10] See ref. 8, p. 199. The recrystallized lead tetraacetate was dried over potassium hydroxide under vacuum for 3 hr.

[11] The 0.25-in. g.l.p.c. columns were of varying lengths (6, 9, and 10 ft.) and operated at three different temperatures (40, 70, and 120°). In most oxidations the products could be analyzed for on one column. The butanol oxidation, however, required both the Reoplex and silicone columns. Also, the solvent benzene was difficult to separate from the reaction products of most alcohols.

[12] Compare D. H. R. Barton and A. Beckwith, *Proc. Chem. Soc.*, 335 (1963).

[13] See R. Partch, *Tetrahedron Letters*, **No. 41**, 3071 (1964).

tion gave largely the aldehyde corresponding to the starting alcohol. The other products are listed in Table II.

Inverse addition (lead tetraacetate to a mixture of alcohol in pyridine) did not alter the product composition. Likewise, reaction for 12 hr. at room temperature gave nearly the same results. When a 2:1 mole ratio of lead tetraacetate to alcohol was used, the per cent of aldehyde remained the same; however, the per cent of acetate ester increased while that of alcohol decreased.

Attempted Decomposition of Lead Tetraacetate in Solvent.—Lead tetraacetate, added to each of the above-mentioned solvents, did not undergo extensive decomposition under reflux conditions. The amount of lead tetraacetate remaining after 18-hr. reflux was not determined quantitatively; however, in each case the qualitative test with water showed considerable amounts to be present.

Attempted Aldehyde Oxidation in Heptane.—An attempt was made to oxidize two aldehydes, butanal and pentanal, by the procedure of alcohol oxidation in heptane. In neither case did reaction occur, as indicated by g.l.p.c. analysis. Lead tetraacetate was shown to be present in the solid reaction products.

Photolytic Oxidation.[14]—A mixture of 8.0 g. (0.018 mole) of lead tetraacetate and 1.6 g. (0.016 mole) of *n*-amyl alcohol was placed under nitrogen in a quartz flask. Irradiation with a Hanovia medium-pressure mercury lamp for 48 hr. produced a small amount of gray material on the vessel wall. This disappeared in the unopened flask within 24 hr. The white slush was extracted with heptane and the heptane solution was analyzed by g.l.p.c. methods (see Table III). The heptane solution contained the same products as obtained from the solution oxidation and *in the same ratio*. The white solid remaining after heptane extraction dissolved in water with no brown coloration, indicating the absence of unreacted lead tetraacetate. Addition of dilute sulfuric acid caused a white precipitate ($PbSO_4$) to form.

TABLE III

PRODUCTS OF PENTANOL OXIDATION UNDER DIFFERENT CONDITIONS[a]

	Products, %				
Condition	THF ether	THP ether	Aldehyde	Acetate	Alcohol
Solution[b]	25	1	20	30	25
Photolysis[c]	22	0	23	20	35
Pyrolysis[c]	24	1	21	30	25

[a] Total per cent compositions based on g.l.p.c. standardized areas. [b] Heptane as solvent. [c] No solvent used.

To ensure that some of the products were not coming from alcohol photolysis alone, *n*-amyl alcohol was photolyzed in the absence of lead tetraacetate. After 48 hr., g.l.p.c. analysis revealed that the alcohol was not effected to any great extent.

Pyrolysis Oxidation.—A mixture of 6.1 g. (0.014 mole) of lead tetraacetate and 1.21 g. (0.014 mole) of *n*-amyl alcohol was heated slowly to 150° over a period of 1 hr.; the temperature was then maintained at 150° for a second hour. As the temperature reached 80° a fog appeared inside the reaction vessel (Scientific Glass Apparatus Co., JD-3570) and a condensate appeared on the cold finger. At 120° the solid reaction material darkened slightly. The clear distillate (2 ml.) was analyzed by g.l.p.c. methods. The product composition was nearly identical with that obtained from the solution oxidations (see Table III).

Discussion

Since the discovery of intramolecular ether formation from secondary alcohol and δ-methyl (or methylene) groups in the presence of lead tetraacetate, an impressive number of compounds have been made to undergo this reaction.[1,6,15] Often the condensing groups have been part of a steroid molecule where a semirigid structure might be imagined. It has been suggested that this "spacial fixation" is necessary for lead tetraacetate to trigger the intramolecular process.[16]

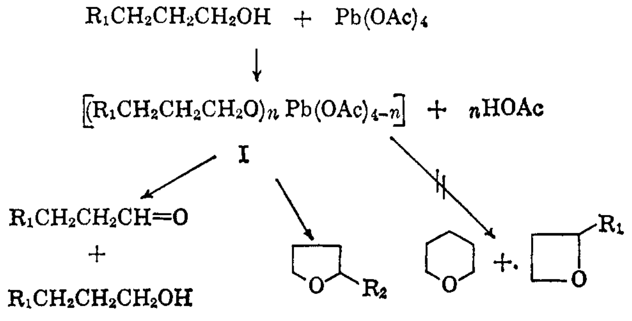
In an attempt to elucidate the effectiveness of lead tetraacetate as an ether-producing agent, a series of 1-alkanols were oxidized under varying conditions. It was hoped that the results would allow some conclusions to be drawn as to the "spacial fixation" requirements for ether formation. Since that time, Eschenmoser[17] and Mihailovic[1] have indicated that the formation of tetrahydrofuran derivatives are favored over those of tetrahydropyran, *even when there is a certain amount of allylic activation* for the pyran derivative (*e.g.*, citronellol). The ring closures are also nonstereospecific. These conclusions have been substantiated in part by the present work.

Tables I–III show the relative amounts of products from each starting alcohol. Note that in all cases some starting alcohol was recovered, even when excess (3:1 molar ratio) lead tetraacetate was used. On the other hand, the lead tetraacetate was always completely consumed. An explanation for this phenomenon has not yet been postulated.

The acetate esters might be formed by the reaction of acetic acid, generated during the reaction, and alcohol. Normally this process requires a catalyst (*e.g.*, strong acid). Unfortunately, there is no information on the catalytic activity of lead tetraacetate in esterification reactions. Alternatively, Moon and Lodge[18] have discussed acetate ester formation *via* a mechanism not requiring a catalyst.

More pertinent to this study was the formation of aldehydes and tetrahydrofuran derivatives, to the virtual exclusion of oxetan and tetrahydropyran ethers. It is generally accepted that the initial process in the oxidation mechanism is the formation of an alkoxide–lead acetate intermediate.[3,19] This then decomposes to yield the various products (Scheme I).

SCHEME I



R_1 = H, methyl, ethyl, propyl
R_2 = H, methyl, ethyl
n = 1, 2

One can imagine the alkoxide–lead acetate intermediate (I) being formed by a concerted displacement (six-membered cyclic transition state) of one or two acetate groups. If the alcohol was not involved directly, then lead tetraacetate would be expected to decompose *by itself* under the same conditions, which it does not! The alkoxyacetyllead intermediate I can take the form where n = 1 or 2. At present there is no experimental evidence for the value of n; however, it cannot exceed

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[14] Compare V. Franzen and R. Edens, *Angew. Chem.*, **73**, 579 (1961).

[15] K. Kitahonoki and A. Matsuura, *Tetrahedron Letters*, **No. 33**, 2263 (1964).

[16] G. Cainelli, B. Kamber, J. Keller, M. L. Mihailovic, D. Arigoni, and O. Jeger, *Helv. Chim. Acta*, **44**, 518 (1961).

[17] C. G. Seidel, D. Felix, A. Eschenmoser, K. Biemann, E. Palluy, and M. Stoll, *ibid.*, **44**, 598 (1961).

[18] S. Moon and J. Lodge, *J. Org. Chem.*, **29**, 3453 (1964).

[19] Compare, Westheimer, *et al.*, *J. Am. Chem. Soc.*, **73**, 65 (1951); **85**, 1771 (1963).

2 as the lead-containing product is always lead diacetate (in anhydrous media). The fact that alcohol appears in the product suggests that the intermediate undergoes a reversible reaction *or* intramolecular rearrangement (Figure 1).

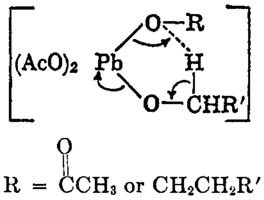
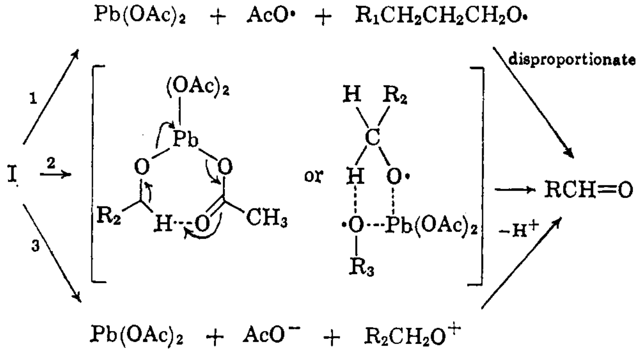


Figure 1

Table I shows that the oxidation of propanol yields none of the cyclic ether, oxetan.[20] This fact, along with the data presented in Tables II and III, suggest that a free-radical pathway is operative part, if not all, of the time.[21] The solvent pyridine gives rise to an exception in that aldehyde formation takes precedence over ether production.

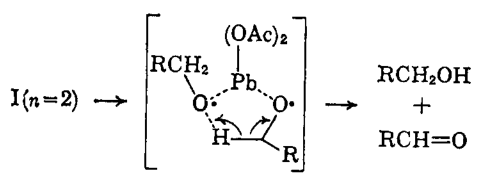
Scheme II shows three possible routes for aldehyde formation. It has not been determined which value of n in the intermediate I is preferable. Intermediate I could take the form in which n is 2 unless the reaction conditions were such that, when n became 1, total decomposition was more favorable. Two experiments bear directly upon this question. The occurrence of alcohol in all *product* mixtures would seem to indicate that n should not exceed 1. The objection to this statement is that the product alcohol might arise *from the reaction itself.* This is particularly true of the room temperature oxidations which produce only aldehyde and alcohol even though all of the lead tetraacetate is decomposed. It should be noted that the alcohol product from the high temperature reaction could arise from path 1; *i.e.*, a nonsolvated alkoxy radical disproportionates with a twin or reacts with the solvent. (An alternative would be that represented in Scheme III. Some of the intermediate I, even at high temperature, takes the structure where n is 2.) Scheme III reveals a pathway quite compatible with *only aldehyde and alcohol* production from the low-temperature reactions. Here n might obtain the value of 2 prior to total decomposition of the intermediate I.

Scheme II



R_1 = H, methyl, ethyl, propyl
R_2 = ethyl, propyl, butyl, pentyl
R_3 = acetyl, propyl, butyl, pentyl, hexyl

Scheme III



Returning now to Scheme II, it is not clear which path is predominant in aldehyde production. Path 3, as shown, is unlikely because the photolytic, pyrolytic, and solvent-containing reactions yield similar products. It is possible, however, that the ions of path 3 could be involved in steps after initial free-radical formation.

The lack of ether product when pyridine is used as solvent deserves some comment. Theoretically, in the reactions containing solvent, calcium carbonate is added to neutralize the acetic acid generated during one or more steps. Since some acetate ester was always found in the product mixtures (high temperature), an attempt was made to incorporate a neutralizing agent into the solvent, the choice being pyridine. Oddly enough, pyridine does not seem to stop ester formation. A similar observation was made by Walling in his elegant study on intramolecular chlorination.[1] It was found that δ-chloro alcohols could be isolated in good yields from hypochlorites when hydrocarbon solvents were used. However, pyridine solvent yielded only large amounts of aldehyde or ketone. When pyridine, with no alcohol present, is treated with lead tetraacetate, a deep brown coloration is observed. Gas chromatography of the brown solution revealed that no reaction had taken place to give reasonably volatile materials. With alcohol present the same coloration was observed; however, the alcohol was oxidized to yield aldehyde and some acetate ester. Apparently pyridine can react (?) more favorably with the α-hydrogen of the alcohol moiety in the intermediate I. This is reasonable in that the inductive effect of the oxygen slightly activates the α-hydrogens whereas no such activation is present for the δ-hydrogens (Figure 2). In pyridine, then, the reaction does not necessarily follow a free-radical decomposition path (the dielectric constant of pyridine is considerably larger than that of the other solvents).

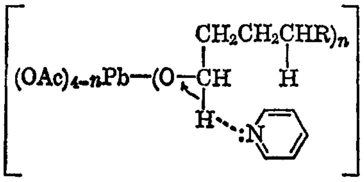


Figure 2

As a result of this and other published work,[22-25] it is probable that the mechanism of *cyclic ether formation* has, in its initial stages, a sequence as shown in Scheme IV. It is as yet unknown what kind or kinds

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[20] V. Micovic, R. Mamucic, D. Jeremic, and M. L. Mihailovic, *Tetrahedron*, **20**, 2279 (1964); see footnote 19.

[21] Compare H. E. Barron, *et al.*, *Chem. Ind.* (London), 76 (1954).

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

[23] Compare E. J. Corey and W. Hertler, *J. Am. Chem. Soc.*, **82**, 1657 (1960).

[24] Compare D. H. R. Barton, J. Beaton, L. Geller, and M. Pechet, *ibid.*, **82**, 2640 (1960).

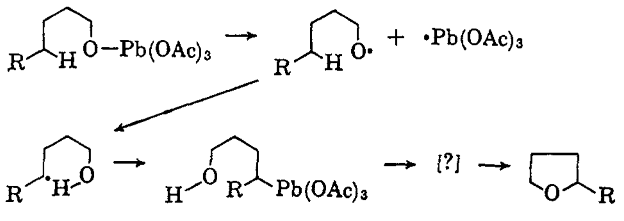
[25] Compare M. Akhtar and M. Pechet, *ibid.*, **86**, 265 (1964).

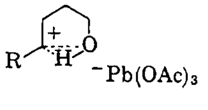
of intermediates follow; however, two possibilities are shown in structures II and III.

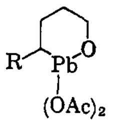
Conclusion

Although the results that are reported here by no means prove the mechanism of alcohol oxidation by lead tetraacetate, they highly suggest, at least in part, a free-radical process. It is important to note that the product ratios indicate that ether and aldehyde formation are equally probable. Aldehydes are not intermediates in the ring closure as they are unchanged in control experiments (solvent type). One fact has been established; namely, a prerequisite for ether formation is not one of molecular rigidity holding the alcohol and δ-carbon functions in close proximity. It can hardly be questioned, however, that any structure having rigid proximity of these groups would give rise to higher yields of the THF derivatives.

SCHEME IV




II


III

Acknowledgment.—This work was supported by the Research Corporation, to which the author extends his thanks. Helpful comments from Drs. Marmor, Small, and Stuckwisch are gratefully appreciated.

The Chemistry of Carbanions. X. The Selective Alkylation of Unsymmetrical Ketones[1]

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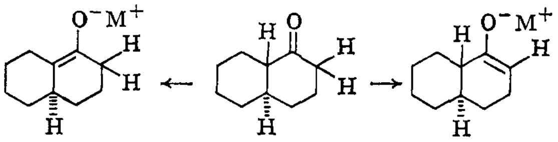
Solutions of enolate anions which retain their structural and stereochemical integrity can be prepared by reaction of the corresponding enol acetates with 2 equiv. of methyllithium in 1,2-dimethoxyethane. By use of this procedure it is possible to effect the selective alkylation of unsymmetrical ketones at either the more or less highly substituted α-position, utilizing the appropriate enol acetate derivative of the ketone. Selective alkylations of 2-heptanone, 2-methylcyclopentanone, 2-methylcyclohexanone, and 1-decalone are described. The proportion of *cis*-fused 9-methyl-1-decalone obtained from alkylation of 1-decalone can be significantly enhanced by use of the very reactive alkylating agent, trimethyloxonium 2,4,6-trinitrobenzenesulfonate.

Because the alkylation of unsymmetrical ketones[3] usually leads to mixtures of structurally isomeric alkylated products, methods have been developed for selective alkylation which involve either blocking one α-position[4] or adding an activating group at one α-position.[3,5] In some cases, conversion of the ketone to an enamine[6] or imine[7] derivative prior to alkylation has been reported to give predominantly one structural isomer of the product. An alternative solution to the problem of selectively alkylating an unsymmetrical ketone would be the conversion of the ketone (*e.g.*, **1**) to one of the structurally isomeric enolate anions (*e.g.*, **2**) with reaction conditions which do not permit subsequent interconversion of the isomeric enolate anions (*e.g.*, **2** ⇌ **3**).



2 **1** **3**

In a previous paper[8] we provided direct experimental evidence for the hypothesis that solutions of structurally isomeric enolate anions such as **2** and **3** are interconverted rapidly only when a proton-donating material, such as a protonic solvent or the un-ionized ketone **1**, is present in the solution. In particular, solutions of lithium enolate anions in 1,2-dimethoxyethane (DME) were found not to interconvert over periods of several hours at room temperature unless a substantial amount (10–100 mole %) of un-ionized ketone was present in the solution to serve as a proton donor. Evidence supporting this hypothesis is also derived from selective alkylation experiments in which solutions of particular enolate anions, apparently free of structural isomers, have been generated by reductions, with alkali metals in liquid ammonia, of α,β-unsaturated ketones,[9] of α-halo or α-acyloxy ketones,[10] or

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