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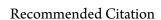
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Mono- and Disubstitutions of (Hepta-2,5-diyne-1,7-diol) Bis(dicobalt) Derivatives: Selectivity in Nicholas Reactions[1]

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[1] Dedicated to Professor Ed Piers for his many contributions to terpene chemistry and the application of organometallic chemistry to organic synthesis.

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Abstract:

Bis(hexacarbonyldicobalt) complexes of benzyl ether/methyl ether or benzyl ether/acetate derivatives of hepta-2,5-diyne-1,7-diols undergo selective Lewis acid mediated Nicholas reactions with enol silanes, silyl ketene acetals, and allylstannanes, preferentially replacing the methyl ether or acetate function. Hydride nucleophiles are similarly incorporated selectively using a benzyl ether/alcohol derivative. Subsequent Nicholas reaction at the benzyloxy- bearing site may be accomplished with an identical or a different nucleophile, affording skipped 1,4-diyne-$Co_4(CO)_{12}$ complexes. In instances of lower selectivity for monosubstitution reactions with benzyl ethers, reverting to the use of a menthyl ether/methyl ether complex gives much improved selectivity for methyl ether substitution.

The chemistry of propargylhexacarbonyldicobalt cations, or the Nicholas reaction, has seen extensive use in organic synthesis.[1] This interest stems from the predictable regiochemical and stereochemical aspects of the Nicholas reaction, and from the ability of cobalt alkyne complexes to protect the alkyne unit,[2] to allow non-conventional alkyne geometries, to participate in synthetically useful cycloaddition reactions,[3,4,5] and to alter the steric size of the formal alkyne function.[6]

We have been interested in the use of tandem Nicholas reactions, both of derivatives of butyne-1,4-diol cobalt complexes, and of derivatives of bis(propargyl alcohol) complexes, for a number of synthetic purposes.[7] The matter of selectivity where two sites for Nicholas reaction chemistry exist is an important issue, but this has been addressed only on rare occasion in butyne-1,4-diol-$Co_2(CO)_6$ derivatives,[7b,8] and not at all in the case of bis(propargyl alcohol)-$Co_4(CO)_{12}$ derivatives.[9] Furthermore, substrates that would serve as synthons for skipped bis(propargyl) cations **1** selectively would give rise to 1,4-diyne complexes **2**, which are promising intermediates in the synthesis of compounds with skipped diene, diyne, or enyne functions, such as petrocortynes/petroformynes/ petrosiacetylenes,[10] eicosanoids and oxoeicosanoids,[11] including several of the leukotrienes.[12] Consequently, we deemed the study of the selectivity in Nicholas reactions of **3** to be of importance; we have reported in preliminary form the substitution reactions of **3** and wish to more fully describe our efforts in this area.[13]

*Suggested location for structures **1-3***

The requisite heptyne-1,7-diol derivatives were prepared from benzyl propargyl ether (Scheme 1). Copper (I) catalyzed coupling of the corresponding bromomagnesium acetylide with propargyl bromide afforded diyne **4** (78% yield), which was functionalized in two ways. Deprotonation of **4** with MeLi and exposure of the resultant acetylide to chloromethyl methyl

ether gave benzyl methyl diether **5a** (59% yield). Alternatively, treatment of the same lithium acetylide with paraformaldehyde gave ether alcohol **6** (55% yield), and subsequent acetylation with acetic anhydride/BF$_3$-OEt$_2$ afforded the benzyl ether acetate **5b** (69% yield). The bis(hexacarbonyldicobalt) complexes of the diynediol derivatives were then prepared in a straightforward manner by subjecting **5a** and **5b** to excess Co$_2$(CO)$_8$, to give **3a** (77% yield) and **3b** (78% yield), respectively.

Suggested location for Scheme 1

With two related substrates in hand, we investigated reactions of **3a** and **3b** with a series of representative nucleophiles, including the allylmetals allyltributylstannane (**7a**) and allyltrimethylsilane (**7b**), propiophenone trimethylsilyl enol ether (**7c**), ethyl cyclohexanecarboxylate trimethylsilyl ketene acetal (**7d**), and cyclohexanone trimethylsilyl enol ether (**7e**), all mediated by BF$_3$-OEt$_2$ (Scheme 2).

Suggested location for structures 7a-7f

Suggested location for Scheme 2

Allylation of **3a** or **3b** could be accomplished by either allyltributylstannane or allyltrimethylsilane; allyltributyltin, however, proved to be the significantly superior nucleophile for monosubstitution reactions. In the case of methyl ether **3a**, for example, reaction of 1.0 equiv of BF$_3$-OEt$_2$ at 0 ^{o}C with 2.0 equiv allyltrimethylsilane gave **8a** in a 39% yield (80% yield based on recovered starting material), and considerable recovered **3a**. Additional amounts of BF$_3$-OEt$_2$ caused greater conversion, but afforded significant amounts of diallylated **9a**. Conversely, allyltributyltin afforded a 63% yield of **8a** (82% based on recovered starting material [brsm] **3a**) in the presence of 2.0 equiv of BF$_3$-OEt$_2$ (0 ^{o}C, 2 equiv allyltributyltin) with more manageable amounts of unreacted **3a** (24%) and **9a** (7.5 % yield). With acetate **3b**, reasonable results could

be obtained with 1.5 equiv BF$_3$-OEt$_2$ (0 ^{o}C, 1.5 equiv allyltributyltin), giving **8a** (62% yield, 75% yield based on recovered starting **3b**), with 17% recovered **3b** (Table 1).

This necessity to optimize nucleophile/electrophile/Lewis acid stoichiometries in each case proved to be a general requirement with **3a** and **3b** and all nucleophiles, but allowed for satisfactory amounts of monosubstitution products in most cases, normally by stopping at the 80%-90% conversion range. The substitution of silyl enol ether **7c** with **3b** was found to be able to give **8b** in a 64% yield (70% brsm), while silyl ketene acetal **7d** with **3b** gave a 63% yield (70% brsm) of **8c**. Silyl enol ether **7e** proved somewhat less selective, and reactions were terminated at lower conversion levels (60-70%) in order to minimize disubstitution. Under these circumstances, acetate **3b** afforded **8d** in 41% (70% brsm), while with methyl ether **3a**, **8d** could be obtained in 43% yield (76% brsm).

Intentional disubstitution reactions were attempted in two cases, using excess BF$_3$-OEt$_2$/nucleophile combinations (4 equiv each). In the case of diallylation of **3a**, allyltributylstannane proved satisfactory, giving **9a** (73% yield) along with 12% of **8a**. Nevertheless, allyltrimethylsilane was superior in this regard, as complete consumption of **3a** occurred to give **9a** in 90% yield. Propiophenone trimethylsilyl enol ether **7c** also was amenable to giving disubstitution, transforming **3b** to **9b** as a 1:1 diastereomeric mixture (70% yield).

Suggested location for Table 1

In addition to the persubstitution reactions described above, we wished to determine whether this framework possessed the ability to incorporate two different nucleophiles in disubstitution reactions. For this purpose, we chose allylation product **8a**, by virtue of the low reactivity of the isolated alkene function to many Lewis acid/nucleophile combinations. In the event, **8a** was subjected to reaction with BF$_3$-OEt$_2$ and 1,3,5-trimethoxybenzene (**7f**) (2 equiv

each, 0 ^{o}C). The benzyloxy function was replaced cleanly, and **10a** could be isolated in 95%

yield. Ester substituted **8c** also was successful in substitution by a second nucleophile, as

allyltrimethylsilane and BF$_3$-OEt$_2$ (2.0 equiv each, 0° C) gave **10b** in 76% yield.

Suggested location for Scheme 3

As a final choice of nucleophile for Nicholas substitution reactions, we also chose to look

at a stannane to induce an overall reduction. In this case, we selected substrate **11**, due to the *n*-

pentyl group often bring present as a (*Z*)-alkene substituent in leukotriene systems, and due to the

fact that an alcohol function should be ionizable without destruction of the stannane nucleophile.

This compound was prepared from **4**, by trapping of the lithium acetylide with pentanal, and

reaction of unpurified alcohol **12** with Co$_2$(CO)$_8$ to form **11** (44% yield from **4**) (Scheme 4).

Reduction of **11** with BF$_3$-OEt$_2$ and a reactive stannane such as Bu$_3$SnH and Me$_3$SnH

tended to be unselective, tending to give complete reduction of the alcohol and ether functions.

Using the less reactive Ph$_3$SnH and BF$_3$-OEt$_2$ under carefully controlled conditions gave greater

selectivity, however. At 5 ^{o}C, with 1.5 equiv Ph$_3$SnH with 1.0 equiv BF$_3$-OEt$_2$, total selectivity

for reduction of the alcohol could be realized, and **13** (84% yield) was isolated as the sole

product.

Suggested location for Scheme 4

The results in Table 1 demonstrate that, in most cases, the benzyloxy function served as

an acceptable potential leaving group which would be retained in monosubstitution reactions in

deference to alcohol, methyl ether, or acetate functions. In the cases of allyltrimethylsilane (**7a**)

and cyclohexanone silyl enol ether (**7e**) as the nucleophile, the reactions had to be terminated at

relatively low levels of conversion and as a result the isolated yields of monosubstitution

products **8a** and **8d** were limited. We deemed the selectivity in these cases insufficient, and

chose to investigate alternatives which would give greater discrimination between oxygen functions, and hence greater monosubstitution selectivity. We have observed selectivity in Nicholas reaction-based 4+3 cycloaddition chemistry by employing an isopropyl ether as the more slowly ionizing oxygen function.[7b] Due to its straightforward preparation relative to isopropyl propargyl ether,[14] we chose instead menthyloxy containing **14**[15] as a starting point. The bromomagnesium acetylide of this propargylic ether was coupled with propargyl bromide to afford diyne **15** (75% yield), which in turn was converted to the menthyl methyl diynyl diether bis(dicobalt) complex **16** by deprotonation and subsequent trapping with chloromethyl methyl ether, and exposure of unpurified intermediate **17** to $Co_2(CO)_8$ (72% yield overall from **15**) (Scheme 1).

With complex **16** in hand, we investigated its reactivity towards allyltrimethylsilane (**7a**) and cyclohexanone trimethylsilyl enol ether (**7e**). With allyltrimethylsilane, the use of near stoichiometric amounts of Lewis acid BF_3-OEt_2 resulted in the recovery of substantial amounts of starting **16**. For example, with even two equivalents of BF_3-OEt_2, allyltrimethylsilane (1.5 equiv, 12 h, -10 ^{o}C), 31% recovery of **16** was found in addition to **18a** (31%, 54% based on recovered **16**). The amount of conversion increased with further excess amounts of BF_3-OEt_2, and at 4 equiv, **16** was consumed completely and a 71% yield of **18a** was obtained (Scheme 5). Further increased amounts of Lewis acid gave a gradual degradation of product yield.

In the case of cyclohexanone trimethylsilyl enol ether (**7e**), an analogous trend was found with increasing amounts of BF_3-OEt_2, but modest amounts of starting material remained even at 4 equiv (6% **16** recovery, 52% yield of **18b**, 60% yield brsm). In this case, switching the Lewis acid to Bu_2BOTf (1.2 equiv), in addition to an excess (3 equiv) of nucleophile gave an improved yield (71%) of **18b**, while greater excesses of this Lewis acid gave near-complete destruction of

the product. In the case of **18b**, a new chiral centre was generated. An apparent doubling of the several of signals was apparent in both the ^{1}H and ^{13}C NMR spectra of **18b**, and integration of the signals showed that **18b** existed as a 1:1 diastereomeric mixture. This was most clearly apparent for ^{1}H NMR resonances for the diastereotopic propargyl methylene group α- to the ether oxygen, which resonated at 4.851 and 4.847 ppm, and 4.53 and 4.52 ppm for the two diastereomers. Due to the distance between the reacting centre and the nearest centre of chirality, this lack of asymmetric induction was not surprising.

Suggested location for Scheme 5

We chose **18a** for study in order to determine whether the removal of the menthyloxy group was facile. Again, the substrate proved to be relatively sluggish in terms of reaction, but in the presence of 3 equiv each of BF_3-OEt_2 and MeOH (0 ^{o}C, CH_2Cl_2), methoxy substitution product **19** could be obtained in 65% yield (75% based on recovered starting material).

A combination of these results with those of reference 7b[7b] suggests the following approximate order in the kinetic ionization of oxygen based functions in Nicholas reactions: OH > OMe, OAc > OBn > OPr[i], O-menthyl, OTBDMS. The dominant factor in this ordering is most likely steric accessibility to the oxygen atom, although it is likely that inductive effects in the benzyl ether plays some role in reducing its basicity. A lower basicity of the acetate function is also known,[16,17] but is offset by its innately better leaving group ability.

With respect to the nucleophiles concerned, no clear pattern of nucleophile reactivity versus selectivity has emerged. For example, in the case of allylation, the more reactive allylstannane gives greater selectivity for monosubstitution; by contrast, a less reactive tin hydride (Ph_3SnH versus Bu_3SnH or Me_3SnH)[18] is more productive in reductions. Nevertheless, by careful choice of conditions and nucleophile, synthetically useful amounts of selective

monosubstitution products can be obtained in most cases using the benzyl substrates **3a** and **3b**. Disubstitution reactions of with either two identical or two different nucleophiles can also be accomplished in good to excellent yields. With the poorer cases for **3a** or **3b**, the menthyl ether complex **16** gives very good selectivity for monosubstitution; in fact, the menthoxy group is removed at all only sluggishly.

Experimental Section

General methods

All solvents were used after distillation from the appropriate drying agent. Diethyl ether and THF were distilled from benzophenone ketyl immediately prior to use. Dichloromethane was distilled from CaH_2 immediately prior to use. Commercial BF_3-OEt_2 was distilled and stored under nitrogen. All reactions were performed under nitrogen unless otherwise noted. Flash chromatography was performed as described by Still[19] using (230 - 240 mesh) silica gel 60.

NMR spectra were run at 500 MHz or 300 MHz for ^{1}H, and 125 MHz or 75 MHz for ^{13}C in $CDCl_3$; chemical shifts are given in ppm and coupling constants (*J*) are given in Hz. Mass spectra were run at the Chemistry and Biochemistry Mass Spectrometry Facility, University of Windsor, and the Mass Spectrometry Facility, Wayne State University.

6-Benzyloxy-1,4-hexadiyne (**4**). To the freshly prepared EtMgBr (25 mmol) in dry THF (20 mL) was added 3-benzyloxy-1-propyne (3.000 g, 20.00 mmol) over 10 min. After several minutes, the THF began to reflux. When the exothermic reaction had subsided, the flask was warmed for 30 min at 55 °C. The solution was then cooled to 30 °C and powdered CuCl (60 mg) was added. After 15 min, propargyl bromide (2.2 mL, 20 mmol) was added over 30 min. The mixture was warmed for 1 h to 60 °C. After cooling to room temperature, the reaction mixture was poured into a solution of NH_4Cl (3.0 g) and KCN (100 mg) in water (10 mL). After

vigorous shaking, the reaction was subjected to a conventional workup. Flash

chromatography (petroleum ether:diethyl ether, 10:1) followed by distillation afforded **4**

(1.160 g, 78%): b.p. 116-120$^{°}$C/0.5 torr; IR (neat, NaCl) v_{max} 3292, 3030, 2856, 1496 cm^{-1};

^{1}H NMR δ 7.35 (m, 5H), 4.62 (s, 2H), 4.20 (t, J = 3.4, 2H), 3.26 (m, 2H), 2.13 (t, J = 4.5, 1

H); ^{13}C NMR δ 137.9, 128.8, 128.5, 128.3, 80.4, 78.2, 77.9, 72.0, 69.5, 57.9, 10.1; MS m/e

184 (M^{+}); HRMS m/e for C$_{13}$H$_{12}$O calcd (M^{+}) 184.0888, found 184.0886.

7-Benzyloxy-2,5-heptadiyn-1-ol (**6**). To **4** (1.000 g, 5.4 mmol) in dry Et$_2$O (10 mL) was

added MeLi (1.5 M in Et$_2$O, 3.6 mL, 5.4 mmol) at -78 ^{o}C over 20 min. Thereafter, the

solution was warmed to -30 ^{o}C and paraformaldehyde (300 mg) was added. After 45 min,

the mixture was heated under reflux for 3 h. After cooling to room temperature, the mixture

was poured into ice water (10 mL), and a conventional workup performed. Flash

chromatography (petroleum ether-diethyl ether, 1:1) followed by distillation afforded **6** (640 mg,

55%): b.p. 125-129 $^{°}$C/0.5 torr; IR (neat, NaCl) v_{max} 3402, 3030, 2914, 2282 cm^{-1}; ^{1}H NMR δ

7.27-7.35 (m, 5H), 4.60 (s, 2H), 4.28 (s, 2H), 4.18 (t, J = 2.1, 2H), 3.29 (m, 2H), 1.62 (s, 1 H);

^{13}C NMR 137.7, 128.8, 128.5, 128.3, 80.9, 79.8, 79.5, 77.1, 72.1, 57.9, 51.4, 10.4; MS m/e 214

(M^{+}); HRMS m/e for C$_{14}$H$_{14}$O$_2$ calcd (M^{+}) 214.0994, found 214.0990.

1-Acetoxy-7-benzyloxy-2,5-heptadiyne (**5b**). To a mixture of compound **6** (1.200 g, 5.60

mmol) and Ac$_2$O (0.75 mL, 8.4 mmol) in THF (10 mL) was added an excess of BF$_3$-Et$_2$O at -78

^{o}C over a period of 20 min. The reaction was warmed to 0 ^{o}C, and monitored by TLC. After 1.5

h, when the starting material had disappeared, the reaction mixture was poured into saturated

NaHCO$_3$ $_{(aq)}$. After a conventional workup, flash chromatography (petroleum ether:diethyl ether,

1:1) afforded product **5b** (985 mg, 69%): bp 108-110$^{°}$C/0.5 torr; IR (neat, NaCl) v_{max} 3030, 2929,

2280, 1722, 1604, 1495 cm^{-1}; ^{1} H NMR δ 7.27-7.40 (m, 5H), 4.68 (t, J = 2.1, 2H), 4.59 (s, 2H),

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4.17 (t, J = 2.1, 2H), 3.29 (pentet, J = 2.1, 2H), 2.09 (s, 3H); ^{13}C NMR 170.0, 137.3, 128.3, 128.0, 127.8, 80.6, 79.8, 76.8, 74.6, 71.6, 57.4, 52.3, 20.6, 9.9; MS: m/e 256 (M$^+$); HRMS: m/e for $C_{16}H_{16}O_3$ calcd. (M$^+$) 256.1099, found 256.1100.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-acetoxy-7-benzyloxy-2,5-heptadiyne)]tetracobalt (2 Co-Co) (3b)

General Procedure for Complexation. To a solution of **5b** (1.000 g, 3.90 mmol) in anhydrous Et$_2$O (20 mL) at 0 ^{o}C was added an excess of dicobalt octacarbonyl. After 4 h, the reaction mixture was allowed to warm to room temperature. The resulting mixture was filtered through Celite$^®$ and the solvent was removed in vacuo. Flash chromatography (petroleum ether:diethyl ether, 15:1) afforded product **3b** (2.580 g, 78%): IR (neat, NaCl) ν_{max} 3031, 2922, 2860, 2087, 2034, 1742, 1626 cm^{-1}; ^{1}H NMR δ 7.27-7.39 (m, 5H), 5.30 (s, 2H), 4.69 (s 2H), 4.66 (s, 2H), 4.61 (s, 2H), 2.09 (s, 3H); ^{13}C NMR 199.4, 170.5, 137.7, 128.4, 127.7, 127.6, 92.8, 91.5, 91.1, 90.3, 73.1, 69.9, 64.3, 41.0, 20.3; MS (LSIMS) m/e 827 (M-1)$^+$, 744 (M-3CO)$^+$, 688 (M-5CO)$^+$, 660 (M-6CO)$^+$. Anal. Calcd. for $C_{28}H_{16}Co_4O_{15}$: C, 40.61%; H, 1.95%. Found: C, 40.49%; H, 1.88%.

1-Benzyloxy-7-methoxy-2,5-heptadiyne (**5a**). To a solution of compound **4** (480 mg, 2.60 mmol) in dry Et$_2$O (10 mL) was added MeLi (1.48 M in Et$_2$O, 2.2 mL, 3.3 mmol) at -78 ^{o}C over 20 min. The mixture was stirred for 30 min at -78 ^{o}C. Chloromethyl methyl ether (0.20 mL, 2.60 mmol) was added dropwise over 20 min, and the temperature was then allowed to rise to room temperature. The reaction was kept at room temperature for 2 h. Thereafter, cold water was added and the mixture subjected to a conventional workup. Flash chromatography (petroleum ether:diethyl ether, 10:1) afforded product **5a** (330 mg, 59%): bp: 112-114 ^{o}C/0.5 torr; IR (neat, NaCl) ν_{max} 3031, 2929, 2280, 1604, 1495 cm^{-1}; ^{1}H

NMR δ 7.27-7.37 (m, 5H), 4.60 (s 2H), 4.18 (t, J = 2.0, 2H), 4.10 (t, J = 2.0, 2H), 3.38 (s, 3H), 3.30 (t, J = 2.0, 2H); ^{13}C NMR 137.2, 128.1, 127.7, 127.5, 80.1, 80.0, 76.4, 76.3, 71.2, 59.6, 57.2, 57.1, 9.6; MS m/e 228 (M$^+$); HRMS m/e for $C_{15}H_{16}O$ calcd (M$^+$) 228.1150, found 228.1155.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-7-methoxy-2,5-heptadiyne)]tetracobalt (2 Co-Co) (**3a**). Compound **5a** (300 mg, 1.32 mmol) was subjected to reaction with $Co_2(CO)_8$ via the general procedure. Flash chromatography (petroleum ether:diethyl ether, 20:1) afforded product **3a** (810 mg, 77%): IR (neat, NaCl) v_{max} 3033, 2926, 2087, 2049, 2021 cm^{-1}; ^{1}H NMR δ 7.27-7.39 (m, 5H), 4.73 (s, 2H), 4.69 (s, 2H), 4.65 (s, 2H), 4.57 (s, 2H), 3.44 (s, 3H); ^{13}C NMR 199.6, 137.9, 128.4, 127.7, 127.5, 93.1, 92.7, 91.5, 91.2, 73.1, 72.6, 69.8, 58.8, 41.1; MS (EI) m/e 744 (M-2CO)$^+$, 716 (M-3CO)$^+$; (LSIMS) m/e 799 (M-1)$^+$, 716 (M-3CO)$^+$, 632 (M-6CO)$^+$.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-9-ene-2,5-decadiyne)]tetracobalt (2 Co-Co) (**8a**). **General Procedure for Substitution Reactions**. To a solution of compound **3b** (300 mg, 0.36 mmol) and nucleophile **7b** (179 mg, 0.54 mmol) in CH_2Cl_2 (15 mL) at 0 ^{o}C was added freshly distilled BF$_3$-Et$_2$O (77 mg, 0.54 mmol) dissolved in CH_2Cl_2 (5 mL) over 30 min. After 5 h, NaHCO$_{3(aq)}$ was added. After a conventional workup, flash chromatography (petroleum ether:diethyl ether, 20:1) afforded product **8a** (183 mg, 62%); a subsequent fraction contained **3b** (50 mg, 16.7%). **8a**: IR (neat, NaCl) v_{max} 3033, 2928, 2087, 2040, 1642 cm^{-1}; ^{1}H NMR δ 7.27-7.39 (m, 5H), 5.89 (m, 1H), 5.14 (dd, J = 1.5, 15.6, 1H), 5.08 (dd, J = 1.5, 10.2, 1H), 4.72 (s, 2H), 4.68 (s, 2H), 4.64 (s, 2H), 2.95 (t, J = 8.0, 2H), 2.40 (m, 2H); ^{13}C NMR 199.6, 137.8, 136.8, 128.4, 127.8, 127.5, 116.0, 93.8, 93.6, 93.5, 92.6, 73.1, 69.8, 41.2,

35.6, 32.8; MS (EI$^+$) m/e 726 (M-3CO)$^+$, 586 (M-8CO)$^+$; MS (LSIMS) m/e 726 (M-3CO)$^+$, 642 (M-6CO)$^+$.

From **3a**: To a solution of complex **3a** (200 mg, 0.25 mmol) in CH_2Cl_2 (15 mL) was condensed with nucleophile **7b** (166 mg, 0.50 mmol) in the presence of BF_3-Et_2O (71 mg, 0.50 mmol, 2 equiv) according to the general procedure. After flash chromatography (petroleum ether$^-$.diethyl ether, 20:1), **8a** (127 mg, 63%) was obtained, followed by **3a** (47 mg, 23.5%).

From **3a** and **7a**: The reaction of the complex **3a** (200 mg, 0.25 mmol) with **7a** (79 μL, 57 mg, 0.50 mmol) in the presence of BF_3-Et_2O (36 mg, 0.25 mmol, 1 equiv) according to the general procedure. After flash chromatography (petroleum ether:diethyl ether, 20:1), **8a** (79 mg, 39%) was obtained, followed by **3a** (102 mg, 51%).

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-8-methyl-9-oxo-9-phenyl-2,5-nonadiyne)] tetracobalt (2 Co-Co) (8b). Complex **3b** (300 mg, 0.36 mmol) was reacted with the nucleophile **7c** (150 mg, 0.72 mmol) in the presence of BF_3-Et_2O (51 mg, 0.36 mmol) via the general procedure. Flash chromatography (petroleum ether:diethyl ether, 10:1) afforded **8b** (208 mg, 64%): IR (neat, NaCl) $ν_{max}$ 3033, 2934, 2085, 2063, 1990, 1683 cm^{-1}; ^{1}H NMR δ 8.04 (d, J = 7.7, 2H), 7.27-7.59 (m, 8H), 4.76 (s, 2H), 4.75 (s, 2H), 4.58 (d, J = 4.8, 2H), 3.74 (m, 1H), 3.71 (1/2AB, J = 11.7, 1H), 2.93 (1/2AB, J = 11.7, 1H), 1.37 (d, J = 6.7, 3H); ^{13}C NMR 201.7, 199.6, 137.9, 135.5, 133.3, 128.7, 128.3, 127.6, 127.5, 127.4, 97.3, 93.9, 93.0, 91.0, 73.0, 69.8, 43.1, 41.0, 36.1, 19.4; MS (EI) m/e 818 (M-3CO)$^+$, 762 (M-5CO)$^+$; (LSIMS) m/e 819 (M+1-3CO)$^+$, 763 (M+1-5CO)$^+$, 735 (M+1-6CO)$^+$. A subsequent fraction contained **3b** (27 mg, 9%).

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-7-(1-ethoxycarbonylcyclohexyl)-2,5-heptadiyne)]tetracobalt (2 Co-Co) (**8c**). Compound **3b** was (300 mg, 0.36 mmol) reacted with nucleophile **7d** (150 mg, 0.72 mmol) in the presence of BF_3-Et_2O (51 mg, 0.36 mmol) according to

the general procedure. Flash chromatography (petroleum ether:diethyl ether, 15:1) afforded product **8c** (210 mg, 63%); IR (neat, NaCl) ν_{max} 3033, 2935, 2094, 2086, 2022, 1730 cm^{-1}; ^{1}H NMR δ 7.27-7.39 (m, 5H), 4.73 (s, 2H), 4.70 (s, 2H), 4.60 (s, 2H), 4.20 (q, J = 7.0, 2H), 3.23 (s, 2H), 1.25-2.17 (m, 13H); ^{13}C NMR 199.7, 175.4, 137.8, 128.4, 127.7, 127.5, 95.2, 93.0, 92.9, 90.9, 73.0, 69.7, 60.6, 48.1, 41.0, 34.6, 25.5, 22.8, 14.0; MS (EI) m/e 840 (M-3CO)$^+$, 700 (M-7CO)$^+$; (LSIMS) m/e 840 (M-3CO)$^+$, 728 (M-6CO)$^+$. A subsequent fraction contained **3b** (28 mg, 9%).

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-7-(2-oxocyclohexyl)-2,5-heptadiyne)]tetracobalt (2 Co-Co) (**8d**). Complex **3b** (200 mg, 0.24 mmol) was condensed with the nucleophile **7e** (86 mg, 0.29 mmol) in the presence of BF$_3$-Et$_2$O (51 mg, 0.36 mmol) via the general procedure. Flash chromatography (petroleum ether:diethyl ether, 10:1) afforded **8d** (85 mg, 41%): IR (neat, NaCl) ν_{max} 3033, 2933, 2085, 2022, 1716 cm^{-1}; 'H NMR δ 7.27-7.39 (m, 5H), 4.75 (s, 2H), 4.72 (s, 2H), 4.64 (s, 2H), 3.58 (m, 1 H), 1.49-2.60 (m, 10H); ^{13}C NMR 210.9, 199.6, 137.9, 128.3, 127.6, 127.5, 98.1, 93.6, 92.9, 91.1, 73.0, 69.8, 53.4, 42.0, 41.2, 35.4, 32.8, 28.2, 25.3; MS (EI) m/e 782 (M-3CO)$^+$, 642 (M-8CO)$^+$; (LSIMS) m/e 782 (M-3CO)$^+$, 698 (M-6CO)$^+$. A subsequent fraction contained **3b** (54 mg, 27%).

From **3a**: The complex **3a** (300 mg, 0.37 mmol) also reacted with the nucleophile **7e** (78 mg, 0.44 mmol) in the presence of BF$_3$-Et$_2$O (54 mg, 0.38 mmol) via the general procedure. Flash chromatography afforded **8d** (141 mg, 43%), followed by **3a** (130 mg, 43%).

Dodecacarbonyl[μ^4-(η,η,η,η)(trideca-1,12-dien-5,8-diyne)]tetracobalt (2 Co-Co) (**9a**). Complex **3a** (200 mg, 0.25 mmol) was condensed with nucleophile **7b** (331 mg, 1.00 mmol) in the presence of BF$_3$-Et$_2$O (142 mg, 1.00 mmol) via the general procedure. Flash chromatography (petroleum ether:diethyl ether, 10:1) afforded **9a** (127 mg, 73%): IR (neat, NaCl) ν_{max} 3085, 2941, 2093, 2022, 1643 cm^{-1}; ^{1}H NMR δ 5.94 (m, 2H), 5.17 (dd, J = 1.4 Hz,

17.2, 2H), 5.10 (dd, J = 1.4, 10.0, 2H), 4.65 (s, 4H), 2.99 (t, J = 7.9, 4H), 2.40 (m, 2H); ^{13}C

NMR 199.9, 136.8, 116.0, 98.5, 92.6, 41.4, 35.6, 32.8; MS (EI) 716 (M-1CO)$^{+}$, 688 (M-2CO)$^{+}$;

(LSIMS) m/e 716 (M-1CO)$^{+}$, 604 (M-5CO)$^{+}$. A subsequent fraction contained **8b** (27.0 mg,

12%)

Under directly analogous conditions, the reaction of complex **3a** (200 mg, 0.25 mmol) with **7a**

(0.16 mL, 1.0 mmol) and BF$_3$-OEt$_2$ (142 mg, 1.00 mmol) afforded product **9a** (170 mg, 90%).

Dodecacarbonyl[μ^4-(η,η,η,η)(2,10-dimethyl-1,11-diphenylundeca-4,7-diyn-1,11-

dione)]tetracobalt (2 Co-Co) (**9b**) Complex **3b** (75.1mg, 0.0907 mmol) was condensed with **7c**

(74.9mg, 0.363 mmol) in the presence of BF$_3$-OEt$_2$ (46 μL, 0.36 mmol) via the general

procedure. Flash chromatography (petroleum ether:diethyl ether 10:1) gave **9b** (59.0 mg, 70%)

as a 1:1 diastereomeric mixture: IR (neat, NaCl) ν_{max} 2093, 2084, 2051, 2017, 1683 cm^{-1}; ^{1}H

NMR δ 8.03 (d, J = 8.0, 4H), 7.57 (t, J = 7.6, 2H), 7.48 (apparent t, J = 7.7, 4H), 4.56+4.46 (AB,

J = 18.1) and 4.52 (s) (2H), 3.73 - 3.81 (m, 4H), 2.91 - 3.03 (m, 2H), 1.41 (d, J = 6.5) and 1.39

(d, J = 6.5) (6H); ^{13}C NMR 201.7, 199.9 and 199.5, 135.5, 133.29 and 133.28, 128.8, 128.4, 97.4

and 97.3, 93.9 and 93.8, 43.1, 41.0 and 40.9 36.0, 19.6 and 19.4; MS (EI) m/e 844 (M-3CO)$^{+}$,

648 (M-10CO)$^{+}$; (LSIMS) m/e 929 (M+1)$^{+}$, 844 (M-3CO)$^{+}$.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-(2,4,6-trimethoxyphenyl)deca-9-en-2,5-diyne)]tetracobalt

(2 Co-Co) (**10a**). Compound **8a** (240 mg, 0.30 mmol) was condensed with 1,3,5-

trimethoxybenzene (**7f**) (101 mg, 0.60 mmol) in the presence of BF$_3$-Et$_2$O (85 mg, 0.60 mmol)

via the general procedure. Flash chromatography (petroleum ether$^-$diethyl ether, 20:1) afforded

10a (245 mg, 95%): IR (neat, NaCl) ν_{max} 3007, 2942, 2082, 2045, 2022, 1615 cm^{-1}. ^{1}H NMR: δ

6.14 (s, 2H), 5.95 (m, 1H), 5.18 (dd, J = 1.5, 17.0, 1H), 5.08 (dd, J = 1.5, 10.0, 1H), 4.59 (s, 2H),

4.17 (s, 2H), 3.81 (s, 3H), 3.77 (s, 6H), 3.06 (t, J = 8.1, 2H), 2.45 (m, 2H); ^{13}C NMR 199.9,

160.5, 158.7, 136.9, 115.8, 108.2, 100.2, 98.4, 93.5, 92.8, 89.9, 55.3, 54.7, 41.2, 35.6, 32.8, 26.0; MS (EI) 842 (M-1CO)$^+$, 786 (M-3CO)$^+$; (LSIMS) m/e 767 (M-3CO)$^+$, 730 (M-5CO)$^+$.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-(1-carboethoxycyclohexyl)-dec-9-en-2,5-diyne)]tetracobalt

(2 Co-Co) (**10b**) Compound **8c** (109.8 mg, 0.119 mmol) was reacted with allyltrimethylsilane (38 μL, 0.24 mmol) and BF$_3$-OEt$_2$ (30 μL, 0.24 mmol) via the standard procedure. Flash chromatography (25:1 petroleum ether:diethyl ether) afforded **10b** (77.6 mg, 76%), as a red-brown oil: IR (neat, KBr) ν$_{max}$ 2094, 2084, 2048, 2014, 1728 cm^{-1}. ^{1}H NMR: δ 5.95 (m, 1H), 5.17 (d, J = 17.1, 1H), 5.10 (d, J = 10.3, 1H), 4.60 (s, 2H), 4.21 (q, J = 7.1, 2H), 3.27 (s, 2H), 2.95 - 3.05 (m, 2H), 2.38 - 2.50 (m, 2H), 2.12 - 2.30 (m, 2H), 1.20 - 1.75 (m, 8H), 1.28 (t, J = 7.1, 3H); ^{13}C NMR 199.9, 199.8, 175.4, 136.8, 115.8, 98.5, 95.2, 92.8, 92.6, 60.6, 48.1, 43.8, 41.2, 35.6, 34.6, 32.5, 29.7, 25.6, 22.8, 14.0; MS (EI) 774 (M-3CO)$^+$, 718 (M-5CO)$^{+;}$ (LSIMS) m/e 774 (M-3CO)$^+$, 718 (M-5CO)$^+$, 690 (M-6CO)$^+$.

Synthesis of Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-7-hydroxy-2,5-undecadiyne)]tetracobalt

(2 Co-Co) (**11**). To a solution of freshly prepared 6-benzyloxy-1,4-hexadiyne (**4**) (56.4 mg, 3.06 mmol) in THF at −78 ºC was added methyllithium (3.06 mL, 1.5 M, 4.59 mmol). The mixture was stirred for 20 min and freshly distilled of pentanal (651 μL, 6.12 mmol) was added dropwise. After stirring for 3 h, the reaction mixture diluted with cold water at 0 ºC. Following a conventional workup, the crude product was diluted with diethyl ether and placed in an ice bath. An excess amount of cobalt carbonyl was added and the mixture stirred for 3.5 h. Following removal of the volatiles under reduced pressure, flash chromatography (20:1 petroleum ether : diethyl ether) gave (**11**) (90.2 mg, 44%) as red-brown oil: IR (neat) ν$_{max}$ 3386, 2919, 2012 cm^{-1}; ^{1}H NMR δ 7.32 (m, 5H), 4.68 (m, 7H), 2.79 (d, J = 5.2, 1H), 1.64 (m, 3H), 1.36 (m, 3H), 0.92 (t,

$J = 7.1$, 3H). ^{13}C NMR 199.6, 199.3, 137.0, 128.5, 128.1, 128.0, 102.4, 92.0, 91.3, 91.0, 73.4, 71.5, 70.1, 41.2, 39.2, 28.5, 22.4, 13.9; MS (EI) m/e: 758 (M – 3CO)$^+$, 618 (M - 8CO)$^+$; (LSIMS) m/e: 757 (M - 1 - 3CO)$^+$, 617 (M -1 - 8 CO)$^+$.

Dodecacarbonyl[μ^4-(η,η,η,η)(1-benzyloxy-2,5-undecadiyne)]tetracobalt (2 Co-Co) (**13**). To a solution of (**11**) (353 mg, 0.41 mmol) and Ph$_3$SnH (220 mg, 0.62 mmol) in CH$_2$Cl$_2$ (10 mL) at 5 ^{o}C was added BF$_3$-Et$_2$O (53 μL, 0.41 mmol). After stirring for 20 h with regular monitoring by TLC, the reaction mixture was diluted with water and subjected to conventional work up. Flash chromatography (100:1 petroleum ether : diethyl ether) afforded (**13**) as a red-brown oil (290 mg, 84%): IR (neat) v_{max} 2933, 2099 cm^{-1}; ^{1}H NMR δ 7.35 (m, 5H), 4.74 (s, 2H), 4.70 (s, 2H), 4.65 (s, 2H), 2.84 (t, J = 8.0, 2H), 1.66 (m, 2H), 1.41 (m, 4H), 0.95 (t, J = 7.0, 3H): ^{13}C NMR 200.0, 199.5, 137.8, 128.3, 127.7, 127.4, 99.7, 93.0, 92.5, 91.1, 73.0, 69.7, 41.2, 33.3, 31.6, 31.5, 22.3, 13.8; MS (EI) m/e: 742 (M-3CO)$^+$, 658 (M-6CO)$^+$; (ES-) m/e: 768.5 (M-2CO-H)$^-$, 740.5 (M-3CO-H)$^-$.

(1'R, 2'S, 5'R)- 1-Menthoxy-2,5-heptadiyne (15). To a solution freshly prepared solution of EtMgBr (15.0 mmol) in dry THF (20 mL) was added 3-menthyloxy-1-propyne (**14**) (1.464 g, 7.53 mmol) in cannula under a stream of nitrogen. The solution was heated for 30 min at 60 ^{o}C and cooled to room temperature. CuCl was added (74 mg, 0.75 mmol), followed by propargyl bromide (1.67 mL, 18.0 mmol). The solution was heated to reflux for 1 h. A conventional work up and subsequent flash chromatography (100 % hexane) afforded (**15**) (1.313 g, 75%) as a colorless oil: $[\alpha]^{25}_D$ -66.9 (c 1.17 acetone); IR (neat) v_{max} 3312, 2954, 2869 cm^{-1}; ^{1}H NMR δ 4.16 (t of ½ AB, J = 2.0, 15.5, 1H), 4.11 (t of ½ AB, J = 1.9, 15.5, 1H), 3.16 (m, 3H), 2.18 (m, 1H), 2.03 (m, 1H), 1.57 (m, 2H), 1.57 (m, 1H), 1.34 (m,1H), 0.70 – 1.00 (m, 4H), 0.87 (d, J = 6.6, 3H), 0.84 (d, J = 7.1, 3H), 0.74 (d, J = 6.9, 3H); ^{13}C NMR 78.5, 77.78, 77.74, 77.72, 68.8,

55.4, 48.0, 39.7, 34.3, 31.3, 25.2, 23.1, 22.2, 20.9, 16.0, 9.5. MS (EI) m/e: 232 (M)$^+$; HRMS calc

for $C_{16}H_{24}O$ 232.1827, found 232.1826.

(1'R, 2'S, 5'R)- Dodecacarbonyl[μ^4-(η,η,η,η)(1-menthoxy-7-methoxy-2,5-

heptadiyne)]tetracobalt (2 Co-Co) **(16)**

To a solution of (**15**) (1.75 g, 7.50 mmol) in diethyl ether (20 mL) at −78 ^{o}C and was added MeLi

(8.0 mL, 1.40 M, 11.2 mmol). The solution was then stirred for 20 min, and chloromethyl methyl

ether (1.13 mL, 15.0 mmol) was added. The reaction mixture was allowed to warm up to room

temperature and stirred overnight. Following a conventional work up, the resulting crude product

was dissolved in anhydrous Et$_2$O (20 mL) and cooled to 0 ^{o}C. An excess of cobalt carbonyl was

added and the solution stirred for 3.5 h. The resulting crude product was filtered though Celite$^®$□

and the resulting filtrate was concentrated under reduced pressure. Flash chromatography

(petroleum ether: diethyl ether, 50:1) gave (**16**) (3.946 g, 72%) as a red-brown oil: [α]^{22}$_D$ +72 (c

0.036 acetone); IR (neat) v$_{max}$ 2923, 2052 cm^{-1}; ^{1}H NMR δ □4.8 (d, J = 12.5, 1H), 4.6 (m, 4H),

4.51 (d, J = 12.5, 1H), 3.52 (s, 3H), 3.26 (apparent dt, J = 4.1, 10.5, 1H), 2.31 (m, 1H), 2.14 (d, J

= 12.0, 1H), 1.67 (m, 2H), 1.41 (m, 1H), 1.31 (m, 1H), 0.88-1.10 (m, 3H), 0.96 (d, J = 6.0, 3H),

0.90 (d, J = 7.0, 3H), 0.80 (d, J = 6.9, 3H); ^{13}C NMR 199.7, 94.7, 92.7, 91.6, 90.7, 79.3, 72.6,

67.8, 58.8, 48.2, 41.0, 40.3, 34.5, 31.6, 25.3, 23.1, 22.3, 20.8, 15.9; MS (EI) m/e 820 (M-CO)$^+$,

596 (M-9CO)$^+$; (ES+) m/e 691 (M + K −7CO)$^+$.

(1'R, 2'S, 5'R)- Dodecacarbonyl[μ^4-(η,η,η,η)(1-menthoxydeca-9-en-2,5-diyne)]tetracobalt

(2 Co-Co) **(18a)**

To a solution of (**16**) (207 mg, 0.244 mmol) in CH$_2$Cl$_2$ (5 mL) at 0 ^{o}C was added BF$_3$.Et$_2$O (144

μL, 1.14 mmol). The solution stirred for 10 min; thereafter, allyltrimethysilane (67 μL, 0.42

mmol) was added and the reaction was continued until none of the starting **16** was detected in

TLC analysis (12 h). A conventional work up and subsequent flash chromatography (100% petroleum ether) afforded (**18a**) (148 mg, 71%) as a red-brown oil: : $[\alpha]^{22}_D$ +52 (c 0.079 acetone) IR (neat) ν_{max} 2924, 2085, 2049 cm^{-1}; ^{1}H NMR δ □5.94 (m, 1H), 5.17 (d, J = 17.0, 1H), 5.10 (d, J = 12.1, 1H), 4.82 (d, J = 12.4, 1H), 4.65 (s, 2H), 4.50 (d, J = 12.4, 1H), 3.24 (apparent dt, J = 4.0, 10.5, 1H), 2.99 (m, 2H), 2.42 (m, 2H), 2.29 (m, 1H), 2.11 (br d, J = 12.1 1H), 1.63 (m, 2H), 1.30 (m, 1H), 1.28 (m, 1H), 0.85 – 1.17 (m, 3H), 0.95 (d, J = 6.4, 3H), 0.89 (d, J = 7.0, 3H), 0.78 (d, J = 7.0, 3H); ^{13}C NMR 199.7, 136.8, 115.9, 98.5, 94.6, 92.9, 90.5, 79.3, 67.8, 48.2, 41.2, 40.2, 35.5, 34.5, 32.8, 31.6, 25.4, 23.1, 22.3, 20.8, 15.9; MS (EI) m/e 802 (M-2CO)$^+$, 774 (M-3CO)$^+$; (ES+) m/e 795 (M-3CO+Na-H$_2$)$^+$, 688 (M-6CO+Na-H$_2$)$^+$.

(1'R, 2'S, 5'R)- Dodecacarbonyl[μ^4-(η,η,η,η)(1-menthoxy-7-(2-oxocyclohexyl)-2,5-heptadiyne)]tetracobalt (2 Co-Co)(**18b**) To a solution of (**16**) (90 mg, 0.12 mmol) and the trimethylsilyl enol ether of cyclohexenone (**7e**) (62 mg, 0.36 mmol) in CH$_2$Cl$_2$ (5 mL) at 0 ^{o}C was added Bu$_2$BOTf (73 μL, 1M). The solution was stirred for 3 h, and further Bu$_2$BOTf (74 μL, 1M) was added; stirring was continued until none of the starting **16** was detected in TLC analysis (12 h) (total amount Bu$_2$BOTf used 147 μL, 0.14 mmol). A conventional work up and subsequent flash chromatography (100% petroleum ether) afforded (**18b**) (70 mg, 71 %, de = 0) as a red brown oil: IR (neat) ν_{max} 2929, 2869, 2085, 2053 cm^{-1}; ^{1}H NMR δ □4.851 (d, J = 12.5) and 4.847 (d, J = 12.5) (1H), 4.61 (m, 2H), 4.53 (d, J = 12.5) and 4.52 (d, J = 12.5) (1H), 3.59 (dd, J = 6.5, 15.5, 1H), 3.24 (apparent dt, J = 4.1, 10.5, 1H), 2.59 (m, 2H), 2.45 (m, 1H), 2.38 (m, 1H), 2.27 (m, 2H), 2.12 (m, 2H), 1.92 (m, 1H), 1.65 (m, 6H), (m, 1H), 0.85-1.15 (m, 3H), 0.95 (d, J = 6.6, 3H), 0.88 (d, J = 6.9, 3H), 0.77 (d, J = 7.2, 3H). ^{13}C NMR 211.0, 199.8, 98.0, 94.7, 94.6, 93.8, 90.4, 79.3, 79.2, 67.7, 53.4, 48.2, 42.1, 40.2, 35.6, 35.5, 34.5, 32.7, 31.6, 28.2, 25.4,

23.1, 22.3, 20.9, 15.9; MS (EI+) m/e: 830 (M − 3CO)[+], 718 (M − 7 CO)[+]; (ES+) m/e: 937 (M + Na)[+], 909 (M + Na − CO)[+].

Dodecacarbonyl[μ[4]-(η,η,η,η)(1-methoxydeca-9-en-2,5-diyne)]tetracobalt (2 Co-Co) **(19)**

 To a solution of (**18a**) (122 mg, 0.16 mmol) in CH_2Cl_2 (5 mL) at 0 °C was added BF_3-Et_2O (83 μL, 0.65 mmol). The solution was stirred for 10 min, and MeOH (20 μL, 0.49 mmol) was added. After stirring for 12 h, the crude reaction mixture was subjected to conventional work up. Flash chromatography (100% petroleum ether) afforded (**19**) (66 mg, 65%, 74 % yield based on recovered **18a**) as red brown oil: IR (neat) ν_{max} 2922, 2085, 2049 cm^{-1}; ^{1}H NMR δ 5.90 (m, 1H), 5.16 (d, J = 17.1, 1H), 5.10 (d, J = 10.7, 1H), 4.6 (d, J =11.7, 4H), 3.5 (s, 3H), 2.9 (m, 2H), 2.42 (m, 2H). ^{13}C NMR 199.8, 199.6, 136.8, 115.9, 98.6, 92.7, 92.6, 91.3, 72.6, 58.9, 41.2, 35.5, 32.7, MS (EI) m/e: 678 (M − 2CO)[+], 650 (M − 3CO)[+]; (ES-) 733 (M-H)[-], 705 (M-H-CO)[-], 677 (M-H-2CO)[-], 649 (M-H-3CO)[-]; HMMS (ES-) m/e for $C_{23}H_{14}Co_4O_{13}$ calcd (M[+]-H-2CO) 676.7786, found 676.7767. A subsequent fraction contained the starting **18a** (14.8 mg, 12%).

Material on Deposit

The ^{1}H NMR spectra of **4** and **5a** and the ^{13}C NMR spectra of **3a-b**, **5a-b**, **6**, **8a-d**, **9a-b**, **10a-b**, **11**, **12**, **15**, **16**, **18a-b** and **19** have been deposited as supplementary material.[2]

Acknowledgements

References

1.	(a) J. R. Green. Curr. Org. Chem. **5**, 809 (2001). (b) T. J. J. Müller. Eur. J. Org. Chem. 2021 (2001). (c) B. J. Teobald. Tetrahedron **58**, 4133 (2002).

2.	D. G. Hamilton and J. K. M. Sanders. Chem. Commun. 1749 (1998), and references therein.

3.	For recent reviews on hexacarbonyldicobalt alkyne complexes, see: (a) M. E. Welker. Curr. Org. Chem. **5**, 785 (2001). (b) M. J. Went. Adv. Organomet. Chem. **41**, 69 (1997).

4.	(a) T. Sugihara, M. Yamaguchi, and M. Nishizawa. Chem. Eur. J. **7**, 1589 (2001). (b) K. M. Brummond and J. I. Kent. Tetrahedron **56**, 3263 (2000). (c) Y. K. Chung. Coord. Chem. Rev. **188**, 297 (1999). (c) A. J. Fletcher and S. D. R. Christie. J. Chem. Soc., Perkin Trans. 1 1657 (2000). (d) O. Geis and H.-G. Schmalz. Angew. Chem. Int. Ed. Engl. **37**, 911 (1998).

5.	(a) T. Sugihara, A. Wakabayashi, H. Takao, H. Imagawa, and M. Nishizawa. Chem. Commun. 2456 (2001). (b) S. U. Son, Y. K. Chung, and S.-G. Lee. J. Org. Chem. **65***, 6142 (2000).

6.	For example, see: a) N. M. Deschamps, J. H. Kaldis, P. E. Lock, J. F. Britten, and M. J. McGlinchey. J. Org. Chem. **66**, 8585 (2001). b) E. J. Corey and C. J. Helal. Tetrahedron Lett. **36,** 9153 (1995); c) J. Bach, R. Berenguer, J. Garcia, T. Loscertales, and J. Vilarrasa, J. Org. Chem. **61**, 9021 (1996).

7.	a) J. R. Green. Chem. Commun. 1751 (1998). b) M. M. Patel and J. R. Green. Chem. Commun. 509 (1999). c) R. Guo and J. R. Green. Chem. Commun. 2503 (1999). d) Y. Lu

and J. R. Green. Synlett 243 (2001). e) R. Gibe and J. R. Green. Chem. Commun. 1550 (2002).

8. a) J. M. Palazón and A. S. Martín. Tetrahedron Lett. **36**, 3549 (1995). b) M. Takase, T. Morikawa, H. Abe, and M. Inouye. Org. Lett. **5,** 625 (2003). c) For selective ionization of an acetal function, see: T. F. Jamison, S. Samayati, W. E. Crowe, and S. L. Schreiber. J. Am. Chem. Soc. **119**, 4353 (1997).

9. Non-selective disubstitution reactions of these complexes are known. For C-C forming reactions, see ref. 7c and a) G. G. Melikyan, M. A. Khan, and K. M. Nicholas. Organometallics **14**, 2170 (1995). For C-X forming reactions, see: b) L. J. Hope-Weeks, M. J. Mays, and A. D. Woods. J. Chem. Soc., Dalton Trans. 1812 (2002). c) H. Amouri, C. Da Silva, B. Malézieux, R. Andrés, J. Vaissermann, and M. Gruselle. Inorg. Chem. **39,** 5053 (2000). d) D. Díaz, T. Martín, and V. S. Martín. Org. Lett. **3**, 3289 (2001).

10. a) J. S. Kim, Y. J. Lim, K. S. Im, C. J. Jung, C. O. Lee, J. Hong, and H. Lee. J. Nat. Prod. **62**, 554 (1999), and references therein; b) Y. Seo, K. W. Cho, J.-R. Rho, J. Shin, and C. J. Sim. Tetrahedron **54**, 447 (1998), and references therein; c) J. S. Kim, K. S. Im, J. H. Jung, Y.-L. Kim, J. Kim, C. J. Shim, and C.-O. Lee. Tetrahedron **54**, 3151 (1998), and references therein.

11. a) G. Saha, M. K. Basu, S. Kim, Y.-J. Jung, Y. Adiyaman, M. Adiyaman, W. S. Powell, G. A. Fitzgerald, and J. Rokach. Tetrahedron Lett. **40**, 7179 (1999), and references therein; b) Eicosanoids and Related Compounds in Plants and Animals, *Edited by* A. F. Rowley, H. Kühn, and T. Schewe. Princeton University, Princeton, 1998.

12. The Leukotrienes : Chemistry and Biology, *Edited by* L. W. Chakrin and D. M. Bailey. Academic, Orlando, 1984.

13. R. Guo and J. R. Green. Synlett 746 (2000).

14. See, for example: T. Takahashi, T. Yokozawa, and T. Endo. Macromolecules **28,** 866 (1995).

15. P. Rochet, J.-M. Vatèle, and J. Goré. Synthesis 795 (1994).

16. a) M. Berthelot, F. Besseau, and C. Laurence. Eur. J. Org. Chem. 925 (1998); b) F. Besseau, C. Laurence, and M. Berthelot. J. Chem. Soc., Perkin Trans. 2 485 (1994).

17. a) P.-C. Maria and J.-F. Gal. J. Phys. Chem. **89**, 1296 (1985); b) A. Rauk, I. R. Hunt, and B. A. Keay. J. Org. Chem. *59*, 6808 (1994).

18 . H. Mayr and H. Patz. Angew Chem. Int. Ed. Engl. **33**, 938 (1994).

19. W. C. Still, M. Kahn and A. Mitra. J. Org. Chem. **43**, 2923 (1978).