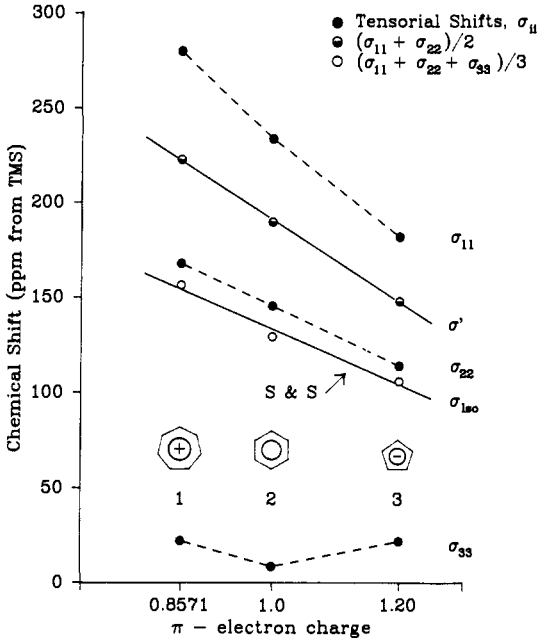


Figure 2. Tensorial chemical shifts for tropylium cation (**1**), benzene (**2**), and cyclopentadienide anion (**3**) as a function of π-electron charge.

values for **1** and **3** are reported here for the first time. Our values for **2** differ from those reported recently[10] by more than our experimental error of ±3 ppm. It is noted that our trace agrees within ±3 ppm with the isotropic liquid values as do the corresponding trace values for the two ions. Our referencing technique involves using an external sample of Me_4Si and therefore may introduce an error as large as ±3 ppm.

Figure 2 clearly indicates that σ_{11}, σ_{22}, σ', and to a reasonable degree σ_{iso} are dependent upon q_π. The plot of σ_{33}, however, shows no simple dependence upon q_π, and the relationship is not even monotonic. The negligible dependence upon q_π in σ_{33} compared with σ_{11} and σ_{22} makes the trace less sensitive to q_π than the two more responsive components.

Waugh and co-workers[4] have used charge-withdrawal arguments to rationalize the changes in tensorial shifts of alkylbenzenes complexes with $Cr(CO)_3$. Such arguments are even more jusitified in the present case. The variations in the tensorial components reflect primarily the behavior of electrons located in the p orbitals oriented perpendicular to the component axis.[5] The value of σ_{33} is characteristic of saturated carbon atoms, and this is reasonable considering that it is determined primarily by the properties of electrons in the σ bonds. Thus, σ_{33} is likely to be more sensitive to the strain in the C-C-C angle than to q_π, upon which the original correlation for σ_{iso} was based.[2] The q_π will affect σ_{33} only through second-order charge-polarization effects upon the σ-electron structure.

Both σ_{11} and σ_{22} are affected by changes in q_π directly as the axes of these components lie in the molecular plane. They differ only in the manner in which they sample the σ-electron distribution in the C-C and C-H bonds, respectively. Because both σ_{11} and σ_{22} depend directly upon q_π, the average, σ', of these two shifts was calculated and is plotted against q_π in Figure 2. A very linear relationship exists between σ' and q_π with a slope for -218 ppm/e compared with the -160 ppm/e slope found for the isotropic shift in ref 2. Thus, the curvature in the plot of the isotropic shift largely arises from the σ_{33} contribution.

This work supports the original premise that chemical shifts depend upon q_π but refines the proposal to focus on only those shift components that reflect the very anisotropic charge distributions associated with charged aromatic systems. As chemical shielding is very sensitive to charge effects, such three-dimensional information is of the utmost importance in understanding this relationship. This work also graphically emphasizes the importance of using the tensorial shifts over the traditional isotropic chemical shift obtained in liquids. Not only does one obtain three times more information but very important directional features also are obtainable. It is hoped that these results will contribute to a greater appreciation of the importance of three-dimensional chemical shift data among chemists interested in structurally selective chemical properties or processes. Furthermore, it should warn against overinterpretation of isotropic chemical shift parameters.

Acknowledgment. This work was sponsored by a grant from the Chemistry Section of the National Science Foundation (CHE 8000256).

Registry No. 1, 26811-28-9; **2**, 71-43-2; **3**, 12127-83-2.

(10) Linder, M.; Höhener, A.; Ernst, R. R. *J. Magn. Reson.* **1979**, *35*, 379.

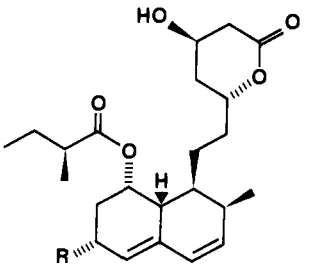
Biosynthesis of Mevinolin. Spectral Assignment by Double-Quantum Coherence NMR after High Carbon-13 Incorporation†

Jean K. Chan, Richard N. Moore, Thomas T. Nakashima, and John C. Vederas*

Department of Chemistry, University of Alberta Edmonton, Alberta, Canada T6G 2G2

Received January 11, 1983

Mevinolin (**1**),[1,2a] compactin (**2**),[2b,c] and analogues such as the



1 R=CH_3
2 R=H

corresponding 4a,5-dihydro derivatives[2d,e] are fungal metabolites that block isoprenoid biosynthesis.[2,3] Competitive inhibition of the key enzyme in the pathway, 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMG-CoA reductase; E.C. 1.1.1.34), by the lactone-opened forms of these compounds decreases availability of mevalonate and thereby lowers plasma cholesterol levels in various mammals, including man.[3,4] Since more than half of the

† Dedicated to Professor Christoph Tamm, University of Basel, on the occasion of his 60th birthday.

(1) Mevinolin (**1**) from *Aspergillus terreus*[2a] and monacolin K from *Monascus ruber* (Endo, A. *J. Antibiot.* **1979**, *32*, 852-854. Endo, A. *Ibid.* **1980**, *33*, 334-336) appear to be the same compound;[2e] compactin (**2**) is also known as ML-236B.[2c]

(2) (a) Alberts, A. W.; Chen, J.; Kuron, G.; Hunt, V.; Huff, J.; Hoffman, C.; Rothrock, J.; Lopez, M.; Joshua, H.; Harris, E.; Patchett, A.; Monaghan, R.; Currie, S.; Stapley, E.; Albers-Schonberg, G.; Hensens, O.; Hirshfield, J.; Hoogsteen, K.; Liesch, J.; Springer, J. *Proc. Natl. Acad. Sci. U.S.A.* **1980**, *77*, 3957-3961. (b) Brown, A. G.; Smale, T. C.; King, T. J.; Hasenkamp, R.; Thompson, R. H. *J. Chem. Soc., Perkin Trans. 1* **1976**, 1165-1170. (c) Endo, A.; Kuroda, M.; Tsujita, Y. *J. Antibiot.* **1976**, *29*, 1346-1348. (d) Albers-Schönberg, G.; Joshua, H.; Lopez, M. B.; Hensens, O. D.; Springer, J. P.; Chen, J.; Ostrove, S.; Hoffman, C. H.; Alberts, A. W.; Patchett, A. A. *Ibid.* **1981**, *34*, 507-512. (e) Lam, Y. K. T.; Gullo, V. P.; Goegelman, R. T.; Jorn, D.; Huang, L.; DeRiso, C.; Monaghan, R. L.; Putter, I. *Ibid.* **1981**, *34*, 614-616.

(3) (a) Endo, A. *Trends Biochem. Sci.* **1981**, *6*, 10-13. (b) Endo, A. *Methods Enzymol.* **1981**, *72D*, 684-689.

(4) (a) Kritchevsky, D.; Tepper, S. A.; Klurfeld, D. M. *Pharmacol. Res. Commun.* **1981**, *13*, 921-926. (b) Tobert, J. A.; Hitzenberger, G.; Kukovetz, W. R.; Holmes, I. B.; Jones, K. H. *Atherosclerosis* **1982**, *41*, 61-65. (c) Kroon, P. A.; Hand, K. M.; Huff, J. W.; Alberts, A. W. *Ibid.* **1982**, *44*, 41-48. (d) Tobert, J. A.; Bell, G. D.; Birtwell, J.; Kukovetz, W. R.; Pryor, J. S.; Buntinx, A.; Holmes, I. B.; Chao, Y. S.; Bolognese, J. A. *J. Clin. Invest.* **1982**, *69*, 913-919.

0002-7863/83/1505-3334$01.50/0

total human body cholesterol originates from de novo biosynthesis, such materials possess obvious potential in treatment of atherosclerosis and coronary heart disease.[4] Analogous effects on dolichol,[5] ubiquinone,[6] and insect juvenile hormone production,[7] as well as influences on plant root elongation,[8] also establish **1** and **2** as important biochemical tools.[3,9] Their unusual structures and biological significance have inspired total[10] and partial[11] syntheses of compactin (**2**) and structural modification studies[12] on mevinolin (**1**). In this communication we report the biosynthesis of mevinolin (**1**) in *Aspergillus terreus* ATCC 20542 from acetate and methionine using multiply labeled ^{13}C, ^{18}O, and ^{2}H precursors. We also describe how recently developed NMR pulse sequences in combination with a high level of biosynthetic multiple labeling allow rapid assignment of ^{13}C NMR spectra on the basis of carbon–carbon coupling.

Since complete determination of NMR spectral positions is the usual prerequisite for stable isotope incorporation studies,[13] the ^{1}H NMR spectrum of mevinolin (**1**) was first assigned by using chemical shifts and selective homonuclear decoupling experiments.[14] However, subsequent examination of both broad band proton-decoupled and spin echo Fourier transform (SEFT)[15] ^{13}C NMR spectra of **1** did not permit complete unambiguous resonance identification, even with selective heteronuclear (^{1}H) decoupling experiments. The similarity of a number of carbon signals in multiplicity and ^{13}C NMR chemical shift was unfortunately reflected by ^{1}H NMR overlap of their attached hydrogen resonances. Recent development of double-quantum coherence NMR now allows determination of the carbon connectivity pattern by observation of natural abundance carbon–carbon coupling,[16] but often large quantities (0.5–1.0 g) of sample are required for spectral analysis. Application of such a two dimensional INADEQUATE experiment[16b,i,17] to mevinolin (**1**) *after* heavy incorporation[18] of doubly labeled sodium [1,2-$^{13}C_2$]acetate[19] by *A. terreus* permitted complete ^{13}C NMR assignment with only 20 mg of sample because of a 200-fold increase in the relative intensity of coupled carbon signals (from 0.01% to about 2% for each coupled pair of carbon atoms). The pulse feeding[18] also led to multiple acetate incorporations within a single molecule of mevinolin (**1**), thereby allowing observation of ^{13}C–^{13}C coupling between carbons of neighboring biosynthetic units and establishing

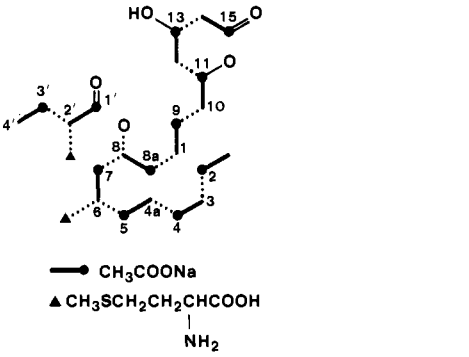


Figure 1.

Table I. ^{13}C NMR Data of Mevinolin (1) Derived from Sodium [1-^{13}C]-, [2-^{13}C]-, and [1-^{13}C,$^{2}H_3$]Acetate[a]

carbon	δ	^{13}C enhancement[b] [1-^{13}C]	^{13}C enhancement[b] [2-^{13}C]	[1-^{13}C,$^{2}H_3$]acetate incorp ^{2}H:^{1}H[c]	[1-^{13}C,$^{2}H_3$]acetate incorp $\Delta\delta$[d]
1	36.7		2.4	24:76	
2	30.7	4.1			−0.25, −0.17, −0.082[e]
2-Me	13.9		2.3	76:8:8:8[e]	
3	133.1		3.1	0:100	
4	128.4	3.3			
4a	131.6		4.4		
5	129.6	3.0			
6	27.5		5.2	0:100	
6-Me	22.9				
7	32.8	3.2			
8	68.0		1.4	45:55	
8a	37.4	4.6			+0.013
9	24.3	4.1			−0.096
10	33.0		2.2	80:20	
11	75.7	4.6			−0.06
12	36.2		2.4	50:50	
13	62.6	7.7			−0.12
14	38.7		3.4	50:50	
15	170.7	2.8			+0.04
1'	176.9	2.4			+0.018
2'	41.6		2.9	75:25	
2'-Me	16.3				
3'	26.8	4.4			−0.21, −0.14, −0.071[e]
4'	11.7		2.9	76:8:8:8[e]	

[a] For spectral conditions see ref 17. [b] Ratio of carbon signal intensities for enriched and natural abundance sample measured under identical conditions. [c] Ratio of carbon peak areas for β-isotope shifted signals. [d] β-Isotope shifts due to ^{2}H are given in ppm. [e] CD_3:CHD_2:CH_2D:CH_3.

(5) Carson, D. D.; Lennarz, W. J. *J. Biol. Chem.* **1981**, *256*, 4679–4686.
(6) Ranganathan, S.; Nambudiri, A. M. D.; Rudney, H. *Arch. Biochem. Biophys.* **1981**, *210*, 592–597.
(7) Monger, D. J.; Lim, W. A.; Kezdy, F. J.; Law, J. H. *Biochem. Biophys. Res. Commun.* **1982**, *105*, 1374–1380.
(8) Bach, T. J.; Lichtenthaler, H. K. *Z. Naturforsch. C* **1982**, *37C*, 46–49.
(9) (a) Ryan, J.; Hardeman, E. C.; Endo, A.; Simoni, R. D. *J. Biol. Chem.* **1981**, *256*, 6762–6768. (b) Chin, D. J.; Luskey, K. L.; Anderson, R. G. W.; Faust, J. R.; Goldstein, J. L.; Brown, M. S. *Proc. Natl. Acad. Sci. U.S.A.* **1982**, *79*, 1185–1189. (c) Quesney-Huneeus, V.; Galick, H. A.; Siperstein, M. D.; Erickson, S. K.; Spencer, T. A.; Nelson, J. A. *J. Biol. Chem.* **1983**, *258*, 378–385.
(10) (a) Wang, N. Y.; Hsu, C. T.; Sih, C. J. *J. Am. Soc.* **1981**, *103*, 6538–6539. (b) Hirama, M.; Uei, M. *Ibid.* **1982**, *104*, 4251–4253. (c) Girotra, N. N.; Wendler, N. L. *Tetrahedron Lett.* **1982**, *23*, 5501–5504. (d) Hsu, C. T.; Wang, N. Y.; Latimer, L. H.; Sih, C. J. *J. Am. Chem. Soc.* **1983**, *105*, 593–601. (e) Grieco, P. A.; Zelle, R. E.; Lis, R.; Fin, J. *Ibid.* **1983**, *105*, 1403–1404.
(11) Lactone portion: (a) Danishefsky, S.; Kerwin, J. F., Jr.; Kobayashi, S. *J. Am. Chem. Soc.* **1982**, *104*, 358–360. (b) Prugh, J. D.; Deana, A. A. *Tetrahedron Lett.* **1982**, *23*, 281–284. (c) Yang, Y. L.; Falck, J. R. *Ibid.* **1982**, *23*, 4305–4308. Hexahydronaphthalene portion: (d) Funk, R. L.; Zeller, W. E. *J. Org. Chem.* **1982**, *47*, 180–182. (e) Deutsch, E. A.; Snider, B. B. *Ibid.* **1982**, *47*, 2682–2684. (f) Heathcock, C. H.; Taschner, M. J.; Rosen, T.; Thomas, J. A.; Hadley, C. R.; Popjak, G. *Tetrahedron Lett.* **1982**, *23*, 4747–4750. (g) Anderson, P. C.; Clive, D. L. J.; Evans, C. F. *Tetrahedron Lett.*, in press.
(12) (a) Lee, T. J.; Holtz, W J.; Smith, R. L. *J. Org. Chem.* **1982**, *47*, 4750–4757. (b) Willard, A. K.; Smith, R. L. *J. Labelled Compd. Radiopharm.* **1982**, *19*, 337–344.
(13) (a) Garson, M. J.; Staunton, J. *Chem. Soc. Rev.* **1979**, 539–561. (b) Wehrli, F. W.; Nishida, T. *Prog. Chem. Org. Nat. Prod.* **1979**, *36*, 1–229.
(14) The ^{1}H NMR assignment of mevinolin (**1**) has been partially reported.[2a] For complete spectral assignment see supplementary material.
(15) (a) Brown, D. W.; Nakashima, T. T.; Rabenstein, D. L. *J. Magn. Reson.* **1981**, *45*, 302–314. (b) Bendall, M. R.; Pegg, D. T.; Doddrell, D. M.; Johns, S. R.; Willing, R. I. *J. Chem. Soc., Chem. Commun.* **1982**, 1138–1140.
(16) (a) Bax, A.; Freeman, R.; Kempsell, S. P. *J. Am. Chem. Soc.* **1980**, *102*, 4849–4851. (b) Bax, A.; Freeman, R.; Frenkiel, T. A. *Ibid.* **1981**, *103*, 2102–2104. (c) Neszmelyi, A.; Lukacs, G. *J. Chem. Soc., Chem. Commun.* **1981**, 991–1001. (d) Bax, A.; Freeman, R.; Frenkiel, T. A.; Levitt, M. H. *J. Magn. Reson.* **1981**, *43*, 478–483. (e) Turner, D. L. *Ibid.* **1982**, *49*, 175–178. (f) Robinson, J. A.; Turner, D. L. *J. Chem. Soc., Chem. Commun.* **1982**, 148–151. (g) Ashworth, D. M.; Robinson, J. A.; Turner, D. L. *Ibid.* **1982**, 491–493. (h) Freeman, R.; Frenkiel, T.; Rubin, M. B. *J. Am. Chem. Soc.* **1982**, *104*, 5545–5547. (i) Neszmelyi, A.; Hull, W. E.; Lukacs, G. *Tetrahedron Lett.* **1982**, *23*, 5071–5074. (j) Pinto, A. C.; Do Prado, S. K.; Filho, R. B.; Hull, W. E.; Neszmelyi, A.; Lukacs, G. *Ibid.* **1982**, *23*, 5267–5270.

(17) All ^{13}C NMR spectra were obtained at 100.6 MHz on a Bruker WH400 spectrometer using ca. 0.1 M solutions of mevinolin (**1**) in $CDCl_3$ (5-mm tubes) with Me_4Si internal standard at 25 °C. Two-dimensional INADEQUATE experiments followed literature procedures[16b,i] optimized for $^{1}J_{CC}$ = 42 Hz and accumulated (128 scans) with a 5-s recycle delay time by using spectral widths of ±3520 Hz (70 ppm) and 3496 Hz with a data block of (148 × 1K).
(18) Incorporation rates were estimated by mass spectral examination of the molecular ion regions of labeled and unlabeled samples, as well as by comparison of ^{13}C NMR spectra. See supplementary material for experimental details of fermentations.
(19) Cambridge Isotope Laboratories, Cambridge, MA: 97% $^{13}C_2$.

the complete connectivity pattern.[20] This technique of spectral assignment requires no knowledge of the biosynthetic distribution of label since it depends exclusively on increasing the level of ^{13}C in the molecule. However, intact biosynthetic units can still be identified because there is a much higher level of coupled signals between carbons comprising them if multiply ^{13}C-labeled precursors are used.[21] Bacher, Floss, and co-workers recently demonstrated[22] the utility of double-quantum coherence NMR for biosyntheses employing [U-$^{13}C_6$]glucose as a presursor.[23]

Incorporations[18] of sodium [1-^{13}C]acetate, sodium [2-^{13}C]-acetate, and [*methyl*-^{13}C]methionine followed by ^{13}C NMR analysis showed that the main portion of mevinolin (**1**) consists of a polyketide chain of nine intact acetate units with a methionine-derived methyl group at C-6 (Figure 1). Interestingly, the α-methylbutyryl side chain is constructed in an analogous fashion. Recent methods to detect oxygen-18[24] or deuterium[13a,25] by isotope shifts induced in ^{13}C NMR provide mechanistic information by limiting possible intermediate oxidation states and revealing precursor bonds to oxygen or hydrogen that remain intact in the product. Administration[18] of sodium [1-^{13}C,$^{18}O_2$]acetate[24b] to cultures of *A. terreus* followed by both normal and SEFT ^{13}C NMR analysis[24b-e] of the resulting mevinolin (**1**) showed extensive labeling of the doubly bonded oxygen at C-1′ (isotope shift 0.038 ppm). Even though ^{13}C incorporation was high (2–7-fold peak enhancement), the amount of oxygen-18 at other expected sites such as C-11, C-13, and C-15 was less than 5% of the carbon labeling. We are currently investigating the problem of solvent-exchange during biosynthesis. Incorporation of sodium [1-^{13}C,$^{2}H_3$]acetate and ^{13}C NMR examination of the β-isotope shifts[25] in mevinolin (**1**) indicated high ^{2}H retention at all expected sites except C-3 and C-6 (Table I). Since the β-isotope shifts may be upfield, downfield, or possibly zero,[25f] there is a small chance that these carbons bear deuterium, but most probably the biogenesis of **1** results in hydrogen loss at these positions. The presence of species bearing three deuteriums at C-4′ and at the C-2 methyl identifies these carbons as starter units of the polyketide chains. These observations were confirmed by ^{2}H NMR of mevinolin (**1**) derived from sodium [$^{2}H_3$]acetate. Our results support biogenesis of **1** either by intramolecular Diels–Alder cyclization of a C-18 polyunsaturated acid or by the more likely mechanism of intramolecular anionic condensations of a partially reduced C-18 polyketide. Work is in progress to elucidate the biochemical details of the formation of mevinolin (**1**) and compactin (**2**).

Acknowledgment. We are grateful to G. Aarts and G. Bigam for NMR assistance and to Merck, Sharp and Dohme Research Laboratories for a generous gift of mevinolin. These investigations were supported by the Natural Sciences and Engineering Research Council of Canada (Grant A0845 and NSERC Summer Studentship to J.K.C.) and the Alberta Heritage Foundation for Medical Research.

Registry No. 1, 75330-75-5; acetic acid, 64-19-7; L-methionine, 63-68-3.

Supplementary Material Available: Listing of ^{1}H NMR data of **1** and conditions for incorporation experiments (1 page). Ordering information is given on any current masthead page.

(20) Most assignments were confirmed by selective homonuclear (^{13}C) decoupling experiments.

(21) DeJesus, A. E.; Hull, W. E.; Steyn, P. S.; Van Heerden, F. R.; Vleggaar, R.; Wessels, P. L. *J. Chem. Soc., Chem. Commun.* **1982**, 837–838.
(22) Bacher, A.; Le Van, Q.; Bühler, M.; Keller, P. J.; Eimicke, V.; Floss, H. G. *J. Am. Chem. Soc.* **1982**, *104*, 3754–3755.
(23) (a) Gould, S. J.; Cane, D. E. *J. Am. Chem. Soc.* **1982**, *104*, 343–346. (b) Rinehart, K. L., Jr.; Potgieter, M.; Wright, D. A. *Ibid.* **1982**, *104*, 2649–2652.
(24) (a) Vederas, J. C. *Can. J. Chem.* **1982**, *60*, 1637–1642 and references therein. (b) Lane, M. P.; Nakashima, T. T.; Vederas, J. C. *J. Am. Chem. Soc.* **1982**, *104*, 913–915. (c) Hill, J. G.; Nakashima, T. T.; Vederas, J. C. *Ibid.* **1982**, *104*, 1745–1748. (d) Nakashima, T. T.; Vederas, J. C. *J. Chem. Soc., Chem. Commun.* **1982**, *206*–208. (e) Nakashima, T. T.; Rabenstein, D. L. *J. Magn. Reson.* **1982**, *47*, 339–343. (f) Smith, G. K.; Mueller, W. T.; Slieker, L. J.; De Brosse, C. W.; Benkovic, S. J. *Biochemistry* **1982**, *21*, 2870–2874. (g) De Jesus, A. E.; Hull, W. E.; Steyn, P. S.; Van Heerden, F. R.; Vleggaar, R. *J. Chem. Soc., Chem. Commun.* **1982**, 902–904. (h) McGarrity, M. J.; King, J. F.; Stothers, J. B. *Tetrahedron Lett.* **1982**, *23*, 4465–4468. (i) Everett, J. R. *Org. Magn. Reson.* **1982**, *19*, 86–88. (j) Cane, D. E.; Liang, T. C.; Hasler, H. *J. Am. Chem. Soc.* **1982**, *104*, 7274–7281. (k) Holker, J. S. E.; O'Brien, E.; Moore, R. N.; Vederas, J. C. *J. Chem. Soc., Chem. Commun.* **1983**, 192–194.
(25) (a) Staunton, J.; Abell, C. *J. Chem. Soc., Chem. Commun.* **1981**, 856–858. (b) Simpson, T. J.; De Jesus, A. E.; Steyn, P. S.; Vleggaar, R. *Ibid.* **1982**, 632–634. (c) Stoessl, A.; Stothers, J. B. *Ibid.* **1982**, 880–881. (d) Simpson, T. J.; Stenzel, D. J. *Ibid.* **1982**, 890–892. (e) Leeper, F. J.; Staunton, J. *Ibid.* **1982**, 911–912. (f) Simpson, T. J.; Stenzel, D. J. *Ibid.* **1982**, 1074–1076. (g) Jurlina, J. L.; Stothers, J. B. *J. Am. Chem. Soc.* **1982**, *104*, 4677–4678.

First Synthesis of Stannacyclobutanes

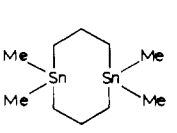
J. W. F. L. Seetz, G. Schat, O. S. Akkerman, and F. Bickelhaupt*

Vakgroep Organische Chemie, Vrije Universiteit 1081 HV Amsterdam, The Netherlands

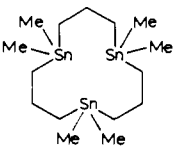
Received January 31, 1983

Stannacyclobutanes were hitherto unknown, although their synthesis has been attempted and claimed repeatedly.[1,2] This is all the more remarkable as 1,3-distannacyclobutanes[3] and cyclotetrastannanes[4] have been prepared, and germacyclobutanes are well-known.[1b] The direct and preparatively useful access to the 1,3-di-Grignard reagent of propane (**2a**)[5] and of its 2,2-dimethyl derivative **2b**[6] from the corresponding dibromides opens a new approach to metallacyclobutanes. We here report the synthesis of 1,1-dimethylstannacyclobutane (**1a**) and 1,1,3,3-tetramethylstannacyclobutane (**1b**).

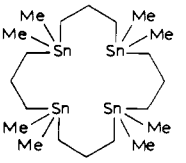
When a stoichiometric amount of dichlorodimethylstannane (**3**) was added to **2a** at room temperature and the reaction mixture was hydrolyzed and subjected to GC–MS, none of the expected **1a** but only its cyclic oligomers **4a** (dimer), **5a** (trimer), and **6a** (tetramer), formed in about 70% total yield, could be observed.



4a



5a



6a

Although **1a** had also been formed, it escaped direct observation with the exception of a singlet in the ^{1}H NMR spectrum when the reaction was performed in dioxane-d_8 (δ 0.39, $^{2}J_{SnH}$ = 52, 54 Hz); due to its characteristic low-field position (cf. **1b**), this signal must be assigned to the methyl groups of **1a**. Attempts to isolate **1a** were thwarted by its high volatility, which prevented its separation from the ether, and by its instability, as it did not survive the conditions of GC–MS. Compelling evidence for the presence of **1a** was obtained when the reaction mixture was subjected to distillation at room temperature under reduced pressure. The distillate was treated with a ca. 10-fold excess of **2a**, followed by H_2O (or D_2O) to give **7**[7] (or **7**-d_2, respectively, Scheme I). Under

(1) Gielen, M. *Ind. Chim. Belg.* **1973**, *38*, 138. (b) Pant, B. C. *J. Organomet. Chem.* **1974**, *66*, 321–403.
(2) Bulten, E. J.; Budding, H. A. *J. Organomet. Chem.* **1979**, *166*, 339–346.
(3) Seyferth, D.; Lefferts, J. L. *J. Am. Chem. Soc.* **1974**, *96*, 6237–6238; *J. Organomet. Chem.* **1976**, *116*, 257–273.
(4) Farrer, W. V.; Skinner, H. A. *J. Organomet. Chem.* **1964**, *1*, 434–436.
(5) Seetz, J. W. F. L.; Hartog, F. A.; Böhm, H. P.; Blomberg, C.; Akkerman, O. S.; Bickelhaupt, F. *Tetrahedron Lett.* **1982**, *23*, 1497–1500.
(6) Seetz, J. W. F. L.; Schat, G.; Akkerman, O. S.; Bickelhaupt, F. *J. Am. Chem. Soc.* **1982**, *104*, 6848–6849.

0002-7863/83/1505-3336$01.50/0