

Gallium(III) Chloride Catalyzed Hydroarylation of Arylacetylenes with Naphthols and Phenols: A Facile Synthesis of Vinylarenes

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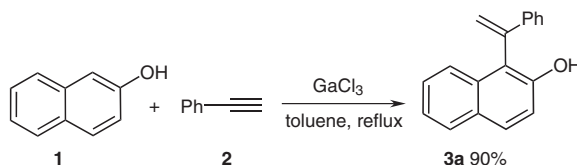
Received 2 December 2008; revised 10 December 2008

Abstract: Arylacetylenes undergo smooth hydroarylation with naphthols and phenols in the presence of 10 mol% of gallium(III) chloride in refluxing toluene to afford the corresponding 2-vinyl-naphthols and -phenols in good yields with high regioselectivity. Similarly, styrenes undergo hydroarylation with naphthols and phenols to provide substituted naphthols and phenols.

Key words: arylations, arylacetylenes, gallium(III) chloride, phenols, addition reactions

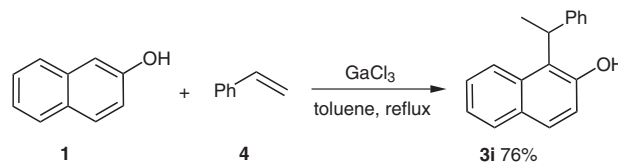
The coupling of alkynes with phenols and naphthols is an important reaction in organic synthesis for generating carbon–carbon multiple bonds.¹ Arenes are important intermediates for the chemical industry as pharmaceuticals and agrochemicals. Generally, Friedel–Crafts alkylations, Friedel–Crafts acylations, nitrations, and halogenations are used for the functionalization of arenes.² Although these methods function reliably on large scale, there are some drawbacks such as strongly acidic conditions, high temperatures, poor regioselectivity, and the formation of large amounts of byproducts (salts). The introduction of a certain C–C bond onto the aromatic core often requires several steps, including the presence of activating groups or protection and deprotection steps.^{3,4} Thus, the development of direct C–C coupling reactions of arenes is an important and ongoing task in organic synthesis.⁵ In recent times, gallium(III) halides have emerged as efficient catalysts for various organic transformations.^{6,7} In particular, gallium(III) chloride is considered as an effective Lewis acid to activate alkynes or alkenes under extremely mild conditions.⁸

In this report, we describe a novel and efficient protocol for the alkenylation and alkylation of naphthols and phenols with arylacetylenes and vinylarenes using a catalytic amount of gallium(III) chloride. Initially, we attempted the hydroarylation of phenylacetylene (**2**), with 2-naphthol (**1**) in the presence of 10 mol% of gallium(III) chloride (Scheme 1). The reaction proceeded smoothly in refluxing toluene to afford 1-(1-phenylvinyl)-2-naphthol (**3a**) in 90% yield.



Scheme 1

Encouraged by this result, we turned our attention towards the reactions of various substituted phenylacetylenes with the hydroxyarenes 1- and 2-naphthol, phenol, *o*-cresol, and *p*-cresol (Table 1, entries 1–8). In all cases, the corresponding vinylarenes **3a–h** were obtained in good yields. Similarly, a facile hydroarylation of 2-naphthol (**1**) with styrene (**4**) in the presence of gallium(III) chloride in toluene was achieved under reflux conditions to furnish 1-(1-phenylethyl)-2-naphthol (**3i**) in 76% yield (Scheme 2, Table 1, entry 9). Styrene (**4**) also reacted with other hydroxyarenes to provide the corresponding 1-(1-phenylethyl)arenes in good yields (Table 1, entries 10 and 11). The hydroarylation reaction of naphthalene-2-thiol with phenylacetylene was also successful, giving product **3l** in very good yield (Table 1, entry 12).



Scheme 2

The scope of this procedure is illustrated in Table 1. Various metal salts such as aluminum(III) chloride, bismuth(III) chloride, zirconium(IV) chloride, iron(III) chloride, yttrium(III) chloride, ytterbium(III) chloride, and gallium(III) chloride were found to be effective in terms of conversion. The high reactivity of gallium(III) chloride towards alkynes may be attributed to its alkynophilicity.

In conclusion, gallium(III) chloride has proven to be an efficient catalyst for the cross coupling of arylalkynes and alkenes with naphthols and phenols. This method provides a direct and easy access for the preparation of vinyl-naphthols and *o*-hydroxystyrenes by means of hydroarylation.

Table 1 Alkylation of Aryl Alcohols Mediated by Gallium(III) Chloride

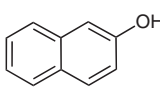
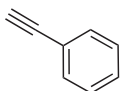
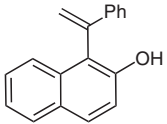
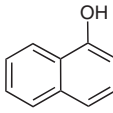
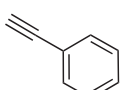
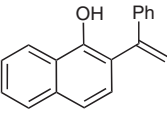
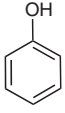
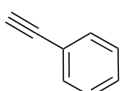
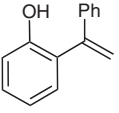
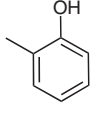
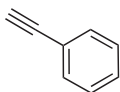
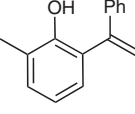
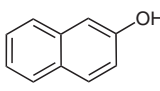
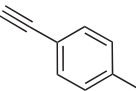
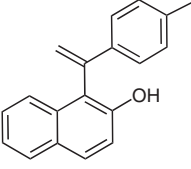
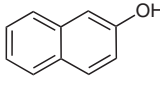
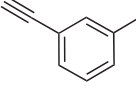
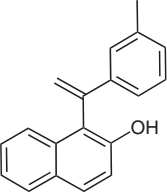
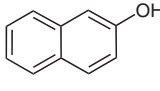
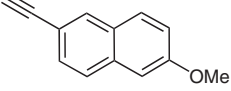
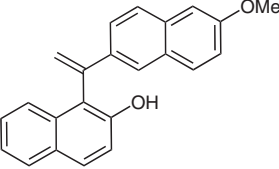
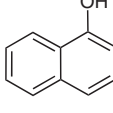
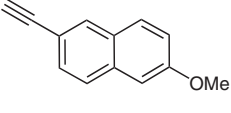
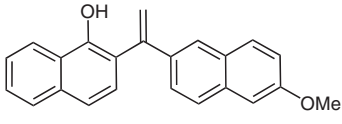
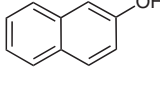
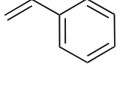
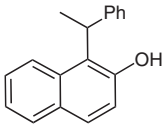
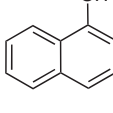
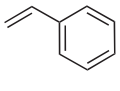
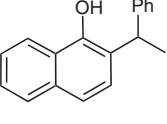
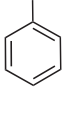
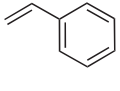
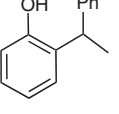
Entry	Naphthol/phenol	Phenylacetylene/styrene	Product 3 ^a	Time (h)	Yield ^b (%)
1				3a	5 90
2				3b	3 70
3				3c	6 75
4				3d	4 80
5				3e	3 72
6				3f	4 76
7				3g	3 75
8				3h	4 71
9				3i	4 76
10				3j	4 69
11				3k	6 72

Table 1 Alkylation of Aryl Alcohols Mediated by Gallium(III) Chloride (continued)

Entry	Naphthol/phenol	Phenylacetylene/styrene	Product 3 ^a	Time (h)	Yield ^b (%)
12				3l	8 92

^a Products were characterized by NMR, IR, and mass spectroscopy.^b Yield of pure products after column chromatography.

Melting points were recorded on a Buchi R-535 apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer FT-IR 240-c spectrophotometer using KBr optics. ¹H and ¹³C NMR spectra were recorded on a Gemini-200 spectrometer (200 MHz); samples were prepared in CDCl₃, and TMS was used as internal standard. Mass spectra were recorded on a Finnigan MAT 1020 mass spectrometer operating at 70 eV. Column chromatography was performed on silica gel (Merck 100–200 mesh).

(1-Arylvinyl)- and (1-Arylethyl)aryl Alcohols **3**; General Procedure

A mixture of the aryl alcohol (1 mmol), phenylacetylene or styrene (1.2 mmol), and GaCl₃ (0.1 mmol) in toluene was stirred under reflux for the appropriate time (Table 1). After complete conversion as indicated by TLC, the reaction mixture was quenched with H₂O (10 mL) and extracted with EtOAc (3 × 10 mL). The combined organic extracts were dried (Na₂SO₄) and then concentrated in vacuo. The resulting product was purified by column chromatography (silica gel, EtOAc–hexane).

1-(1-Phenylvinyl)-2-naphthol (**3a**)

Solid; mp 112–115 °C.

IR (KBr): 3394, 3058, 2925, 1808, 1653, 1621, 1600, 1513, 1463, 1239, 977, 810, 751, 691 cm⁻¹.

¹H NMR (300 MHz, CDCl₃): δ = 7.76–7.71 (m, 2 H), 7.46–7.42 (m, 1 H), 7.35–7.30 (m, 2 H), 7.27–7.21 (m, 6 H) 6.30 (s, 1 H), 5.52 (br, 1 H), 5.50 (s, 1 H).

¹³C NMR (75 MHz, CDCl₃): δ = 117.3, 118.9, 123.3, 124.8, 125.8, 126.2, 126.5, 127.9, 128.0, 128.5, 128.7, 129.6, 132.7, 138.7, 142.4, 150.3.

LC-MSD Trap SL: *m/z* = 248 [M + 2]⁺, 246 [M]⁺, 238.

HRMS (EI): *m/z* calcd for C₁₈H₁₄O: 246.1044; found: 246.1053.

2-(1-Phenylvinyl)-1-naphthol (**3b**)

Liquid.

IR (KBr): 3302, 3052, 2921, 2851, 1630, 1579, 1513, 1457, 1386, 1365, 1270, 1238, 1146, 1080, 1014, 876, 789, 765, 704, 567, 416 cm⁻¹.

¹H NMR (200 MHz, CDCl₃): δ = 8.24–8.19 (m, 1 H), 7.75–7.72 (m, 2 H), 7.47–7.35 (m, 3 H), 7.32–7.29 (m, 3 H), 7.11 (d, *J* = 8.3 Hz, 2 H), 5.96 (s, 1 H), 5.83 (s, 1 H), 5.51 (d, *J* = 1.5 Hz, 1 H).

ESI-MS: *m/z* = 269 [M + 23]⁺, 341, 363.

2-(1-Phenylvinyl)phenol (**3c**)

Liquid.

IR (KBr): 3421, 2922, 2852, 2361, 1741, 1601, 1453, 1376, 1229, 1114, 755, 698 cm⁻¹.

¹H NMR (300 MHz, CDCl₃): δ = 7.35–7.29 (m, 1 H), 7.24–7.20 (m, 3 H), 7.17–7.06 (m, 4 H), 6.93–6.87 (m, 1 H), 5.83 (d, *J* = 1.5 Hz, 1 H), 5.40 (d, *J* = 1.5 Hz, 1 H), 5.05 (s, 1 H).

¹³C NMR (75 MHz, CDCl₃): δ = 119.1, 120.5, 125.1, 127.0, 129.1, 129.8, 130.7, 132.2, 134.5, 144.1, 162.5.

LC-MSD Trap SL: *m/z* = 219 [M + 23]⁺, 210.

2-Methyl-6-(1-phenylvinyl)phenol (**3d**)

Liquid.

IR (KBr): 3521, 3055, 2923, 2854, 2365, 1606, 1462, 1325, 1223, 1173, 1080, 909, 776, 701, 567, 415 cm⁻¹.

¹H NMR (200 MHz, CDCl₃): δ = 7.35–7.26 (m, 5 H), 7.03 (d, *J* = 7.3 Hz, 1 H), 6.88 (d, *J* = 7.3 Hz, 1 H), 6.75 (t, *J* = 7.3 Hz, 1 H), 5.84 (d, *J* = 1.4 Hz, 1 H), 5.38 (d, *J* = 1.4 Hz, 1 H), 5.18 (s, 1 H), 2.25 (s, 3 H).

¹³C NMR (75 MHz, CDCl₃): δ = 16.1, 76.9, 116.6, 119.8, 126.4, 127.0, 127.8, 128.5, 128.6, 130.6, 139.4, 145.4, 151.1.

ESI-MS: *m/z* = 211 [M + 1]⁺, 241.

1-[1-(4-Tolyl)vinyl]-2-naphthol (**3e**)

Liquid.

IR (KBr): 3501, 3054, 2920, 1664, 1598, 1510, 1464, 1196, 1135, 817, 747 cm⁻¹.

¹H NMR (200 MHz, CDCl₃): δ = 7.88–7.68 (m, 2 H), 7.48–7.38 (m, 1 H), 7.27–7.16 (m, 5 H), 7.06–6.98 (d, *J* = 7.8 Hz, 2 H), 6.27 (s, 1 H), 5.55 (br s, 1 H), 5.44 (s, 1 H), 2.32 (s, 3 H).

¹³C NMR (75 MHz, CDCl₃): δ = 21.1, 117.2, 117.8, 120.2, 124.8, 126.1, 126.4, 127.9, 128.3, 128.8, 129.1, 129.4, 132.8, 135.8, 138.4, 142.2, 150.3.

ESI-MS: *m/z* = 261 [M + 1]⁺, 245, 199, 141.

1-[1-(3-Tolyl)vinyl]-2-naphthol (**3f**)

Liquid.

IR (KBr): 3504, 3055, 2920, 1744, 1622, 1519, 1438, 1277, 1195, 1133, 900, 888, 745, 455 cm⁻¹.

¹H NMR (200 MHz, CDCl₃): δ = 7.73–7.69 (m, 2 H), 7.47–7.44 (m, 1 H), 7.29 (d, *J* = 1.1 Hz, 2 H), 7.25–7.22 (m, 3 H), 7.15–7.12 (m, 1 H), 7.10–7.08 (m, 1 H), 6.26 (d, *J* = 1.5 Hz, 1 H), 5.59 (br s, 1 H), 5.46 (d, *J* = 1.5 Hz, 1 H), 2.28 (s, 3 H).

ESI-MS: *m/z* = 261 [M + 1]⁺, 274, 329, 371.

1-[1-(6-Methoxy-2-naphthyl)vinyl]-2-naphthol (**3g**)

Liquid.

IR (KBr): 3499, 3260, 3052, 2923, 1917, 1626, 1596, 1509, 1462, 1384, 1270, 1211, 1172, 1023, 956, 846, 813, 741, 616, 580, 474 cm⁻¹.

¹H NMR (200 MHz, CDCl₃): δ = 7.80–7.46 (m, 7 H), 7.28–7.20 (m, 2 H), 7.05–6.98 (m, 3 H), 6.38 (d, *J* = 1.4 Hz, 1 H), 5.52 (d, *J* = 1.4 Hz, 1 H), 5.50 (br s, 1 H), 3.88 (s, 3 H).

^{13}C NMR (75 MHz, CDCl_3): δ = 55.3, 105.8, 119.0, 120.3, 123.4, 123.6, 124.2, 125.0, 125.9, 126.4, 126.6, 127.3, 128.0, 128.9, 129.7, 129.8, 130.0, 132.9, 134.6, 150.4, 153.3, 157.9, 158.1.

ESI-MS: m/z = 349 $[\text{M} + \text{Na}]^+$, 333, 386.

2-[1-(6-Methoxy-2-naphthyl)vinyl]-1-naphthol (3h)

Liquid.

IR (KBr): 3490, 3256, 3048, 2922, 1889, 1625, 1596, 1509, 1463, 1404, 1270, 1201, 1170, 1029, 956, 840, 803, 741, 615, 580, 474 cm^{-1} .

^1H NMR (200 MHz, CDCl_3): δ = 8.18 (d, J = 8.7 Hz, 2 H), 7.71–7.50 (m, 5 H), 7.42–7.25 (m, 4 H), 6.98 (d, J = 2.9 Hz, 1 H), 5.97 (d, J = 1.4 Hz, 1 H), 5.36 (d, J = 1.4 Hz, 1 H), 5.21 (s, 1 H), 3.89 (s, 3 H).

^{13}C NMR (75 MHz, CDCl_3): δ = 55.3, 105.8, 116.4, 120.0, 120.6, 122.6, 123.6, 123.6, 125.0, 126.8, 126.9, 127.8, 128.6, 129.6, 129.9, 131.5, 131.8, 132.4, 134.8, 136.5, 150.4, 153.4, 158.1.

ESI-MS: m/z = 327 $[\text{M} + 1]^+$, 276.

1-(1-Phenylethyl)-2-naphthol (3i)

Liquid.

IR (KBr): 3371, 2922, 2852, 1662, 1459, 1279, 1073, 700 cm^{-1} .

^1H NMR (200 MHz, CDCl_3): δ = 8.00 (d, J = 8.6 Hz, 1 H), 7.75 (d, J = 7.8 Hz, 1 H), 7.63 (d, J = 9.4 Hz, 1 H), 7.46–7.23 (m, 7 H), 6.97 (d, J = 9.4 Hz, 1 H), 5.15 (q, J = 7.03 Hz, 1 H), 4.75 (br s, 1 H), 1.77 (d, J = 7.03 Hz, 3 H).

^{13}C NMR (75 MHz, CDCl_3): δ = 17.1, 34.8, 119.3, 122.6, 123.1, 123.8, 126.5, 126.7, 127.1, 128.7, 128.9, 129.0, 129.7, 132.8, 143.7, 151.5.

ESI-MS: m/z = 249 $[\text{M} + 1]^+$, 220, 201, 175, 132, 110.

2-(1-Phenylethyl)-1-naphthol (3j)

Liquid.

IR (KBr): 3442, 3025, 2925, 2854, 1712, 1659, 1595, 1491, 1453, 1379, 1301, 1252, 1159, 1026, 900, 761, 699, 554 cm^{-1} .

^1H NMR (200 MHz, CDCl_3): δ = 8.04–8.01 (m, 1 H), 7.87–7.84 (m, 1 H), 7.74–7.69 (m, 2 H), 7.38 (dd, J = 3.7, 3.0 Hz, 1 H), 7.30–7.27 (m, 4 H), 7.24 (t, J = 4.5 Hz, 2 H), 4.97 (s, 1 H), 4.41 (q, J = 7.5 Hz, 1 H), 1.71 (dd, J = 6.5, 1.5 Hz, 3 H).

ESI-MS: m/z = 271 $[\text{M} + 23]^+$, 376, 393.

2-(1-Phenylethyl)phenol (3k)

Liquid.

IR (KBr): 3533, 3060, 3027, 2966, 2926, 2873, 1644, 1599, 1495, 1452, 1373, 1330, 1255, 1207, 1110, 1027, 840, 753, 700, 587, 542 cm^{-1} .

^1H NMR (200 MHz, CDCl_3): δ = 7.22–7.15 (m, 3 H), 7.06–7.02 (m, 3 H), 6.87 (t, J = 7.3 Hz, 2 H), 6.70–6.58 (m, 1 H), 5.53 (s, 1 H), 4.08 (q, J = 7.3 Hz, 1 H), 1.61 (d, J = 7.3 Hz, 3 H).

ESI-MS: m/z = 199 $[\text{M} + 1]^+$, 287, 282.

1-(1-Phenylvinyl)naphthalene-2-thiol (3l)

Solid.

IR (KBr): 3445, 3047, 2924, 2361, 1744, 1586, 1490, 1439, 1349, 1269, 1159, 1122, 1071, 1022, 941, 854, 817, 778, 743, 682, 630, 530, 474, 419 cm^{-1} .

^1H NMR (200 MHz, CDCl_3): δ = 7.93–7.88 (m, 1 H), 7.81–7.73 (m, 3 H), 7.53–7.40 (m, 3 H), 7.32–7.24 (m, 4 H), 6.59 (s, 1 H), 6.57 (s, 1 H), 1.37 (br, 1 H).

^{13}C NMR (75 MHz, CDCl_3): δ = 123.1, 125.6, 125.7, 126.0, 126.2, 126.7, 127.3, 127.6, 127.7, 128.2, 128.4, 128.6, 128.9, 132.1, 133.4, 136.4.

ESI-MS: m/z = 301 $[\text{M} + 39]^+$, 278.

Acknowledgment

S.S. and S.K.B. thank CSIR New Delhi for the award of fellowships.

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