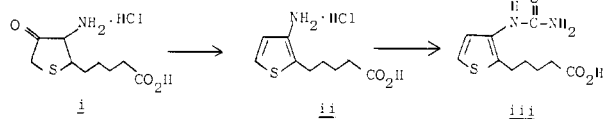


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- (2) Several methods are available for the formation of the aldehyde. (a) Rosenmund on the acid chloride of the half ester of adipic acid: A. I. Rachlin, H. Gurien, and D. P. Wagner, *Org. Synth.*, **51**, 8 (1971). (b) ϵ -Caprolactone opened with methanol and oxidized with pyridinium chlorochromate: E. J. Corey and J. W. Suggs, *Tetrahedron Lett.*, 2647 (1975). (c) Same as (b) but gas phase oxidation with copper and air: D. Valentine, Jr., private communication.
- (3) All compounds have the expected analytical and spectral properties. We thank the staff of the Physical Chemistry Department for this data. We also thank the personnel of the Kilo Laboratory and the High Pressure Laboratory for providing intermediates and running the large number of hydrogenations and Mr. W. P. May and Mr. J. Vermeulen for skillful technical assistance.
- (4) The enantiomeric excess was determined by use of a NMR shift reagent on the (+)- α -methylbenzyl amide.
- (5) DCA as opposed to (+)- α -methylbenzylamine leads to a cleaner product and a higher yield.
- (6) α -Nitro ketones have been prepared from acyl cyanides,⁷ but the combination of only moderate yields⁸ and the difficult preparation of the starting materials⁹ makes this approach unsuitable. (-)-MBA was used in this cyclization to avoid the isolation of any of the wrong isomer if racemization should occur.
- (7) G. B. Bachman and T. Hokama, *J. Am. Chem. Soc.*, **81**, 4882 (1959).
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- (9) J. F. Normant and C. Piechucki, *Bull. Soc. Chim. Fr.*, 2402 (1972); K. E. Koenig and W. P. Weber, *Tetrahedron Lett.*, 2275 (1974).
- (10) In acyclic cases we have used a modified procedure in which the phenyl ester is added to a cold (0–10 °C) suspension of the potassium salt of nitromethane (>2 equiv) in Me₂SO followed by warming to room temperature to obtain α -nitro ketones in 50–70% yields (not optimized). Another solution to this problem has been reported recently. The reaction requires extremely basic conditions not compatible with our substrate and use inconveniently low temperatures: D. Seebach and F. Lehr, *Angew. Chem.*, **88**, 540 (1976).
- (11) The enantiomeric excess is determined by ring opening to **2a**, amide formation, and then NMR.⁴
- (12) *d*-Dehydrobiotin and its methyl ester have been reported with melting points quite different from those found here: S. R. Safir, S. Bernstein, B. R. Baker, W. L. Mc Ewen, and Y. Subbarow, *J. Org. Chem.*, **12**, 475 (1974). We have repeated the literature preparation and found that the compound obtained previously was the isomeric thiophene iii. Compound iii is obtained because



the amino ketone undergoes dehydration, i.e. aromatization, when heated with mineral acid. The product ii gives the substituted urea upon treatment with cyanate.

- (13) The enantiomeric purity is determined by differential scanning calorimetry. As little as 0.3% of the racemic material can be easily detected since its melting range is totally resolved from that of the pure enantiomer.
- (14) Precedents for the reduction of acetyl imidazolones are found in R. Duschinsky and L. A. Dolan, *J. Am. Chem. Soc.*, **70**, 657 (1948), and G. Guilterm, J. C. Tabel, and A. Marquet, *J. Org. Chem.*, **42**, 3776 (1977).

Janis Vasilevskis, Joseph A. Gualtieri

Stanley D. Hutchings, Ronald C. West, John W. Scott
David R. Parrish, Fred T. Bizzarro, George F. Field*

Chemical Research Department, Hoffmann-La Roche Inc.
Nutley, New Jersey 07110

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A New Synthetic Method for Medium- and Large-Membered Lactones by Intramolecular Alkylation of ω -Haloalkyl Phenylthioacetates, and Its Application to the Syntheses of Recifeiolide and 9-Decanolide Using Butadiene Telomers Obtained by Palladium Catalyzed Telomerization

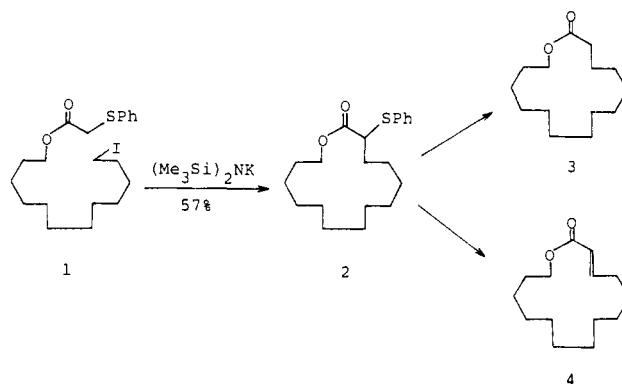
Sir:

Synthesis of macrolides is a current problem of intensive investigation.¹ The most crucial problem inherent in the macrolide synthesis is the efficient method of cyclization which is easy to be operated and gives high yields of lactones. The

most widely used method is intramolecular esterification of ω -hydroxy acids, and various methods for activation of acid derivatives have been devised for this purpose.^{2–8} Recently a new approach to this problem by intramolecular carbon–carbon bond formation has attracted attention, and a few acceptable methods are now known.⁹

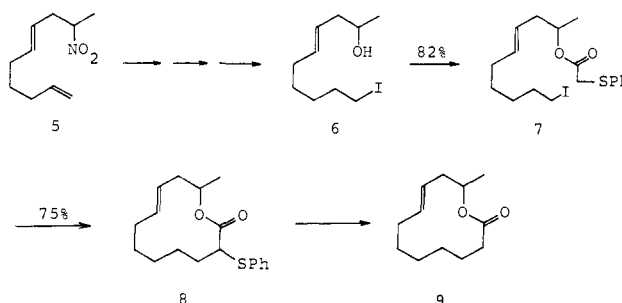
In this paper, we report a new method of lactone formation by carbon–carbon bond formation based on intramolecular alkylation of a carbanion generated from phenylthioacetate such as **1**. Subsequent oxidative or reductive removal of the phenylthio group leads to unsaturated and saturated lactones. The present method of alkylation is rapid and irreversible, and hence requires short reaction time.

At first, a 15-membered lactone was synthesized. The ester **1** was readily prepared by the acylation of 12-iodododecanol



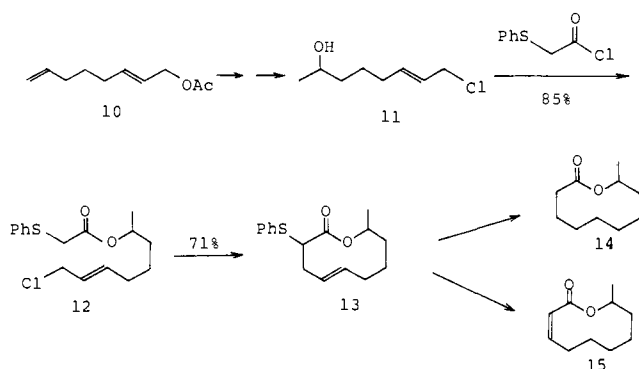
with phenylthioacetyl chloride in dichloromethane. The ester **1** (253 mg, 0.53 mmol) in THF (10 mL) was added slowly over 2.5 h at 65 °C under a nitrogen atmosphere to potassium hexamethyldisilazane (0.8 mmol) in THF (25 mL). The reaction mixture was stirred for 20 min and quenched. The 15-membered lactone **2** was isolated as an oil in 57% yield after chromatographic purification (silica gel): IR (film) 1730 cm⁻¹; NMR (CCl₄) δ 4.0 (2 H, m, -CH₂O), 3.5 (1 H, m, PhSCH). Similarly, a 13-membered lactone was prepared by the cyclization of 10-tosyldecyl phenylthioacetate in 49% yield by using sodium hydride in HMPA. The reductive elimination of phenylthio group from **2** by treatment with an excess of Raney nickel (W-2) in boiling ethanol gave 14-tetradecanolide (**3**) in 92% yield: IR 1735 cm⁻¹; NMR (CCl₄) δ 2.25 (2 H, m, CH₂CO), 4.0 (2 H, m, CH₂OCO); mass spectrum *m/e* 226 (M⁺). The oxidation of **2** with sodium periodate¹⁰ and heating in toluene produced 2-tetradecen-14-olide (**4**) in 71% yield: IR 1720 cm⁻¹; NMR (CCl₄) δ 6.8 (1 H, dt, *J* = 7 and 16 Hz, olefinic), 5.65 (1 H, d, *J* = 16 Hz, olefinic), 4.1 (2 H, t, *J* = 4 Hz, CH₂O); mass spectrum *m/e* 224 (M⁺).

Then we prepared 10- and 12-membered lactones, which are generally regarded to be cyclized less efficiently than 15-membered lactones.^{2d} As a 12-membered lactone, we selected the naturally occurring recifeiolide (**9**) as a target. Several known syntheses of this lactone were achieved by the internal esterification of 11-hydroxy-*trans*-8-dodecenoic acid.^{11,12} We have reported the facile synthesis of this acid



from the butadiene telomer **5**.¹³ The alcohol **6** was acylated with phenylthioacetyl chloride to give the ester **7** in 82% yield: IR 1730 cm⁻¹; NMR (CCl₄) δ 5.3 (2 H, m, olefinic), 4.5–5.05 (1 H, m, CHOCO), 3.5 (2 H, s, CH₂SPh), 3.1 (2 H, t, *J* = 7 Hz, CH₂I). The ester **7** (0.93 mmol in 15 mL of THF) was added to a THF solution (35 mL) of potassium hexamethyldisilazane (1.4 mmol) at 60 °C in 3.5 h. The cyclized product **8** was obtained in 75% yield after chromatography: IR 1730 cm⁻¹; NMR (CCl₄) δ 4.7–5.5 (3 H, m, olefinic and CHOCO), 3.3–3.8 (1 H, m, CHSPh). The high yield of the cyclization seems to be due to the presence of the double bond in **7**. The cyclization of the corresponding saturated 12-membered ring gave the lactone in 51% yield. Reductive elimination of the phenylthio group with deactivated Raney nickel¹⁵ gave recifeolide (**9**) as an oil in 80% yield: IR 1730 cm⁻¹; NMR (CCl₄) δ 4.7–6.0 (3 H, m, olefinic and CHOCO), 1.9–2.4 (6 H, m, =CCH₂ and CH₂CO), 1.2 (3 H, d, *J* = 6.2 Hz, CH₃); mass spectrum *m/e* 196 (M⁺). Anal. Calcd: C, 73.43; H, 10.27. Found: C, 73.54; H, 10.36.

The 10-membered lactone **13** was then prepared from the telomer **10**, readily obtained by the palladium catalyzed telomerization of butadiene with acetic acid.¹⁶ The acylation of the alcohol **11**^{9c} with phenylthioacetyl chloride afforded the desired ester **12**. The cyclization proceeded smoothly to give



the 10-membered lactone **13** in 71% yield. The treatment of **13** with Raney nickel afforded 9-decanolide (**14**) in 90% yield, which is a natural product isolated from *Phoracantha synonyma* by Moore and Brown:¹⁷ IR 1725 cm⁻¹; NMR (CCl₄) δ 4.6–5.1 (1 H, br, CHOCO), 2.0–2.8 (2 H, br, CH₂CO); mass spectrum *m/e* 170 (M⁺). The double bond in **13** was hydrogenated by using PtO₂ and the subsequent oxidative removal¹⁰ of the phenylsulfonyl group produced the unsaturated lactone **15** in 91% yield, which was prepared by Wakamatsu et al. as a precursor of (±)-diploidalide C:¹⁸ IR 1710 cm⁻¹; NMR (CCl₄) δ 6.23 (1 H, dt, *J* = 7 and 11 Hz, olefinic), 5.75 (1 H, d, *J* = 11 Hz, olefinic), 4.8–5.5 (1 H, m, CHOCO), 2.4–3.2 (2 H, m, =CCH₂), 1.3 (3 H, d, *J* = 6 Hz, CH₃); mass spectrum *m/e* 168 (M⁺).

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Takashi Takahashi, Shohei Hashiguchi
Kazuyuki Kasuga, Jiro Tsuji*

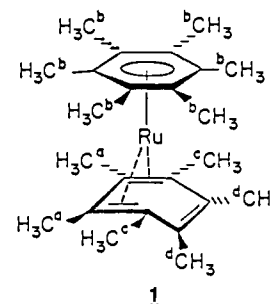
Tokyo Institute of Technology
Meguro, Tokyo 152, Japan

Received June 19, 1978

Arene-Transition Metal Complexes. 1. Site Exchange and Chemical Characteristics of $\eta^6\text{-C}_6(\text{CH}_3)_6\text{Ru-}\eta^4\text{-C}_6(\text{CH}_3)_6$

Sir:

The implication of η^4 -arene-metal complexes as intermediates^{1–3} in coordination catalysis of arene hydrogenation has raised a number of basic questions about arene-metal complexes such as what factors affect $\eta^6 \rightleftharpoons \eta^4$ interconversions, intermolecular arene (η^6 or η^4) exchange, and hydrogen-deuterium exchange between D₂ and the C–H bonds in the arene complexes. Bis(hexamethylbenzene)ruthenium(0), **1**, is an excellent model for study—first and foremost because it is a catalyst precursor for arene hydrogenation,² second because the ground-state structure in the solid⁴ and solution⁵ states has both η^4 -arene and η^6 -arene ligands, and third because the molecule is fluxional. We describe here spectroscopic and chemical studies for the ruthenium complex that resolve some of the dynamic issues and also establish a unique alane catalysis of a new fluxional process. The exchange studies have implicated alkyl alanes as possible promoters for the ruthenium-catalyzed arene hydrogenation reaction, and such a pro-



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