Ultraviolet spectra were recorded on a Varian Associates Cary 118 spectrophotometer. Elemental analyses were carried out by the Stanford University Microanalytical Laboratory. Melting points were determined on a Fisher-Johns melting point apparatus and are uncorrected.

High-pressure liquid chromatography (LC) was performed on a Waters Associates system equipped with a Model 660 solvent programmer, two Model M-6000A pumps, a Schoeffel Instrument Corp. variable-wavelength ultraviolet detector, and a 30-cm, C-18 on μ-Bondapak column. Vapor-phase chromatography (VPC) was carried out on a Varian Associates Aerograph Model 920 employing a 6-ft, 5% SE-30 on Chromosorb G column. Thin-layer chromatography (TLC) was carried out on EM Laboratories precoated silica gel 60 F-254 plates (5 × 10 cm).

The diethyl ether, hexane, ethyl acetate, chloroform, and methylene chloride used were reagent grade solvents from J. T. Baker Chemical Co. Triethylamine was distilled from phosphorus pentoxide and stored over activated 4A molecular sieves. Dimethylformamide (DMF) was distilled from calcium hydride and stored over activated 4A molecular sieves. Pyridine was distilled from barium oxide and stored over activated 4A molecular sieves. Sulfuryl chloride was subjected to simple distillation prior to use.

Catechol Sulfate (4). The procedure employed is a modification of that reported by Denivelle[14] with the suggestions of Kaiser.[15]

A 55-g (0.50 mol) sample of catechol was dissolved in 79 g of pyridine and the mixture stirred vigorously with an overhead stirrer under dry argon in a 1-L, three-necked flask equipped with a thermometer and addition funnel. A 500-mL portion of hexane was then added, after which the reaction mixture was cooled to −5 °C in an ice–salt bath. A solution of 68 g (0.50 mol) of sulfuryl chloride in 100 mL of hexane was then added dropwise over 4 h while the temperature was carefully maintained between −5 and 0 °C. Stirring at 0 °C was continued overnight, after which the reaction mixture was allowed to warm to ambient temperature over 6 h. The upper layer of the two-layer reaction mixture was decanted, after which the lower layer was washed (2 × 100 mL) with ethyl acetate. The combined washes and upper layer were then washed with 5% $Cu(OAc)_2 \cdot H_2O$ until TLC (hexane–ethyl acetate, 3:1) indicated the absence of catechol (R_f 0.14). The solution was then dried over magnesium sulfate and concentrated, yielding 56.7 g of an amber liquid. TLC (hexane–ethyl acetate, 3:1) showed one component having R_f 0.40. VPC (165 °C, 60 cm^3/min He flow) showed one major component having RT = 5.0 min which was contaminated by an impurity at 7.5 min. Distillation through a 15-cm Vigreux column yielded 45.1 g (52%) of a colorless liquid, bp 76–78 °C (1.25 mm). Recrystallization from hexane yielded 38.0 g of long colorless needles, mp 35.5–36 °C (lit.[8] mp 34–35 °C).

General Procedure for Preparation of 2-Hydroxyphenyl *N*-Alkylsulfamates. A solution of 1.89 g (11.0 mmol) catechol sulfate in 2.0 mL of methylene chloride was added dropwise to a solution of 10.0 mmol of amine and 1.11 g (11.0 mmol) of triethylamine in 25 mL of DMF with vigorous stirring at 0 °C under dry argon. After 2.5 h at 0 °C, the reaction mixture was poured into 100 mL of 1% hydrochloric acid and extracted with ether (3 × 25 mL), and the combined portions were washed with water (6 × 50 mL), dried over magnesium sulfate, and concentrated, yielding the ester as a white solid, which on recrystallization from chloroform yielded an analytical sample.

2-Hydroxyphenyl *N*-[[(2,3′,6-Trihydroxy-4′-methoxydihydrochalcon-4-yl)oxy]eth-2-yl]sulfamate (5). According to the general method, 991 mg (2.85 mmol) of 2,3′,6-trihydroxy-4′-methoxy-4-(aminoethoxy)dihydrochalcone was reacted with 541 mg (3.14 mmol) of catechol sulfate in 15 mL of DMF in the presence of 318 mg (3.14 mmol) of triethylamine. Recrystallization of the crude product from chloroform yielded 1.14 g (77%) of light tan granular crystals, mp 78–80 °C. TLC (chloroform–methanol, 95:5) showed one component: R_f 0.11; IR (KBr) 2.93 (OH, NH), 6.17 (C=O) μm; UV (EtOH) 283 nm (ε 21 900); NMR (acetone-d_6) δ 2.86 (t, 2 H, J = 7 Hz, $ArCOCCH_2Ar'$), 3.36 (t, 2 H, J = 7 Hz, $ArCOCH_2CAr'$), 3.63 (t, 2 H, J = 6 Hz, CH_2N), 3.82 (s, 3 H, OCH_3), 4.14 (t, 2 H, J = 6 Hz, $ArOCH_2$), 5.97 (s, 2 H, ArH). Anal. ($C_{24}H_{25}NO_{10}S \cdot H_2O$) C, H.

General Procedure for Hydrolysis of 2-Hydroxyphenyl *N*-Alkylsulfamate. A 10-mmol sample of 1.00 M potassium hydroxide was added to 10.0 mmol of the solid sulfamate ester in a 100-mL, one-necked flask equipped with a magnetic stir bar. A 40-mL portion of distilled water was then added, and the reaction apparatus was purged with argon. The reaction mixture was then refluxed vigorously for 30 min or until TLC of an aliquot indicated the absence of starting material. The pH was adjusted to 5–6 by addition of 2% hydrochloric acid and the reaction mixture concentrated to dryness at reduced pressure. The white solid thus obtained was then extracted with boiling ether (3 × 25 mL) and dried in vacuo. Analytical samples were obtained by recrystallization from distilled water.

Potassium *N*-[[(2,3′,6-Trihydroxy-4′-methoxydihydrochalcon-4-yl)oxy]eth-2-yl]sulfamate (3). Treatment of 5.20 g (10.0 mmol) of **5** with 20.0 mmol of potassium hydroxide according to the general procedure for 60 min yielded 5.02 g of a light tan solid. High-pressure LC (10–100% MeOH in 0.03 M KH_2PO_4, linear gradient; 15-min program; flow rate 2.0 mL/min; 286 nm) showed the desired product having R_t = 12.0 min. Comparison with a standard solution of authentic material indicated a yield of 4.65 g (100%). Recrystallization from distilled water yielded 4.15 g (89%) of **3** as tiny white granular crystals: IR (KBr) 2.95 (OH), 3.03 (NH), 6.17 (C=O) μm; UV (H_2O) 282 nm (ε 20 200); NMR (Me_2SO-d_6) δ 2.97 (t, 2 H, J = 6 Hz, $ArCOCCH_2Ar'$), 3.16 (t, 2 H, J = 6 Hz, $ArCOCH_2CAr'$), 3.54 (t, 2 H, J = 5 Hz, NCH_2), 3.70 (s, 3 H, OCH_3), 4.03 (t, 2 H, J = 5 Hz, $ArOCH_2$), 5.96 (s, 2 H, ArH). Anal. ($C_{18}H_{20}KNO_9S \cdot 0.5H_2O$) C, H, N, S.

Acknowledgment. We thank Dr. G. A. Crosby and Dr. C. Ward for valuable discussion on this work, Ms. Janice Lee for sensory studies, and Dr. E. T. Kaiser for useful comments on the preparation of catechol sulfate. This research was supported by the National Institute of Dental Research under Contract No. 1-DE-62479.

Registry No. **2**, 74282-79-4; **3**, 70412-97-4; **4**, 4074-55-9; **5**, 74282-80-7; **6**, 74282-81-8; **7**, 74282-82-9; **8**, 74282-83-0; **9**, 74282-84-1; **10**, 74282-85-2; 2,3,6-trihydroxy-4′-methoxy-4-(2-aminoethoxy)dihydrochalcone, 74282-79-4; benzylamine, 100-46-9; cyclohexylamine, 108-91-8; 3-benzyloxy-4-methoxybenzylamine, 54170-11-5; diethylamine, 109-89-7; phenylamine, 62-53-3; potassium benzylsulfamate, 74282-86-3; potassium cyclohexylsulfamate, 7758-04-5; potassium 3-benzyloxy-4-methoxybenzylsulfamate, 74282-87-4; catechol, 120-80-9.

(14) Denivelle, L. *C. R. Hebd. Seances Acad. Sci.* **1936**, *203*, 194.
(15) Kaiser, E. T., University of Chicago, personal communication, 1978.

Amination of Aryl Sulfamate Esters. A Convenient General Synthesis of Aliphatic Sulfamides

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Received June 24, 1980

Recently,[1] we demonstrated that 2-hydroxyphenyl *N*-alkylsulfamate esters **1–3** could be obtained in near quantitative yields by reaction of the appropriate aliphatic amine with catechol sulfate (**4**), under very mild conditions (1 h, 0 °C).

Aromatic amines, on the other hand, being much less nucleophilic,[2] undergo a very lethargic reaction with **4**.

(1) DuBois, G. E.; Stephenson, R. *J. Org. Chem.*, preceding paper in this issue.

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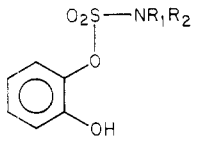


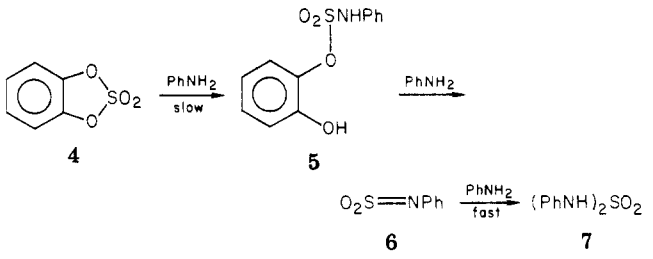
1, R_1 = H; R_2 = CH_2Ph
2, R_1 = H; R_2 = c-C_6H_{11}
3, R_1 = R_2 = CH_2CH_3

Interestingly, however, the sluggish reaction of aniline (Scheme I), which required 68 h at 42 °C for 94% conversion (66% yield of **5**), also produced a 28% yield of *N,N'*-diphenylsulfamide (**7**).[1] Presumably, the rate of attack on **4**, by the poorly nucleophilic aniline, is low enough such that unreacted aniline promotes base-catalyzed elimination of the aryl ester **5** to the transiently stable *N*-sulfonylamine **6** which is quickly trapped by aniline to give **7**. This observation, coupled with the absence of a mild, high-yield preparative method for symmetrical and mixed sulfamides,[3] which avoids the use of strongly electrophilic agents such as SO_2Cl_2 and PCl_5, prompted us to examine the reactions of **1** with amines in some detail.

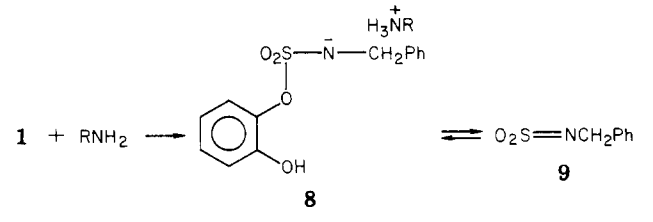
We viewed the proposed reaction of **1** with amines to produce sulfamides with some apprehension since the acidity of the N–H proton[4] of **1** and the basicity of aliphatic amines, as suggested by pK_a measurements in aqueous media, would mandate the formation of a salt **8** (Scheme II). Without a significant concentration of free amine, the *N*-sulfonylamine **9**, derived from **8**, could not be trapped by the amine to yield sulfamide products. The use of the amine in large excess does not represent a solution since the dianion of **1**, if formed, as is apparently the case on reaction of **1** with inorganic bases,[1] would be unlikely to fragment. We were thus pleasantly surprised to find that treatment of **1** with 1 equiv of benzylamine in boiling dioxane for 2 h resulted in a quantitative cleavage to produce catechol and *N,N'*-dibenzylsulfamide (**10**). Apparently enough free amine is present to allow a high-yield conversion. The results of treatment of **1** with several amines are summarized in Table I.

Thus, animation of **1** appears to proceed well with primary amines, branched primary amines, and secondary amines. Aromatic amines react only with difficulty, however. This reaction therefore appears to be a good general method for preparation of dialkylsulfamides. Preparation of arylalkyl- or diarylsulfamides is less attractive, however, due to a very slow reaction of **4** with aromatic amines and an even more sluggish reaction of the intermediate sulfamate ester with aromatic amines.

Scheme I



Scheme II



Scheme III

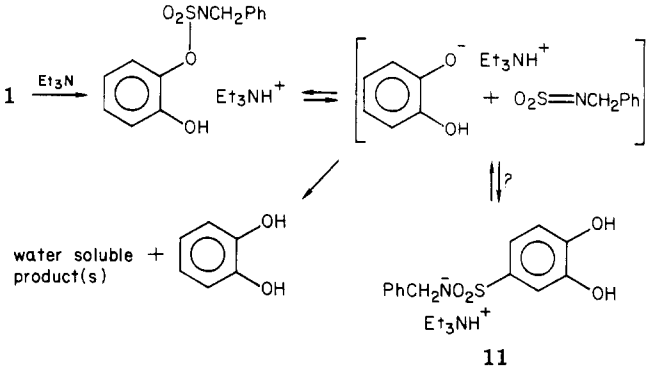
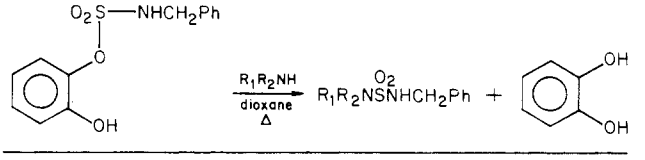


Table I. Amination of 2-Hydroxyphenyl *N*-Benzylsulfamate (**1**)



compd	R_1	R_2	sulfamide yield, %[a]
10	CH_2Ph	H	91
11	c-C_6H_{11}	H	90
12	CH_2CH_3	CH_2CH_3	96
13	Ph	H	60

[a] Isolated yield.

The above results and earlier work[1] clearly illustrate the utility of sulfonylamine intermediates for preparation of sulfamic acid salts and sulfamides. We were also interested in investigating the fate of the sulfonylamine generated from **1** in the absence of extraneous nucleophilic species. Thus, **1** was treated with 1.1 equiv of Et_3N in dioxane at reflux (Scheme III). It was considered reasonable that the sulfonylamine formed on fragmentation of **1** may be trapped by sulfonylation of the catecholate anion aromatic ring to yield **11**. After 2 h of reflux, approximately 75% of **1** had been consumed to produce catechol as the only EtOAc-soluble product. Apparently, **11** is not formed or, if it does, fragments back to the sulfonylamine which, in

(2) Nucleophilicity roughly parallels basicity (March, J. "Advanced Organic Chemistry", 2nd ed.; McGraw-Hill: New York, 1977, pp 322–5 and references therein) and, e.g., since aniline's basicity is much lower than that of benzylamine [pK_a (aniline) = 4.63, pK_a (benzylamine) = 9.33 ("Handbook of Chemistry and Physics", 50th ed.; The Chemical Rubber Co.; Cleveland, OH, 1969, p D115)], the nucleophilicity is expected to be lower by a comparable amount.

(3) For discussion of preparative methods of chemistry of sulfamides, see: (a) Dorlars, A. In "Methoden der Organischen Chemie (Houben-Weyl)", 4th ed.; Müller, E., Ed.; Thieme Verlag: Stuttgart, 1958; Vol. XI, part 2, pp 711–30; (b) Andersen, K. K. In "Comprehensive Organic Chemistry"; Jones, D. N., Ed.; Pergamon Press: New York, Vol. 3, pp 363–5; (c) Spillane, W. J. *Int. J. Sulfur Chem.* **1973**, *8*, 469–81; (d) Gilbert, E. E. "Sulfonation and Related Reactions", Interscience: New York, 1965; Chapter 7; (e) Burckhardt, H.; Dieter, W. J. *Prakt. Chem.* **1961**, *14*, 177–91.

(4) Although the pK_a of the NH proton of **1** is not known, an alkylation experiment on **1** (**1**, K_2CO_3, DMF, CH_3I; 20 °C; 16 h) in which the *N*-methyl derivative was obtained (80%) as the only monoalkylation product (DuBois, G., unpublished results) suggests a pK_a in the 8–10 region. The dibasic sulfamate ester **1**, when titrated potentiometrically vs. aqueous NaOH in dioxane–water (1:1), exhibits the behavior of a monobasic acid having pK_a = 10.1. The ionization of the first acidic group renders the second too weakly acidic for titration. The measured pK_a may be viewed as a hybrid of O–H and N–H acidities.

the absence of a suitable trapping agent, decomposes to water-soluble products.[5]

The sulfonylamine mechanism which is used extensively in the above discussion is supported by the observation that the *N,N*-diethylsulfamate ester **3**, which lacks the acidic N-H required for base-promoted elimination, is inert to benzylamine in refluxing dioxane (16 h of reflux). This is in good agreement with observations made earlier on the reaction of **3** with inorganic bases.[1]

Experimental Section

Infrared spectra were recorded on a Perkin-Elmer Model 137 spectrophotometer. Proton magentic resonance spectra were recorded on a Varian Associates T-60A spectrometer (60 MHz) and are recorded in parts per million from tetramethylsilane. Elemental analyses were carried out by the Stanford University Microanalytical Laboratory. Melting points were determined on a Thomas-Hoover melting-point apparatus and are uncorrected. Thin-layer chromatography (TLC) was carried out on EM Laboratories precoated silica gel 60 F-254 plates (5 × 10 cm). Solvents and reagents used were reagent grade as obtained from either J. T. Baker or Aldrich Chemical Co., except for dioxane which was distilled from $LiAlH_4$ and stored over activated molecular sieves (4 Å).

General Procedure for Amination of 2-Hydroxyphenyl *N*-Benzylsulfamate (1). Dry dioxane (5 mL) was added to a mixture of 279 mg (1.00 mmol) of **1** and 1.10 mmol of amine after which the resultant solution was refluxed under dry argon until TLC ($CHCl_3/CH_3OH$, 93:2) indicated that all **1** (R_f 0.17) had been consumed. The reaction mixture was then allowed to cool and poured into 50 mL of 5% HCl. The precipitated sulfamide was then suction filtered and recrystallized from absolute EtOH.

***N,N'*-Dibenzylsulfamide (10).** According to the general procedure, 118 mg (1.10 mmol) of benzylamine was reacted with 1.00 mmol of **1** for 2 h to give 252 mg (91%) of **10** as colorless plates: mp 180–182 °C (lit.[3e] mp 181–182 °C); TLC R_f 0.27; IR (KBr) 3.02 (NH), 7.64 (S=O), 8.75 (S=O) μm; NMR (acetone-d_6) δ 4.17 (br s, 4 H, $PhCH_2N$), 7.00 (br s, 2 H, NH), 7.37 (s, 10 H, Ph H). Anal. ($C_{14}H_{16}N_2O_2S$) C, H.

***N*-Benzyl-*N'*-cyclohexylsulfamide (11).** According to the general procedure, 109 mg (1.10 mmol) of cyclohexylamine was reacted with 1.00 mmol of **1** for 2.5 h to give 241 mg (90%) of **11** as colorless plates: mp 133–135 °C; TLC R_f 0.28; IR (KBr) 3.03 (N-H), 7.61 (S=O), 8.75 (S=O) μm; NMR ($CDCl_3$) δ 0.83–2.25 (m, 10 H, $(CH_2)_5$), 3.20 (m, 1 H, NCH), 4.08–4.90 (br s, 2 H, NH), 4.18 (d, 2 H, J = 6 Hz, $PhCH_2N$), 7.33 (s, 5 H, Ph H). Anal. ($C_{13}H_{20}N_2O_2S$) C, H.

***N*-Benzyl-*N,N'*-diethylsulfamide (12).** According to the general procedure, 82 mg (1.10 mmol) of diethylamine was reacted with 1.00 mmol of **1** for 2 h to give 232 mg (96%) of **12**. Workup required EtOAc extraction (3 × 10 mL) of the product, the combined portions of which were washed with H_2O (6 × 10 mL), dried over $MgSO_4$, and concentrated. The crude product was purified by thick-layer chromatography on two 20 × 20 cm × 2 mm silica gel PF-254 (E. Merck) plates, eluting with $CHCl_3/CH_3OH$ (95:5), to give **12** as a colorless oil: TLC R_f 0.51; IR (film) 3.00 (N-H), 7.64 (S=O), 8.74 (S=O) μm; NMR ($CDCl_3$) δ 1.19 (t, 6 H, J = 7 Hz, CH_3), 3.26 (q, 4 H, J =7 Hz, $N(CH_2)_2$), 4.15 (d, 2 H, J = 6 Hz, $PhCH_2N$), 4.64 (br s, 1 H, NH), 7.34 (s, 5 H, Ph H). Anal. ($C_{11}H_{18}N_2O_2S$) C, H.

***N*-Benzyl-*N'*-phenylsulfamide (13).** According to the general procedure, 102 mg (1.10 mmol) of aniline was reacted with 1.00 mmol of **1**. After 44 h of reflux, considerable **1** was still present. Nevertheless, workup and recrystallization yielded 157 mg (60%) of **13** as colorless needles: mp 182–184 °C; IR (KBr) 3.05 (N-H), 7.70 (S=O), 7.80 (S=O) μm; NMR (acetone-d_6) δ 4.15 (d, 2 H, J = 6 Hz, $PhCH_2N$), 6.76–7.51 (m, 12 H, aromatic H, NH). Anal. ($C_{13}H_{14}N_2O_2S$) C, H.

Acknowledgment. We are grateful to Mr. G. McGarraugh for potentiometric studies.

Registry No. **1**, 74-282-81-8; **10**, 42731-71-5; **11**, 75420-75-6; **12**, 75420-76-7; **13**, 75420-77-8; benzylamine, 100-46-9; cyclohexylamine, 108-91-8; diethylamine, 109-89-7; aniline, 62-53-3.

(5) Burgess [Burgess, E. M.; Atkins, G. M., Jr. *J. Am. Chem. Soc.* **1967**, *89*, 2502] has described a similar decomposition of $CH_3CH_2N{=}SO_2$ when generated at −78 °C and allowed to warm to ambient temperature.

Convenient Preparative Routes to 1,8-Bishomocubane, 1,8-Bishomocubanone, Snoutanone, and Homocubanone

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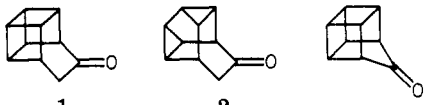
Received July 2, 1980

Among the various polycyclic molecules of current interest, the caged pentacyclic ketones, pentacyclo[4.4.0.0^{2,5}.0^{3,8}.0^{4,7}]decan-9-one (1,8-bishomocubanone, **1**),[1] pentacyclo[4.4.0.0^{2,4}.0^{3,8}.0^{5,7}]decan-9-one (snoutanone, **2**),[1] and pentacyclo[4.3.0.0^{2,5}.0^{3,8}.0^{4,7}]nonan-9-one (homocubanone, **3**),[2] occupy positions of special vintage as they



1 **2** **3**

are interesting substrates for a variety of theoretical, mechanistic, and synthetic studies, and they also serve as ready precursors for several derivatives of these ring systems. We describe here new, short and preparatively useful routes to **1** and **2** and a modified economical preparation of **3**, all of which represent significant improvements over existing literature methods. A simple three-step preparation of parent 1,8-bishomocubane[3] (**4**) from cyclooctatetraene (COT) is also described.

The starting material for the preparation of **1** and **2** was the readily available[4] COT–acrylonitrile adduct **5**. Photolysis of **5** under our conditions (see the Experimental Section) proceeded smoothly to furnish intramolecular [$_\pi2_s + {}_\pi2_s$] addition product **6** in 70% yield.[5] The caged cyano compound **6** served as the common precursor for the preparation of **1**, **2**, and **4** (Scheme I). When **6** was subjected to oxidative decyanation according to the procedure of Watt,[6] 1,8-bishomocubanone (**1**) was obtained in nearly 50% yield. For the preparation of **2** it was essential to effect the transition metal catalyzed rearrangement[7] of **6**.

(1) W. G. Dauben, C. H. Schallhorn, and D. L. Whalen, *J. Am. Chem. Soc.*, **93**, 1446 (1971).
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(6) S. J. Selikson and D. S. Watt, *J. Org. Chem.*, **40**, 267 (1975).
(7) For a detailed study of Ag(I)-catalyzed rearrangements of 1,8-bishomocubanes, see L. A. Paquette and R. S. Beckley, *J. Am. Chem. Soc.*, **97**, 1084 (1975).

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