Methylation of Phenol and Its Derivatives with Dimethyl Carbonate in the Presence of Mn₂(CO)₁₀, W(CO)₆, and Co₂(CO)₈

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Received June 26, 2014

Abstract—Aryl methyl ethers were synthesized by reactions of phenol, substituted phenols, and α - and β -naphthols with dimethyl carbonate in the presence of manganese, tungsten, and cobalt carbonyls. Optimal reactant and catalyst ratios and reaction conditions were found to ensure selective formation of aryl methyl ethers.

DOI: 10.1134/S1070428015030070

Aryl methyl ethers constitute an important class of chemical compounds that are widely used as solvents and reactants for the preparation of dyes, agrochemicals, antioxidants, and polymer stabilizers [1, 2]. The simplest aryl methyl ether, methoxybenzene (anisole), is a large-scale product which is obtained by alkylation of phenol with methanol in the presence of γ -Al₂O₃. Anisole can also be synthesized by methvlation of phenol with dimethyl sulfate or methyl halides in the presence of an equimolar amount of a base [3, 4]. Bomben et al. [5] demonstrated the possibility for methylation of phenol with a "green reagent," dimethyl carbonate. The reaction was carried out at 90°C (50 h) in the presence of 1.2 equiv of potassium carbonate, and the yield of anisole was 30%. Alkylation of phenol and its derivatives with dimethyl carbonate in the presence of metal complex catalysts was not studied previously.

We have recently found that tungsten and cobalt carbonyls $W(CO)_6$ and $Co_2(CO)_8$ catalyze alkylation of primary, secondary, and tertiary alcohols with dimethyl carbonate [6]. The present study was aimed at extending the scope of this reaction and examining its general and specific features.

Tungsten hexacarbonyl catalyzed methylation of phenol with dimethyl carbonate with formation of anisole, whereas no reaction occurred in the presence of $Co_2(CO)_8$ [6]. Manganese carbonyl $Mn_2(CO)_{10}$ showed an appreciable catalytic activity in the alkylation of phenol with dimethyl carbonate; it ensured

quantitative formation of anisole in 1 h at 180°C. We examined the effect of substituents in the substrate on the conversion and yield of the corresponding methyl ether. The reactions of *o*-, *m*-, and *p*-cresols **1–3** with dimethyl carbonate in the presence of $Mn_2(CO)_{10}$ at a $Mn_2(CO)_{10}$ -cresol-Me₂CO₃ molar ratio of 3:100:300 (180°C, 1 h) gave methyl ethers **4–6** in 30, 81, and 95% yield, respectively; in addition, methanol and carbon dioxide were formed (Scheme 1). The yields of **4–6** in the presence of W(CO)₆, other conditions being equal, were 4, 5, and 22%, respectively. In all cases, excess dimethyl carbonate was used since it acted simultaneously as reagent and solvent. No transesterification of dimethyl carbonate was observed.

The results of the reactions of dimethyl carbonate with phenol derivatives containing two and more substituents in the benzene ring in the presence of $Mn_2(CO)_{10}$, $W(CO)_6$, and $Co_2(CO)_8$ under the optimal

Scheme 1.



1, **4**, $R^{*} = Me$, $R^{2} = R^{3} = H$; **2**, **5**, $R^{*} = R^{2} = H$, $R^{2} = M$ **3**, **6**, $R^{1} = R^{2} = H$, $R^{3} = Me$.

conditions are given in table. It is seen that substituted phenols react with dimethyl carbonate to produce the corresponding methyl ethers with high selectivity. The substrate conversion is largely determined by the metal nature in the catalyst. The most efficient catalyst is $Mn_2(CO)_{10}$. The nature of substituents in the substrate does not affect the conversion and yield of methyl ether to an appreciable extent. 3,4-Dichlorophenol, 3-aminophenol, methyl and 3-hydroxybenzoate reacted with dimethyl carbonate to afford 3,4-dichloro-1-methoxybenzoate in 85, 99, and 99% yield, respectively. The number of substituents in the phenol molecule insignificantly affects the yield (see the data for 2,3,4,5,6-pentamethylphenol).

On the other hand, the position of substituent with respect to the hydroxy group is significant. In the reaction of 2-propylphenol with dimethyl carbonate, the substrate conversion was as low as 50%, whereas 2-chlorophenol failed to react with dimethyl carbonate.

β-Naphthol (7) reacted with dimethyl carbonate in the presence of $Mn_2(CO)_{10}$, $W(CO)_6$, and $Co_2(CO)_8$ (180°C, 1 h) to give 2-methoxynaphthalene (8) in quantitative yield (Scheme 2).



The reaction of α -naphthol (9) with (MeO)₂CO catalyzed by Mn₂(CO)₁₀ and W(CO)₆ was accompanied by partial isomerization of 9 into β -naphthol (7), and the products were isomeric methyl natphthyl ethers 8 and 10. The conversion of 9 in the presence of Co₂(CO)₈ was considerably lower (42%), but no isomerization was observed (Scheme 3).

In the reaction with a dihydric phenol, resorcinol (11), we obtained a mixture of exhaustive and partial methylation products 12a and 12b (Scheme 4). Hydroquinone (13) reacted with dimethyl carbonate in a similar way. Neither resorcinol (11) nor hydroquinone (13) reacted with dimethyl carbonate in the presence of cobalt carbonyl. Unlike 11 and 13, pyrocatechol failed to react with dimethyl carbonate, Alkylation of substituted phenols with dimethyl carbonate in the presence of metal carbonyls^a

Substrate	Catalyst	Yield of methyl ether, %
Phenol	$Mn_2(CO)_{10}$	98
o-Cresol	$Mn_2(CO)_{10}$	30
o-Cresol	W(CO) ₆	4
<i>m</i> -Cresol	$Mn_2(CO)_{10}$	81
<i>m</i> -Cresol	W(CO) ₆	5
<i>p</i> -Cresol	$Mn_2(CO)_{10}$	95
<i>p</i> -Cresol	W(CO) ₆	22
2,3-Dimethylphenol	$Mn_2(CO)_{10}$	99
2,3-Dimethylphenol	W(CO) ₆	70
3,4-Dimethylphenol	Mn ₂ (CO) ₁₀	99
3,4-Dimethylphenol	W(CO) ₆	56
3,5-Dimethylphenol	$Mn_2(CO)_{10}$	99
3,5-Dimethylphenol	W(CO) ₆	99
3,5-Dimethylphenol	$Co_2(CO)_8$	99
2,6-Dimethylphenol	$Mn_2(CO)_{10}$	99
2,6-Dimethylphenol	W(CO) ₆	46
2,6-Dimethylphenol	$Co_2(CO)_8$	72
2,3,5-Trimethylphenol	$Mn_2(CO)_{10}$	99
2,3,5-Trimethylphenol	W(CO) ₆	98
2,3,5-Trimethylphenol	$Co_2(CO)_8$	99
2,3,6-Trimethylphenol	$Mn_2(CO)_{10}$	99
2,3,6-Trimethylphenol	W(CO) ₆	20
2,3,6-Trimethylphenol	$Co_2(CO)_8$	90
2,3,4,5,6-Pentamethylphenol	$Mn_2(CO)_{10}$	99
2-Propylphenol	$Mn_2(CO)_{10}$	50
2-Chlorophenol	$Mn_2(CO)_{10}$	2
3,4-Dichlorophenol	$Mn_2(CO)_{10}$	85
3-Aminophenol	$Mn_2(CO)_{10}$	99
Methyl 3-hydroxybenzoate	$Mn_2(CO)_{10}$	99

^a Ratio catalyst-phenol-(MeO)₂CO 3:100:300, 180°C, 1 h.

regardless of the catalyst (whether manganese, tungsten, or cobalt carbonyl was used), presumably because of chelation of the metal atom in the catalyst.

The structure of the isolated compounds was determined by spectral methods, as well as by comparing their properties with those of authentic samples and published data [7–10].







EXPERIMENTAL

The ¹H and ¹³C NMR spectra were recorded on a Bruker Avance-400 spectrometer at 400.13 and 100.62 MHz, respectively, using CDCl₃ as solvent. The mass spectra were obtained on a Shimadzu GCMS-QP2010Plus instrument (SPB-5 capillary column, 30 m×0.25 mm, carrier gas helium, oven temperature programming from 40 to 300°C at a rate of 8 deg/min, injector temperature 280°C; ion source temperature 200°C, electron impact, 70 eV). The elemental compositions were determined on a Carlo Erba 1106 analyzer. The progress of reactions and the purity of products were monitored by GLC on Shimadzu GC-9A and GC-2014 instruments (2-m×3-mm column packed with 5% SE-30 on Chromaton N-AW-HMDS; oven temperature programming from 50 to 270°C at a rate of 8 deg/min; carrier gas helium, flow rate 47 mL/min).

General procedure for the alkylation of phenols with dimethyl carbonate. A 17-mL stainless steel high-pressure micro reactor was charged with 3 mmol of $Mn_2(CO)_{10}$, $W(CO)_6$, or $Co_2(CO)_8$, 100 mmol of the corresponding phenol, and 300 mmol of dimethyl carbonate, and the reactor was hermetically closed and heated for 1 h at 180°C. The reactor was then cooled to room temperature and opened, and the mixture was filtered through a layer of alumina. Unreacted dimethyl carbonate was distilled off, and the residue was distilled under atmospheric or reduced pressure or recrystallized from ethanol.

Anisole. Yield 98%, bp 153.6–154°C [6].

1-Methoxy-2-methylbenzene (4). Yield 30%, bp 170–171°C. ¹³C NMR spectrum, δ_{C} , ppm: 16.02 (CH₃), 55.32 (OCH₃), 110.23 (C⁶), 120.28 (C⁴), 126.55 (C², C⁵), 157.64 (C¹). Found, %: C 78.54; H 8.19. C₈H₁₀O. Calculated, %: C 78.65; H 8.25. **1-Methoxy-3-methylbenzene (5).** Yield 81%, bp 75.9–76°C (30 mm). ¹³C NMR spectrum, $\delta_{\rm C}$, ppm: 21.76 (CH₃), 55.37 (OCH₃), 110.72 (C⁶), 114.68 (C²), 121.44 (C⁴), 129.18 (C⁵), 139.47 (C³), 159.52 (C¹). Found, %: C 78.49; H 8.21. C₈H₁₀O. Calculated, %: C 78.65; H 8.25.

1-Methoxy-3-methylbenzene (6). Yield 95%, bp 173.5–174°C. ¹³C NMR spectrum, δ_{C} , ppm: 20.48 (CH₃), 54.62 (OCH₃), 113.92 (C², C⁶), 129.75 (C⁴), 129.90 (C³, C⁵), 157.88 (C¹). Found, %: C 78.55; H 8.19. C₈H₁₀O. Calculated, %: C 78.65; H 8.25.

1-Methoxy-2,3-dimethylbenzene. Yield 99%, bp 95.8–96°C (30 mm). ¹³C NMR spectrum, δ_C , ppm: 11.99 (CH₃), 20.56 (CH₃), 55.83 (OCH₃), 110.02 (C⁶), 122.43 (C⁴), 124.78 (C²), 128.74 (C⁵), 137.70 (C³), 157.36 (C¹). Found, %: C 79.29; H 8.82. C₉H₁₂O. Calculated, %: C 79.37%; H 8.88.

1-Methoxy-3,4-dimethylbenzene. Yield 99%, bp 72.8–73°C (8 mm). ¹³C NMR spectrum, δ_{C} , ppm: 19.05 (CH₃), 19.75 (CH₃), 54.20 (OCH₃), 110.92 (C⁶), 115.65 (C²), 128.30 (C⁴), 130.44 (C⁵), 137.48 (C³), 157.43 (C¹). Found, %: C 79.25; H 8.84. C₉H₁₂O. Calculated, %: C 79.37%; H 8.88.

1-Methoxy-3,5-dimethylbenzene. Yield 99%, bp 77–78°C (14 mm). ¹³C NMR spectrum, δ_C , ppm: 21.36 (2C, CH₃), 111.85 (C², C⁶), 122.50 (C⁴), 139.34 (C³, C⁵), 159.92 (C¹). Found, %: C 79.27; H 8.85. C₉H₁₂O. Calculated, %: C 79.37; H 8.88.

1-Methoxy-2,6-dimethylbenzene. Yield 99%, bp 74–75°C (20 mm). ¹³C NMR spectrum, δ_C , ppm: 15.49 (2C, CH₃), 58.88 (OCH₃), 123.32 (C⁴), 128.24 (C³, C⁵), 130.20 (C², C⁶), 156.65 (C¹). Found, %: C 79.31; H 8.85. C₉H₁₂O. Calculated, %: C 79.37; H 8.88.

1-Methoxy-2,3,5-trimethylbenzene. Yield 99%, bp 84.5–85°C (7 mm). ¹³C NMR spectrum, δ_{C} , ppm: 11.60, 20.03, 21.38 (CH₃); 110.52 (C⁶), 119.95 (C²), 124.92 (C⁴), 137.32 (C³), 137.54 (C⁵), 157.43 (C¹). Found, %: C 79.87; H 9.35. C₁₀H₁₄O. Calculated, %: C 79.96; H 9.39.

1-Methoxy-2,3,6-trimethylbenzene. Yield 99%, bp 80.5–81°C (8 mm). ¹³C NMR spectrum, $\delta_{\rm C}$, ppm: 13.80, 15.84, 19.86 (CH₃); 124.32 (C⁴), 125.54 (C²), 127.11 (C⁶), 128.45 (C⁵), 135.25 (C³), 156.95 (C¹). Found, %: C 79.89; H 9.37. C₁₀H₁₄O. Calculated, %: C 79.96; H 9.39.

1-Methoxy-2,3,4,5,6-pentamethylbenzene. Yield 99%, bp 110–111°C (4 mm). ¹³C NMR spectrum, δ_C , ppm: 11.30, 16.52, 17.16 (CH₃); 121.84 (C², C⁶),

130.45 (C⁴), 136.15 (C³, C⁵), 154.68 (C¹). Found, %: C 80.74; H 10.12. C₁₂H₁₈O. Calculated, %: C 80.85; H 10.18.

1-Methoxy-2-propylbenzene. Yield 50%, bp 82–83°C (14 mm). ¹³C NMR spectrum, δ_C , ppm: 14.45 (CH₃), 23.42 (CH₂), 32.17 (CH₂), 55.32 (OCH₃), 110.62 (C⁶), 120.76 (C⁴), 126.58 (C⁵), 129.96 (C³), 131.05 (C²), 157.74 (C¹). Found, %: C 79.87; H 9.32. C₁₀H₁₄O. Calculated, %: C 79.96; H 9.39.

1-Chloro-2-methoxybenzene. Yield 2%. Found, %: C 58.85; H 4.92; Cl 24.78. C₇H₇ClO. Calculated, %: C 58.97; H 4.95; Cl 24.86.

1,2-Dichloro-4-methoxybenzene. Yield 85%, bp 88–89°C (7 mm). ¹³C NMR spectrum, δ_C , ppm: 56.94 (OCH₃), 114.69 (C⁵), 115.53 (C³), 124.49 (C¹), 131.33 (C⁶), 131.62 (C²), 158.52 (C⁴). Found, %: C 47.25; H 3.39; Cl 39.95. C₇H₆Cl₂O. Calculated, %: C 47.49; H 3.42; Cl 40.05.

3-Methoxyaniline. Yield 99%, bp 117–118°C (9 mm). ¹³C NMR spectrum, δ_C , ppm: 55.06 (OCH₃), 101.02 (C²), 103.98 (C⁴), 107.96 (C⁶), 130.11 (C⁵), 147.72 (C¹), 160.76 (C³). Found, %: C 68.12; H 7.31; N 11.29. C₇H₉NO. Calculated, %: C 68.29; H 7.31; N 11.38.

Methyl 3-methoxybenzoate. Yield 99%, bp 96– 97°C (3 mm). ¹³C NMR spectrum, δ_C , ppm: 52.42 (OCH₃), 56.16 (OCH₃), 113.93 (C²), 119.15 (C⁴), 121.86 (C⁶), 129.19 (C⁵), 131.70 (C¹), 159.42 (C³), 166.42 (C=O). Found, %: C 64.95; H 6.03. C₉H₁₀O₃. Calculated, %: C 65.05; H 6.07.

2-Methoxynaphthalene (8). Yield 99%, mp 73–74°C (from EtOH). ¹³C NMR spectrum, δ_C , ppm: 55.50 (OCH₃), 106.69 (C¹), 119.15 (C³), 123.72 (C⁶), 124.75 (C⁸), 125.68 (C⁵), 127.01 (C⁷), 127.55 (C⁴), 130.12 (C¹⁰), 135.77 (C⁹), 157.72 (C²). Found, %: C 83.42; H 6.34. C₁₁H₁₀O. Calculated, %: C 83.51; H 6.37.

1-Methoxynaphthalene (9). Yield 89%, bp 109–110°C (4 mm). ¹³C NMR spectrum, δ_C , ppm: 55.32 (OCH₃), 103.64 (C²), 120.12 (C⁴), 121.99 (C⁸), 125.78 (C⁹), 127.14 (C⁷), 127.35 (C⁵), 127.92 (C³), 128.36 (C⁶), 134.70 (C¹⁰), 155.32 (C¹). Found, %: C 83.45; H 6.32. C₁₁H₁₀O. Calculated, %: C 83.51; H 6.37.

1,3-Dimethoxybenzene (12a). Yield 86%, bp 78–79°C (6 mm). ¹³C NMR spectrum, δ_{C} , ppm: 55.20 (OCH₃), 100.42 (C²), 106.09 (C⁴, C⁶), 129.84 (C⁵), 160.85 (C¹, C³). Found, %: C 69.34; H 7.25. C₈H₁₀O₂. Calculated, %: C 69.54; H 7.30.

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3-Methoxyphenol (12b). Yield 14%, bp 113–114°C (5 mm). ¹³C NMR spectrum, δ_{C} , ppm: 55.22 (OCH₃), 101.67 (C²), 106.52 (C⁴), 108.16 (C⁶), 130.25 (C⁵), 156.73 (C¹), 160.27 (C³). Found, %: C 67.66; H 6.47. C₇H₈O₂. Calculated, %: C 67.73; H 6.50.

1,4-Dimethoxybenzene (14a). Yield 56%, bp 85–86°C (10 mm). ¹³C NMR spectrum, δ_C , ppm: 55.60 (OCH₃), 114.82 (C², C³, C⁵, C⁶), 154.16 (C¹, C⁴). Found, %: C 69.42; H 7.27. C₈H₁₀O₂. Calculated, %: C 69.54; H 7.30.

4-Methoxyphenol (14b). Yield 44%, mp 56–57°C (from EtOH). ¹³C NMR spectrum, δ_{C} , ppm: 55.75 (OCH₃), 115.35 (C³, C⁵), 116.39 (C², C⁶), 150.72 (C¹), 153.93 (C⁴). Found, %: C 67.62; H 6.46. C₇H₈O₂. Calculated, %: C 67.73; H 6.50.

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