ments in these laboratories show that the latter conclusion is correct and that the nitrogen molecule in nitrogenpentaammineruthenium(II) salts cannot be reduced with borohydride.

Distillation of an aqueous alkaline (NaOH) mixture of $[Ru^{II}(NH_3)_5N_2]Cl_2$ or $[Ru^{II}(NH_3)_5N_2]I_2$ and $NaBH_4$ into either nickel ammonium sulfate solution[5] or hydrochloric acid yields more base when $NaBH_4$ is present than when it is absent. The amount of excess base varies with the amount of NaOH in the starting material and with the salt (chloride or iodide) used. The excess base (over that required for five molecules of ammonia per complex ion) is not reproducible, but up to 16% excess has been obtained. However, experiments using hexaammineruthenium(II) ($[Ru^{II}(NH_3)_6]Cl_2$ or $[Ru^{II}(NH_3)_6]I_2$[6]) gave exactly similar results, and ammonium chloride yields a slight excess (approximately 3%) on treatment with borohydride.

The source of the excess base is unknown. Blank experiments on $NaBH_4$ and NaOH solutions were negative. $[Ru^{II}(NH_3)_5N_2]Cl_2$ was prepared by the reaction between aquopentaammineruthenium(III), $[Ru^{III}(NH_3)_5H_2O]^{3+}$, and sodium azide, NaN_3 (method 3 of ref 2), and was recrystallized three times from water. The iodide salt was prepared metathetically from this material. Tests for hydrazine with *p*-dimethylaminobenzaldehyde[7] on both the nitrogenpentaammineruthenium(II) starting material and on the distillate from the reactions were also negative. However, it is clear from the results using hexaammineruthenium(II) that the source of the excess base is not the nitrogen molecule.

Acknowledgment. We wish to thank Dr. L. R. Melby of E. I. du Pont de Nemours, Wilmington, Del., for advice and assistance with this work, and the National Research Council of Canada for financial support.

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(6) F. M. Lever and A. R. Powell, Special Publication No. 13, The Chemical Society, London, 1959, p 135.
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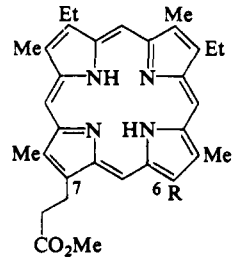
Formation of the Isocyclic Ring in Chlorophyll

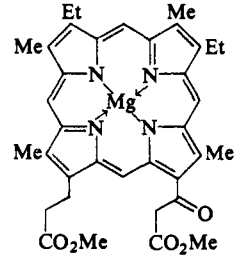
Sir:

Magnesium protoporphyrin IX is a biogenetic precursor of chlorophyll,[1] and much is known about the intervening steps.[2] However, the mode of formation of the isocyclic ring has hitherto remained obscure. Fischer[3] drew attention to the formal possibility that the propionate side chain at position 6 could be transformed to a β-keto acid derivative before cyclization, and speculations about cyclization of such derivatives have been advanced.[4] We now report the first *in vitro* cyclization of a porphyrin β-keto ester to a phaeoporphyrin derivative, and we believe that this is analogous to the *in vivo* process.

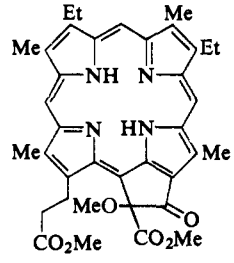


Ia, R = CO_2Me c, R = $COCH(CO_2Me)CO_2Bu$-*t*
b, R = CO_2H d, R = $COCH_2CO_2Me$

Rhodoporphyrin XV dimethyl ester (Ia), synthesized by the b-oxobilane route,[5] was saponified and then partially reesterified (methanolic sulfuric acid, 16 hr at 18°) to the monoester Ib.[6] The acid chloride derived from Ib was condensed with *t*-butyl methyl sodiomalonate, suspended in tetrahydrofuran. The resultant Ic was not purified, but treated directly with trifluoroacetic acid (20 min at 18°), yielding the crystalline β-keto ester Id, which was partially enolized in $CDCl_3$ (nmr spectrum); visible spectrum in chloroform, λ_{max} 410, 509, 544, 573, and 630 nm (log ε_{max} 5.35, 4.08, 4.20, 4.03, and 3.32, respectively), in 0.1 *M* sodium methoxide, λ_{max} 396, 497, 533, 568, and 620 nm (log ε_{max} 5.24, 4.11, 3.98, 3.80, and 3.58, respectively). The mass spectrum of Id did not show a molecular ion but included ions derived by fragmentation of the keto ester side chain,[7] *i.e.*, *m/e* 550 ($M-C_2H_2O_2$) and 508 ($M-C_4H_4O_3$).



II



III

Attempted cyclizations of Id under acidic or basic catalysis were all unsuccessful, as was base-catalyzed cyclization of its magnesium complex II. However, II underwent rapid oxidative cyclization on treatment with iodine in 98% methanol containing sodium carbonate at 20°. After removal of the magnesium, 10-methoxyphaeoporphyrin a_5 dimethyl ester (III)[8] was isolated in 7% yield. Formation of the isocyclic ring may be envisaged

(1) Direct proof for this has been obtained in these laboratories by Carr and Cox using specifically tritiated material [synthesized by the method of R. P. Carr, P. J. Crook, A. H. Jackson, and G. W. Kenner, *Chem. Commun.*, 1025 (1967)] in the isolated chloroplast system developed by J. M. Charlton, K. J. Treharne, and T. W. Goodwin, *Biochem. J.*, **105**, 205 (1967).
(2) L. Bogorad in "The Chlorophylls," L. P. Vernon and G. R. Seely, Ed., Academic Press, New York, N.Y., Chapter 15.
(3) H. Fischer and A. Stern, "Die Chemie des Pyrrols," Vol. II (ii), Akademische Verlag, Leipzig, 1940.
(4) A. C. Jain and G. W. Kenner, *J. Chem. Soc.*, 185 (1959); R. B. Woodward, *Ind. Chim. Belge*, 1293 (1962).
(5) A. H. Jackson, G. W. Kenner, G. McGillivray, and G. S. Sach, *J. Am. Chem. Soc.*, **87**, 676 (1965); A. H. Jackson, G. W. Kenner, G. McGillivray, and K. M. Smith, *J. Chem. Soc., C*, 294 (1968); T. T. Howarth, Ph.D. Thesis, Liverpool, 1967.
(6) Location of the free carboxylic acid group in conjugation with the macrocycle was shown by change of visible absorption spectrum from "rhodo type" in chloroform to "etio type" in methanolic sodium methoxide, and the assignment was confirmed by nmr and by the mass spectrum of the 6-ethyl-7-methyl ester prepared *via* the acid chloride of Ib.
(7) Other porphyrin β-keto esters behaved in an analogous manner on electron impact (A.E.I. MS9 spectrometer, 50 μA, 70 eV, direct inlet at 240°).

as reaction between the radical cation[9] derived from the magnesium–macrocycle complex and the radical derived from the enolate. There is ample precedent[3] for subsequent incorporation of the 10-methoxy group under these conditions.

It is our intention to test the biosynthetical validity of this scheme with labeled 2-vinyl- and 2,4-divinylporphyrin 6-monomethyl esters, analogous to II, in the chloroplast system.[1]

(8) Identified by high-resolution mass spectrum and comparison with an authentic sample.[3]

(9) J-H. Fuhrhop and D. Mauzerall, *J. Am. Chem. Soc.*, **90**, 3875 (1968).

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Base-Catalyzed Carboxylation of Organic Halides by Nickel Carbonyl in Protic Media

Sir:

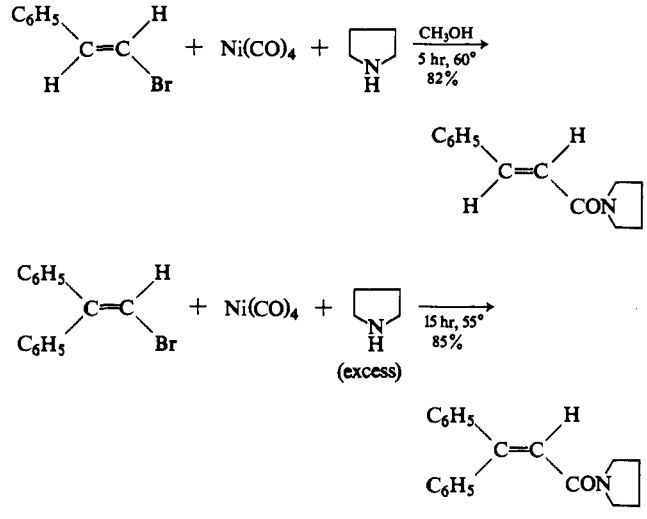
A new method for carbon–carbon bond formation in which halogen attached to trigonal or tetrahedral carbon is replaced by carbon, *e.g.*, *n*-alkyl, using organocopper–lithium complexes has recently been reported.[1] The copper reagents appear to function as electron donors to generate simultaneously two mutually reactive species which combine to form the observed coupling product. This concept suggested the possibility of finding electropositive, transition metal reagents which would function in a similar way to replace halogen by carbon functional groups. As a consequence of studies so directed, a new general method has been developed for the replacement of halogen bound to trigonal or tetrahedral carbon by *carboxylic* functional groups. The method depends on the well-known tendency of certain metal carbonyls to form more strongly electropositive anionic species under the influence of bases.[2,3]

Treatment of a wide variety of organic halides, RHal, with several equivalents of nickel carbonyl in alcoholic medium (R′OH) containing 2–3 equiv of the corresponding sodium or potassium alkoxide results in formation of the esters RCOOR′. The examples cited in Table I illustrate the synthesis of methyl esters using the indicated reactants and reaction conditions.[4] In general, and in accord with the expected reactivity sequence RI > RBr > RCl, the chlorides corresponding to the halides in Table I are unreactive under the conditions there listed. Bromobenzene is unaffected under the conditions which suffice for methoxycarbonylation of iodobenzene. Alkyl halides, including iodides, do not undergo methoxycarbonylation under even more forcing conditions than those given in Table I, and hence it appears that halogen attached to saturated carbon is much less reactive than that on trigonal carbon. Finally, the transformations outlined in Table I proceed much more slowly or (in most cases) not at all in the absence of the methoxide base under the conditions specified. Even iodobenzene, which is known to react with nickel carbonyl in methanol at reflux to form methyl benzoate,[5] is unchanged when sodium methoxide is omitted from the experiment outlined in Table I.[6]

A mixture of nickel carbonyl and potassium *t*-butoxide in *t*-butyl alcohol is a much more powerful carboxylating system than the methanol–methoxide–nickel carbonyl reagent.[7] As indicated in Table II the former mixture effectively *t*-butoxycarbonylates not only trigonal halides but also *alkyl* iodides. Furthermore, it can be seen that even vinylic chlorides can undergo the replacement reaction. Although the nickel carbonyl–*t*-butoxide reagent appears more general than the methoxide reagent, the observed yields of ester were often lower with the former for two reasons: (1) the presence of water in the reaction mixture which leads to formation of carboxylic acid rather than ester is much more critical in the *t*-butyl alcohol–*t*-butoxide system, and (2) dehydrohalogenation is a more serious side reaction in the more strongly basic *t*-butoxide system. Both systems fail in cases where the alkoxycarbonylation product is very reactive toward bases, *e.g.*, with 2-bromopropene as substrate.

Allylic halides, which undergo rapid alkoxycarbonylation by treatment with nickel carbonyl in alcohol solvents,[8] react similarly in the presence of added alkoxide, *e.g.*, 3-bromocyclooctene affords esters of 2-cyclooctenylcarboxylic acid.

Aminocarbonylation has been observed with mixtures of amines and nickel carbonyl as reagents, the following cases being typical.



In addition, direct formation of nitriles is possible as indicated by the following reaction.[9]

(1) (a) E. J. Corey and G. H. Posner, *J. Am. Chem. Soc.*, **89**, 3911 (1967); (b) *ibid.*, **90**, 5615 (1968).

(2) (a) R. B. King, *Advan. Organometal. Chem.*, **2**, 157 (1964); (b) T. A. Manuel, *ibid.*, **3**, 181 (1965).

(3) F. Calderazzo, R. Ercoli, and G. Natta in "Organic Synthesis via Metal Carbonyls," Vol. 1, I. Wender and P. Pino, Ed., Interscience Publishers, New York, N. Y., 1968, pp 1–200.

(4) Reaction products were identified by infrared, nuclear magnetic resonance, and mass spectra and elemental analysis and, for known compounds, comparison with authentic samples.

(5) N. L. Bauld, *Tetrahedron Letters*, 1841 (1963).

(6) All of the experiments described in this note were conducted on a scale of *ca.* 1 mmol, and so the use of excess nickel carbonyl (to compensate for volatilization losses during reaction) was not inconvenient. In larger scale work a modest excess (*e.g.*, 1.5 mol equiv based on halide) would be more satisfactory.

(7) Addition of *t*-butoxide to a solution of nickel carbonyl in *t*-butyl alcohol at 20° produces an immediate deep red coloration, whereas solutions of methoxide and nickel carbonyl in methanol remain colorless for at least 24 hr at 20°.

(8) R. F. Heck, *J. Am. Chem. Soc.*, **85**, 2013 (1963), has demonstrated that these reactions proceed *via* π-allyl- and σ-acylnickel intermediates.