Use of Phenylselenium Trichloride For Simple and Rapid Preparation of α-Phenylselanyl Aldehydes and Ketones

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α-Phenylselanyl aldehydes are prepared on a large scale by reaction of $PhSeCl_3$ with the corresponding aldehydes in acetonitrile without isolation of the intermediate dichloro adducts. This method has been applied to α-phenylselanyl ketones derived from alkyl aryl ketones, symmetrical aliphatic ketones and alkyl isopropyl ketones. *cis*-4-*tert*-Butyl-2-phenylselanylcyclohexanone was also prepared in the same way.

The growing interest for organoselenium compounds in synthesis[1-4] prompts the development of general and efficient methods for large scale preparation of the most important substrates such as α-phenylselanyl carbonyl compounds. Among them, α-phenylselanyl aldehydes and ketones are useful bifunctional synthons. They give access to polyunsaturated and polyfunctional molecules and are suited to natural product synthesis. In our laboratory, we have been particularly interested in reactions leading to allylic selenides,[5] phenylselanyl enoxysilanes,[6] α,β-unsaturated carboxylic acids,[7] α,α-bis(phenylselanyl) aldehydes[8] and ketones[9] as well as α-phenylselanylimines.[10] We have also studied the decomposition of dihalo adducts derived from α-phenylselanyl aldehydes giving access to α-bromo aldehydes and α-chloro-α-phenylselanyl aldehydes.[11] Engman and co-workers have shown that α-phenylselanyl ketones can be also chlorinated at the α-position through decomposition of the corresponding dichloro adducts.[12]

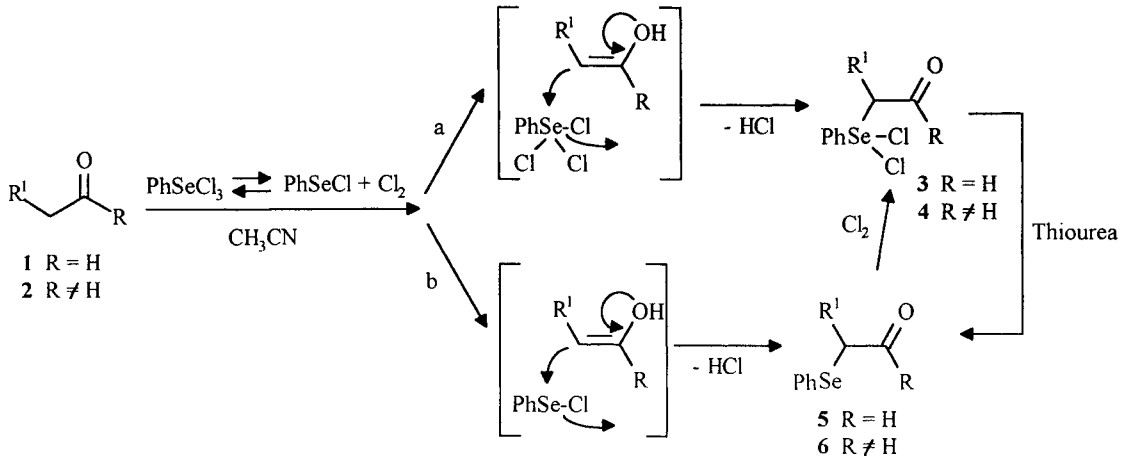
Most methods devised for the preparation of α-selanyl carbonyl compounds rely on derivatives such as enol acetate,[13] enol ethers,[14,15] silyl enol ethers[16] and enamines.[17] In these cases, benzeneselenenyl halides are used as electrophilic selenium reagents. Phenylselenenylation of enolates derived from ketones is also an efficient procedure.[18] A method only fitted to aldehydes involves the use of rather unstable morpholino benzeneselenenamide[9,19] or diethyl benzeneselenenamide.[20,21]

Starting from the carbonyl compounds, the electrophilic phenylselenium cation can be generated in situ from diphenyl diselenide through SeO_2[22] or electrochemical oxidation.[23] The simplest method, described by Sharpless,[24] takes advantage of the reaction of PhSeCl on the carbonyl compound in ethyl acetate at room temperature. This procedure is well adapted to alkyl aryl ketones and symmetrical dialkyl ketones but requires excess of reagent, presence of acid[24,25] or heat[26] for the aldehydes. The substrate is partially recovered and sometimes satisfying yields are reached only after long reaction times.

We have turned our attention to the method proposed by Engman which uses the easily prepared phenylselenium trichloride to synthesise the α-phenylselanyl ketones starting from the corresponding ketones.[27] He has also shown that these adducts can be reduced by a simple thiourea treatment in acetone.[28] Since the goal was, in general, the preparation of α,β-unsaturated compounds through syn-elimination reaction of the corresponding selenoxides, no efforts were made to isolate the intermediate α-phenylselanyl carbonyl compounds.[24,27,28]

We have found that $PhSeCl_3$ reacts with one equivalent of enolisable aldehydes **1** and ketones **2**, in acetonitrile without addition of acid, to give the corresponding adducts **3** and **4** which are then reduced with good yields into α-phenylselanyl aldehydes **5** and α-phenylselanyl ketones **6** (Scheme 1).

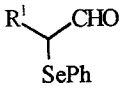
Isolation of dichloro adducts **3** derived from linear aldehydes **1** can be avoided by directly adding thiourea to the reaction medium at room temperature. α-Phenylselanyl aldehydes **5a–i** have been prepared in good yields in less than two hours on a 50 mmoles scale (Table 1). A simple purification by silica gel chromatography was



Scheme 1

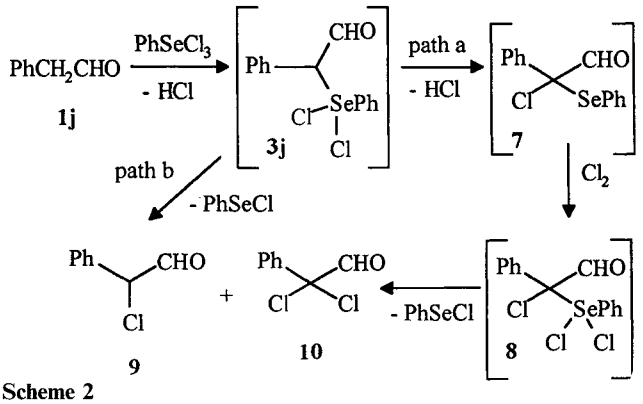
carried out to eliminate the diphenyl diselenide. When the reduction of the dichloro adduct was performed in acetone, as for ketones,[28] phenylselanylpropanone **6a** was found with the α-phenylselanyl aldehyde **5**.

Table 1. Preparation of α-Phenylselanyl Aldehydes **5**



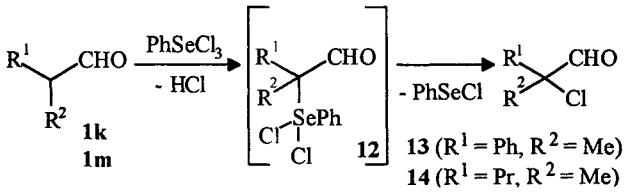
Entry	Compound	R^1	Time (min) for adduct formation	Yield (%)
1	**5a**	H	30	85
2	**5b**	Me	10	80
3	**5c**	Et	10	88
4	**5d**	Bu	7	91
5	**5e**	*i*-Pr	40	75
6	**5f**	*t*-Bu	70	80
7	**5g**	$PhCH_2$	10	70
8	**5h**	PhCH(Me)	60	70
9	**5i**	$c\text{-}C_6H_{13}CH_2$	30	68

The reaction did not succeed with phenylacetaldehyde and α-branched aldehydes. In the first case the unstable dichloro adduct **3j** gave the α-chloro α-phenylselanyl aldehyde **7** as already observed for the chlorination of α-phenylselanyl aldehydes.[11] The corresponding adduct **8** decomposes immediately into α,α-dicholorophenylacetaldehyde **(10)** recovered as a mixture with α-chlorophenylacetaldehyde **(9)** which results from the substitution of the selenonium group by the chloride ion[11] (Scheme 2). When the reaction was achieved on 2-phenylpropanal **(1k)** or 2-methylpentanal **(1m)**, only the substitution of the selenonium group occurred and α-chloro aldehydes **13** and **14** were formed respectively (Scheme 3). The instability of such adducts constitutes a limitation in the aldehyde series.



Scheme 2

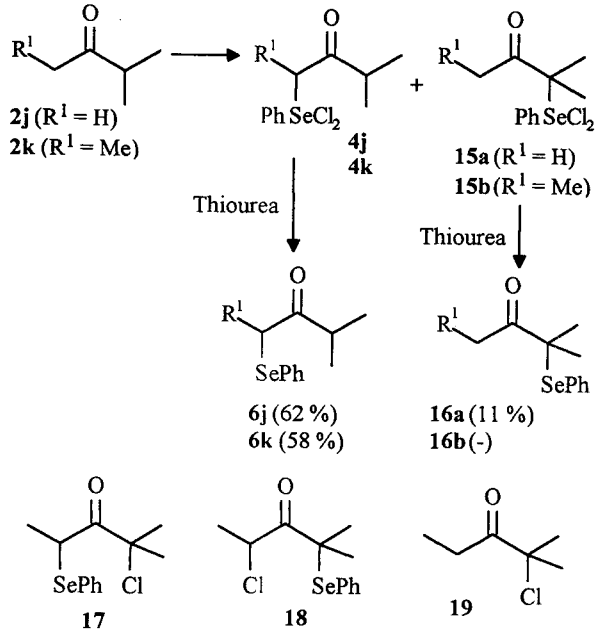
Dichloro adducts **4** derived from ketones **2** are crystalline compounds except those derived from ketones **2h**, **2i** and **2j** which are oily mixtures of isomers. The separation of these dichloro derivatives from the media allows elimination of byproducts such as α-chloro ketones which appear during the chloroselenenylation of some ketones (for example **2j** and **2k**, Scheme 4). The α-selanyl ketones **6** are thus recovered without any further purification.



Scheme 3

The reaction occurred instantaneously for acetone and pentan-3-one (Table 2, entries 1 and 2). Thiourea reduction then led with good yields to α-phenylselanyl ketones such as **6a–g**, derived from symmetrical ketones, alkyl aryl ketones and from ketones of general formula $RCOCH_2R^1$ (R = tertiary alkyl group) (Table 2).

$PhSeCl_3$ treatment of 3-methylbutanone **2j** in acetonitrile at −30 °C gave an oily mixture of adducts **4j** and **15a** (Scheme 4). Triturating this mixture with petroleum ether at −30 °C led to selective extraction of most of the minor adduct **15a**. The silica gel chromatography of the oily residue obtained after reduction (**6j**/**16a**: 85/15) afforded pure α-phenylselanyl ketone **6j** (yield: 62%) (entry 10, Table 2). Similarly, the petroleum ether solution led after reduction and purification to the 3-methyl-3-phenylselanylbutanone **16a** (11%).



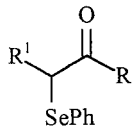
Scheme 4

After reduction of the isolated adduct **4k**, 2-methylpentan-3-one provided 4-methyl 2-phenylselenopentan-3-one **6k** in moderate yield when the selenenylation was achieved at the same temperature (entry 11, Table 2). Selenenylation of the isopropyl group occurs competitively. The corresponding adduct **15b** is not stable enough to be isolated and decomposes partially. A second reaction on the methylene group probably then occurs. The presence of 2-chloro-2-methylpentan-3-one **19** was not detected in the mixture obtained after reduction of the mother liquor but small amounts of ketones **6k**, **17** and

18 were characterized by GC/MS. Sometimes, traces of the α-selanyl ketone **16b** were also observed.

As previously reported,[27] formation and precipitation of adducts **4** was favoured by addition of a small amount of sulfuryl chloride. In our work, and as already mentioned, only one equivalent of $PhSeCl_3$ was added to the ketones.

Table 2. Preparation of α-Phenylselanyl Ketones **6**

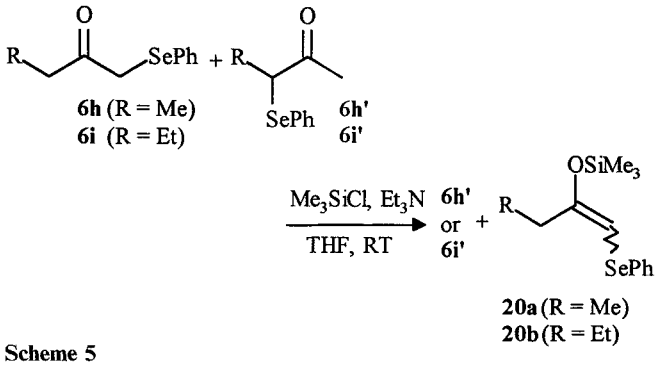


Entry	Compound	R^1	R	T (0°C)	Time (min) for adduct formation	Yield (%)
1	**6a**	H	Me	+20	2	79
2	**6b**	Me	Et	+20	2	85
3	**6c**	H	*t*-Bu	0	10	61
4	**6d**	H	Ph	0	30	72
5	**6e**	Me	Ph	0	30	70
6	**6f**	$(CH_2)_3$		0	20	73
7	**6g**	$(CH_2)_4$		0	5	76
8	**6h**	H	Et	−30	480	86[a]
	6h'	Me	Me			
9	**6i**	H	Pr	−30	360	83[a]
	6i'	Et	Me			
10	**6j**	H	*i*-Pr	−30	180	62[b]
11	**6k**	Me	*i*-Pr	−30	390	58
12	**6l**	$CH_2CH(t\text{-Bu})(CH_2)_2$		+5	6	60 (*cis*)

[a] Mixture of regioisomers: **6h/6h'**: 10/90. **6i/6i'**: 30/70.
[b] Separated from the isomeric α-phenylselanyl ketone **16a** (11%).

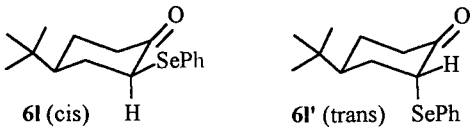
α-Selenenylation of butanone was especially studied. $PhSeCl_3$ and PhSeCl were used under various experimental conditions (Table 3). We observed that the reaction occurs faster in acetonitrile than in diethyl ether at room temperature (entries 2 and 6). The regioselectivities were similar for the two reagents ($PhSeCl_3$, entry 2 ; **6h/6h'** : 21/79 ; PhSeCl, entry 9, **6h/6h'** : 20/80) while the formation of **6h'** was favoured (10/90) at low temperature (entry 5). In diethyl ether,[27] the two isomers were formed in similar amounts (entry 6).

The experimental conditions leading to the best regioselectivity were applied to the selenenylation of pentan-2-one. α-Phenylselanyl ketones **6i** and **6i'** were formed in a 30/70 ratio at −30°C (Table 2, entry 9). This poor regioselectivity associated with a slow rate of reaction prevents the use of this method for the preparation of 3-phenylselanylpentan-2-one **6i'**. Resorting to the experimental procedure used previously[6] we were able to prepare silyl enol ether **20a** corresponding to 1-phenylselenobutan-2-one **6h** from a mixture **6h/6h'** (57/43) obtained by reduction of the dichloro adducts **4h/4h'** prepared in diethyl ether[27,28] or by selenenylation of the corresponding enolates[18] (**6h/6h'** : 80/20) (Scheme 5). After chromatography, the ketone **6h'** was always contaminated with ketone **6h**. The same transformation was achieved on a mixture (80/20) of isomeric ketones **6i/6i'** formed according to the same procedure. The silyl enol ether **20b** was also prepared in a pure form (Scheme 5).



Scheme 5

α-Selenenylation of 4-*tert*-butylcyclohexanone by the Sharpless method[24] (PhSeCl, EtOAc, r.t.) gave in our hands a mixture of *cis* and *trans* isomers **6l**, **6l'** (ratio : 35/65) in 77% yield. We have observed that the *trans* (axial) isomer **6l'** is unstable and decomposes slowly even at low temperature with formation of diphenyl diselenide. Engman[27] reports a 9/1 ratio of dichloro adducts **4l** and **4l'** when the reaction with $PhSeCl_3$ was achieved in diethyl ether. The major *cis*-adduct **4l** was isolated in pure form after crystallization and the minor *trans*-adduct **4l'** after sulfuryl chloride precipitation from the mother liquor. Phenylselanyl ketones **6l** and **6l'** have never been prepared before.[27] We have carried out the reaction in an acetonitrile-diethyl ether mixture and hexane was added at +5°C to improve the precipitation of the adducts which have been obtained in 66% yield and reduced to α-selanyl ketones **6l** and **6l'** in a 95/5 ratio. The crystalline *cis* isomer **6l** was isolated in a 60% overall yield after purification (Table 2, entry 12).



Two routes can be proposed for the formation of dichloro adducts **3** and **4**[27] (Scheme 1). It is difficult to predict which is the effective pathway but three observations can be made : i) The dark red color of the solution after addition of $PhSeCl_3$ is probably due to the presence of PhSeCl as a consequence of an equilibrium. ii) We have verified that addition of chlorine to **5** or **6** is a very fast process. iii) α-Phenylselenenylation of butanone using $PhSeCl_3$ or PhSeCl in the same solvent and at the same temperature (Table 3, entries 2 and 9) led to comparable regioisomer ratios (**6h/6h'** : 21/79 and 20/80).

In conclusion, we describe a rapid, simple and efficient procedure for the multigram-scale synthesis of α-phenylselanyl aldehydes from linear aliphatic aldehydes RCH_2CHO and α-phenylselanyl ketones from symmetrical ketones (RCH_2COCH_2R), alkyl aryl ketones ($ArCOCH_2R$) and nonsymmetrical ketones with at least one linear alkyl group ($R'COCH_2R$). 1-Phenylselanylalkan-2-ones, derived from methyl ketones (RCH_2COCH_3) and obtained as a mixture of the two regioisomeric α-phenylselanyl ketones, can be selectively transformed into β-phenylselanylenoxysilanes.

Table 3. α-Phenylselenenylation of Butanone

Entry	Reagent	Solvent	T (0 °C)	Time(min) for adduct formation	Yield (%)	**6h**/**6h'**	
1	$PhSeCl_3$	MeCN	+40	3	80	27	73
2	$PhSeCl_3$	MeCN	+20	10	82	21	79
3	$PhSeCl_3$	MeCN	0	20	85	16	84
4	$PhSeCl_3$	MeCN	−15	120	78	12	88
5	$PhSeCl_3$	MeCN	−30	480	86	10	90
6	$PhSeCl_3$	Et_2O	+20	30	58	50	50
7	PhSeCl	Et_2O	+20	180	67	33	66
8	PhSeCl	EtOAc	+20	40	83	29	71
9	PhSeCl	MeCN	+20	10	80	20	80

All the solvents, aldehydes and ketones were distilled prior to use. Flash chromatography was carried out on silica gel. ^1H and ^{13}C NMR spectra were recorded on a Bruker A.C. 200 operating at 200 MHz for ^1H in $CDCl_3$ solution. α-Phenylselanyl aldehydes **5** and α-phenylselanyl ketones **6** were all known compounds, except aldehydes **5f**, **5g**, **5h**, **5i** and ketones **6k** and **16a**, which gave C, H analysis ± 0,4 %. Petroleum ether, bp fraction 45–50 °C, was used.

Preparation of $PhSeCl_3$:

a) From selenophenol : SO_2Cl_2 (14.85 g, 0.11 mol) dissolved in $CHCl_3$ (40 mL) was added dropwise to a stirred solution of selenophenol (7.85 g, 0.05 mol) in a petroleum ether/$CHCl_3$ mixture 80/20 (200 mL) protected from moisture. The stirring was continued for 30 min and the pale yellow solid was rapidly filtered, washed with light petroleum ether (2 × 50 mL) and stored in the refrigerator protected from moisture (91 % yield).

b) From Ph_2Se_2 : SO_2Cl_2 (14.85 g, 110 mmol) dissolved in $CHCl_3$ (30 mL) was added dropwise to a solution of Ph_2Se_2 (11.5 g, 36.7 mmol) in the same mixture of solvents (150 mL). $PhSeCl_3$ was obtained with a similar yield.

c) From benzeneselenenyl chloride : the same experimental procedure was followed. One equivalent of SO_2Cl_2 was added.

α-Phenylselenenylation of Aldehydes 1:

$PhSeCl_3$ (13.12 g, 50 mmol) was added in portions to a stirred solution of aldehyde (50 mmol) in MeCN (40 mL) in a flask protected from moisture and cooled with an ice-bath. $PhSeCl_3$ dissolved progressively and the solution became dark red. The mixture was then stirred at r.t. until disappearance of the red color. When the solution turned light yellow (time indicated in Table 1), thiourea (3.81 g, 50 mmol) dissolved in H_2O (20 mL) was added. Petroleum ether (40 mL) was then introduced. The organic phase was separated, washed with water (2 × 30 mL), dried and concentrated under reduced pressure. The oily α-phenylselanyl aldehydes **5** were purified by silica gel chromatography. Petroleum ether elution eliminates Ph_2Se_2 and the aldehydes **5** were then isolated from a petroleum ether-$CHCl_3$ (80/20) mixture. Aldehydes **5g** and **5i** were also purified by Kugelrohr distillation.

Phenylselanylacetaldehyde (**5a**):[15]
Yield: 85 %.

^1H NMR: δ = 9.48 (1 H, t, J = 4.0 Hz), 7.55–7.22 (5 H, m), 3.50 (2 H, d, J = 4.0 Hz).

^{13}C NMR: δ = 192.2, 132.8, 128.9, 127.6, 127.1, 36.1.

2-Phenylselanylpropanal (**5b**):[8]
Yield: 80 %.

^1H NMR: δ = 9.43 (1 H, d, J = 2.8 Hz), 7.15–7.55 (5 H, m), 3.70 (1 H, m, J = 2.8, 7.0 Hz), 1.43 (3 H, d, J = 7.0 Hz).

^{13}C NMR: δ = 193.1, 135.8, 128.9, 128.6, 125.4, 46.2, 13.2.

2-Phenylselanylbutanal (**5c**):[8]
Yield: 88 %.

^1H NMR: δ = 9.40 (1 H, d, J = 3.0 Hz), 7.50–7.20 (5 H, m), 3.50 (1 H, dt, J = 7.3, 3.0 Hz), 1.75 (1 H, m), 1.04 (3 H, t, J = 7.3 Hz).

^{13}C NMR: δ = 192.8, 135.6, 129.1, 128.6, 125.3, 54.5, 20.9, 12.4.

2-Phenylselanylhexanal (**5d**):[29]
Yield: 91 %.

^1H NMR: δ = 9.35 (1 H, d, J = 3.7 Hz), 7.60–7.15 (5 H, m), 3.57 (1 H, dt, J = 7.2, 3.7 Hz), 1.90–1.30 (6 H, m), 0.89 (3 H, t, J = 7.2 Hz).

^{13}C NMR: δ = 192.9, 135.7, 128.2, 127.6, 125.9, 52.8, 30.0, 27.2, 22.3, 13.8.

3-Methyl-2-phenylselanylbutanal (**5e**):[6]
Yield: 75 %.

^1H NMR: δ = 9.34 (1 H, d, J = 5.0 Hz), 7.55–7.20 (5 H, m), 3.35 (1 H, dd, J = 8.9, 5.0 Hz), 2.05 (1 H, m), 1.16 (3 H, d, J = 6.7 Hz), 1.05 (3 H, d, J = 6.7 Hz).

^{13}C NMR: δ = 192.2, 135.1, 129.1, 128.4, 61.6, 26.8, 21.0, 20.9.

3,3-Dimethyl-2-phenylselanylbutanal (**5f**):
Yield: 80 %.

^1H NMR: δ = 9.47 (1 H, d, J = 6.7 Hz), 7.50–7.15 (5 H, m), 3.33 (1 H, d, J = 6.7 Hz), 1.16 (9 H, s).

^{13}C NMR: δ = 192.4, 134.7, 129.3, 128.2, 127.7, 66.9, 33.1, 28.3.

3-Phenyl-2-phenylselanylpropanal (**5g**):
Yield: 70 %.

^1H NMR: δ = 9.46 (1 H, d, J = 3.0 Hz), 7.50–7.10 (5 H, m), 3.85 (1 H, m), 3.25 (1 H, dd, J = 15.0, 8.3 Hz), 3.00 (1 H, dd, J = 15.0, 6.6 Hz).

^{13}C NMR: δ = 191.7, 137.9, 135.7, 129.0, 128.7, 128.3, 126.5, 125.4, 53.1, 33.7.

3-Phenyl-2-phenylselanylbutanal (**5h**):
Yield: 70 % (diast. mixture 1/1).

^1H NMR: δ = 9.41 (0.5 H, d, J = 5.0 Hz), 9.21 (0.5 H, d, J = 5.0 Hz), 7.55–7.10 (10 H, m), 3.82 (1 H, m), 3.16 (1 H, m), 1.55 (1.5 H, t, J = 7.0 Hz), 1.39 (1.5 H, d, J = 7.0 Hz).

^{13}C NMR: δ = 191.5, 191.0, 135.2, 129.0, 128.9, 128.4, 128.3, 127.5, 127.1, 126.8, 126.3, 60.3, 59.6, 38.4, 38.0, 21.4, 20.5.

3-Cyclohexyl-2-phenylselanylpropanal (**5i**):
Yield: 68 %.

^1H NMR: δ = 9.31 (1 H, d, J = 4.2 Hz), 7.55–7.20 (5 H, m), 3.70 (1 H, m), 1.80–0.75 (13 H, m).

^{13}C NMR: δ = 192.8, 135.6, 129.2, 128.7, 126.1, 50.7, 36.1, 34.9, 33.0, 26.3, 26.0.

Reaction of $PhSeCl_3$ with Phenylacetaldehyde:

The reaction of $PhSeCl_3$ with phenylacetaldehyde in MeCN at r.t. led to an oily mixture of α-chlorophenylacetaldehyde **9**[30] and α,α-dichlorophenylacetaldehyde **10** as demonstrated by GC/MS and ^1H NMR experiments.

α-Chlorophenylacetaldehyde (**9**):

^1H NMR: δ = 9.50 (1 H, d, J = 2.6 Hz), 7.60–7.25 (5 H, m), 5.20 (1 H, d, J = 2.6 Hz).

α,α-Dichlorophenylacetaldehyde (**10**):

^1H NMR: δ = 9.25 (1 H, s), 7.60–7.25 (5 H, m).

Reaction of $PhSeCl_3$ with 2-Phenylpropanal:

Following the same experimental conditions, impure 2-chloro-2-phenylpropanal **13**[30] was obtained.

13:

^1H NMR: δ = 9.44 (1 H, s), 7.70–7.20 (5 H, m), 1.97 (3 H, s).

Reaction of $PhSeCl_3$ with 2-Methylpentanal:

As in the two preceding reactions, an oily mixture was recovered among which 2-chloro-2-methylpentanal **14**[31] was the major compound identified. In all cases, a minor unidentified contaminant was present.

14:

^{1}H NMR: δ = 9.40 (1 H, s), 1.80–1.40 (4 H, m), 1.56 (3 H, s), 0.93 (3 H, t, J = 7.3 Hz).

α-Phenylselenenylation of Ketones (except 21):

$PhSeCl_3$ (13.12 g, 50 mmol) was added to a stirred solution of the ketone considered (60 mmol) in MeCN (40 mL) at the temperature indicated in Table 2. As for aldehydes, the colour faded progressively and three drops of SO_2Cl_2 were added after the time indicated in Table 2. The solvent was evaporated under reduced pressure at r.t. and petroleum ether was added (100 mL). Except for **4j**, which contains **15a** corresponding to ketone **16a**, the crystallized dichloro adducts were collected and quickly treated with thiourea (3.9 g, 50 mmol) in acetone (150 mL). H_2O (100 mL) and CH_2Cl_2 (150 mL) were then added. The organic solution was washed with H_2O (2 × 30 mL), dried and evaporated. Purification of the α-phenylselanyl ketones **6** was carried out as for aldehydes **5**. The ketones **6d**, **6e**, **6g** were recrystallized in hexane.

Phenylselanylpropanone **(6a)**:[32]

Oil. Yield: 79%.

^{1}H NMR: δ = 7.55–7.20 (5 H, m), 3.57 (2 H, s), 2.24 (3 H, s).

^{13}C NMR: δ = 202.9, 134.7, 129.2, 128.7, 127.7, 36.4, 27.7.

2-Phenylselanylpentan-3-one **(6b)**:[32]

Oil. Yield: 85%.

^{1}H NMR: δ = 7.55–7.20 (5 H, m), 3.78 (1 H, q, J = 7.0 Hz), 2.90–2.65 (1 H, m), 2.60–2.35 (1 H, m), 1.45 (3 H, d, J = 7.0 Hz), 1.05 (3 H, t, J = 7.3 Hz).

^{13}C NMR: δ = 206.6, 135.4, 128.7, 128.2, 126.8, 44.6, 32.6, 16.2, 8.1.

3,3-Dimethyl-1-phenylselanylbutan-2-one **(6c)**:[28]

Oil. Yield: 61%.

^{1}H NMR: δ = 7.60–7.20 (5 H, m), 3.86 (2 H, s), 1.17 (9 H, s).

^{13}C NMR: δ = 210.5, 135.0, 133.0, 129.0, 127.2, 44.1, 32.5, 26.7.

1-Phenyl-2-phenylselanylethanone **(6d)**:[16,32]

Mp = 31–32 °C. Lit.[16] = 31.5–33 °C. Yield: 72%.

^{1}H NMR: δ = 7.88–7.83 (2 H, m), 7.56–7.41 (6 H, m), 7.27–7.22 (2 H, m), 4.15 (2 H, s).

^{13}C NMR: δ = 194.9, 135.5, 135.2, 133.8, 133.1, 129.1, 128.7, 128.6, 128.5, 127.9, 47.5, 32.6.

1-Phenyl-2-phenylselanylpropanone **(6e)**:[16,28]

Mp = 33–34 °C. Lit.[16] = 34–35 °C. Yield: 70%.

^{1}H NMR: δ = 7.85–7.82 (2 H, m), 7.60–7.40 (8 H, m), 4.67 (1 H, q, J = 6.9 Hz), 1.62 (3 H, d, J = 6.9 Hz).

^{13}C NMR: δ = 196.1, 136.6, 135.8, 132.8, 129.0, 128.9, 126.9, 39.7, 17.3.

2-Phenylselanylcyclopentanone **(6f)**:[32]

Oil. Yield: 73%.

^{1}H NMR: δ = 7.60–7.20 (5 H, m), 3.72 (1 H, m), 2.40–1.85 (6 H, m).

^{13}C NMR: δ = 214.1, 134.9, 129.2, 128.8, 127.5, 46.1, 44.1, 35.9, 26.7.

2-Phenylselanylcyclohexanone **(6g)**:[16,32]

Mp = 53–54 °C. Lit.[16] = 53–54 °C. Yield: 76%.

^{1}H NMR: δ = 7.55–7.20 (5 H, m), 3.95–3.80 (1 H, m), 3.05–2.85 (1 H, m), 2.40–1.60 (7 H, m).

^{13}C NMR: δ = 207.4, 134.2, 128.9, 128.5, 127.7, 51.3, 38.3, 33.7, 26.6, 22.6.

1-Phenylselanylbutan-2-one **(6h)**[33] *and 3-Phenylselanylbutan-2-one* **(6h')**:[34]

Obtained as an oily mixture **(6h/h'** : 10/90) at −30 °C in 86% yield. Compound **6h'** was previously prepared in pure form by bromine substitution of 3-bromobutan-2-one with thallium benzeneselenolate.[34]

6h:

^{1}H NMR: δ = 7.45–7.05 (5 H, m), 3.47 (2 H, s), 2.45 (2 H, q, J = 7.3 Hz), 0.91 (3 H, t, J = 7.3 Hz).

^{13}C NMR: δ = 205.3, 132.2, 128.5, 127.0, 126.4, 34.9, 33.1, 7.4.

6h':

^{1}H NMR: δ = 7.55–7.20 (5 H, m), 3.78 (1 H, q, J = 7.0 Hz), 2.28 (3 H, s), 1.45 (3 H, d, J = 7.0 Hz).

1-Phenylselanylpentan-2-one **(6i)**[28] *and 3-Phenylselanylpentan-2-one* **(6i')**:[6]

Obtained as an oily mixture **6i/6i'** = 30/70) at −30 °C in 83% yield.

6i:

^{1}H NMR: δ = 7.55–7.15 (5 H, m), 3.56 (2 H, s), 2.52 (2 H, t, J = 7.3 Hz), 1.70–1.50 (2 H, m), 0.86 (3 H, t, J = 7.3 Hz).

^{13}C NMR: δ = 205.3, 132.2, 128.5, 127.0, 126.4, 34.9, 33.1.

6i':

^{1}H NMR: δ = 7.60–7.20 (5 H, m), 3.55 (1 H, t, J = 7.6 Hz), 2.26 (3 H, s), 1.95–1.60 (2 H, m), 0.98 (3 H, t, J = 7.3 Hz).

^{13}C NMR: δ = 203.5, 135.1, 128.7, 128.2, 126.8, 53.8, 27.1, 23.2, 12.3.

3-Methyl-1-phenylselanylbutan-2-one **(6j)**:[15,32]

According to the general procedure, the reaction of $PhSeCl_3$ on 3-methylbutanone was performed in MeCN at −30 °C. The solution was then stirred for 3 h and concentrated. The oily mixture of dichloro adducts **4j, 4j'** was triturated in petroleum ether at −30 °C. The residual oil was treated with thiourea. The ketone **6j** containing small amounts of the isomeric ketone **16a** was purified by chromatography on silica gel (elution petroleum ether-CH_2Cl_2 90/10).

Oil. Yield: 62%.

^{1}H NMR: δ = 7.53–7.45 (2 H, m), 7.29–7.24 (3 H, m), 3.65 (2 H, s), 2.88 (1 H, h, J = 6.9 Hz), 1.07 (6 H, d, J = 6.9 Hz).

^{13}C NMR: δ = 208.8, 137.2, 133.0, 129.0, 127.5, 36.5, 34.4, 18.4.

3-Methyl-3-phenylselanylbutan-2-one **(16a)**:

The petroleum ether solution obtained after trituration contains the dichloro compound **4j'** which was reduced with thiourea. The chromatographic purification of ketone **16a** contained in the oily residue was achieved as for ketone **6j**.

^{1}H NMR: δ = 7.54–7.21 (5 H, m), 2.36 (3 H, s), 1.50 (6 H, s).

^{13}C NMR: δ = 208.0, 137.1, 129.1, 128.8, 53.1, 24.8, 24.4.

4-Methyl-2-phenylselanylpentan-3-one **(6k)**:

The reaction was carried out at −30 °C and the adduct **4k** was collected after addition of petroleum ether at the same temperature. The reduction was achieved as previously described.

Oil. Yield: 65%.

^{1}H NMR: δ = 7.55–7.20 (5 H, m), 3.89 (1 H, q, J = 7.0 Hz), 2.97 (1 H, m, J = 6.8 Hz), 1.43 (3 H, d, J = 7.0 Hz), 1.12 (3 H, d, J = 6.8 Hz), 1.06 (3 H, d, J = 6.8 Hz).

^{13}C NMR: δ = 208.8, 135.7, 128.8, 128.4, 126.7, 43.6, 37.9, 19.6, 18.2, 16.5.

The mother liquor was also treated with thiourea after addition of water. The organic phase was dried and evaporated under reduced pressure. GC/MS analysis of the residual oil has shown the presence of several compounds. Among them, 4-methyl-2-phenylselanylpentan-3-one **(6k)**, 2-chloro-2-methyl-4-phenylselanylpentan-3-one **(17)**, 4-chloro-2-methyl-2-phenylselanylpentan-3-one **(18)** were characterized. Traces of ketone **16b** were also observed in some cases.

β-Phenylselanylenoxysilanes 20a and 20b:

The silyl enol ethers **20** were selectively synthesised in fair yields from mixtures of α-phenylselanyl ketones **6h/6h'** (80/20) and **6i/6i'** (80/20), obtained according to a literature procedure[18] and by the procedure previously used for the preparation of analogous β-phenylselanylenoxysilanes, respectively.[6] (Me_3SiCl, Et_3N, THF, r.t.). The solution was stirred 30 h for **6h/6h'** and 72 h for **6i/6i'**. The formation of the isomeric enoxysilanes corresponding to **6h'** and **6i'** was practically avoided. Flash chromatography on silica gel with petroleum ether elution provided enoxysilanes **20** of analytical purity. In each case, the major geometric isomer can be isolated. The stereochemistry of these compounds is under investigation. Elution with a petroleum ether/CH_2Cl_2 mixture (90/10) gave respectively the α-phenylselanyl ketones **6h'** and **6i'** which could be

isolated in pure form. Small amounts of the regioisomeric ketones were always present.

1-Phenylselanyl 2-trimethylsilyloxybut-1-ene **(20a)**:

Oil, yield 49% (2/1 mixture of geometric isomers). (Major isomer) ^{1}H NMR: δ = 7.47–7.40 (2H, m), 7.28–7.17 (3H, m), 5.43 (1H, s), 2.20 (2H, q, J = 7.4 Hz), 1.10 (3H, t, J = 7.4 Hz), 0.23 (9H, s).

^{13}C NMR: δ = 158.7, 131.9, 130.6, 128.7, 125.9, 94.3, 29.8, 11.4, 0.5.

The minor geometric isomer was not isolated in pure form but was characterized by ^{1}H NMR and GC/MS analysis of the crude product.

1-Phenylselanyl 2-trimethylsilyloxypent-1-ene **(20b)**:

Oil, yield 72% (7/3 mixture of geometric isomers). (Major isomer) ^{1}H NMR: δ = 7.46–7.41 (2H, m), 7.26–7.19 (3H, m), 5.43 (1H, s), 2.15 (2H, t, J = 7.4 Hz), 1.65–1.45 (2H, m), 0.93 (3H, t, J = 7.4 Hz). 0.24 (9H, s).

^{13}C NMR: δ = 155.3, 132.0, 130.6, 129.0, 127.5, 125.9, 95.1, 38.8, 19.9, 13.5, 0.5. The minor geometric isomer was also characterized by ^{1}H NMR and GC/MS analysis.

***cis*-4-*tert*-Butyl 2-phenylselanylcyclohexanone (6l):**

4-*tert*-Butylcyclohexanone (3.73 g, 24.2 mmol) was quickly added to a stirred suspension of $PhSeCl_3$ (5.23 g, 20 mmol) in an MeCN-Et_2O 1/4 mixture (40 mL) at +5°C. The red colour faded in one minute and turned light yellow. Hexane (100 mL) was added under stirring and a white solid precipitated after some minutes. It was collected, washed with hexane (2 × 10 mL) then with Et_2O (2 × 5 mL). The *cis*/*trans* mixture of adducts **4l** and **4l'** was isolated in 66% yield.

These adducts (3.80 g, 10 mmol) were introduced in one portion to a stirred solution of thiourea (0.76 g, 10 mmol) in acetone at r.t. H_2O (30 mL) and CH_2Cl_2 (30 mL) were then added. The organic phase was separated and the aqueous solution extracted with CH_2Cl_2 (2 × 15 mL). The organic phases were dried and evaporated at r.t. The ^{1}H NMR spectrum of the crude product indicated a 95/5 ratio of isomers **6l**/**6l'**. The oil crystallized in the refrigerator. *cis*-4-*tert*-Butyl 2-phenylselanylcyclohexanone **6l** was obtained in a pure form after crystallization in hexane (mp = 65°C, yield: 60%). The Sharpless method[24] led to a 35/65 ratio but the *trans* isomer **6l'** was found very unstable even in the refrigerator.

^{1}H NMR: δ = 7.10–7.70 (5H, m), 4.07 (1H, dd, J = 12.5, 6.0 Hz, H_2 axial), 2.65–2.53 (1H, m), 2.48–2.25 (2H, m), 2.15–2.0 (1H, m), 1.70–1.45 (3H, m), 0.82 (9H, s).

^{13}C NMR: δ = 207.8, 134.8, 128.8, 128.2, 127.6, 52.5, 47.6, 40.6, 36.7, 32.4, 27.6, 27.3.

trans-4-tert-Butyl 2-phenylselanylcyclohexanone **(6l')**:

^{1}H NMR: δ = 7.10–7.70 (5H, m), 3.84 (1H, m, H_2 equatorial), 3.75–3.05 (1H, m).

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