The Invention of Radical Reactions. 32. Radical Deoxygenations, Dehalogenations, and Deaminations with Dialkyl Phosphites and Hypophosphorous Acid as Hydrogen Sources[1]

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Received June 29, 1993•

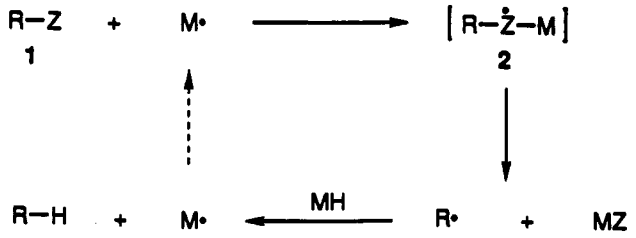
Reagents, containing a P–H bond, such as dimethyl phosphite, diethyl phosphite, hypophosphorous acid and various salts of hypophosphorous acid are effective radical reducing agents for organic halides, thionoesters, and isocyanides affording high yields of the corresponding hydrocarbons. Reduction of tertiary phenyl selenides and tertiary nitro compounds are not efficient under these conditions. Olefination of 1,2-diols is also accomplished *via* the corresponding thiocarbonyl derivatives using hypophosphorous acid and triethylamine in the presence of a suitable "sacrificial olefin" in moderate to good yields.

Introduction

Replacement of functional groups by a hydrogen atom is of considerable importance in organic synthesis. Such reactions as dehalogenations,[2] deoxygenations,[3] deaminations,[4] decarboxylations,[5] and deselenations[6] can be carried out effectively by radical processes that are more applicable to sensitive polyfunctional compounds than the relatively more drastic ionic reactions. Radical reactions are also less susceptible to steric retardation and have less tendency to give rearranged products than ionic reactions. In radical chemistry, generally, the functional group Z in 1 is removed by reducing agent MH *via* intermediate 2 (Scheme I).

The majority of radical reactions are based on tin hydrides as reducing agents and chain carriers,[7,8] mainly tri-*n*-butyltin hydride. However, organotin compounds are toxic and expensive, and are difficult to remove completely from the desired reaction products. Therefore, various attempts have been made to overcome these problems.[9]

Scheme I



It seems that silanes are good alternatives to tri-*n*-butyltin hydride. It has indeed been demonstrated recently that tris(trimethylsilyl)silane,[10] tris(methylthio)-silane,[11] 1,1,1,2,3,3,3,-heptamethyltrisilane,[12] triethylsilane,[13] phenylsilane,[14] diphenylsilane,[15] and triphenylsilane[15b,16] are all good hydrogen atom sources in radical reactions. The Si–H bond strength is very different in these silanes, but depending on the reaction conditions

• Abstract published in *Advance ACS Abstracts*, October 15, 1993.

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Table I. Deoxygenation of Various Alcohols with Dimethyl Phosphite or Diethyl Phosphite

entry	substrate	$(MeO)_2P(=O)H$ (equiv)	benzoyl peroxide (equiv)[a]	solvent	time (h)	yield (%)[c]
1	**3b**	5	0.6	dioxane	1.5	92
2	**3b**	0	0.6	dioxane	1.5	18 (82)[d]
3	**3b**	2	2.0	dioxane	5	82
4	**3c**	10	1.0[b]	benzene	2.5	0
5	**3c**	10	1.0[b]	toluene	2.5	0
6	**3c**	5	0.6	dioxane	1.5	97
7	**3c**	5	1.0	toluene	2.5	92
8	**3d**	5	0.8	dioxane	2	100
9	**4a**	5	0.8	dioxane	2	91[e]
10	**5a**	5	0.8	dioxane	2	91[f]
11	**6a**	5	0.6	dioxane	1.5	90
12	**3b**	5[g]	0.4	dioxane	1	91
13	**3b**	*g,h*	0.4		1	90
14	**3c**	5[g]	0.4	dioxane	1	90

[a] Benzoyl peroxide or AIBN (0.2 mol equiv) was added portionwise until the reaction was completed. [b] AIBN. [c] Analyzed by ^1H NMR. [d] Starting material. [e] Isolated yield. [f] Analyzed by GC. [g] Diethyl phosphite. [h] As a solvent.

even the silanes with strong Si–H bonds can be used successfully in radical deoxygenations and dehalogenations. Although silanes are much less toxic and expensive than tin hydrides, they cannot be considered a cheap alternative to tin hydrides. Consequently, large-scale application of these reagents could be costly.

In a search for other hydrogen sources and chain carriers for radical reactions we have studied various possible hydrogen atom reagents. We have found that commercially available and inexpensive dialkyl phosphites[17] and hypophosphorous acid[18] can be used efficiently instead of tri-*n*-butyltin hydride. We report a full account of our work on the radical reduction of various functional groups using the P–H bond.

Results and Discussion

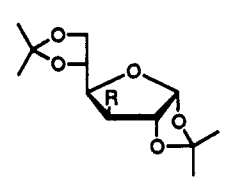
Dialkyl Phosphites. The model compound, thionocarbonate **3b**,[1b] was treated with dimethyl phosphite and benzoyl peroxide in refluxing dioxane to furnish the deoxygenated product **3e**[19] in 92% yield (Table I, entry 1). In the blank experiment, 82% of starting thionocarbonate **3b** remained unchanged and only 18% deoxygenated product **3e** was observed (entry 2), indicating that dimethyl phosphite is the major hydrogen source in the reaction. When the amount of dimethyl phosphite was decreased (entry 3), more benzoyl peroxide was needed to finish the reaction, and the yield was somewhat lowered.

Table II. Reduction of Various Functional Groups with Dimethyl Phosphite (10 equiv) and Benzoyl Peroxide in Refluxing Dioxane

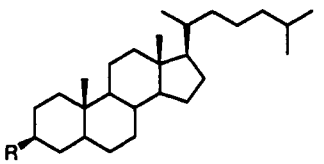
entry	substrate	benzoyl peroxide (equiv)[a]	time (h)	RH (%)[b]
1	**7a**	1.2	3	98
2	**7b**	1.0	2.5	92
3	**8**	1.2	3	93
4	**7c**	1.0	2.5	0
5	**7f**	2.0	5	41 (13)[c]

[a] Benzoyl peroxide (0.2 mol equiv) was added portionwise until the reaction was completed. [b] Analyzed by GC. [c] Starting material.

One disadvantage of this process is that the reaction cannot be initiated by AIBN in refluxing benzene or toluene (entries 4 and 5). However various alcohols could be deoxygenated using benzoyl peroxide (entries 6–11).[20]



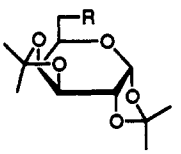
3a: R = OH
3b: R = O(C=S)OC$_6$H$_4$-4-F
3c: R = O(C=S)SMe
3d: R = O(C=S)OC$_6$F$_5$
3e: R = H



4a: R = O(C=S)OC$_6$H$_4$-4-F
4b: R = H

$CH_3(CH_2)_{16}CH_2$–R

5a: R = O(C=S)OC$_6$H$_4$-4-F
5b: R = H



6a: R = O(C=S)OC$_6$H$_4$-4-F
6b: R = H

Dimethyl phosphite and diethyl phosphite work comparably well (entries 12 and 14). The yield of the deoxy product **3e** remained essentially unchanged when diethyl phosphite was used as a solvent and hydrogen source (entry 13).

Various adamantane derivatives were prepared and transformed to the hydrocarbon. While the reduction of iodide and bromides **7a**,[21] **7b**, and **8** is relatively facile (Table II, entries 1–3), the corresponding chloro compound **7c** remained unchanged in the attempted radical dehalogenation reaction (entry 4). The phenylselenyl group in **7f**[22] was removed only in a moderate yield (entry 5).

We also observed that dimethyl phosphite was added to olefins easily.[23] Thus, the reaction of cholesteryl acetate with dimethyl phosphite and benzoyl peroxide in refluxing

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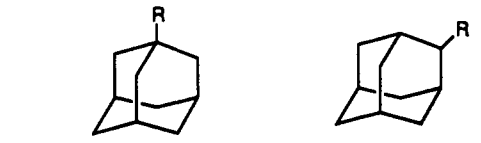
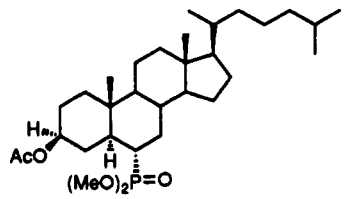


7a: R = I
7b: R = Br
7c: R = Cl
7d: R = O(C=S)SMe
7e: R = NC
7f: R = SePh
7g: R = NO_2
7h: R = H
7i: R = NHCHO

8: R = Br



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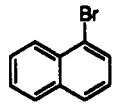

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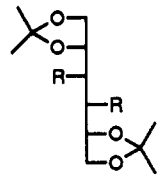

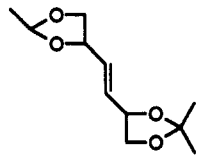

11
R = O(C=S)SMe

12

dioxane gave the addition product **9** in 79% isolated yield. The hydrogen atom geminal to the acetate group in **9** gave a multiplet (at 4.50–4.70 ppm) with $W_{1/2}$ 20 Hz in the ^1H NMR. This value corresponds to axial orientation, implying 5α-hydrogen.[24]

The reactivity of di-isopropyl phosphite[25] and di-*tert*-butyl phosphite[26] as hydrogen sources was also examined. The reaction of *S*-methyl dithiocarbonate **3c** with di-isopropyl phosphite and benzoyl peroxide in refluxing toluene gave 81% of the deoxy compound **3e** and 19% of the starting material **3c** after adding 2 equiv of benzoyl peroxide. However, di-*tert*-butyl phosphite gave a complex mixture. Diphenylphosphine and bis(trimethylsilyl) hypophosphite[27] were also tried as hydrogen sources in the radical deoxygenation of alcohols. These compounds were not efficient deoxygenation reagents.

A competitive study between diphenylsilane and diethyl phosphite in refluxing toluene-d_8 in the deoxygenation of thionocarbonate **3b** showed that while 69% of the diphenylsilane was consumed, only 29% of the diethyl phosphite was used in the reaction. This shows that diphenylsilane is more reactive than diethyl phosphite.

Hypophosphorous Acid and Its Salts. The reaction of *S*-methyl dithiocarbonate **3c** with commercial hypophosphorous acid in refluxing acetonitrile in the presence of AIBN gave the deprotected product at the 5,6-position in **3c** due to the acidity of the hypophosphorous acid. The acidity was neutralized by the addition of triethylamine. The reaction of *S*-methyl dithiocarbonate **3c** with hypophosphorous acid and triethylamine in refluxing dioxane in the presence of AIBN gave 77% of the deoxy product **3e** and 14% of the alcohol **3a** (Table III, entry 1). As the amount of triethylamine is increased, the yield of the deoxy product **3e** also increased (entries 2 and 3). Triethylamine protects the thiocarbonyl moiety, as well as acid-labile protecting groups from acidic hydrolysis during the reaction. The blank experiment without hypophosphorous acid gave no sign of the formation of the deoxy product (entry 4). This indicates that the P–H bond in hypophosphorous acid is the hydrogen source. The corresponding 4-fluorophenyl thionocarbonate **3b** was hydrolyzed less easily than *S*-methyl dithiocarbonate **3c** (entries 2 and 5). However, pentafluorophenyl thionocarbonate **3d** hydrolyzed easily giving the alcohol **3a** under these conditions (entry 6). This system also works well in the deoxygenation of various alcohols giving high yields of the corresponding deoxy products (entries 7–9).

This process is also applicable for the dehalogenation of alkyl halides. Treatment of 1-iodoadamantane **7a** with hypophosphorous acid and triethylamine in refluxing dioxane in the presence of AIBN furnished adamantane **7h** in a quantitative yield (Table IV, entry 1). This reaction could be performed with a catalytic amount of AIBN giving the same amount of the reduced product (entry 2). 1-Bromoadamantane **7b** was also easily reduced under these reaction conditions (entry 3). However, the attempted reaction of 1-chloroadamantane **7c** gave no reduced product (entry 4). Reduction of an aryl bromide and a phenylselenide was not efficient under these conditions (entries 5 and 6). The reduction of the nitro

Table III. Deoxygenation of Various Alcohols with Hypophosphorus Acid and Triethylamine in Refluxing Dioxane in the Presence of AIBN

entry	substrate	H_3PO_2 (equiv)	Et_3N (equiv)	AIBN (equiv)[a]	time (min)	yield (%)[b]
1	**3c**	5	5	0.1	240	77 (14)[c]
2	**3c**	5	5.5	0.4	40	84 (16)[c]
3	**3c**	5	11	0.5	45	91[d] (5)[c]
4	**3c**	0	0	0.4	40	0
5	**3b**	5	5.5	0.4	40	100
6	**3d**	5	5.5	0.33	60	39 (61)[c]
7	**4a**	5	5.5	0.83	150	93[d]
8	**7d**	5	5.5	0.33	60	100[e]
9	**6a**	10	11	0.66	120	91

[a] AIBN (0.2 mol equiv) was added portionwise until the reaction was completed. [b] Analyzed by ^1H NMR. [c] Alcohol **3a**. [d] Isolated yield. [e] Analyzed by GC.

Table IV. Reduction of Various Functional Groups with Hypophosphorus Acid and Triethylamine in Refluxing Dioxane in the Presence of AIBN

entry	substrate	H_3PO_2 (equiv)	Et_3N (equiv)	AIBN (equiv)[a]	time (min)	yield (%)[b]
1	**7a**	5	5.5	0.5	60	100
2	**7a**	5	5.5	0.17	90	100
3	**7b**	5	5.5	1.33	160	95
4	**7c**	10	11	1.66	200	0
5	**10**	10	11	1.66	200	41 (41)[c]
6	**7f**	10	11	1.66	200	21 (31)[c]
7	**7g**	10	11	1.66	200	0
8	**7e**	10	11	0.5	90	74 (4)[d]
9	**7e**	10	15	0.5	90	97 (3)[d]
10	**7a**	5[e]	11	2.0	300	41 (59)[c]

[a] AIBN (0.17 mol equiv) was added portionwise until the reaction was completed. [b] Analyzed by GC. [c] Starting material. [d] The formamide **7i**. [e] H_3PO_3.

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Table V. Reduction of Various Functional Groups with the Salt of Hypophosphorus Acid and *N*-Ethylpiperidine in Refluxing Dioxane in the Presence of AIBN

entry	substrate	H_3PO_2·*N*-ethylpiperidine (equiv)	AIBN (equiv)[a]	time (min)	yield (%)[b]
1	**3b**	5	0.33	60	99
2	**3b**	5	0.66	120	91[c]
3	**3c**	5	0.33	60	87 (13)[d]
4	**7d**	5	0.33	60	100
5	**6a**	10	1.16	210	91
6	**7a**	5	0.5	150	100[e]
7	**7b**	10	0.83	150	100[e]

[a] AIBN (0.2 mol equiv) was added portionwise until the reaction was completed. [b] Analyzed by ^1H NMR. [c] In benzene. [d] Alcohol **3a**. [e] Analyzed by GC.

group of **7g**[28] was not effected at all (entry 7). Only the starting material was recovered. Reduction of an isonitrile **7e**[29] gave a moderate yield of the hydrocarbon along with a hydrolyzed product, the formamide **7i**[29] (entry 8). The formation of the formamide was minimized by using excess triethylamine resulting in the increase of the amount of the hydrocarbon (entry 9). Phosphorous acid was also used in radical dehalogenation. However, it was not as efficient as hypophosphorous acid (entry 10). With various bases (tri-*n*-butylamine, tri-isooctylamine, DABCO, DBU, DBN, and *N*-ethylpiperidine), the system works equally well.

Although the radical reaction can be carried out in aqueous solutions, water-sensitive substrates give hydrolyzed products. In order to avoid hydrolysis of sensitive protecting groups, a crystalline salt of hypophosphorous acid and a base is required. Hypophosphorous acid did not give crystalline salts with triethylamine, tri-*n*-butylamine, or tri-isooctylamine. However, a crystalline salt of hypophosphorous acid was obtained with *N*-ethylpiperidine. After removing the water from the commercial 50% aqueous hypophosphorous acid solution in vacuum, *N*-ethylpiperidine was slowly added to the anhydrous hypophosphorous acid at 0 °C to afford a white crystalline salt, which is very hygroscopic. Using this salt, various alcohols were deoxygenated in high yield (Table V, entries 1–5). Dehalogenation of an alkyl iodide **7a** and a bromide **7b** was also very effective giving high yields of the corresponding hydrocarbon (entries 6 and 7).

The attempted deoxygenation of thionocarbonate **3b** was not successful with the sodium, ammonium, or pyridinum salts of hypophosphorous acid.

A vicinal diol was dideoxygenated to the corresponding olefin *via* the bis-xanthate. In this reaction, however, a so-called "sacrificial olefin" was needed in order to protect the product olefin from an attack by the phosphorus-centered reagent radical. The presence of an excess of a terminal olefin prevents the consumption of the olefin produced by the dideoxygenation process by phosphonate radical addition. The reduction of bis-xanthate **11**[30] with hypophosphorous acid, triethylamine, and AIBN in refluxing dioxane gave only 25% of the desired olefin **12**[30,31] and presumably the addition product. A similar reaction was performed in the presence of 1-dodecene for the olefination of bis-xanthate **11** resulting in a moderate yield

Table VI. Synthesis of Olefins from Bis-Xanthates 11 with Hypophosphorus Acid (5 equiv) and Triethylamine (5.5 equiv) in Refluxing Dioxane in the Presence of AIBN

entry	sacrificial olefin (equiv)[a]	AIBN (equiv)[b]	time (min)	yield (%)[c]
1	A (1)	0.83	100	63
2	A (1.5)	0.33	60	78
3	A (2)	0.33	60	72
4	A (5)	0.33	60	60
5	B (5)	0.33	60	62
6	B (2.5)	0.33	60	49
7	B (57.6)	0.33	60	60

[a] A: 1-Dodecene. B: Isobutyl vinyl ether. [b] AIBN (0.2 mol equiv) was added portionwise until the reaction was completed. [c] Analyzed by ^1H NMR.

of the desired olefin **12** (Table VI, entry 1). The highest yield was obtained with 1.5 equiv of 1-dodecene (entry 2). As the amount of the sacrificial olefin increased, the yield of the product olefin was somewhat decreased (entries 3 and 4). This can be explained as a result of trapping the reagent radical. Isobutyl vinyl ether was also used as a sacrificial olefin. This system gave only a moderate yield of the target olefin (entries 5–7).

Conclusions

Dimethyl phosphite, diethyl phosphite, hypophosphorous acid, and organic salts of hypophosphorous acid are effective radical reducing agents for organic halides, thionoesters, and isocyanides. These reagents are ideal alternatives to organic tin hydrides. They are cheap and less toxic than organotin hydrides. A simple workup procedure can be applied for the purification of the products. The excess reagents and phosphorous-containing byproducts were washed out from the reaction mixture after the radical reaction.

Experimental Section

General Procedures and Starting Materials. Melting points were determined with a Kofler hot-stage melting point apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer 881 spectrophotometer. Specific rotations were determined on a Jasco Model DIP-360 digital polarimeter. ^1H and ^{13}C NMR spectra were determined for solutions in deuterochloroform with TMS internal reference on Varian Gemini 200, Varian XL 200E, Varian XL 400, or Varian Unity 500 NMR spectrometers. ^{31}P NMR spectra were obtained on Varian XL 200 or Varian XL 400 spectrometers with H_3PO_4 as internal reference. Gas chromatography (GLC) measurements were performed on a Chrompack Packard Model 439 gas chromatograph on 30-m capillary columns. Mass spectra were obtained on a VG Analytical 70S high resolution double focusing magnetic sector mass spectrometer with attached VG 11/250J data system in the electron impact (EI) mode. Microanalyses were performed by Atlantic Microlab, Inc., Norcross, GA. Thin-layer chromatography (TLC) was performed on aluminum sheets precoated with silica gel (Merck, Kieselgel 60 F-254). Column chromatography was performed on silica gel (Merck, Kieselgel 60 230–400 mesh). Solvents were used either as purchased or dried and purified by standard methodology under argon. Other reference compounds and starting materials were purchased from Aldrich Chemical Co., Inc., Milwaukee, WI.

General Procedure for Deoxygenation with Dimethyl Phosphite. To a solution of a thionocarbonate (0.4 mmol) in dry dioxane (3 mL) was added dimethyl phosphite (2 mmol, 180 μL) under argon. Then the solution was heated to reflux and treated at 30-min intervals with 150-μL portions of a solution of 387 mg of benzoyl peroxide in 3 mL of dry dioxane. The reaction was monitored by TLC. When the reaction was complete, the

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solvent was removed in vacuum and the product was isolated by column chromatography on silica gel.

General Procedure for Deoxygenation with Diethyl Phosphite. To a solution of a thionocarbonate (0.4 mmol) in dry dioxane (3 mL) was added diethyl phosphite (270 μL, 2.0 mmol) under argon. Then the solution was heated to reflux and treated at 30-min intervals with 150-μL portions of a solution of 387 mg of benzoyl peroxide in 3 mL of dry dioxane. The reaction was monitored by TLC. When the reaction was complete the solvent was removed in vacuum and the product was isolated by column chromatography on silica gel.

1,2:5,6-Di-*O*-isopropylidene-3-*O*-[(pentafluorophenoxy)-thiocarbonyl]-α-D-glucofuranose (3d). To a solution of 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose **3a** (1.00 g, 3.84 mmol), *N*-hydroxysuccinimide (44 mg, 0.38 mmol), and pyridine (0.93 mL, 11.52 mmol) in benzene (20 mL) under argon was added pentafluorophenyl chlorothionoformate[32] (1.54 mL, 5.76 mmol) dropwise. The mixture was stirred for 2 h at room temperature. The reaction mixture was washed with 1 M HCl and saturated $NaHCO_3$ and dried over anhydrous $MgSO_4$. After evaporation of the solvent the residue was purified by column chromatography on silica gel eluting with hexane/EtOAc (8:2) to give 1.45 g (77%) of **3d**: mp 65–66 °C (hexane/CH_2Cl_2); $[\alpha]^{26}_D$ = −19.0° (*c* 1.2, $CHCl_3$); IR ($CHCl_3$) 3016, 2991, 1518, 1206, 1161, 1078, 1021, 998, 727 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.35 (s, 6 H), 1.44 (s, 3 H), 1.56 (s, 3 H), 4.00–4.20 (m, 2 H), 4.25–4.35 (m, 2 H), 4.74 (d, *J* = 4 Hz, 1 H), 5.64 (d, *J* = 2 Hz, 1 H), 6.00 (d, *J* = 4 Hz, 1 H); MS *m/e* (rel inten) 486 (M^+, 0.1), 471 (M^+ − 15, 34), 413 (12), 353 (11), 185 (35), 127 (33), 101 (100), 43 (100). Anal. Calcd for $C_{19}H_{19}F_5O_7S$: C, 46.91; H, 3.94; S 6.59. Found: C, 47.02; H, 3.88; S 6.66.

Reaction of Cholesteryl Acetate with Dimethyl Phosphite. A solution of cholesteryl acetate (0.50 g, 1.17 mmol) and dimethyl phosphite (0.54 mL, 5.84 mmol) in dioxane (10 mL) under argon was treated at 30-min intervals with 150-μL portions of a solution of 387 mg of benzoyl peroxide in 3 mL of dioxane (five times) during reflux. The reaction mixture was then treated with saturated K_2CO_3 for 12 h at room temperature. The organic layer was dried over $MgSO_4$. After evaporation of the solvent the residue was purified by column chromatography on silica gel eluting with hexane/EtOAc (3:7) giving 79% of **9**: mp 141–143 °C (acetone); $[\alpha]^{26}_D$ = −20.0° (*c* 1.15, $CHCl_3$); IR (Nujol) 2923, 2854, 1730, 1460, 1375, 1243, 1211, 1185, 1151, 1030 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.60–2.20 (m, 48 H), 3.60–3.80 (m, 6 H), 4.50–4.70 (m, 1 H); ^{31}P NMR ($CDCl_3$) δ 35.4; MS *m/e* (rel inten) 538 (M^+, 10), 478 (36), 428 (20), 368 (100), 228 (26). Anal. Calcd for $C_{31}H_{55}O_5P$: C, 69.15; H, 10.22. Found: C, 69.20; H, 10.28.

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General Procedure for Deoxygenation with Hypophosphorous Acid and a Base. The solution of a thionocarbonate (0.4 mmol) and hypophosphorous acid (207 μL, 2 mmol, 50% in H_2O) and a base (2.2 mmol) in dioxane (3 mL) under argon was treated at 30-min intervals with 150-μL portions of a solution of 218 mg of AIBN in 3 mL of dioxane during reflux. The solution was then washed with water and dried over anhydrous $MgSO_4$. After evaporation of the solvent the residue was separated by column chromatography on silica gel.

***S*-Methyl Dithiocarbonate of 1-Adamantanol (7d).** 1-Adamantanol (1.52 g, 10 mmol) was dissolved in freshly distilled dry THF (20 mL) and treated with a solution of *n*-butyllithium (2.5 M solution in hexanes) and carbon disulfide (15.0 mL, 0.25 mol) followed by methyl iodide (18.6 mL, 0.30 mol). Evaporation and recrystallization from acetone gave 1.0g (42%) of the title compound **7d**: mp 104–105 °C (acetone); ^1H NMR ($CDCl_3$) δ 1.69 (br, s, 6 H), 2.23 (br, s, 3 H), 2.41 (br, s, 9 H); ^{13}C NMR ($CDCl_3$) δ 19.1, 31.4 (3 C), 36.0 (3 C), 41.1 (3 C), 91.3, 212.6. Anal. Calcd for $C_{12}H_{18}OS_2$: C, 59.46; H, 7.48; S, 26.45. Found: C, 59.58; H, 7.46; S, 26.37.

Deiodination of 7a with Phosphorous Acid and Triethylamine. A solution of **7a** (110 mg, 0.4 mmol), H_3PO_3 (164 mg, 2 mmol), and triethylamine (0.6 mL, 4.4 mmol) in dioxane (3 mL) under argon was treated at 30-min intervals with 150-μL portions of a solution of 218 mg of AIBN in 3 mL of dioxane (ten times) during reflux. The reaction mixture was analyzed by GC to give 41% of **7h** and 59% of **7a**.

Preparation of the *N*-Ethylpiperidine Salt of Hypophosphorous Acid. Water was removed completely from hypophosphorous acid (5 g, 37.9 mmol, 50% in water) in vacuum. *N*-Ethylpiperidine (5.2 mL, 37.9 mmol) was added to the water-free hypophosphorous acid at 0 °C. A hygroscopic solid salt was formed immediately. This salt was used without further purification as a reagent.

Typical Procedure for the Dideoxygenation of 1,2:5,6-di-*O*-isopropylidene-3,4-di-*O*-[(*S*-methylthio)thiocarbonyl]-D-mannitol (11) with Hypophosphorous Acid and Triethylamine. A solution of bis-xanthate 11[30] (180 mg, 0.4 mmol), 1-dodecene (0.13 mL, 0.6 mmol), hypophosphorous acid (0.21 mL, 2.0 mmol, 50% in H_2O), and triethylamine (0.30 mL, 2.2 mmol) in dioxane (3 mL) under argon was treated twice (one portion in every 30 min) with 150-μL portions of a solution of 218 mg of AIBN in 3 mL of dioxane during reflux. The solution was passed through a silica gel pad eluting with EtOAc. After evaporation of the solvent, the residue was analyzed by ^1H NMR to give 78% of **12**.[30]

Acknowledgment. We thank the NIH and the Schering-Plough Corp. for financial support. Dr. D. O. Jang is a Schering-Plough Scholar. We also thank Dr. Tibor Timár (Alkaloida Chem. Co., Tiszavasvári, Hungary) for the preparation of xanthate **7d**.