Table I. Products and Rate Constants for Oxidation of Cobalt(II)–Ethylenediaminetetraacetate Complex at 25° (I = 0.5)

No.	Oxidant	pH	% product[a] of Co(EDTA)$^-$	k_1,[b] M^{-1} sec^{-1}	k_2,[c] M^{-1} sec^{-1}
1	Fe(bipy)$_3^{3+}$	5.0	⩾95[d]	3.3×10^4	2.8×10^3
		2.5	86[d]		
2	Fe(phen)$_3^{3+}$	4.4	⩾97[d]	9.1×10^4	1.6×10^4
3	Fe(phen-5-SO$_3$)$_3^0$	. . .	. . .	4.6×10^4	1.0×10^4
4	Ru(bipy)$_3^{3+}$	2.5	73[d]	7.9×10^5 [e]	7.3×10^4 [e]
5	Co(py)$_4$Cl$_2^+$	5.0	Co(EDTA)Cl^{2-}	48	48
		2.7	Co(EDTA)Cl^{2-}		
6	Mn(EDTA)(H$_2$O)$^-$	5.0	17	1.6[f]	
		4.3	37		
7	Mn(CyDTA)(H$_2$O)$^-$	5.5	62		
		4.5	80		

[a] Error depends on measurement of optical density ±0.02 unit representing *ca.* ±5% Co(EDTA)$^-$. [b] Oxidation of unprotonated Co–EDTA^{2-} complex. [c] Oxidation of protonated Co–EDTA complex, Co(EDTAH)(H$_2$O)$^-$. [d] Estimated spectrally after removal of the iron(II) or ruthenium(II) complex on a cation-exchange resin. [e] At 5.0° and I = 1.0 M. [f] Second-order rate constant at pH ~5. The dependence on pH is complex since several paths contribute, and we have not investigated the system thoroughly.

in the cobalt(II) solution. For the other oxidants, Fe(bipy)$_3^{3+}$ and Ru(bipy)$_3^{3+}$, our experiments show also that a preponderance of the six-coordinated complex exists in nonprotonated solutions.

The use of the other oxidants 5–7 has been less fruitful in shedding light on the structure of cobalt(II)–EDTA. The oxidation by Co(py)$_4$Cl$_2^+$ is unambiguously inner-sphere since Co(EDTA)Cl^{2-} is the sole product at all pH's. An inner-sphere reaction has been previously observed in the oxidation[7] by Fe(CN)$_6^{3-}$ and has been postulated[8] to occur with IrCl$_6^{2-}$. Such behavior of course is compatible with either formulation of the cobalt(II) complex since the carboxylate is easily ruptured from the metal.

The reactions with the strong oxidants Mn(EDTA)(H$_2$O)$^-$ and Mn(CyDTA)(H$_2$O)$^-$ (CyDTA = *trans*-1,2-diaminocyclohexanetetraacetate) are best understood also in terms of an inner-sphere process. The large amount of five-coordinate product produced by Mn(EDTA)(H$_2$O)$^-$ arises we feel because an effective hydroxo-bridged path can operate with the substantial amount of Mn(EDTA)(OH)$^{2-}$, pK = 5.1,[9] present in the oxidation solution. A five-coordinate product then results by addition of a proton to the cobalt(III)-hydroxo species formed after collapse of the bridge. This viewpoint is supported by the fact that increasing amounts of six-coordinate product arise (a) as the acidity increases and (b) when Mn(CyDTA)(H$_2$O)$^-$ with a much higher pK value (8.1)[10] is used as oxidant.

Summarizing, our work using outer-sphere oxidants indicates that some 80% or more of the six-coordinate species is present in the Co(II)–EDTA solutions at pH ⪆4.5, and there is no reason to doubt that large amounts of six-coordinate EDTA also may be present in other EDTA–metal complexes. Indeed, the manganese(II) complex contains seven-coordinate manganese, Mn(EDTA)(H$_2$O)$^{2-}$, in the solid state[1] and, it has been suggested, in solution also.[11,12]

Acknowledgment. The authors are grateful to the National Science Foundation for a Grant (GP 5671).

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[7] A. W. Adamson and E. Gonick, *Inorg. Chem.*, **2**, 129 (1963); D. H. Huchital and R. G. Wilkins, *ibid.*, **6**, 1022 (1967).

[8] R. Dyke and W. C. E. Higginson, *J. Chem. Soc.*, 2802 (1963).

[9] Y. Yoshino, A. Ouchi, T. Tsunoda, and M. Kojima, *Can. J. Chem.*, **40**, 775 (1962).

[10] R. E. Hamm and M. A. Suiwyn, *Inorg. Chem.*, **6**, 137 (1967).

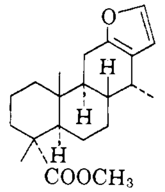
[11] L. Sacconi, P. Paoletti, and M. Ciampolini, *J. Chem. Soc.*, 5046 (1964).

[12] Professor W. C. E. Higginson has informed us that the results of measurements of the association constant of the protonated and nonprotonated cobalt(II)–EDTA complex as well as the hydroxyethylethylenediaminetriacetate complex with a variety of unidentate ligands lead him now to believe that there is a predominance of the six-coordinated EDTA in the cobalt(II) complex (provisional results 77 ± 3%). We thank him for this information prior to publication.

Total Synthesis of Racemic Methyl Vinhaticoate

Sir:

We wish to report the stereoselective total synthesis of the racemic form of the tetracyclic furanoid diterpene methyl vinhaticoate.[1] On the the basis of this synthesis, the previously undefined configuration of the secondary methyl group of the natural product can be assigned as shown in complete structure **1**.



1

In an improved synthesis of a suitable bicyclic intermediate,[2] reductive carbomethoxylation[3] of **2**[4] afforded 68% of **3**.[5] Methylation of **3** (NaH, CH$_3$OCH$_2$CH$_2$OCH$_3$, CH$_3$I), followed by methanolysis of the protecting group, yielded 62% of **4**, mp 123–124°. Preparation of the ethylene dithioketal derivative and Raney nickel reduction afforded **5**, mp 95–96° (90%), which was oxidized to **6**, mp 82–83° (97%).

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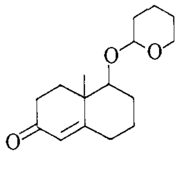
[1] F. E. King and T. J. King, *J. Chem. Soc.*, 4158 (1953); F. E. King, T. J. King, and K. G. Neill, *ibid.*, 1055 (1953).

[2] *Cf.* T. A. Spencer, T. D. Weaver, M. A. Schwartz, W. J. Greco, Jr., and J. L. Smith, *Chem. Ind.* (London), 577 (1964); T. A. Spencer, T. D. Weaver, and W. J. Greco, Jr., *J. Org. Chem.*, **30**, 3333 (1965).

[3] G. Stork, P. Rosen, N. Goldman, R. V. Coombs, and J. Tsuji, *J. Am. Chem. Soc.*, **87**, 275 (1965).

[4] J. D. Cocker and T. G. Halsall, *J. Chem. Soc.*, 3441 (1957).

[5] Infrared, nmr, and, where appropriate, ultraviolet spectral data in agreement with all structural assignments have been obtained. Satisfactory elemental analyses have been obtained for all compounds for which a melting point is given, except racemic **1**.



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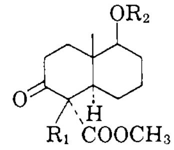
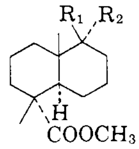
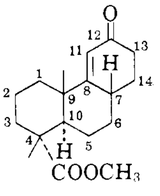


3, $R_1 = H$; $R_2 = THPE$
4, $R_1 = CH_3$; $R_2 = H$



5, $R_1 = OH$, $R_2 = H$
6, $R_1, R_2 = O$

Annelation of **6** was conducted *via* its α-hydroxymethylene derivative[6] to afford 54% of **7**, mp 90.5–91°. Formation of **7** required heating with methanolic sodium methoxide, conditions which ensured opportunity for formation of the more stable C_7 epimer, presumably **7**. Titration of **7** with lithium in ammonia produced a saturated ketone, mp 126–127° (42%),[7] to which the *trans,anti,trans* structure **8** was assigned on the basis of the well-known stereochemical course of lithium–ammonia reductions.[8] Thus five of the six contiguous asymmetric centers of **1** were established with the desired configurations.



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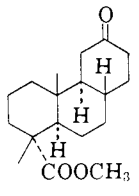
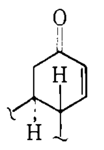
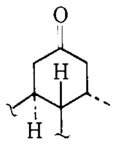


8

Bromination of **8** and dehydrobromination with $CaCO_3$-$(CH_3)_2NCOCH_3$[9] produced **9**, mp 116.5–117.5° (65%), into which the C_{14} methyl group was introduced by reaction with methylmagnesium iodide–cupric acetate.[10] The major product, mp 118.5–120° [$\delta_{\mathrm{TMS}}^{\mathrm{CDCl_3}}$ 0.82 ppm (3H, doublet, J = 6 Hz)], was assigned structure **10** on the basis of precedents in which conjugate addition afforded predominantly axially methylated products.[11] Evidence consistent with this assignment was obtained from nmr spectra of the products from bromination (Br_2–HOAc) of **10**. The only solid derivative isolated had $\lambda_{\max}^{\mathrm{EtOH}}$ 310 mμ (ε ~100) (axial Br)[12] and $\delta_{\mathrm{TMS}}^{\mathrm{CDCl_3}}$ 4.04 ppm (equatorial >C*H*Br).[13] The peak at 4.04 ppm was a singlet, and the apparently unusually small vicinal coupling constant[14] ($J_{13,14}$) is best accounted for by structure **11**, in which the cyclohexanone ring is distorted so as to make the C_{13}–H, C_{14}–H dihedral angle approach 90°.[15] The bromination residues after separation of **11** showed, in addition to the 4.04-ppm singlet, a doublet at 4.42 ppm with J = 5 Hz, ascribable to the presence of **12**. These data are difficult to reconcile with bromination products from the isomeric methylation product **13**.



9



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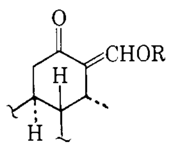
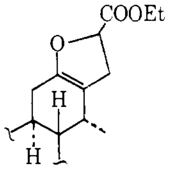
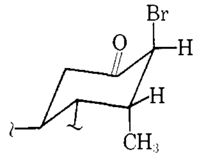


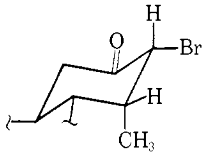
14, R = CH_3
15, R = H
16, R = Ac



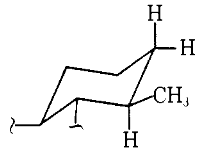
17



11



12



13

A novel furan synthesis[16] was devised to meet the final challenge presented by structure **1**. α-Methoxymethylene ketone **14** was prepared by conversion of **10** to α-hydroxymethylene derivative **15**, acetylation to **16**,[17] and treatment of **16** with methanol and *p*-toluenesulfonic acid.[18] Reaction of **14** with ethyl diazoacetate in the presence of copper sulfate at 160°[16] afforded furoic ester **17** as the principal product (*ca.* 30%). Without purification, **17** was selectively hydrolyzed and decarboxylated[16] to racemic **1**, mp 119–122°. Comparison of the distinctive infrared, ultraviolet, nmr, and mass spectral properties of synthetic **1** with those of natural methyl vinhaticoate[19] established their identity. In particular, both samples displayed the doublet due to the C_{14} methyl at exactly the same chemical shift ($\delta_{\mathrm{TMS}}^{\mathrm{CDCl_3}}$ 0.97 ppm, J = 6–7 Hz[20]) and gave richly detailed high-resolution mass spectra (found for racemic **1**: mol wt 330.2197) which were completely identical, except that a peak with *m/e* 344, due to an unknown impurity, was more abundant in the spectrum of the synthetic material.

Acknowledgment. The authors are grateful for the financial support provided by U. S. Public Health

[6] *Cf.* A. L. Wilds and C. H. Shunk, *J. Am. Chem. Soc.*, **72**, 2388 (1950).

[7] A better yield of **8** (55%) was obtained *via* reduction to saturated diol, oxidation to keto acid, and reesterification.

[8] G. Stork and S. D. Darling, *J. Am. Chem. Soc.*, **86**, 1761 (1964).

[9] G. F. H. Green and A. G. Long, *J. Chem. Soc.*, 2532 (1961).

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[11] (a) J. A. Marshall and N. H. Andersen, *ibid.*, **31**, 667 (1966); (b) W. J. Wechter, *ibid.*, **29**, 163 (1964); (c) R. Wiechert, U. Kerb, and K. Kieslich, *Chem. Ber.*, **96**, 2765 (1963); (d) H. Mori, *Chem. Pharm. Bull.* (Tokyo), **12**, 1224 (1964); (e) *cf.* H. O. House and H. W. Thompson, *J. Org. Chem.*, **28**, 360 (1963).

[12] A. I. Scott, "Interpretation of the Ultraviolet Spectra of Natural Products," Pergamon Press, Oxford, 1964, p 35.

[13] N. S. Bhacca and D. H. Williams ("Applications of NMR Spectroscopy in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1964, p 74) list four α-bromo ketones in which equatorial >C*H*Br has δ 4.06, 4.13, 4.17, and 4.28 ppm, and five α-bromo ketones in which axial >C*H*Br has δ 4.61, 4.63, 4.64, 4.80, and 5.03 ppm.

[14] These spectra were determined on very small samples (~1 mg) using a Varian DA-60-IL spectrometer with a Varian C-1024 time-averaging computer. With the spectrometer conditions used, it was possible to resolve couplings of 0.9 Hz in the spectrum of a dilute sample of furoic acid. However, all lines in all spectra so determined were broadened and it is impossible to give an accurate lower limit to $J_{13,14}$ which would surely have been observed.

[15] Reference 13, pp 49–54 and 75, provides discussion of, and references to, uses of the dihedral angular dependence of vicinal coupling constants.

[16] D. L. Storm and T. A. Spencer, *Tetrahedron Letters*, 1865 (1967).

[17] Further evidence for the α configuration of the C_{14} methyl group was found in the nmr spectrum of **16** which showed the vinyl H as a sharp singlet at δ 7.85 ppm. If the C_{14} H were α (axial) this vinyl proton should appear as a doublet with J = 1.5–2.0 Hz: *cf.* H. Hauth, D. Stauffacher, P. Niklaus, and A. Melera, *Helv. Chim. Acta*, **48**, 1087 (1965); T. A. Wittstruck, S. K. Malhotra, and H. J. Ringold, *J. Am. Chem. Soc.*, **85**, 1699 (1963).

[18] *Cf.* P. Hodge, J. A. Edwards, and J. H. Fried, *Tetrahedron Letters*, 5175 (1966).

[19] We thank Dr. T. J. King for providing a generous sample of natural **1**.

[20] One peak of the doublet is buried beneath the angular methyl singlet at 0.92 ppm, so the exact J value is not known.

Service Grant AM-05104 and, in part, by the Research Corporation.

[21] Alfred P. Sloan Foundation Research Fellow.
[22] Goodyear Foundation Fellow, 1963–1964.

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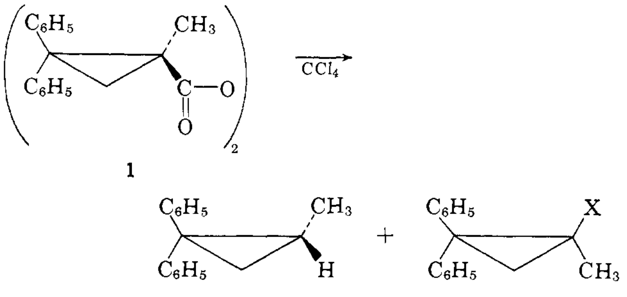
Cyclopropanes. XXII. Cage Disproportionation of Optically Active 1-Methyl-2,2-diphenylcyclopropyl Radical[1]

Sir:

In our previous studies[2] on the decomposition of the diacyl peroxide (**1**) of (+)-(*R*)-1-methyl-2,2-diphenylcyclopropanecarboxylic acid, we found that, in hydrogen atom donating solvents, the 1-methyl-2,2-diphenylcyclopropane (**2**) formed was racemic. This was interpreted to mean that the 1-methyl-2,2-diphenylcyclopropyl radical was incapable of maintaining its configuration, a conclusion which had also been reached for radicals generated at a trigonally hybridized carbon[3] as well as for those produced at a tetrahedrally hybridized carbon.[4] Although the latter radicals have been shown to be planar, the vinyl and cyclopropyl radicals are believed to be bent and to possess inversion frequencies of 10^8–10^{10} sec^{-1}.[5] In order for the vinyl or cyclopropyl radical to be able to maintain its configuration to any appreciable extent, it must react with another substrate at a rate equal to or greater than this inversion frequency. The most likely place to find such a rapid reaction would be within a solvent cage. At this time, we wish to report on the stereochemistry of what we believe to be a reaction occurring in a solvent cage.



1

2

3a, X = Cl
b, X = I

The diacyl peroxide **1** of (+)-1-methyl-2,2-diphenylcyclopropanecarboxylic acid when decomposed in hydrogen atom donating solvents (*i.e.*, toluene, ether, THF, etc.) leads to the formation, *inter alia*, of 1-methyl-2,2-diphenylcyclopropane (**2**) which is racemic. When the decomposition is carried out in pure (vpc) carbon tetrachloride one obtains, besides the expected essentially racemic 1-chloro-1-methyl-2,2-diphenylcyclopropane (**3a**), a 2% yield of **2**. We feel that **2** results from a disproportionation of the 1-methyl-2,2-diphenylcyclopropyl radical within the solvent cage.

Our evidence for the above supposition is based not only on the formation of **2** in a completely halogenated solvent such as carbon tetrachloride but also on the fact that **2** is also formed in a 3% yield when a good radical trap such as iodine[6] is added. Under these conditions no **3a** is formed, only **3b**. Another criterion for cage product is that the amount of product formed is independent of concentration of the initial substrate. As can be seen from Table I the yield of **2** was the same whether one started with a 0.02 *M* solution of **1** or a 0.01 *M* solution. Finally, the best evidence is the stereochemical result. Decomposition of (−)-(*S*)-**1**-yielded (−)-(*R*)-**2** with an optical purity of 37% and with over-all retention of configuration.[7] Starting with the enantiomer, (+)-(*R*)-**1**, the hydrocarbon (+)-(*S*)-**1** was obtained with an optical purity of 31%.

Table I. Decomposition of (+)-, (−)-, and (±)-Diacyl Peroxides of 1-Methyl-2,2-diphenylcyclopropanecarboxylic Acid in CCl_4 at 67°

Run	**1** $[\alpha]^{25}$ Hg, deg	Concn, *M*	% yield (**2**)	**2** $[\alpha]^{25}$ Hg, deg
1	(±)	0.02	2.13 ± 0.07	...
2	(±)	0.01	2.12 ± 0.02	...
3	−30.0^a	0.015	...	−40.0^c
4	+40.0^b	0.016	...	+46.2^d

^{a} Optical purity of **1** 72%. ^{b} Optical purity of **1** 98%. ^{c} Optical purity of **2** 37.4%. ^{d} Optical purity of **2** 31.4%.

To our knowledge the only other example of retention of configuration in a cage reaction is the example provided by Bartlett,[8] who demonstrated that the photolyses of *meso*- and (±)-azobis(3-methyl-2-phenyl-2-butane) in frozen solvents (−196°) yield pure *meso*- and (±)-2,3,4,5-tetramethyl-3,4-diphenylhexane, respectively. At temperatures greater than 0° the stereospecificity is lost. This contrasts the stereochemical behavior of a tetrahedrally hybridized radical[9] with the bent cyclopropyl radical which was able to maintain its configuration to a large extent in a cage reaction at 67°.

[1] This investigation was supported by Public Service Research Grant No. CA 04065-09 from the National Cancer Institute, and in part by the National Science Foundation.
[2] H. M. Walborsky, C. Chen, and J. L. Webb, *Tetrahedron Letters*, 3551 (1964).
[3] J. A. Kampmeier and R. M. Fantazier, *J. Am. Chem. Soc.*, **88**, 1959 (1966); L. A. Singer and N. P. Kong, *ibid.*, **88**, 5213 (1966).
[4] W. A. Pryor, "Free Radicals," McGraw-Hill Book Co., Inc., New York, N. Y., 1966.
[5] R. W. Fessenden and R. H. Schuler, *J. Chem. Phys.*, **39**, 2147 (1963).
[6] G. S. Hammond, *J. Am. Chem. Soc.*, 72, 3737 (1950).
[7] H. M. Walborsky and C. G. Pitt, *ibid.*, **84**, 4831 (1962).
[8] P. D. Bartlett, *Chem. Eng. News*, **42**, 106 (Feb 2, 1966).
[9] E. I. Heibe and R. M. Dessau, *J. Am. Chem. Soc.*, **89**, 2238 (1967), have reported trapping an asymmetric radical before it completely racemized. The reaction involved was an intramolecular cyclization reaction. The optical purities of the diastereomeric products were not given.

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Received August 11, 1967

Structure and Infrared Spectrum of the Solvated Proton in Dimethyl Sulfoxide

Sir:

In the course of other work we have recently found that the equilibrium constant for reaction 1[1] in di-

[1] I. M. Kolthoff and T. B. Reddy, *Inorg. Chem.*, **1**, 189 (1962).