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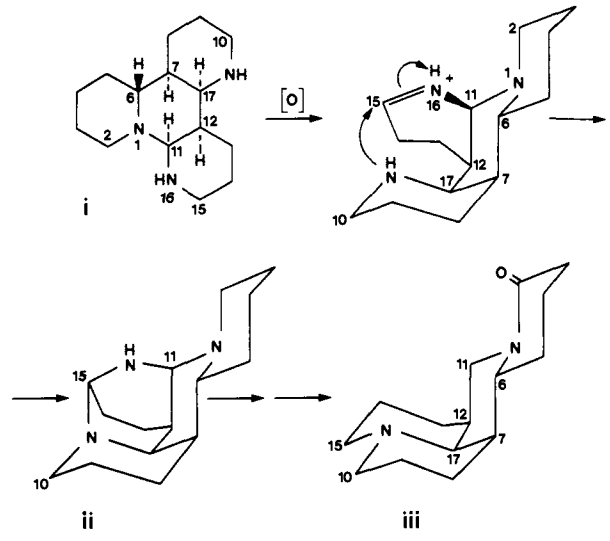
(21) That a compound other than sparteine is the primary alkaloidal product of the biosynthetic sequence is indicated by the finding[9] that sparteine is not an intermediate in the formation of lupanine. The structure of the primary intermediate demanded by the new hypothesis is closely related to 17-oxosparteine or to 10-oxosparteine (aphylline), both of which are naturally occurring compounds.[18,19]
(22) The hypothesis is also applicable to the alkaloids of the matrine series. The piperideine trimer from which these bases are derivable is aldotripiperideine (i),[11,23,24] a compound which has been isolated from a plant source.[25] The route from the required stereoisomer of aldotripiperideine (i) to matrine (iii) via the "prematrine" trimer (ii) is shown below. Matrine as a modified trimer of Δ^1-piperideine (numbering of carbon atoms in all formulas corresponds to the numbering in sparteine).



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(26) Prepared[27] in 50% yield by oxidative decarboxylation of DL-[2-^{14}C]lysine (specific activity 4.7 mCi per mmol, total activity 0.1 mCi, New England Nuclear) and of DL-[6-^{14}C]lysine (specific activity 48 mCi per mmol, total activity 0.1 mCi, Commissariat a l Energie Atomique, France), respectively.
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(29) O. E. Edwards, F. H. Clarke, and B. Douglas, *Can. J. Chem.*, **32**, 235 (1954).
(30) On leave of absence from the Department of Organic Chemistry, University of Warsaw, Poland.

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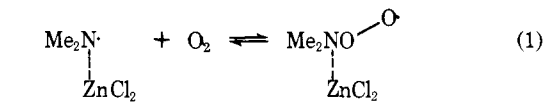
Radical Catalyzed Epoxidation with Oxygen[1]

Sir:

We wish to report the following reactions of oxygen, catalyzed by amino radicals complexed with zinc chloride. Under



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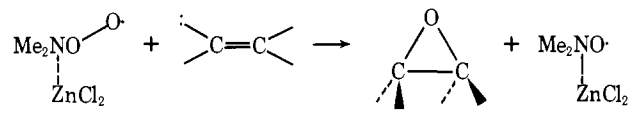
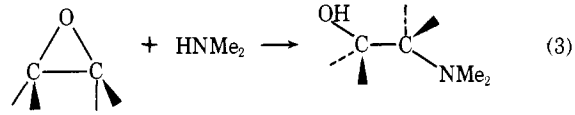
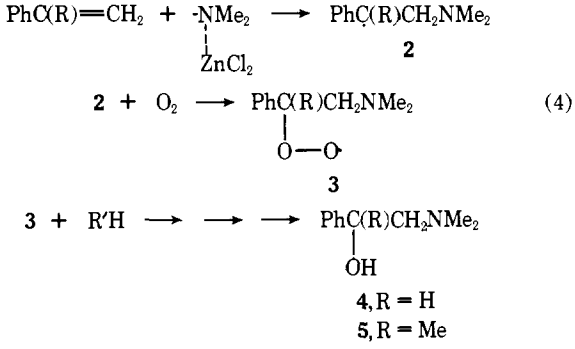


the experimental conditions used, these reactions were usually followed by a third. The case for the unique reactions (eq 1 and



2) rests on the following observations and arguments. Tetramethyl-2-tetrazene (TMT) in dry THF solution was mixed with an excess of anhydrous $ZnCl_2$ and the appropriate olefin. The mixture was warmed at 40–50 °C from 5 to 10 h under a stream of oxygen. The reaction mixture was separated by acid extraction (1 M HCl) of the basic products[2] and fractionation of these by GLC. The components of this fraction were subjected to mass spectral and NMR analysis.[3] The reaction of styrene and α-methylstyrene gave the amino alcohols **4** and **5**, respectively, in 30–40% yields.

These products are consistent with the following (eq 4). The reactions (eq 4) have precedent in the mechanism proposed by Minisci and Galli[4] to explain their results on addition of redox generated amino radicals to alkenes in presence of oxygen.



Mechanism 4, however, does not explain the behavior of the other alkenes studied. Indene gave two amino alcohols, *trans*-2-dimethylamino-1-indanol (**6**)[5] and *trans*-1-dimethylamino-2-indanol (**7**)[6] in 5–10% yields, each. While amino alcohol **6** is consistent with mechanism 4, the amino alcohol **7** is not, because it would require the addition of the amino radical to the benzylic position, an energetically unfavorable site. The reaction of *trans*-β-methylstyrene produced, *exclusively, erythro*-1-dimethylamino-1-phenyl-2 propanol (**8**). This reaction was both regio- and stereospecific. The products from *cis*-β-methylstyrene were *threo*-1-dimethylamino-1-phenyl-2-propanol (**9**) and *threo*-2-dimethylamino-1-phenyl-1-propanol (**10**). Again, the reaction was stereospecific but, in this case, not regiospecific. In the case of the β-methylstyrenes only amino alcohol **10** is consistent with mechanism 4.

All of the "abnormal" products can be accounted for if it is assumed that they are formed by reaction 3. Thus, treatment of indene oxide with dimethylamine gave **7**, *trans*-β-methyl-

styrene oxide and gave exclusively **8,** and *cis*-β-methylstyrene oxide gave a mixture of **9** and **10,** in the same proportion as in the reaction with the TMT:$ZnCl_2$:O_2 mixture. In fact, treatment of the epoxides with a mixture of TMT and $ZnCl_2$ gave the same products.[8] The case for an epoxide intermediate was further strengthened by the observation that treatment of cyclooctene with TMT:$ZnCl_2$:O_2 mixture in the THF gave a 12% isolated yield of cyclooctene oxide **11.** This epoxide is extraordinarily unreactive toward nucleophilic ring opening. No amino alcohol was formed when **11** was treated with dimethylamine or with the TMT:$ZnCl_2$ mixture.[9]

There is some evidence that mechanism 4 may be competing with the epoxidation mechanism under our conditions. The reaction of indene oxide with dimethylamine of the TMT:$ZnCl_2$ complex fails to give any **6,** and yet this product is formed in the reaction with the TMT:$2nCl_2$:O_2 mixture. A small (5%) but significant yield of 1-dimethylamino-2-octanol was obtained in the reaction of 1-octene with TMT:$ZnCl_2$:O_2. This product was also formed when octane-1,2-epoxide was stirred with dimethylamine for several days. However, there was also obtained a small amount of *N,N*-dimethyl-6-hydroxy-1-octylamine in the TMT:$ZnCl_2$:O_2 reaction. This product could only have been formed by intramolecular H-atom transfer in the intermediate 1-dimethylamino-2-octyl radical, followed by reaction with oxygen.

Reaction 1 is reversible. Little or no amino alcohols were formed if the temperature of the reaction was raised to 100 °C or if the oxygen flow was restricted. The main product under those conditions was the addition of two dimethylamino groups to the double bond.[10] In the absence of $ZnCl_2$ the epoxidation reaction does not proceed well. Only a trace of (<1%) was obtained when TMT was photolyzed in the presence of cyclooctene and oxygen. The role of $ZnCl_2$ is not understood yet. It may force the equilibrium (eq 1) further to the right or it may stabilize the nitroxyl radical (or both).[11] There is little precedent for reactions 1 and 2 in the literature. Reaction 1 is reminiscent of the formation of peroxy nitrogen trioxide from nitric oxide and oxygen,[12] but the closest analogy for eq 2 are reactions such as those of acylperoxy radicals with alkenes to give epoxides and the corresponding carboxylic acids.[13] The latter, however, may have an alternative explanation. The present data indicate the epoxide formation is stereospecific and consequently the reaction seems to be a concerted transfer of an oxygen atom from **1** to the alkene. This type of reaction may be a fairly general phenomenon. In fact, something like this may be occurring during biological epoxidations where atmospheric oxygen is introduced stereospecifically into double bonds (such as in squalene [14]) or aromatic systems (such as carcinogenic polynuclear aromatic hydrocarbons[15]). Further work on this reaction is progressing in our laboratory.

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References and Notes

(1) This is paper 3 of a series dealing with complexed radicals. Paper 2 is V. W. Day, D. H. Campbell, and C. J. Michejda, *J. Chem. Soc., Chem. Commun.*, 118 (1975).
(2) The neutral fraction was also examined, but not in as much detail. No epoxides were found in this fraction for the first groups of alkenes discussed.
(3) The components of interest were also compared with authentic samples and, where these were not available, satisfactory microanalytical data were obtained. Details of the structural assignments will be published in a full paper.
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(5) C. F. Huebner, E. M. Donaghue, C. J. Novak, L. Dorfman, and E. Wenkert, *J. Org. Chem.*, **35,** 1149 (1970).
(6) Structure confirmed by single-crystal x-ray structure analysis of the hydrobromide salt (to be submitted for publication).
(7) These products were formed in low yields (ca. 5%), but trace amounts of the other isomers would have been detected by our analytical procedure.
(8) The nucleophilic opening of the epoxides may be a fairly complicated reaction. Some dimethylamine is formed in the disproportionation of amino radicals. However, TMT may also react with the epoxides in a manner similar to that of its' reactions with other alkylating agents. Cf. C. J. Michejda and D. Romans, *Tetrahedron Lett.*, 281 (1968).
(9) A referee made a reasonable suggestion that **11** could be formed by an autooxidation mechanism (cf. D. E. Van Sickle, F. R. Mayo, E. S. Gould, and R. M. Arluck, *J. Am. Chem. Soc.*, **89,** 977 (1967)). This does not seem to be the case here. An increase in O_2 pressure over the reaction (up to 3 atm) did not inhibit epoxide formation, as seems to be the case in the autooxidation reaction. An increase in temperature (up to 100 °C), however, did decrease the amount of epoxide, presumably because of the reversibility of eq 1, but contrary to what is expected for an autooxidation reaction.
(10) C. J. Michejda and D. H. Campbell, *J. Am. Chem. Soc.*, **96,** 929, (1974).
(11) Nitroxyl radicals, which have an H-atom next to the nitrogen, decompose primarily by disproportionation (K. Adamic, D. F. Bowman, J. Gillian, and K. U. Ingold, *J. Am. Chem. Soc.*, **93,** 902 (1971)). Consonant with that, we find dimethylhydroxylamine in the products of the reaction. When the reaction is carried out in the cavity of an ESR spectrometer, the spectrum of the very stable tetramethyl hydrazine radical cation is observed, together with the spectrum of another, unstable, nitrogen radical. The spectrum of the unstable radical (obtained by subtracting away the $TMH^{\cdot+}$ spectrum) is consistent with that of dimethylnitroxyl. The spectrum could be simulated by assuming a_N = 15.2 G, a_H = 12.3 G, line width of 3.9 G.
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(13) P. I. Valov, E. A. Blyumberg, and N. M. Emanuel, *Izv. Akad. Nauk*, 1334 (1966); cf. N. M. Emanuel in Special Lectures, XXIIIrd International Congress, IUPAC, Boston, Mass., Butterworths, London, 1971, p 337.
(14) S. Yamamoto and K. Bloch in "Natural Substances Formed from Mevalonic Acid", T. W. Goodwin, Ed., Academic Press, New York, N.Y., 1969, p. 35.
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A Novel Stereospecific Alkenyl–Alkenyl Cross-Coupling by a Palladium- or Nickel-Catalyzed Reaction of Alkenylalanes with Alkenyl Halides

Sir:

Direct and selective coupling of two unlike alkenyl groups by the reaction of an alkenylmetal derivative with an alkenyl halide has been difficult. None of the known alkenylmetals of the main group elements appears to undergo satisfactorily a stereospecific substitution reaction with an alkenyl halide.[1] Although the reaction of alkenylcuprates with alkenyl halides is promising, it does not appear to have been well developed.[2]

We wish to report that a general and selective procedure for the synthesis of conjugated (*E,E*)- and (*E,Z*)-dienes can now be provided by the reaction of (*E*)-alkenylalanes, readily obtainable via hydroalumination of alkynes,[3] with alkenyl halides in the presence of suitable palladium or nickel complexes (eq 1).

The scope of the new procedure is indicated by the results summarized in Table I and a few representative examples shown below.

Although no detailed mechanistic study has been made, the initial step must involve the oxidative addition of an alkenyl halide to a Pd or Ni complex to form the intermediate (**1**),[4] since no other binary combinations induce any noticeable reaction under these conditions. The following mechanism which is analogous to those proposed for other related cross-coupling reactions[4] seems to accommodate all of the experimental results (eq 5).

The following observations and interpretations may be worth noting. (1) The Pd-catalyzed reaction in each case is highly stereospecific (≥97%), supporting an assumption that all steps proceed with retention of configuration.[5] Moreover, no ho-