physical evidence for the configurational assignments for V, VI and their corresponding esters. The proton–proton coupling constants for the vinylic hydrogens in V (J_{HH} = 9.7 ± 0.5 cps.; ester 10.4 cps.) and VI (J_{HH} = 15.4 ± 0.5 cps.; ester 14.9 cps.) are in agreement with the observation that *trans* ethenes of this type invariably have higher coupling constants than do the corresponding *cis* isomers. Infrared evidence can be ambiguous (*e.g.*, both geometrically isomeric ethyl *p*-tolylmercaptoacrylates show medium to strong absorption in the region of approx. 10.3–10.6 μ) and definite correlations between spectra and structures should be made with caution. Similarly, dipole moment studies can aid in structural assignments, but a background of model compounds must first be measured in order to isolate the various individual "group" effects.

These results demonstrate that the driving force for thiolates to add in a trans manner is so strong as even to overcome the adverse steric and electronic factors in the present examples.

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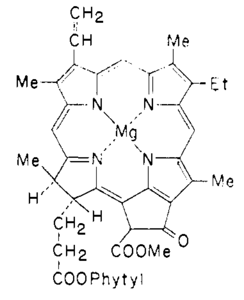
THE TOTAL SYNTHESIS OF CHLOROPHYLL

Sir:

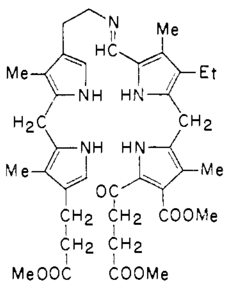
The chemical study of the ubiquitous green pigment of the plant world, chlorophyll *a*, was initiated with the classical investigations of Willstätter just after the turn of the century. The subsequent researches of Stoll and of Conant, and the massive contributions of the Munich school, were crowned by the proposal of a complete structure in 1940 by Hans Fischer. With the addition of stereochemical and other definitive detail during the last few years by Linstead and the Imperial College school, the structural investigations had culminated in the expression I.[1] We now wish to record the total synthesis of chlorophyll *a*, by methods which confirm the structure I in every respect.



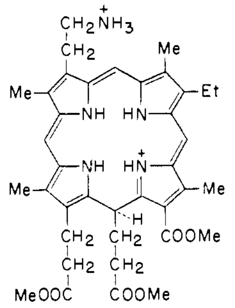
I

2 - (β,β - Dicyanovinyl) - 3,5 - dimethyl - 4 - ethylpyrrole[2] was converted by sulfuryl chloride in acetic acid at 55° to 2-(β,β-dicyanovinyl)-3-methyl-4-ethyl-5-chloromethylpyrrole [m.p. 189–192°], and thence, by condensation with 3-carbethoxy-4-methylpyrrole[3] in hot aqueous ethanolic hydrochloric acid to 3′,4-dimethyl-3-ethyl-4′-carbethoxy-5-(β,β-dicyanovinyl)-dipyrrylmethane [m.p. 195–197°], which, with β-carbomethoxypropionyl chloride in dichloromethane in the presence of anhydrous zinc chloride, gave 3′,4-dimethyl-3-ethyl-4′-carbethoxy - 5 - (β,β - dicyanovinyl) - 5′ - (β - carbomethoxypropionyl)-dipyrrylmethane [m.p. 134–135°]. The acid obtained from the latter by cleavage and hydrolysis with hot 33% aqueous sodium hydroxide was converted by diazomethane to 3′,4-dimethyl-3-ethyl-4′-carbomethoxy-5-formyl-5′ - (β - carbomethoxypropionyl) - dipyrrylmethane [m.p. 203–204°], which, condensed with ethylamine in the presence of acetic acid, gave 3′,4-dimethyl - 3 - ethyl - 4′ - carbomethoxy - 5 - (N - ethylformimino) - 5′ - (β - carbomethoxypropionyl)-dipyrrylmethane [m.p. 85–87°], whose hydrobromide [m.p. 100°], with hydrogen sulfide in benzene/methanol in the presence of sodium methoxide, yielded 3′,4-dimethyl-3-ethyl-4′-carbomethoxy-5-thioformyl - 5′ - (β - carbomethoxypropionyl) - dipyrrylmethane [m.p. 145–146°].

2,5-Dicarboxy-3-methyl-4-formylpyrrole[4] was converted, by condensation with nitromethane in boiling ethanol in the presence of diethylamine, to 2,5 - dicarboxy - 3 - methyl - 4 - (β - nitrovinyl) - pyrrole [m.p. > 300°, $\lambda\lambda_{max}$ mμ: 219, 272, 335], and thence, by reduction with sodium borohydride in aqueous sodium bicarbonate, to 2,5-dicarboxy-3-methyl-4-(β-nitroethyl)-pyrrole [m.p. 244–245°], which was decarboxylated in fused sodium acetate/potassium acetate at 120° to 3-methyl-4-(β-nitroethyl)-pyrrole [b.p. 93° (0.04 mm.), n_D^{25} 1.5200]. The nitro compound was hydrogenated in methanol over reduced platinum oxide to give 3-methyl-4-(β-aminoethyl)-pyrrole [b.p. 80° (0.10 mm.), n_D^{23} 1.5331], which, condensed with 2-formyl-3-methyl-4-(β-carbomethoxyethyl)-pyrrole[5] in methanolic hydrogen bromide, gave 3,3′-dimethyl-4-(β-aminoethyl) - 4′ - (β - carbomethoxyethoxyethyl) - dipyrromethene dihydrobromide [monohydrate, d.p. 200–201°]. The methene was reduced in aqueous



II



III

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[1] (a) *Cf.* A. Stoll and E. Wiedemann, *Fortschr. chem. Forsch.*, **2**(3), 538 (1952); (b) G. E. Ficken, R. B. Johns and R. P. Linstead, *J. Chem. Soc.*, 2273 (1956); (c) J. W. K. Burrell, L. M. Jackman and B. C. L. Weedon, *Proc. Chem. Soc.*, 263 (1959).

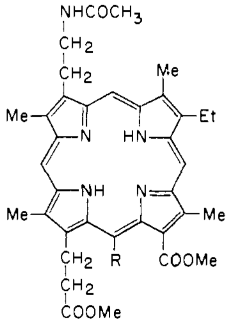
[2] H. Fischer and M. Neber, *Ann.*, **496**, 1 (1932).

[3] A. Treibs, R. Schmidt and R. Zinsmeister, *Ber.*, **90**, 79 (1957).

[4] H. Fischer and K. Zeile, *Ann.*, **483**, 266 (1930).

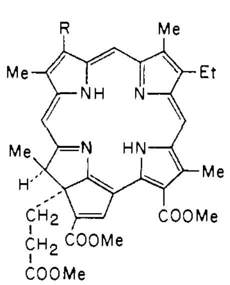
[5] H. Fischer and Z. Csukás, *Ann.*, **508**, 175 (1934).

solution by a large excess of sodium borohydride to the very sensitive 3,3′-dimethyl-4-(β-aminoethyl)-4′-(β-carbomethoxyethyl)-dipyrrylmethane, which was extracted into dichloromethane and converted forthwith, by rapid reaction with 3′,4-dimethyl-3-ethyl-4′-carbomethoxy-5-thioformyl-5′-(β-carbomethoxypropionyl)-dipyrrylmethane [*vide supra*], into the Schiff base II, and thence, by treatment with 12 *N* methanolic hydrogen chloride, to the novel hydroporphyrin salt III [dihydrobromide, $\lambda\lambda_{max}$ mμ (ϵ), 429 (64,000), 514 (5,500), 550 (3,800), 716 (24,220) (CH_2Cl_2)]. Oxidation of the cation with excess iodine, followed by acetylation with acetic anhydride/pyridine gave the porphyrin IV*a* [m.p. 233.5–234°; 50% over-all yield of pure crystalline material from methene and thioaldehyde], which was rapidly and quantitatively oxidized by air in warm acetic acid to IVb [m.p. 251–252°]. The latter, in acetic acid at 110° under nitrogen, was smoothly equilibrated [$K_{purpurin/porphyrin} \sim 5/3$] with the purpurin Va [d.p. 310°, $\lambda\lambda_{max}$ mμ (ϵ): 705 (45,600), 648 (7,100), 574 (17,500), s543 (6,000), 502 (4,100) (CH_2Cl_2)], which was hydrolyzed with hot 1 *N* methanolic hydrogen chloride and treated with methyl sulfate and methanolic sodium hydroxide to give Vb [d.p. 285–290°, $\lambda\lambda_{max}$ mμ (ϵ): 714 (47,400), 657 (6,900), 582 (16,800), s550 (6,200), 505 (3,800) (CH_2Cl_2)]. With air in the presence of visible light, Vb was smoothly oxidized to the purpurin VIa [d.p. 250–255°, $\lambda\lambda_{max}$ mμ (ϵ): 701 (41,300), 644 (7,450), s590 (2,500), 551 (16,600), 512 (6,800), 486 (4,200) (CH_2Cl_2)], which was converted by dilute methanolic potassium hydroxide to *racemic* isopurpurin 5 methyl ester, VIIa [m.p. 220–221°; quantitative infrared and visible spectra identical in all details with those of an optically active sample from natural sources[6]]. Hydrolysis of *racemic* isopurpurin 5 methyl ester with *N*/25 sodium hydroxide in dioxane/water gave *racemic* chlorin 5, VIIb [visible spectrum identical with that of an optically active sample from natural sources[7]], from which a quinine salt [$[\alpha]_{5460.7}^{23}$ + 1236° ($c = 9.72 \times 10^{-3}$, Me_2CO)] was obtained which was identical with material of natural provenance [$[\alpha]_{5460.7}^{23}$ + 1220° ($c = 1.19 \times 10^{-2}$, Me_2CO); $\lambda\lambda_{max}$ mμ (ϵ): 667 (47,600), 610 (5,800), 558 (2000), 528 (7,800), 498 (11,000) (Me_2CO)]. Decomposition of the salt yielded synthetic *active* chlorin 5, VIIb [$[\alpha]_{5460.7}^{23}$ + 1810° ($c = 8.02 \times 10^{-3}$, Me_2CO); visible spectrum identical with that of an authentic sample, $[\alpha]_{5460.7}^{23}$ + 1823° ($c = 8.83 \times 10^{-3}$, Me_2CO); $\lambda\lambda_{max}$ mμ (ϵ): 667 (46,900), 610 (5,500), 560 (2,500), 529 (7,100), 498 (10,300) (Me_2CO)], which was converted by diazomethane to totally synthetic *active* purpurin 5 dimethyl ester, VIb [needles, m.p. 191.5–195°; quantitative infrared (KBr) and visible spectra identical in all details with those of a sample from natural sources, needles, m.p. 192–195°; mixture m.p. not depressed; *cf.* racemic purpurin 5, m.p. 221–222.5°]. Brief treatment of purpurin 5 dimethyl ester (VIb) with hydrogen cyanide in dichloromethane/triethylamine gave the cyanolactone VIIc[8] [m.p. 269–270°], which was treated with zinc and acetic acid, and then with diazomethane, to give chlorin e_6 dimethyl ester nitrile, VIIIa [m.p. 207°]. Treatment of the nitrile with methanolic hydrogen chloride at room temperature gave chlorin e_6 trimethyl ester, VIIIb [m.p. 207.5–208.5°; quantitative infrared (Nujol and CH_2Cl_2) and visible spectra identical in all details with those of an authentic sample, m.p. 208–209.5°; mixture m.p. not depressed]. The conversion of chlorin e_6 trimethyl ester, through phaeophorbide a (IXa) and phaeophytin a (IXb) to chlorophyll *a* (I), follows well-trodden paths.[1a,c]



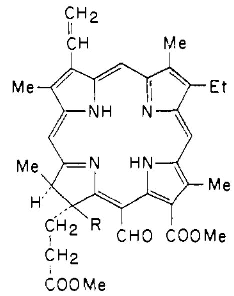
IV

a R = –CH2CH2COOMe
b R = –CH=CHCOOMe



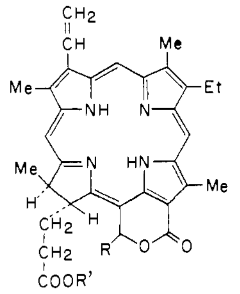
V

a R = –CH2CH2NHAc
b R = –CH=CH2



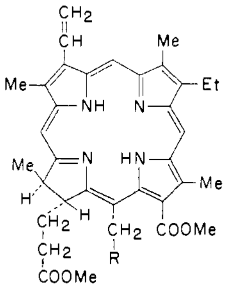
VI

a R = –COCOOMe
b R = –H



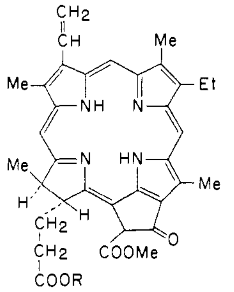
VII

a R = OMe, R' = Me
b R = OH, R' = H
c R = CN, R' = Me



VIII

a R = CN
b R = COOMe



IX

a R = H
b R = Phytyl

All new substances mentioned above have been characterized by ultraviolet or visible and infrared

(6) Isopurpurin 5 is described, but assigned an incorrect structure, by H. Fischer and M. Strell, *Ann.*, **540**, 232 (1939).

(7) H. Fischer and M. Conrad, *Ann.*, **538**, 152 (1939).

(8) *Cf.* H. Fischer and M. Strell, *Ann.*, **543**, 157 (1940).

spectra confirmatory of the structures presented, and satisfactory elementary analyses have been obtained for all except those utilized without isolation.

We wish to express our warm appreciation to the National Institutes of Health, the National Science Foundation, and Research Corporation for generous support, to Chas. Pfizer and Co., Inc., for support and invaluable assistance in preparation of primary intermediates in quantity, to Professor Dr. Arthur Stoll and Sandoz A. G. for a handsome gift of methyl phaeophorbide *a*, and to Drs. Stephan Sallay and Wolfgang H. F. Sasse for their coöperation in certain phases of our work.

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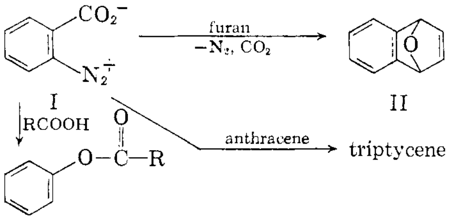
DECOMPOSITION OF BENZENEDIAZONIUM-2-CARBOXYLATE

Sir:

Benzenediazonium-2-carboxylate (I) was prepared by Hantzsch and Davidson,[1] who reported only that its aqueous solution decomposed to furnish salicylic acid in unspecified yield. Recent experiments, here reported, indicate that the decomposition may take an entirely different course in other media.

Freshly prepared samples of the anhydrous crystalline salt are soluble in water ($\lambda_{\max}$ 257 and 302, log ϵ 3.87 and 3.43, respectively), insoluble in nonpolar solvents, and possess sharp peaks at 2283, 1652, and 1624 cm.$^{-1}$ (Nujol mull). The crystalline substance is therefore better represented by the zwitterion formula (I) than by alternative[2] cyclic structures.



Aqueous solutions of I lose nitrogen slowly at room temperature and rapidly upon heating. At 45° during 36 hours an 88% yield of salicylic acid was produced.

Heating suspensions of the inner salt (I) in benzene or toluene results in the evolution of both nitrogen and carbon dioxide, the yield of the latter depending somewhat upon conditions. At 39° during 48 hours in benzene the yield of nitrogen was 100% and of carbon dioxide 59%. The product of decomposition under these conditions is a complex mixture, largely polymeric, which has not been resolved.

Refluxing a suspension of I in furan for 64 hours led to a 55% yield of 1,4-dihydronaphthalene-1,4-endoxide (II),[3] m.p. 55–56°, which was identified by conversion to 1-naphthol (81%) in methanolic hydrochloric acid.[3] Similar decomposition of I in a benzene solution of anthracene gave triptycene (30%).[4] Although direct evidence for an intermediate is lacking, these products are readily visualized as derived from benzyne.[5]

Decomposition of I in the presence of carboxylic acids leads to phenyl esters. Heating the salt to 45–55° with a slight excess of benzoic acid in either benzene or *p*-xylene solution yielded phenyl benzoate (25% and 22%, resp.). Similar reaction with *m*-toluic acid gave phenyl *m*-toluate.[6] Since benzoylsalicylic acid is not measurably decarboxylated under these conditions, and since the rate of decomposition of I at any given temperature is not strongly dependent upon the nature of the other reactant, the postulation of benzyne or an equivalent intermediate in this transformation is also attractive. The types of bonds which are broken in the decomposition of I are sufficiently different from those in molecules which are currently believed to yield benzyne[5] that critical study will be required to determine whether the reaction intermediates are structurally similar. In particular it must be emphasized that there is no necessity in the present case for postulating an intermediate with the symmetry properties which have been demonstrated[7] for the intermediate in the reaction of halobenzenes with various strong bases. Current work aims at testing this point.

The reactions outlined here may find some use in synthesis because of the ease of preparing I,[1] and its compatibility with a wide variety of reagents. A major limitation is the hazard associated with handling large quantities of the substance, owing to its sensitivity to heat and shock.[8]

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RECEIVED MAY 23, 1960

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[1] A. Hantzsch and W. B. Davidson, *Ber.*, **29**, 1535 (1896).

[2] A. Hantzsch and R. Glogauer, *ibid.*, **30**, 2548 (1897).

[3] G. Wittig and L. Pohmer, *Chem. Ber.*, **89**, 1334 (1956).

[4] G. Wittig, *Org. Syn.*, **39**, 75 (1959).

[5] For recent reviews see: (a) G. Wittig, *Angew. Chem.*, **69**, 245 (1957); (b) J. D. Roberts, *Chemical Society (London) Special Publication No. 12*, 115 (1958); (c) R. Huisgen and J. Sauer, *Angew. Chem.*, **72**, 91 (1960).

[6] These three experiments, involving variation of both the aromatic solvent and the acid reactant, indicate that the aryl esters are derived from both I and the acid, and eliminate mechanisms in which benzoate radicals form phenyl benzoate by partial decarboxylation or by attack upon solvent.

[7] J. D. Roberts, H. E. Simmons, Jr., L. A. Carlsmith and C. W. Vaughan, THIS JOURNAL, **75**, 3290 (1953); J. D. Roberts, D. Semenow, H. E. Simmons, Jr., and L. A. Carlsmith, *ibid.*, **78**, 601 (1956); A. T. Bottini and J. D. Roberts, *ibid.*, **79**, 1458 (1957); E. Jenny and J. D. Roberts, *Helv. Chim. Acta*, **38**, 1248 (1955).

[8] Of some twenty preparations of the compound, two were encountered which detonated upon being scraped against the surface of a porcelain funnel.