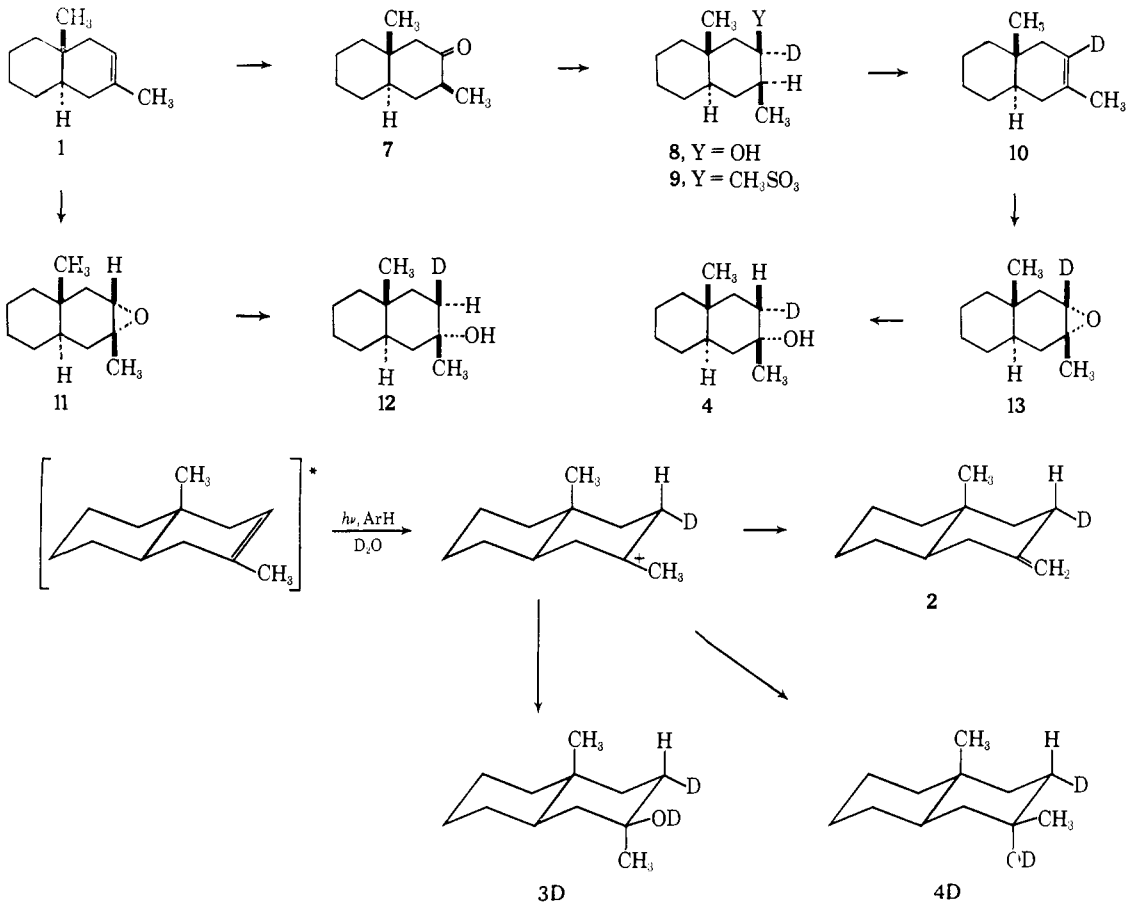

with water to produce alcohols **3** and **4**. In the latter case, steric factors favor formation of the equatorial alcohol **3**. Notably, samples of olefin **1** recovered from photochemical hydration experiments contained significant amounts (10–20%) of deuterium. Thus the proposed cation intermediate can collapse to endocyclic as well as to exocyclic olefin. Presumably both isomeric endocyclic olefins are thereby formed, but since we were unable to separate these olefins by gas chromatography we cannot yet confirm this point.

As noted previously, a certain amount of internal strain seems essential to the addition reaction.[1] Thus, exocyclic olefins such as **2** are unreactive. The hydration of olefin **1** proceeded about seven times as fast in H_2O as in D_2O. This rate difference underscores the importance of acidity [$K_A(H_2O)/K_A(D_2O) \sim 6$][7] to the addition reaction. Our previous findings on photochemically initiated alcohol additions[1b] and rearrangements[8] support this interpretation. The stereochemical results presented in this report clearly support a stepwise addition mechanism for photosensitized cycloalkene hydration and related reactions.[1] The nature of the species undergoing protonation is currently under investigation.

Acknowledgments. We thank the National Science Foundation for supporting this work through Research Grant GP 4174 and the Public Health Service for providing a research fellowship. We are indebted to Dr. P. J. Kropp for his cooperation and interest in this work. Deuterium analyses were performed by the Morgan Schaffer Corporation, Montreal, Quebec, Canada.

(7) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp 120–121.

(8) J. A. Marshall and A. R. Hochstetler, *Chem. Commun.*, 732 (1967).

(9) (a) Fellow of the Alfred P. Sloan Foundation; (b) Public Health Service Fellow of the National Institute of General Medical Sciences.

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Steroids. CCCXXXIII.[1] Synthetic Studies on Insect Hormones. V.[2] The Synthesis of Crustecdysone (20-Hydroxyecdysone)

Sir:

The moulting hormone crustecdysone (20-hydroxyecdysone) (Ia) was first isolated from the crayfish *Jasus lalandei* and its structure proposed by Hampshire and Horn.[3] Later work showed this compound to be the major moulting hormone of the insect *Antherea pernyi*[4] and suggested the stereochemistry 20*R*,22*R* by analogy with that of the moulting hormone ecdysone[5]

(1) The material presented in this communication formed the basis of a presentation by one of us to a Gordon Research Conference on June 20, 1967. Part CCCXXXII: A. Cervantes, P. Crabbé, J. Iriarte, and G. Rosenkranz, submitted for publication.

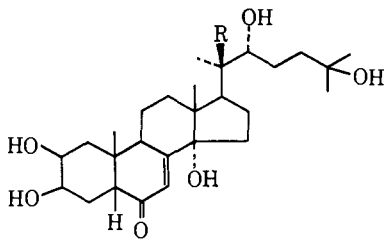
(2) Part IV: J. B. Siddall, D. H. S. Horn, and E. J. Middleton, *Chem. Commun.*, 899 (1967).

(3) F. Hampshire and D. H. S. Horn, *ibid.*, 37 (1966). 20-Hydroxyecdysone has since been isolated from several plant and insect sources; *e.g.*, T. Takemoto, S. Ogawa, N. Nishimoto, and H. Hoffmeister, *Z. Naturforsch.*, **22b**, 681 (1967), and references therein.

(4) D. H. S. Horn, E. J. Middleton, J. A. Wunderlich, and F. Hampshire, *Chem. Commun.*, 339 (1966).

(5) 22*R* configuration determined by X-ray crystallography [R. Huber and W. Hoppe, *Chem. Ber.*, **98**, 2403 (1965)].

(Ib) and the known biological hydroxylation of cholesterol.[6] We now wish to report the first synthesis of crustecdysone (Ia) by a stereoselective process.

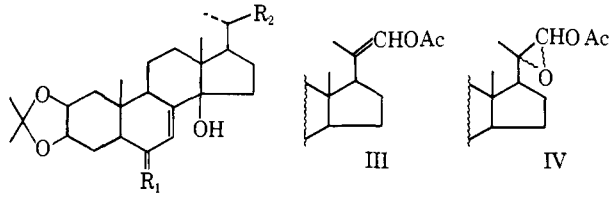


Ia, R = OH
b, R = H

The previously reported synthesis[7,8] of ecdysone (Ib) from this laboratory had solved the problems of elaborating the nucleus common to both hormones.[2] An alternative synthesis of ecdysone and 22-isoecdysone[9a,b] employed an alkylation step for construction of the hydroxylated side chain, suggesting a synthesis of crustecdysone *via* a suitably hydroxylated aldehyde precursor.

(20*S*)-2β,3β-Diacetoxy-5α-hydroxy-20-methoxycarbonylpregn-7-en-6-one[7,10] was converted by acid-catalyzed acetylation and stereospecific chromous chloride reduction[7] to the 5α-H derivative[10] [mp 200–202°; lit.[9b] mp 195–196°], which on mild alkaline hydrolysis followed by treatment with acetone–*p*-toluenesulfonic acid gave the acetonide[10] IIa [mp 255–257°; $[\alpha]$D +19°].

Sequential reduction of IIa with lithium tri-*t*-butoxyaluminum hydride to the 6β-alcohol[10] IIb [mp 214–216°; $[\alpha]$D −6°] and lithium aluminum hydride gave the 6β,22-diol[10] IIc [mp 242–244°; $[\alpha]$D −21°]. Stepwise oxidation of IIc with chromium trioxide–pyridine to the 6-ketone[10] IId [mp 258–260°; $[\alpha]$D +10°] followed by dimethyl sulfoxide–diethylcarbodiimide–pyridinium trifluoroacetate oxidation[11] led to the aldehyde[10] IIe [mp 250–252°; $[\alpha]$D +8°; nmr[12a] 9.61 (doublet, J = 6 cps) (20-CHO)].



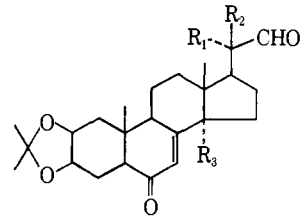
III

IV

IIa, R_1 = O; R_2 = COOMe
b, R_1 = ; R_2 = COOMe
c, R_1 = ; R_2 = CH_2OH
d, R_1 = O; R_2 = CH_2OH
e, R_1 = O; R_2 = CHO

Introduction of oxygen at C-20 was effected without steric control by epoxidation of the $\Delta^{20(22)}$ enol acetate III[10] [mp 185–189°; ν_{max}^{KBr} 1760 cm^{-1}] prepared by selective enol acetylation (acetic anhydride–sodium acetate) of the keto aldehyde IIe. Treatment of III with *m*-chloroperbenzoic acid led to a crystalline mixture of inseparable epoxides (IV)[10] [mp 190–205°; nmr 0.70 and 0.80 (18-H), 1.50 and 1.55 (21-H)], which was hydrolyzed in 1% potassium bicarbonate–aqueous methanol and the isomeric hydroxy aldehydes were separated by silica gel chromatography to afford Va (20*R*)[10,12b] [mp 228–231°; nmr 0.69 (18-H), 1.36 (21-H), and 9.61 (CHO)] and Vb (20*S*)[10,12b] [mp 234–237°; nmr 0.62 (18-H), 1.27 (21-H), and 9.62 (CHO)] in a ratio of 5:3, respectively.

Protection of the 20-hydroxyl groups of Va and Vb as the tetrahydropyranyl ethers Vc (20*R*)[10,13] [mp 229–233°; nmr 0.70 (18-H) and 1.33 (21-H)] and Vd (20*S*)[10,14] [mp 211.5–215°; nmr 0.85 (18-H) and 1.31 (21-H)], respectively, followed by selenium dioxide hydroxylation[7] at $C_{14\alpha}$ afforded Ve[10] (20*R*) [mp 230–234°; nmr 0.77 (18-H) and 1.36 (21-H)] and Vf[10] (20*S*) [mp 226–230°; nmr 0.94 (18-H) and 1.36 (21-H), respectively.



Va, R_1 = Me; R_2 = OH; R_3 = H
b, R_1 = OH; R_2 = Me; R_3 = H
c, R_1 = Me; R_2 = OTHP; R_3 = H
d, R_1 = OTHP; R_2 = Me; R_3 = H
e, R_1 = Me; R_2 = OTHP; R_3 = OH
f, R_1 = OTHP; R_2 = Me; R_3 = OH

Selective alkylation of the keto aldehyde Ve in tetrahydrofuran solution with 3 equiv of the chloromagnesium derivative of 3-methyl-3-(tetrahydropyran-2-yloxy)butyne afforded in 55% yield after chromatography an apparently homogeneous (tlc, nmr) product, VIa [nmr 0.80 (18-H), 1.03 (19-H), 1.45 (21-H), 1.49 and 1.57 (26- and 27-H)], indicating high stereoselectivity of alkylation during formation of the cholestane side chain.

Inversion of configuration at C_5 to the desired A/B *cis* fusion was effected on exposure of VIa to aqueous potassium carbonate in methanol giving a 3:1 mixture of 5β isomer VIb and starting material. The same equilibrium mixture resulted from similar treatment of the chromatographically isolated 5β isomer VIb, demonstrating the absence of other rearrangements.

Selective hydrogenation of the triple bond of VIb in ethanol solution over 5% palladized charcoal catalyst led to the required saturated derivative VIc. Completion of the synthesis by 0.05 *N* aqueous hydrochloric

(6) K. Shimizu, M. Gut, and R. I. Dorfman, *J. Biol. Chem.*, **237**, 699 (1962).

(7) J. B. Siddall, J. P. Marshall, A. Bowers, A. D. Cross, J. A. Edwards, and J. H. Fried, *J. Am. Chem. Soc.*, **88**, 379 (1966).

(8) J. B. Siddall, A. D. Cross, and J. H. Fried, *ibid.*, **88**, 862 (1966).

(9) (a) I. T. Harrison, J. B. Siddall, and J. H. Fried, *Tetrahedron Letters*, 3457 (1966); (b) A. Furlenmeier, A. Fürst, A. Langemann, G. Waldvogel, U. Kerb, P. Hocks, and R. Wiechert, *Helv. Chim. Acta*, **49**, 1591 (1966).

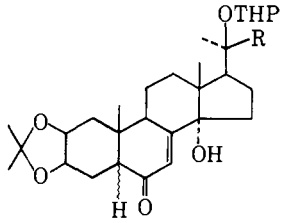
(10) Satisfactory elemental analytical data were obtained for this substance.

(11) *Cf.* J. G. Moffatt and K. E. Pfitzner, *J. Am. Chem. Soc.*, **85**, 3027 (1963).

(12) (a) Nmr spectra were recorded on a Varian HA-100 spectrometer using deuteriochloroform as solvent unless indicated otherwise and are quoted as δ (parts per million) downfield from tetramethylsilane as internal standard. (b) Tentative assignments of configuration at C_{20} are based on chemical shifts of 18- and 21-methyl proton resonances compared with (20*R*)- and (20*S*)-hydroxypregnanes.

(13) A diastereoisomer [mp 225–228°; nmr 0.70 (18-H), 1.44 (21-H)] differing from Ve only at C_2 of the hydropyran ring was also isolated.

(14) Diastereoisomer, *cf.* ref 13 [mp 181–183°; nmr 0.80 (18-H), 1.40 (21-H)].



VI , 5α-H, R = (22*R*)-CH(OH)C≡CC(CH$_3$)$_2$OTHP
b, 5β-H, R = (22*R*)-CH(OH)C≡CC(CH$_3$)$_2$OTHP
c, 5β-H, R = (22*R*)-CH(OH)CH$_2$CH$_2$C(CH$_3$)$_2$OTHP

acid hydrolysis of the protecting groups of VIc and chromatographic purification of the product afforded crustecdysone (Ia) [mp 240–242° (from methanol–ethyl acetate); λ_{max}^{EtOH} 240 mμ (ε 12,670); ν_{max}^{KBr} 1656, 1615, 1387, 1229, 1053, 917, and 878 cm^{-1}; nmr (pyridine-d_5) 1.07 (19-H), 1.20 (18-H), 1.36 (26- and 27-H), 1.56 (21-H), and 6.17 (7-H)].

A mixture melting point with authentic crustecdysone[15] (mp 247–248°) showed no depression. The two samples were identical in spectroscopic[16] and chromatographic behavior and biological activity in *Samia cynthia* silkmoth assay for moulting hormone activity.

Further evidence for the stereochemical identity of the natural and synthetic crustecdysones is available from alkylation of the 20*S* isomer Vf and subsequent elaboration of the products by the above method. This led to two compounds (isomeric at C$_{22}$), one considerably more polar than authentic crustecdysone and the other closely similar in R_f to Ia. However, chemical shifts of the latter compound [nmr (pyridine-d_5) 1.38 (21-H) and 1.48 (26- and 27-H)] showed it to be a stereoisomer (probably 20*S*,22*R*) of the natural product.

(15) We are deeply indebted to Dr. D. H. S. Horn for this sample.
(16) Mass spectra of synthetic and natural crustecdysone determined on an Atlas CH-4 spectrometer showed a fragment *m/e* 462 (M − H$_2$O) followed by loss of three molecules of water. Fragments observed at *m/e* 363 and 117 are characteristic of C$_{20}$–C$_{22}$ cleavage of the trihydroxylated side chain.
(17) Syntex Postdoctoral Fellow, 1966–1967.

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Received September 30, 1967

The Electronic Absorption Spectra of Aminosilanes[1]

Sir:

The departure from tetrahedral geometry[2] and the anomalously weak donor properties[2,3] of various aminosilanes provide positive experimental evidence for the existence of (p → d)π Si–N bonding. On the basis of a Pariser–Parr–Pople SCF treatment, Perkins[4] has estimated that the energy of this bond in trisilylamine is ~16 kcal. However, this assessment must be contrasted with the agnostic attitude of Randall and Zuckerman,[5] who failed to observe any difference in *J*(^{15}N–H), and hence the nitrogen hybridization, on trimethylsilylation of [^{15}N]aniline. Similarly, nmr experiments[6] designed to evaluate the transmission of substituent effects through the N–Si–N system in silaimidazolidines did not reveal any differences from the analogous carbon system (N–C–N), and the force constant of the Si–N bond is more consistent with single than with double bond character.[7] We have now measured the electronic absorption spectra of selected aminosilanes and have found this to be a fruitful approach to the understanding of the nature of the (p → d)π Si–N bond.

In contrast to alkyl substitution,[8] stepwise silylation of ammonia results in a progressive hypsochromic shift of the absorption maxima (Table I). The transparency of the analogous carbon[9] and oxygen[10] derivatives (Me$_3$Si–X–SiMe$_3$, X = O, CH$_2$) in the ultraviolet, coupled with the weak hypsochromic shift on changing the solvent from isooctane to ethanol and the strong hypsochromic shift on N-acetylation, demonstrates that the nonbonding nitrogen electrons rather than σ electrons are involved in the transition. The excited state of the transition may be the Si–N σ* orbital. In this case the transition corresponds to the long-wavelength absorption of alkylamines, and the hypsochromic shift produced on progressive substitution with the more electropositive trialkylsilyl group[11] is explained in terms of the delocalization (and hence stabilization) of the nitrogen lone pair into the silicon d orbitals and is in agreement with the reported[3] trend in the basicity of

Table I. Absorption Maxima and Basicities of Aminosilanes

Compd	λ_{max}, mμ[a]	ε	$\Delta\nu_1$,[b] cm^{-1}
Et$_3$SiNH$_2$	208.8	1780	38
(Et$_3$Si)$_2$NH	205.5	1810	*e*
(Me$_3$Si)$_2$NH	203.7	2870	30[d]
	202.6[c]		
(Me$_3$Si)$_3$N	200.4	4850	*d*, *e*
	200.1[c]		
Me$_3$SiNHCOMe	<195.0	2200 (200 mμ)	
(Me$_3$Si)$_2$NCOMe	<195.0	3700 (200 mμ)	
PhNH$_2$	233.7, 287.5	9130, 1860	
PhNHSiMe$_3$	239.8, 291.0	10700, 1860	
PhN(SiMe$_3$)$_2$	234.0, 265.0	3250, 445	
Me(Me$_2$SiNH)$_2$SiMe$_3$	200.0	4840	30
Me(Me$_2$SiNH)$_3$SiMe$_3$	201.8	6800	29
(Me$_2$SiNH)$_3$	201.8	6160	31[d]
(Me$_2$SiNH)$_4$	201.1	7730	
Me$_8$Si$_3$	216.5	7900	
n-Me$_7$Si$_3$NH$_2$	213.0[f]	6420	39
(*n*-Me$_7$Si$_3$)$_2$NH	217.5[f]	13200	*e*

[a] Determined in dry spectral grade isooctane using 1-mm cells and a Cary 14 spectrometer. [b] C–D stretching frequency shift of CDCl$_3$ (~1 mole) in amine (~10 mole) relative to corresponding mode of gaseous CDCl$_3$. [c] Determined in absolute ethanol; extinction coefficient uncertain because of ethanolysis. [d] Values from Abel, Armitage, and Willey.[3] [e] No trace of shifted C–D absorption. [f] Inflection point.

(1) This work was supported in part by the Electronic Technology Division of the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, under Contract No. AF-33(615)-67-C-1175.
(2) For recent summaries, see R. Fessenden and J. S. Fessenden, *Chem. Rev.*, 61, 361 (1961); U. Wannagat, *Advan. Inorg. Chem. Radiochem.*, 6, 225 (1964). For a discussion of the relationship between geometry and the magnitude of (p → d)π bonding, see E. A. V. Ebsworth, *Chem. Commun.*, 530 (1966).
(3) E. W. Abel, D. A. Armitage, and G. R. Willey, *Trans. Faraday Soc.*, 60, 1257 (1964); E. W. Abel, D. A. Armitage, and D. B. Brady, *ibid.*, 62, 3459 (1966).
(4) P. G. Perkins, *Chem. Commun.*, 268 (1967).
(5) E. W. Randall and J. J. Zuckerman, *ibid.*, 732 (1966).
(6) C. H. Yoder and J. J. Zuckerman, *Inorg. Chem.*, 6, 103 (1967).
(7) E. A. V. Ebsworth, J. R. Hall, M. J. Mackillop, D. C. McKean, N. Sheppard, and L. A. Woodward, *Spectrochim. Acta*, 13, 202 (1958).
(8) E. Tannenbaum, E. M. Coffin, and A. J. Harrison, *J. Chem. Phys.*, 21, 311 (1953).
(9) Unpublished results, C. G. Pitt.
(10) A. P. Kreshkov, Yu. Ya. Mikhailov, and I. P. Smirenkina, *Zh. Fiz. Khim.*, 32, 834 (1958).
(11) D. R. M. Walton, *J. Organometal. Chem.* (Amsterdam), 3, 438 (1965).