δ 1.3–2.5 (m, 8 H), 3.74 (s, 8 H, OCH_2), 3.85–4.15 (m, 3 H, OCH_2), 4.40 (m, 2 H, $COOCH_2$), 4.80 (m, 1 H, COOCH), 7.8–8.4 (m, 3 H).

Anal. Calcd for $C_{19}H_{25}NO_7$: C, 60.14; H, 6.64; mol wt 379.4. Found: C, 60.08; H, 6.70; mol wt 363.

Potassium Thiocyanate Complex of 22. Compound **22** (0.475 g, 0.001 25 mol) and potassium thiocyanate (0.12 g, 0.001 25 mol) were dissolved in methanol, and the mixture was evaporated to a volume of about 5 mL. This mixture was then cooled to −20 °C. After several days clumps of clear quartzlike crystals formed; mp 174–175.5 °C; IR (KBr) 2050, 1725 cm^{-1}; ^1H NMR δ 1.2–2.70 (m, 8 H), 3.77 (s, 8 H, OCH_2), 3.86 (m, 3 H, OCH_2), 4.67 (m, 2 H, $COOCH_2$), 4.88 (m, 1 H, COOCH), 8.1–8.6 (m, 3 H).

Anal. Calcd for $C_{19}H_{25}NO_7$·KSCN: C, 50.40; H, 5.29. Found: C, 50.51; H, 5.19.

***trans*-Dicyclohexano[*d*,*m*]-3,6,9,12,15-pentaoxa-21-azabicyclo[15.3.1]heneicosa-1(21),17,19-triene-2,16-dione (23).** 2,6-Pyridinedicarbonyl chloride (9.18 g, 0.045 mol) and glycol **30** (13.6 g, 0.045 mol) were used. The crude product was extracted with hexane and recrystallized from hot hexane to give both large clear prisms and white powder: 1.03 g (6.2%); mp 137–138.5 °C; IR (KBr) 1710, 1735 cm^{-1}; ^1H NMR δ 1.2–2.4 (m, 16 H), 3.50 (m, 6 H, OCH_2), 3.80 (2 s, 4 H, OCH_2), 5.00 (m, 2 H, COOCH), 7.8–8.3 (m, 3 H).

Anal. Calcd for $C_{23}H_{31}NO_7$: C, 63.72; H, 7.21; mol wt 433.5. Found: C, 63.51; H, 7.21; mol wt 423.

Potassium Thiocyanate Complex of 23. Compound **23** (0.2 g, 4.6×10^{-4} mol) and potassium thiocyanate (0.045 g, 4.6×10^{-4} mol) were dissolved in methanol. The solvent was then evaporated to leave a pink solid. The solid was recrystallized from methanol to give a light pink crystaline solid: mp 226–227.5 °C; IR (KBr) 2050, 1725, 1715 cm^{-1}; ^1H NMR δ 1.20–2.60 (m, 16 H), 3.63 (s, 8 H, OCH_2), 3.9 (m, 2 H, OCH), 5.18 (m, 2 H, COOCH), 8.6–9.1 (m, 3 H).

Anal. Calcd for $C_{23}H_{31}NO_7$·KSCN: C, 54.32; H, 5.89. Found: C, 54.38; H, 6.78.

Attempted Synthesis of Thia and Pyridino Analogues of Compound 9. The general procedure to prepare these compounds from glycol **28** gave reaction mixtures which exhibited IR peaks at 1730 cm^{-1} and essentially no hydroxy peaks at 3400 cm^{-1}. Attempts to purify the products by recrystallization gave only starting glycol **28**. The cyclization reaction was also tried by using repurified starting materials and by using triethylamine to remove hydrochloric acid. Both these attempts resulted in the isolation of starting glycol **28**.

Acknowledgment. The authors wish to thank Professor E. G. Paul for his help with the ^1H NMR spectra. This work was supported by National Science Foundation Grant No. CHE-8000059.

Registry No. 6, 74262-06-9; **7**, 74262-07-0; **7**·KSCN complex, 74263-31-3; **8**, 74262-08-1; **9**, 74262-09-2; **10**, 74262-10-5; **11a**, 74262-11-6; **11b**, 74310-48-8; **12**, 74262-12-7; **13**, 74262-13-8; **14**, 74262-14-9; **15**, 74262-15-0; **16**, 74262-16-1; **17**, 74262-17-2; **18**, 74262-18-3; **19**, 74262-19-4; **20**, 74262-20-7; **21**, 74262-21-8; **22**, 74262-22-9; **22**·KSCN complex, 74263-33-5; **23**, 74262-23-0; **23**·KSCN complex, 74263-35-7; **24**, 74262-24-1; **25**, 74262-25-2; **26**, 74262-26-3; **27**, 74262-27-4; **28**, 74262-28-5; **29**, 74262-29-6; **30**, 74310-49-9; 1,2-butanediol, 584-03-2; 1,2-epoxybutane, 106-88-7; ethylene glycol, 107-21-1; diethylene glycol, 111-46-6; triethylene glycol, 112-27-6; 1,2-epoxydecane, 2404-44-6; 1-decene, 872-05-9; cyclohexene oxide, 286-20-4; diglycolyl dichloride, 21062-20-4; thiadiglycolyl dichloride, 7646-91-5; 2,6-pyridinedicarbonyl chloride, 3739-94-4.

Synthesis of Adamantane Derivatives. 49.[1] Substitution Reaction of 1-Adamantyl Chloride with Some Trimethylsilylated Unsaturated Compounds

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Catalytic substitution reactions at the adamantane bridgehead were studied by using α,β- and β,γ-unsaturated trimethylsilanes. Treatment of 1-adamantyl (Ad) chloride (1) with allyltrimethylsilane and its heteroanalogues, X=Y—Z—$SiMe_3$, in the presence of Lewis acid as a catalyst gave the products Ad—X—Y=Z, X=Y^+(Ad)—Z^-, and X=Y—Z—Ad, depending on the attack site of the adamantyl group on each X, Y, and Z atom. Treatment of 1 with (phenylethynyl)trimethylsilane also gave a substituted adamantane in a good yield. The substitution reactions of 1 with aryl- and heteroaryltrimethylsilanes under similar conditions occurred at a position distinct from that of acetylation, indicating that adamantylation was not influenced by an electronic effect of the trimethylsilyl group.

The synthetic study of adamantane derivatives is of considerable interest, and numerous preparative methods for them have been developed.[2] In the substitution reactions at the adamantane bridgehead, nucleophilic conditions are disfavored because of the difficulty in generating the unstable adamantyl anion[3] and since nucleophilic attack on adamantane is prohibited from the back side, dictating that drastic conditions are generally required to perform the substitution reaction.[4] Therefore, bond formation at the bridgehead of adamantane has been realized mostly under electrophilic conditions. In the past decade, the use of organosilicon compounds as reagents in organic synthesis has become a field of considerable interest.[5] Their wide applicabilities are based on the characteristic properties of the silicon atom. For instance,

(1) Part 48: T. Sasaki, S. Eguchi, and T. Okano, submitted for publication in *Synthesis*.

(2) R. C. Fort, Jr., "Adamantane", Marcel Dekker, New York, 1976.

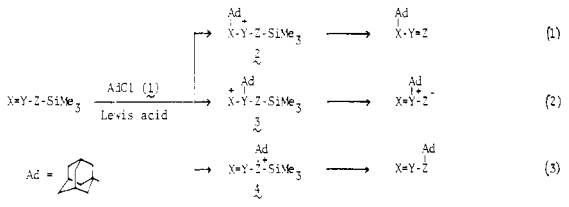
(3) (a) P. T. Lansbury and J. D. Sidler, *Chem. Commun.*, 373 (1965); (b) G. Molle, J. E. Dubois, and P. Bauer, *Synth. Commun.*, 8, 39 (1978); (c) P. Bauer and G. Molle, *Tetrahedron Lett.*, 4853 (1978).

(4) E. Osawa, Z. Majerski, and P. R. Schleyer, *J. Org. Chem.*, **36**, 205 (1971).

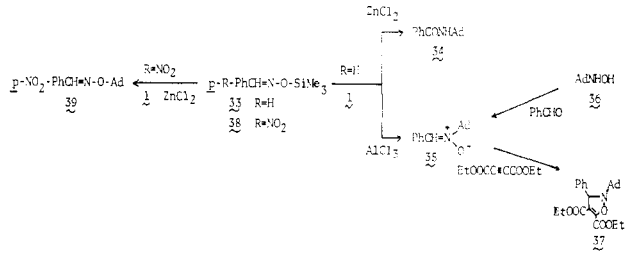
(5) (a) P. F. Hudrlick, "New Applications of Organometallic Reagents in Organic Synthesis", D. Seyferth, Ed., p 127, Elsevier, New York, 1976; (b) C. W. Colvin, *Chem. Soc. Rev.*, **7**, 15 (1978).

0022-3263/80/1945-3559$01.00/0

Scheme I



Scheme II



the cation-stabilizing ability of silicon increases the nucleophilicity of an unsaturated bond containing a silyl moiety. Accordingly, the adamantane system can take advantage of such a nucleophilicity enhancement of an unsaturated bond by a trimethylsilyl group in its electrophilic substitution reactions. A number of electrophilies have been documented to react with such an unsaturated bond,[6] but few reactions of this type are known for an alkyl cation from an alkyl halide in the presence of Lewis acid.[7] Our purpose was to study the feasibility of a Friedel–Crafts-type of reaction of α,β- and β,γ-unsaturated trimethylsilanes and adamantyl cation as a representative reaction of the tertiary alkyl cations and thereby to develop the synthetic method for bridgehead-substituted adamantane derivatives. In a preliminary communication we have briefly described the reaction of 1-adamantyl chloride (1) with some organosilicon regents in the presence of a Lewis acid.[8] Presented herein are some results of extended studies on the reactions of 1 with allyltrimethylsilane and its heteroanalogues, (phenylethynyl)- and styryltrimethylsilanes, and some aryl- and heteroaryltrimethylsilanes.

Results

Reactions with Allyltrimethylsilanes and Their Heteroanalogues. As for the mode of reaction, there are three possibilities, depending on the attack site of the adamantyl group in the first step. The intermediate **2** is stabilized by σ–π conjugation between the Si–C bond and the vacant p orbital.[9] In the second step, desilylation gives rise to adamantane-substituted products (Scheme I). Actually each type of reaction could be observed.

A typical example is the case where the X, Y, and Z atoms are all carbon; 1-adamantyl chloride (**1**) reacted smoothly with allyltrimethylsilane (**5**) at room temperature in the presence of titanium tetrachloride to give 1-allyladamantane (**6**) in an 85% yield. This reactivity implies that the adamantyl cation, accordingly a tertiary cation,[10] is also a reactive species with **5** in addition to known electrophiles like acyl, sulfenyl, alkoxycarbonium, and bromonium cations.[11] The reaction with **7** is an indication of the orienting effect of the trimethylsilyl group to determine the regiochemistry of the product (**8**), while the site of attack of an electrophile is usually the β position. These two statements are in accordance with eq 1. In analogy to the case of **5**, the reactivities of **9** and **11** were examined; propargylsilane (**9**) might lead to allene (**10**) and **11** to *o*-adamantyltoluene if a cyclic transition state is involved. However, the former gave no products, and the latter resulted in the formation of a Friedel–Crafts-type product (**12**).

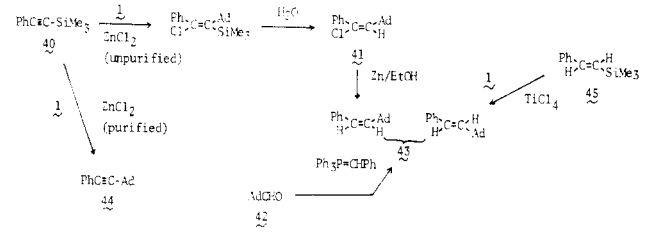
Under the same conditions, 1 underwent an electrophilic substitution reaction with the trimethylsilyl enol ethers of aldehydes and ketones (eq 1). Thus, the trimethylsilyl enol ethers of isobutyraldehyde and cyclohexanone (**13** and **15**) afforded α-(1-adamantyl)isobutyraldehyde (**14**) and α-(1-adamantyl)cyclohexanone (**16**) in 91 and 61% yields, respectively. Similar observations have been communicated recently by German chemists.[12]

Trimethylsilylated amides and related compounds were also reactive with 1. In these experiments the choice and amount of catalyst are critical. Titanium tetrachloride was not so effective, but 2 equiv of aluminum chloride accomplished the reaction. Furthermore, the reaction mixture, after being poured onto ice–water, should be made alkaline prior to extraction. Under these conditions *N*-(trimethylsilyl)-*N*-methylacetamide (**17**) reacted with 1 to give *N*-adamantylamide **18** in a 56% yield. There seem to be two possible explanations for the course of the reaction, i.e., direct substitution on nitrogen (eq 3) and substitution via the equilibrated imidate formed (eq 1). It is not possible to distinguish between these pathways on the basis of the products of the reaction. *N*-(Trimethylsilyl)-2-mercaptothiazoline (**19**) afforded S-adamantylated product **20** by following eq 1 and the benzo analogue **21** was obtained in the same manner. This method was also applied to *O*-trimethylsilyl nitrogen heterocycles. As is well-defined in glycoside synthesis,[13] the reaction of 1 with trimethylsilylated uracils and pyridone proceeded smoothly to give their *N*-adamantyl derivatives.

O-Trimethylsilylated oximes showed different behavior from the previously described allyltrimethylsilane heteroanaloues. O-(Trimethylsilyl)propionaldoxime (**31**) produced only the *O*-adamantyl oxime **32** on catalytic action of zinc chloride, but *O*-(trimethylsilyl)benzaldoxime (**33**), in contrast, produced *N*-adamantylbenzamide (**34**). Although a mechanism for the formation of the amide was not clarified, the intuitive evidence for attack of the adamantyl group on the central nitrogen atom (eq 2) was obtained under the conditions in which the aluminum chloride catalyzed reaction at low temperature was conducted, giving a nitrone (**35**) as a product (Scheme II). The structure of **35** was determined by an independent condensation of *N*-(1-adamantyl)hydroxylamine (**36**) and benzaldehyde and also by its cycloaddition reactivity with diethyl acetylenedicarboxylate.[14] These facts seem to stem from the more nucleophilic character of the central nitrogen enhanced by a phenyl group. An additional observation supported this: O-adamantylation prevailed over N-adamantylation in the zinc chloride catalyzed reaction with aldoxime **38** containing an electron-withdrawing group in the para position.[15]

(6) T. H. Chan and I. Fleming, *Synthesis*, 446 (1979).
(7) I. Paterson, *Tetrahedron Lett.*, 1519 (1979).
(8) T. Sasaki, A. Usuki, and M. Ohno, *Tetrahedron Lett.*, 4925 (1978).
(9) E. C. Eaborn, *J. Chem. Soc., Chem. Commun.*, 1255 (1972).
(10) I. Fleming and I. Paterson, *Synthesis*, 446 (1979).
(11) B. W. Au-Yeung and I. Fleming, *J. Chem. Soc., Chem. Commun.*, 79 (1979).
(12) M. T. Reetz, W. F. Maier, K. Schwellnus, and I. Chatziisoifidid, *Angew. Chem., Int. Ed. Engl.*, **18**, 72 (1979).
(13) U. Niedballa and H. Vorbrueggen, *J. Org. Chem.*, **39**, 3654, 3660, 3664, 3668, 3673 (1974).
(14) D. St. C. Black, R. F. Crozier, and V. C. Davis, *Synthesis*, 205 (1975).

Scheme III



Reactions with Alkynyl- and Alkenyltrimethylsilanes. Since electrophilic substitution on alkynylsilanes is also known,[6] the reaction using **40** was carried out with a large excess of zinc chloride. After a prolonged reaction time and the usual workup, colorless crystals were obtained, the structure of which was assigned as α-chloro-β-(1-adamantyl)styrene (**41**) which was a rather unexpected product (Scheme III). An independent synthesis confirmed its structure. Wittig reaction of **42** with benzylidenetriphenylphosphorane afforded β-(1-adamantyl)styrene (**43**), the cis isomer of which was consistent with the product from reduction of **41** with zinc metal in refluxing ethanol. The formation of **41** may be explained by trans addition of **1** to **40** and subsequent electrophilic substitution with water, which the catalyst combined with. As a matter of fact, acetylene **44**, a normal product, was obtained in an 80% yield when the reaction was catalyzed by zinc chloride purified by recrystallization from dioxane. The reaction of **1** with *trans*-β-styryltrimethylsilane (**45**) was found to be more sluggish; no appreciable change of **1** was observed with zinc chloride, and only 19% conversion to *trans*-**43** (^{1}H NMR analysis) was achieved even with titanium tetrachloride.

Reaction with Aryl- and Heteroaryltrimethylsilanes. Finally electrophilic substitutions for aryl- and heteroaryltrimethylsilanes were attempted. Thus *N*-(trimethylsilyl)imidazole (**46**) was substituted by **1** under the catalytic conditions at the C_4 carbon, which is different from the substitution at nitrogen observed in acetylation and (carbomethoxy)methylation.[16] Similarly, benzo analogue **48** was substituted at C_5 but not at nitrogen. A substitution reaction on 2-(trimethylsilyl)benzothiazole (**50**) also proceeded, but the isolated product contained the adamantyl group on the benzene ring (C_6 position) instead of on the thiazole ring where acetylation was reported to occur.[17] A further interesting example was found in *o*-(trimethylsilyl)toluene (**52**). It is well-known that electrophilic aromatic substitution normally takes place at the site of the silicon atom; acetylation of **52** leads to the formation of *o*-methylacetophenone.[19] However, the substitution by **1** was observed at only the para position, giving *p*-adamantyltoluene (**53**). The positional reactivity of phenol **55** resembled that of **52**. A steric reason for these results is omitted because in like manner *m*-(trimethylsilyl)toluene (**54**) also gave **53**; therefore, they are explicable in terms of protodesilylation of a primarily formed adamantylated intermediate with liberated hydrogen chloride.[20]

All above discrepancies between acetylation and adamantylation indicate that in the aromatic substitution adamantylation is not dominated by the orienting electronic effect of the trimethylsilyl substituent.

Structural determinations of all the adamantane derivatives described above were performed by spectral inspections, elemental analyses, and independent syntheses where necessary. Their properties and characterizations are summarized in Tables I and II.

In summary, 1-adamantyl chloride (**1**) was shown to react with various unsaturated organosilanes in the presence of a Lewis acid such as titanium tetrachloride, aluminum chloride, and zinc chloride to form new bonds, C–C, C–O, C–N, and C–S, at its bridgehead. We believe that this substitution method furnishes a convenient method for the synthesis of adamantane derivatives.

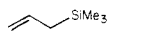
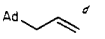
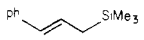
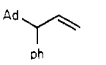
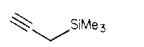
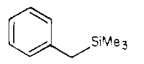
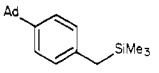
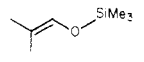
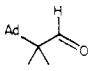
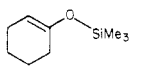
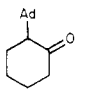
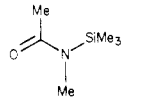
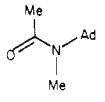
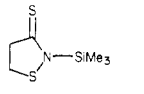
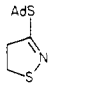
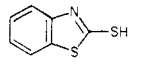
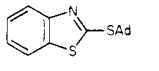
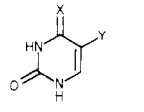
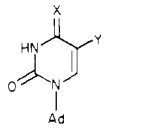
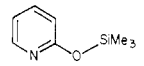
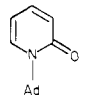
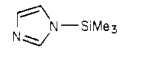
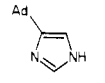
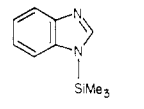
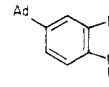
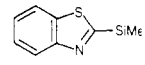
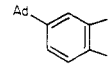
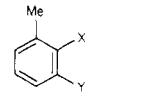
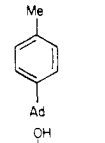
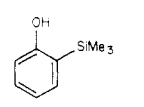
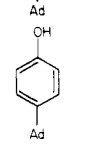
Experimental Section

Materials. All the organosilicon reagents were synthesized according to reported procedures. *C*-Trimethylsilyl compounds **5**,[21] **7**,[22] **9**,[23] **11**,[24] **40**,[25] **45**,[26] **50**,[17] **52**,[27] **54**,[27] and **55**[28] were prepared from the corresponding alkali metal reagents and trimethylsilyl chloride. Trimethylsilyl enol ethers **13** and **15** were prepared according to House's method.[29] In the case of trimethylsilylation on nitrogen or oxygen, **17**,[30] **19**,[31] **29**,[32] **31**,[33] **33**,[34] and **38**[35] were prepared by treatment of the corresponding amides or oximes with trimethylsilyl chloride and triethylamine and **46**[16] and **48**[16] by treatment of the corresponding imidazoles with hexamethyldisilazane. Chloroform and methylene chloride used as reaction solvents were dried over $CaCl_2$, distilled, and kept over 4-Å molecular sieves.

1-Allyladamantane (6). To a solution of **1** (171 mg, 1 mmol) containing $TiCl_4$ (190 mg, 1 mmol) in CH_2Cl_2 (3 mL) was added **5** (114 mg, 1 mmol) in CH_2Cl_2 (2 mL) dropwise at room temperature, and the mixture was stirred for 12 h. The reaction mixture was poured onto ice–water, and the separated organic layer was washed with water and dried (Na_2SO_4). After evaporation of the solvent, purification by silica gel chromatography

(15) A referee suggested that O- vs. N-alkylation of oxime is also dependent upon the stereochemistry of the oxime, and this is an important point for consideration since stereochemistry can be altered by Lewis acids. Cf. E. Buehler, *J. Org. Chem.*, **32**, 261 (1967).
(16) L. Birkofer, P. Richter, and A. Ritter, *Chem. Ber.*, **93**, 2804 (1960).
(17) F. H. Pinkerton and S. F. Thames, *J. Heterocycl. Chem.*, **8**, 257 (1971).
(18) For example, see ref 5a, p 138, and ref 5b, p 18.
(19) We could not find a definite example for acetylation of **52**; therefore, this reaction was conducted with acetyl chloride and $TiCl_4$ in CH_2Cl_2 at −78 °C and then at room temperature to give *o*-methylacetophenone in 45% isolated yield.
(20) Some comparative experiments support this process. *o*-Adamantyltoluene (**57**) prepared from *o*-tolylmagnesium bromide and 1-adamantyl bromide was never rearranged to the para isomer during the reaction and workup, eliminating the possibility of **57** as a primary product. Furthermore, when **52** was used as a solvent which played the role of HCl quencher as well as reactant, there was obtained 2-(trimethylsilyl)-4-(1-adamantyl)toluene (**58**) in addition to **53** (**58**/**53** ratio of 3:7). Compound (**58**) disappeared within 10 min with HCl–$TiCl_4$ at −78 °C (GLC analysis), indicating a desilylation process of **58** with liberated HCl to be very reasonable. On substitution reaction of **1** with an equal amount of *m*-deuteriotoluene and **52**, deuterium incorporation in the product was shown to be about 25% (mass spectral analysis), suggesting that reaction of **1** with simultaneously liberated toluene may be a competitive process to some extent. An analogous observation was reported: T. Hashimoto, *Yakugaku Zasshi*, **87**, 530 (1967).
(21) J. D. Park, J. D. Groves, and J. R. Lacher, *J. Org. Chem.*, **25**, 1628 (1960).
(22) R. M. G. Roberts and F. E. Kaissi, *J. Organomet. Chem.*, **12**, 79 (1968).
(23) J. C. Masson, M. LeQuan, and P. Cadiot, *Bull. Soc. Chim. Fr.*, 770 (1967).
(24) Y. P. Egorov, *Chem. Abstr.*, **53**, 12832*f* (1955).
(25) J. J. Eisch and M. W. Foxton, *J. Org. Chem.*, **36**, 3520 (1971).
(26) D. Seyferth, L. G. Vaughan, and R. Suzuki, *J. Organomet. Chem.*, **1**, 437 (1964).
(27) H. Soffer and T. DeVries, *J. Am. Chem. Soc.*, **73**, 5817 (1951).
(28) J. L. Speier, *J. Am. Chem. Soc.*, **74**, 1003 (1952).
(29) H. O. House, L. J. Czuba, M. Gall, and H. D. Olmstead, *J. Org. Chem.*, **34**, 2324 (1969).
(30) M. J. Hurwitz and P. L. De Beneville, *Chem. Abstr.*, **53**, 12238*e* (1955).
(31) H. R. Kircheldorf, *Justus Liebigs Ann. Chem.*, 772 (1973).
(32) L. Birkofer, A. Ritter, and H. P. Kuehithau, *Chem. Ber.*, **97**, 934 (1964).
(33) B. N. Dolgov, Z. I. Sergeeva, N. A. Zubkova, and M. G. Voronkov, *Zh. Obshch. Khim.*, **30**, 3347 (1960).
(34) Z. I. Sergeeva, Z. M. Matveeva, and M. G. Voronkov, *Zh. Obshch. Khim.*, **31**, 2017 (1961).
(35) U. Klaus and K. Annegret, *Z. Chem.*, 14, 63 (1974).

Table I. Reaction Conditions for the Substitution Reaction of 1 and Properties of the Products

starting material	no.	reaction conditions: catal[a]	solv[b]	time	T,[n] °C	product[c]	no.	yield, %	mp, °C (recryst solv)
	5	T	M	12 h	rt		6	85	oil
	7	T	M	30 min	0		8	48	oil
	9	T, Z	M	12 h	rt		10	0	
	11	T	M	12 h	rt		12	45	129-131 (methanol)
	13	T	M	3 h	rt		14	91	98-103[e] (*n*-hexane)
	15	T	M	12 h	rt		16	61	87-88 (methanol)
	17	A	M	12 h	rt		18	56	122-123 (lit. 122-123[f])
	19	A	C	12 h	rt		20	61	97-99 (*n*-hexane)
	21[g]	A	C	12 h	rt		22	35	58-60 (*n*-hexane)
	23 (X = O, Y = H)[g]	A	C	12 h	rt		24	53	290-292 ($CHCl_3$)
	25 (X = S, Y = H)[g]	A	C	12 h	rt		26	38	300 ($CHCl_3$)
	27 (X = O, Y = F)[g]	A	C	12 h	rt		28	38	300 ($CHCl_3$)
	29	A	M	12 h	rt		30	56	180-182 (ether)
EtCH=NOSiMe$_3$	31	Z	M	48 h	rt	EtCH=NOAd	32	50	oil
	33	Z	M	96 h	rt		34	35	150-151 (lit. 152-153[h])
		A	C	100 min	−40		35	43	118-120 (*n*-hexane)
	38	Z	M	120 h	rt		39	68	123-125 (methanol)
	40	Z (unpurified)	M	48 h	rt		41	64	74-75 (methanol)
		Z (purified)	M	48 h	rt		44	80	88-90 (methanol)
	45	T	M	24 h	rt		*trans*-43	19[i]	
	46	T	C	12 h	rt		47	52	227-230 (lit. 222-225[j])
	48	A	C	3 h	0		49	49	135-142 (methanol)
	50	A	C	12 h	rt		51	15	170-172
	52 (X = SiMe$_3$, Y = H)	T	M	30 min	−78		53	80	97-99 (lit. 100[k])
	54 (X = H, Y = SiMe$_3$)	T	M	2 h	−78		53	75	97-99 (lit. 100[k])
	55[l]			5 h	140		56	61	181-183 (lit. 182.4-182.8[m])

Footnotes to Table I.

[a] T = $TiCl_4$, A = $AlCl_3$, and Z = ZnCl. [b] M = methylene chloride and C = chloroform. [c] Ad = 1-adamantyl. [d] E. C. Capaldi and A. E. Borchert, *Chem. Abstr.*, 71, 81931 (1969). [e] Its 2,4-dinitrophenylhydrazone has a melting point of 252 °C. [f] E. I. du Pont de Nemours and Co., *Chem. Abstr.*, 63, 9838a (1965). [g] These amides were mixed directly with 1 after trimethylsilylation and evaporation of the solvent and excess reagents. [h] A. Kreutzberger and H. H. Schroeder, *Tetrahedron Lett.*, 4523 (1970). [i] This yield was estimated from the ^1H NMR spectrum of the recovered hydrocarbon mixture. [j] F. N. Stepanov and S. D. Isaev, *Zh. Org. Khim.*, 6, 1195 (1970). [k] H. Stetter, J. Weber, and C. Wulff, *Chem. Ber.*, 97, 3488 (1964). [l] 1-Adamantyl bromide was used instead of 1. [m] K. Okamoto, K. Matsubara, and T. Kinoshita, *Bull. Chem. Soc. Jpn.*, 45, 1191 (1972). [n] rt is room temperature.

Table II. Analytical Data for the Products Obtained in the Substitution Reaction[a]

compd	IR,[b] cm^{-1}	^1H NMR,[c] δ	molecular formula	anal.[d] calcd/found C	H	N
8	1635, 990, 910	6.8-7.2 (m, 5 H, phenyl), 4.7-6.5 (ABX, 3 H, vinyl), 2.75 (d, 1 H, J = 9.0 Hz, C_3H)	$C_{19}H_{24}$	90.42 90.47	9.58 9.54	
12	1600, 1250, 840	6.85 and 7.15 (AB q, each 2 H, J = 9.0 Hz, phenyl), 2.13 (s, 2 H, CH_2), 0.00 (s, 9 H, $SiCH_3$)	$C_{20}H_{30}Si$	80.46 80.42	10.13 9.77	
14	1720	9.64 (s, 1 H, CHO), 0.96 (s, 6 H, CH_3)	$C_{20}H_{26}N_4O_4$[e]	62.16 61.98	6.78 6.81	14.50 14.38
16	1705	1.5-2.5 (m, 24 H, adamantane and cyclohexane ring H)	$C_{16}H_{24}O$	82.70 82.56	10.41 10.12	
20	1570	4.23 and 3.23 (t, each 2 H, J = 8.0 Hz, CH_2)	$C_{13}H_{19}NS_2$	61.61 61.52	7.56 7.46	5.52 5.56
22[f]	1450, 1420	7.0-8.0 (m, 4 H, phenyl)	$C_{17}H_{19}NS_2$	67.72 67.92	6.35 6.47	4.65 4.65
24	3030, 1660	8.8 (br s, 1 H, NH),[g] 7.35 (d, 1 H, J = 9.0 Hz, C_6H), 5.58 (dd, 1 H, J = 9.0, 3.0 Hz, C_5H)	$C_{14}H_{18}N_2O_2$	68.27 68.50	7.36 7.33	11.37 11.18
26	3060, 1640	9.54 (br s, 1 H, NH),[g] 7.65 (d, 1 H, J = 9.0 Hz, C_6H), 5.82 (dd, 1 H, J = 9.0, 3.0 Hz, C_5H)	$C_{14}H_{18}N_2OS$	64.09 63.85	6.91 7.00	10.68 10.85
28	3040, 1690	11.52 (br s, 1 H, NH),[g] 7.93 (d, 1 H, J = 9.0 Hz, C_6H)	$C_{14}H_{17}N_2O_2F$	63.62 63.69	6.48 6.49	10.60 10.70
30	1640	6.9-7.4 and 5.8-6.4 (m, each 2 H, olefinic H)	$C_{15}H_{19}NO$	78.56 78.90	8.35 8.14	6.11 6.05
32	1640	7.23 and 6.43 (each t, 0.64 H and 0.36 H, syn and anti CH=N), 1.9-2.6 (m, 2 H, CH_2), 0.9-1.2 (m, 3 H, CH_3)	$C_{13}H_{21}NO$	75.31 75.58	10.21 10.22	6.76 6.47
35	1560	8.1-8.2 and 7.2-7.4 (m, 2 H and 3 H, phenyl), 7.30 (s, 1 H, CH=N)	$C_{17}H_{21}NO$	79.96 80.24	8.29 8.29	5.49 5.46
39	1600, 1520, 1345	8.25 (s, 1 H, CH=N), 8.27 and 7.76 (AB q, each 2 H, J = 8.0 Hz, phenyl)	$C_{17}H_{20}N_2O_3$	67.98 68.14	6.71 6.82	9.33 9.31
41	1640, 1600	7.0 (br s, 5 H, phenyl), 5.45 (s, 1 H, CH=C)	$C_{18}H_{21}Cl$	79.25 79.21	7.76 7.49	
44	2150	7.2 (m, 5 H, phenyl)	$C_{18}H_{20}$	91.47 91.74	8.53 8.48	
49	3400-2400, 1450	9.86 (br s, 1 H, NH), 7.92 (s, 1 H, C_2H), 7.48 (d, 1 H, J = 9.0 Hz, C_7H), 7.45 (s, 1 H, C_4H), 7.15 (d, 1 H, J = 9.0 Hz, C_6H)	$C_{17}H_{20}N_2 \cdot CH_3OH$[h]	76.02 76.32	8.51 8.52	9.85 9.53
51	1600, 1450	8.92 (s, 1 H, C_2H), 8.07 (d, 1 H, J = 9.0 Hz, C_4H), 7.90 (d, 1 H, J = 1.5 Hz, C_7H), 7.55 (dd, 1 H, J = 9.0, 1.5 Hz, C_5H)	$C_{17}H_{19}NS$	75.79 75.51	7.12 6.99	5.20 4.99

[a] IR and ^1H NMR spectra of known compounds **6**, **18**, **34**, **47**, **53**, and **56** were superimposable with those of the authentic specimens. [b] IR spectra were obtained with a JASCO IRA-1 spectrophotometer. Compounds **6**, **8**, and **32** were scanned as films, **16** was scanned in $CHCl_3$, and all the others were scanned in KBr disks. [c] ^1H NMR spectra were determined at 60 MHz with a JEOL 60-HL spectrometer. Compounds **6**, **8**, **12**, **14**, **16**, **32**, **41**, and **44** were measured in CCl_4, **39** was measured in acetone-d_6, and all the others were measured in $CDCl_3$, with tetramethylsilane as an internal standard. In all spectra, signals due to adamantane ring protons were recognized usually in the δ 1.5-2.2 region as a multiplet. [d] Microanalyses were performed with a Perkin-Elmer 240 elemental analyzer. [e] Analysis was done as its 2,4-dinitrophenylhydrazone. [f] The ultraviolet spectrum is more informative; the characteristic absorption appeared at 280 nm (methanol) with log ε = 4.06. See K. J. Morgan, *J. Chem, Soc.*, 854 (1958). [g] Deuteration removed the NH signal and changed the doublet of doublets of C_5 to a doublet. [h] The signal at δ 3.50 (s, 3 H) in the ^1H NMR spectrum also indicates that 1 mol of methanol is included in one crystal.

(*n*-hexane) afforded **6** as an oil. Compounds **8**, **12**, **14**, **16**, *trans*-**43**, and **53** were also obtained in this way.

***N*-(1-Adamantyl)-*N*-methylacetamide (18).** To a mixture of **1** (171 mg, 1 mmol) and $AlCl_3$ (267 mg, 2 mmol) in CH_2Cl_2 (3 mL) was added **17** (145 mg, 1 mmol) in CH_2Cl_2 (2 mL), and the mixture was stirred for 12 h at room temperature. The reaction mixture was poured onto ice–water and neutralized with aqueous Na_2CO_3, and then the separated organic layer was washed with water and dried (Na_2SO_4). Evaporation of the solvent gave a solid which was recrystallized from *n*-hexane to give **18**. Compounds **20**, **30**, **47**, **49**, and **51** were also obtained in this way.[36]

2-(1-Adamantylthio)benzothiazole (22). To a solution of **21** (171 mg, 1 mmol) containing triethylamine (111 mg, 1.1 mmol) in dioxane (10 mL) was added trimethylsilyl chloride (120 mg, 1.1 mmol), and the mixture was stirred for 1 day at room temperature. After the precipitates were filtered off through sintered glass under a nitrogen atmosphere, the solvent and excess reagents were evaporated in vacuo, and the residue was dissolved in $CHCl_3$ (5 mL). This solution was then added to a mixture of **1** (171 mg, 1 mmol) and $AlCl_3$ (267 mg, 2 mmol) in $CHCl_3$ (5 mL), and the mixture was stirred for 12 h at room temperature. Workup as above gave a syrup which was crystallized from *n*-hexane to give **22**.[36]

1-(1-Adamantyl)uracil (24). Hexamethyldisilazane (3 mL) was added to **23** (336 mg, 3 mmol) and the mixture refluxed for 1 day. After excess hexamethyldisilazane was completely distilled

(36) For their yields, properties, and characterizations, see Tables I and II.

off in vacuo, the residual oil was dissolved in $CHCl_3$ (6 mL). This solution was added to a mixture of **1** (512 mg, 3 mmol) and $AlCl_3$ (800 mg, 6 mmol) in $CHCl_3$ (9 mL), and this was stirred for 12 h at room temperature. The reaction mixture was poured onto small amounts of ice and neutralized with aqueous Na_2CO_3. Products were extracted with $CHCl_3$, and the combined $CHCl_3$ extract was evaporated to give a solid which was recrystallized from $CHCl_3$ to give **24**. Compounds **26** and **28** were also obtained in this way.[36]

***O*-(1-Adamantyl)propionaldoxime (32).** A mixture of 1 (171 mg, 1 mol), **31** (145 mg, 1 mmol), and $ZnCl_2$ (273 mg, 2 mmol) in $CHCl_3$ (5 mL) was stirred vigorously for 48 h at room temperature. Water was then added to this mixture, and the organic layer was separated and dried (Na_2SO_4). Evaporation of the solvent gave an oil which was purified by chromatography on silica gel (benzene) to give **32**. Compounds **34** and **39** were also obtained in this way.[36]

α-Phenyl-*N*-(1-adamantyl)nitrone (35). To a mixture of 1 (171 mg, 1 mmol) and $AlCl_3$ (133 mg, 1 mmol) in $CHCl_3$ (5 mL) was added **33** (193 mg, 1 mmol) dropwise at −40 °C under a nitrogen atmosphere. Stirring was continued for 100 min while the reaction temperature was gradually raised to 0 °C. The reaction mixture was then poured onto ice–water, and the separated organic layer was washed with water and dried (Na_2SO_4). The solvent was evaporated off to leave the residue which was chromatographed on a silica gel column ($CHCl_3$) to give **35**.[36] An independent synthesis was carried out by condensation of **36** with benzaldehyde as follows. Free **36**[37] liberated from its HCl salt (30 mg, 0.15 mmol) with triethylamine in benzene was refluxed with benzaldehyde (21 mg, 0.2 mmol) and a trace of acetic acid in ethanol (2 mL) for 2 h. After removal of the solvent, the residue was chromatographed on a silica gel column ($CHCl_3$) to give **35** (30 mg, 82%). The spectral comparison of this authentic sample with the product obtained as above affirmed the assigned structure. A solution of **35** (100 mg, 0.39 mmol) and diethyl acetylenedicarboxylate (68 mg, 0.4 mmol) in benzene (5 mL) was refluxed for 90 min. After removal of the solvent, the residue was chromatographed on an alumina column (ethyl acetate/benzene, 2:1) to give a 1:1 adduct (**37**): 100 mg (66%); mp 95–96 °C; IR (KBr) 1745, 1695, 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.2–7.5 (m, 5 H, phenyl), 5.53 (s, 1 H, C_3 H), 4.36 and 4.04 (dq, J = 7.0 Hz, OCH_2), 1.5–2.3 (m, 15 H, adamantane), 1.37 and 1.12 (dt, 6 H, J = 7.0 Hz, CH_3). Anal. Calcd for $C_{25}H_{31}NO_5$: C, 70.57; H, 7.34; N, 3.29. Found: C, 70.86; H, 7.43; N, 3.41.

α-Chloro-β-(1-adamantyl)styrene (41). A mixture of 1 (307 mg, 1.8 mmol), **40** (348 mg, 2 mmol), and $ZnCl_2$ (800 mg, 5.9 mmol; commercial product) in CH_2Cl_2 (4 mL) was stirred for 48 h at room temperature. After filtration of the catalyst and removal of the solvent, the residual oil was chromatographed on a silica gel column (*n*-hexane) to give **41**. Acetylene **44** was obtained under the same conditions except for the use of purified $ZnCl_2$ (recrystallized from dioxane).[36]

Wittig Reaction of 42. To an ethereal solution of benzylidenetriphenylphosphorane[38] prepared from the corresponding phosphonium bromide (650 mg, 1.5 mmol) and phenyllithium (1.5 mmol) was added **42** (164 mg, 1 mmol) in dry ether under a nitrogen atmosphere, and this mixture was stirred overnight at room temperature. After decomposition with water, the ether layer was separated and dried (Na_2SO_4). The solvent was evaporated off, and the residual oil was subjected to silica gel chromatography (*n*-hexane). The first fraction was identified as *cis*-β-(1-adamantyl)styrene: oil; 70 mg (29%); IR (film) 1630, 1600, 1490, 710 cm^{-1}; ^1H NMR (CCl_4) δ 7.08 (s, 5 H, phenyl), 6.30 and 5.23 (AB q, each 1 H, J = 12.7 Hz, HC=CH), 1.5–2.0 (m, 15 H, adamantane). The second fraction was identified as the trans isomer: crystalline; 30 mg (13%); mp 72–74 °C; IR (KBr) 1630, 1600, 1490, 960 cm^{-1}; ^1H NMR (CCl_4) δ 7.15 (s, 5 H, phenyl), 6.22 and 5.90 (AB q, each 1 H, J = 16.5 Hz, HC=CH), 1.6–2.2 (m, 15 H, adamantane). Anal. Calcd for $C_{18}H_{22}$: C, 90.70; H, 9.30. Found (cis): C, 90.75; H, 9.25. Found (trans): C, 90.98; H, 9.02.

The cis isomer was consistent with the reduced product of the reaction of **41** (40 mg) with zinc metal (100 mg) in refluxing ethanol (2 mL) for 16 h.

***p*-(1-Adamantyl)phenol (56).** A mixture of 1-adamantyl bromide (215 mg, 1 mmol) and **55** (332 mg, 2 mmol) was heated for 5 h at 140 °C. After the mixture cooled, the resulting solid was recrystallized from ether to give **56**.[36]

Registry No. 1, 935-56-8; **5**, 762-72-1; **6**, 22922-62-9; **7**, 19752-23-9; **8**, 74203-25-1; **9**, 13361-64-3; **10**, 74203-26-2; **11**, 770-09-2; **12**, 70624-77-0; **13**, 6651-34-9; **14**, 74203-27-3; **14**-DNP, 74203-28-4; **15**, 6651-36-1; **16**, 41031-34-9; **17**, 7449-74-3; **18**, 3717-37-1; **19**, 74203-29-5; **20**, 74203-30-8; **21**, 149-30-4; **22**, 74203-31-9; **23**, 66-22-8; **24**, 74203-32-0; **25**, 591-28-6; **26**, 74203-33-1; **27**, 51-21-8; **28**, 74203-34-2; **29**, 18292-04-1; **30**, 70624-78-1; **31**, 18140-10-8; **32**, 74203-35-3; **33**, 17876-73-2; **34**, 19026-84-7; **35**, 31463-28-2; **38**, 74203-36-4; **39**, 74203-37-5; **40**, 2170-06-1; **41**, 74203-38-6; **42**, 2094-74-8; *trans*-**43**, 70624-80-5; *cis*-**43**, 70624-81-6; **44**, 74203-39-7; **45**, 19372-00-0; **46**, 18156-74-6; **47**, 26845-71-6; **48**, 13435-08-0; **49**, 74203-40-0; **50**, 32137-73-8; **51**, 74203-41-1; **52**, 7450-03-5; **53**, 1459-55-8; **54**, 3728-44-7; **55**, 15288-53-6; **56**, 29799-07-3; benzaldehyde, 100-52-7; diethyl acetylenedicarboxylate, 762-21-0; benzylidenetriphenylphosphorane, 16721-45-2; 1-adamantyl bromide, 768-90-1.

(37) G. Zinner and U. Dybowski, *Arch. Pharm. (Weinheim, Ger.)*, **303**, 488 (1970).

(38) G. Wittig and U. Schoellkopf, *Chem. Ber.*, **87**, 1318 (1954).

Syntheses and Properties of Dimethylbisdehydro[15]annulenone, -[17]annulenone, -[19]annulenone, and -[21]annulenone

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Syntheses of 5,10-dimethyl-6,8-bisdehydro[15]annulenone (**2**), 7,12-dimethyl-8,10-bisdehydro[17]annulenone (**3**), 7,12-dimethyl-8,10-bisdehydro[19]annulenone (**4**), and 9,14-dimethyl-10,12-bisdehydro[21]annulenone (**5**) are described. The ^1H NMR spectra of these annulenones indicate that both **2** and **4** are diatropic, whereas both **3** and **5** are paratropic, and these ring currents are increased by dissolution in deuteriotrifluoroacetic acid.

Syntheses of a series of bis(cyclohexene)-annelated bisdehydro[13]-, -[15]-, and -[17]annulenones have been described previously.[2] Since this work was carried out, it has been shown that monocyclic bisdehydroannulenes with methyl substituents on the propargylic positions are superior to the corresponding cyclohexene-fused compounds for the investigation of conformational mobility

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(2) P. D. Howes, E. LeGoff, and F. Sondheimer, *Tetrahedron Lett.*, 3691, 3695 (1972).

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