mum rotation of (+)-I is known, the maximum rotations of (−)-III and (−)-IV are known, and the stereospecificity of each reaction can be inferred. The conversion of (−)-IV to (+)-I must have followed the same stereochemical course as was observed for the nitrenation reaction of (+)-I to give (−)-III. Since (−)-IV → (+)-I involves substitution at nitrogen and not at sulfur, it very likely proceeds with retention of configuration at sulfur and provides one more piece of interlocking evidence for the configurational assignments to compounds and stereochemical paths for their interconversions.

The discovery of the reaction (−)-(*R*)-IV → (+)-(*R*)-I provides a convenient route for the preparation of optically active sulfoxides not available through the usual Grignard synthesis or the platinium complex resolution.[11] Racemic sulfoxides can be readily converted in good yield by treatment with hydrazoic acid[12] into sulfoximines which in turn are basic enough to be resolvable as salts of optically active sulfonic acids.[13] Finally, optically active sulfoximines can be converted stereospecifically to optically active sulfoxides.

Another reaction broadens the use of optically active sulfoximines as interesting reaction intermediates. Treatment of sulfoximine (−)-(*R*)-IV in aqueous solution with 1 equiv of cold sodium hypochlorite gave (−)-(*R*)-V as an oily precipitate which was extracted with chloroform. The organic layer was dried and evaporated to give (−)-(*R*)-V in 60% yield, mp 66–68.5°, $[\alpha]^{25}{}_{546}$ −266° (*c* 1.35, acetone), which when recrystallized from ether–hexane gave mp 67.5–68.5°, $[\alpha]^{25}{}_{546}$ −264.4° (*c* 0.63, acetone).[5,14] A final recrystallization from acetone did not alter the physical constants. The stability of the sulfoximine group, coupled with the fact that both N-metallo and N-chloro derivatives are readily prepared, suggests that these substances can be used to prepare a large variety of compounds by electrophilic or nucleophilic substitution on nitrogen. Such possibilities are being actively explored.

(11) A. C. Cope and E. A. Caress, *J. Am. Chem. Soc.*, **88**, 1711 (1966).

(12) (a) J. K. Whitehead and H. R. Bentley, *J. Chem. Soc.*, 1572 (1952); (b) F. Misani, T. W. Fair, and L. Reiner, *J. Am. Chem. Soc.*, **73**, 459 (1951).

(13) R. Fusco and F. Tenconi, *Chim. Ind.* (Milan), **47**, 61 (1965); *Chem. Abstr.*, **62**, 10357*h* (1965).

(14) The authors have not found any examples of N-chlorosulfoximines in the literature, but note that N-bromo-S,S-dimethylsulfoximine has been prepared by direct bromination [see R. Appel, H. W. Fehlhaber, D. Hänssgen, and R. Schöllhorn, *Chem. Ber.*, **99**, 3108 (1966)].

(15) National Institutes of Health Postdoctoral Fellow, University of California at Los Angeles, 1966–1967.

Dennis R. Rayner, Don M. von Schriltz[15]
J. Day, Donald J. Cram
Contribution No. 2223, Department of Chemistry
University of California at Los Angeles
Los Angeles, California 90024

Received February 19, 1968

The Induced Oxidation of Cobalt(II) Mesoporphyrin IX Dimethyl Ester by Unsaturated Hydrocarbons[1]

Sir:

We wish to report the induced oxidation of cobalt(II) mesoporphyrin IX dimethyl ester, Co(II)MPIXDME, by unsaturated hydrocarbons. Addition of unsaturated hydrocarbons to a freshly prepared solution of Co(II)MPIXDME in various organic solvents results in an immediate shift of the Soret band from 393 to 411 mμ due respectively to Co(II)- and Co(III)MPIXDME.[2–4] The metal oxidation is followed by porphyrin degradation. Similar results have been obtained which show that Fe(II) in hemoglobin also undergoes oxidation with subsequent porphyrin degradation.[5]

The initial step in the reaction sequence, however, is olefin to metal coordination as shown by the isomerization of *cis*-2-butene to *trans*-2-butene by Co(II)MPIXDME.[6] Co(II)MPIXDME has a d^7 electron configuration and is square planar. Olefin complexation along the coordinately unsaturated *z* axis leads to a d^7 octahedral structure which eventually undergoes oxidation to form the d^6 octahedral Co(III)MPIXDME.[7] This coordination is probably π-complex formation[8] between the olefin and Co(II)MPIXDME without cobalt oxidation.[9] Examples of this type of nonoxidative olefinic–metal coordination are known.[10]

The unsaturated hydrocarbons which induce the oxidation of Co(II)MPIXDME in chloroform are categorized into two classes. Class I hydrocarbons, which cause an immediate spectral shift, consist of unsaturated hydrocarbons with an isolated double or triple bond such as cyclohexene, 1-heptene, 1-pentene, 1-hexyne, 1-octyne, and 1,5- and 1,3-cyclooctadienes. Class II hydrocarbons, which cause a slow spectral shift, consist of unsaturated hydrocarbons with conjugated double or triple bonds such as diphenylacetylene, stilbene, 1,4-diphenyl-1,3-butadiene, acrylonitrile, and fumaric and maleic acids. Conjugated systems are less reactive due probably to resonance energy considerations which lead

---

(1) Presented in part at the Xth International Conference on Coordination Compounds, Nikko, Japan, Sept 1967.

(2) The Soret band is a very intense absorption found in highly conjugated pyrrole-type systems. The position of the Soret band is dependent upon metal oxidation states: J. E. Falk, "Porphyrins and Metalloporphyrins," Elsevier Publishing Co., New York, N. Y., 1964; D. G. Whitten, E. W. Baker, and A. H. Corwin, *J. Org. Chem.*, **28**, 2363 (1963). We have reconfirmed cobalt oxidation by magnetic susceptibility measurements. The oxidation reactions were also carried out in an inert atmosphere and in oxygen- and air-saturated solutions as well as under usual atmospheric reaction conditions. These reactions were carried out in darkness, in the Cary spectrophotometer cell block, and in light (natural and fluorescent), and in various solvents such as benzene, ethyl acetate, thiophene, chloroform, ethanol, and methanol. Under all conditions, no immediate oxidation occurred unless unsaturated hydrocarbons were added.

(3) J. F. Taylor, *J. Biol. Chem.*, **135**, 569 (1940).

(4) V. Caglioti, P. Silvestroni, and C. Furlani, *J. Inorg. Nucl. Chem.*, **13**, 95 (1960).

(5) M. Tsutsui, K. Suzuki, J. Sadai, and R. Velapoldi, to be published.

(6) *cis*- and *trans*-2-butenes in a chloroform solution of Co(II)MPIXDME and in chloroform were allowed to stand for several hours at room temperature in sealed capsules. Butene analyses were carried out using a Perkin-Elmer Model 54GC with an ethyl malonate on Chromosorb P column. No *trans* to *cis* isomerization was observed. This stereospecificity is not unexpected and only verifies the fact that *cis*-2-butene is not as sterically hindered in complexing with Co(II)MPIXDME as the *trans* isomer. No isomerizations were observed in the blank runs. The usual Soret band shift was observed in the *cis–trans* isomerization.

(7) The crystal-field stabilization energies for d^7 octahedral structures are only slightly below those for d^7 square planar with ligands of strong ligand fields. Square-planar to octahedral structural conversions are common using a d^7 square-pyramidal structure as an intermediate: F. Basolo and R. G. Pearson, "Mechanisms of Inorganic Reactions," John Wiley and Sons, Inc., New York, N. Y., 1958, pp 57, 203; J. M. Pratt and R. J. P. Williams, *J. Chem. Soc., Sect. A*, 1291 (1967).

(8) J. Chatt and L. A. Duncanson, *J. Chem. Soc.*, 2939 (1953).

(9) Co(II)MPIXDME dissolved in purified cyclohexene is stable and is not oxidized to Co(III)MPIXDME.

(10) E. O. Fischer and H. Werner, "Metal π-Complexes," Vol. I, Elsevier Publishing Co., New York, N. Y., 1966; J. Halpern, *Ann. Rev. Phys. Chem.*, **16**, 103 (1965); M. A. Bennett, *Chem. Rev.*, **62**, 611 (1962); D. N. Lawson, J. A. Gibson, and G. Wilkinson, *J. Chem. Soc., Sect. A*, 1733 (1966).

to an increase in the energy necessary for localization of electrons to form a simple olefin–metal π complex. *cis*-Stilbene gave typical class II shifts; however *trans*-stilbene gave very slow[11] spectral changes, further evidence for conjugation effects. Maleic and fumaric acids gave results which were analogous to the isomeric stilbenes.

Since Co(II)MPIXDME is coordinately unsaturated, solvation would be expected to affect the oxidation reaction. Oxidation of Co(II)MPIXDME in solvents of high dielectric constants such as methanol occurs very slowly,[12] while Co(II)MPIXDME is stable in solvents of low dielectric constants such as *n*-hexane, *p*-dioxane, and chloroform. This dependence of oxidation on dielectric constant may be related to Jahn–Teller distortion of the square-planar d^7 Co(II)MPIXDME. As solvent dielectric constants increase, Jahn–Teller distortion decreases and the Co(II)MPIXDME approaches octahedral symmetry, thus facilitating oxidation from a d^7 octahedral Co(II) species to the more stable d^6 octahedral Co(III)MPIXDME.[13] It is known that solvent coordination to square-planar Co(II) complexes lowers the oxidation potential of the metal by over 2 V.[5,14] The addition of olefins to the Co(II)MPIXDME in organic solvents results in a replacement of one or both of the solvent molecules[15,16] which are associated along the *z* axis. This π complexation of the olefin along the positive *z* axis would decrease the electron density along the negative *z* axis. Octahedral symmetry would be more closely approximated by "tighter" coordination of the remaining solvent molecule followed by rapid metal oxidation.[17]

In contrast to solvent-caused oxidation in which the Co(III)MPIXDME is stable,[18] olefin addition gives only a transitory Co(III)-type spectrum. The final spectrum, in the latter case, showed a conspicuous absence of the Soret band. This, and the color loss of the solution, indicate that the porphyrin moiety was decomposed.[19]

Three mechanisms may be postulated for the Co(II)-MPIXDME oxidation. The first is that olefin coordination facilitates octahedral symmetry formation and electron transfer; the second, which is analogous to the homogeneous hydrogenation mechanism suggested by Halpern,[20] involves H· abstraction from the solvent; the third is oxidative olefin addition.[21] The first mechanism is preferred in this case due to solvent dielectric considerations, while the other two are not favored since free-radical reactions are generally not solvent dependent.

The mechanisms of metal oxidation and porphyrin decomposition are being investigated by determining the fates of the olefin and porphyrin moiety.

Acknowledgment. This investigation was supported by National Science Foundation Grant NSF GB-5732. Acknowledgment is also made to Mr. Y. Masada who partially assisted in the experimental part of this investigation.

---

[11] *cis*-Stilbene gave 25% oxidation and *trans*-stilbene gave 5% metal oxidation after 2.5 hr.

[12] Approximately 25 hr are needed for total oxidation.

[13] Crystal-field stabilization energies are higher for d^6 octahedral Co(III) than for d^6 octahedral Co(II) species; see ref 7.

[14] J. E. Falk and J. N. Phillips, "Chelating Agents and Metal Chelates," F. P. Dwyer and D. P. Mellor, Ed., Academic Press Inc., New York, N. Y., 1964, p 470; F. A. Cotton and G. Wilkinson, "Advanced Inorganic Chemistry," Interscience Publishers, Inc., New York, N. Y., 1966, p 867.

[15] C. H. Langford and H. B. Gray, "Ligand Substitution Processes," W. A. Benjamin, Inc., New York, N. Y., 1965.

[16] J. P. Collman, M. Jubota, and J. W. Hosking, *J. Am. Chem. Soc.*, **89**, 4809 (1967).

[17] Cobalt oxidation occurs upon olefin addition if the solvent dielectric constant is higher than the dielectric constant of the olefin.

[18] Only two species, Co(II)- and Co(III)MPIXDME, are present in solution as evidenced by an isosbestic point in the spectra of solvent-caused oxidation. The Co(III)MPIXDME absorption at 411 mμ does not decrease with time.

[19] Loss of electronic conjugation in the porphyrin moiety would also account for the absence of the Soret absorption band.

[20] J. Halpern, *Chem. Eng. News*, **46**, 68 (Oct 31, 1966).

[21] J. P. Collman, "The Role of Vacant Coordination Sites in Homogeneous Catalysis," presented at the New York Academy of Sciences, Dec 1967; J. P. Collman, K. W. Kang, W.F. Little, and M. F. Sullivan, Abstracts, 3rd International Symposium on Organometallic Chemistry, Munich, Aug 1967, p 334.

M. Tsutsui, R. Velapoldi
K. Suzuki, A. Ferrari
New York University
New York, New York 10453
Received January 24, 1968

Studies on the Action of 2,3-Oxidosqualene–Sterol Cyclase on Unnatural Substrates Produced by Alkylidene Transfer from Sulfonium Alkylides to 4,8,13,17,21-Pentamethyldocosa-4,8,12,16,20-pentaenal

Sir:

Studies carried out in these laboratories during the period 1961–1966 established that 2,3-oxidosqualene (**1**) is an intermediate in the biosynthesis of sterols from squalene.[1,2] More recently the enzyme which effects the cyclization of **1** to sterol has been obtained in partially purified, soluble form[3] and has been shown to cyclize certain unnatural analogs of **1**.[4–6] In addition, a powerful inhibitor of 2,3-oxidosqualene–sterol cyclase, the corresponding imine, has been developed.[7]

The ^{14}C-labeled 2,3-oxidosqualene used in most of our work was prepared very conveniently and with high specific activity by the reaction of diphenylsulfonium isopropylide (**3**)[8,9] with the aldehyde **2** which is readily available from 2,3-oxidosqualene[1a] by hydration to the 2,3-diol[1a] followed by periodate oxidation. Specifically, aldehyde **2** (2 mmoles) was allowed to react at −70 to −30° with ^{14}C-labeled diphenylsulfonium isopropylide prepared[8,9] from diphenylsulfonium ethylide (2 mmoles) and ^{14}C-labeled methyl iodide (286 mg, 2.00 mCi) to give, after isolation[8,9] and purification using thin layer chromatography (tlc) on silica gel (buffered to pH 10), 2,3-oxidosqualene (**1**) (30–35%) of specific activity 2.8×10^6 dpm/μmole.

---

[1] (a) E. J. Corey and W. E. Russey, *J. Am. Chem. Soc.*, **88**, 4751 (1966); (b) E. J. Corey, W. E. Russey, and P. R. Ortiz de Montellano, *ibid.*, **88**, 4750 (1966); (c) W. E. Russey, Ph.D. Thesis, Harvard University, 1966.

[2] The same conclusion has been reached by other workers; see J. D. Willet, K. B. Sharpless, K. E. Lord, E. E. van Tamelen, and R. B. Clayton, *J. Biol. Chem.*, 242, 4182 (1967).

[3] P. D. G. Dean, P. R. Ortiz de Montellano, K. Bloch, and E. J. Corey, *ibid.*, 242 3014 (1967).

[4] E. E. van Tamelen, K. B. Sharpless, J. D. Willett, R. B. Clayton, and A. L. Burlingame, *J. Am. Chem. Soc.*, **89**, 3920 (1967).

[5] E. J. Corey and S. K. Gross, *ibid.*, **89**, 4561 (1967).

[6] E. E. van Tamelen, K. B. Sharpless, R. Hanzlik, R. B. Clayton, A. L. Burlingame, and P. C. Wszolek, *ibid.*, **89**, 7150 (1967).

[7] E. J. Corey, P. R. Ortiz de Montellano, K. Lin, and P. D. G. Dean, *ibid.*, **89**, 2797 (1967).

[8] E. J. Corey, M. Jautelat, and W. Oppolzer, *Tetrahedron Letters*, 2325 (1967).

[9] E. J. Corey and M. Jautelat, *J. Am. Chem. Soc.*, **89**, 3912 (1967).