13, 100021-14-5; **14**, 100021-15-6; **15**, 100021-16-7; (–)-**15**, 100101-50-6; **16**, 100021-17-8; **18**, 100021-18-9; **19**, 100021-19-0; **20**, 100021-20-3; **21**, 100021-21-4; **22**, 100021-22-5; **23**, 100021-23-6; **24**, 100021-24-7; **25**, 24587-86-8; **26**, 100021-25-8; **27**, 100101-49-3; **28**, 100021-26-9; **29**, 100021-27-0; **30**, 100021-28-1; **31**, 85026-59-1; cyclopentadiene, 542-92-7; benzyl chloromethyl ether, 3587-60-8; 5-amino-4,6-dichloropyrimidine, 5413-85-4; diethoxymethyl acetate, 14036-06-7; adenine, 73-24-5.

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^{1}H NMR 2D Conformational Study of 2-Selenated 3-Substituted Cyclohexanones. Evidence of Trans Diaxial Conformers

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Syntheses of various cis and trans 2-phenylseleno 3-substituted cyclohexanones (**1**–**4**) are described as well as related ketals (**5**–**6**). The ^{1}H NMR 2D study shows that the 2-SePh group is located in axial position in both cis (**1**–**4c**) and trans (**1**, **2**, and **4t**) ketones, the cyclohexanone ring adopting a chair conformation; the two substituents lie in axial position in the trans isomer while a twist-boat is observed for the **3t** isomer. The stabilization of a single conformation was explained by a balance between electronic effect (π–σ^* interaction) and steric effects. On the contrary, in the trans ketals (**5**–**6t**) the 2-SePh moves to the equatorial position while in the corresponding cis isomers (**5**–**6c**) it remains in the axial position. The phenylseleno group elimination leading to α,β-unsaturated enones (**13**–**16**) was also examined.

In our previous work we have shown that conjugate addition of lithiated carbanionic species as a masked benzoyl group on 2-methyl-2-cycloalkenones led exclusively to cis 1,4 adducts.[1a] Moreover, under mild deprotection conditions we have been able to obtain the corresponding γ-diketones retaining the cis stereochemistry.

On the other hand, the trans 2,3-disubstituted cyclalkanones can be obtained by conjugate addition of benzoyl precursors followed by methyl iodide enolate trapping.[1b]

We now examine the influence of the phenylseleno group as the 2-substituent on the stereochemistry of these reactions. The choice of this group seemed particularly interesting from a synthetic point of view since it gives access to 3-substituted 2-cyclohexenones,[2,3] some of which were still unknown.

The unexpected conformational behavior of the obtained 2,3-disubstituted cyclohexanones led us to study compounds bearing a 3-alkyl or 3-aryl substituent and to examine the influence of the carbonyl group by protecting it as dioxolane.

The configurational and conformational analysis of the various cis and trans 2-phenylseleno 3-substituted cyclohexanones and corresponding ketals are made by ^{1}H 2D NMR. Furthermore, the structural information allows us to examine the phenylseleno group elimination.

Synthesis of the Various Compounds. 1,4-Adducts were prepared by conjugate addition of nucleophiles either to 2-(phenylseleno)-2-cyclohexenone (**7**) followed by protonation (method 1) or to 2-cyclohexenone (**8**), followed by enolate PhSeBr trapping (method 2)[4,5] (Scheme I). The structural assignments of the cis **1**–**6c** and trans **1**–**6t** isomers will be discussed later on. The ratios of isomers were determined by ^{1}H NMR 400-MHz integration of the H_2 signals.

According to the literature,[6] the addition of Me_2CuLi (**9**) to **7** has been realized in ether, followed by quenching with NH_4Cl saturated aqueous solution (method 1a). A mixture of compounds in which the trans isomer is highly predominent (**1t**/**1c** = 95/5) has been obtained. Use of $Me_2CuCNLi_2$ (**10**) and quenching with a solution of 10% NH_4OH/90% NH_4Cl (method 1b)[7] gave identical results. After simple preparative thin-layer chromatography on SiO_2 the obtained **1t**/**1c** mixture in a 35/65 ratio corresponds very likely to the thermodynamic equilibrium, since it remains unchanged after several chromatographies. Compounds **2** were obtained from $Ph_2CuCNLi_2$ (**11**): method 1 gives a **2c**/**2t** cis/trans mixture in a 45/55 ratio, while method 2 leads exclusively to the trans isomer **2t**. Attempts of purification of either the **2t**/**2c** mixture or **2t** alone by column chromatography on silica gel led to the same **2c**/**2t** = 60/40 mixture. This ratio corresponds to the thermodynamic equilibrium as it was mentioned above for compounds **1c** and **1t**.

The reaction of lithiated *N*-(dimethylamino)phenylacetonitrile **12** on **7** followed by protonation with saturated NH_4Cl solution leads exclusively to the cis isomer, in accordance with our previous results.[1] Our inability to epimerize **3c**, due to the known fragility of the amino nitrile group, led us to synthesize the trans isomer **3t** by method 2. It is well-known[1,8,9] that amino nitriles can be easily

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(4) Taylor, R. J. K. *Synthesis* **1985**, *4*, 364.

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(6) The literature data concerning the preparation of **1** refer to cis/trans mixtures in undefined ratios. See details in the following report: Zima, G.; Barnum, C.; Liotta, D. *J. Org. Chem.* **1980**, *45*, 2736.

(7) (a) Lipshutz, B. H.; Wilhelm, R. S.; Kozlowski, J. A. *J. Org. Chem.* **1984**, *49*, 3938. (b) Lipshutz, B. H.; Wilhelm, R. S.; Kozlowski, J. A. *Tetrahedron Lett.* **1982**, *23*, 3755.

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0022-3263/86/1951-1293$01.50/0

Table I. ^1H NMR Data of Cis 2,3-Disubstituted Cyclohexanones

	compound							
	1c		**2c**		**3c**		**4c**^{c}	
H	δ^a	J^b	δ	J	δ	J	δ	J
H_{2e}	3.75	2e4e 2e6e	3.88	2e4e, 1.7 2e6e, 1.7	3.24	2e4e 2e6e	3.98	2e4e 2e6e
H_{3a}	2.13	3a4a, 11.0 3a2e, 3.8 3a4e, 3.8	3.36	3a4a, 12.3 3a2e, 4.1 3a4e, 3.0	2.65	3a4a, 13.0 3a2e	4.10	3a4a, 8.5 3a2e, 4.3 3a4e, 4.3
H_{4e}	1.63		1.97	4e4a, −13.0 4e6e	2.42	4e4a, −13.0 4e6e	2.05	
H_{4a}	1.54		2.20	4a5a, 13.5 4a5e, 4.0	2.07	4a5a, 13.0 4a5e, 3.5	2.05	
H_{5e}	1.97		2.12	5e5a, −13.5	2.20	5e5a, −13.5	2.05	
H_{5a}	1.64		1.70	5a4e, 4 5a6e, 4	1.70	5a4e, 4.0 5a6e, 5.0	1.77	5a6e, 5
H_{6a}	3.05	6a5a, 11.1 6a5e, 7.1	3.06	6a5a, 13.5 6a5e, 6.5	3.32	6a5a, 13.7 6a5e, 7.3	3.03	6a5a, 10.5 6a5e, 5.5
H_{6e}	2.24	6e6a, −14.5	2.32	6e6a, −14.5	2.30	6e6a, −15.1	2.35	6e6a, −15.0 6e5e, 5
CH_3	1.19	CH_3H_3, 6.6						

[a] Chemical shifts in ppm vs. Me_4Si. [b] Coupling constants in Hz. Couplings quoted without indication of the numerical value were detected by the observation of the cross peaks in the correlated 2D NMR (COSY) spectra. [c] For purpose of comparison, chemical shifts were extracted from the spectrum recorded with the $CDCl_3$ solution. Coupling constants were measured after addition of a small amount of C_6D_6 to separate the signal of H_3 which overlaps with that of the H_2 proton of isomer. **4t**.

Table II. ^1H NMR Data of Trans 2,3-Disubstituted Cyclohexanones

	compound							
	1t		**2t**		**3t**		**4t**	
H	δ^a	J^b	δ	J	δ	J	δ	J
H_{2e}	3.56	2e4e 2e6e	4.10	2e4e, 1.3 2e6e, 1.3	3.97		4.11	2e4e 2e6e
H_{3e}	2.46	3e2e, 4.2 3e4e, 4.2 3e4a, 4.2 3e5e	3.54	3e2e, 4.8 3e4e, 5.1 3e4a, 5.1 3e5e	3.12	3.2, 2.2 3.4, 9.0 3.4′, 7.0	4.26	3e2e, 4.6 3e4e, 4.6 3e4a, 4.6
H_{4e}	1.54	4e4a, −13.9 4e5a, 4.5 4e5e, 4.5 4e6e	1.86	4e4a, −14.0 4e5a, 5 4e5e, 5 4e6e, 1.3	1.94	⟨34⟩^{d}	1.98	4e4a −14.3 4e5a, 4.6 4e5e, 4.6 4e6e
H_{4a}	2.07	4a5a, 10.5 4a5e, 4.2 $4aCH_3$	2.24	4a5a, 10 4a5e, 5	1.46	⟨41⟩	2.25	4a5a, 11.0 4a5e, 4.1
H_{5e}	1.86		1.74		1.82		1.76	5e5a, −14
H_{5a}	1.91		1.76		1.74		1.84	
H_{6e}	2.24	6e6a, −14.5	2.37	6e6a, −14.9 6e5a, 5.3 6e5e, 5.3	1.78		2.39	6e6a, −15.5 6e5a, 4.9 6e5e, 4.9
H_{6a}	3.05	6a5a, 11.5 6a5e, 6.8	3.02	6a5a, 10 6a5e, 6	2.70		2.90	6a5a, 10.8 6a5e, 6.3
CH_3	1.08	CH_3H_3, 7.1						

[a] Chemical shifts in ppm vs. Me_4Si. [b] Coupling constants in Hz. Couplings quoted without indication of the numerical value were detected by the observation of the cross peaks in the correlated 2D NMR (COSY) spectra. [c] The label, axial or equatorial of the protons does not apply for this compound. [d] Half height width of the signal.

transformed into the corresponding ketones, without isomerization, by treatment with aqueous $AgNO_3$[8] or copper sulfate.[10] As expected, reaction of 0.5 N $AgNO_3$ aqueous solution on **3t** gives only diketone **4t**. Attempts of hydrolysis of **3c** lead to a mixture of isomers **4c** and **4t** and of the product resulting from the elimination of the phenylseleno group (vide infra), in ratios depending on the reaction time and on the concentration of the reagent $AgNO_3$. Attempts to purify **4c** by chromatography were unsuccessful.

The dioxolanes **5c**, **5t** and **6c**, **6t** were obtained from cis/trans mixtures of **1** and **2** following a method described by Reich.[3]

NMR Spectra. Characterizations and assignments to the diastereoisomers as well as structural information relative to the ring shape[11] and preferred location of the substituents were obtained by ^1H NMR using $CDCl_3$ as solvent. Compounds **1c**, **2c**, **2t**, **4c**, **5c**, **5t**, **6c**, and **6t** were examined in the presence of their isomer. Even at 500.13 MHz some resonances below $\delta = 2.4$ ppm overlap precluding worthwhile irradiation experiments so that the complete assignment of the signals results from 2D correlated NMR studies. Chemical shifts and coupling constants which can be extracted by first-order analysis and/or simulation of the one dimension 500.13-MHz

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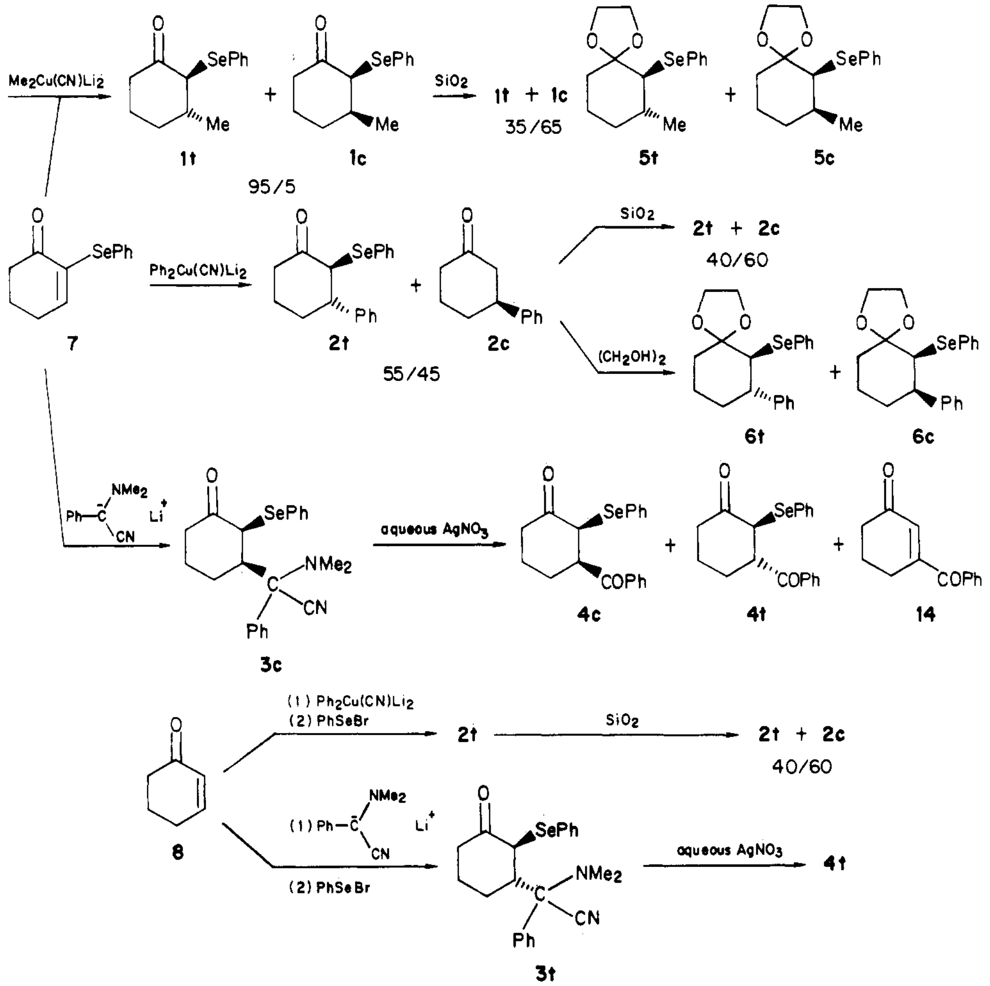
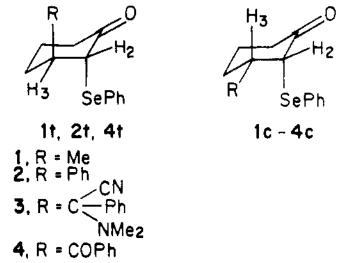
Scheme I



spectra are collected in Table I for isomers **1**–**4c** and Table II for isomers **1**–**4t**.

In the first set of isomers **1**–**4c** the values of the vicinal coupling constants of the ring protons H_3 and H_2 are a good structural indication of the cis relationship of the two substituents and of their preferential position, equatorial for R_3 and axial for SePh; the signal of the H_3 proton is a doublet of triplet with only one large coupling (${}^3J_{H_{3ax}H_{4ax}}$), that of H_2 is a narrow multiplet with a medium coupling (${}^3J_{H_2H_{3ax}}$). Furthermore, small long range couplings typical of the interaction between equatorial protons distant from four bonds have been detected in the 2D NMR COSY contour plots (${}^4J_{H_{2eq}H_{4eq}} - {}^4J_{H_{2eq}H_{6eq}} - {}^4J_{H_{4eq}H_{6eq}}$) showing thus that in these isomers the chair conformation of the cyclohexanone ring is retained. The values of the vicinal coupling constants between axial protons are very large, 12.3–14.5 Hz, in compounds **2c** and **3c** which bear the bulkier equatorial substituents. The ring conformation is thus likely to be very close to the classical tetrahedral chair. In the two other compounds, vicinal axial–axial coupling constants have lower values. (In the case of compound **4**, of course, lowering of ${}^3J_{H_{3ax}H_{4ax}}$ may be due in part to the attractive electronic effect of the 3-substituent.[12]) For these two compounds the conformation of the ring may be close to the flattened chair of the unsubstituted cyclohexanone.[13]

As regards the isomers **1t**, **2t**, and **4t**, their spectra exhibit at first sight very similar patterns (the main differences are related to the effects of the substituents on the chemical shifts of H_2 and H_3). For these compounds (the methyl group being irradiated in the case of **1**) the signal of H_3 exhibits three moderate coupling constants equal to one another within the limits of resolution, and the signal of H_2 is an unresolved narrow multiplet. Once more, weak W stereospecific couplings between protons separated by four bonds (among which H_2) are observed in the one dimension spectra or detected in the 2D COSY contour plots. These results demonstrate that the cyclohexanone ring of these isomers **1t**, **2t**, and **4t** adopts a basic chair form with, quite surprisingly, both substituents in axial position and, therefore, in trans relationship. Furthermore, lowering the temperature from 295 K to 223 K does not alter the spectra of compounds **1** and **2** but for small shifts (less than 0.07 ppm) of some resonances and for the unavoidable slight loss of resolution. Thus, the same conformation seems to be locked over all the examined temperature range. The use of a more polar solvent as Me_2SO in the place of $CDCl_3$ does not show any significant modification in the coupling constants of **4t**, indicative of the presence of one highly predominating conformer, whose



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[12] Lambert, B. *J. Am. Chem. Soc.* **1967**, *89*, 1836.

[13] Allinger, N. L.; Blatter, H. M.; Frieberg, L. A.; Karkowski, F. M. *J. Am. Chem. Soc.* **1966**, *88*, 2999.

Table III. ^{1}H NMR Data of Cis and Trans 2,3-Disubstituted Ketals

	compound							
	5c		5t		6c		6t	
H	δ^a	J^b	δ	J	δ	J	δ	J
H_2	3.21	2e3a, 3.5 2e4e 2e6e	2.92	2a3a, 11.9	3.22	2e3a, 3 2e4e 2e6e	3.38	2a3a, 12.6
H_{3a}	2.13	3a4a, 11.0 3a4e, 3.5	1.88	3a4a, 12.3	3.42	3a4a, 12.1 3a4e, 3	3.02	3a4a, 12.4 3a4e, 3.8
H_{4e}	1.43		1.78	4e6e	1.83		1.89	4e6e
H_{4a}	1.15		1.03	4a4e, −12.3 4a5a, 12.3 4a5e, 3.5	1.73		1.47	4a4e, −13.0 4a5a, 13.0 4a5e, 4.0
H_{5e}	1.64		1.62		1.6–1.75		1.6–1.75	
H_{5a}	1.53		1.56					
H_{6e}	1.61		1.91		1.75		1.98	
H_{6a}	1.93		1.45		1.96		1.6–1.75	
CH_3	1.12	CH_3H_3, 6.8	1.12	CH_3H_3, 6.8				

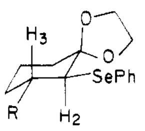
^{a,b}Same as for Table I.

population is not sensitive to the solvent polarity.

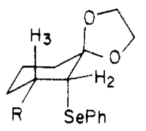
More accurate investigation of the NMR data shows that distorsions in the ring shape seem to increase with the size of the 3-substituent. In the case of compounds **1** which bear the smallest 3-substituent, the signals of H_{6eq} and H_{6ax} of the trans isomer are respectively superimposed to those of the cis isomer indicating very similar conformations of the cyclohexanone rings. For compounds **2** with the more bulky 3-substituent (compounds **3** excluded), when going from the cis to the trans isomer the magnitude of the vicinal coupling constants between all pairs of axial protons is significantly decreased while the opposite trend is observed for most of the vicinal coupling constants involving one or two equatorial protons. These results are consistent with a progressive flattening of the chair which alters the dihedral angles but releases steric 1–3 diaxial interactions.

In contrast, the spectra of compound **3t** is very different from those of the three former ones. Most signals are poorly resolved. W stereospecific couplings are no longer detected by 2D NMR. The signal of H_3 exhibits three different coupling constants, one smaller and two larger than the usual ones. The signals of the H_6 protons and of the most widely coupled H_4 proton are significantly shifted to high fields. The above results suggest for the cyclohexanone ring a twist-boat conformation in which the values of the dihedral angles $H_2C_2C_3H_3$, $H_3C_3C_4H_4$, and $H_3C_3C_4H_4$ approximate, respectively, 100, 30, and 150°. Of course, if the SePh substituent is still in a quasi-axial position, the bulky 3-substituent is in bisectional position.

Ketals obtained, starting from the mixture of isomers **1c** + **1t**, **2c** + **2t**, were also examined by ^{1}H NMR without further separation. Pertinent data are collected in Table III. In both cases, the two diastereoisomers cis and trans were identified. For the cis isomers **5c** and **6c** arguments identical with those developed above in the case of the cis ketones show that the six-membered ring adopts the chair conformation with the SePh in the axial position and the methyl or phenyl group in the equatorial one. As regards to the trans isomers, the signal of H_3 (the protons of the methyl group being irradiated for **5t**) exhibits two large coupling constants and a small one. H_2 is coupled to H_3 with a typical $^3J_{axax}$ constant, and no further couplings are detected for this proton by 2D NMR. The only W stereospecific coupling identified by 2D NMR correlates H_{4eq} and H_{6eq}. These results demonstrate that the shape of the cyclohexane ring is still that of a chair but with the 2- and 3-substituents both in equatorial position.



5t, 6t



5c, 6c

5, R = Me
6, R = Ph

Discussion

With one exception (**3t**) in all the 2,3-disubstituted cyclohexanones investigated in this work, the cyclohexanone ring adopts a chair conformation, and the conformer bearing the phenylseleno group in the axial position is the only observed one. Stabilization of a simple conformation reflects a highly favorable balance between several effects: electronic interaction between the carbonyl and the carbon–selenium bond and steric effects which might have opposite results whether the substituents lie in the equatorial or in the axial position. In the cis series (**1c**–**4c**) the occurrence of an equatorial 3-substituent contributes to the stabilization of such a form, this effect being more pronounced with increasing bulkiness of the substituent. Nevertheless, when the 3-substituent is a small group such as a methyl considering only steric effects, one would expect a conformational equilibrium shifted toward the conformer bearing the bulkier phenylseleno group in equatorial position. Since the reverse is observed, we may consider that the electronic effect must itself provide a stabilization: this could be explained by overlap of a π-orbital of the carbonyl group with the σ^*-orbital of the C–Se bond.[14] The importance of this electronic effect is best exemplified when considering the trans series where, surprisingly (**3t** excepted), the chair conformation is retained with both substituents in the axial location. Of course, when the size of the 3-substituent is tremendously increased (compound **3t**), the cyclohexanone ring can no longer accommodate a chair conformation due to strong steric interactions of 1–3 diaxial type if both substituents were in axial position or between proximate substituents in the trans diequatorial situation. A twist conformation is likely to allow the release of the major steric interactions

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(14) (a) A similar explanation is adopted by Trost for the preference of the benzenesulfonyl group for the axial orientation in cyclohexenes. See details in the following report: Trost, B. M.; Schmuff, N. R. *J. Am. Chem. Soc.* **1985**, *107*, 396. (b) After this work had been accepted for publication, a conformational study showing a similar preference of the ArSePh group for the axial position in the case of 2-(arylseleno)-1,3-dithianes appeared: Pinto, M.; Sandoval-Ramirez, J.; Dev Sharma, R. *Tetrahedron Lett* **1985**, *26*, 5235.

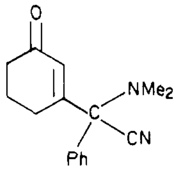
(15) (a) Duddeck, H.; Wagner, P.; Gegner, S. *Tetrahedron Lett.* **1985**, *26*, 1205. (b) Stevens, R. V.; Albizati, K. F. *J. Org. Chem.* **1985**, *50*, 632.

while preserving the stabilizing electronic interaction between the carbonyl and the SePh substituent. The conformational analysis gives an account of the fact that the thermodynamic equilibrium is in favor of the cis isomer for compounds **1** and **2**. This is not the case for **4t** which appears more stable than **4c**. The important role of the electronic effects was confirmed by the conformational changes occurring for trans isomers in which the carbonyl group has been protected; so, in **5t** and **6t** the SePh group moved to the equatorial position. Of course, 1,3-diaxial steric interactions would also contribute to destabilize the conformer bearing trans diaxial substituents. Comparison of the conformation of these trans ketals to that of various selenated cyclohexanes indicates a clear preference of the SePh group for the equatorial position in both series. However, no change occurs in the respective positions of the 2- and 3-substituents for cis isomers, the carbonyl function being protected or not and the 2-SePh remaining axial.

Some of our conclusions are in line with earlier results reported in the literature. A ^{1}H NMR study[16] on the unsubstituted 2-(phenylseleno)cyclohexanone indicated that only 32% of the more polar equatorial conformer is present in $CDCl_3$, this percentage increasing with the solvent polarity; however, such an influence of the solvent polarity did not take place in our case for **4t**. On the other hand, the SePh group is observed in the equatorial location in the **cis**-2-(phenylseleno)-4-*tert*-butyl[16] and 2-phenylseleno 4,4′-disubstituted cyclohexanones.[17,18] In both cases, the strong steric effects must counterbalance the electronic one.

Oxidation–Elimination. As expected, treatment by H_2O_2 of **3t** and **4t** which possess the proper stereochemistry gives respectively **13** and **14**, the selenoxide elimination occurring in a syn fashion.[2,3]

Moreover, Liotta has shown[2,6] that both epimers **1c** and **1t** led to 3-methyl-2-cyclohexenone (**15**), presuming that an epimerization at the α-carbon of the β-keto selenoxide intermediate should occur under the reaction conditions prior to or during the elimination reaction. We observed the same phenomenon since **2c**, **2t** and **4c**, **4t** mixtures were easily converted to **16** and to **14**, respectively.



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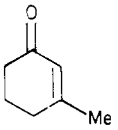

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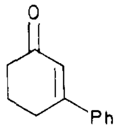
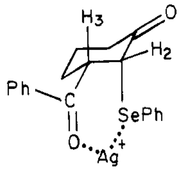


16

On the contrary, H_2O_2 treatment of **3c** does not give **13**. This can be explained by the great stability of the cis isomer, precluding its isomerization to the trans one.

On the other hand, we have observed that the deprotection of the masked benzoyl group of **3c** by aqueous $AgNO_3$ leads surprisingly to **14** and **4t** besides **4c** (see Scheme I). To explain the formation of **14** we propose a mechanism involving a trans diaxial nonoxidative elimination of the SePh group.[18] Nevertheless, such a process is more likely to take place in **4c** rather than directly in **3c** due to a stronger acidity of H_3 in the former and to the possible intervention of a six center electrophilic assistance of Ag^+. The above hypothesis is comforted by the fact that a mixture of **2c**/**2t** does not lead to **16** after the same treatment.



In conclusion, the ^{1}H NMR 2D study showed a clear preference of the 2-SePh group for the axial position in both cis and trans 2,3-disubstituted cyclohexanones, the cyclohexanone ring retaining the chair conformation (except in one case: the ring adopting a twist-boat when the size of the 3-substituent increases enormously). These observations can be interpreted by the intervention of a stabilizing electronic effect between the C—Se bond and the C=O function next to steric ones.

In the case of the trans ketals, the phenylseleno group moves to the equatorial position due to the lack of the stabilizing electronic effect. As expected, the 2-SePh group remains in axial position in the corresponding cis ones.

Experimental Section

NMR. The 1D spectra and the 2D SECSY or COSY spectra were recorded with a WM 500 Bruker spectrometer. ^{1}H 1D spectra were measured with $CDCl_3$ as solvent: quadrature detection, pulse width 4 μs (90° pulse is 11 μs), sweep width 4500 Hz, 64 K data points resulting to digital resolution of 0.14 Hz. For SECSY spectra and applied pulse sequence was (D_1 90° $t_{1/2}$ 90° $t_{1/2}$ acquisition with spectrum width and time domain 1500 Hz, 1 K in f_2, 400 Hz, 128 points in f_1, zero-filling in f_1, and sine bell resolution enhancement in both directions. For COSY spectra the applied pulse sequence was (D_1 90° t 45° acquisition). Quadrature detection was used in both dimensions. The data size of the time domain was 256 (f_1) × 1 K (f_2). The time domain matrix was expanded by zero-filling to 512 points in f_1. Sine bell resolution enhancement was used in both directions. Depending on the spectrum width (1280–1792 Hz) resolution achieved in the frequency domain was 3.5 ± 0.5 Hz. Chemical shifts determined by slices from 2D spectra are thus accurate to 0.01 ppm. If needed the COSYLR sequence (D_1 90° t_1D_2 45° D_2 acquisition) was used to favor cross peaks relating weakly coupled protons, and D_2 was set to 0.2 s. The assignments for overlapped cross peaks were supported by homonuclear decoupling.

Chemicals. All reactions concerning conjugate additions were run in a three-necked flask equipped with a mechanical stirrer, a thermometer, a rubber septum cap, and a nitrogen entrance. Tetrahydrofuran (THF) was freshly distilled from lithium aluminum hydride ($LiAlH_4$) under argon. Diethyl ether was also distilled from $LiAlH_4$. Pyridine was distilled over diphosphorus pentoxide (P_2O_5) and stored over KOH. Copper cyanide and copper iodide were purchased from Merck and used after having been oven-dried overnight. *n*-Butyllithium in hexane was purchased from Janssen Chemica or Ega-Chemie, and methyllithium in diethyl ether was purchased from Aldrich Chemical. Phenyllithium in ether was prepared according to the literature.[19]

Preparative thin-layer chromatography (TLC) was carried out on 20 × 20 cm glass plates coated with 1.5 mm of silica gel (Merck 60 F_{254}). Column chromatography was performed with silica gel 60 (Merck 70–230 mesh).

2-(Phenylseleno)-2-cyclohexenone (7). Following the experimental method described in the literature[20] we observed that in fact the expected product **8** is accompanied by the 2-bromo-2-cyclohexenone in about a 1/1 ratio. After separation of the two products by several successive column chromatographies on silica gel with Et_2O/hexane (10/90), we were able to isolate **7** (30%).

2-(Phenylseleno)-3-methylcyclohexanone (1) and 2-(Phenylseleno)-3-phenylcyclohexanone (2) (Method 1b).[7] A

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slurry of CuCN (5 mmol) in dry Et_2O (5 mL) was cooled to –78 °C, and RLi (MeLi or PhLi, 9.85 mmol) was added. The mixture was allowed to warm to 0 °C until it became a homogeneous light tan solution. The flask was then recooled to –78 °C, and **7** (2.5 mmol) in Et_2O was introduced. The reaction mixture was stirred to –50 °C for various times (15 min for R = Me, 1 h for R = Ph). Upon completion, the reaction was quenched at –78 °C with a 10% NH_4OH/90% saturated aqueous NH_4Cl solution followed by filtration under pressure, extractions in Et_2O, and drying on Na_2SO_4. Chromatography on silica gel with Et_2O/hexane (20/80) gave **1** (88%) and **2** (85%), respectively.

Compound **1** was also prepared as described above by using CuI in the place of CuCN and quenching with a NH_4Cl saturated solution[6] (method 1a) giving the same results. **1**: IR (film) ν_{max} 1700 cm^{-1}; MS, (*m/e*) for $C_{13}H_{16}OSe$ 264–270, 111. **2**: IR (film) ν_{max} 1700 cm^{-1}; MS, (*m/e*) for $C_{18}H_{18}OSe$ 326–332, 173.

***trans*-2-(Phenylseleno)-3-phenylcyclohexanone (2t).** 2-Cyclohexenone (5 mmol) in Et_2O is added at –78 °C to the $Ph_2Cu(CN)Li_2$ (10 mmol) prepared as above. After stirring for 1 h at –60 °C, PhSeBr (21.67 mmol)[5] in THF is added, and stirring is continued for 30 min. After extractions and usual workup, the ^1H NMR spectrum of the crude product shows the presence of **2t**. Column chromatography on silica gel with Et_2O/hexane (20/80) gives a mixture of **2c**/**2t** (60/40) (65%).

***cis*-2-(Phenylseleno)-3-[cyano(dimethylamino)phenylmethyl]cyclohexanone (3c).** *n*-BuLi (5.5 mmol) is added dropwise to a solution of dimethylaminophenylacetonitrile (5 mmol) in THF, and the mixture was cooled at –78 °C.[1] After stirring for 10–15 min. the α-enone **7** (5 mmol) in THF is added, and the reaction mixture is stirred for 40 min at –78 °C and then quenched with a saturated aqueous NH_4Cl solution. After usual workup and recrystallization from Et_2O, **3c** was obtained (65–70%): mp 111–112 °C; IR ($CDCl_3$) ν_{max} 1705 cm^{-1}. Anal. Calcd for $C_{22}H_{24}N_2OSe$: C, 64.23; H, 5.88; N, 6.81; O, 3.89. Found: C, 64.04; H, 5.87; N, 6.78; O, 3.62.

***trans*-2-(Phenylseleno)-3-[cyano(dimethylamino)phenylmethyl]cyclohexanone (3t).** To the carbanion **12** (5 mmol) prepared as above is added the 2-cyclohexenone (5 mmol) in THF at –78 °C. After stirring for 15 min, PhSeBr (5.77 mmol)[5] in THF is added, and stirring is continued for 40 min at –60 °C. Extractions, workup, and recrystallization for **3c** yielded **3t** (60–65%): mp 91–92 °C; IR ($CDCl_3$) ν_{max} 1705 cm^{-1}. Anal. Calcd for $C_{22}H_{24}N_2OSe$: C, 64.23; H, 5.88; N, 6.81; O, 3.89. Found: C, 64.22; H, 5.85; N, 7.08; O, 3.77.

2-(Phenylseleno)-3-benzoylcyclohexanone (4). Compound **3** (0.28 mmol) is stirred for 40 min at room temperature with a solution of 0.5 N aqueous $AgNO_3$ (0.5 mL), THF (1 mL), and Et_2O (0.5 mL). After usual workup, **4c** is obtained as a mixture of **4c**, **4t**, and **14** while crude **4t** is purified by preparative TLC Et_2O/hexane (55/45) to yield diketone **4t** (95%): IR (film) ν_{max} 1715, 1680 cm^{-1}; MS, (*m/e*) for $C_{19}H_{18}OSe$: 354–360, 201.

Ethylene ketals of 2-(phenylseleno)-3-methylcyclohexanone (5) and 2-(phenylseleno)-3-phenylcyclohexanone (6) were prepared according to the method described in the literature.[3] Preparative TLC with Et_2O/hexane (40/60) gave the ketal selenides (90%) **5**: MS, *m/e* for $C_{15}H_{20}O_2Se$ 308–314, 155. **6**: MS, *m/e* for $C_{20}H_{22}O_2Se$ 370–377, 217.

3-Methyl-2-cyclohexenone (15), 3-phenyl-2-cyclohexenone (16), 3-[cyano(dimethylamino)phenylmethyl]-2-cyclohexenone (13), and 3-benzoyl-2-cyclohexenone (14) were prepared after oxidation with H_2O_2 according to ref 3. **13**: mp 88–89 °C; IR ($CDCl_3$) ν_{max} 1660, 1610 cm^{-1}; ^1H NMR 90 MHz ($CDCl_3$) δ 7.7–7.35 (m, 5 H), 6.7 (d, 1 H) H_2, 2.7–1.5 (m, 6 H), 2.3 (s, 6 H) $N(CH_3)_2$. Anal. Calcd for $C_{16}H_{18}NO$: C, 75.56; H, 7.14; N, 11.01; O, 6.29. Found: C, 75.59; H, 7.22; N, 11.27; O, 6.31. **14**: IR (film) ν_{max} 1680–1660 cm^{-1}; ^1H NMR 90 MHz ($CDCl_3$) δ 7.65–7.15 (m, 5 H), 6.1 (m, 1 H) H_2, 2.6–1.9 (m, 6 H). **15**: IR (film) ν_{max} 1660, 1615 cm^{-1}; ^1H NMR 90 MHz ($CDCl_3$) δ 5.9 (s, 1 H) H_2, 2.45–1.8 (m, 6 H), 1.95 (s, 3 H) CH_3. **16**: mp 53–54 °C; IR ($CDCl_3$) ν_{max} 1660, 1610 cm^{-1}; ^1H NMR 90 MHz ($CDCl_3$) δ 7.7–7.35 (m, 5 H), 6.15 (m, 1 H) H_2, 2.95–2.2 (m, 6 H).

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Registry No. **1t**, 73824-98-3; **1c**, 73824-95-0; **2t**, 100514-91-8; **2c**, 100514-92-9; **3t**, 100514-94-1; **3c**, 100514-93-0; **4t**, 100514-95-2; **4c**, 100514-96-3; **5t**, 100514-97-4; **5c**, 100514-98-5; **6t**, 100514-99-6; **6c**, 100515-00-2; **7**, 57204-95-2; **8**, 930-68-7; **10**, 80473-70-7; **11**, 80473-66-1; **12**, 94517-02-9; **13**, 100515-01-3; **14**, 100515-02-4; **15**, 1193-18-6; **16**, 10345-87-6; PhSeBr, 34837-55-3.

Supplementary Material Available: 2D J correlated (COSY et SECSY) spectra of **1c**, **1t**, **2c**, and **2t** compounds showing long range W stereospecific couplings and proton assignments (4 pages). Ordering information is given on any current masthead page.

Empirical Force Field Calculations. 27.[1] A Study on the Conformations of the Simple Vicinal Diols

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The results of molecular mechanics calculations using the MM2 force field on 1,2-ethanediol, 1,2-propanediol, and the 2,3-butanediols are reported; results on 1,3-propanediol and 1,2-dimethoxyethane are included for comparison. The preference of the 1,2-diols for gauche O–C–C–O forms is evoked by the torsional energy function in the force field and is strengthened by electrostatic interactions between the hydroxyl groups at low dielectric constant. The effects of solvation are discussed. Calculations show that the gauche O–C–C–O forms of the diols are stabilized in protic media by specific solvation. A cyclic structure composed of the diol and a hydroxyl group of the solvent molecule is proposed. Energy increments for gauche Me/Me, Me/OH, and OH/OH interactions are calculated; those involving hydroxyl groups are dependent on the dielectric constant.

Dihydroxy compounds react with boric acid and borate in aqueous medium with formation of boric acid esters, borate monoesters, and borate diesters.[2,3] These were of importance in the configurational analysis of carbohydrates[2] and are applied in various separation techniques[4] and in the sequestration of cations by mixtures of borate and sugar acids.[5,6] An experimental study of the relative

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