t, J = 5 Hz, 3 H), 1.75–2.87 (m, 5 H), 3.00 (dd, J = 6, 1.5 Hz, 1 H), 5.65–6.65 (m, 2 H), 7.08–7.52 (m, 5 H).

Acknowledgment. We are grateful to Dr. David Gustafson for ^{13}C NMR spectra and Dr. Arthur Sill for gas chromatography/mass spectroscopy studies. We are indebted to Drs. Gary Flynn, Boyd Harrison, and Philip Weintraub for helpful suggestions and to Mrs. Brenda Harry for skilled technical assistance.

Registry No. 1, 39546-32-2; 2, 76447-96-6; 3, 76447-97-7; 4, 76447-98-8; 5, 76447-99-9; 6, 76448-00-5; 7, 76448-01-6; 7·HCl, 76448-02-7; 11, 76448-03-8; 12, 76448-04-9; (3-chloropropenyl)-benzene, 102-92-1; dihydrocinnamaldehyde, 104-53-0; dihydrocinnamaldehyde semicarbazone, 27843-08-9; 3-deuterio-3-phenylpropionaldehyde, 76448-05-0.

N-Phenylselenophthalimide. A Useful Reagent for the Facile Transformation of (1) Carboxylic Acids into either Selenol Esters or Amides and (2) Alcohols into Alkyl Phenyl Selenides

Paul A. Grieco* and John Yan Jaw

Department of Chemistry, Indiana University, Bloomington, Indiana 47405

D. A. Claremon and K. C. Nicolaou*

Department of Chemistry, University of Pennsylvania, Philadelphia, Pennsylvania 19104

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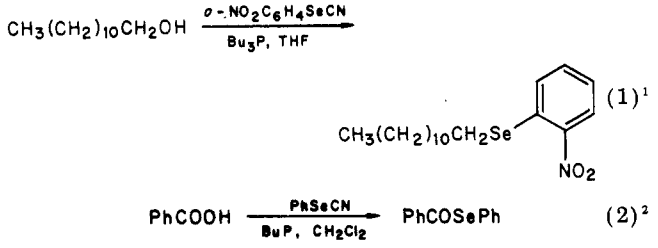
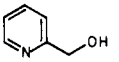
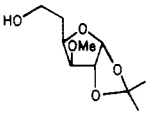
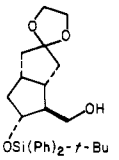
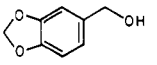
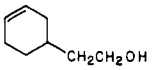
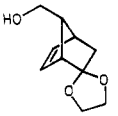
It has previously been reported that aryl selenocyanates react with alcohols (eq 1) and carboxylic acids (eq 2) in



the presence of tri-*n*-butylphosphine, giving rise to alkyl aryl selenides[1] and selenol esters, respectively.[2] The reactions depicted in eq 1 and 2 are general and can be applied to a variety of alcohols and acids. In contrast to *o*-nitrophenyl selenocyanate which is an easy to handle, yellow crystalline substance, phenyl selenocyanate is an extremely sensitive, unpleasant smelling liquid which slowly decomposes on storage after a few days.

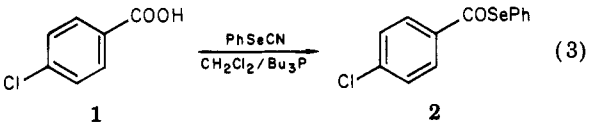
We report herein the reactions of carboxylic acids and alcohols with *N*-phenylselenophthalimide (*N*-PSP),[3] a stable, crystalline, relatively odorless substance. The use of *N*-PSP as detailed below obviates the necessity of working with the difficult to handle phenyl selenocyanate. Treatment of a variety of alcohols with *N*-PSP in tetrahydrofuran at 0 °C (method A) or in methylene chloride (method B) in the presence of tri-*n*-butylphosphine gives rise to high yields of alkyl phenyl selenides (Table I).[4] The major advantage of this new one-step process is the ready availability of *N*-PSP[3] as compared to PhSeCN which is a nuisance to prepare and difficult to work with. As illustrated in Table I, *N*-PSP is compatable with acetals, ketals, silyl ethers, olefins, acetylenes, and aromatic residues.

Table I. Conversion of Alcohols to Alkyl Phenyl Selenides

starting alcohol	method[a]	time, min	temp, °C	% yield of[b,c] selenide
geraniol	A	40	0	82
$CH_3(CH_2)_5CH_2OH$	A	35	0	84
$CH_3CH_2C{\equiv}CCH_2CH_2OH$	A	60	0	75
$C_6H_5CH_2OH$	A	60	0	95
	B	60	−20–0	70
	B	120	−20–25	90
	B	180	−20–25	73
	A	30	0	95
	A	90	25	87
	A	30	0	72

[a] Method A: reactions were carried out in tetrahydrofuran employing 2.0 equiv of *N*-PSP and 2.0 equiv of tri-*n*-butylphosphine. Method B: reactions were carried out in dry, oxygen-free CH_2Cl_2 (0.4 M) with 1.5–2.0 equiv of *N*-PSP and 2.0 equiv of tri-*n*-butylphosphine. [b] All compounds were fully characterized by spectral methods. [c] Yields reported are for isolated, chromatographically pure substances.

We have also observed that carboxylic acids dissolved in either tetrahydrofuran or methylene chloride react with *N*-PSP in the presence of tri-*n*-butylphosphine, providing selenol esters in good to excellent yield (Table II). As illustrated in the table, a variety of aryl- and alkylcarboxylic acids have been examined. In contrast to the reaction of phenyl selenocyanate with *p*-chlorobenzoic acid (eq 3) which gave us only 32% yield of selenol ester **2**, use



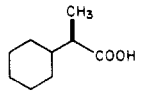
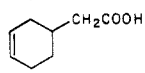
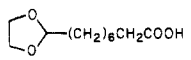
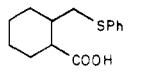
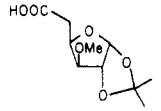
1 **2**

of *N*-PSP provided **2** in 91% isolated yield. Reaction of β,β-dimethylacrylic acid at 0 °C with 1.2 equiv of *N*-PSP

(1) Grieco, P. A.; Gilman, S.; Nishizawa, M. *J. Org. Chem.* **1976**, *41*, 1485.
(2) Grieco, P. A.; Yokoyama, Y.; Williams, E. *J. Org. Chem.* **1978**, *43*, 1283.
(3) (a) Nicolaou, K. C.; Claremon, D. A.; Barnett, W. E.; Seitz, S. P. *J. Am. Chem. Soc.* **1979**, *101*, 3704. (b) Also see: Frejd, T.; Sharpless, K. B. *Tetrahedron Lett.* **1978**, 2239; Hori, T.; Sharpless, K. B. *J. Org. Chem.* **1979**, *44*, 4208.
(4) The corresponding sulfur reagent has been reported to transform alcohols into phenyl sulfides in a similar manner: Walker, K. A. M. *Tetrahedron Lett.* **1977**, 4475.
(5) Lown, W. J.; Akhtar, M. H.; Dadson, W. M. *J. Org. Chem.* **1975**, *40*, 3363.

0022-3263/81/1946-1215$01.25/0

Table II. Synthesis of Selenol Esters

starting acid	method[a]	time, h	% yield of[b,c] selenol ester
$CH_3(CH_2)_6COOH$	A	1.5	90
$C_6H_5CH_2COOH$	A	3	98
p-$CH_3OC_6H_4COOH$	A	3	56
p-$C_6H_5C_6H_4COOH$	A	4	58
p-ClC_6H_4COOH	A	0.7	91
cyclohexanecarboxylic acid	A	2	94
	A	3	91
	A	3	82
	B	3	75
	B	3	92
	B	5	94

[a] Method A: reactions were carried out at 25 °C in tetrahydrofuran employing 2.0 equiv of N-PSP and 2.0 equiv of tri-n-butylphosphine. Method B: reactions were were carried out in dry, oxygen-free CH_2Cl_2 (0.4 M) with 1.5–2.0 equiv of N-PSP and 2.0 equiv of tri-n-butylphosphine. [b] All compounds were fully characterized by spectral methods. [c] Yields reported are for isolated, chromatographically pure substances.

in THF containing 1.2 equiv of tri-n-butylphosphine provided a 2:1 mixture of selenol esters **3** and **4**, respectively, in 83% yield (eq 4). In general the yields of selenol

$$(CH_3)_2C{=}CHCOOH \xrightarrow[THF/Bu_3P]{N\text{-PSP}} \underset{\mathbf{3}}{(CH_3)_2C{=}CHCOSePh} + \underset{\mathbf{4}}{PhSeC(CH_3)_2CH_2COSePh} \quad (4)$$

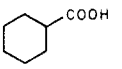
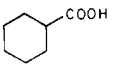
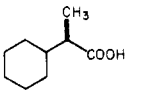
esters prepared from N-PSP/Bu_3P are higher than those obtained previously by employing ArSeCN/Bu_3P.[2] We have also observed that the reaction of carboxylic acids with N-PSP/Bu_3P in the presence of amines provides direct access to amides in high yield (Table III).

The new reactions described above for the facile preparation of alkyl phenyl selenides, selenol esters, and amides employing N-phenylselenophthalimide (N-PSP), coupled with the oxyselenation of olefins reported by Nicolaou,[3a] attest to the ability of N-PSP to efficiently introduce the phenylseleno group (PhSe) into a variety of substrates.[6] While many carriers of the PhSe group exist (e.g., PhSeCN, PhSeCl, PhSeBr, PhSeSePh), it is clear that there are distinct advantages offered by N-PSP.

Experimental Section

General Procedure for Preparation of Amides. A solution of phenylacetic acid (95 mg, 0.7 mmol) and N-phenylselenophthalimide (302 mg, 1.0 mmol) in 4.0 mL of dry tetrahydrofuran was treated at room temperature with 0.25 mL (1.0 mmol) of tri-n-butylphosphine followed by the addition of 0.08 mL (1.0 mmol) of isopropylamine. After 2 h, the solvent was removed in vacuo. Chromatography of the residue on silica gel using hexane–ether (15:1) (to remove diphenyl diselenide) followed by hexane–ether (1:1) provided 124 mg (95%) of pure crystalline N-isopropylphenylacetamide, mp 101–102 °C (lit.[5] mp 102.0–103.5 °C).

Table III. Direct Conversion of Acids into Amides[a]

acid	amine	time, h	% yield of[b,c] amide
$C_6H_5CH_2COOH$	isopropyl	3.0	95
$C_6H_5CH_2COOH$	diethyl	2.3	98
$C_6H_5CH_2COOH$	benzyl	2.0	93
p-$MeOC_6H_4COOH$	isopropyl	3.0	95
p-$MeOC_6H_4COOH$	diethyl	2.5	88
p-ClC_6H_4COOH	isopropyl	3.5	95
p-ClC_6H_4COOH	diethyl	2.5	92
$CH_3(CH_2)_6COOH$[d]	isopropyl	2.5	98
	isopropyl	3.0	90
	diethyl	1.8	82
	isopropyl	2.0	93

[a] All reactions were run in tetrahydrofuran at room temperature, using 1.3 equiv of N-PSP, 1.3 equiv of Bu_3P, and 1.3 equiv of amine unless stated otherwise. [b] Yields are based on pure compounds isolated chromatographically on silica gel. [c] All compounds were fully characterized by spectral methods. [d] Reaction carried out at 0 °C.

Acknowledgment. This investigation was supported by a Public Health Research Grant (CA 28865) from the National Cancer Institute. We are grateful to Mr. Eric Williams for experimental assistance and discussions during the early stages of this work.

Registry No. 1, 74-11-3; 2, 38447-69-7; 3, 76358-88-8; 4, 76358-89-9; N-phenylselenophthalimide, 71098-88-9; β,β-dimethylacrylic acid, 541-47-9; geraniol, 106-24-1; 1-heptanol, 111-70-6; 3-hexyn-1-ol, 1002-28-4; benzenemethanol, 100-51-6; 2-pyridinemethanol, 586-98-1; 5-deoxy-3-O-methyl-1,2-O-(methylethylidene)-α-D-$xylo$-hexofuranose, 62853-46-7; (3'aα,4α,5'β,6'aα)-5'-[[(1,1-dimethylethyl)diphenylsilyl]oxy]hexahydrospiro[1,3-dioxolane-2,2'(1'H)-pentalene]-4'-methanol, 76358-90-2; 1,3-benzodioxole-5-methanol, 495-76-1; 3-cyclohexene-1-ethanol, 18240-10-3; 1α,4α,7(R*)-spiro[bicyclo[2.2.1]-hept-5-ene-2,2'-[1,3]dioxolane]-7-methanol, 76419-56-2; $trans$-1-(phenylseleno)-3,7-dimethylocta-2,6-diene, 71518-14-4; 1-(phenylseleno)heptane, 76376-91-5; 1-(phenylseleno)hex-3-yne, 76358-91-3; [(phenylmethylseleno]benzene, 18255-05-5; 2-[(phenylseneno)-methyl]pyridine, 76358-92-4; 5-deoxy-3-O-methyl-1,2-O-(1-methylethylidene)-6-Se-phenyl-6-seleno-α-D-$xylo$-hexofuranose, 76358-93-5; (3aα,4α,5β,6aα)-5'-[[(1,1-dimethylethyl)diphenylsilyl]oxy]hexahydro-4-[(phenylseleno)methyl]spiro[1,3-dioxolane-2,2'(1'H)-pentalene], 76376-92-6; 5-[(phenylseleno)methyl]-1,3-benzodioxole, 76358-94-6; 1-[(2-phenylseleno)ethyl]cyclohex-3-ene, 76358-95-7; 1α,4α,7(R*)-7-[(phenylseleno)methyl]spiro[bicyclo[2.2.1]hept-5-ene-2,2'-[1,3]dioxolane], 76358-96-8; octanoic acid, 124-07-2; benzeneacetic acid, 103-82-2; 4-methoxybenzoic acid, 100-09-4; [1,1'-biphenyl]-4-carboxylic acid, 92-92-2; cyclohexanecarboxylic acid, 98-89-5; 2-methylcyclohexaneacetic acid, 6051-13-4; 3-cyclohexene-1-acetic acid, 10468-32-3; 1,3-dioxolane-2-octanoic acid, 834-33-3; 2-[(phenylthio)methyl]cyclohexanecarboxylic acid, 76358-97-9; 5-deoxy-3-O-methyl-1,2-O-(1-methylethylidene)-α-D-$xylo$-hexofuranuronic acid, 76358-98-0; heptyl(phenylseleno)methanone, 65842-36-6; 2-phenyl-1-(phenylseleno)ethanone, 30876-65-4; (4-methoxyphenyl)(phenylseleno)methanone, 65842-37-7; (4-phenylphenyl)-(phenylseleno)methanone, 76358-99-1; cyclohexyl(phenylseleno)-methanone, 60718-41-4; (α-cyclohexylethyl)(phenylseleno)-methanone, 76359-00-7; (cyclohex-3-en-1-ylmethyl)(phenylseleno)-methanone, 76359-01-8; 1,3-dioxolane-2-octaneselenoic acid Se-

(6) The last 8 years have witnessed extensive efforts to develop methods for the introduction and oxidation and/or reductive removal of phenylseleno groups: Sharpless, K. B.; Gordon, K. M.; Lauer, R. F.; Patrick, D. W.; Singer, S. P.; Young, M. W. *Chem. Scr.* **1975**, *8A*, 9; Reich, H. J. In "Oxidation in Organic Chemistry, Part C"; Trahanovsky, W., Ed.; Academic Press: New York, 1978; p 1; Reich, H. J. *Acc. Chem. Res.* **1979**, *12*, 22; Clive, D. L. J. *Tetrahedron* **1978**, *34*, 1049.

phenyl ester, 76359-02-9; 2-[(phenylthio)methyl]cyclohexanecarboselenoic acid *Se*-phenyl ester, 76359-03-0; 5-deoxy-3-*O*-methyl-1,2-*O*-(1-methylethylidene)-α-D-*xylo*-hexofuranuronoselenoic acid *Se*-phenyl ester, 76359-04-1; 2-propanamine, 75-31-0; *N*-ethylethanamine, 109-89-7; benzenemethanamine, 100-46-9; *N*-(1-methylethyl)benzeneacetamide, 5215-54-3; *N,N*-diethylbenzeneacetamide, 2431-96-1; *N*-(phenylmethyl)benzeneacetamide, 7500-45-0; 4-methoxy-*N*-(1-methylethyl)benzamide, 7464-44-0; *N,N*-diethyl-4-methoxybenzamide, 7465-86-3; 4-chloro-*N*-(1-methylethyl)benzamide, 7464-41-8; 4-chloro-*N,N*-diethylbenzamide, 7461-38-3; *N*-(1-methylethyl)octanamide, 76359-05-2; *N*-(1-methylethyl)cyclohexanecarboxamide, 6335-52-0; *N,N*-diethylcyclohexanecarboxamide, 5461-52-9; α-methyl-*N*-(1-methylethyl)cyclohexaneacetamide, 76359-06-3.

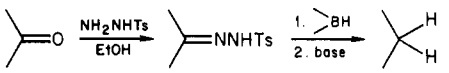
A Mild and Convenient Conversion of Ketones to the Corresponding Methylene Derivatives via Reduction of Tosylhydrazones by Bis(benzoyloxy)borane

George W. Kabalka* and S. Timothy Summers

Department of Chemistry, University of Tennessee, Knoxville, Tennessee 37916

Received October 22, 1980

The conversion of carbonyl compounds to the corresponding methylene derivatives is one of the key transformations in organic synthesis. Not surprisingly, a great deal of literature exists concerning this transformation.[1] The classical reduction procedures utilize strong acids (Clemmensen) or bases (Wolff–Kishner) which preclude the presence of sensitive functional groups. However, the reduction of tosylhydrazones with boron hydride reagents offers a mild and convenient alternative to the classical methods.[2-5]



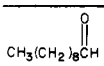
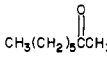
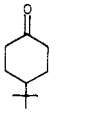
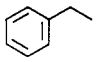
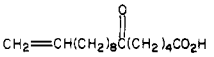
One of the most versatile of these procedures involves the use of catecholborane as the reducing agent.[2] The catecholborane–tosylhydrazone procedure offers a number of advantages over methods utilizing sodium borohydride[3,5] and sodium cyanoborohydride.[4] These advantages include (a) efficient use of hydride (only 1 equiv is necessary compared to the large excesses required in the other procedures), (b) mild reaction conditions (room temperature, neutral pH, and the use of common aprotic solvents), (c) the inertness of most functional groups toward catecholborane (only aldehydes are reduced faster than tosylhydrazones), and (d) formation of only a single hydrocarbon product. The catecholborane procedures reduces a variety of saturated[6] and unsaturated carbonyl compounds.[7,8] Regiospecific isomerizations occur during the reduction of α,β-unsaturated carbonyl derivatives often leading to unique alkenes[7,8] and allenes (from the reduction of acetylenic reagents).[9] The reaction can also be used to incorporate deuterium regiospecifically by using deuterium oxide as the source of deuterium.[10]

The purpose of this study was to investigate reducing agents which are as versatile as catecholborane but which can be more readily prepared. We report that bis(benzoyloxy)borane, I,[11,12] effectively reduces tosylhydrazones to

$$(PhCO_2)_2BH$$
I

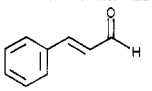
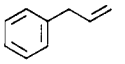
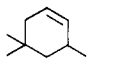
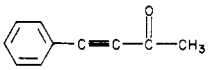
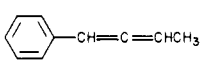
the corresponding methylene derivatives. The results parallel those obtained using catecholborane.

Table I. Conversion of Carbonyl Reagents into the Corresponding Methylene Derivatives[a]

carbonyl reagent[a]	product[b]	% yield[c]
	$CH_3(CH_2)_8CH_3$	91 (99)[d]
	$CH_3(CH_2)_6CH_3$	78
		82
		82 (92)[d]
		68
	$CH_2{=}CH(CH_2)_{13}CO_2H$	96

[a] The carbonyl reagents were first converted into the corresponding tosylhydrazone derivatives. [b] Products exhibited physical and spectral parameters in agreement with literature reports. [c] Isolated yields. [d] GLC analysis.

Table II. Conversion of α,β-Unsaturated Carbonyl Reagents into the Corresponding Methylene Derivatives[a]

carbonyl reagent[a]	product[b]	% yield[c]
		85 (95)[d]
		83 (90)[d]
		21

[a] The carbonyl reagents were first converted into the corresponding tosylhydrazone derivatives. [b] Products exhibited physical and spectral parameters in agreement with literature reports. [c] Isolated yields. [d] GLC analysis.

Results and Discussions

Catecholborane exhibits a stability and reactivity which is greater than most boronic acid esters presumably due to delocalization of the nonbonding p electrons on oxygen into the benzene ring.[13] Apparently, the carbonyl groups in the acyloxyboranes behave similarly since a number of bis(acyloxy)boranes are stable.[11]

(1) See, for example: (a) Reusch, W. "Reduction"; Augustine, R. L., Ed.; Marcel Dekker: New York, 1968; pp 171–211; (b) House, H. O. "Modern Synthetic Reactions", 2nd ed; W. A. Benjamin: Menlo Park, CA, 1972; Chapter 4.
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