Palladium-catalysed sequential carboxylation–alkoxycarbonylation of acetylenic amines

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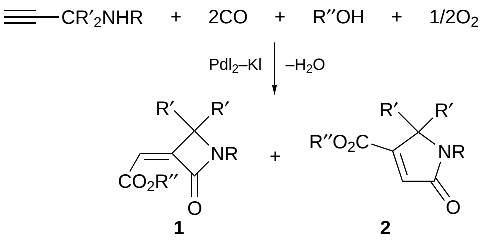
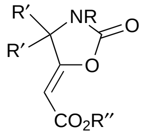
Carbon dioxide and carbon monoxide react in sequence in an intramolecular carboxy–carbonylation reaction of *N*-alkyl-substituted dialkylpropynylamines, under the catalytic action of palladium iodide–potassium iodide in methanol in the presence of oxygen.

In the course of our investigation of the palladium-catalysed synthesis of β- and γ-lactams by oxidative carbonylation of acetylenic amines[1] [eqn. (1), R = alkyl, R′,R″ = alkyl], we noticed the presence of small amounts of compounds containing an additional oxygen atom, the formation of which was promoted by a little water in the reaction mixture.

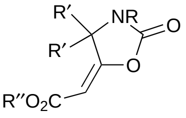


(1)

These compounds turned out to be (*Z*)- and (*E*)-[(alkoxycarbonyl)methylene]oxazolidin-2-ones **3a** and **3b**† in 2 : 1–3 : 1 ratio. The X-ray structure of one of them (**3a**, R = Bn; R′,R″ = methyl)‡ is shown in Fig. 1. In the crystal of **3a**, the methoxycarbonyl moiety and the five-membered ring are coplanar within 0.2 Å and oxygens O(2) and O(3) are in close contact [O(2)··O(3) 2.835(2) Å] due to the *Z* configuration of the C(2)–C(4) double bond [torsion angle C(3)–C(2)–C(4)–C(5) −175.9(2)°].



3a



3b

The formation of compounds **3** could be attributed to the sequential reaction of one molecule of carbon dioxide and one of carbon monoxide with the triple bond, according to eqn. (2).

$$\equiv\!\!-\mathrm{CR'_2NHR} + \mathrm{CO_2} + \mathrm{CO} + \mathrm{R''OH} + 1/2\mathrm{O_2} \xrightarrow[-\mathrm{H_2O}]{\mathrm{PdI_2-KI}} \mathbf{3} \quad (2)$$

In fact carbon dioxide could originate through decarboxylation of a hydroxycarbonylpalladium species[2] formed in the presence of water [eqn. (3)].

$$\mathrm{PdI_2} + \mathrm{CO} + \mathrm{H_2O} \xrightleftharpoons{-\mathrm{HI}} \mathrm{I{-}Pd{-}CO_2H} \rightleftharpoons [\mathrm{H{-}Pd{-}I}] + \mathrm{CO_2} \quad (3)$$

To test our hypothesis we treated a mixture of carbon dioxide (40 bar), carbon monoxide (5 bar) and air (5 bar) with *N*-(dimethylpropynyl)benzylamine in methanol (20 ml, 0.15 M), with a 100 : 1 molar ratio of amine to catalyst (PdI_2 or Pd–C 10% + 10 mol KI per mol of Pd). After stirring at 52 °C for 45 h products **3a** and **3b** (R = Bn; R′,R″ = Me) were obtained in an 88% yield (2 : 1 ratio) by GLC. With R = Bu the yield was 69% (3.2 : 1 ratio). Unconverted substrate (2% for R = Bn, R′ = Me; 4% for R = Bu, R′ = Me), oxazolidinone **4** (3% for R = Bn, R′ = Me; 2% for R = Bu, R′ = Me), β-lactam **1** (only traces for R = Bn; R′,R″ = Me; 4% for R = Bu; R′, R″ = Me) and compounds derived from a trimethoxycarbonylation at the nitrogen and triple bond carbons of starting propynylamines (5% for R = Bn; R′, R″ = Me; 9% for R = Bu; R′,R″ = Me) were present as by-products. A higher pressure of carbon monoxide or higher temperature led to a decrease in the yield of **3**. Under the same conditions as above the use of CO in the absence of CO_2 gave a less than 2% yield of **3** (R = Bu; R′,R″ = Me), which increased to 17% (**3a** : **3b** = 3) in the presence of 15% water in the reaction mixture.

The course of the reaction leading to **3a** and **3b** can be interpreted according to Scheme 1, which implies the intermediate formation of a palladium carbamate (anionic iodide ligands are omitted for simplicity).

Products **3a** and **3b** are proposed to originate from different reaction pathways, the former from *cis* attack of palladium carbamate on the triple bond, the latter from *trans* attack of the carbamate anion on the triple bond coordinated to palladium.[3] It was ascertained that isomerization of **3a** into **3b** or *vice versa* did not occur under the reaction conditions. An isomerization of the vinylpalladium precursors of **3** shown in Scheme 1 cannot be excluded but it is not likely in view of the fact that a larger availability of potassium carbamate for *trans* attack on the triple bond obtained by increasing the KI excess led to a decrease of the **3a** : **3b** ratio (for example, from 3.2 to 1.7 for R = Bu; R′,R″ = Me on passing from 10 to 100 KI : Pd molar ratio under the conditions reported in the example above).

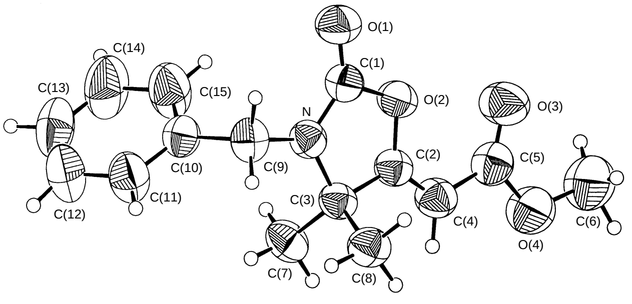
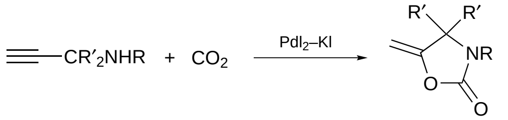


Fig. 1 ORTEP diagram of **3a** with 50% probability thermal ellipsoids. Relevant distances (Å) and angles (°) are: N–C(1) 1.327(3), C(1)–O(2) 1.399(2), C(2)–O(2) 1.369(2), C(2)–C(3) 1.509(2), N–C(3) 1.467(2), C(2)–C(4) 1.325(3), O(2)–C(1)–N 108.7(2), O(2)–C(2)–C(3) 109.4(1), C(2)–C(3)–N 99.4(1), O(2)–C(2)–C(4) 122.9(2), C(3)–C(2)–C(4) 127.6(2). In the five-membered ring, endocyclic angles centred on the atoms N, C(1), O(2) and C(2) range from 108.7 to 112.7°, while the angle N–C(3)–C(2) is noticeably reduced [99.4(1)°].

We also caused carbon dioxide (40 bar) to react with the same acetylenic amine (3.0 mmol) in MeOH (20 ml) in the presence of PdI_2 (100 : 1 molar ratio to the substrate) and KI (15 : 1 molar ratio to Pd) in the absence of carbon monoxide and oxygen at 75 °C for 24 h. The result was the formation of compound **4** (R = Bu, R′ = Me; 27% yield, 64% unconverted propynylamine) [eqn. (4)], which originates from protonation of the (*Z*)- or (*E*)-vinylpalladium precursor of **3**.

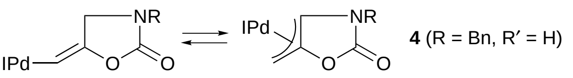


4

(4)

Although this reaction is catalytic, more satisfactory results were reached under the reported conditions in the presence of air (10 bar), a 58% yield of **4** (R = Bu, R′ = Me) being obtained at 65% conversion.

It is worth noting that in the absence of alkyl groups α to the triple bonds (R′ = H) the introduction of carbon dioxide only and not that of carbon monoxide was observed under the conditions of eqn. (2), compound **4** (61% yield; R = Bn, R′ = H) being formed exclusively. This is likely to be due to stabilization through formation of an allylpalladium complex[4] which, being poorly reactive towards carbon monoxide,[5] undergoes selectively hydrogenolysis [eqn. (5)] (the isomer with an endocyclic double bond was not detected).



(5)

Compound **4** was previously obtained also by direct incorporation of CO_2 under the catalytic action of superbases in aprotic solvents.[6]

The carboxylation–alkoxycarbonylation reported here is the first catalytic reaction in which cabon dioxide and carbon monoxide are caused to react in sequence. A stoichiometric sequence in two steps was described by Carmona[7] in the formation of an anhydride from a metallacyclic complex, CO and CO_2.

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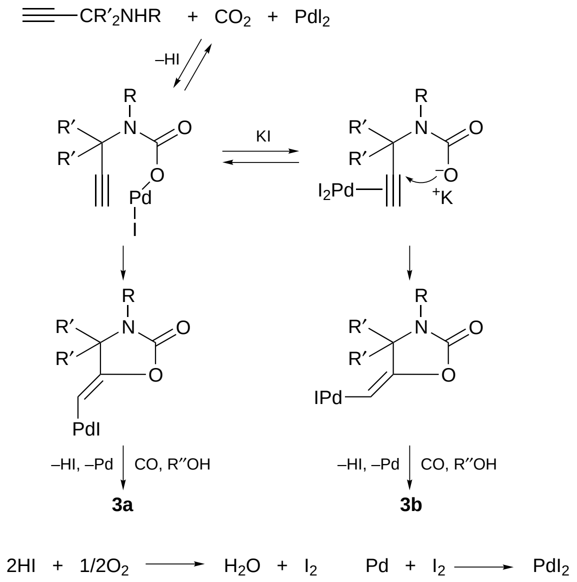

Scheme 1

Footnotes

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[†] *Selected data* for **3a** (R = Bu, R′ = Me, R″ = Me): pale yellow solid, mp 71–72 °C; ^1H NMR (300 MHz, $CDCl_3$): δ 0.93 (t, 3 H, *J* 7.3 Hz, Me), 1.30–1.40 (m, 2 H, CH_2), 1.43 (s, 6 H, 2 Me), 1.57–1.67 (m, 2 H, CH_2), 3.17 (t, 2 H, *J* 7.9 Hz, NCH_2), 3.74 (s, 3 H, OMe) and 5.07 (s, 1 H, =CH); ^{13}C NMR 75 MHz, $CDCl_3$): δ 13.52 (Me), 20.04 (CH_2), 27.00 (2 Me), 31.13 (CH_2), 40.41 (CH_2), 51.41 (OMe), 62.48 (qC), 91.70 (=CH), 152.65 (qC), 164.46 (qC) and 166.63 (qC); *m*/*z* 241 (M^+, 3%), 226 (68), 170 (52), 138 (37), 69 (100) and 59 (14); ν (KBr) cm^{-1} 2930 (w), 1786 (s), 1721 (s), 1677 (m), 1401 (m), 1173 (m), 1033 (m) and 1011 (m). For **3b** (R = Bu, R′ = Me, R″ = Me, R″ = Me): colourless oil; ^1H NMR (300 MHz, $CDCl_3$): δ 0.95 (t, 3 H, *J* 7.3 Hz, Me), 1.31–1.41 (m, 2 H, CH_2), 1.60–1.71 (m, 2 H, CH_2), 1.69 (s, 6 H, 2 Me), 3.16 (t, 2 H, *J* 7.9 Hz, NCH_2), 3.70 (s, 3 H, OMe) and 5.61 (s, 1 H, =CH); ^{13}C NMR 75 MHz, $CDCl_3$): δ 13.55 (Me), 20.10 (CH_2), 23.02 (2 Me), 31.05 (CH_2), 40.09 (CH_2), 51.24 (OMe), 63.95 (qC), 94.91 (=CH), 152.19 (qC), 165.74 (qC) and 169.63 (qC); *m*/*z* 241 (M^+, 5%), 226 (83), 69 (100), 59 (26) and 55 (32); ν (film) cm^{-1} 2960 (m), 2874 (w), 1801 (s), 1720 (s), 1661 (s), 1403 (m), 1267 (m), 1088 (s), 1048 (s) and 1002 (m). For **3a** (R = Bn, R′ = Me, R″ = Me): pale yellow solid, mp 125–126 °C; ^1H NMR (300 MHz, $CDCl_3$): δ 1.32 (s, 6 H, 2 Me), 3.74 (s, 3 H, OMe), 4.48 (s, 2 H, CH_2), 5.07 (s, 1 H, =CH) and 7.28 (m, 5 H, Ph); ^{13}C NMR 75 MHz, $CDCl_3$): δ 27.20 (2 Me), 44.27 (CH_2), 51.52 (OMe), 62.78 (qC), 92.03 (=CH), 127.76 (2 =CH), 128.04 (=CH), 128.79 (2 =CH), 136.82 (qC), 153.37 (qC), 164.46 (qC) and 166.51 (qC); *m*/*z* 275 (M^+, 3%), 260 (7), 132 (19), 91 (100) and 65 (11); ν (KBr) cm^{-1} 2880 (w), 1787 (s), 1724 (s), 1673 (s), 1401 (s), 1209 (m), 1165 (m), 1033 (s) and 704 (m).

[‡] *Crystal data* for **3a**: $C_{15}H_{17}NO_4$, $M = 275.30$, monoclinic, $a = 19.254(5)$, $b = 6.416(2)$, $c = 23.592(5)$Å, $\beta = 93.27(2)°$ $V = 2910(1)$ Å^3, $T = 293$ K, space group *C*2/*c* (no. 15), filtered Cu-Kα radiation, $\lambda = 1.54178$ Å, $Z = 8$, $Dc = 1.257$ Mg m^{-3}, $F(000) = 1168$, colourless thin plates, μ(Cu-Kα) = 7.557 cm^{-1}, ENRAF-NONIUS CAD4 diffractometer, ω–2θ scan, $6 < 2\theta < 140°$, 5530 measured reflections, 2768 unique reflections, 1946 unique observed reflections [$I > 2\sigma(I)$]. The phase problem was solved by direct methods (SIR92).[8] and the structure was refined by full-matrix least-squares on all measured F_o^2 (SHELXL96).[9] The empirical absorption correction by Parkin, Moezzi and Hope[10] was applied on the best isotropic model as implemented in SHELXL96. All non-hydrogen atoms were refined anisotropically. Hydrogens were located in the difference Fourier map and refined isotropically. Final refinement on 249 parameters gave $R_1 = 0.047$ (on observed data), $R_1 = 0.068$ (on all data), $wR_2 = 0.147$, gof = 1.054.

Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre (CCDC). See information for Authors, Issue No. 1. Any request to the CCDC for this material should quote the full literature citation and the reference number 182/476.

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