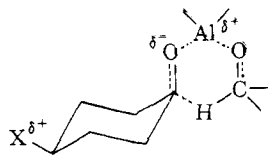

IV

plying that product formation is controlled by other factors than the field effect of the remote substituent.

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STUDIES OF CHLOROBIUM CHLOROPHYLLS. V. CHLOROBIUM CHLOROPHYLLS (660)[1]

Sir:

The evidence presented below suggests that Chlorobium chlorophylls (660) are derivatives of δ - methyl - 2 - desvinyl - 2 - α - hydroxyethyl-pyropheophorbide *a*.[2,3]

Hydrolysis of crude "pheophytin" (660) in dilute hot methanolic KOH and partition chromatography between aqueous HCl and ether on Celite columns[4] gave seven fractions which were designated 1–7. All fractions possessed a conjugated carbonyl group[5]; all possessed a hydroxyalkyl group which could be oxidized to a conjugated carbonyl group[6] or dehydrated to an alkenyl group[7]; all gave a negative Molisch phase test.[8] Comparison of their visible absorption spectra revealed no significant differences among them.

The neutral imides obtained from the fractions by oxidative degradation were examined by gas–liquid partition chromatography.[4,9] Fractions 1 and 2 yielded an unidentified product; fractions 3 and 4 yielded methyl-*n*-propylmaleimide; and fractions 5, 6 and 7 yielded methylethylmaleimide. After conversion of the hydroxyalkyl group to an alkyl group, fractions 3 and 4 yielded methylethylmaleimide in addition to methyl-*n*-propylmaleimide. Dihydrohematinic acid imide was shown earlier to occur in the acid fraction from partially purified pheophorbide (660).[5,9] These results indicate the nature of the substituents on Rings I, II and IV.

Fraction 5 (I) (*Anal.* Calcd. for $C_{35}H_{40}O_4N_4$: C, 72.39; H, 6.94; N, 9.65. Found: C, 72.45; H, 7.43; N, 9.39) was used for the following studies: Dehydration of (I) in phosphoric acid (100%, 65°, 30 min.) yielded the alkenyl derivative (II). *Anal.* Calcd. for $C_{35}H_{38}O_3N_4$: C, 74.70; H, 6.81; N, 9.96. Found: C, 75.09; H, 6.83; N, 10.00. Hydrogenation[10] of (II) yielded the alkyl derivative (III). *Anal.* Calcd. for $C_{35}H_{40}O_3N_4$: C, 74.44; H, 7.14; N, 9.92. Found: C, 73.86; H, 7.17; N, 9.94. Oxidative degradation of (III) yielded only methylethylmaleimide in the neutral fraction.

Oxidation of (I) by oxygen in alkaline dimethylformamide yielded a dicarbonyl derivative (IV). *Anal.* Calcd. for $C_{35}H_{38}O_5N_4$: C, 70.68; H, 6.44; N, 9.42. Found: C, 70.31; H, 6.32; N, 9.46. Under the same conditions mesopyropheophorbide *a* (V) yielded the C_9–C_{10} ring diketone.[11] (III) was likewise oxidized to its dicarbonyl derivative (VI). Further oxidation of (VI) by H_2O_2 in alkaline dimethylformamide yielded a tricarboxylic acid (VII). A portion was methylated and converted to its zinc complex. *Anal.* Calcd. for Zn-$C_{35}H_{35}O_3N_4(OCH_3)_3$: OCH_3, 13.0. Found: OCH_3, 12.9. The remainder was dried at 100° to yield a product (VIII) whose visible absorption spectrum resembled that of purpurin 18.[12] It was methylated and converted to its zinc complex. *Anal.* Calcd. for $ZnC_{35}H_{35}O_4N_4(OCH_3)$: OCH_3, 4.62. Found: OCH_3, 5.05. Dilute methanolic KOH converted (VIII) back to (VII). Treatment of the trimethyl ester of (VII) with methanolic KOH in pyridine did not generate the Molisch phase test intermediate as it does when chlorine$_6$-trimethyl ester is treated likewise.[13] This result excluded the possibility of a cyclohexanone ring in (I).

HI in acetic acid converted (I) into a porphyrin containing a conjugated carbonyl group and an ethyl in place of a hydroxyethyl group.[3] *Anal.* Calcd. for $C_{35}H_{38}O_3N_4$: C, 74.70; H, 6.81; N, 9.96. Found: C, 74.32; H, 7.03; N, 10.02. The visible absorption spectrum was of the "etio" type.[12] (VII) was heated in HCl (1%) in a sealed tube at 185° for three hours. The wave lengths of the absorption maxima of the resulting porphyrin and of phylloporphyrin[14] were identical. However, bands II and III of the Chlorobium product absorbed with equal intensities.

The above result suggested that (I) possessed an alkyl group attached to one of the methine bridge carbon atoms. It was shown to be at C_δ by the following: (V) exposed to somewhat aged, ethanol-free, dry chloroform was converted to a chlorine-containing product (IX) whose visible absorption spectrum was almost superposable upon that of (I).[15] *Anal.* Calcd. for $C_{33}H_{35}O_3N_4Cl$: C, 69.40; H, 6.18; N, 9.81; Cl, 6.20. Found: C, 69.14; H, 5.97; N, 9.75; Cl, 6.10. The same product was obtained using the method described by Woodward and Skarić.[16] The proton magnetic resonance spectra of (III), (V) and (IX) were measured in $CDCl_3$. The signal assigned to the C_δ-proton[16] was absent from the spectra of (III) and (IX) but present in that of (V). In

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(16) R. B. Woodward and V. Škarić, *J. Am. Chem. Soc.*, **83**, 4676 (1961).

addition, the spectra indicated that all contained the same number of methyl groups, but that (III) contained an extra ethyl group. It remains to be determined whether the C_5 substituent is methyl and the C_δ substituent is ethyl or *vice versa*.

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(17) N. R. C. Postdoctoral Fellow, 1959–1961.
(18) N. R. C. Postdoctoral Fellow, 1960–1961.
(19) N. R. C. Postdoctoral Fellow, 1961–1962.

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CONFORMATIONAL ANALYSIS. XXXI. THE ISOPROPYL GROUP[1,2,3]

Sir:

Conformational energies of simple alkyl groups are the fundamental quantities on which conformational analysis is based, and values for the methyl and ethyl groups are known[4] to be about 1.8 kcal./mole. The numerical values previously reported for the isopropyl group range from 2.5 to 3.55 kcal./mole,[5-7] with the value 3.3 being commonly quoted.[4a] Other evidence[8] has been taken as support for a value for isopropyl which is considerably greater than those of methyl and ethyl. A rough statistical treatment of the problem suggests that while the axial isopropyl loses rotational freedom to a greater extent than do the smaller groups, the effect is small, and partially cancelled by an opposing enthalpy difference, and it can be predicted that at ordinary temperatures the free energy of an axial isopropyl should be only slightly greater than those of methyl and ethyl. If this prediction were to be correct, it would mean that the *a priori* assumption often made that an isopropyl group is almost as "big" as a *t*-butyl group[9] and is sufficient to establish a fair degree of conformational homogeneity in simple molecules would have to be abandoned, except as a rough approximation.

The free energy of an axial isopropyl (relative to an equatorial) has therefore been determined in two independent ways. First, 1,3-diisopropylcyclohexane has been equilibrated at elevated temperatures with a palladium catalyst,[10] the composition of the equilibrium mixture was determined by gas phase chromatography on a column of γ-methyl-γ-nitropimelonitrile, and the ΔF^0 for the isomerization[11] *trans* ⇄ *cis*-1,3-diisopropylcyclohexane was found to be -1.91 ± 0.01 kcal./mole at 560°K. When the symmetry properties of the molecule are taken into account, from this value one calculates that for the reaction *equatorial* isopropyl ⇄ *axial* isopropyl, $\Delta F^0_{298} = 2.10$ kcal./mole.

An independent measurement of the free energy of an axial isopropyl group was also made by determining the equilibrium point for the isomerization of the *cis* and *trans* ethyl 4-isopropylcyclohexanecarboxylates. The free energy of an axial ethyl carboxylate group was determined in the present work (by equilibration of the ethyl 4-*t*-butylcyclohexanecarboxylates) as 1.24 kcal./mole at 373°K., in agreement with literature values.[12] One can then calculate the free energy of the alkyl group from the measured equilibrium constant using the equation $\Delta F^0_{alkyl} = RT \ln [(K_i K_{COOEt} - 1)/(K_{COOEt} - K_i)]$, where K_i is the observed constant for the *cis* ⇄ *trans*-isomerization and K_{COOEt} is the constant for an axial ⇄ equatorial carbethoxyl.

In this work the equilibration was carried out at temperatures in the range of 329–416°K. using ethanol as solvent with sodium ethoxide catalyst. The analysis was done by gas chromatography on a Tide column, and the observed equilibrium constants gave $\Delta F^0 = 2.49$ (at 416°) and 2.22 (at 329°), which gives a value of $\Delta F^0 = 2.12$ kcal./mole at 298°. Similar studies were carried out with the 4-methyl and 4-ethyl carboxylates and the data are summarized in Table I. These values lead to standard free energy changes as given in Table II.

TABLE I

EQUILIBRIUM CONSTANTS FOR THE REACTION ETHYL *cis*-4-ALKYLCYCLOHEXANECARBOXYLATE ⇄ ETHYL *trans*-4-ALKYLCYCLOHEXANECARBOXYLATE

T, °K.	Me	Et	*i*-Pr	*T*, °K.	*t*-Bu
416.2	3.30	3.33	3.78	415.7	4.61
375.1	3.97	4.01	4.44	376.7	5.26
352.9	4.34	4.26	4.85	352.4	5.83
329.1	4.90	4.77	5.38	329.4	6.55

TABLE II

VALUES[a] FOR THERMODYNAMIC QUANTITIES FOR THE REACTION EQUATORIAL ⇄ AXIAL ALKYLCYCLOHEXANE AT 298°K.

Alkyl	ΔF^0, kcal./mole
Methyl	1.87
Ethyl	1.80
Isopropyl	2.11

[a] Calculated from the experimental data in Table I. The probable error in ΔF^0 estimated to be 0.1 kcal./mole.

The qualitative conclusion is that the isopropyl group is essentially the same size (in the present

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(2) This research was supported by a grant from the National Science Foundation.
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