HCl in 20 ml of absolute ethanol was heated under reflux for 5 hr to give 65 mg (98%) of a pale yellow oil. Two recrystallizations from methanol gave 55 mg (80%) of **16**: mp 70–71°; $[\alpha]^{27}D$ −136° (*c* 0.472); $\nu_{max}^{CS_2}$ 837, 813, 734, and 698 cm^{-1}; $\lambda_{max}^{cyclohexane}$ 238 mμ (ε 9410), 245 (9860), and 253 (6570); nmr (CCl_4) τ 3.92 (1 H, doublet of triplets, $J_{2,3}$ = 10 Hz, $J_{1,3}$ = 2 Hz, C-3 vinyl), 4.38 (1 H, d, $J_{2,3}$ = 10 Hz, C-2 vinyl), 4.66 (1 H, s, C-7 vinyl), and 7.93 (3 H, m, allylic).

Anal. Calcd for $C_{25}H_{40}$: C, 88.16; H, 11.84. Found: C, 87.87; H, 11.60.

Enol Acetylation of AB-Dinor-5β-cholestan-2-one (7).—A solution of 2.00 g (5.58 mmol) of **7** and 0.40 g of *p*-toluenesulfonic acid in 200 ml of redistilled isopropenyl acetate was allowed to reflux for 3 days under forcing conditions.[6b] Chromatography of the crude product on silica gel gave 2.3 g of an oil that crystallized from methanol to give 2.10 g (97%) of an approximately 1:1 mixture of the Δ¹- and Δ²-enol acetates of **7**: mp 36–37°; $\nu_{max}^{CCl_4}$ 1766, 1665, 1645, and 1215 cm^{-1}; $\lambda_{max}^{cyclohexane}$ 193 mμ (ε 9680); nmr (CCl_4) τ 4.72 (1 H, m, vinyls) and 7.99 (3 H, s, acetyl).

Anal. Calcd for $C_{27}H_{44}O_2$: C, 80.94; H, 11.07. Found: C, 80.83; H, 11.30.

17β-Hydroxy-2-hydroxymethylene-B-norandrost-4-en-3-one (18).—A suspension of 1.79 g (6.53 mmols) of B-nortestosterone (**17**), 1.88 ml (23.5 mmol) of ethyl formate, and 0.56 g (23.6 mmol) of sodium hydride in 38 ml of benzene was stirred under N_2 for 3 days at room temperature and worked up as usual[9] to give 1.95 g (99%) of **18**. Recrystallization from methylene chloride–petroleum ether gave an analytical sample: mp 214–216°; $[\alpha]^{25}D$ −73° (*c* 0.430); $\nu_{max}^{CHCl_3}$ 3450, 1640, and 1562 cm^{-1}; λ_{max}^{EtOH} 250 mμ (ε 11,300) and 307 (6810).

Anal. Calcd for $C_{19}H_{26}O_3$: C, 75.46; H, 8.66. Found: C, 75.37; H, 8.66.

17β-Hydroxy-2,3-seco-B-norandrost-4-ene-2,3-dioic Acid (19).—A solution of 1.00 g (3.31 mmol) of **18** in 30 ml of 1:1 glacial acetic acid–ethyl acetate was treated with 3.31 mmol of ozone at −15° to give 0.74 g (69%) of crystalline seco diacid **19**, mp 212–214°. Recrystallization from aqueous methanol gave an analytical sample: mp 230–232°; $[\alpha]^{25}D$ −46° (*c* 0.450); ν_{max}^{KBr} 3330, 2597, 1712, and 1645 cm^{-1}; λ_{max}^{EtOH} 223 mμ (ε 12,600); nmr (CH_3OD) τ 5.30 (1 H, m, vinyl).

Anal. Calcd for $C_{18}H_{26}O_5$: C, 67.06; H, 8.13. Found: C, 66.86; H, 8.11.

17β-Hydroxy-AB-dinorandrost-3-en-2-one Acetate (20).—A solution of 4.75 g (14.75 mmol) of **19** and 3.82 g (59 mmol) of KCN in 250 ml of acetic anhydride was allowed to reflux under argon for 2 days and then worked up as described for **4**. Chromatography of the crude product on alumina gave 3.03 g (68%) of an oil, which was crystallized from methylene chloride–petroleum ether to give 2.64 g (60%) of crystalline **20**: mp 109–112°; $[\alpha]^{26}D$ −155° (*c* 0.491); ν_{max}^{CCl} 1742, 1712, and 1633 cm^{-1}; λ_{max}^{EtOH} 235 mμ (ε 13,500); nmr ($CDCl_3$) τ 4.25 (1 H, t, *J* = 1.5 Hz, vinyl), 5.40 (1 H, t, *J* = 7 Hz, 17α H), 7.97 (3 H, s, acetyl), 8.94 (3 H, s, C-19), and 9.13 (3 H, s, C-18).

Anal. Calcd for $C_{18}H_{26}O_3$: C, 75.46; H, 8.67. Found: C, 75.53; H, 8.45.

17β-Hydroxy-AB-dinorandrost-3-en-2-one (21).—A solution of 2.64 g (8.75 mmol) of **20** and 5 g of KOH in 125 ml of 95% methanol was allowed to reflux for 1 hr under nitrogen to give 1.9 g of crude **21** that was chromatographed on alumina to yield 1.70 g of crystalline **21**, mp 114–116°. Recrystallization from methylene chloride–petroleum ether gave an analytical sample: mp 116–117°; $[\alpha]^{25}D$ −150° (*c* 0.479); $\nu_{max}^{CCl_4}$ 3610, 3448, 1709, and 1626 cm^{-1}; λ_{max}^{EtOH} 235 mμ (ε 13,500); nmr ($CDCl_3$) τ 4.24 (1 H, t, *J* = 1.5 Hz, vinyl), 6.32 (1 H, t, *J* = 7.5 Hz, 17α H), and 7.78 (2 H, s, C-1 methylene); ORD (*c* 0.0024, ethanol) $[\alpha]_{400}$ −553°, $[\alpha]_{250}^{trough}$ −18,700°, $[\alpha]_{215}^{peak}$ +44,200° (*a* = −1636).

Anal. Calcd for $C_{17}H_{24}O_2$: C, 78.40; H, 9.29. Found: C, 78.13; H, 9.27.

17β-Hydroxy-AB-dinor-5β-androtan-2-one (22).—A solution of 515 mg (1.98 mmol) of **21** in 50 ml of 95% ethanol was hydrogenated at atmospheric pressure over 50 mg of 5% palladium on charcoal to give 514 mg (99%) of **22**, mp 128–130°. Two recrystallizations from chloroform gave an analytical sample: mp 131–133°; $[\alpha]^{29}D$ −10° (*c* 0.460); $\nu_{max}^{CCl_4}$ 1739 cm^{-1}; nmr ($CDCl_3$) τ 8.93 (3 H, s, C-19) and 9.25 (3 H, s, C-18); ORD (*c* 0.085, methanol) $[\alpha]_{400}$ −24°, $[\alpha]_{311}^{trough}$ −530°, $[\alpha]_{272}^{peak}$ + 647° (*a* = −30.9).

Anal. Calcd for $C_{17}H_{26}O_2$: C, 77.82; H, 9.90. Found: C, 77.57; H, 9.82.

Registry No.—**2**, 19955-03-4; **3**, 19933-87-0; **4**, 19933-77-8; **7**, 19933-78-9; **7** (Δ¹-enol acetate), 19933-79-0; **7** (Δ²-enol acetate), 19933-80-3; **10**, 19933-89-2; **12**, 19955-04-5; **13**, 19933-81-4; **15**, 19955-05-6; **16**, 19933-82-5; **18**, 19933-83-6; **19**, 19933-88-1; **20**, 19933-86-9; **21**, 19933-84-7; **22**, 19933-85-8.

Photoisomerization of Acyclic Conjugated Cyclopropyl Carbonyl Compounds[1]

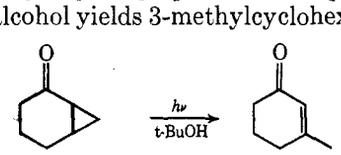
WILLIAM G. DAUBEN AND GARY W. SHAFFER[2]

University of California, Berkeley, California 94720, and Givaudan Corporation, Clifton, New Jersey 07014

Received December 30, 1968

The photochemistry of the acyclic vinylcyclopropane carbonyl chromophore has been studied. Using Corex-filtered light, dihydrofurans (**4**–**6**), δ,ε-unsaturated acids (**7** and **8**), and epoxycyclobutanes (**9** and **10**) were found. The mechanism for the formation of these materials are discussed, and all reactions involve conjugative opening of the cyclopropane ring (eq 6 and 7). The formation of a ketene from an acyclic aldehyde is a new process and it has been shown to proceed intramolecularly (eq 8).

The photoisomerization of the cyclopropyl carbonyl chromophore, when contained in a bicyclic system, has been shown generally to bring about the cleavage of the better overlapped bond of the cyclopropyl ring. For example, bicyclo[4.1.0]heptan-2-one upon photolysis in *t*-butyl alcohol yields 3-methylcyclohexenone (eq 1).[3]



(1)

When this chromophore is not geometrically constrained into a fused-ring system, isomerization to an α,β-unsaturated enone still occurs if the cyclopropyl ring is unsubstituted (eq 2);[4] however, when the cyclopropyl ring is substituted with an alkyl group *cis* to the carbonyl group, only a Norrish type II reaction is observed (eq 3).[5]

The related ene-cyclopropane-one chromophore when contained in a bicyclo[3.1.0]hexane ring system, the so-

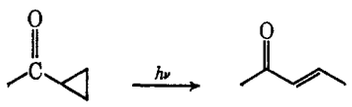
(1) This work was supported in part by PHS Grant No. 00709, National Institutes of Arthritis and Metabolic Diseases, U. S. Public Health Service.

(2) National Institutes of Health Predoctoral Fellow, 1965–1967.

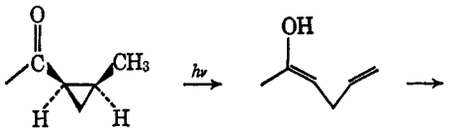
(3) W. G. Dauben and G. W. Shaffer, *Tetrahedron Lett.*, 4415 (1967).

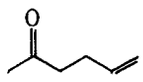
(4) J. N. Pitts, Jr., and I. Norman, *J. Amer. Chem. Soc.*, **76**, 4815 (1954); L. D. Hess, J. L. Jacobsen, K. Schaffner, and J. N. Pitts, Jr., *ibid.*, **89**, 3684 (1967).

(5) W. G. Dauben, L. Schutte, and R. E. Wolf, *J. Org. Chem.*, **34**, 1849 (1969).



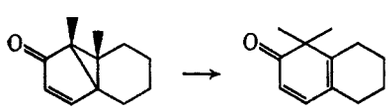
(2)



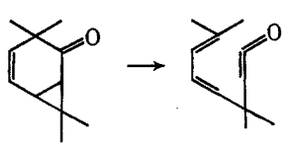


(3)

called lumiproduct of cross-conjugated cyclohexadienones, also undergoes photoisomerization involving cleavage of the cyclopropane ring (eq 4).[6] However, when this chromophore is part of a bicyclo[4.1.0]heptane system, the photoreaction yields an acyclic ketene (eq 5).[7] This vinylcyclopropane carbonyl



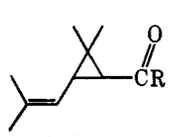
(4)



(5)

system has now been studied in an acyclic system in order to evaluate the various steric and electronic factors involved in the photoisomerization of this chromophore.

The materials chosen for this study were 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (**1**), 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde-d_1 (**2**), and 1-acetyl-2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropane (**3**). The syntheses of these compounds from ethyl chrysanthemumate is described in the Experimental Section. As prepared, each material was a mix-

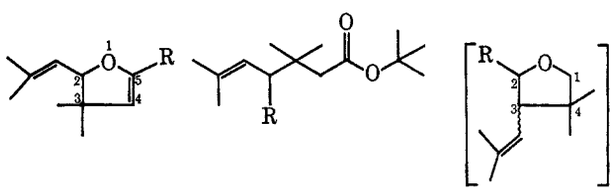


1, R = H
2, R = D
3, R = CH_3

ture of the *cis* and *trans* isomer and this mixture could be resolved on a Carbowax vpc column. The assignment of the stereochemical configuration was made on the basis of the nmr spectra and the behavior of the mixture on a vpc column which had been impregnated with potassium hydroxide. It has been shown[8] for chrysanthemumic acid and its *t*-butyl ester that the olefinic proton nmr absorption occurs at higher field for the *trans* isomer than for the *cis* isomer. Injection of a *cis–trans* mixture of **1** or **2** on a basic Carbowax column, followed by collection and reinjection on a neutral Carbowax column, shows an increase in the percentage of that isomer which is eluted first. The *trans* isomer is thermodynamically more stable than the *cis* isomer and Julia has shown[9] that *cis* chrysanthemumic esters, when treated with base and saponified, yielded mainly the *trans* acid. On this basis, the isomer whose vinylic nmr absorption is at the higher field and which is eluted first from a Carbowax vpc column is assigned the *trans* configuration.

The irradiations of **1–3** were carried out in dilute *t*-butyl alcohol solutions with Corex-filtered (>255 mμ) light. Photointerconversion of the *cis–trans* isomers of **1–3**, an expected reaction of conjugated cyclopropyl carbonyl compounds, was observed in each case. Solutions of either **1** or **2**, consisting of mainly the *trans* isomer before irradiation, showed a rapid decrease of this isomer and an increase of the *cis* isomer after light exposure for 0.5–1.0 hr. In the case of **3**, the percentage of the *cis* isomer never increased over that present prior to irradiation; however, its rate of disappearance was much slower than for the *trans* isomer.

Both aldehydes **1** and **2** yielded three photoproducts, which were isolated by preparative vpc after solvent removal. The major products from each irradiation, eluted from vpc shortly after the solvent *t*-butyl alcohol, were obtained in 61 and 51%, respectively, and were



4, R = H
5, R = D
6, R = CH_3

7, R = D
8, R = H

9, R = H
10, R = D

identified as 2-[1′-(2-methylpropenyl)]-3,3-dimethyl-Δ^4-dihydrofuran (**4**) and 2-[1′-(2-methylpropenyl)]-3,3-dimethyl-5-deuterio-Δ^4-dihydrofuran (**5**), respectively. Mass spectra indicated the compounds were isomeric with **1** and **2** and ir spectra showed the absence of carbonyl or hydroxyl functions. Identification was made on the basis of the nmr spectra, which showed the very characteristic vinylic proton absorptions for a dihydrofuran.[10] The spectrum of **4** has a doublet at τ 3.87 (J = 2.5 Hz) for the proton at C-5 and a doublet at τ 5.26 (J = 2.5 Hz) for the proton at C-4. The spectrum of **5** is identical with that of **4** except that the doublet at τ 3.87 is no longer present and the doublet at τ 5.26 has changed to a singlet at τ 5.26, thus proving that the aldehydic proton becomes the C-5 proton of the dihydrofuran photoproduct.

The remainder of the nmr spectrum of **4** showed the expected absorptions (see Experimental Section) for four methyl groups, two of which reside on a double bond, and for one additional vinylic proton. The final proton appeared as a sharp doublet at τ 5.43 (J = 9 Hz). This low-field position indicates that the hydrogen must be both allylic and geminal to the oxygen atom, therefore the methylpropenyl side chain must be located at C-2.

(6) P. J. Kropp, "Organic Photochemistry," Vol. 1, O. L. Chapman, Ed., M. Dekker, Inc., New York, N. Y., 1967, pp 1–86.
(7) A. J. Bellamy and G. H. Whitman, *J. Chem. Soc.*, 4035 (1964).
(8) T. Matsumoto, A. Nagai, and Y. Takahashi, *Bull. Chem. Soc. Jap.*, **36**, 481 (1963).
(9) M. Julia, S. Julia, B. Bemont, and G. Tchernoff, *C. R. Acad. Sci., Paris*, **248**, 242 (1959); *Chem. Abstr.*, **53**, 17922*g* (1959).
(10) L. M. Jackman, "Applications of NMR Spectroscopy in Organic Chemistry," The Macmillan Co., New York, N. Y., 1964, p 62.

Similarly, 2-[1′-(2-methylpropenyl)]-3,3,5-trimethyl-Δ^4-dihydrofuran (**6**) was the major photoproduct (52%) from the irradiation of **3**. The vinylic proton on the dihydrofuran ring has nmr absorption at τ 5.45 (broadened singlet), thus showing that the methyl group is attached at C-5.

Dihydrofuran **4**, when isolated and irradiated without a filter, yielded small amounts of two products whose vpc retention times were identical with those of *cis* and *trans* **1**. This photoisomerization of a dihydrofuran to a vinylcyclopropylcarboxaldehyde has already been observed.[11]

The second photoproduct from **1** and **2**, found in 14 and 10% yield, respectively, was identified as *t*-butyl 3,3,6-trimethyl-Δ^5-heptenoate (**7**) and *t*-butyl 3,3,6-trimethyl-4-deuterio-Δ^5-heptenoate (**8**), respectively. The mass spectrum of **7** has the last peak at 170, which is consistent with the facile loss of isobutylene from *t*-butyl esters. An ester was also indicated from infrared absorptions at 1727, 1170, and 1140 cm^{-1}. Samples of **7**, vpc collected, were always contaminated with *cis* **1** and the nmr spectrum was run with impure material. This caused no difficulties with the interpretation except for the vinylic absorption of ester **7**. The expected triplet for the vinylic proton of **7** actually appeared in the 60-Mc spectrum as a broad quartet at τ 4.49–5.01. However, a 100-Mc spectrum resolved this quartet into a doublet at τ 4.64 for *cis* **1** and the triplet (J = 7.5 Hz) at τ 4.79 for ester **7**. The remainder of the spectrum (see Experimental Section) was consistent with **7** and peaks for *cis* **1** could be easily subtracted.

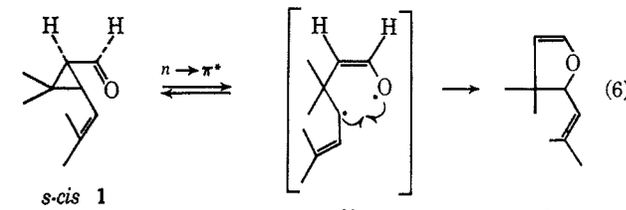
A mass spectrum of the ester isolated from the irradiation of **2** has the molecular ion at 171 with no detectable peak at 170; therefore, the one deuterium of **2** has quantitatively retained during formation of the ester. A 100-Mc nmr spectrum of **8** is essentially identical with that of **7** except that the absorption for the vinylic proton has changed from a triplet at τ 4.79 (J = 7.5 Hz) to a broad doublet at τ 4.82 (J = 7.5 Hz), thus proving that the deuterium is located at C-4 of the ester.

The third photoproduct from **1** and **2**, found in 11 and 10% yield, respectively, has been tentatively identified as *cis*- and *trans*-1,2-epoxy-3-[1′-(2-methylpropenyl)]-4,4-dimethylcyclobutane (**9**) and *cis*- and *trans*-1,2-epoxy-2-deuterio-3-[1′-(2-methylpropenyl)]-4,4-dimethylcyclobutane (**10**), respectively.

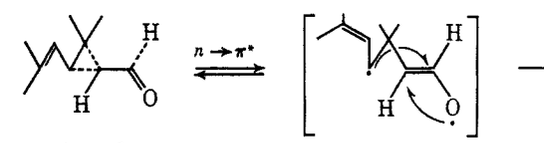
The nmr spectrom of **9** shows absorption for one vinylic proton (broad peak), two protons geminal to the oxygen atom, one allylic proton (two broad doublets), two vinylic methyl groups, and four other methyl groups. The assignment of a *cis–trans* mixture was made on the basis that the allylic proton absorption appears as two nonequivalent doublets and the methyl absorption as four nonequivalent signlets; both assignments were confirmed by the 100-Mc spectrum.

The spectrum indicates that the methylpropenyl side chain is still intact, which, in addition to the two methyl groups situated at fully substituted centers, accounts for six of the original ten carbon atoms. Therefore, the remaining four carbon atoms and one oxygen atom must compose two rings in order to account for the three unsaturation sites of **1**, since there is no indication of a second double bond and the mass spectrum shows the compound to be isomeric with **1**. There are not many possibilities for such a ring system and the choice, represented by **9** and **10**, was based mainly on the fact that this type of ether could logically arise from **1** or **2** in a manner similar to the formation of **4–6**. Ether **10** has retained the deuterium atom at a carbon geminal to the oxygen atom but the deuterium could not be shown conclusively to reside at C-2. Therefore, structures **9** and **10** must remain equivocal at this time. Products analogous to **7** or **9** were not found in the irradiation of the ketone **3**.

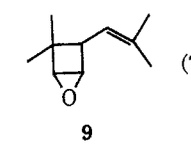
Turning now to a brief consideration of the mechanistic aspects of these photochemical transformations, it is important to appreciate that initial excitation is restricted by the Corex filter to the carbonyl n $\rightarrow$ π^* band; therefore, reaction is expected to occur through rupture of one of the cyclopropyl bonds which is conjugated with the electronically excited carbonyl group. The dihydrofuran photoproducts, which are photoisomerized to starting ketone using unfiltered light, are viewed as simply a cyclization of the diradical formed when carbonyl n $\rightarrow$ π^* excitation induces cleavage of that cyclopropyl arm which is cross conjugated with the double bond and the carbonyl group (eq 6). The reason the other conjugated cyclopropane bond does not open is probably because intermediate **11** with a secondary allylic radical is the more stable. It is possible that **1–3** concertedly cyclize to **4–6**, however, the *cis–trans* interconversion of **1–3** implies that **11** is first formed and then recyclizes either to starting material or to product.



s-cis **1** **11** **4**



s-trans **1**



9

The photoequilibrium *cis–trans* ratio of **1–3** could not be determined owing to the rapid formation of **4–6**, but apparently this equilibrium lies in the direction of the *cis* isomer. There is no obvious reason why the thermodynamically less stable isomer should be photochemically more stable; the uv spectra of the two isomers are very similar.

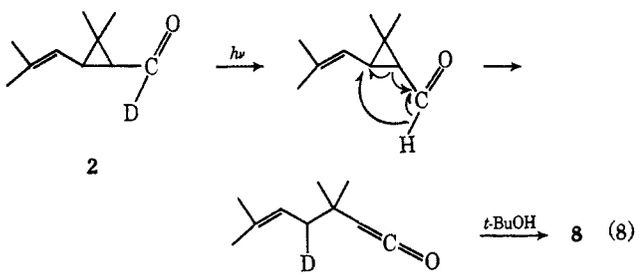
Cyclopropanes **1–3** can exist in either *s-cis* or *s-trans* configurations and once excitation and bond cleavage occurs this configuration is frozen because of the double-bond character between the carbonyl group and the

(11) J. Wiemann, N. Thoai, and F. Weisbuch, *Bull. Soc. Chim. Fr.*, 575 (1966); P. Scribe, M. R. Monot, and J. Wiemann, *Tetrahedron Lett.*, 5157 (1967).

cyclopropyl ring. Dihydrofuran formation is most certainly restricted to the *s-cis* isomer (eq 6), which suggests that *s-trans* **1** might cyclize to epoxycyclobutane **9** (eq 7). This would also explain the absence of a product analogous to **9** (R = CH_3) for methyl ketone **3** because the acetyl methyl group introduces steric hindrance to *s-trans* **3** whereas *s-cis* **3** is relatively unaffected.[12]

Formation of dihydrofurans **4–6** have very little literature precedent, but can be thought of as the oxygen-containing analog to the known rearrangement, both thermally[13] and photochemically,[14] of conjugated vinylcyclopropanes to cyclopentenes.

The formation of esters **7** and **8** is a new type of rearrangement for cyclopropyl carbonyl compounds. Mechanistically, the ester can arise by the transfer of the aldehydic proton to the β position of the cyclopropyl ring with formation of a ketene which then would be expected to yield an ester by reaction with *t*-butyl alcohol (eq 8). There is no experimental evidence for



the formation of the proposed ketene; however, it already has been demonstrated[15] that the photochemical formation of acids and esters from carbonyl compounds occurs through reaction of a hydroxyl solvent with a ketene.

The hydrogen transfer step of eq 8, which is entirely intramolecular, could occur through a solvent-caged diradical as depicted or could be completely concerted. In either case, some electronic interaction between the cyclopropyl ring and the excited carbonyl group must occur prior to hydrogen migration because the migration specifically occurs to only one of the two β positions of the cyclopropyl ring.

The absence of a product analogous to **7** (R = CH_3) from ketone **3** is consistent with the fact that alkyl radical migrations are far less common than hydrogen atom migrations.

The reactions of vinylcyclopropyl carbonyl compounds **1–3** are probably quite general for this chromophore provided that the carbonyl group and the cyclopropyl ring are not part of a fused skeleton such that cyclization would be prevented by the geometry of the system.

Rearrangements like those observed in eq 2 and 3 were not observed for compounds **1–3** which indicates that the electronic effect of the double bond must be the influential factor leading to the observed photoproducts.

An interesting sidelight to these photorearrangements is the fact that the mass spectra of dihydrofurans **4–6** are extremely similar to the spectra of the respective cyclopropanes **1–3**. This implies that these cyclopropane–dihydrofuran interconversions might also be induced by electron impact as well as photon absorption.

(12) J. L. Pierre and P. Arnaud, *Bull. Soc. Chim. Fr.*, 2299 (1967).

(13) M. C. Flowers and H. M. Frey, *J. Chem. Soc.*, 3547 (1961); C. S. Elliott and H. M. Frey, *ibid.*, 345 (1965).

(14) P. J. Kropp, *J. Amer. Chem. Soc.*, **89**, 1126 (1967).

(15) G. Quinkert, E. Blanke, and F. Hamburg, *Chem. Ber.*, **97**, 1799 (1964).

Experimental Section

Irradiations, except where noted, were conducted using a Hanovia 450-W mercury arc lamp (679A-36) inserted into a water-cooled, quartz immersion probe. The filter employed was Corex (9700) which was a glass sleeve insertable between the lamp and the probe. Solutions were stirred and degassed with argon for a minimum of 1 hr preceding irradiation. Argon was continuously bubbled through the solution during irradiation. Irradiation *t*-butyl alcohol was prepared by refluxing and distilling commercial *t*-butyl alcohol from sodium.

Irradiations were monitored by vapor phase chromatography (vpc) on a Carbowax 20M column using a hydrogen flame detector. The percentage of nonmonomeric material formed in the irradiation was arrived at indirectly through integration of the starting material vpc trace before irradiation and the photoproducts plus starting material vpc trace after irradiation. The per cent decrease in the total peak areas after irradiation, using a constant volume injection, was used as an approximate percentage of nonmonomeric material and is probably accurate to 5–10%.

2,2-Dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (1)—To a stirred solution of 5.50 g (0.0357 mol) of 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarbinol, prepared by lithium aluminum hydride reduction of ethyl chrysanthemumate (Benzol Products), in 60 ml of reagent-grade acetone, cooled in an ice bath, was added, rapidly but dropwise, 8.0 ml (0.032 mol) of Jones reagent.[16] After addition, the mixture was stirred for 1 min and then diluted with 300 ml of water and 100 ml of ether. The layers were separated and the aqueous phase was extracted with two 100-ml portions of ether. The combined ethereal extracts were washed with two 25-ml portions of 5% sodium carbonate solution, dried, and concentrated.

Distillation of the colorless oil (5.04 g) yielded pure 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (1): 1.678 g (31% yield; 74% *trans* 1 and 25% *cis* 1); bp 58–59° (3 mm); mass spectrum, trace peak at 152, peak at 137 (m − 15), very large peak at 123 (m − 29); ν_{max} 2732 (m), 1704–1706 (s), 978 (m), 850 cm^{-1} (m) [spectra of *cis* and *trans* 1 were very similar but had definite differences in the fingerprint region; *trans* had ν_{max} 1110 cm^{-1} (s) and *cis* had ν_{max} 1136 (m), 1115 (m), 1052 cm^{-1} (m)]; $\lambda_{max}^{95\%\ EtOH}$, a sample consisting of mainly *trans* 1 had 198 mμ (ϵ 14,000), 229 shoulder (4450), 283 shoulder (423), a sample consisting of mainly *cis* 1 had 198 mμ (ϵ 14,400), 231 shoulder (2720), $\epsilon_{283\ m\mu}$ 335; nmr (τ, ppm, CCl_4) 0.77 (*trans*) and 0.85 (*cis*) (0.9 H, two doublets which appeared as three peaks, J_t = 5 Hz, J_c = 6 Hz, aldehydic H), 4.64 (*cis*) and 5.11 (*trans*) (1.0 H, two broad doublets, J_c = 7 Hz, J_t = 7.5 Hz, vinylic H), 7.62–8.54 (7.4 H, multiplet with a strong broad singlet at 8.31, vinylic methyl and cyclopropyl H), 8.55–9.04 (6.7 H, multiplet with strong singlets at 8.68 (*cis*), 8.72 (*trans*), 8.79 (*cis*), and 8.84 (*trans*) (methyl and cyclopropyl H). A 100-Mc nmr resolved the three-peak aldehydic H absorption into two doublets, confirmed the vinylic H doublets, and confirmed the four methyl singlets.

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 78.71; H, 10.77.

cis and *trans* 1 could be resolved by vpc on a 20% Carbowax 20M column (*trans* retention time relative to *cis* equaled 0.90). The isomer assignment was made by base isomerization of 1. A mixture of 46% *trans* 1 and 54% *cis* 1 was eluted from a 20% Carbowax 20M–10% KOH column (5 ft × 0.25 in.) as a single symmetrical peak. This peak was collected and its ir spectrum was identical with that of a sample consisting of mainly the *trans* isomer. This peak, reinjected on a plain Carbowax 20M column (5 ft × 0.25 in.), was again resolved into two peaks in the ratio of 74% *trans* and 23% *cis*. Repetition of this process isomerized an 80% *trans*–20% *cis* mixture to 84% *trans* and 13% *cis*. Molecular models indicate that *trans* is the thermodynamically favored isomer; therefore, the isomer which increased when 1 was injected on the basic column was assigned the *trans* configuration.

(16) A. Bowers, T. G. Halsall, E. R. H. Jones, and A. J. Lemin, *J. Chem. Soc.*, 2548 (1953).

2,2-Dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde-d_1 (2).—The synthesis was carried out as described above using 6.54 g (0.0419 mol) of 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarbinol-d_2, prepared by lithium aluminum deuteride reduction of ethyl chrysanthemumate, and 10.0 ml (0.040 mol) of Jones reagent. Work-up and distillation of the colorless oil (4.87 g) yielded 2.11 g of recovered alcohol (32%), bp 70–72° (2.5–3.0 mm), and 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde-d_1 (**2**): 0.710 g (12% yield; 67% *trans* **2**, 29% *cis* **2**, and 4% of alcohol starting material and another impurity); bp 54–55° (2.5–3.0 mm); mass spectrum, trace peak at 153, peak at 138 (m − 15), very large peak at 123 (m − 30); ν_{max} 2075 (m), 1686 (s), 1374 (m), 1111 (s), 942 (w), 847 cm^{-1} (w); nmr (τ, ppm, CCl_4), the spectrum was essentially identical with that of a *cis–trans* mixture of undeuterated 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (**1**) except that the aldehydic proton absorption at 0.77 and 0.85 had completely disappeared.

1-Acetyl-2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropane (3).—From 50.0 g (0.250 mol) of ethyl chrysanthemumate, according to the procedure of Corey,[17] there was obtained 1-acetyl-2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropane (**3**): 18.1 g (44% over-all yield, *cis* and *trans* mixture with *trans* predominating); mass spectrum, last peak at 166, peak at 151 and base peak at 123; ν_{max} 1701 (s), 1376 (m), 1193 (m), 1172 (m), 1112 (m), 952 (m), 851 cm^{-1} (m); uv$^{abs\ EtOH}$ sample consisted of mainly *trans* **3**, $\epsilon_{280\ m\mu}$ 205, $\epsilon_{233\ m\mu}$ 5580 (shoulder), $\epsilon_{210\ m\mu}$ 9850; nmr (τ, ppm, $CDCl_3$) 4.56 (*cis*, broad absorption) and 5.06 (*trans*, doublet, J = 7.5 Hz) (1.0 H, vinylic H), 7.64–8.10 (4.7 H, multiplet with the acetyl methyl absorptions at 7.78 (*trans*, singlet) and 7.80 (*cis*, singlet)), 8.31 (6.6 H, broad singlet, vinylic methyl H), 8.79 (*cis*) and 8.83 (*trans*) (5.7 H, two singlets, methyl H).

Anal. Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.28; H, 10.94.

Irradiation of 2,2-Dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (1).—A solution of 398 mg of 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropyl carboxaldehyde (80% *trans*–20% *cis*) in 125 ml of *t*-butyl alcohol (0.021 *M*) was irradiated 6.25 hr using Corex-filtered light. The vpc monitor showed the formation of three photoproducts with the following yields at the end of the irradiation: 61% product A (retention time relative to *cis* **1** equaled 0.23), 11% product B (retention time relative to *cis* **1** equaled 0.37), 14% product C (retention time relative to *cis* **1** equaled 0.87, this product was unresolved from *trans* **1**), 6% *cis* **1**, and 8% several minor products and nonmonomeric material. Also, the monitor showed that *trans* **1** was photoisomerized to *cis* **1**; before irradiation there was 80% *trans* and 20% *cis*, after 0.5 hr there was 46% *trans* and 44% *cis*, and after 1.25 hr there was 18% *trans* and 43% *cis*.

Solvent was removed and the three photoproducts were isolated by vpc of the colorless oil (382 mg) on a 20% Carbowax 20M column (5 ft × 0.25 in.). The 61% photoproduct (A) was identified as 2-[1′-(2-methylpropenyl)]-3,3-dimethyl-Δ^1-dihydrofuran (**4**) on the basis of the following data: mol wt 152 (mass spectrum); ν_{max} 1613 (m), 1130 (s), 1045 (s), 1034 (s), 721 cm^{-1} (s); uv$^{95\%\ EtOH}$ $\epsilon_{220\ m\mu}$ 3580, $\epsilon_{200\ m\mu}$ 12,600; nmr (τ, ppm, CCl_4) 3.87 (0.9 H, doublet, J = 2.5 Hz, vinylic H at C_5), 4.71 (1.1 H, broad doublet, J = 9 Hz, side-chain vinylic H), 5.26 (1.0 H, doublet, J = 2.5 Hz, vinylic H at C_4), 5.43 (1.0 H, doublet, J = 9 Hz, H which is both allylic and geminal to the oxygen), 8.22 and 8.30 (6.0 H, two doublets, both J's = 1 Hz, vinylic methyl H), 8.92 (3.0 H, singlet, methyl H), 9.11 (3.0 H, singlet, methyl H).

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 79.04; H, 10.36.

The 11% photoproduct (B) was tentatively identified as *cis*- and *trans*-1,2-epoxy-3-[1′-(2-methylpropenyl)]-4,4-dimethylcyclobutane (**9**) on the basis of the following data: mol wt 152 (mass spectrum), the next peaks were at 137 (m − 15) and 123 (large, m − 29); ν_{max} 1374 (m), 1361 (w), 1326 (m), 943 (w), 839 cm^{-1} (s); nmr (τ, ppm, CCl_4) 4.69–5.07 (1.0 H, broad absorption, vinylic H), 6.30–6.70 (1.5 H, absorption that appeared as a broad singlet at 6.37 and three doublets at 6.54, 6.61 and 6.68, all J's = 2 Hz, epoxy H), 7.55 and 7.64 (0.9 H, two broad doublets, both J's = 9 Hz, allylic H), 8.28 (3.0 H, doublet, J = 1 Hz, vinylic methyl H), 8.45 (2.5 H, doublet, J = 1 Hz, vinylic methyl H), 8.80, 9.02, 9.04, and 9.27 (7.1 H, four singlets, methyl H).

A 100-Mc nmr spectrum showed the vinylic proton as a triplet (separation = 9–10 Hz, probably two overlying doublets), confirmed the assignment for the epoxy protons, showed the allylic proton as a triplet (separation = 8 Hz, two overlying doublets), and confirmed the four methyl singlets as nonequivalent, uncoupled peaks. Irradiation of the vinylic proton collapsed the allylic triplet to a doublet and irradiation of the allylic proton collapsed the vinylic triplet to a broad doublet. Irradiation of the allylic proton definitely changed the pattern for the epoxy proton absorption but did not seem to simplify it.

The 14% photoproduct (C) was identified as *t*-butyl 3,3,6-trimethyl-Δ^5-heptenoate (**7**) on the basis of the following data: mass spectrum, last peak at 170; ν_{max} 1727 (s), 1706 (shoulder, *cis* **1**), 1385 (w), 1362 (m), 1170 (m), 1140 (s), 1115 (m), 978 (w), 962 (w), 881 cm^{-1} (w); nmr (τ, ppm, CCl_4) 4.49–5.01 (1.0 H, broad quartet, separation = 8 Hz, vinylic H), 7.82–8.16 (4.4 H, multiplet with a singlet at 7.97, allylic H and H α to the carbonyl), 8.29 (8.1 H, broad singlet, vinylic methyl H; there was also a smaller broad singlet at 8.40, included in the integration, which was assigned to an impurity), 8.58 (6.8 H, singlet, *t*-butyl H), 9.05 (5.7 H, singlet, methyl H). The nmr spectrum was contaminated with a small amount of *cis* aldehyde **1**, which gave small methyl absorption peaks at 8.68 and 8.79 as well as a small doublet for the aldehydic proton.

A 100-Mc nmr spectrum resolved the vinylic proton quartet into a doublet (τ 4.64, J = 7 Hz, *cis* aldehyde **1**) and a triplet (τ 4.79, J = 7.5 Hz). Also, addition of *cis* **1** to the 60-Mc nmr sample caused the two lower field peaks of the vinylic proton quartet to increase in amplitude.

There was no indication from the nmr spectrum that ester **7** was contaminated with any *trans* aldehyde **1**, although the two compounds were unresolved by vpc. Also, the very rapid decrease of *trans* **1** during the irradiation indicates that it was probably all gone by the end of the irradiation.

Irradiation of 2,2-Dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde-d_1 (2).—A solution of 371 mg of 2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde-d_1 (**2**) (76% *trans*, 20% *cis*, 4% impurity) in 125 ml of *t*-butyl alcohol (0.019 mol) was irradiated for 5.5 hr using Corex-filtered light. The vpc monitor showed that this irradiation exactly paralleled the irradiation of 2,2-dimethyl-3-3[1′-(2-methylpropenyl)]cyclopropylaldehyde (**1**), and the final yields were 51% product A, 10% product B, 10% product C, 4% *cis* **2**, and 25% several minor products and nonmonomeric material:

Product A was 2-[1′-(2-methylpropenyl)]-3,3-dimethyl-5-deuterio-Δ^4-dihydrofuran (**5**): mass spectrum, small peaks at 153 and 138 (m − 15), very large peak at 123 (m − 30); ν_{max} 1585 (s), 1376 (m), 1357 (w), 1193 (m), 1047 (m), 1035 (s), 983 (s), 995 cm^{-1} (m); nmr (τ, ppm, CCl_4) the spectrum was identical with that for undeuterated 2-[1′-(2-methylpropenyl)]-3,3-dimethyl-Δ^4-dihydrofuran (**4**), except that the doublet at 3.87 had disappeared and the doublet at 5.26 had changed to a singlet at 5.26.

Product B was *cis*- and *trans*-1,2-epoxy-2-deuterio-3-[1′-(2-methylpropenyl)-4,4-dimethylcyclobutane (**10**): mass spectrum, a trace peak at 153, peak at 138 (m − 15), peaks at 123 (m − 30) and 124 (m − 29); ν_{max} 1374 (m), 1359 (m), 1309 (m), 913 (w), 909 (m), 702 (w), 694 cm^{-1} (w); nmr (τ, ppm, CCl_4), the spectrum was essentially identical with that for undeuterated 1,2-epoxy-3-[1′-(2-methylpropenyl)]-4,4-dimethylcyclobutane (**9**), except that the absorption for the epoxy protons had changed from a broad singlet at 6.37 and three doublets at 6.54, 6.61 and 6.68 to a singlet at 6.62 and a doublet at 6.66 (J = 2 Hz). There was still some weak absorption at 6.37 which probably was an impurity. Irradiation of the allylic proton collapsed the doublet at 6.66 to a singlet.

Product C was *t*-butyl 3,3,6-trimethyl-4-deuterio-Δ^5-heptenoate (**8**): mass spectrum, a last peak at 171 (no peak at 170); ν_{max} 1727 (s), 1689 (shoulder, *cis* **2**), 1385 (w), 1362 (m), *ca* 1139 (s, broad), 961 (w), 842 cm^{-1} (w); 100-Mc nmr (τ, ppm, CCl_4), the spectrum was essentially identical with that for undeuterated *t*-butyl 3,3,6-trimethyl-Δ^5-heptenoate (**7**), except that the absorption for the vinylic proton had changed from a triplet at 4.79 (J = 7.5 Hz) to a broad doublet at 4.82 (J = 7.5 Hz). Again, the sample was contaminated with *cis* **2** (small doublet at τ 4.64, J = 7 Hz). Addition of *cis* **2** to the nmr sample caused the 4.64 doublet intensity to increase, relative to the doublet at 4.82.

(17) E. J. Corey and M. Chaykovsky, *J. Amer. Chem. Soc.*, **87**, 1345 (1965).

Irradiation of 1-Acetyl-2,2-dimethyl-3-[1′-(2-methylpropenyl)]-cyclopropane (3).—A solution of 1.11 g of 1-acetyl-2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropane (**3**) (57% *trans*–43% *cis*; the sample also contained 9% ethyl crysanthemumate and 1% another impurity but these compounds were stable to the irradiation conditions and did not interfere) in 170 ml of *t*-butyl alcohol (0.039 *M*) was irradiated 4 hr using Corex-filtered light. The vpc monitor showed the formation of one major photoproduct with the following percentages at the end of the irradiation: 52% product A (retention time relative to *cis* **3** equaled 0.38), 1% a minor unidentified product (retention time relative to *cis* **3** equaled 0.79), 17% *cis* **3**, 12% *trans* **3** (retention time relative to *cis* **3** equaled 0.96), and *ca.* 18% nonmonomeric material. Also, the monitor showed that *trans* **3** disappeared faster than *cis* **3**.

Solvent was removed and the photoproduct, isolated by vpc of the colorless oil (0.71 g) on a 25% Carbowax 20M column (9 ft × 3/8 in.), was identified as 2-[1′-(2-methylpropenyl)]-3,3,5-trimethyl-Δ^4-dihydrofuran (**6**) on the basis of the following data: mass spectrum, last peak at 166, peaks at 151, 137, 109, base peak at 123; ν_{max} 1672 (s), 1380 (s), 1248 (s), 1009 (s), 948 (s), 735 cm^{-1} (s); uv$^{abs\ EtOH}$ $\epsilon_{220\ m\mu}$ 4620, $\epsilon_{210\ m\mu}$ 7410; nmr (τ, ppm, $CDCl_3$) 4.59 (1.0 H, broad doublet, J = 10 Hz, side chain vinylic H), 5.25 (0.9 H, doublet, J = 10 Hz, H which is both allylic and geminal to the oxygen), 5.45 (0.8 H, broad singlet, vinylic H at C_4), 8.10–8.31 (8.8 H, multiplet, vinylic methyl H), 8.92 and 9.08 (6.5 H, two singlets, methyl H).

Anal. Calcd for $C_{11}H_{18}O$: C, 79.46; H, 10.91. Found: C, 79.55; Hr, 11.19.

An nmr specrtrum of recovered **3**, vpc collected, showed no indication that any ester photoproduct similar to **7** had been formed.

Irradiation of 2-[1′-(2-Methylpropenyl)]-3,3-dimethyl-Δ^4-dihydrofuran (4).—A solution of 33 mg of **4** in 15 ml of cyclohexane (0.014 *M*) was irradiated in a quartz flask for 0.5 hr using light from a 100-W Hanovia lamp (Model 608A-36). Vpc monitoring of the irradiation showed three photoproducts with retention times relative to starting material of 2.61, 4.31, and 4.97. The final yields were 51% starting material, 3, 4, and 8% photoproducts, in order of glpc elution, and 34% nonmonomeric material. The 4 and 8% products had identical vpc retention times as *trans*- and *cis*-2,2-dimethyl-3-[1′-(2-methylpropenyl)]cyclopropylcarboxaldehyde (**1**), respectively. The 3% product was not identified and the irradiation was not investigated further.

Irradiation of **4** with a 450-W lamp (21 mg, 10 ml of cyclohexane, 0.014 *M*, quartz flask, 0.75 hr) resulted in almost complete polymerization of both starting material and photoproducts.

Registry No.—*trans* **1**, 20104-05-6; *cis* **1**, 20104-06-7; *trans* **2**, 20104-07-8; *cis* **2**, 20104-08-9; *trans* **3**, 20104-09-0; *cis* **3**, 20104-10-3; **4**, 20104-11-4; **5**, 20104-12-5; **6**, 20104-13-6; **7**; 20104-14-7; **8**, 20104-15-8; *trans* **9**, 20104-16-9; *cis* **9**, 20104-17-0; *trans* **10**, 20104-18-1; *cis* **10**, 20104-19-2.

Acknowledgment.—The authors would like to thank Mr. P. Porcaro (Givaudan) for aid in some of the analytical work.

The Synthesis of Racemic *threo*- and *erythro*-β-Hydroxylysines

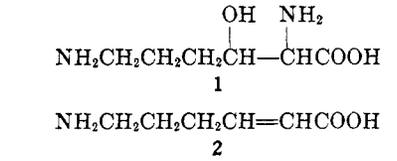
CHARLES H. STAMMER[1] AND RONALD G. WEBB[2]

Department of Chemistry, University of Georgia, Athens, Georgia 30601

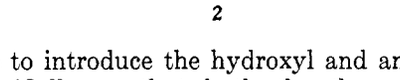
Received December 30, 1968

The synthesis of both *threo*- and *erythro*-β-hydroxy-DL-lysines from an *erythro*-β-methoxy-α-bromohexanoic acid derivative has been accomplished. Amination of this acid in ammonium hydroxide proceeded with retention while treatment with sodium azide proceeded with inversion of the configuration at the α-carbon atom giving intermediates convertible into the two diastereomeric amino acids.

In connection with our program on the synthesis of cycloserines, the unknown β-hydroxylysine (**1**) was a required intermediate. β-Hydroxyamino acids have been synthesized in the past by (1) the condensation of acid chlorides with diazoacetates and azlactones followed by several steps,[3] (2) condensation of aldehydes with glycine[4] and esters of acetamidomalonic and nitroacetic acids, and (3) multistep formation of the α-amino-β-hydroxy structure from the appropriate α,β-unsaturated acid.[5] After several attempts to use the second method, the longer surer approach through the α,β-unsaturated acid led to the desired compound. In this reaction sequence, a 6-amino-2-hexenoic acid (**2**) derivative was required which could be converted into **1** by the introduction of the appropriate functional groups. Two stereoisomers of **1** are possible and it was



1



2

desirable to introduce the hydroxyl and amino groups stereospecifically so that both the *threo* and *erythro* isomers would both be available.

The synthesis of **2** appeared feasible by the Doebner condensation[6] of an N-substituted γ-aminobutyraldehyde with malonic acid. The problem, then was to synthesize the required aldehyde. N-Benzoyl-γ-aminobutyraldehyde had been reported as quite unstable,[7] possibly owing to a tendency toward ring closure giving a pyrrolidine. Attempts to prepare N-benzoyl-γ-aminobutyric acid chloride had indeed led to the ring-closed product, N-benzoyl-2-pyrrolidone. Consequently, it seemed necessary to block the amino function with a group such as phthaloyl which would effectively pro-

(1) To whom inquiries should be addressed.

(2) Taken from the Ph.D. Thesis of R. G. Webb which was presented to the University of Georgia Graduate School, Oct 1968.

(3) J. H. Looker and D. N. Thatcher, *J. Org. Chem.*, **22**, 1233 (1957); H. E. Carter, J. B. Harrison, and D. Shapiro, *J. Amer. Chem. Soc.*, **75**, 4705 (1953); J. M. Stewart and D. W. Wooley, *ibid.*, **78**, 5336 (1956).

(4) T. Wieland, H. Cords, and E. Keck, *Ber.*, **87**, 1312 (1954); T. T. Otani and M. Winitz, *Arch. Biochem. Biophys.*, **102**, 464 (1963); M. Sato, K. Okawa, and S. Akabori, *Bull. Chem. Soc. Jap.*, **30**, 937 (1957); H. Mix and F. W. Wilcke, *Z. Physiol. Chem.*, **337**, 40 (1964); H. Hellmann and H. Piechota, *ibid.*, **318**, 66 (1960); H. Hellmann and H. Piechota, *Ann. Chem.*, **631**, 175 (1960); S. Umezawa and S. Zen, *Bull. Chem. Soc. Jap.* **36**, 1143 (1963); D. I. Weisblatt and D. A. Lyttle, U. S. Patent 2,570,297 (1951).

(5) (a) W. Schrauth and H. Geller, *Chem. Ber.*, **55**, 2783 (1922); (b) H. D. West and H. E. Carter, *J. Biol. Chem.*, **119**, 103 (1937); (c) H. D. West, G. S. Krummel and H. E. Carter, *ibid.*, **122**, 605 (1937); (d) H. E. Carter and C. L. Zirkle, *ibid.*, **178**, 709 (1949); (e) K. Pfister, III, E. E. Howe, C. A. Robinson, A. C. Shabica, E. W. Pietrusza, and M. Tishler, *J. Amer. Chem. Soc.*, **71**, 1096 (1949); (f) T. Kanebo and H. Katsura, *J. Chem. Soc. Jap.* **36**, 899 (1963).

(6) J. R. Johnson, *Org. Reactions*, **1**, 226 (1942).

(7) S. Sugasan and Y. Zusshi, *J. Pharm. Soc. Jap.*, **550**, 1044 (1927).