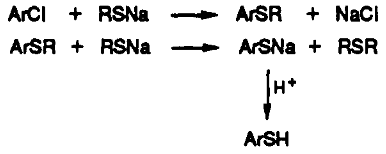
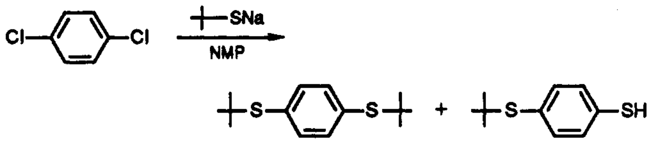
Scheme I



of thiophenols. Reaction of 1,4-dichlorobenzene with the sodium salt of *tert*-butyl mercaptan gave compounds 2 and 3 in yields of 89 and 7%, respectively. Thiophenol 3 was probably formed from 2 by elimination of isobutene rather than by nucleophilic substitution since no di-*tert*-butyl sulfide was observed.



2 3

In all the reactions of aryl chlorides with sodium alkanethiolates, the thiolate was prepared by reaction of an alkyl mercaptan with sodium hydroxide in NMP. Before addition of the aryl chloride, it was necessary to remove the water that was formed since the reaction rates were too slow with water present. This was accomplished by addition of toluene and azeotropic distillation of water with toluene. In small-scale reactions, the sodium alkanethiolates can be produced using sodium hydride so water is not formed and the azeotropic distillation step can be avoided.

Experimental Section

4-Methylbenzenethiol. To a 3-L, three-necked flask equipped with a N_2 inlet, thermowell, magnetic stirring bar, and Dean Stark trap with condenser were added 900 mL of NMP, 96 g (2.4 mol) of sodium hydroxide, and 183 g (218 mL, 2.4 mol) of *n*-propyl mercaptan. The mixture was stirred and heated at 40 °C until the NaOH dissolved. Then, 375 mL of toluene was added and the mixture was heated at reflux with water being removed by the Dean Stark trap. After all the water (~45 mL) was removed, the toluene (375 mL) was distilled off. An extra 25 mL of liquid was distilled off to ensure complete removal of toluene. The reaction flask was allowed to cool almost to room temperature. The Dean Stark trap was removed, but the condensor was retained. Then, 76.0 g (0.60 mol) of 4-chlorotoluene was added and the solution was refluxed (~186 °C) overnight (20 h). The solution was cooled to room temperature. A solution of 225 mL of concentrated hydrochloric acid and 225 mL of water was added slowly with stirring and cooling until the mixture reached pH 3. After addition of an additional 450 mL of water, the mixture was extracted with 900 mL of ethyl ether. The aqueous layer was extracted a second time with 450 mL of ether. The combined ether extract was washed with three 150-mL portions of water, dried with anhydrous sodium sulfate, and evaporated under reduced pressure to give 172 g of liquid. GC analysis (20 in. × $^1/_8$ in. 2% OV-101 with programmed temperature rise of 15 °C/min starting at 50 °C) of the liquid showed that it contained 41.6% 4-methylbenzenethiol and 30.7% di-*n*-propyl sulfide. The yield of 4-methylbenzenethiol by GC was 96%. The liquid was fractionally distilled on a column containing high-efficiency stainless steel packing. The isolated yield of 4-methylbenzenethiol (bp 109-110 °C (50 Torr)) was 87%. All products were identified by comparison with authentic materials by IR, NMR, and GC retention time.

When the above reaction was carried out with *n*-butyl mercaptan instead of *n*-propyl mercaptan, the yield (GC) of 4-methylbenzenethiol was 90%.

2-Methylbenzenethiol. The reaction was carried out in the same way as for 4-methylbenzenethiol except one-third scale, and *n*-butyl mercaptan was used instead of *n*-propyl mercaptan. The amount of 2-chlorotoluene used was 25.3 g (0.20 mol). Workup gave 67.2 g of a liquid that was shown by GC analysis to contain 35.3% of 2-methylbenzenethiol and 44.0% of di-*n*-butyl sulfide. The yield of 2-methylbenzenethiol by GC was 96%. All products were identified by comparison with authentic materials.

Thiophenol. The reaction procedure was the same as that described for 4-methylbenzenethiol except at one-third scale, with use of chlorobenzene. The reaction temperature was 172 °C, and the reaction time was 9 h. The yield (GC) of thiophenol was 92%.

4-(*n*-Butylthio)benzenethiol (1). The procedure was the same as that described for 4-methylbenzenethiol except on a smaller scale, using 0.133 mol of 1,4-dichlorobenzene and 0.80 mol of sodium butanethiolate derived from *n*-butyl mercaptan. The reflux temperature was 185-190 °C and the reaction time was 9 h. After the workup described previously, GC analysis of the crude product showed the yield was 94%.

Compound 1 was isolated by extraction of an ether solution of the crude product with 10% aqueous NaOH solution. The aqueous layer was acidified with 4 M HCl solution and then extracted with ether. The ether extract was washed two times with water, dried over anhydrous sodium sulfate, evaporated, and distilled: bp 162-165 °C (15 Torr) (lit.[3] bp 165 °C (16 Torr)); IR (neat) 1475, 1388, 1107, 1009, 803, 484 cm^{-1}; ^{1}H NMR (90 MHz, CDCl$_3$) δ 0.87 (t, 3 H, J = 7.2 Hz), 1.12-1.78 (m, 4 H), 2.81 (t, 2 H, J = 7.0 Hz), 3.53 (s, 1 H), 7.02-7.53 (m, 4 H). Anal. Calcd for $C_{10}H_{14}S_2$: C, 60.55; H, 7.12; S, 32.33. Found: C, 60.84; H, 7.01; S, 32.01.

1,4-Bis(*tert*-butylthio)benzene (2) and 4-(*tert*-Butylthio)benzenethiol (3). The procedure was the same as that described previously, except on a smaller scale, with use of 0.40 mol of 1,4-dichlorobenzene and 1.6 mol of sodium alkanethiolate derived from *tert*-butyl mercaptan. The reaction mixture was heated at 150 °C rather than refluxed and the reaction time was 6.5 h. After workup, 100.9 g of a white solid was obtained. GC analysis of the solid showed it contained 89.8% of 2 and 5.5% of 3. The yields (GC) of 2 and 3 were 89 and 7%, respectively.

The two compounds were separated by the extraction procedure described for 1. Compound 2 was obtained as white crystals: mp 111-113 °C (lit.[4] mp 112-113 °C); IR (neat) 1462, 1367, 1171, 832, 578, 508 cm^{-1}; ^{1}H NMR (90 MHz, CDCl$_3$) δ 1.31 (s, 18 H), 7.52 (s, 4 H); MS m/z 254 (M$^+$), 142 (base), 57, 41. Anal. Calcd for $C_{14}H_{22}S_2$: C, 66.08; H, 8.72; S, 25.20. Found: C, 65.98; H, 8.65; S, 24.98.

Compound 3 was a pale yellow liquid: IR (neat) 1473, 1360, 1164, 1104, 1011, 814, 499 cm^{-1}; ^{1}H NMR (90 MHz, CDCl$_3$) δ 1.24 (s, 9 H), 3.52 (s, 1 H), 7.12-7.50 (m, 4 H); MS m/z 198 (M$^+$), 142 (base), 78, 57. Anal. Calcd for $C_{10}H_{14}S_2$: C, 60.55; H, 7.12; S, 32.33. Found: C, 60.56; H, 7.04; S, 32.16.

Acknowledgment. I wish to thank Marilyn G. McAfee for doing many of the experiments.

---

(3) Protiva, M.; Rajsner, M.; Adlerova, E.; Scidlova, V.; Vejdelek, Z. J. *Collect. Czech. Chem. Commun.* 1964, *29*, 2161-2181.
(4) Cogolli, P.; Testaferri, L.; Tingoli, M.; Tiecco, M. *J. Org. Chem.* 1979, *44*, 2636-2642.

Effective Transformation of Unactivated Alkynes into Ketones or Acetals by Means of Au(III) Catalyst

Yukitoshi Fukuda[†] and Kiitiro Utimoto*

Department of Industrial Chemistry, Faculty of Engineering, Kyoto University, Yoshida, Kyoto, 606 Japan

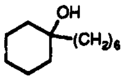
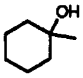
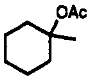
Received October 4, 1990

Hydration is one of the most useful functionalizations of simple alkynes, especially for the preparation of methyl ketones from terminal alkynes. Therefore, a variety of catalysts for this reaction have been extensively studied.[1-14]

[†] On leave from Kyowa Yuka Co., Ltd., Yokkaichi, Mie, Japan.

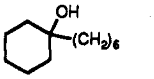
0022-3263/91/1956-3729$02.50/0 © 1991 American Chemical Society

Table I. Ketones 2 and 3 from Alkynes 1 by Au(III)-Catalyzed Hydration (Scheme I)

entry	alkyne	R^1	R^2	reactn time (h)	yield (%)	product (ratio)
1	**1a**	$n\text{-}C_6H_{13}$	H	1	91	**2a**[c]
2	**1b**	$n\text{-}C_{10}H_{21}$	H	1	94	**2b**[c]
3	**1c**	Ph	H	1	91	**2c**[c]
4	**1d**		H	1	83	**2d**
5	**1e**	$HO(CH_2)_9$	H	1	91	**2e**[d]
6	**1f**		H	5	0[a]	
7	**1g**		H	1	92	**2g**
8	**1h**	$HOCH_2$	H	5	0[a]	
9	**1i**	$C_5H_{11}CH(OAc)$	H	1	96	**2i**
10	**1j**	$n\text{-}C_6H_{13}$	$n\text{-}C_6H_{13}$	5	94	**2j** = **3j**[e]
11	**1k**	$n\text{-}C_6H_{13}$	CH_3	5	94	**2k**/**3k**[c] (40/60)
12	**1l**	Ph	C_2H_5	10	28[b]	**2l**/**3l**[c] (57/43)

[a] Starting material was recovered. [b] Determined by ^{1}H NMR. [c] Reference 25. [d] Reference 20. [e] Reference 21.

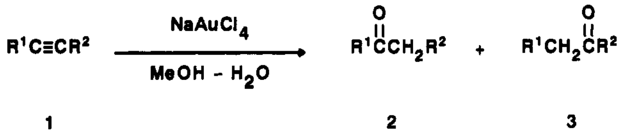
Table II. Acetals 4 and 5 from Alkynes 1 (Scheme II)

entry	alkyne	R^1	R^2	reactn time (h)	yield (%)	product
1	**1a**	$n\text{-}C_6H_{13}$	H	1	85	**4a**[a]
2	**1b**	$n\text{-}C_{10}H_{21}$	H	1	86	**4b**[b]
3	**1c**	Ph	H	1	96	**4c**[c]
4	**1d**		H	1	95	**4d**
5	**1j**	$n\text{-}C_6H_{13}$	$n\text{-}C_6H_{13}$	10	93	**4j** = **5j**

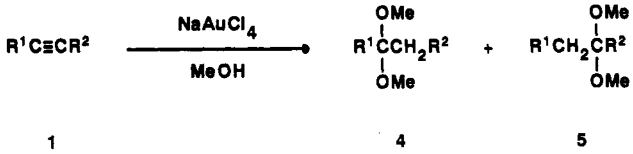
[a] Reference 22. [b] Reference 23. [c] Reference 24.

Mercury(II) salts are effective for the hydration of many alkynes and have been commonly utilized; however, the reaction requires strongly acidic conditions.[1-10] Although other transition-metal salts, including Pd(II), have been used as catalysts,[11-13] unactivated simple alkynes are sometimes recovered unchanged.[12,13] Hydration of unactivated alkynes by the use of Zeise-type platinum compound has also been reported.[14] On the other hand, it was reported that a gold(III) salt was effective for the intramolecular addition of an amine to an acetylene bond under mild conditions, whereas Pd(II) catalyst provided unsatisfactory results.[15] These observations were ascribed to the effective activation of alkynes by Au(III) catalyst and prompted successful application of unactivated alkynes. This study describes the use of Au(III) in aqueous methanol for the hydration of alkynes to ketones. Direct formation of dimethyl acetals from alkynes by addition of 2 equiv of methanol is also achieved under appropriate reaction conditions in contrast to the recovery of the starting alkyne in the platinum-catalyzed reaction.[14]

Scheme I



Scheme II



Treatment of 1-alkynes **1** (R^2 = H) with 2 mol % of sodium tetrachloroaurate in refluxing aqueous methanol[16] afforded the corresponding methyl ketones **2** (R^2 = H) in excellent yields (Scheme I). Internal acetylenes were also smoothly hydrated to mixtures of ketones due to the lack of regioselectivity. Although a terminal acetylene possessing a remote hydroxyl group gives the corresponding ketone smoothly, hydration of an alkyne bearing a propargylic hydroxyl group proceeded sluggishly (entries 6 and 8, Table I). Protection of the hydroxyl group as an acetate, however, improves the yield of the products; an ester function is tolerated under the reaction conditions. The results are summarized in Table I. Although the results shown in Table I were obtained from milligram-scale re-

---

(1) Hudrlik, P. F.; Hudrlik, A. M. *The Chemistry of Carbon-Carbon Triple Bond*; John Wiley and Sons: New York, 1978; Part I.

(2) Jager, V.; Viehe, H. G. *Methoden der Organishen Chemie (Houben-Weyl)*; Muller, E., Ed.; 1977; 4th ed., Vol. V/2a.

(3) Rutledge, T. F. *Acetylenes and Allenes*; Reinhold: New York, 1969.

(4) Olah, G. A.; Meidar, D. *Synthesis* **1978**, 671.

(5) Chandra, G.; Devaprahakara, D.; Muthana, M. S. *Curr. Sci.* **1971**, *40*, 400.

(6) Stacy, G. W.; Mikulec, R. A. *Organic Syntheses*; Wiley: New York, 1963; Collect. Vol. IV, p 13.

(7) Newman, M. S. *J. Am. Chem. Soc.* **1953**, *75*, 4740.

(8) Islam, A. M.; Raphael, R. A. *J. Chem. Soc.* **1952**, 4086.

(9) Janout, A.; Regen, S. L. *J. Org. Chem.* **1982**, *47*, 3331.

(10) Stork, G.; Borch, R. *J. Am. Chem. Soc.* **1964**, *86*, 935, 936.

(11) Harman, W. D.; Dobson, J. C.; Taube, H. *J. Am. Chem. Soc.* **1989**, *111*, 3061.

(12) Imi, K.; Imai, K.; Utimoto, K. *Tetrahedron Lett.* **1987**, *28*, 3127.

(13) Utimoto, K. *Pure Appl. Chem.* **1983**, *55*, 1845.

(14) Hiscox, W. C.; Jennings, P. W. *Organometallics* **1990**, *9*, 1997.

(15) Fukuda, Y.; Utimoto, K.; Nozaki, H. *Heterocycles* **1987**, *25*, 297.

(16) The pH value of the reaction medium was roughly 5, determined by pH test paper (Toyo Roshi Co., Ltd.).

actions, gram-scale reactions afforded the corresponding products in analogously excellent yields.

Under the above-described condition, olefins were recovered unchanged as exemplified by the competitive reaction of 1-dodecyne (**1b**) and 1-dodecene. Treatment of an equimolar mixture of **1b** and 1-dodecene under the above-described condition for 1 h afforded 2-dodecanone (**2b**) in 96% yield and 1-dodecene was recovered almost quantitatively. Other products could not be detected by ^{1}H NMR analysis of the crude product.

A gold(I) complex was not effective for the hydration of acetylenes; upon substituting $KAu(CN)_2$ in place of $NaAuCl_4$, alkynes were not hydrated and were recovered unchanged.

Alkynes **1** were directly converted to dimethyl acetals **4** and **5** in excellent yields by the addition of 2 equiv of methanol, when the reaction was carried out in anhydrous methanol (Scheme II). The dimethyl acetal of the methyl ketone is obtained exclusively from 1-alkyne. Examples are shown in Table II. Acetal formation from 1-alkynes described here can be applied to gram-scale reaction; 2,2-dimethoxydodecane (**4b**) was obtained in 89% yield from 5 g (30.1 mmol) of 1-dodecyne (**1b**).

Although dimethyl acetals were successfully obtained by the reaction as above, direct conversion of alkynes to cyclic acetals even by the same treatment with 1 equiv of diols was not successful. However, as dimethyl acetals can be converted into other cyclic acetals, including acetals derived from optically active diols,[17-19] the above-described acetal preparation from acetylene should be useful in organic synthesis.

Experimental Section

^{1}H NMR were measured at 200 MHz.

Hydration of an Alkyne (General Procedure). To a stirring solution of an alkyne (6 mmol) and water (1 mL) in 10 mL of methanol was added $NaAuCl_4{\cdot}2H_2O$ (48 mg, 0.12 mmol, 0.02 equiv), and the mixture was heated at reflux for 1 to 10 h. The reaction mixture was concentrated under reduced pressure and the residue was diluted with ether and washed with a 1:1 mixture of brine and aqueous ammonia. The ethereal solution was dried over Na_2SO_4 and concentrated to give the product.

1-(7-Octynyl)-1-cyclohexanol (1d): bp 140 °C (2 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 1.20–1.75 (20 H, m), 1.94 (1 H, t, J = 2.5 Hz), 2.20 (2 H, dt, J = 2.5, 6.8 Hz); IR (neat) 3550–3100, 3250 cm^{-1}. Anal. Calcd for $C_{14}H_{24}O$: C, 80.71; H, 11.61. Found: C, 80.62; H, 11.86.

8-(1-Hydroxycyclohexyl)-2-octanone (2d): bp 145 °C (2 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 1.10–1.68 (20 H, m), 2.04 (3 H, s), 2.33 (2 H, t, J = 6.1 Hz); IR (neat) 3620–3100, 1710 cm^{-1}. Anal. Calcd for $C_{14}H_{26}O_2$: C, 74.29; H, 11.58. Found: C, 74.31, H, 11.78.

1-Ethynylcyclohexyl acetate (1g): bp 100 °C (2 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 1.25–2.23 (10 H, m), 2.05 (3 H, s), 2.61 (1 H, s); IR (neat) 3280, 2105, 1744, 1368, 1264, 1230, 1145, 1043, 1025, 956 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.26; H, 8.48. Found: C, 72.26; H, 8.54.

1-Acetoxycyclohexyl methyl ketone (2g): bp 105 °C (2 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 1.40–1.78 (10 H, m), 2.10 (3 H, s), 2.13 (3 H, m); IR (neat) 1738, 1732, 1715, 1369, 1266, 1138 cm^{-1}. Anal. Calcd for $C_{10}H_{16}O_3$: C, 65.19; H, 8.75. Found: C, 65.30; H, 9.00.

3-Acetoxy-1-octyne (1i): bp 80 °C (2 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 0.90 (3 H, t, J = 6.0 Hz), 1.26–1.90 (8 H, m), 2.07 (3 H, s), 2.46 (1 H, d, J = 2.3 Hz), 5.36 (1 H, dt, J = 2.3, 6.6 Hz); IR (neat) 3280, 2120, 1740, 1372, 1236, 1120, 1020 cm^{-1}. Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.29; H, 9.54.

3-Acetoxy-2-octanone (2i): bp 98 °C (8 mmHg); ^{1}H NMR ($CDCl_3$) δ 0.87 (3 H, t, J = 6.0 Hz), 1.23–1.80 (8 H, m), 2.12 (3 H, s), 2.13 (3 H, s), 4.98 (1 H, dd, J = 5.0, 7.4 Hz); IR (neat) 1743, 1736, 1241, 1120, 1078, 1040 cm^{-1}. Anal. Calcd for $C_{10}H_{18}O_3$: C, 64.49; H, 9.74. Found: C, 64.35; H, 9.79.

Hydration of Alkyne in Gram-Scale Reaction. To a solution of 1-dodecyne (5 g, 30.1 mmol) and water (6 mL) in methanol (60 mL) was added $NaAuCl_4{\cdot}2H_2O$ (240 mg, 0.60 mmol, 0.02 equiv), and the whole was heated at reflux for 1 h. After removal of methanol under reduced pressure from the reaction mixture, the residue was diluted with ether and washed with a 1:1 mixture of brine and aqueous ammonia. The ethereal solution was dried over Na_2SO_4 and concentrated. Distillation [bp 107 °C (8 mmHg)] of the concentrate gave 4.6 g of 2-dodecanone (25 mmol, 83% yield).

By the analogous treatment of 3-acetoxy-1-octyne (5 g, 29.8 mmol) with $NaAuCl_4{\cdot}2H_2O$ (237 mg, 0.60 mmol, 0.02 equiv) in a refluxing mixture of methanol (60 mL) and water (6 mL) for 1 h, 4.8 g of 3-acetoxy-2-octanone (25.8 mmol, 87% yield) was isolated by distillation [bp 98 °C (8 mmHg)].

Competitive Hydration of 1-Dodecyne and 1-Dodecene. A mixture of 415 mg (2.5 mmol) of 1-dodecyne and 420 mg (2.5 mmol) of 1-dodecene was treated with 20 mg of $NaAuCl_4{\cdot}2H_2O$ (0.05 mmol, 0.02 equiv) in refluxing methanol (10 mL, containing ca. 10% H_2O) for 1 h. The reaction mixture was worked up as described above to give 817 mg of oily product, which contained 441 mg (95% yield) of 2-octanone and 376 mg (90% recovery) of 1-dodecene.

Direct Formation of Dimethyl Acetal from an Alkyne (General Procedure). A solution of an alkyne (5 mmol) and $NaAuCl_4{\cdot}2H_2O$ (40 mg, 0.1 mmol, 0.02 equiv) in anhydrous methanol (10 mL) was heated at reflux for 1 h to 10 h. To the cooled reaction mixture was added triethylamine (1 mL), and the solution was then concentrated in vacuo. The residue was diluted with ether and washed with a 1:1 mixture of brine and aqueous ammonia. The ethereal solution was dried over Na_2SO_4 and concentrated to afford the product.

1-(7,7-Dimethoxyoctyl)cyclohexanol (4d): bp 140 °C (1 mmHg, Kugelrohr); ^{1}H NMR ($CDCl_3$) δ 1.16 (3 H, s), 1.20–1.75 (22 H, m), 3.09 (6 H, s); IR (neat) 3650–3200 cm^{-1}. Anal. Calcd for $C_{16}H_{32}O_3$: C, 70.54; H, 11.84. Found: C, 70.53; H, 11.87.

7,7-Dimethoxytetradecane (4i = 5i): bp 160 °C (2 mmHg, Kugelrohr); ^{1}H NMR (C_6D_6) δ 0.89 (3 H, t, J = 6.5 Hz), 0.90 (3 H, t, J = 6.5 Hz), 1.15–1.80 (22 H, m), 3.10 (6 H, s); IR (neat), 1380, 1275, 1090 cm^{-1}. Anal. Calcd for $C_{16}H_{34}O_2$: C, 74.36; H, 13.26. Found: C, 74.49; 13.39.

---

(17) Bartlett, P. A.; Johnson, W. S.; Elliott, J. D. *J. Am. Chem. Soc.* **1983**, *105*, 2088.

(18) Johnson, W. S.; Elliott, R.; Elliott, J. D. *J. Am. Chem. Soc.* **1983**, *105*, 2904.

(19) Mori, A.; Fujiwara, J.; Maruoka, K.; Yamamoto, H. *Tetrahedron Lett.* **1983**, *24*, 4581.

(20) Nonaka, T.; Kanemoto, S.; Oshima, K.; Nozaki, H. *Bull. Chem. Soc. Jpn.* **1984**, *57*, 2019.

(21) Pelter, A.; Harrison, C. R.; Sburahamanyan, C.; Kirkpatrick, D. *J. Chem. Soc., Perkin Trans. I* **1976**, 2435.

(22) Shono, T.; Matsumura, Y.; Kashimura, S. *J. Org. Chem.* **1983**, *48*, 3338.

(23) Shin, K. H. U.S. Patent 4209643, 1980; *Chem. Abstr.* **1980**, *93*, P185768t.

(24) Basseti, M.; Floris, B. *J. Chem. Soc., Perkin Trans. II* **1988**, 227. They obtained acetophenone dimethyl acetal (**4c**) in 49% yield from ethynylbenzene (**1c**) by $Hg(OAc)_2$-catalyzed reaction in methanol.

(25) Listed in *Catalog Handbook of Fine Chemicals*; Aldrich: 1990–1991.

Synthesis of Methyl- and Methoxy-Substituted β-D-Ribofuranosylnaphthalene Derivatives by Lewis Acid Catalyzed Ribofuranosylation

Norimitsu Hamamichi*,[1] and Tadashi Miyasaka

School of Pharmaceutical Sciences, Showa University, Hatanodai 1-5-8, Shinagawa-ku, Tokyo 142, Japan

Received March 29, 1990

Lewis acid catalyzed C-ribofuranosylation is an important synthetic introduction to naturally occurring *C*-

0022-3263/91/1956-3731$02.50/0 © 1991 American Chemical Society