CSIRO Publishing

AUSTRALIAN JOURNAL OF CHEMISTRY

AN INTERNATIONAL JOURNAL FOR CHEMICAL SCIENCE

publishing research papers from all fields of chemical science, including synthesis, structure, new materials, macromolecules, supramolecular chemistry, biological chemistry, nanotechnology, surface chemistry, and analytical techniques.

Volume 54, 2001

All enquiries and manuscripts should be directed to:

Dr Alison Green
Australian Journal of Chemistry – an International Journal for Chemical Science
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood, Vic. 3066, Australia

Telephone: +61 3 9662 7630
Fax: +61 3 9662 7611
E-mail: publishing.ajc@csiro.au

Published by CSIRO PUBLISHING
for CSIRO and the Australian Academy of Science

www.publish.csiro.au/journals/ajc

Aust. J. Chem. **2001**, *54*, 401–404

Palladium-Catalysed Cross Coupling of Arylboronic Acids with 2-Chloro-1,4-naphthoquinones: the Synthesis of 2-Aryl- and 2,3-Bisaryl-1,4-naphthoquinones

Wayne M. Best,[A,B] *Colette G. Sims*[A] *and Merilyn Winslade*[A]

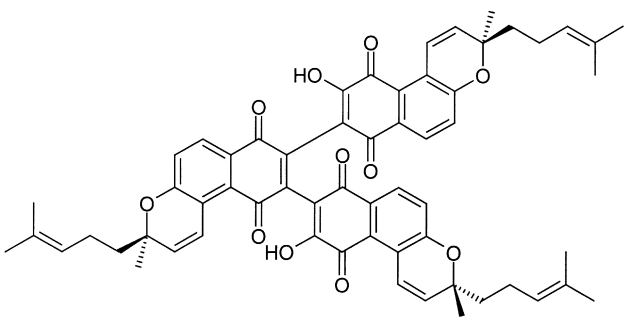
[A] The Chemistry Centre (WA), 125 Hay St, East Perth, W.A. 6004, Australia.
[B]Author to whom correspondence should be addressed (e-mail: wbest@ccwa.wa.gov.au).

2-Chloro-1,4-naphthoquinones underwent palladium-catalysed cross coupling reactions with arylboronic acids to give the corresponding 2-aryl-1,4-naphthoquinones. Similarly, 2,3-dichloro-1,4-naphthoquinone underwent efficient cross coupling reactions with arylboronic acids to give mono or bis adducts. The required 2-chloro-1,4-naphthoquinones were conveniently prepared from the corresponding 2-hydroxy-1,4-naphthoquinones by treatment with oxalyl chloride.

Manuscript received: 26 March 2001.
Final Version: 3 September 2001.

Introduction

In connection with investigations we were conducting into the naturally occurring anti-HIV compound conocurvone (1),[1] we were interested in methodologies for the synthesis of 2,3-bisaryl-1,4-naphthoquinones. Traditionally, Meerwein type reactions have been used to arylate 1,4-naphthoquinones, and Takahashi et al. have employed this methodology to prepare a number of 2,3-bisaryl-1,4-naphthoquinones.[2] However, the yields of Meerwein reactions are often poor, and the range of compatible functional groups is somewhat limited. More recently, Yoshida et al. have published the palladium-catalysed cross couplings of aryl and heteroarylstannanes with 2,3-dibromo-1,4-quinones to give a number of 2,3-bisaryl-1,4-naphthoquinones.[3,4] Similarly, Stagliano et al. have reported a three-step procedure for the preparation of 2,3-bisaryl-1,4-quinones involving palladium-catalysed cross couplings of arylstannanes with activated 1,4-naphthoquinones,[5] and they have recently exploited this methodology in the synthesis of conocurvone analogues.[6]



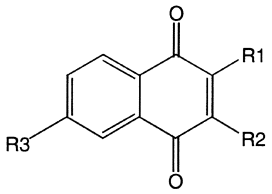
conocurvone (1)

We sought a simple one-step procedure to 2,3-bisaryl-1,4-naphthoquinones from readily available starting materials, that would also be amenable to a wide range of functional groups, and would avoid the use of tin. Procedures involving tin were unattractive to us because of the potential for tin contamination in the final products, and the associated toxicity.

The palladium-catalysed cross coupling of aryl halides with arylboronic acids (the Suzuki coupling) has been widely applied to the formation of biaryl compounds.[7] However, this technique has received limited attention for the arylation of haloquinones, with only a handful of bromoquinones having been tried[4,8,9] and not always successfully.[10] This appears to be due, at least in part, to the poor stability of bromoquinones, particularly under the aqueous conditions usually employed in the Suzuki coupling. The iodoquinones are even less stable and more difficult to obtain. Chloronaphthoquinones do not appear to have been used in Suzuki couplings, perhaps because aryl and vinyl chlorides are, in general, much less susceptible to Suzuki couplings than the corresponding bromides and iodides.[11]

However, we were encouraged to attempt such couplings on 2-chloro-1,4-naphthoquinones, with the expectation that they would be more reactive than their unactivated vinyl counterparts, and the knowledge that they are considerably more stable than the corresponding bromo or iodonaphthoquinones. In addition, we had access to a number of chloroquinones produced by a simple method developed in our laboratory and later described in this paper. More importantly, 2,3-dichloro-1,4-naphthoquinone (DCNQ) (2) is commercially available and inexpensive. To our delight, Suzuki couplings on these 2-chloro-1,4-naphthoquinones

 10.1071/CH01024 0004-9425/01/060401



Compound	R1	R2	R3
(2)	Cl	Cl	H
(3)	Ph	Ph	H
(4)	4-chlorophenyl	4-chlorophenyl	H
(5)	4-methoxyphenyl	4-methoxyphenyl	H
(6)	2,6-dimethoxyphenyl	2,6-dimethoxyphenyl	H
(7)	1-naphthyl	1-naphthyl	H
(8)	6-methoxy-2-naphthyl	6-methoxy-2-naphthyl	H
(9)	1-naphthyl	Cl	H
(10)	1-naphthyl	2,6-dimethoxyphenyl	H
(11)	Me	Ph	H
(12)	H	Ph	H
(13)	H	n-Bu	H
(14)	H	Cl	H
(15)	Me	Cl	H
(16)	H	Cl	MeO
(17)	H	OH	H
(18)	Me	OH	H
(19)	H	OH	MeO

proceeded smoothly to give the desired adducts in good to excellent yields.

Results and Discussion

A number of 2-chloro-1,4-naphthoquinones were mono-arylated to give the corresponding 2-aryl-1,4-naphtho-quinones (Table 1, entries g–j), by treatment with 1.0 to 2.5 equivalents of an arylboronic acid and aqueous sodium carbonate, in the presence of a catalytic amount of tetrakis(triphenylphosphine)palladium(0). Reactions were carried out in either refluxing benzene or toluene, under an inert atmosphere, and were generally complete within 15 h. Similarly, DCNQ (2) was converted into a number of 2,3-bisaryl-1,4-naphthoquinones (Table 1, entries a–f), using 2.2 to 3.5 equivalents of arylboronic acids. The yields of these couplings, which ranged from 51–100%, were generally the result of a single experiment and were not optimized. The reactions were usually quite clean, although small amounts of biaryl derivatives (derived from dimerization of the boronic acids) were often observed, and were occasionally difficult to separate from the desired products by chromatography. Small amounts of hydroxyquinones (resulting from hydrolysis of the chloroquinones) were also observed in some cases, but were easily removed. In theory, this hydrolysis could be prevented by using anhydrous conditions,[12] but this was not investigated.

Table 1. Arylation and alkylation of 2-chloro-1,4-naphthoquinones

Entry	Chloride	Product	Equiv. $R\text{-}B(OH)_2$	Time (h)	Yield (%)	m.p. (°C)
a	(2)	(3)	2.5	4	74	140 (lit.[15] 135–136)
b	(2)	(4)	2.5	6	99	188–189 (lit.[2] 189.5–190.5)
c	(2)	(5)	2.5	4	100	167–168.5 (lit.[2] 156–157)
d	(2)	(6)	3.5	40	51	225
e	(2)	(7)	2.3	6	89	>230
f	(2)	(8)	2.2	15	78	229–230
g	(2)	(9)	1.0	15	75	201–202
h	(9)	(10)	2.5	40	57	166–168
i	(15)	(11)	1.2	3	86	68 (lit.[20] 112–113[A])
j	(14)	(12)	1.2	3	62	111–112 (lit.[15] 110)
k	(14)	(13)	1.2	20	66	38–40 (lit.[21] 45–46)

[A] The combustion analysis reported in this reference is 0.55% less than the theoretical value for H; however, both C and H are consistent with 2-phenyl-1,4-naphthoquinone (14) as is the reported m.p. of 112–113°C.

These couplings can tolerate considerable steric hindrance, as illustrated by the reaction of 2,6-dimethoxyphenylboronic acid with DCNQ (2) (Table 1, entry d) which still proceeds in an acceptable yield. In the case of the bisnaphthyl adduct (7), where the substituents are asymmetrical, this steric crowding was reflected in the observation of two distinct rotamers which could be detected by both nuclear magnetic resonance (NMR) spectroscopy and thin-layer chromatography (TLC) analysis. While ^{13}C NMR indicated a ratio of approximately 1:3 for these rotamers, gas chromatography (GC) analysis indicated only a single component, possibly because of the higher temperature required for GC.

Attempts to prepare monoaryl adducts from DCNQ (2) by restricting the amount of arylboronic acid and reducing reaction times met with only limited success. In most cases, gas chromatography mass spectroscopy (GCMS) analysis of the crude reaction products indicated that mixtures of starting material, monoaryl adduct, and bisaryl adduct were produced. Furthermore, the separation of these mixtures into pure mono or bis adduct, by column chromatography, was often difficult. However, reasonably good selectivities were observed using the more sterically hindered boronic acids, such as 1-naphthyl and 2-methoxyphenyl boronic acids. The preparation of mono adducts from DCNQ (2) allows a different group to be introduced in a subsequent Suzuki reaction, thereby enabling the preparation of unsymmetrical 2,3-diaryl naphthoquinones. This process is illustrated by the preparation of the unsymmetrical diaryl naphthoquinone (10) from DCNQ (2) in two steps, via the monoaryl naphthoquinone (9).

In addition to the preparation of aryl substituted naphthoquinones, this Suzuki methodology also allows the synthesis of alkyl naphthoquinones, as demonstrated by the preparation of 2-butyl-1,4-naphthoquinone (13) from 2-chloro-1,4-naphthoquinone (14) and butylboronic acid in 66% yield (Table 1, entry k).

Many substituted arylboronic acids are now commercially available, which adds to the attraction of these Suzuki couplings. Where they are not commercially available, they can be conveniently prepared by treating the corresponding Grignard reagent, or organolithium reagent, with trimethyl borate followed by hydrolysis of the intermediate borate ester. More recently, Miyaura et al. have developed bis(pinacolato)diboron as a useful reagent for the preparation

of arylboronic esters when functional groups preclude the use of organometallic intermediates.[13]

With the exception of DCNQ (2), the required 2-chloro-1,4-naphthoquinones are not commercially available, and although several methods are available for their synthesis,[14–16] we were keen to find a quick, simple, and high yielding method amenable to laboratory scale. A number of 2-hydroxy-1,4-naphthoquinones are either commercially available, occur as natural products, or are easily synthesized. In addition, we have found that they can be readily converted into the corresponding 2-chloro-1,4-naphthoquinones in almost quantitative yields by treatment with oxalyl chloride, under mild conditions (Table 2). In a typical procedure, a 2-hydroxy-1,4-naphthoquinone is treated with excess oxalyl chloride, and a catalytic amount of DMF, in benzene at 20–50ºC, for 0.5–2 h. This transformation appears to be quite general and high yielding, and is presumably analogous to the conversion of carboxylic acids to acid chlorides, and 1,3-diones to 3-chloro-2-enones.[17] Indeed, 2-hydroxy-1,4-naphthoquinones are quite acidic, and can be considered as vinylogous carboxylic acids.

Table 2. Preparation of 2-chloro-1,4-naphthoquinones

Entry	Hydroxy quinone	Chloride	Equiv. oxalyl chloride	Time (min)	Yield (%)	m.p. (°C)
a	(17)	(14)	2.8	45	95	114.5–115 (lit.[16]114–115)
b	(18)	(15)	5.8	60	94	155 (lit.[22]151–152)
c	(19)	(16)	2.8	45	95	170–172

Conclusions

In summary, we have shown that the palladium-catalysed cross coupling reaction of 2-chloro-1,4-naphthoquinones with boronic acids is a mild and efficient way of preparing 2-aryl-1,4-naphthoquinones. The ready availability of DCNQ (2) makes this method ideal for the synthesis of 2,3-bisaryl-1,4-naphthoquinones. In addition, we have found that 2-chloro-1,4-naphthoquinones are easily prepared from the corresponding 2-hydroxy-1,4-naphthoquinones in almost quantitative yields. 2-Chloro-1,4-naphthoquinones are important intermediates, not just for this work, but for a variety of syntheses, particularly the syntheses of anthracyclinones.[18]

Experimental

NMR spectra were recorded in deuterated chloroform at either 200 MHz (Varian Gemini 200) or 300 MHz (Bruker AM-300). Mass spectra were recorded using an HP-5890 Gas Chromatograph fitted with an HP-5972 Mass Selective detector. Melting point (m.p.) analyses were determined on a Kofler block, and are uncorrected. Combustion analyses were performed by Chemical & Micro Analytical Services Pty Ltd (Victoria). Boronic acids have not been thoroughly characterized, due to their propensity to lose water and form varying amounts of the cyclic trimeric anhydrides. Tetrakis(triphenylphosphine)palladium(0) was purchased from Lancaster Synthesis, and used without further purification. All reactions were carried out under an inert atmosphere. Unless otherwise stated, all chromatography was conducted over silica gel 60 (0.040–0.063 mm, Merck 9385).

Arylation of 2-Chloro-1,4-naphthoquinones. General Procedure A

2,3-Bisphenyl-1,4-naphthoquinone (3)

A mixture of DCNQ (2) (230 mg, 1.0 mmol) and phenylboronic acid (300 mg, 2.5 mmol) in benzene (5 mL), was treated with $Pd(PPh_3)_4$ (65 mg) and 2 M aqueous sodium carbonate solution (2.2 mL). The mixture was stirred under reflux for 4 h before being poured into water and worked up by ether extraction in the usual way. The crude product was chromatographed (elution with 1:6 ethyl acetate/hexane), and then recrystallized from ethanol to give 2,3-bisphenyl-1,4-naphthoquinone (3) as bright yellow prisms (230 mg, 74%), m.p. 140°C (lit.[15] 135–136°C). ^{1}H NMR (300 MHz) δ 7.05–7.11, m, 4H, Ph; 7.19–7.27, m, 6H, Ph; 7.76–7.82, m, H6, H7; 8.17–8.23 m, H5, H8. Mass spectrum *m/z* 311 (24%); 310 (100, M^+); 281 (44); 252 (21); 104 (27); 76 (28).

2,3-Bis(2,6-dimethoxyphenyl)-1,4-naphthoquinone (6)

A mixture of DCNQ (2) (200 mg, 0.87 mmol) and 2,6-dimethoxyphenylboronic acid (364 mg, 2.0 mmol), in toluene (5 mL), was treated with $Pd(PPh_3)_4$ (60 mg) and 2 M aqueous sodium carbonate solution (2.0 mL). The mixture was stirred under reflux overnight before further 2,6-dimethoxyphenylboronic acid (182 mg, 1.0 mmol), $Pd(PPh_3)_4$ (20 mg) and 2 M aqueous sodium carbonate solution (1.0 mL) were added. The reaction was refluxed for a further 24 h before being poured into 5% aqueous sodium carbonate and worked up with dichloromethane extraction in the usual way. The crude product was chromatographed (elution with 1:4 to 1:1 ethyl acetate/hexane) to give *2,3-bis(2,6-dimethoxyphenyl)-1,4-naphthoquinone* (6) as a yellow–brown solid (190 mg, 51%). A small sample was recrystallized from ethanol for analysis to give yellow microneedles. Upon heating, the microneedles slowly melted and changed form from 180 to 218°C, before finally becoming completely liquid at approximately 225°C (Found: C, 72.5; H, 5.1. $C_{26}H_{22}O_6$ requires C, 72.6; H, 5.1%). ^{1}H NMR (200 MHz) δ 3.56, s, OMe; 6.42, d, *J* 8.4 Hz, H3′, H5′; 7.15, t, *J* 8.4 Hz, H4′; 7.69–7.74, m, H6, H7; 8.15–8.19, m, H5, H8. Mass spectrum *m/z* 430 (100%, M^+); 399 (21); 292 (33); 263 (25); 165 (22); 161 (23); 149 (42); 133 (23); 104 (43); 76 (30).

2,3-Bis(1-naphthyl)-1,4-naphthoquinone (7)

Following General Procedure A, but refluxing for 6 h, (7) was prepared in 89% yield (after chromatography; elution with benzene) from DCNQ (2) and 2.3 equiv. of 1-naphthylboronic acid. Obtained as a bright orange *solid*, m.p. >230°C (Found: C, 87.8; H, 4.5. $C_{30}H_{18}O_2$ requires C, 87.8; H, 4.4%). ^{1}H NMR (300 MHz) δ 6.89, dd, 1.5H, *J* 7.1, 1.2 Hz, H2′ (major rotamer); 6.99, dd, 1.5H, *J* 8.2, 7.1 Hz, H3′ (major rotamer); 7.13–7.30, m, 2H; 7.44–7.53, m, 3H; 7.59–7.66, m, 3H; 7.73–7.80, m, 3H; 7.81–7.87, m, H6, H7; 8.21–8.28, m, H5, H8. ^{13}C NMR (75 MHz) δ 184.60, CO (relative peak height 0.8); 184.37, CO (2.4); 148.59, C2 and C3 (2.1); 147.96, C2 and C3 (0.8); 134.09, CH (10.0); 133.02, C (1.6); 132.94, C (3.4); 132.41, C (0.9); 132.33, C (2.6); 131.94, C (3.0); 130.93, C (1.3); 130.90, C (1.3); 128.84, CH (8.1); 128.78, CH (3.8); 128.46, CH (7.6); 128.20, CH (4.1); 128.17, CH (4.0); 126.99, CH (9.6); 126.41, CH (7.6); 125.84, CH (8.4); 125.76, CH (4.2); 125.54, CH (8.3); 125.47, CH (10.2); 124.91, CH (8.9); 124.30, CH (3.0). Mass spectrum *m/z* 410 (100%, M^+); 381 (8); 363 (11); 276 (19); 252 (9); 104 (14); 76 (16).

2,3-Bis(6-methoxy-2-naphthyl)-1,4-naphthoquinone (8)

6-Bromo-2-methoxynaphthalene (2.4 g, 10 mmol) in THF (10 mL) was treated with magnesium turnings (0.25 g, 10 mmol), and the resulting Grignard reagent was diluted with THF (10 mL) and cooled in an ice bath. Trimethyl borate (1.2 mL, 11 mmol) was added, and the mixture stirred for 15 min before water (20 mL) was added. Stirring was continued for a further 15 min before the mixture was acidified with 1 M HCl, and worked up by ether extraction in the usual manner. The crude product was triturated with hexane, and the resulting colourless, 6-methoxy-2-naphthylboronic acid (1.6 g, 80%) collected by filtration.

This material was of sufficient purity for use in Suzuki couplings and was not characterized further.

A portion of this boronic acid (1.1 g, 5.4 mmol) and DCNQ (2) (575 mg, 2.5 mmol) in benzene (25 mL), was treated with $Pd(PPh_3)_4$ (100 mg) and 2 M aqueous sodium carbonate solution (5.5 mL). The mixture was refluxed overnight before being poured into water and worked up using dichloromethane extraction in the usual manner. The crude product was chromatographed (elution with benzene) to give *2,3-bis(6-methoxy-2-naphthyl)-1,4-naphthoquinone* (8) as a red solid (0.92 g, 78%). A small sample was recrystallized from ethyl acetate for analysis, m.p. 229–230°C (Found: C, 82.0; H, 4.7. $C_{32}H_{22}O_4$ requires C, 81.7; H, 4.7%). ^{1}H NMR (300 MHz) δ 3.86, s, OMe; 6.99, d, *J* 2.5 Hz, H5′; 7.06, dd, *J* 8.9, 2.5 Hz, H7′; 7.10, dd, *J* 8.5, 1.7 Hz, H3′; 7.48, d, *J* 8.5 Hz, H4′; 7.59, d, *J* 8.9 Hz, H8′; 7.64, br. d, *J* 1.4 Hz, H1′; 7.78–7.84, m, H6, H7; 8.20–8.26, m, H5, H8.

2-Chloro-3-(1-naphthyl)-1,4-naphthoquinone (9)

Following General Procedure A, but refluxing for 15 h, (9) was prepared in 75% yield (after chromatography; elution with 1:1 benzene/hexane) from DCNQ (2) and 1.0 equiv. of 1-naphthylboronic acid. Obtained as a bright yellow *solid*, m.p. 201–202°C (Found: C, 75.3; H, 3.3. $C_{20}H_{11}ClO_2$ requires C, 75.4; H, 3.5%). ^{1}H NMR (300 MHz) δ 7.37, dd, *J* 7.1, 1.1 Hz, H2′; 7.42–7.55, m, 3H; 7.60, dd, *J* 8.3, 7.1 Hz, H3′; 7.80–7.86, m, H6, H7; 7.93–8.00, m, 2H; 8.14–8.19, m, H5 or H8; 8.27–8.31, m, H5 or H8. Mass spectrum *m/z* 320 (47%, M^+); 318 (100, M^+); 284 (20); 283 (78); 255 (45); 227 (30); 226 (92); 151 (24); 150 (22); 127 (18); 113 (55); 76 (18).

3-(2,6-Dimethoxyphenyl)-2-(1-naphthyl)-1,4-naphthoquinone (10)

Following General Procedure A, but refluxing for 40 h, (10) was prepared in 57% yield (after chromatography; elution with 1:6 ethyl acetate/hexane) from 2-chloro-3-(1-naphthyl)-1,4-naphthoquinone (9) and 2.5 equiv. of 2,6-dimethoxyphenylboronic acid. Obtained as a yellow *solid*, m.p.166–168°C (Found: C, 80.0; H, 4.8. $C_{28}H_{20}O_4$ requires C, 80.0; H, 4.8%). ^{1}H NMR (200 MHz) δ 3.11, s, OMe; 3.76, s, OMe; 6.14, d, *J* 8.4 Hz, H3′; 6.43, d, *J* 8.4 Hz, H5′; 7.04, t, *J* 8.4 Hz, H4′; 7.15–7.46, m, 4H, naphthyl; 7.67–7.88, m, 5H, naphthyl; 8.16–8.30, m, H5, H8. Mass spectrum *m/z* 421 (30%); 420 (100, M^+); 104 (15); 76 (15).

3-Methyl-2-phenyl-1,4-naphthoquinone (11)

Following General Procedure A, but refluxing for 3 h, (11) was prepared in 86% yield (after chromatography; elution with hexane) from 2-chloro-3-methyl-1,4-naphthoquinone (15) and 1.2 equiv. of phenylboronic acid. Obtained as bright yellow plates from ethanol, m.p. 68°C (lit. see footnote to Table 1, entry i) (Found: C, 82.3; H, 4.9. $C_{17}H_{12}O_2$ requires C, 82.2; H, 4.9%). ^{1}H NMR (200 MHz) δ 2.08, s, Me; 7.19–7.26, m, 2H, Ph; 7.40–7.52, m, 3H, Ph; 7.69–7.78, m, H6, H7; 8.06–8.19, m, H5, H8. Mass spectrum *m/z* 249 (18%); 248 (100, M^+); 247 (32); 233 (30); 231 (40); 219 (46); 191 (19); 189 (17); 165 (10); 115 (18); 104 (39); 76 (48).

Preparation of 2-Chloro-1,4-naphthoquinones. General Procedure B

2-Chloro-1,4-naphthoquinone (14)

2-Hydroxy-1,4-naphthoquinone (17) (350 mg, 2.0 mmol) in benzene (20 mL) was treated with oxalyl chloride (0.50 mL, 5.7 mmol) and DMF (2 drops). The mixture was stirred at 50°C for 45 min. The resulting yellow solution was decanted into a clean round-bottom flask (to separate it from a small amount of dark oil which adheres to the side) and evaporated to dryness under reduced pressure. The crude product (388 mg, m.p. 112–114°C) was chromatographed (elution with 1:9 ethyl acetate/hexane) to give 2-chloro-1,4-naphthoquinone (14) (367 mg, 95%) as bright yellow needles, m.p. 114.5–115°C (lit.[16] 114–115°C). ^{1}H NMR (200 MHz) δ 7.23, s, H3; 7.75–7.84, m, H6, H7; 8.08–8.20, m, H5, H8. Mass spectrum *m/z* 194 (32%, M^+); 192 (100, M^+); 164 (19); 157 (52); 129 (92); 104 (27); 101 (34); 76 (40); 75 (29); 74 (24); 50 (29).

2-Chloro-7-methoxy-1,4-naphthoquinone (16)

Following General Procedure B, (16) was prepared in 95% yield from 2-hydroxy-7-methoxy-1,4-naphthoquinone (19).[19] Obtained as a bright yellow *solid*, m.p. 170–172°C (Found: C, 59.4; H, 3.1. $C_{11}H_7ClO_3$ requires C, 59.4; H, 3.2%). ^{1}H NMR (200 MHz) δ 3.97, s, OMe; 7.17, s, H3; 7.24, dd, *J* 8.7, 2.6 Hz, H6; 7.60, d, *J* 2.6 Hz, H8; 8.04, d, *J* 8.7 Hz, H5. Mass spectrum *m/z* 224 (33%, M^+); 222 (100, M^+); 194 (24); 187 (82); 179 (14); 159 (16); 116 (16); 106 (13); 63 (28); 62 (15).

Acknowledgments

We thank the Chemistry Department of the University of Western Australia, and in particular Dr Lindsay Byrne, for generous access to their NMR instruments. We also thank Ms Hiromi Eaton for her assistance with some of this work. This article is published with the permission of the Director, Chemistry Centre (WA).

References

[1] J. A. Armstrong, R. W. Baker, W. M. Best, L. T. Byrne, J. R. Cannon, S. M. Colegate, A. R. Gray, N. G. Marchant, N. Rothnie, M. V. Sargent, C. G. Sims, Z. E. Spadek, R. D. Trengove, *Aust. J. Chem.* **1999**, *52*, 57.

[2] I. Takahashi, N. Takeyama, H. Mori, M. Yamamoto, H. Nishimura, H. Kitajima, *Chemistry Express* **1992**, *7*, 709 (see also reference 17).

[3] S. Yoshida, H. Kubo, T. Saika, S. Katsumura, *Chem. Lett.* **1996**, 139.

[4] S. Katsumura, S. Yoshida, H. Kubo, T. Saika, Jap. Pat. 09077743.

[5] K. W. Stagliano, H. C. Malinakova, *Tetrahedron Lett.* **1997**, *38*, 6617.

[6] K. W. Stagliano, H. C. Malinakova, *J. Org. Chem.* **1999**, *64*, 8034.

[7] A. R. Martin, Y. Yang, *Acta Chem. Scand.* **1993**, *47*, 221. A. Suzuki. *J. Organomet. Chem.* **1999**, 576, 147.

[8] S. Mohri, M. Stefinovic, V. Snieckus, *J. Org. Chem.* **1997**, *62*, 7072.

[9] Y. Fukuyama, Y. Kiriyama, M. Kodama, *Tetrahedron Lett.* **1993**, *34*, 7637.

[10] N. Tamayo, A. M. Echavarren, M. C. Paredes, *J. Org. Chem.* **1991**, *56*, 6488.

[11] D. W. Old, J. P. Wolfe, S. L. Buchwald, *J. Am. Chem. Soc.* **1998**, *120*, 9722. A. F. Littke, G. C. Fu, *Angew. Chem., Int. Ed. Engl.* **1998**, *37*, 3387.

[12] Y. Hoshino, N. Miyaura, A. Suzuki, *Bull. Chem. Soc. Jpn* **1988**, *61*, 3008.

[13] T. Ishiyama, M. Murata, N. Miyaura, *J. Org. Chem.* **1995**, *60*, 7508.

[14] J. M. Lyons, R. H. Thomson, *J. Chem. Soc*. **1953**, 2910; R. B. Gupta, R. W. Franck, *Synlett* **1990**, 355.

[15] D. E. Kvalnes, *J. Am. Chem. Soc.* **1934**, *56*, 2478.

[16] L. R. Buzbee, G. G. Ecke, British Patent 1,128,115 (*Chem. Abstr.* **1969**, *70*, 47169x).

[17] R. D. Clark, C. H. Heathcock, *Synthesis* **1974**, 47.

[18] G. Roberge, P. Brassard, *J. Org. Chem.* **1981**, *46*, 4161; Y. Tamura, M. Sasho, S. Akai, A. Wada, Y. Kita, *Tetrahedron* **1984**, *40*, 4539.

[19] A. C. Baillie, R. H. Thomson, *J. Chem. Soc. (C)* **1966**, 2184.

[20] R. F. Silver, H. L Holmes. *Can. J. Chem*. **1968**, *46*, 1859.

[21] H. Pluim, H. Wynberg, *J. Org. Chem*. **1980**, *45*, 2498.

[22] R. Adams, J. E. Dunbar, *J. Am. Chem. Soc.* **1956**, *78*, 4774.