Acknowledgment. This work was supported by grants from the Centre National de la Recherche Scientifique (ATP 823) and from Rhône-Poulenc Santé. We thank Miss E. Pacini for typing the manuscript.

Registry No. 2, 5033-95-4; **3a**, 114529-80-5; **3b**, 114529-81-6; **4a**, 50707-54-5; **4b**, 114466-82-9; **5a**, 50896-31-6; **5′a**, 114529-88-3; **5b**, 50707-55-6; **5c**, 114529-82-7; **5d**, 114529-83-8; **6a**, 114466-83-0; **6′a**, 114529-89-4; **6b**, 114529-84-9; **6b**·HCl, 114578-92-6; **6c**, 114529-85-0; **6c**·HCl, 114578-90-4; **6d**, 114529-86-1; **6d**·HCl, 114578-91-5; **7a**, 114529-87-2; **7b**, 47226-25-5; **8a**, 21772-58-7; **8b**, 56994-38-8; **11′a**, 114466-84-1; **11c**, 114529-90-7; **12′a**, 114466-85-2; **12c**, 114466-86-3; NpysCl, 68206-45-1; *p*-MeOC$_6$H$_4$CH$_2$SH, 6258-60-2.

Reaction of Raney Nickel with Alcohols

Marie E. Krafft,* William J. Crooks III, Branka Zorc, and Stephen E. Milczanowski

Department of Chemistry, Florida State University, Tallahassee, Florida 32306-3006

Received December 15, 1987

The reaction of Raney nickel with a variety of functional groups was studied. Ethers, esters, and alkyl chlorides were found to be stable to Raney nickel in refluxing toluene; however, alcohols were found to be reactive. Primary alcohols were oxidized to aldehydes and then subsequently decarbonylated, secondary alcohols were oxidized to the corresponding ketone, and tertiary alcohols were deoxygenated.

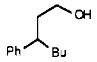
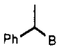
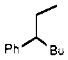
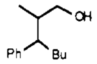
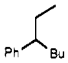
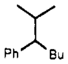
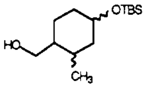
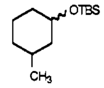
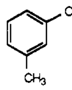
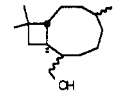
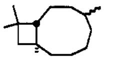
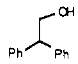
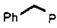
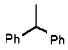
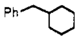
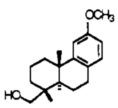
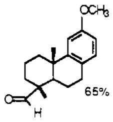
Over the years, Raney nickel has been used for many purposes, including reductive desulfurization reactions,[1] reductive alkylations of amines,[2a] and as a hydrogenation catalyst in the reduction of olefins, aromatic rings, nitro groups,[3] isoxazolidines,[4] and imines.[5] Recently we reported the use of Raney nickel in the oxidation of secondary alcohols to ketones[6] and in the deoxygenation of tertiary alcohols.[7] We have concluded our investigations of the reactivity of Raney nickel toward a variety of functional groups and now summarize the results obtained for the reaction of Raney nickel with primary, secondary, and tertiary alcohols.

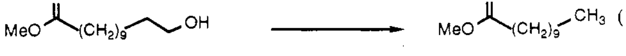
Primary Alcohols

In the presence of Raney nickel in refluxing toluene primary alcohols were oxidized to aldehydes, which subsequently underwent decarbonylation. Aldehydes have been decarbonylated with a variety of transition metals, including rhodium,[8-10] ruthenium,[10] and palladium.[10,11]

Primary alcohols, when refluxed with Raney nickel in toluene, gave rise to new, deoxygenated compounds that contained one less carbon. For example, heating a toluene solution of methyl 12-hydroxydodecanoate with Raney nickel for 3.5 h gave rise to a 73% isolated yield of methyl undecanoate (eq 1). This dehydroxymethylation procedure was found to be suitable for use with a number of substrates, and the results are summarized in Table I.

Table I

Entry	Alcohol	Product(s)			
1	$CH_3O_2C(CH_2)_{10}CH_2OH$	$CH_3O_2C(CH_2)_9CH_3$	—	73%	
2	$TBSO\text{-}(CH_2)_{11}CH_2OH$	$TBSO\text{-}(CH_2)_{10}CH_3$ 100 :	$TBSO\text{-}(CH_2)_{11}CH_3$ 1	69%	
3		 10 :	 1	72%	
4		 23 :	 1	73%	
5			—	62%	 15%
6			—	72%	
7		 3 :	 1	70%	 20%
8		—	—		 65%



$$MeOC(O)(CH_2)_9CH_2CH_2OH \longrightarrow MeOC(O)(CH_2)_9CH_3 \quad (1)$$

A plausible mechanism for the transformation involves a reversible dehydrogenation (i.e., oxidation) of the alcohol to the aldehyde, followed by an irreversible decarbonylation. The aldehyde intermediates were observed by

---

[1] Pettit, G. R.; Van Tamelen, E. E. *Org. React.* (*N.Y.*) **1962**, *12*, 356.

[2] (a) De Angeles, F.; Ferretti, G.; Botta, M.; Grgurina, I.; Nicoletti, R. *Gazz. Chim. Ital.* **1982**, *112*, 267. (b) Botta, M.; De Angeles, F.; Nicoletti, R. *Synthesis* **1977**, 722.

[3] Williams, H. W. R. *Can. J. Chem.* **1976**, *54*, 3377.

[4] Kozikowski, A. P.; Stein, P. D. *J. Am. Chem. Soc.* **1982**, *104*, 4023. Curran, D. P. *J. Am. Chem. Soc.* **1982**, *104*, 4024.

[5] Botta, M.; De Angeles, F.; Gambacorta, A.; Labbiento, L.; Nicoletti, R. *J. Org. Chem.* **1985**, *50*, 1916. Balcom, D. M.; Noller, C. R. *Organic Syntheses*; Wiley: New York, 1963; Collect. Vol. IV, p 603. Kohn, E. J.; Rice, R. G. *Organic Syntheses*; Wiley: New York, 1963; Collect. Vol. IV, p 283.

[6] Krafft, M. E.; Zorc, B. *J. Org. Chem.* **1986**, *51*, 5482.

[7] Krafft, M. E.; Crooks, W. J. *J. Org. Chem.* **1988**, *53*, 432.

[8] Ohno, K.; Tsuji, J. *J. Am. Chem. Soc.* **1968**, *90*, 99. Dawson, D. J.; Ireland, R. E. *Tetrahedron Lett.* **1968**, 1899. Ireland, R. E.; Pfister, G. *Tetrahedron Lett.* **1969**, 2145.

[9] Tsuji, J.; Ohno, K. *Tetrahedron Lett.* **1967**, 2173.

[10] Tsuji, J.; Ohno, K. *Synthesis* **1969**, 157.

[11] Wilt, J. W.; Abegg, V. P. *J. Org. Chem.* **1968**, *33*, 923.

0022-3263/88/1953-3158$01.50/0

thin-layer chromatography (TLC) analysis, and ^1H NMR analysis if the reaction was stopped before completion. In one case of a sterically hindered alcohol (Table I, entry 8), the aldehyde was isolated as the only product in 65% yield.

When methyl 12-oxododecanoate, the proposed intermediate in the dehydroxymethylation of methyl 12-hydroxydodecanoate (eq 1), was independently prepared and subjected to the action of Raney nickel in refluxing toluene, it was observed by TLC analysis that the aldehyde was almost completely reduced to the alcohol. Slowly, during the course of the reaction, approximately 3.5 h, the alcohol was reoxidized to the aldehyde and then decarbonylation occurred to give rise to methyl undecanoate.

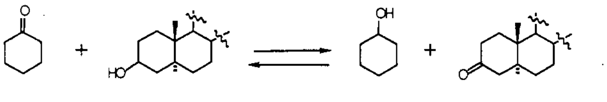
In several cases (entries 2–4), simple deoxygenation was observed as a minor competing process. The deoxygenated hydrocarbons were detected by GC–mass spectral analysis.[12] In addition, dehydrogenation of cyclohexane rings under the reaction conditions was a problem as a disubstituted benzene was isolated from the reaction of the substituted cyclohexane methanol in entry 5. Also, hydrogenation of one of the aromatic rings of 2,2-diphenylethanol occurred under the reaction conditions. Interestingly, only the diphenylmethyl functionality led to aromatic hydrogenation and neither of the other aromatic rings were reduced (i.e., entries 3, 4, and 8).

As the substitution α to the alcohol was increased, the rate of the reaction decreased. For example, the reaction shown in entry 3 in Table I required 5 h whereas the reaction shown in entry 4 took 12 h in refluxing toluene to proceed to completion. Primary neopentyl alcohols (entry 8 in Table I) were unreactive toward decarbonylation using Raney nickel, and the corresponding aldehyde was obtained in 65% yield. Adamantanemethanol gave rise to numerous products after 24 h in refluxing toluene.

Secondary Alcohols

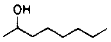
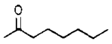
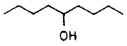
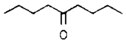
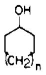
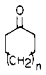
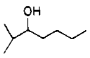
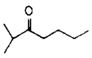
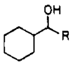
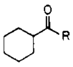
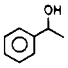
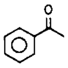
Raney nickel in refluxing benzene can be used to efficiently oxidize secondary alcohols to ketones. Numerous methods exist for the oxidation of secondary alcohols;[13] however, the use of Raney nickel provides a mild and inexpensive method of oxidation.

Oxidation of secondary alcohols to ketones using a Raney nickel catalyst has been reported. However, the reaction was carried out either at very high temperatures[14] or under equilibrating conditions in the presence of a large excess of a reversible hydrogen acceptor, cyclohexanone, to drive the reaction to completion[2,15] (eq 2). It would be more desirable if one could use mild conditions and an irreversible hydrogen acceptor to eliminate the need for a large excess of cyclohexanone.



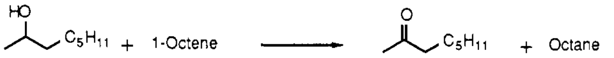
(2)

Table II

ENTRY	ALCOHOL	PRODUCT	YIELD(%)[a]	PROCEDURE[b]
1			93 91	A B
2			93	A
				
3	n=2		93	A
4	n=3		95 94	A B
5	n=5		98	A
6	n=7		96 95	A B
7			70	A
				
8	R = CH_3		85	A
9	R = nBu		89	A
10			—[c] 90	A B

[a] All yields refer to isolated materials. [b] See text for a description of procedures A and B. [c] See text for discussion.

Heating a benzene solution of 2-octanol and 2 equiv of 1-octene with Raney nickel for 3 h gave 2-octanone in 91% yield (eq 3). Unfortunately, the reaction was sluggish with other secondary alcohols and did not proceed to completion. Longer reaction times and the use of other hydrogen acceptors (1-hexyne, diethyl maleate, and valeraldehyde) did not facilitate the complete conversion of alcohol to ketone.



(3)

We found that the oxidation proceeded cleanly and in high yield in the absence of a hydrogen acceptor as is illustrated by the results in Table II. For example, the oxidation of 5-nonanol with Raney nickel in the presence of 1-octene (procedure B) proceeded only to ca. 25% completion after 9 h at 80 °C; however, 5-nonanone was obtained in 93% isolated yield by using Raney nickel in refluxing benzene for 9 h in the absence of a hydrogen acceptor (entry 2, procedure A).

Hydrogenolysis of benzylic alcohols presented a minor problem.[15] Oxidation of *sec*-phenethyl alcohol (entry 10, Table II) using Raney nickel yielded a 1:1 mixture of acetophenone and ethylbenzene, in 70% yield, when the reaction was carried out in the absence of 1-octene but yielded exclusively acetophenone in 90% yield when the reaction was carried out in the presence of 1-octene. Benzyl alcohol yielded toluene[16] as the only product upon attempted oxidation with Raney nickel in the absence of 1-octene. No benzaldehyde was detected in the 270-MHz ^1H NMR spectrum of the reaction mixture. Oxidation of benzhydrol, even in the presence of 1-octene, yielded a 2:1 mixture of benzophenone and diphenylmethane in 95% yield. Under the reaction conditions, cyclohexanol and substituted cyclohexanols reacted sluggishly and only low conversions (~25–40%) to the corresponding ketones were obtained. Using numerous different conditions, we were unable to improve the yield of the cyclohexanones, and no

---

[12] (a) We incorrectly identified the minor product obtained from the Raney nickel oxidation of 1,12-dihydroxytridecane as 2-tridecanone in our ref 6 above. It has now been correctly identified as 2-dodecanone. (b) The direct reduction of alcohols to hydrocarbons has been observed to take place at 190 °C in the presence of a Ni/Al_2O_3 catalyst: Maier, W.; Thies, I.; Schleyer, P. v. R. *Z. Naturforsch., B* **1982**, *37b*, 392.

[13] House, H. O. *Modern Synthetic Reactions*; W. A. Benjamin: Menlo, CA, 1972 and references cited therein. Cainelli, G.; Cardillo, G. *Chromium Oxidations in Organic Chemistry*; Springer-Verlag: Berlin, 1984 and references cited therein.

[14] Paul, R. *C. R. Seances Acad. Sci.* **1939**, *208*, 1319. Palfray, L.; Sabatay, S. *C. R. Seances Acad. Sci.* **1939**, *208*, 107, 1654. See also: Sandner, M. R.; Trecker, D. J. *J. Org. Chem.* **1973**, *38*, 3954. Badin, E. J. *J. Am. Chem. Soc.* **1943**, *65*, 1809.

[15] Kleiderer, E. C.; Kornfield, E. C. *J. Org. Chem.* **1948**, *13*, 455. Mahato, S. B.; Banerjee, S. K.; Chakravarti, R. N. *Tetrahedron* **1971**, *27*, 177. Forsek, J. *Tetrahedron Lett.* **1980**, *21*, 1071. Chang, F. C. *J. Org. Chem.* **1979**, *44*, 4567. Ito, K.; Harada, T.; Tai, A.; Izumi, Y. *Chem. Lett.* **1979**, 1049.

[16] The reaction was carried out in benzene-d_6 so direct ^1H NMR analysis of the reaction mixture was possible.

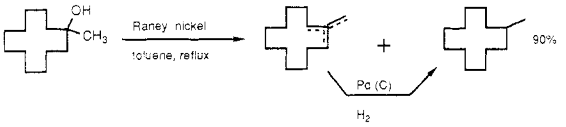
other products were found (i.e., substituted phenols).

As with the reaction of the primary alcohols with Raney nickel, increased steric hindrance about the alcohol resulted in a decrease in the rate of the reaction. A comparison can be seen with entries 7 and 9 in Table II. The reaction listed in entry 7 required 13 h in refluxing toluene but entry 9 required 24 h in refluxing toluene with additional Raney nickel in order to proceed to completion (see Experimental Section for details).

Tertiary Alcohols[7]

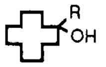
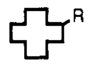
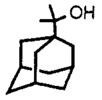
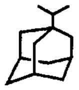
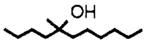
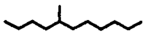
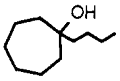
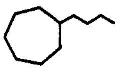
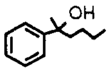
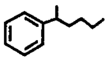
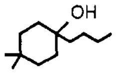
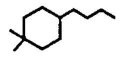
During the course of our investigation of the oxidation of secondary alcohols to ketones using Raney nickel,[6] we found that tertiary alcohols were easily deoxygenated by Raney nickel under similar reaction conditions. Tertiary alcohols have been deoxygenated[17] by a number of different routes. These include reduction of tertiary alcohol thioformates using tributylstannane,[18] acid-catalyzed hydrogenolysis using palladium or platinum catalysts in the presence of hydrogen,[19] benzylic hydrogenolysis under dissolving-metal conditions,[20] ionic deoxygenations using silanes and Lewis acids,[21] and the use of transition-metal catalysis.[22]

Heating a toluene solution of 1-methyl-1-cyclododecanol with washed Raney nickel for 40 min resulted in the formation of a mixture of methylcyclododecenes and methylcyclododecane (eq 4). For substrates that were deoxygenated very rapidly, olefin isomers were the major products; however, with longer reaction times, more alkane was observed. Filtration and subsequent hydrogenation of the olefins [Pd(C), H_2, EtOH, EtOAc] gave a 90% yield of methylcyclododecane. The deoxygenation and olefin reduction sequence could also be carried out in one step. For example, reaction of 1-methyl-1-cyclododecanol with a large excess of Raney nickel (eight times the weight of the alcohol) yielded exclusively methylcyclododecane in 90% yield after 12 h in refluxing toluene. Attempted hydrogenation of the crude reaction mixture using Raney nickel as the catalyst was unsuccessful. Addition of ethanol to the unfiltered reaction mixture followed by stirring for 24 h at ambient temperature under 1 atm of hydrogen gave rise to only very small amounts of alkane. We found that with other tertiary alcohols the reduction proceeded cleanly and in high yield, using the two-step procedure, as is illustrated by the results in Table III.



(4)

Table III

Entry	Alcohol	Product(s)^a	Yield(%)^b
			
1	R = CH_3		90
2	R = n-Bu		89
3	R = t-Bu		91^c
4			90
			
5	R = TBDMS		86
6	R = Ac		90
7			80
8			83
9			94
10		 	71 13
11			90
12			99

^{a}Products obtained after hydrogenation of the olefins. ^{b}All yields refer to isolated materials. ^{c}Yield of olefins. See text for explanation.

tert-Butyldimethylsilyl ethers and acetates were stable to the reaction conditions as is demonstrated by entries 5 and 6 in Table III. Unlike the reaction of Raney nickel with primary and secondary alcohols, the deoxygenation of tertiary alcohols appeared to be insensitive to steric hindrance. Even tertiary neopentyl alcohols could be smoothly deoxygenated (entries 3 and 4). However, we were unable to cleanly hydrogenate [Rh(alumina), Rh(COD)Clpy(PCy$_3$)PF$_6$, PtO$_2$, Pd(C)/H$_2$] the olefins that were obtained from the deoxygenation of 1-*tert*-butyl-1-cyclododecanol. Alkyl chlorides were stable to Raney nickel in refluxing toluene (entry 11), but alkyl bromides were partially hydrogenolyzed under the reaction conditions (entry 10, Table III).

Several functional groups—ethoxyethyl ethers, epoxides, olefins, and amines—were too sensitive to withstand the conditions of the reaction. Ethoxyethyl ethers and acetals reacted immediately and gave products resulting from cleavage and deoxygenation. Raney nickel reacted with cyclooctene oxide, giving rise to a 1:4 mixture of cyclooctanol and cyclooctanone[6,23] after 2.5 h in refluxing tol-

---

(17) For the deoxygenation of primary and/or secondary alcohols, see; Barton, D. H. R.; McCombie, S. W. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574; Masamune, S.; Rossy, P. A.; Bates, G. S. *J. Am. Chem. Soc.* **1973**, *95*, 6452 and references cited therein; Hartwig, W. *Tetrahedron* **1983**, *39*, 2609; Ueno, Y.; Tanaka, C.; Okawara, M. *Chem. Lett.* **1983**, 795; Fujimoto, Y.; Tatsuno, T. *Tetrahedron Lett.* **1976**, 3325; Corey, E. J.; Achiwa, K. *J. Org. Chem.* **1969**, *34*, 3667; Garbisch, E. W.; Schreader, L.; Frankel, J. J. *J. Am. Chem. Soc.* **1967**, *89*, 4233; Watanabe, Y.; Araki, T.; Ueno, Y.; Endo, T. *Tetrahedron Lett.* **1986**, *27*, 5385. For isolated examples of the reductive deoxygenation of tertiary alcohols, see: Ireland, R. E.; Muchmore, D. C.; Hengartner, U. *J. Am. Chem. Soc.* **1972**, *94*, 5098; Redlich, H.; Neumann, H. J.; Paulsen, H. *Chem. Ber.* **1977**, *110*, 2911; Pfenninger, J.; Heuberger, C.; Graf, W. *Helv. Chim. Acta* **1980**, *63*, 2328; Zderic, J. A.; Cabezas Rivera, M. E.; Limmon, D. *J. Am. Chem. Soc.* **1960**, *82*, 6373.

(18) Barton, D. H. R.; Hartwig, W.; Motherwell, R. S. H.; Motherwell, W. B.; Stange, A. *Tetrahedron Lett.* **1982**, *23*, 2019.

(19) Khan, A. M.; McQuillin, F. J. *J. Chem. Soc. C* **1967**, 136. Peterson, P. E. *J. Org. Chem.* **1964**, *29*, 2325.

(20) Small, G. H.; Minella, A. E.; Hall, S. S. *J. Org. Chem.* **1975**, *40*, 3151.

(21) Adlington, M. G.; Orfanopolous, M.; Fry, J. L. *Tetrahedron Lett.* **1976**, 2955.

(22) Alper, H.; Salisova, M. *Tetrahedron Lett.* **1980**, *21*, 801.

(23) Parish, E. J.; Schroepfer, G. J. *Chem. Phys. Lipids* **1980**, *26*, 141. For examples of the Raney nickel catalyzed (H$_2$) opening of epoxides to give rise to alcohols, see: Mitsui, S.; Senda, Y.; Shimodaira, T.; Ichikawa, H. *Bull. Chem. Soc. Jpn.* **1965**, 38, 1897. Ott, G. H.; Reichstein, T. *Helv. Chim. Acta* **1943**, *26*, 1799.

uene. Olefins were isomerized and partially reduced in the initial deoxygenation reaction and then completely reduced during the catalytic hydrogenation reaction. Primary amines have been shown to react and give rise to secondary amines[24-27] under our reaction conditions.

Deoxygenation of 1-*n*-butyl-1-cycloheptanol (Table III, entry 8) occurred cleanly in 2 h to give the corresponding hydrocarbon after catalytic hydrogenation. However, with 1-*n*-butyl-1-cyclohexanol, dehydrogenation was the major pathway and *n*-butylbenzene was obtained as the major product. The dehydrogenation pathway was thwarted when a quaternary center was introduced into the cyclohexanol ring (Table III, entry 12), and a 99% yield of the deoxygenated product was obtained.

Commercially available (Aldrich Chemical Co.) Raney nickel was used for the reactions. We found it necessary to wash the nickel with distilled water until neutral and then wash twice with 1- or 2-propanol. Reactions conducted with unwashed Raney nickel were extremely slow and the alcohol washes greatly facilitated the reaction.

The reactions of both the primary and secondary alcohols with Raney nickel required large amounts of metal. For primary alcohols, the weight of the Raney nickel should be equal to six times the weight of the alcohol, and for secondary alcohols, the weight of the nickel should be equal to four times the weight of the alcohol. We tried unsuccessfully to obtain acceptable results using less Raney nickel.

Conclusion

We feel that Raney nickel in refluxing toluene provides an efficient method for the oxidation of secondary alcohols to ketones and the deoxygenation of primary and tertiary alcohols. Although large quantities of nickel are required in some of the reactions, Raney nickel is inexpensive. One major advantage of all of the reactions described is the convenient workup procedure—filtration and solvent removal.

Experimental Section

General Information. Toluene was distilled from sodium immediately prior to use. Tetrahydrofuran (THF) and diethyl ether were distilled from potassium immediately prior to each use. Methylene chloride (CH_2Cl_2), diisopropylamine, triethylamine, and hexamethylphosphoramide (HMPA) were distilled from calcium hydride. ^{1}H NMR spectra were obtained at 270 MHz on a Bruker WP270SY instrument. Low-resolution mass spectra were obtained on a Finnigan 4510 GC/MS instrument. High-resolution mass spectra were obtained on an AEI MS 902 instrument. Chromatography refers to flash chromatography as reported by Still.[28] Elemental analyses were performed by Galbraith Laboratories, Knoxville, TN. Raney nickel was obtained from Aldrich Chemical Co. *Caution*! Nickel catalysts, in general, are thought to be carcinogenic. Special care should be taken to avoid contact.

Primary Alcohols. 12-((*tert*-Butyldimethylsilyl)oxy)-1-dodecanol. To a stirred solution of 1.02 g of methyl 12-hydroxydodecanoate (4.43 mmol) in 22 mL of CH_2Cl_2 was added 868 mg of *tert*-butyldimethylsilyl chloride (8.63 mmol) and a catalytic amount of (dimethylamino)pyridine (DMAP). After stirring for 30 min at 25 °C, the solution was diluted with CH_2Cl_2 and then washed with successive portions of 5% hydrochloric acid, saturated aqueous sodium bicarbonate, and saturated sodium chloride. The organic layer was dried over anhydrous sodium sulfate and concentrated in vacuo. The resulting oil was chromatographed with hexane/ethyl acetate (5:1) to give an 88% yield of methyl 12-((*tert*-butyldimethylsilyl)oxy)-1-dodecanoate as a clear oil (1.3 g, 3.89 mmol): ^{1}H NMR δ 0.05 (s, 6 H), 0.9 (s, 9 H), 1.3–1.4 (m, 14 H), 1.4–1.7 (m, 4 H), 2.30 (t, 2 H, J = 7.0 Hz), 3.62 (t, 2 H, J = 7.0 Hz), 3.69 (s, 3 H); IR ($CHCl_3$) 2940, 2880, 1715, 1460, 1445, 1260, 1110, 844 cm^{-1}. Methyl 12-((*tert*-butyldimethylsilyl)oxy)-1-dodecanoate (679 mg, 1.97 mmol) in 3 mL of dry ethyl ether was added to 86 mg (2.16 mmol) of lithium aluminum hydride (LAH) in 10 mL of dry ether at 25 °C. After 3 h at room temperature, the excess LAH was quenched by successive addition of 0.1 mL of water, 0.1 mL of 15% sodium hydroxide, and 0.28 mL of water. The wet ether solution was dried over sodium sulfate and filtered through a pad of Celite. Removal of the solvent yielded 12-((*tert*-butyldimethylsilyl)oxy)-1-dodecanol as a waxy white solid (511 mg, 1.62 mmol, 82%): mp 33–35 °C; ^{1}H NMR ($CDCl_3$) δ 0.05 (s, 9 H), 1.3–1.4 (m, 14 H), 1.4–1.6 (m, 4 H), 3.61 (t, 2 H, J = 7.0 Hz), 3.63 (t, 2 H, J = 7.0 Hz); IR ($CHCl_3$) 3450, 2940, 2870, 1474, 1258, 1000, 804 cm^{-1}.

2-Methyl-3-phenylheptanol. To a solution of 0.16 mL of diisopropylamine (4.13 mmol) in 25 mL of tetrahydrofuran (THF) at −78 °C was slowly added 2.2 mL of a 1.6 M solution of *n*-butyllithium in hexane (3.5 mmol). After 15 min of stirring at −78 °C, 700 mg (3.18 mmol) of methyl 3-phenylheptanoate in 7 mL of THF was added. The resulting solution was stirred for 5 min at −78 °C, warmed to 0 °C for 20 min, and recooled to −78 °C before the addition of 0.21 mL (3.34 mmol) of methyl iodide and 0.54 mL of HMPA. After 5 min, the reaction was warmed to 0 °C and stirred for 40 min before being diluted with ethyl acetate and washed with saturated sodium chloride, saturated aqueous sodium bicarbonate, and saturated sodium chloride. The organic layer was dried over anhydrous sodium sulfate and concentrated in vacuo to yield a pale oil. Chromatography using 4% ethyl acetate in hexane yielded 639 mg (2.73 mmol, 86%) of methyl (2-methyl-3-phenyl)heptanoate as a pair of diastereomers: ^{1}H NMR ($CHCl_3$) δ 0.78 (t, 3 H, J = 7.0 Hz), 0.81 (t, 3 H, J = 7.0 Hz), 0.88 (d, 2 H, J = 7.0 Hz), 1.20 (d, 2 H, J = 7.0 Hz), 0.9–1.4 (m, 4 H), 1.5–1.7 (m, 2 H), 2.6–2.9 (m, 2 H), 3.42 (s, 3 H), 3.83 (s, 3 H), 7.1–7.4 (m, 5 H); IR ($CHCl_3$) 3040, 2940, 1724, 1459, 1442, 1167 cm^{-1}. The ester (601.2 mg, 2.56 mmol) was dissolved in 10 mL of dry ether and added to a suspension of 230 mg (5.36 mmol) of LAH in 50 mL of ether. After 2 h of stirring at room temperature, 0.25 mL of water, 0.25 mL of 15% sodium hydroxide, and 0.75 mL of water were slowly added. The resulting suspension was filtered through a pad of sodium sulfate and Celite. The filtrate was reduced in vacuo to yield a clear oil. Chromatography using 25% ethyl acetate in hexane gave 442 mg (2.42 mmol, 86%) of a clear oil: ^{1}H NMR ($CDCl_3$) δ 0.77 (t, 3 H, J = 7.0 Hz), 0.82 (t, 3 H, J = 7.0 Hz), 1.05 (d, 3 H, J = 7.0 Hz), 0.9–1.1 (m, 3 H), 1.2–1.4 (m, 2 H), 1.7–1.9 (m, 2 H), 2.4–2.5 (m, 1 H), 2.6–2.7 (m, 1 H), 3.3–3.4 (m, 2 H), 3.4–3.6 (m, 2 H), 7.1–7.4 (m, 5 H); IR ($CHCl_3$) 3460, 3040, 2890, 1604, 1505, 1478, 1462, 1025 cm^{-1}. Anal. Calcd for $C_{14}H_{22}O$: C, 81.50; H, 10.75. Found: C, 81.51; H, 10.61.

4-((*tert*-Butyldimethylsilyl)oxy)-2-methylcyclohexanemethanol. To a stirred solution of 1.24 g of 4-carbethoxy-3-methylcyclohexanone (6.74 mmol) in 34 mL of methanol at 0 °C was added 96 mg of sodium borohydride (2.48 mmol). After 10 min at 0 °C, the excess sodium borohydride was quenched by the addition of several drops of water. The reaction mixture was diluted with ethyl acetate and washed with saturated aqueous sodium chloride. The aqueous layer was reextracted six times with a 1:1 mixture of ethyl acetate in hexane. The organic layers were combined, dried over anhydrous sodium sulfate, and reduced to afford a clear oil. Chromatography on silica gel using a 1:1 mixture of ethyl acetate in hexane afforded 1.15 g (6.18 mmol, 92%) of 4-carbethoxy-3-methylcyclohexanol as a mixture of diastereomers: ^{1}H NMR ($CDCl_3$) δ [0.92 (d, 3 H, J = 2.8 Hz), 0.94 (d, 3 H, J = 2.0 Hz), 1.04 (d, 3 H, J = 6.4 Hz)], 1.26 (t, 3 H, J = 7.0 Hz), 1.4–2.1 (m, 8 H), 2.4–2.6 (m, 1 H), 3.5–3.7 (m, 1 H), 4.13 (q, 2 H, J = 7.0 Hz); IR ($CHCl_3$) 3440, 2945, 1720, 1458, 1369, 1182, 1100, 1022 cm^{-1}. To a stirred solution of 1.11 g (5.96 mmol)

---

[24] Kindler, K.; Melamed, G.; Matthies, D. *Justus Liebigs Ann. Chem.* **1961**, *644*, 23.

[25] Zderic, J. A.; Bonner, W. A.; Greenlee, T. W. *J. Am. Chem. Soc.* **1957**, *79*, 1696.

[26] Ainsworth, C. *J. Am. Chem. Soc.* **1956**, *78*, 1635.

[27] We found that some secondary amines reacted in the presence of Raney nickel and gave rise to tertiary amines. For example, reaction of dibutylamine with Raney nickel (equal to eight times the weight of the amine) for 10 h in refluxing toluene gave rise to a 75% yield of tributylamine. Unfortunately, with other secondary amines, the reactions were very sluggish and only low conversions to the tertiary amines were observed.

[28] Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

Table IV. Data for Raney Nickel Reactions Listed in Table I

entry	time, h	yield, %	entry	time, h	yield, %
1	3.5	73	5	14	62
2	3.5	69[a]	6	3	72
3	5	72[a]	7	2	70[b]
4	12	73[a]	8	24	64[c]

[a] Ratio determined by gas chromatography. [b] Ratio determined by NMR integration. [c] Aldehyde.

Table V. Data for Raney Nickel Reactions Listed in Table II

entry	amt of Ni	procedure	time, h
1	4×	A	4
	4×	B	3
2	4×[a]	A	9
3	4×	A	3
4	4×	A	1.5
	4×	B	2
5	4×[a]	A	7
6	4×	A	1
	4×	B	3
7	4×[a]	A	13
8	4×[a]	A	20
9	4×[b]	A	24
10	4×	B	1

[a] Raney nickel (equal to three times the weight of the alcohol), washed as previously described, was added to the reaction mixture after 6 h. [b] Raney nickel (equal to three times the weight of the alcohol), washed as previously described, was added to the reaction mixture after 7 and 12 h.

of 4-carbethoxy-3-methylcyclohexanol in 30 mL of methylene chloride at room temperature were added 1.2 g of *tert*-butyldimethylsilyl chloride (7.96 mmol), 1.66 mL of triethylamine (11.92 mmol), and a catalytic amount of (dimethylamino)pyridine. After 52 h, the reaction mixture was diluted with a 1:1 mixture of ethyl acetate in hexane and washed with portions of 5% HCl, saturated aqueous sodium bicarbonate, and saturated aqueous sodium chloride. The organic layer was dried over anhydrous sodium sulfate and reduced to afford a yellow oil. Chromatography over silica gel using hexane/ethyl acetate (9:1) yielded 1.56 g of 1-((*tert*-butyldimethylsilyl)oxy)-4-carbethoxy-3-methylcyclohexane (4.78 mmol, 80%): ^{1}H NMR (CDCl$_3$) δ 0.05 (s, 6 H), 0.84 (s, 9 H), 1.15 (d, 3 H, J = 6.8 Hz), 1.21 (t, 3 H, J = 7.0 Hz), 1.5–2.1 (m, 7 H), 2.48 (dt, 1 H, J = 4.6, 4.6 Hz), 3.68 (m, 1 H), 4.13 (q, 2 H, J = 7.0 Hz); IR (CHCl$_3$) 2940, 1720, 1464, 1378, 1258, 1180, 1107, 1076, 865 cm^{-1}. A solution of 1.46 g (4.48 mmol) of 1-((*tert*-butyldimethylsilyl)oxy)-4-carbethoxy-3-methylcyclohexane in 10 mL of anhydrous ether was added to a suspension of 123 mg (3.08 mmol) of LAH in 15 mL of ether at room temperature. After 30 min, the excess LAH was quenched by successive addition of 0.12 mL of water, 0.12 mL of 15% NaOH, and 0.36 mL of water, with vigorous stirring, to leave a crystalline precipitate. Filtration of the precipitate through a pad of Celite and sodium sulfate and removal of the solvent provided a clear oil, which was chromatographed on silica gel using a 3:1 mixture of hexane/ethyl acetate. Evaporation of the solvent yielded 1.23 g (4.32 mmol, 96%) of 4-((*tert*-butyldimethylsilyl)oxy)-2-methylcyclohexanemethanol as a clear oil: ^{1}H NMR (CDCl$_3$) δ 0.05 (s, 6 H), 0.84 (s, 9 H), 0.93 (d, 3 H, J = 7.0 Hz), 1.1–1.9 (m, 7 H), 3.5–3.7 (m, 3 H); IR (CHCl$_3$) 3440, 2940, 2875, 1464, 1258, 1112, 1068, 878, 842 cm^{-1}. Anal. Calcd for C$_{14}$H$_{30}$O$_2$Si: C, 65.06; H, 11.70. Found: C, 64.83; H, 11.70.

General Procedure for the Decarbonylation of Primary Alcohols. A solution of 198 mg (1 mmol) of methyl 12-hydroxydodecanoate in 4 mL of toluene was added to 1.2 g of a washed Raney nickel slurry. [The Raney nickel was weighed as an aqueous slurry where most of the water had been removed before weighing. The weight of the Raney nickel was equal to six times the weight of the alcohol. Immediately before each use the slurry was washed eight times, with vigorous stirring, with distilled water and twice with 2-propanol.] The residual water and 2-propanol were azeotropically removed from the slurry using an efficient Dean–Stark trap and a hot oil bath (~140–150 °C). Less than 10 min was necessary for complete removal of the water. The remaining suspension was refluxed for 3.5 h with vigorous stirring, cooled to room temperature, and filtered through a pad of Celite using 30% ethyl acetate in hexane. (Caution! The Raney nickel may still be pyrophoric.) The solvent was removed in vacuo to leave a pale oil, which was chromatographed on silica gel using 5% ethyl acetate in hexane. Evaporation of the solvent yielded 122 mg (73%) of methyl undecanoate as a colorless oil.

Secondary Alcohols. All of the secondary alcohols listed in Table II were prepared by the addition of alkyllithium reagents to aldehydes or by the addition of hydride to the corresponding ketone.

General Procedure for the Oxidation of Secondary Alcohols. Procedure A. A solution of 200 mg (1.54 mmol) of 2-octanol in 2.2 mL of benzene was added to 800 mg of a washed Raney nickel slurry. [The Raney nickel was weighed as an aqueous slurry where most of the water had been removed before weighing. The weight of the Raney nickel was equal to four times the weight of the alcohol. Five of the alcohols required the addition of more Raney nickel during the course of the reaction (see below). Immediately before each use the slurry was washed eight times, with vigorous stirring, with distilled water and twice with 1-propanol.] The residual water and 1-propanol were azeotropically removed from the slurry using an efficient Dean–Stark trap and a hot oil bath (~125–135 °C). Less than 10 min was necessary for complete removal of the water. The remaining suspension was refluxed for 3.5 h with vigorous stirring, cooled to room temperature, and filtered through a pad of Celite using 30% ethyl acetate in hexane. (Caution! The Raney nickel may still be pyrophoric.) The solvent was removed in vacuo to leave a pale oil, which was chromatographed on silica gel using 5% ethyl acetate in hexane. Evaporation of the solvent yielded 184 mg (93%) of 2-octanone as a colorless oil. **Procedure B.** This procedure was the same as procedure A except that a solution of 2 equiv of 1-octene and 1 equiv of the alcohol in 2.2 mL of benzene was added to the Raney nickel slurry.

Tertiary Alcohols. All of the alcohols listed in Table III were prepared by the addition of the appropriate alkyllithium reagent to a ketone or ester.

General Procedure for the Addition of Alkyllithium Reagents to Ketones. Preparation of 5-Methyl-5-undecanol. To a stirred solution of 1.72 g of 2-octanone (13.5 mmol) in 40 mL of THF at −78 °C was added 12 mL of a 1.5 M solution of *n*-butyllithium in hexane (18 mmol) slowly down the edge of the cooled flask. After 15 min, the excess butyllithium was quenched with 1 mL of saturated aqueous sodium chloride. The reaction mixture was warmed to room temperature, washed with saturated aqueous sodium chloride, dried over anhydrous sodium sulfate, and evaporated to afford a mixture of starting ketone and 5-methyl-5-undecanol. Since enolization was a major side reaction, the *n*-butyllithium addition procedure was repeated twice. The resulting oil was chromatographed using a 20:1 mixture of hexane in ethyl acetate to yield 2.0 g of 5-methyl-5-undecanol as a colorless oil (10.75 mmol, 80%): ^{1}H NMR (CDCl$_3$) δ 0.81 (t, 3 H, J = 7.0 Hz), 0.83 (t, 3 H, J = 7.0 Hz), 1.2–1.7 (m, 19 H); IR (CHCl$_3$) 3500, 2973, 2900, 1475, 1385, 1225 cm^{-1}. Anal. Calcd for C$_{12}$H$_{26}$O: C, 77.35; H, 14.06. Found: C, 77.25; H, 14.15. Yields for the preparation of other tertiary alcohols (entry, yield): 1, 67%; 2, 79%; 3, 50%; 7, 80%; 8, 65%; 9, 58%; 10, 69%; 12, 69%.

Preparation of 2-Methyl-13-acetoxy-2-tridecanol. To a stirred solution of 2-methyl-13-hydroxy-2-tridecanol (480 mg, 2.08 mmol) in 10 mL of methylene chloride at 0 °C were added acetic anhydride (0.26 mL, 2.71 mmol), triethylamine (0.6 mL, 4.16 mmol), and a catalytic amount of DMAP. After 30 min at 0 °C, the reaction mixture was diluted with 80 mL of diethyl ether/hexane (1:1) and washed with successive portions of 5% HCl, saturated sodium bicarbonate, and saturated sodium chloride. The organic layer was dried over anhydrous sodium sulfate, reduced to an oil, and chromatographed on silica gel using hexane/ethyl acetate (7:3) to afford 2-methyl-13-acetoxy-2-tridecanol (521 mg, 1.91 mmol, 92%): ^{1}H NMR (CDCl$_3$) δ 1.20 (s, 6 H), 1.2–1.6 (m, 22 H), 2.05 (s, 3 H), 4.06 (t, 2 H, J = 6.5 Hz); IR (CHCl$_3$) 3445, 2945, 2870, 1725, 1473, 1395, 1368, 1255 cm^{-1}. Anal. Calcd for C$_{16}$H$_{32}$O: C, 70.54; H, 11.84. Found: C, 70.94; H, 12.02.

Preparation of 13-Bromo-2-methyl-2-tridecanol. To a stirred solution of 13-hydroxy-2-methyl-2-tridecanol (285 mg, 1.24

Table VI. Data for Raney Nickel Reactions Listed in Table III

entry	time, min	yield, %	entry	time, min	yield, %
1	40	90	7	40	80
2	40	89	8	120	83
3	40	91	9	20	94
4	40	90	10	120	71
5	40	86	11	40	90
6	90	90	12	40	99

mmol) in 7 mL of methylene chloride at 0 °C was added 414 mg of carbon tetrabromide (1.25 mmol). Triphenylphosphine (433 mg, 1.65 mmol) was added slowly to prevent warming of the reaction mixture. Upon addition the reaction was warmed to room temperature. After 9 h at room temperature, the reaction mixture was diluted with ethyl acetate and hexane and washed twice with saturated sodium chloride, dried over anhydrous sodium sulfate, and concentrated to afford an oily solid. The residue was filtered through a 1-in. plug of silica gel using ethyl acetate/hexane (1:9). The filtrate was concentrated to a clear oil and chromatographed on silica gel using ethyl acetate/hexane (1:9) to afford 249 mg of 13-bromo-2-methyl-2-tridecanol as a clear oil (0.850 mmol, 69%): ^1H NMR ($CDCl_3$) δ 1.22 (s, 6 H), 1.2–1.5 (m, 18 H), 1.85 (t, 2 H, J = 6.5 Hz), 3.37 (t, 2 H, J = 6.5 Hz); IR ($CHCl_3$) 3445, 2895, 2745, 1568, 1378, 1220 cm^{-1}. Anal. Calcd for $C_{14}H_{29}OBr$: C, 57.33; H, 9.97. Found: C, 57.26; H, 10.11.

General Procedure for the Deoxygenation of Tertiary Alcohols. A solution of 200 mg (1.01 mmol) of 1-methyl-1-cyclododecanol in 3 mL of toluene was added to 400 mg of a Raney nickel slurry. [The Raney nickel was weighed as an aqueous slurry where most of the liquid had been removed before weighing. The weight of the Raney nickel slurry was equal to two times the weight of the alcohol. Immediately before each use the slurry was washed eight times, with vigorous stirring, with 8 mL of distilled water and two times with 1-propanol.] The residual water and the 1-propanol were azeotropically removed from the slurry very rapidly using an efficient Dean–Stark trap and a hot oil bath (~140 °C). Less than 10 min was necessary for complete removal of the water. The remaining suspension was refluxed for 40 min with vigorous stirring, cooled to room temperature, and filtered through a pad of Celite using 30% ethyl acetate in hexanes. (Caution! The Raney nickel may still be pyrophoric.) The solvent was removed in vacuo, leaving a pale oil, which was diluted with a 1:1 mixture of ethanol and ethyl acetate and stirred under 1 atm of hydrogen for 8 h at room temperature in the presence of a catalytic amount of 5% Pd(C). Filtration and solvent removal yielded 181 mg of methylcyclododecane (90%).

Acknowledgment. This work was supported by the National Science Foundation (Grant CHE-8704933), the donors of the Petroleum Research Fund, administered by the American Chemical Society, an Atlantic Richfield Foundation Grant of Research Corporation, and the Florida State University Center for Research and Creativity. B.Z. acknowledges the Florida State University Center for Yugoslav–American Studies for a fellowship.

Registry No. TBCl, 18162-48-6; Ni, 7440-02-0; $CH_3O_2C(CH_2)_{10}CH_2OH$, 71655-36-2; $CH_3O_2C(CH_2)_9CH_3$, 1731-86-8; $CH_3O_2C(CH_2)_{10}CH_2OTBS$, 95841-29-5; $TBSO(CH_2)_{11}CH_2OH$, 114302-23-7; $TBSO(CH_2)_{10}CH_3$, 114302-27-1; (±)-$PhCH(Bu)(CH_2)_2OH$, 114376-30-6; (±)-$PhCH(CH_3)Bu$, 114376-31-7; (±)-$PhCH(C_2H_5)Bu$, 114302-28-2; (±)-$PhCH(Bu)CH_2CO_2CH_3$, 114302-30-6; (R*,R*)-(±)-$PhCH(Bu)CH(CH_3)CO_2CH_3$, 114302-32-8; (R*,S*)-(±)-$PhCH(Bu)CH(CH_3)CO_2CH_3$, 114302-31-7; (R*,R*)-(±)-$PhCH(Bu)CH(CH_3)CH_2OH$, 114302-33-9; (R*,S*)-(±)-$PhCH(Bu)CH(CH_3)CH_2OH$, 114302-24-8; $CH_3C_6H_4$-3-OTBS, 62790-75-4; Ph_2CHCH_2OH, 1883-32-5; Ph_2CH_2, 101-81-5; Ph_2CHCH_3, 612-00-0; $CH_2{=}CHC_6H_{13}$, 111-66-0; (±)-$CH_3CH(OH)C_6H_{13}$, 4128-31-8; $CH_3COC_6H_{13}$, 111-13-7; Bu_2CHOH, 623-93-8; Bu_2CO, 502-56-7; (±)-$(CH_3)_2CHCH(OH)Bu$, 100296-26-2; $(CH_3)_2CHCOBu$, 13019-20-0; (±)-$PhCH(OH)CH_3$, 13323-81-4; $PhCOCH_3$, 98-86-2; PhC_2H_5, 100-41-4; $(CH_3)_2C(OH)(CH_2)_{11}OTBDMS$, 111772-84-0; $(CH_3)_2CH(CH_2)_{11}OTBDMS$, 111772-89-5; $(CH_3)_2C(OH)(CH_2)_{11}OH$, 109183-00-8; $(CH_3)_2C(OH)(CH_2)_{11}OAc$, 111772-85-1; $(CH_3)_2CH(CH_2)_{11}OAc$, 88591-30-4; (±)-$BuCH_3C(OH)C_6H_{13}$, 114302-35-1; (±)-$BuCH(CH_3)C_6H_{13}$, 114376-34-0; (±)-$PhC(CH_3)(OH)Bu$, 114376-33-9; $(CH_3)_2C(OH)(CH_2)_{11}Br$, 111772-86-2; $(CH_3)_2CH(CH_2)_{11}Br$, 111772-90-8; $(CH_3)_2CH(CH_2)_{10}CH_3$, 1560-96-9; $(CH_3)_2C(OH)(CH_2)_{11}Cl$, 111772-87-3; $(CH_3)_2CH(CH_2)_{11}Cl$, 111793-80-7; 4-carbethoxy-3-methylcyclohexanone, 62617-91-8; 4-carbethoxy-3-methylcyclohexanol, 72641-04-4; 1-[(*tert*-butyldimethylsilyl)oxy]-4-carbethoxy-3-methylcyclohexane, 114302-34-0; 4-[(*tert*-butyldimethylsilyl)oxy]-2-methylcyclohexanemethanol, 114302-25-9; 1-[(*tert*-butyldimethylsilyl)oxy]-3-methylcyclohexane, 114302-29-3; 6,10,10-trimethylbicyclo[7.2.0]undecane-2-methanol, 114302-26-0; 6,10,10-trimethylbicyclo[7.2.0]undecane, 114324-39-9; benzylcyclohexane, 4410-75-7; 12-*O*-methylpodocarpol, 16826-86-1; 12-*O*-methylpodocarpal, 16826-83-8; cycloheptanol, 502-41-0; cycloheptanone, 502-42-1; cyclooctanol, 696-71-9; cyclooctanone, 502-49-8; cyclodecanol, 1502-05-2; cyclodecanone, 1502-06-3; cyclododecanol, 1724-39-6; cyclododecanone, 830-13-7; (±)-α-methylcyclohexanemethanol, 104713-60-2; cyclohexyl methyl ketone, 823-76-7; (±)-α-butylcyclohexanemethanol, 114376-32-8; cyclohexyl butyl ketone, 5445-35-2; 1-methylcyclododecanol, 32400-09-2; methylcyclododecane, 1731-43-7; 1-butylcyclododecanol, 16282-71-6; butylcyclododecane, 102860-64-0; 1-*tert*-butylcyclododecanol, 111772-83-9; *tert*-butylcyclododecane, 61682-11-9; 2-(1-adamantyl)-2-propanol, 775-64-4; 1-isopropyladamantane, 773-32-0; 1-butylcycloheptanol, 3898-34-8; butylcycloheptane, 13152-41-5; 1-butyl-4,4-dimethylcyclohexanol, 111772-88-4; 1,1-dimethyl-4-butylcyclohexane, 111772-91-9.