may be that a major contribution to the solvolysis of the hydroxy intermediate comes from the higher dielectric constant of the aqueous medium.

Regardless of such mechanistic details, the easy and stereoselective closure of the open aldehydolactone **6** leads to a considerable conceptual simplification in the construction of gibberellic acid.[12]

Acknowledgment. We thank the National Institutes of Health and the National Science Foundation for their support of this work.

References and Notes

(1) Stork, G., Newman, H. *J. Am. Chem. Soc.* **1959**, *81*, 5518–5519. See also J. W. Cornforth as quoted by Cross, B. E., *Chem. Ind.* (*London*) **1959**, 183–185.

(2) Cross, B. E.; Grove, J. F.; MacMillan, J.; Mulholland, T. P. C.; Sheppard, N. *Proc. Chem. Soc.* **1958**, 221–222.

(3) Dolby, L. J.; Skold, C. N. *J. Am. Chem. Soc.* **1974**, *96*, 3276–3279.

(4) Cross, B. E.; Grove, J. F.; Morrison, A. *J. Chem. Soc.* **1961**, 2498–2515.

(5) (a) Cross, B. E. *J. Chem. Soc.* **1960**, 3022–3038. (b) Voigt, B.; Adam, G.; Kobrina, N. S.; Serebryakov, E. P. *Z. Chem.* **1977**, *17*, 372–374.

(6) All crystalline compounds were recrystallized from ethyl acetate–hexane and gave ^{1}H NMR data, as well as infrared and mass spectral data, in agreement with those of the assigned structures.

(7) R_F values from thin layer chromatography (silica gel with 3:1 ethyl acetate–hexane) were 0.20, 0.64, 0.35, and 0.50, respectively, for **8**, its mixed anhydride, **9**, and **6**. We believe that the unsaturated acid **8** and the unsaturated aldehyde **6** have a cis double bond, in spite of the rather large coupling constant for the hydrogens labeled H_A and H_B. This is based on the observations (a) that the isomeric unsaturated ester from elimination of the sulfoxide corresponding to the thiophenol adduct of the ester of **8** showed a 16-Hz coupling constant for the hydrogens in question; (b) that the same coupling constant was observed for the unsaturated aldehyde obtained from the alcohol **9** by oxidation with the chromic acid–pyridine complex rather than with manganese dioxide. The cis aldehyde **6** showed the resonance of the aldehyde hydrogen at δ 10.3 while the chromic acid isomer had it at 9.6. The coupling constant of the doublet for that hydrogen was 7 Hz in both cases.

(8) The $R_F{}^7$ for methyl gibberellate was 0.51 and for the 3 epimer, 0.47.

(9) Goldman, I. M. *J. Org. Chem.* **1969**, *34*, 1979–1981. This manganese dioxide oxidizes 3-epigibberellic ester, as well as the natural substance in high yield. Compare ref 5b.

(10) Another sequence, applicable to either methyl gibberellate, its C_3 epimer, or a mixture of the two, was carried out: This involves conversion into the 1-bromide (cf. Corey, E. J.; Brennan, T. M.; Carney, R. L. *J. Am. Chem. Soc.* **1971**, *93*, 7316–7317) which gave the acetate of methyl gibberellate with tetrabutylammonium acetate (acetone, 3-h reflux) by an access-controlled S_N2'-type reaction.[11] Free methyl gibberellate (**4**, R = CH_3) was obtained by hydrolysis with sodium bicarbonate in methanol–water (6 h at room temperature).

(11) Stork, G.; Clarke, F. H. *J. Am. Chem. Soc.* **1956**, *78*, 4619–4624. Ganem, B.; Ikota, N. *Ibid.* **1978**, *100*, 351–352.

(12) A successful synthesis of gibberellic acid, based on a different approach, has been reported recently: Corey, E. J., Danheiser, R. L.; Chandrasekaran, S.; Keck, G. E.; Gopalan, B.; Larsen, S. E.; Siret, P.; Grass, J. L. *J. Am. Chem. Soc.* **1978**, *100*, 8034–8036.

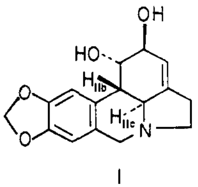
Gilbert Stork,* Janak Singh
Department of Chemistry, Columbia University
New York, New York 10027

Received May 14, 1979

A Simple, Stereospecific Synthesis of the Skeleton of the Lycorine Alkaloids

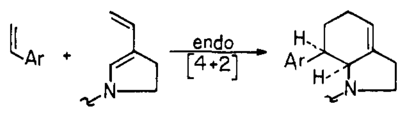
Sir:

We report here a particularly direct route to the galanthan (α-lycorane) system which forms the basic skeleton of lycorine (**1**), the most prevalent of the Amaryllidaceae alkaloids.[1,2]



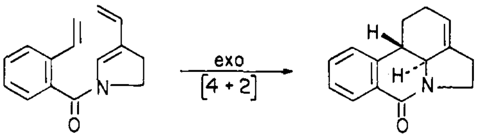
1

The position of the double bond in lycorine immediately suggests a construction based on a [4 + 2] cycloaddition such as a → b, but the normal endo course of such a cycloaddition would lead to the incorrect cis relationship of the hydrogen at C$_{11b}$ and C$_{11c}$, a problem which had been encountered previously in intramolecular approaches to **1** from this laboratory.[3]



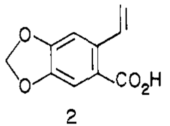
a b

The situation is entirely changed, however, if a connection between the A and B fragments is established via an amide link, thus making the cycloaddition intramolecular.[4] In such a case, the constraints imposed by the planarity of the amide system are such that only the exo transition state may reasonably be expected (cf. c → d). We describe here the realization of such a scheme.

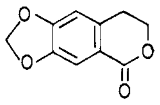


c d

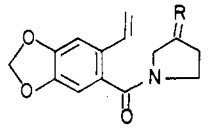
The requisite acid **2**, mp 160–163 °C,[5] readily prepared in 90–95% yield from lactone **3**[7] (addition of **3** and 1.2 equiv of HMPA to 1.2 equiv of LiN(SiMe$_3$)$_2$ in THF at −78 °C) could be efficiently coupled with 3-pyrrolidinol[8] (1 equiv of **2**, 1.2 equiv of Ph$_3$P and 5 equiv of CCl$_4$ in MeCN,[9] 2 h; then, after cooling to 0 °C, treatment with 2 equiv of 3-pyrrolidinol, 0–25 °C, 1 h; 93%) to yield **4a.** Oxidation of **4a** (addition of 4 equiv of pyridine–SO$_3$ complex in Me$_2$SO[10] and 10 equiv of triethylamine in Me$_2$SO, followed by quenching after 15 min with ~20 equiv of acetic acid) afforded (79% yield) the keto amide **4b,** which was further elaborated to **5a** either (57% yield) by Emmons-Horner reaction (1.2 equiv each of (EtO)$_2$P(O)CH$_2$CO$_2$CH$_3$ and NaH in glyme, 0 °C, 3 h; then quenched with 2 equiv of acetic acid), which led directly to the thermodynamic β,γ-unsaturated ester, or (60% yield) by Wittig olefination, followed by equilibration (3 equiv of Ph$_3$P=CHCO$_2$CH$_3$ in methylene chloride, 36 h, followed, after chromatography, by DBU in THF, 18 h). Amide **5a** was transformed further by reduction (5.7 equiv of LiBH$_4$, THF, 22 h) and then selenation (1.2 equiv each of *o*-nitrophenyl selenocyanate and Bu$_3$P[11] in methylene chloride, 5 min) of the



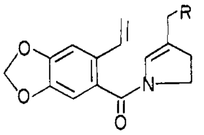
2

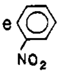


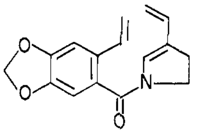
3



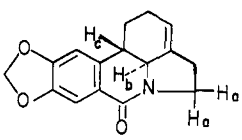
4a R=H,OH
4b R=O



5a R=CO$_2$CH$_3$
5b R=CH$_2$Se 



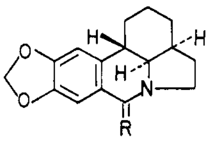
6



7

0002-7863/79/1501-7110$01.00/0

crude alcohol to **5b**, mp 136–137 °C, in 50–55% overall yield. Conversion of **5b** into **6** could be accomplished in high yield under carefully defined conditions (i.e., 0.176 mmol of **5b** in 5 mL of THF, 1 mL of MeOH, 2 mL of H_2O, 5 equiv of $NaIO_4$,[12] 6.75 equiv of $NaHCO_3$, for 24 h, and then an additional 5 equiv of $NaIO_4$–2 mL of H_2O, 18 h; 94%). The triene **6** cyclized in 51% yield to a single compound **7**, mp 218–220 °C at 140 °C (0.145 mmol of **6** in 600 mL of chlorobenzene, 2 mg of 3-*tert*-butyl-4-hydroxy-5-methylphenyl sulfide, 0.5 mL of O,N-bis(trimethylsilyl)acetamide at reflux under argon, in ammonia-treated glassware for 24 h). At 80 MHz, the ^1H NMR spectrum in $CDCl_3$ offered little information concerning the stereochemistry at the ring junction of the adduct. Both the benzylic and amide methine protons were obscured by other resonances. In benzene-d_6 the resonances due to H_a and H_b were separated, allowing observation of $J_{bc} = 12$ Hz, upon irradiation of the H_a signal. This value, which is in accord with the expected values for galanthan systems,[13] establishes **7** as the structure of the sole adduct obtained. Furthermore, hydrogenation of this substance (EtOAc, 5% Pd/C, 1 atm, 25 °C) afforded the galanthan **8a**, 7-oxo-α-lycorane, mp 169–171 °C, identical in all respects (IR, NMR, mass spectral fragmentation pattern, TLC, and mixture melting point) with material prepared from an authentic sample of (±)-α-lycorane[14] (**8b**)



8a R=O

8b R=H,H

(potassium permanganate-acetone-water, 0 °C, 20 min;[15] 50–60% yield). The simplicity and potential versatility of this route suggests that it will be valuable in the construction of a number of lycorine alkaloids.

Acknowledgments. We express our appreciation to Dr. B. Umezawa of the Science University of Tokyo who kindly supplied us with a sample of (±)-lycorane. We thank the National Science Foundation and the National Institutes of Health for their support.

References and Notes

(1) For a review, see Fuganti, C. In "The Alkaloids", Manske, R. H. F., Ed.; Academic Press: New York, 1975; Vol. XV, Chapter III.
(2) A total synthesis of lycorine has been recorded: Tsuda, Y.; Sano, T.; Taga, J.; Isobe, K.; Toda, J.; Irie, H.; Tanaka, S.; Takagi, S.; Yamaki, M.; Murota, M. *J. Chem. Soc.* **1979,** 1358. For other recent synthetic work in this area, see: Umezawa, B.; Hoshino, O.; Sawaki, S.; Sato, S.; Numao, N. *J. Org. Chem.* **1977,** *42*, 4272. Moller, O.; Steinberg, E.; Torsell, K. *Acta Chem. Scand., Ser. B* **1978,** *32*, 98. Iida, H.; Yuasa, Y.; Kibayashi, C. *J. Org. Chem.* **1979**, *44*, 1074.
(3) Morgans, D. J., Jr.; Stork, G. *Tetrahedron Lett.* **1979**, 1959.
(4) For a recent review of intramolecular Diels–Alder additions, see Oppolzer, W. *Angew. Chem.* **1977,** *16*, 10.
(5) All intermediates gave satisfactory spectral (IR, NMR, mass) data.
(6) Compare Pogosyan, G. M.; Karapetian, T. G.; Matsoyan, S. G. *Zh. Org. Khim.* **1970,** *6*, 139.
(7) Srivastava, J. N.; Chaudhury, D. N. *J. Org. Chem.* **1962,** *27*, 4337.
(8) Obtained from Aldrich Chemical Co.
(9) Cf. Borstow, L. E.; Hruby, V. J. *J. Org. Chem.* **1971,** *36*, 1305.
(10) Parikh, J. R.; Doering, W. E. *J. Am. Chem. Soc.* **1967**, *89*, 5505.
(11) Grieco, P. A.: Gilman, S.; Nishizawa, M. *J. Org. Chem.* **1976**, *41*, 485.
(12) Cf. Reich, H. J.; Reich, I. L.; Renga, J. M. *J. Am. Chem. Soc.* **1973**, *95*, 5814.
(13) Kotera, K.; Hamade, Y.; Tori, K.; Aono, K.; Kuriyama, K. *Tetrahedron Lett.* **1966,** 2009.
(14) Cf. Umezawa et al.[2]
(15) Cf. Kondo, H.; Katsura, H. *Chem. Ber.* **1940**, *73*, 112.

Gilbert Stork,* D. J. Morgans, Jr.
Department of Chemistry, Columbia University
New York, New York 10027

Received July 9, 1979

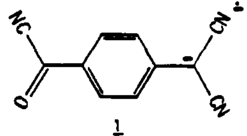
Synthesis and Characterization of the Metamagnetic 1:1 1-D Phase of the Decamethylferrocenium 7,7,8,8-Tetracyano-*p*-quinodimethanide: $Fe[C_5(CH_3)_5]_2{}^{+}\cdot(TCNQ)^{-}\cdot$

Sir:

The reaction of decamethylferrocene (DMeFc) and 7,7,8,8-tetracyano-*p*-quinodimethane (TCNQ) results in the formation of several interesting substances, namely, phase I and phase II 1:1 charge-transfer salts and a third substance of 1:2 composition, $(DMeFc)(TCNQ)_2$.[1] In a previous paper we reported the structure of the paramagnetic phase I substance, i.e., $(DMeFc^+)_2\cdot(TCNQ)_2{}^{2-}$, which exists as isolated dimers in the solid state.[2] Large crystals (~18 mg) of the phase I material are isolated upon long standing from an acetonitrile solution of DMeFc and TCNQ (1:1). Quick crystal growth (~2 h), however, results in the reproducible formation of a phase II polymorph of identical composition, but with an enhanced oxygen sensitivity. Furthermore, the phase II substance exhibits unusual magnetic properties,[3] i.e., metamagnetism.

Initially only one 1:1 substance was assumed; however, the optical absorptions characteristic of an isolated $TCNQ^-\cdot$ (Figure 1), which differ markedly from that predicted for the $TCNQ^-$ dimer[4] present in the dimeric phase I polymorph, and the observation of simple Curie-like paramagnetism for large single crystals led us to suspect a second phase. Furthermore, in contrast to crystals of the dimeric substance, on standing in the ambient atmosphere sublimed thin films turned red and gave a red-yellow solution in acetonitrile (λ_{max} ~480 nm). These differences in reactivity again suggested the presence of two distinct phases. Herein we report the characterization of the metamagnetic phase II material, $(DMeFc^+\cdot)(TCNQ^-\cdot)$. We also show structural evidence for the formation of α,α-dicyano-*p*-toluoylcyanide anions, formed from the solid-state reaction of $(DMeFc^+\cdot)(TCNQ^-\cdot)$ and air.

The large phase I crystals are stable with respect to reaction with oxygen presumably owing to the unreactiveness of the tight $(TCNQ)_2{}^{2-}$ dimer which is formed. A freshly sublimed thin film of the phase I dimer exhibits an ESCA spectrum containing a single N_{1s} peak at 398.2 eV. Upon exposure to the atmosphere for 24 h, the film had a pronounced O_{1s} peak at 532.8 eV and the N_{1s} peak split into a double at 400.3 and 398.3 eV. These data confirmed that oxygen reacted with the $TCNQ^-\cdot$. A possible reaction product consistent with the ESCA data is the α,α-dicyano-*p*-toluoylcyanide anion ($DCTC^-\cdot$, **1**), which has been previously reported to result from the oxygenation of $TCNQ^{2-}$.[5a] Resonance Raman spectra taken on aged bulk crystals of the phase II polymorph by using 514.5-nm radiation confirmed the presence of **1**. This radiation enhanced the $DCTC^-\cdot$ absorptions at 1624, 1331, 1282, and 1172 cm^{-1}. Additionally using 459.9-nm radiation, a frequency of 1392 cm^{-1} characteristic of $TCNQ^-\cdot$ (ν_4) absorption was observed.[5b]



1

The green phase II material crystallizes as rectangular block crystals in the monoclinic, centrosymmetric, space group, $P2_1/n$ (C_{2h}, No. 14) with unit cell constants $a = 10.840$ (5), $b = 30.999$ (13), $c = 8.628$ (3) Å; $\beta = 99.20$ (3)°; $Z = 4$; $\rho_{calcd} = 1.238$ g cm^{-3} ($\rho_{obsd} = 1.238$ (5) g cm^{-3} by flotation in cyclohexane-1,2-dibromoethane). The only crystal found suitable for X-ray studies was unfortunately kept unprotected from the atmosphere for 18 months. Attempts to grow larger crystals

0002-7863/79/1501-7111$01.00/0