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Selenium and Tellurium Tetrachlorides as Reagents for the Conversion of Alcohols to Alkyl Chlorides and Tellurium Tetrachloride as a Lewis Acid Catalyst for Aromatic Alkylation

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Selenium tetrachloride($SeCl_4$) reacts smoothly with alcohols in various nonpolar solvents to give the corresponding alkyl chlorides in 44—97% yield. Similar reaction also proceeds with tellurium tetrachloride ($TeCl_4$), while the treatment of benzyl, 1-phenylethyl, and *t*-butyl alcohols with $TeCl_4$ in aromatic solvents results in a high yield formation of alkylated aromatics instead of alkyl chlorides. Such Friedel-Crafts aromatic alkylation hardly occurs in the $SeCl_4$ case. The chlorinating species is not chlorine which might be evolved by dissociation of $SeCl_4$ or $TeCl_4$, but the metal chloride itself. The conversion of optically active (*R*)-(+)-1-phenylethanol to 1-phenylethyl chloride proceeds with nearly complete racemization.

During a search for direct aryl migration method of 2-hydroxypropiophenones to 2-arylpropionic acids by various sulfur, selenium, and tellurium reagents[1] we came across the replacement of hydroxyl group by chlorine when the ketones were treated with selenium or tellurium tetrachloride ($SeCl_4$ or $TeCl_4$). Although $SeCl_4$ has been known as chlorinating agent of olefins,[2] acetylenes,[3] and isocyanides,[3] there is no precedent for the use of $TeCl_4$ as chlorinating agent as well as the reactions of each reagent with alcohols to our knowledge.[4] In order to know the scope and limitation of this replacement reaction the reactions of typical primary, secondary, and tertiary alcohols with $SeCl_4$ or $TeCl_4$ were carried out in various solvents. It is worthwhile to note that selenium tetrafluoride is known to react with alcohols to give the corresponding alkyl fluorides in good yields.[5] During this study we also disclosed that $TeCl_4$, but not $SeCl_4$, works as a mild Lewis acid catalyst for aromatic alkylation. We report here the details of our new findings.

Results and Discussion

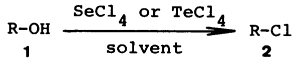
Conversion of Alcohols to Alkyl Chlorides by $SeCl_4$ or $TeCl_4$. Treatment of 1- and 2-phenylethanols, diphenylmethanol, triphenylmethanol, and 1- and 2-octanols with $SeCl_4$ in toluene, dichloromethane, or 1,2-dichloroethane as solvent at 25—60 °C for 1.5—15 h afforded the corresponding alkyl chlorides respectively in 44—97% yield. The addition of amine sometimes improved the product yield. Selenium tetrafluoride-pyridine complex is known to be a good fluorinating agent of alcohols.[5] Similar treatment with $TeCl_4$ also gave alkyl chlorides in 65—86% yield, but the addition of triethylamine or pyridine resulted in lowering the product yield probably because of the

Table 1. Conversion of Alcohols to Alkyl Chlorides Using $SeCl_4$ or $TeCl_4$

R in **1** (2 mmol)	$SeCl_4$ or $TeCl_4$ (2.4 mmol)	Base (equiv)[a]	Solvent (4 ml)	Temp/°C	Time/h	Products/%[b]	
						2	**1**
$PhCH_2CH_2$	$SeCl_4[TeCl_4]$		Toluene	50	4	44[65]	24[20]
$PhCH_2CH_2$	$SeCl_4$	Et_3N(1.0)	Toluene	50	4	71[0]	25[94]
Ph_2CH	$SeCl_4$		Toluene	50	4	90	0
Ph_2CH	$TeCl_4$		DMF-Toluene[c]	25	3	85	0
Ph_2CH	$SeCl_4[TeCl_4]$	Et_3N(1.5)	Toluene	25	3	97[8]	2[90]
$PhCHCH_3$[d]	$SeCl_4$		Toluene	25	6	96[e]	—[f]
$PhCHCH_3$[d]	$TeCl_4$		CH_2Cl_2	−50	3.5	86[e]	—[f]
$PhCHCH_3$[d]	$SeCl_4[TeCl_4]$	Et_3N(1.0)	CH_2Cl_2	25	1.5	96[e][39][e]	—[f][7][e]
Ph_3C	$SeCl_4[TeCl_4]$		CH_2Cl_2	25	15	95[77]	3[3]
Ph_3C	$SeCl_4[TeCl_4]$	C_5H_5N(1.2)	CH_2Cl_2	25	15	92[22]	2[64]
1-C_8H_{17}	$SeCl_4[TeCl_4]$		$ClCH_2CH_2Cl$	60	2	92[2]	0[98]
2-C_8H_{17}	$SeCl_4[TeCl_4]$		$ClCH_2CH_2Cl$	60	2	49[71]	22[0]

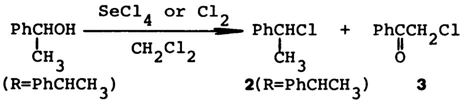
a) Equivalent to $SeCl_4$ or $TeCl_4$. b) GLC yield based on **1** charged unless otherwise stated. c) *N,N*-Dimethylformamide-toluene (2 ml-2 ml). d) **1** (30 mmol), $SeCl_4$ or $TeCl_4$ (36 mmol), and solvent (60 ml) were used. e) Isolated yield. f) Not determined.

formation of too stable adducts between $TeCl_4$ and the amine.[6] Applicability of the reaction with $TeCl_4$ for this conversion seems to be more limited than that with $SeCl_4$ from the following observations: 1) Primary alcohols such as 1-octanol and 1-butanol were almost recovered intact, 2) secondary alcohols sometimes reacted very slowly; e.g., 2-butanol gave *s*-butyl chloride in less than 20% yield even under somewhat severe conditions, and 3) in toluene as solvent aromatic alkylation often predominated (vide infra). Typical results are shown in Table 1.



$$\underset{\mathbf{1}}{\text{R-OH}} \xrightarrow[\text{solvent}]{SeCl_4 \text{ or } TeCl_4} \underset{\mathbf{2}}{\text{R-Cl}}$$

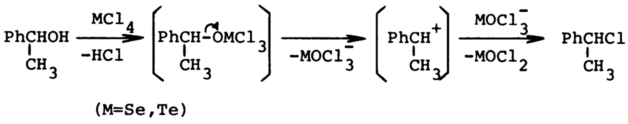
It is knwon that $SeCl_4$ is almost completely dissociated to lower chlorides and chlorine in the vapor, while there is little such dissociation in the case of $TeCl_4$.[7] In order to know whether a true chlorinating species is $SeCl_4$ itself or chlorine evolved by dissociation in the liquid phase, the reaction of 1-phenylethanol with $SeCl_4$ in dichloromethane was compared with that with chlorine gas. As a result it was revealed that in the chlorine case the reaction is slow and always accompanied by the formation of 1-chloroacetophenone (**3**), while only the expected 1-phenylethyl chloride, **2** (R=$PhCHCH_3$), is obtained quantitatively in the $SeCl_4$ case (Table 2). These results show $SeCl_4$ itself to be a reactive species for this conversion in accord with the observation obtained so far in the liquid-phase chlorination of various olefins with $SeCl_4$.[2]



$$\underset{\mathbf{1}(R=PhCHCH_3)}{\underset{CH_3}{PhCHOH}} \xrightarrow[CH_2Cl_2]{SeCl_4 \text{ or } Cl_2} \underset{\mathbf{2}(R=PhCHCH_3)}{\underset{CH_3}{PhCHCl}} + \underset{\mathbf{3}}{PhC(=O)CH_2Cl}$$

Next, the stereochemistry of this conversion to alkyl chlorides was investigated using almost optically pure (*R*)-(+)-1-phenylethanol as follows. Treatment of the alcohol with $SeCl_4$ in toluene at 25 °C for 6 h afforded 1-phenylethyl chloride in 90% isolated yield which did not show any optical activity. The reaction of the alcohol with $TeCl_4$ in dichloromethane at −50 °C for 6 h produced the chloride in 89% isolated yield, optical rotation $[\alpha]_D^{20}$ of which being −0.5° (optical purity, 0.5%; inversion), while similar reaction at 25 °C for 48 h in the presence of pyridine gave the chloride of $[\alpha]_D^{20}$ +1.6° in 18% isolated yield (optical purity, 1.5%; retention). These results show that the replacement of hydroxyl group by chlorine with either $SeCl_4$ or $TeCl_4$ proceeds with nearly complete racemization in the case of 1-phenylethanol.

From experimental observations described above an S_N1 like reaction scheme may be conceivable for this chlorination at least in the cases of secondary and tertiary alcohols as exemplified using 1-phenylethanol as a substrate as follows.



$$\underset{CH_3}{PhCHOH} \xrightarrow[-HCl]{MCl_4} \left[\underset{CH_3}{PhCH}\text{-}OMCl_3\right] \xrightarrow[-MOCl_3^-]{} \left[\underset{CH_3}{PhCH^+}\right] \xrightarrow[-MOCl_2]{MOCl_3^-} \underset{CH_3}{PhCHCl}$$

(M=Se,Te)

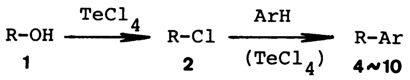
Friedel-Crafts Alkylation Catalyzed by $TeCl_4$. When the reaction of 1-phenylethanol with $TeCl_4$ was carried out in toluene as solvent at 25 °C, the product was not the expected 1-phenylethyl chloride but an isomeric mixture of 1-phenyl-1-tolylethanes (**4**) in a sharp contrast to the reaction with $SeCl_4$ under similar conditions. On the other hand, the same reaction at −50 °C afforded mainly 1-phenylethyl chloride. This fact suggests that the alkyl chloride initially produced further reacts with aromatic solvent at higher temperature and $TeCl_4$ works as a Lewis acid catalyst. In fact, this was confirmed by a separate experiment using 1-phenylethyl chloride and a catalytic amount of $TeCl_4$ which revealed the formation of **4** of the same isomer ratio as that obtained directly from 1-phenylethanol. Namely, $TeCl_4$ worked as a reagent for the conversion of alcohols to alkyl chlorides and then as a catalyst for aromatic alkylation. Similar phenomenon was also observed in the reactions using *t*-butyl alcohol and *t*-butyl chloride as substrates, an equivalent and a catalytic amount of $TeCl_4$ being required in the former and the latter case respectively. The alkylation using 1-phenylethanol could be applied to other aromatic compounds such as benzene, *p*-xylene, and anisole to produce 1-phenylethylated aromatics, **7**—**10**, in moderate yields. One of the characteristic features of the reaction is the formation of only o- and p-isomers from toluene and

Table 2. Chlorination of **1**(R=$PhCHCH_3$) with $SeCl_4$ or Cl_2

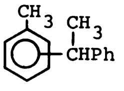
1 (R=$PhCHCH_3$) (mmol)	Reagent (equiv)[a]	Solvent CH_2Cl_2/ml	Temp/°C	Time/h	Products/%[b]		
					2 (R=$PhCHCH_3$)	**3**	**1** (R=$PhCHCH_3$)
30	Cl_2(1.4)	30	−50	4.5	2	16	75
30	Cl_2(1.4)	30	25	15	77	12	trace
8	$SeCl_4$(1.2)	12	−50	4	99	0	0
8	$SeCl_4$(1.2)	12	25	4	98	0	0

a) Equivalent to **1**. b) Isolated yield in the case of Cl_2 and GLC yield in the case of $SeCl_4$, respectively, based on **1** charged.

anisole, none of m-isomer being produced. In the case of benzene as solvent the initially formed product, 1,1-diphenylethane (**7**), was far more reactive than benzene itself and alkylated further to give dialkylated benzene **8** highly selectively. Typical results are summarized in Table 3. The catalytic activity of $TeCl_4$ seems to be not so strong, as alkylation proceeded only with very reactive (benzyl, 1-phenylethyl, *t*-butyl etc.) alcohol or chloride and even *s*-butyl chloride did not alkylate toluene under similar conditions. It has been known that $TeCl_4$[8] and tellurium(IV) oxide(TeO_2)[9] work as a mild catalyst for aromatic acylation and alkylation respectively. However, no data are so far available on the catalytic activity of $TeCl_4$ for Friedel-Crafts aromatic alkylation. We are sure that this is a first example of $TeCl_4$ working as Friedel-Crafts alkylation catalyst, though its activity is mild.



$$\underset{\mathbf{1}}{\text{R-OH}} \xrightarrow{TeCl_4} \underset{\mathbf{2}}{\text{R-Cl}} \xrightarrow[(TeCl_4)]{ArH} \underset{\mathbf{4\sim10}}{\text{R-Ar}}$$



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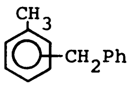

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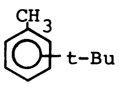

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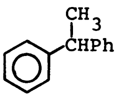

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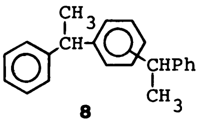

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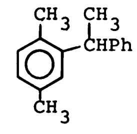

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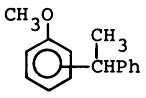

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Experimental

General. ^1H NMR spectra were recorded with JEOL FX-90Q (90 MHz) instrument on solutions in $CDCl_3$ with Me_4Si as an internal standard. GLC analyses were carried out with a Shimadzu 4CMPF apparatus using Thermon-1000(5% or 0.5%)-Chromosorb-W(3 mm×3 m or 1.5 m), SILAR-10C(5%)-Chromosorb-W(3 mm×1 m), PEG 20 M(10%)-Chromosorb-W(3 mm×2 m), Silicone CBP 5-M-25-025(0.2 mm×25 m), and Silicone OV-101(0.24 mm×30 m) columns (N_2 as carrier gas). Optical rotations were measured on a UNION PM-201 automatic polarimeter. All organic and inorganic materials were commercial products of the purest grade and used without further purification. Authentic samples of **2** were all commercially available for GLC analyses.

Conversion of Alcohols to Alkyl Chlorides by $SeCl_4$ or $TeCl_4$ (Table 1). A typical experimental procedure is as follows. To a solution of 2-phenylethanol, [**1**(R=$PhCH_2CH_2$)], (0.244 g, 2 mmol) in toluene (4 ml) was added selenium tetrachloride (0.533 g, 2.4 mmol) and the resulting mixture was stirred at 50 °C for 4 h. After being cooled down to room temperature, the mixture was added with water (6 ml) and stirred for 0.5 h. The precipitated red-brown solids were filtered off. The organic layer was separated, washed with brine (3 ml), and dried ($MgSO_4$). GLC analysis using Thermon-1000(5%)-Chromosorb-W(3 mm×3 m) column and propiophenone as an internal standard revealed the presence of 2-phenylethyl chloride, [**2**(R=$PhCH_2CH_2$)], (0.88 mmol, 44%) and unreacted 2-phenylethanol (0.48 mmol, 24%). The reactions with $TeCl_4$ were similarly carried out. In the case of 1-phenylethanol the experiment of 15 times scale was carried out and the product 1-phenylethyl chloride was isolated by distillation.

Reaction of 1-Phenylethanol[1(R=$PhCHCH_3$)] with Chlorine (Table 2). To a solution of chlorine (3.06 g, 43.2 mmol) in dichloromethane (30 ml) was added 1-phenylethanol[**1**(R=$PhCHCH_3$)] (3.67 g, 30 mmol) at −50 °C and the mixture was stirred at the same temperature for 4.5 h. After the addition of 10% aqueous sodium thiosulfate (20 ml) the resulting solution was stirred at room temperature for 0.5 h. The organic layer was separated, washed with brine (10 ml×2), and dried ($MgSO_4$). Evaporation of the solvent left an oily residue which was subjected to column chromatography on SiO_2 [hexane-ethyl acetate (20:1) as eluent] to give 1-phenylethyl chloride [**2**(R=

Table 3. Aromatic Alkylation Using $TeCl_4$

1 or **2** (30 mmol)	$TeCl_4$ (equiv)$^{a)}$	Solvent (30 ml)	Temp/°C	Time/h	Product/%$^{b)}$ (o/p ratio)$^{c)}$
1(R=$PhCHCH_3$)	1.2	Toluene	25	3	**4** 83(12/88)$^{d)}$
1(R=$PhCHCH_3$)	1.2	Toluene	−50	4	**2**(R=$PhCHCH_3$) 62$^{e)}$, **4** 7
2(R=$PhCHCH_3$)	0.1	Toluene	25	3	**4** 93(11/89)$^{d)}$
1(R=$PhCH_2$)	1.2	Toluene	25	4	**5** 87(35/65)
1(R=*t*-Bu)	1.2	Toluene	80	5	**6** 34(1/99)
2(R=*t*-Bu)	0.2	Toluene	25	20	**6** 71$^{e)}$ (1/99)$^{d)}$
1(R=$PhCHCH_3$)	1.2	Benzene	5	1	**7** 3, **8** 44(24/76)
1(R=$PhCHCH_3$)	1.2	*p*-Xylene	25	24	**9** 40
1(R=$PhCHCH_3$)	1.2	Anisole	25	24	**10** 59(17/83)

a) Equivalent to **1** or **2**. b) Isolated yield based on **1** or **2** charged. c) Determined by NMR unless otherwise stated. d) Determined by GLC. e) GLC yield based on **1** or **2** charged.

$PhCHCH_3$)] (0.10 g, 0.71 mmol, 2.4% yield), 1-chloroacetophenone (**3**) (0.73 g, 4.72 mmol, 15.7% yield) and the starting **1**(R=$PhCHCH_3$) (2.74 g, 22.5 mmol, 74.9% yield), respectively.

Treatment of Optical Active Alcohol with $SeCl_4$ or $TeCl_4$. A typical example is as follows. To a solution of commercially available optical active (*R*)-(+)-1-phenylethanol($[\alpha]_D^{20}$ +42°, 1.00 g, 8.19 mmol) in dichloromethane (10 ml) was added tellurium tetrachloride (2.65 g, 9.84 mmol) at −50 °C; the reported maximum optical rotation of the alcohol is $[\alpha]_D^{25}$ +43.4°.[10] The resulting mixture was stirred at the same temperature for 6 h. The mixture was then added with water (20 ml) and stirred at room temperature for 10 min. The precipitated white solids were filtered off. The organic layer was separated, washed with brine (20 ml) and dried ($MgSO_4$). Evaporation of the solvent left an oily residue which was distilled in vacuo to give 1-phenylethyl chloride (1.02 g, 7.26 mmol, 88.6% yield) at bp 64 °C/8 mmHg (1 mmHg=133.322 Pa). It shows the optical rotation of $[\alpha]_D^{20}$ −0.5°, the value corresponding to the optical purity of 0.5% calculated from $[\alpha]_D^{20}$ +109° of optically pure (*R*)-(+)-1-phenylethyl chloride.[11]

Friedel-Crafts Aromatic Alkylation Catalyzed by $TeCl_4$ (Table 3). A typical experimental procedure starting from alcohol is as follows. To a solution of 1-phenylethanol, **1**(R=$PhCHCH_3$), (3.7 g, 30 mmol) in toluene (30 ml) was added slowly tellurium tetrachloride (9.7 g, 36 mmol) keeping the reaction temperature at 25 °C (exothermic reaction). Small amounts of white precipitates appeared immediately and then the color of the mixture turned dark-brown in a few minutes. The mixture was stirred for 3 h and then quenched with water (20 ml). The organic layer was separated, washed with brine (20 ml×2) and dried ($MgSO_4$). Evaporation of the solvent left an oily residue which was distilled in vacuo to afford a mixture of 1-phenyl-1-tolylethanes (**4**)(4.9 g, 25 mmol, 83.3% yield) at bp 117—128 °C/1 mmHg. GLC analysis of **4** using Silicone OV-101 (0.24 mm×30 m) capillary column at 100→260 °C (4 °C min^{-1}) revealed the presence of two isomers of ortho/para=12/88: ^1H NMR, para-isomer, δ=1.57 (d, *J*=7 Hz, 3H), 2.26 (s, 3H), 4.07 (q, *J*=7 Hz, 1H), 7.05 (m, 4H), 7.18 (m, 5H); ortho-isomer, 2.19 (s, 3H). Found: C, 91.92; H, 8.08%. Calcd for $C_{15}H_{16}$: C, 91.78; H, 8.22%.

Analytical data of other alkylated aromatics are as follows.

Benzyltoluenes (5): A colorless liquid of o/p=35/65 by ^1H NMR; ^1H NMR, para-isomer, δ=2.40 (s, 3H), 4.02 (s, 2H), 7.14—7.28 (m, 9H); ortho-isomer, 2.35 (s, 3H), 4.06 (s, 2H).

***t*-Butyltoluenes (6):** A colorless liquid, bp 38 °C/1 mmHg; ^1H NMR δ=1.25 (s, 9H), 2.24 (s, 3H), 6.98 (d, 2H), 7.17 (d, 2H). The isomer ratio (o/p) was determined by GLC using Silicone OV-101 capillary column as 1/99.

1,1-Diphenylethane (7): A colorless liquid isolated by column chromatography on SiO_2 (hexane as eluent); ^1H NMR δ=1.57 (d, 3H), 4.03 (q, 1H), 6.92—7.32 (m, 10H).

Bis(1-phenylethyl)benzenes (8): A colorless liquid isolated by column chromatography on SiO_2 (hexane as eluent), o/p=24/76 by ^1H NMR; ^1H NMR, para-isomer, δ=1.65 (d, 6H), 4.87 (q, 2H), 6.88—7.24 (m, 14H); ortho-isomer, 1.46 (d, 6H), 3.95 (q, 2H).

1,4-Dimethyl-2-(1-phenylethyl)benzene (9): A colorless liquid, bp 129 °C/2 mmHg; ^1H NMR, δ=1.55 (d, 3H), 2.13 (s, 3H), 2.47 (s, 3H), 4.22 (q, 1H), 6.80—7.24 (m, 8H).

(1-Phenylethyl)anisoles (10): A colorless liquid of o/p=17/83 by ^1H NMR, bp 156 °C/5 mmHg; ^1H NMR, para-isomer, δ=1.58 (d, 3H), 3.71 (s, 3H), 4.05 (q, 1H), 6.68—7.20 (m, 9H); ortho-isomer, 1.55 (d, 3H).

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