Reductions Using Alkoxyaluminum Hydrides. I. Reduction of Epoxides

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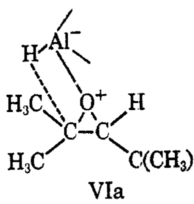
The reactions of β-diisobutylene oxide and styrene oxide with various alkoxyaluminum hydrides have been studied. This is the first report involving the use of alkoxyaluminum hydrides as selective reducing agents in organic chemistry. Alkoxyaluminum hydrides are less reactive reducing agents toward epoxides than the "mixed hydride reagents," although more reactive than LiAlH$_4$. Whereas mixed hydride reagents, such as HAlCl$_2$, exhibit strong Lewis acidity as evidenced by the substantial production of migration product induced by ring opening with the Lewis acid, alkoxyaluminum hydride reduction of these epoxides produces much less of the migration product, indicating weaker Lewis acidity of these reagents. The differences in Lewis acidity and resulting differences in reactivity between the alkoxyaluminum hydrides and "mixed hydride" reagents can be explained in terms of the different states of association exhibited by the two types of reagents. The role of association through bridging alkoxy groups in reducing the expected Lewis acidity of these reagents is discussed.

Alkoxyaluminum hydrides have been postulated as intermediates in reductions of epoxides involving mixed hydride reagents.[4,5] Also the assumption has been made that alkoxyaluminum hydrides and hydridoaluminum halides are similar in their behavior as reducing agents[5] for the system studied. This is not an unreasonable assumption since hydriodoaluminum halides, the so-called "mixed hydride reagents,"[6] and alkoxyaluminum hydrides are formally similar. However, previous workers did not prepare authentic alkoxyaluminum hydrides and allow them to react with epoxides. It has been found recently[7] that alkoxyaluminum hydrides can be synthesized by reaction of aluminum hydrides in tetrahydrofuran with the corresponding alcohol in the proper stoichiometric ratios. Dimethoxyaluminum hydride, mono- and diisopropoxyaluminum hydride, and mono- and di-*t*-butoxyaluminum hydride have been prepared in this manner and characterized. The product ratios from reactions of both β-diisobutylene oxide and styrene oxide with these reagents were significantly different from those ratios obtained by reaction with the corresponding hydridoaluminum halides.

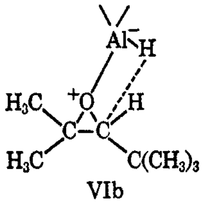
Results and Discussion

When β-diisobutylene oxide is treated with a hydride possessing Lewis acidity, the products given in Scheme I are obtained and the pathways shown are operative.[4,8–10] Products II and III are formed by direct reduction *via* a four-center transition state VI[4]

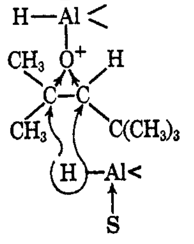


VIa

or

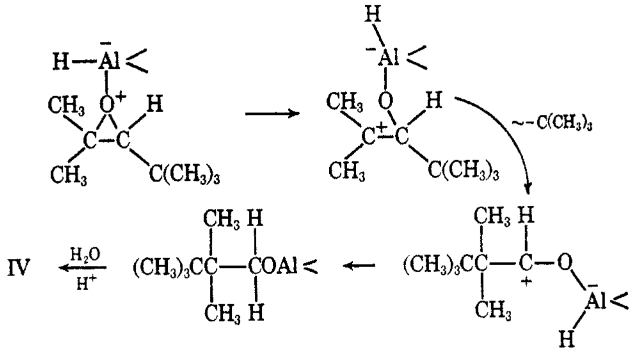


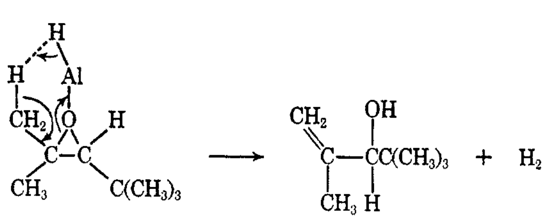
VIb



VII

and by bimolecular backside attack VII.[5] Compound IV is formed by ring opening of the complexed epoxide followed by migration of the *t*-butyl group.[4] Compound V has been proposed as the result of internal elimination[9] and is always formed to some extent in reductions of this type.[6b,10,11] Compound V becomes a major product when the reducing agent employed is a relatively strong hydride donor or weak Lewis acid.[10,11] Zakharkin and coworkers[9] report considerable formation of V in reductions of I using limited amounts of ethereal aluminum hydride in refluxing solvent.





V

Since compound IV is formed *via* a ring-opening step, any factor that increases the extent of ring opening

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(1) Abstracted in part from the M.S. Thesis of B. Cooke, Georgia Institute of Technology, 1967. NASA Predoctoral Fellow 1963–1966.

(2) Alfred P. Sloan Fellow 1965–1967. To whom all inquiries should be sent.

(3) Abstracted in part from the senior thesis of J. Lott, Georgia Institute of Technology, 1966–1967.

(4) E. C. Ashby and J. Prather, *J. Amer. Chem. Soc.*, **88**, 729 (1966).

(5) P. T. Lansbury, D. J. Scharf, and V. A. Pattison, *J. Org. Chem.*, **32**, 1748 (1967).

(6) (a) E. L. Eliel, *Rec. Chem. Progr.* (Kresge-Hooker Sci. Lib.), **22**, 129 (1961), and references cited therein; (b) M. N. Rerick and E. L. Eliel, *J. Amer. Chem. Soc.*, **84**, 2356 (1962), and references cited therein.

(7) K. Suchy, Dissertation, University of Munich, Munich, Germany, 1966, working under Professor H. Nöth.

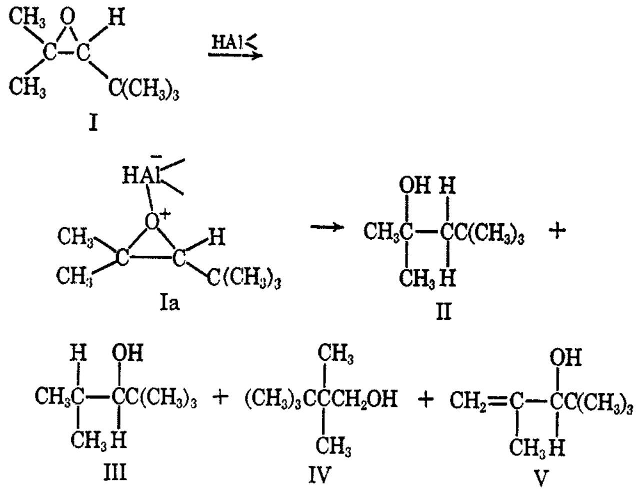
(8) E. L. Eliel and Mark N. Rerick, *J. Amer. Chem. Soc.*, **82**, 1362 (1960).

(9) L. I. Zakharkin and I. M. Khorlina, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 862 (1965).

(10) B. J. Cooke and E. C. Ashby, Abstracts, 153rd National Meeting of the American Chemical Society, Miami Beach, Fla., April 1967, Division of Organic Chemistry, paper 38.

(11) E. C. Ashby and B. Cooke, *J. Amer. Chem. Soc.*, in press.

SCHEME I



should increase the amount of IV produced. The extent of ring opening should be a function of the Lewis acidity of the aluminum hydride reagent complexed to the epoxide oxygen. Therefore formation of IV should be increased as the Lewis acidity of the reducing agent is increased. Consideration of the data in Table I indicates that these conclusions are valid; *i.e.*, as the Lewis acidity of the reagent increases ($AlH_3 < H_2AlCl < HAlCl_2$, so does the amount of IV produced in the reaction.

TABLE I

PRODUCT RATIOS FROM REDUCTIONS OF I INVOLVING HYDRIDOALUMINUM HALIDES[a]

Reducing agent	II	III	IV	V	Yield of Products, %	Ref
$LiAlH_4$[b]	100	...	...	...	21	6[b]
$LiAlH_4$	...	...	...	...	0	10, 11
AlH_3[c]	19	55	5	21	84	10, 11
H_2AlCl[c]	3	31	60	6	92	10, 11
$HAlCl_2$[c]	1	16	74	9	85	10, 11

[a] Threefold molar excess of hydride to epoxide was employed in diethyl ether solvent at room temperature. [b] These results were obtained under forcing conditions (reflux 24 hr). [c] LiCl present.

Inspection of these data also shows that β-diisobutylene oxide is rather inert to attack by even potent hydride donors, such as lithium aluminum hydride, unless the reagent possesses some Lewis acidity, *i.e.*, prior complexation with resultant weakening of the C–O bonds in the oxirane ring is a prerequisite for the occurrence of hydride reduction to any appreciable extent.

Since alkoxy substituents on aluminum are thought to function solely as inductive electron withdrawers,[12] it would be expected that alkoxyaluminum hydrides should exhibit reactivities similar to the mixed hydrides and that product distributions from the reductions of β-diisobutylene oxide involving alkoxyaluminum hydrides should show the trends outlined in Table I. However, comparison of the data presented in Tables II and III with that in Table I indicates that this is not the case.

These data show that there are important differences between the reducing properties exhibited by the mixed hydrides and alkoxyaluminum hydrides. The following generalities can be made. (1) β-Diisobutylene oxide is reactive toward mixed hydride reagents, but is fairly inert to alkoxyaluminum hydrides, especially the dialkoxyaluminum hydrides. This is shown by the fact that the total product yields are low and that a significant amount of starting material could be detected in the reaction mixtures, even in the case of the reactions run under forcing conditions. (2) The yield of V is significantly higher in the case of the reductions involving alkoxyaluminum hydrides than for those involving the mixed hydride reagents, especially in the case of the reactions run under forcing conditions. (3) The reductions involving alkoxyaluminum hydrides yield significantly less migration product than do those involving mixed hydrides, indicating in general the weaker Lewis acidity of the alkoxyaluminum hydrides. (4) Under normal reaction conditions, the yield of III shows a steady decreasing trend in going from aluminum hydride as the reducing agent to dimethoxyaluminum hydride, whereas the yield of II under the same conditions remains relatively constant. (5) Reductions at room temperature produce trends which are interpretable whereas under forcing conditions trends are distorted due to the high yield of V produced.

TABLE II

PRODUCT RATIOS FROM REDUCTION OF I WITH ALKOXYALUMINUM HYDRIDES UNDER NORMAL CONDITIONS IN TETRAHYDROFURAN[a]

Reducing agent	II	III	IV	V	Yield of products, %	Recovery of epoxide, %
AlH_3	30	69	...	1	65–100	...
H_2AlO-*t*-Bu	28	59	3	10	12–24	47–64
$HAl(O$-*t*-$Bu)_2$	...	...	...	...	...	65–77
H_2AlO-*i*-Pr	28	49	6	17	16	58
$HAl(O$-*i*-$Pr)_2$	25	25	25	25	1	58
$HAl(OMe)_2$[b]	23	20	27	30	2	64
$HAlCl_2$[c]	2	27	61	9	75–78	...

[a] Threefold molar excess of hydride to epoxide, room temperature, 2 hr. [b] All solutions of the hydrides were clear except this one because of its polymeric nature. $HAl(OMe)_2$ disproportionates to H_2AlOMe and $Al(OMe)_3$. [c] In admixture with LiCl.

TABLE III

PRODUCT RATIOS FROM REDUCTION OF I WITH ALKOXYALUMINUM HYDRIDES UNDER FORCING CONDITIONS IN TETRAHYDROFURAN[a]

Reducing agent	II	III	IV	V	Yield of products, %	Recovery of epoxide, %
H_2AlO-*t*-Bu	7	25	9	59	53	25
$HAl(O$-*t*-$Bu)_2$	2	2	6	90	51	35
H_2AlO-*i*-Pr	19	45	4	33	76	...
$HAlO(i$-$Pr)_2$	9	3	15	73	9	50
$HAl(OMe)_2$[b]	22	14	14	60	4	50

[a] Threefold molar excess of hydride to epoxide, reflux, 6 hr. [b] All solutions clear except this one.

In short, the alkoxyaluminum hydrides in general act as weaker Lewis acids than the hydridoaluminum halides. The question that must be answered is how can the substitution of an alkoxy group, which supposedly functions only as an inductive electron withdrawer when bound to aluminum, for hydrogen in aluminum hydride yield a reagent of lesser Lewis acidity than aluminum hydride.

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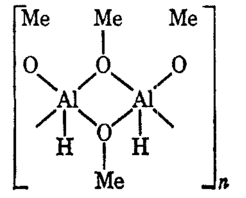
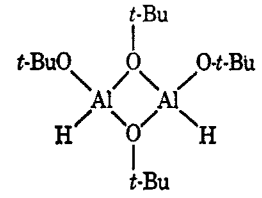
[12] H. C. Brown, E. J. Mead, and C. J. Shoaf, *J. Amer. Chem. Soc.*, **78**, 3616 (1956).

The answer to this question can be found by comparison of the properties of the mixed hydrides and alkoxyaluminum hydrides. Wiberg[13] found that hydridoaluminum halides exist as monomeric etherates in diethyl ether. Nöth and Suchy[7], on the other hand, found that alkoxyaluminum hydrides exist as dimers, trimers, or insoluble polymers in tetrahydrofuran, as shown below, depending on the nature of the alkoxy substituents. These aggregates were found to be associated through bridge bonding involving the alkoxy groups.



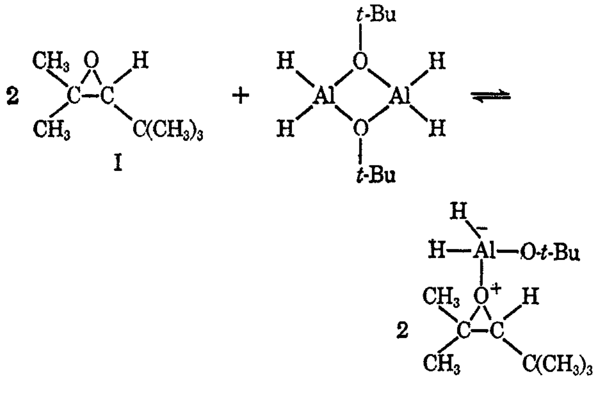
$[AlH(OMe)_2]_n$



$[AlH(O\text{-}t\text{-}Bu)_2]_2$

The difference in association between the two types of reducing agents explains the observed difference in reactivity in the following manner. First of all, it is to be expected that a polymeric species, such as an alkoxyaluminum hydride, would be less reactive than a monomeric species, such as mixed hydride, on steric grounds alone, especially toward a hindered epoxide, such as β-diisobutylene oxide. This would explain the observed over-all low product yields and in particular the high yield of V in these reactions. The fact that product II (direct reduction from least hindered side) remains reasonably constant with an increase in the steric requirement of the reducing reagent whereas product III decreases considerably under the same conditions is reasonable since reduction to product III (direct reduction from more hindered side) should be affected to a greater extent by a bulky reducing agent. The fact that product II is indeed the result of attack from the least hindered side is shown by the fact that only product II is formed when $LiAlH_4$ is the reducing agent (Table I).

The association of alkoxyaluminum hydrides into higher aggregates can also furnish an explanation for the unexpected lack of Lewis acidity exhibited by these reagents. The fact that these compounds were prepared in tetrahydrofuran and yet exist as dimers, trimers, etc., indicates the the alkoxy bridge bonds must be fairly strong and may significantly satisfy the Lewis acidity of the aluminum atom. Also, the first step in the reduction of I involving acidic aluminum reducing agents has been amply demonstrated to be complexation of the type shown (1). Nöth and Suchy have shown[7] that the equilibrium (2) lies far to the left.



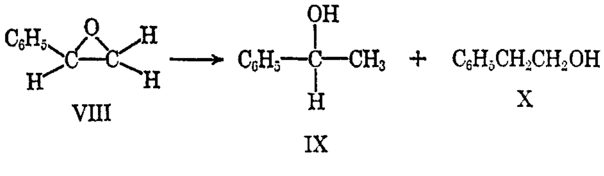
(1)

$$(ROAlH_2)_n + nTHF \rightleftharpoons nROAlH_2\cdot THF \qquad (2)$$

As tetrahydrofuran does not cleave the bridge bonds to a detectable extent, it would be unreasonable to expect a bulky epoxide, such as I, to do so; thus, the equilibrium above should lie far to the left, resulting in little activation of the epoxide by complex formation. Therefore more direct reduction rather than migration product is expected and this is what is observed. Approximately ten times more of product II is formed than when mixed hydride reagents are employed. The fact that the migration product (IV) increases from top to bottom in Table II shows that once the complex is formed and the alkoxyaluminum hydrides dissociated, these reagents do show greater Lewis acidity than AlH_3. The increase in product IV from the *t*-butoxy to the methoxy reagent can be explained by assuming that equilibrium 1 (above) lies further to the right when $R = CH_3$ than when $R =$ *t*-butyl and thus more migration product would be expected. On the other hand, when $R = CH_3$, the resulting alkoxyaluminum hydride is polymeric producing a lower yield than when $R =$ *t*-Bu and the resulting alkoxyaluminum hydride is dimeric. The fact that when $R =$ *i*-Pr the over-all yields are very low (*e.g.*, when $R = CH_3$) as compared to when $R =$ *t*-Bu indicates that diisopropoxyaluminum hydride is more highly associated than the corresponding *t*-butyl compound. Unfortunately Suchy did not study the isopropoxyaluminum hydrides.

Aluminum hydride, of course, is strongly solvated to THF. Because aluminum hydride is monomeric in THF this reagent has a low steric requirement. Also since aluminum hydride possesses no electron-withdrawing groups such as halogen or alkoxy it is a very good hydride donor. Thus products II and III are found in high yield and no migration product is observed. The low yield of V indicates facile reaction. In summary then the results reported in Table II are easily explained in terms of the steric requirement of the hydride and the position of the epoxide–hydride equilibrium to form the complex.

An unfortunate aspect of the reactions of I with alkoxyaluminum hydrides is that they proceed to such a limited extent (especially those with the dialkoxyaluminum hydrides). A study of the reactions of these reducing agents with a more reactive epoxide was carried out in order to see if the trends observed in the reactions of I are observable in the reduction of less hindered epoxides. The epoxide chosen was styrene oxide. When this epoxide was treated with hydrides of various types, products IX and X were obtained (eq 3)



(3)

in varying relative yields, depending on the nature of the reducing agent.[14] Since VIII is well known[14] to be

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[13] E. Wiberg, K. Modritzer, and R. Uson Lacel, *Rev. Acad. Cienc. Exact. Fis-Quim. Nat. Zaragoza*, **9**, 91 (1954).

[14] (a) L. W. Trevoy and W. G. Brown, *J. Amer. Chem. Soc.*, **71**, 1675 (1949); (b) E. L. Eliel and D. W. Delmonte, *ibid.*, **80**, 1744 (1960).

very reactive toward all aluminum-containing hydrides, no statement can be made concerning the role of prior complexation in reductions involving this epoxide. Complexation of styrene oxide by a Lewis acid is obviously not a prerequisite for reduction. Inspection of the data from reductions involving triphenylethylene oxide[6b] shows that there are two pathways involved in the formation of X:[11] (1) complexation followed by direct reduction and (2) complexation followed by hydride migration followed by subsequent reduction of the resulting intermediate. Whichever pathway is involved, the amount of X contained in the reduction products of styrene oxide should be a function of the Lewis acidity of the reducing agent employed. The product ratios from reductions of styrene oxide with various mixed hydrides and alkoxyaluminum hydrides in tetrahydrofuran are shown in Table IV.

TABLE IV
PRODUCT RATIOS FROM REDUCTION OF VIII INVOLVING ALKOXYALUMINUM HYDRIDES AND HYDRIDOALUMINUM HALIDES

Reducing agent	Yield of IX, %	Yield of X, %	Total product yield, %	Recovery of epoxide, %	Ref
$LiAlH_4$	90–95	5–10	82	...	14^{b}
$LiAlH_4$^{a}	91	9	91	...	*b*
$LiAlH_4$	99	1	93	...	*b*
AlH_3	76	24	...	...	*c*
AlH_3	74	26	55	...	*b*
AlH_2O-*t*-Bu	79	21	97	...	*b*
$AlH(O$-*t*-$Bu)_2$	80	20	76	...	*b*
AlH_2O-*i*-Pr	85	15	53	36	*b*
$AlH(O$-*i*-$Pr)_2$	...	...	0	20	*b*
$HAlCl_2$^{a,d}	1	99	69	10	9
$HAlCl_2$^{d}	2–5	95–98	71	...	14^{b}
H_2AlCl^{d}	10	90	75	...	14^{b}
AlH_3^{e}	72	28	80	...	14^{b}

[a] Three moles of hydride per mole of epoxide in diethyl ether at room temperature for 2 hr. [b] This work (THF solvent). [c] H. C. Brown and N. M. Yoon, *J. Amer. Chem. Soc.*, **88**, 1464 (1965). [d] Complexed LiCl was present. [e] LiBr and $LiAlH_4$ present. Yield of IX using pure AlH_3 should be lower.

Comparison of the data from reductions involving mixed hydride reagents and alkoxyaluminum hydrides yields the following information. (1) There is a significant solvent effect observed in going from diethyl ether to tetrahydrofuran. This is shown by comparison of the data from reductions of VIII involving lithium aluminum hydride and from previous studies using mixed hydride reagents.[10,11,14b] Thus in a solvent such as tetrahydrofuran, which increases the hydride donor ability of the mixed hydride reagent and using a nonhindered epoxide, it is found that direct reduction is the predominant product. These results also indicate that the majority of the direct reduction must not involve complexed epoxide since this should result in the predominant formation of X. An indication of the strong donor properties of hydrides in tetrahydrofuran was already indicated with the mixed hydride reagents.[10,11] (2) The product ratios arising from the reductions involving all of the alkoxyaluminum hydrides and aluminum hydride are similar with a noticeable decrease in X when proceeding from AlH_3 to AlH_2O-*t*-Bu to AlH_2O-*i*-Pr. Such a trend is easily understood on steric grounds when proceeding from monomeric AlH_3 to dimeric AlH_2O-*t*-Bu to what is believed to be a more highly associated AlH_2O-*i*-Pr.

Note in Table IV a product yield of 0% for $AlH(O$-*i*-$Pr)_2$ as compared for the same reduction using $AlH(O$-*t*-$Bu)_2$ (76%). Also Table III shows a lower product yield (9% under forcing conditions) for $AlH(O$-*i*-$Pr)_2$ as compared to $AlH(O$-*t*-$Bu)_2$ (51% under forcing conditions). The product yield from Table III involving $AlH(OMe)_2$ (4%) which is known to be polymeric is very similar to that produced from $AlH(O$-*i*-$Pr)_2$ (9%). Thus the trend observed for both product yield and yield of X in Table IV is to be expected on steric grounds of the hydride reagent.

These observations corroborate the arguments outlined above. Alkoxyaluminum hydrides are significantly weaker as Lewis acids than the "mixed hydride" reagents and are similar to the parent compound, aluminum hydride, of both types of reagents. In short, the following order of increasing Lewis acidity is observed: $HAlOR_2 \simeq H_2AlOR \simeq AlH_3 < AlH_2X < AlHX_2$, where $R = CH_3$, *i*-Pr, and *t*-Bu and $X =$ I, Br, and Cl.

The data and arguments outlined above amply demonstrate the fact that alkoxyaluminum hydrides and hydridoaluminum halides are dissimilar in exhibited reactivity as reducing agents.

Experimental Section

Materials Used.—Tetrahydrofuran was obtained from Fisher Scientific Co. and purified by distillation from sodium aluminum hydride under a nitrogen atmosphere. Methanol and isopropyl alcohol were distilled from magnesium turnings. *t*-Butyl alcohol was purified by distillation from sodium under a nitrogen atmosphere. Lithium aluminum hydride was obtained from Metal Hydrides Inc. Solutions were prepared by stirring hydride–tetrahydrofuran slurries overnight, filtering the solid material, and standardizing the clear filtrate by titration of aliquots with EDTA. H_2SO_4 (100%) was prepared from water and fuming sulfuric acid was obtained from Fisher Scientific.

Styrene oxide was obtained from the Aldrich Chemical Co. and purified by drying over potassium carbonate, followed by distillation through a Teflon-coated annular spinning-band column. β-Diisobutylene oxide was dried over potassium carbonate and purified by distillation through a spinning-band column. Vapor phase chromatography analysis showed that this epoxide was 97% pure after two distillations.

Reductions of epoxides were carried out under dry nitrogen in a heat-dried and nitrogen-purged round-bottom flask fitted with a magnetic stirrer and a stopper with two inlet tubes. One inlet was fitted with a nitrogen purge and the other with a serum cap. All reagents were introduced into the reaction vessel by injection through the serum cap with the appropriately sized multifit syringes. Reductions of β-diisobutylene oxide were carried out by first preparing the appropriate alkoxyaluminum hydride from a standardized solution of aluminum hydride in tetrahydrofuran and a stoichiometric amount of the appropriate alcohol, according to the method of Suchi.[7] The aluminum hydride was prepared by combining a standardized lithium aluminum hydride solution with 100% sulfuric acid, according to the method of Brown and Yoon.[15] To the resulting reagent was added a measured amount of a standard epoxide solution. Reductions on this epoxide were carried out either at room temperature for 2 hr (normal conditions) or at reflux for 6 hr (forcing conditions). The reactions were carried out in tetrahydrofuran. After the appropriate time had elapsed, the reaction mixtures were subjected to hydrolytic work-up, dried over potassium carbonate, and concentrated at reduced pressure. A measured amount of 1-octanol, the internal standard for vpc analysis, was added.

Reductions of styrene oxide were carried out in an analogous manner, except that all reactions were carried out at room temperatures for 2 hr. The internal standard for vpc analysis was 1-octanol.

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(15) See Table IV, footnote *c*.

Method of Analysis of Products.—All product analyses were carried out using an F & M Model 720 dual-column temperature-programming vapor phase chromatograph. Columns packed with Carbowax 20M were found to be suitable for product analyses from reductions involving both β-diisobutylene oxide and styrene oxide. The products were identified by comparison of retention times with those of authentic samples. Product ratios were calculated from the areas under the corresponding peaks and the relative responses of the products with respect to 1-octanol, the internal standard. Over-all product yields and material balances were also determined in this manner. The relative responses of the products with respect to 1-octanol were determined by analysis of mixtures of carefully weighed amounts of the products and 1-octanol. All areas were determined by tracing the peaks with a planimeter.

Products from Reductions of β-Diisobutylene Oxide.—2,2,4-Trimethylpentanol-3 for comparison purposes was synthesized from isobutyraldehyde and *t*-butylmagnesium chloride.[16] 2,2,4-Trimethylpenten-1-ol for comparison purposes was synthesized according to the procedure for Rerick and Eliel.[6b]

Products from Reductions of Styrene Oxide.—1-Phenylethanol and 2-phenylethanol for comparison purposes were obtained from Aldrich Chemical Co., and were purified by distillation through a packed column under reduced pressure.

Registry No.—I, 96-06-0; VIII, 96-09-3; $\mathrm{H_2AlO}$-*t*-Bu, 15649-64-6; $\mathrm{HAl(O}$-*t*-$\mathrm{Bu)_2}$, 15649-65-7; $\mathrm{H_2AlO}$-*i*-Pr, 15649-66-8; $\mathrm{HAl(O}$-*i*-$\mathrm{Pr)_2}$, 15649-67-9; $\mathrm{HAl(OMe)_2}$, 15649-68-0.

Acknowledgment.—The authors are indebted to Professor E. L. Eliel for samples of 2,2,4-trimethylpentanol-3, 2,2,3,3-tetramethylbutanol, and β-diisobutylene oxide. The authors are also indebted to the National Aeronautics and Space Administration for partial financial support of this work.

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[16] B. J. Cooke, M.S. Thesis, Georgia Institute of Technology, Atlanta, Ga., 1967.

Imine Photoalkylations. Papaverine, Phenanthridine, and a General Mechanism[1]

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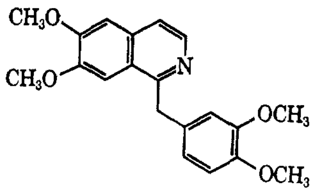
Irradiation of papaverine (or its hydrochloride) in methanol and ethanol produced 1-methyl-6,7-dimethoxyisoquinoline and 1-ethyl-6,7-dimethoxyisoquinoline, respectively. Irradiation of phenanthridine in ethanol yielded 6-ethylphenanthridine. A mechanism is described which serves to correlate the present results with a number of alcohol incorporations in imine photochemistry.

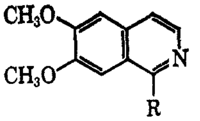
A recent report[2] on the photoalkylation of some pyrimidines and pyrazolopyrimidines prompts us to describe the details of our results[3,4] on alcohol incorporation in the photolysis of papaverine and the photoalkylation of phenanthridine. On the surface, our results and those of Ochiai[2] might appear to involve novel photochemistry. However, closer inspection and consideration of a number of seemingly unrelated literature reports on other imine photochemistry suggested to us that a general mechanism could be written which would correlate a considerable body of C=N photoreactivity. Such a correlation seems valuable at the present time since recent books on photochemistry (with one exception) have largely ignored this topic. This is in spite of the fact that sufficient data is already present in the literature to indicate a versatility of C=N photoreactivity unsurpassed by that of C=O.

Results

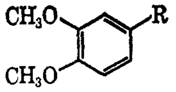
Irradiation of 10^{-3} *M* solutions of papaverine (I) or its hydrochloride in methanol or ethanol for 5–11 days caused 40–60% photolysis and formation of essentially a single basic product (II) in each case, isolated in corresponding yields. With methanol solvent, the product was 1-methyl-6,7-dimethoxyisoquinoline (IIa) and with ethanol solvent, the product was 1-ethyl-6,7-dimethoxyisoquinoline (IIb). Photolysis proceeded only slightly faster in quartz than when a Pyrex filter was used and photolysis did not occur in the same length of time with benzene as solvent. With isopropyl alcohol as solvent, photolysis was relatively rapid (I decreased significantly in hours rather than days) and a mixture of as yet unknown basic products was formed. These products appeared to undergo further photoreactions. In the case of photolysis in methanol and ethanol, the nonbasic products were separated and analyzed. Typical results are given in Table I. The relative yields of methyl and ethyl veratryl ethers (IIIa and IIIb) as compared to veratraldehyde (IIIc) were considerably variable since the former are autoxidizable to the latter. The yields



I



IIIa, R = CH_2OCH_3
b, R = $CH_2OCH_2CH_3$
c, R = CHO
d, R = CH_3
e, R = $COOCH_3$
f, R = $COOCH_2CH_3$
g, R = OCH_3
h, R = H



IIa, R = CH_3
b, R = CH_2CH_3

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[2] M. Ochiai and K. Morita, *Tetrahedron Lett.*, 2349 (1967).

[3] Preliminary results on papaverine photolysis have been reported: Abstracts, the 146th National Meeting of the American Chemical Society, Denver, Colo., Jan 1964, p 40C; see also ref 4.

[4] F. R. Stermitz, R. Pua, and H. Vyas, *Chem. Commun.*, 326 (1967).