Palladium-catalyzed formation of oxazolidinones from biscarbamates: a mechanistic study

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Abstract

Oxazolidinones can be synthesized starting from cyclic biscarbamates via a palladium-catalyzed reaction. To test the proposed mechanism of this reaction, first, bicyclonorcarrene endoperoxides derived from cyano and carbomethoxy cycloheptatrienes were synthesized and converted into the corresponding diols. The reaction of diols with toluenesulfonyl isocyanate followed by a palladium catalyzed reaction furnished oxazolidinone derivatives in similar yields. It was shown that, if one face of the double bond is blocked by substituents such as H or CN, the reaction also takes place. On the basis of these results, it was assumed that an antiperiplanar orientation of the metal and nucleophile is not necessary to form oxazolidinones. The metal is probably bonded to the allylic system from the same face as the nucleophile.

Introduction

Palladium-catalyzed carbon–carbon bond formation reactions in synthetic organic chemistry have attracted considerable attention in recent years [1]. Palladium-catalyzed allylation is also a particularly useful method for the activation of allylic substrates [2]. Trost et al. described a highly stereoselective synthesis of oxazolidinone 2 starting from cyclic biscarbamate 1 via a palladium-catalyzed reaction, as shown in Scheme 1.
The basic catalytic cyclization (Scheme 1) consists of metal–olefin complexation, ionization, substitution, and decomplexation. The tandem reaction sequence has been frequently applied in the synthesis of many complex rings and open chain systems containing diverse functionalities. It has been reported that the complexation takes place exclusively anti to the leaving group (Figure 1) [3-6].

On the other hand, Kurosawa et al. [7] and Greenberg et al. [8] reported that the palladium(0)–olefin and platinum(0)–olefin complexes add to 5-(methoxycarbonyl)-2-cyclohexenyl chloride and bromide from the syn-side of the leaving group and that the leaving group is capable of coordinating the metal to give the corresponding (η³-allyl)–palladium or –platinum complexes. In order to determine from which side the complexation takes place during oxazolidinone formation, we synthesized the cyclic systems 3 with enantiotopic leaving groups at allylic positions on different olefinic faces, where one face of the olefin can be blocked by the substituents Y (Figure 2).

**Results and Discussion**

The cycloheptatriene–norcaradiene (CHT–NOR) system 4a 4b was an ideal starting point for construction of skeleton of 3. The CHT–NOR 4a 4b equilibrium has been substantially delineated by means of both physical and chemical methods (Scheme 2) [9-12].

Electron accepting substituents, such as –CHO, –COOR, –CN etc. at C-7 tend to shift the equilibrium to the norcaradiene 4b side, while electron donating substituents, such as –OR, –NR₂ favor the cycloheptatriene 4a structure. It has been shown that singlet oxygen and 4-phenyl-1,2,4-triazoline-3,5-dione (PTAD) are sufficiently reactive to intervene in the cyclohepta-triene–norcaradiene equilibrium via cycloadDITION [13-15]. For the construction of the skeleton 3, compounds 5 and 11 were chosen as the starting materials (Scheme 3).

The ester 5 was obtained in high yield by the hydrolysis of cyanocycloheptatriene 11 as reported in the literature [16].
Tetraphenylporphyrin sensitized photooxygenation of the cycloheptatriene derivative 5a $\rightarrow$ 5b at room temperature resulted exclusively in the formation of the norcarene endoperoxide 6 [14,17]. The exact configuration of the endoperoxide 6 was determined by the single crystal X-ray analysis of the bisepoxide formed by the thermolysis of 6 [18]. Selective reduction of the peroxide linkage in 6 was carried out with thiourea under very mild conditions to give the diol 7 [19]. Since only the oxygen–oxygen bond is broken in this reaction, the configuration at all carbon atoms is preserved. Oxazolidinone 9 was synthesized by two consecutive reactions, i.e., the generation of 8 and a subsequent a stereospecific Pd(0)-catalyzed cyclization [3-5,20]. Thus, the ene-diol 7 was first treated with 2 equiv of toluenesulfonyl isocyanate to give the corresponding biscarbamate 8. A solution of biscarbamate 8 was then added to a 5% solution of the palladium catalyst in THF, prepared from tris(dibenzylideneacetone)dipalladium chloroform complex and trisopropyl phosphite. The resulting oxazolidinone 9 was purified by chromatography on silica gel column to give a crystalline product in 58% yield. The structure and configuration of 9 was assigned from $^1$H (COSY, HSQC, HMBC) and $^{13}$C NMR spectroscopic data. The most conspicuous features in the $^1$H NMR spectrum of this compound were the five-membered oxazolidinone ring proton resonances. The proton H-6b adjacent to the oxygen atom resonates at 5.12 ppm as a doublet of doublets, ($J_{6b,3a} = 7.8$ Hz, $J_{6b,6a} = 1.4$ Hz). Geometry optimization calculations (MM2) on the molecule show a dihedral angle $\Phi$ of 71° for H-6a–H-6b in 9, which is in agreement with the measured coupling constant $J_{6b,6a} = 1.4$ Hz. In case of a syn-configuration of the oxazolidinone ring one would expect a much larger coupling constant due to the calculated smaller dihedral angle (32°). This indicates the anti-configuration of the oxazolidinone ring in 9. Furthermore, the observed large aliphatic coupling ($J_{3a,5} = 1.7$ Hz) also supports an anti-configuration. A maximum $x$-contribution to the aliphatic coupling is observed when $\Phi$ is 90° [21]. Our calculation for anti-configuration shows that the dihedral angle between the protons H-3a and H-5 is 67°, which is in agreement with the proposed configuration. In the case of syn-configuration, the calculated dihedral angle between H-3a and H-5 is 43°, which would give a smaller coupling constant. The measured coupling between the oxazolidinone ring protons ($J_{3a,6b} = 7.8$ Hz) shows the cis-relation between those protons. After the successful formation of the oxazolidinone derivative 9, we tried to synthesize the endo-isomer 10, where one face of the double bond is blocked by the bulky carboxylate group. Unfortunately, all efforts to isomerize the configuration of the carboxylate group in 7 failed (Scheme 4). After this attempted isomerization, we turned our attention to cyanocycloheptatriene (11a).

The starting material, 7-cyanocycloheptatriene 11a, was synthesized by the reaction of the trypinium cation with cyanide anion as described in the literature [16]. The tetraphenylporphyrin sensitized photooxygenation of the cycloheptatriene derivative 11a $\rightarrow$ 11b at room temperature gave a mixture of norcarene endoperoxides 12–13 in 42 and 33% yields, respectively (Scheme 5) [22]. The exact configuration of the cyano groups in 12 and 13 were determined by measuring the coupling constants between the cyclopropane protons. The cyclopropyl proton H-3 in 12 resonates as a triplet with a coupling constant of $J = 3.3$ Hz, whereas the endo-isomer 13 shows a coupling of 7.9 Hz. Since the cis-coupling in cyclopropane is larger than the trans-coupling [23,24], we assigned the exo-configuration to the cyano group in 12.

Selective reduction of the peroxide linkages in 12 and 13 with thiourea under very mild conditions afforded the diols 14 and 18a, respectively. For further characterization, the diols were converted to the diacetates 15 and 18b. The isomeric diols 14 and 18a were treated with 2 equiv of toluenesulfonyl isocyanate as described above to give the corresponding biscarbamates 16 and 19. Treatment of 16 and 19 with the palladium catalyst (as described above) resulted in the formation of oxazolidinone derivatives 17 and 20 in 51 and 45% yield, respectively. Careful examination of the reaction mixture did not reveal the formation of any other isomers. The compounds were characterized by NMR spectroscopic data (COSY, HSQC, and HMBC). To determine the exact configuration of the oxazolidinone derivatives 17 and 20, all assignments of all the protons were first made with the help of the COSY spectrum and the coupling constants determined. The coupling constants of the ring protons clearly support the fact that all three oxazolidinone derivatives 9, 17 and 20 have the same configuration (Table 1). According to the proposed mechanism of oxazolidinone formation [3], the first step is complex formation between the metal and olefin. Steric and electronic effects of the olefin determine the stability of the complex. For example, bulky groups decrease the stability of the complex via steric interactions, while electron-withdrawing groups will enhance the stability of...
Scheme 5: Synthesis of oxazolidinones 17 and 20.

Table 1: The coupling constants of compounds 9, 17, and 20.

| Compound | Coupling constants in Hz |
|----------|--------------------------|
|          | $J_{4,5}$ | $J_{4,3a}$ | $J_{5,3a}$ | $J_{5,5a}$ | $J_{3a,6b}$ | $J_{5a,6b}$ | $J_{6a,6a}$ | $J_{6,6a}$ |
|Compound 9 | 10.3 | 1.7 | 1.7 | 5.3 | 7.8 | 1.4 | 7.5 | 3.8 | 5.0 |
|Compound 17 | 10.4 | 1.9 | 1.5 | 5.3 | 7.9 | 1.8 | 7.9 | 4.1 | 5.3 |
|Compound 20 | 10.4 | 2.3 | 1.7 | 5.0 | 8.3 | — | — | — | — |

*aThese coupling constants could not be determined due to overlapping resonances.*
the complex [25,26]. The next step is the ionization step followed by allylic substitution. The final step is the decomplexation.

Trost et al. [3] and Fiaud et al. [6] have proposed that only metal–olefin complexation anti to the leaving group will lead to the product (Scheme 6). In the case of 8, 16 and 19, the leaving groups, carbamates, are in anti (referred to the cyclopropane ring) positions and, therefore, the palladium complex should approach the double bond in 8, 16, and 19 from the side of the three-membered ring to form a complex.

According to the $S_{n}2'$ substitution reaction mechanism [27-30], nucleophiles attack the double bond from the same side from which the leaving group departs, as shown below (Figure 3).

Therefore, we assume that metal is bonded to the allylic system from the same side as the nucleophile attacking the double bond to form the final product.

**Experimental**

**General:** Melting points are uncorrected. Infrared spectra were obtained from KBr pellets on an FT-IR Bruker Vertex 70 instrument. The $^1$H and $^{13}$C NMR spectra were recorded on a Bruker BioSpin (DPX-400) instrument. Apparent splitting is given in all cases. Column chromatography was performed on silica gel (60-mesh, Merck), and TLC was carried out on Merck 0.2 mm silica gel 60 F$_{254}$ analytical aluminum plates. Elemental analyses were carried out on a Leco-932 model CHNS analyzer.

**rel-(1R,2S,5S,6S)-Methyl 2,5-bis(tosylcarbamoyloxy) bicyclo[4.1.0]hept-3-ene-7-carboxylate (8):** To a magnetically stirred solution of diol 7 [17] (1.00 g, 5.43 mmol) in THF (40 mL), was added a solution of $p$-toluenesulfonyl isocyanate (2.13 g, 10.88 mmol) in THF (5 mL) dropwise over 15 min at room temperature under a nitrogen atmosphere. The mixture was stirred at room temperature for 8 h. The solvent was then removed under reduced pressure. The residue was purified by rapid filtration through silica gel (110 g) with hexane/ethyl acetate (1:1) as eluent. Evaporation of solvent gave white crystals (2.57 g, 82%, mp 176–178 °C).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.39 (br s, –NH, 2H), 7.91 (d, $J$ = 8.0 Hz, 4H, aromatic)), 7.32 (d, $J$ = 8.0 Hz, 4H, aromatic), 5.92 (br s, 2H, H-3 and H-4), 5.39–5.40 (m, 2H, H-2 and H-5), 3.66 (s, 3H, –OCH$_3$), 2.44 (s, 6H, –CH$_3$), 1.94 (d, $J$ = 4.0 Hz, 2H, H-1 and H-6), 1.43 (t, $J$ = 4.0 Hz, H-7); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 171.6 (C=O), 150.1 (C=O), 145.2, 135.4, 129.7, 128.5, 127.5, 66.2 (C-2 and C-5), 52.4 (–OCH$_3$), 21.7, 21.6, 21.0; IR ($\nu$$_{\text{max}}$,
rel-(3R,5aR,6R,6aS,6bS)-Methyl 2-oxo-3-tosyl-3,3a,5a,6,6a,6b-hexahydro-2H-cyclopropa[3,4]benzo [1,2-d][1,3]oxazole-6-carboxylate (9): Tris(dibenzylideneacetone)dipalladium chlorof orm complex (0.2 g, 193.6 mmol) was dissolved in freshly distilled THF (20 mL) under a nitrogen atmosphere. Triisopropyl phosphate (1.6 mL) in THF (5 mL) was then added. The mixture was stirred at room temperature until a clear green solution was obtained. The prepared catalyst solution was added to a stirred solution of the biscarbamate 8 (1.00 g, 1.73 mmol) and thiourea (513 mg, 6.75 mmol) in MeOH/CHCl₃ (30 mL) was reacted as described above. After evaporation of solvent under reduced pressure, diol 18a was obtained as colorless crystals (0.94 g, 93%, mp 160–162 °C). ¹H NMR (400 MHz, methanol-d₄) δ 5.73 (br s, 2H, H-3 and H-4), 5.40–5.43 (m, 2 H, H-2 and H-5), 2.05 (s, 6H, –CH₃), 2.03 (d, J = 4.8 Hz, 2H, H-1 and H-6), 1.16 (t, J = 4.8 Hz, H-7); ¹³C NMR (100 MHz, methanol-d₄) δ 170.2 (C=O), 126.3 (C-3 and C-4), 119.2 (–CN), 62.8 (C-2 and C-5), 21.5 (C-1 and C-6), 21.0 (–CH₃), 3.6 (C-7); IR (νmax, cm⁻¹) 2238, 1727, 1369, 1226, 1052, 1015, 990, 968. Anal. Calcd for C₁₂H₁₂N₄O₂: C, 61.27; H, 5.57; N, 5.95. Found: C, 61.20; H, 5.44; N, 6.04.

rel-(1R,2S,5R,6S)-2,5-Dihydroxybicyclo[4.1.0]hept-3-en-2-yl acetate (15): A mixture of diol 14 (0.96 g, 6.35 mmol), acetic anhydride (4 mL) and pyridine (6 mL) was stirred at room temperature for 18 h. The mixture was then cooled to 0 °C, diluted with water, neutralized with aqueous HCl and extracted with ethyl acetate. The combined organic layer was washed with saturated NaCl, dried over Na₂SO₄ and concentrated under reduced pressure. Recrystallization of residue from ethyl acetate/hexane gave colorless crystals (1.36 g, 91%, mp 103–105 °C). ¹H NMR (400 MHz, CDCl₃) δ 5.89–5.87 (m, 2H, H-3 and H-4), 5.40–5.43 (m, 2 H, H-2 and H-5), 2.05 (s, 6H, –CH₃), 2.03 (d, J = 4.8 Hz, 2H, H-1 and H-6), 1.16 (t, J = 4.8 Hz, H-7); ¹³C NMR (100 MHz, CDCl₃) δ 170.3 (C=O), 126.3 (C-3 and C-4), 119.2 (–CN), 62.8 (C-2 and C-5), 21.5 (C-1 and C-6), 21.0 (–CH₃), 3.6 (C-7); IR (νmax, cm⁻¹) 2238, 1727, 1369, 1226, 1052, 1015, 990, 968. Anal. Calcd for C₁₂H₁₂N₄O₂: C, 61.27; H, 5.57; N, 5.95. Found: C, 61.20; H, 5.44; N, 6.04.

rel-(1R,2S,5R,6S)-2,5-Dihydroxybicyclo[4.1.0]hept-3-en-2-yl acetate (18a): A solution of endoperoxide 13 (1.00 g, 6.71 mmol) and thiourea (513 mg, 6.75 mmol) in MeOH/CHCl₃ (30 mL) was reacted as described above. After evaporation of solvent under reduced pressure, diol 18a was obtained as colorless crystals (0.94 g, 93%, mp 160–162 °C). ¹H NMR (400 MHz, methanol-d₄) δ 5.73 (br s, 2H, H-3 and H-4), 4.7 (br s, –OH) 4.17 (br s, 2H, H-2 and H-5), 1.84–1.71 (m, AB₂ system, 3H, cyclopropane); ¹³C NMR (100 MHz, methanol-d₄) δ 129.5 (C-3 and C-4), 118.9 (–CN), 61.4 (C-2 and C-5), 23.0 (C-1 and C-6), 4.1 (C-7); IR (νmax, cm⁻¹) 3236, 3050, 2238, 1022, 993, 980. Anal. Calcd for C₁₂H₁₀O₂N: C, 63.6; H, 6.00; N, 9.27. Found: C, 63.47; H, 5.77; N, 9.33.

rel-(1R,2S,5R,6S)-5-(Acetoxy)-7-exo-cyanobicyclo[4.1.0]hept-3-en-2-yl acetate (18b): A mixture of diol 18a (0.94 g, 6.22 mmol), acetic anhydride (4 mL) and pyridine (6 mL) was stirred at room temperature for 18 h. The mixture was then cooled to 0 °C, diluted with water, neutralized with aqueous HCl and extracted with ethyl acetate. The combined organic layer was washed with saturated NaCl, dried over Na₂SO₄ and concentrated under reduced pressure. Recrystallization of residue from ethyl acetate/hexane gave colorless crystals (1.30 g, 89%, mp 119–121 °C). ¹H NMR (400 MHz, CDCl₃) δ 7.13–7.10 (m, 2H, H-3 and H-4), 5.73 (br s, 2H, H-3 and H-4), 4.17 (br s, 2H, H-2 and H-5), 1.84–1.71 (m, AB₂ system, 3H, cyclopropane); ¹³C NMR (100 MHz, CDCl₃) δ 177.0 (C=O), 126.9 (C-3 and C-4), 116.3 (–CN), 62.2 (C-2 and C-5), 21.1 (–CH₃), 18.9 (C-1 and C-6), 2.5 (C-7); IR (νmax, cm⁻¹) 3257, 2927, 2234, 1481, 1306, 1094, 1015, 777. Anal. Calcd for C₉H₁₂NO₂: C, 63.56; H, 6.00; N, 9.27. Found: C, 63.38; H, 5.87; N, 9.42.
151.5 (C=O), 145.6, 135.3 (C-aromatic), 130.2 (C-aromatic), 115.8 (C-aromatic), 108.6 (C-aromatic), 106.7 (C-aromatic), 73.9 (C-aromatic).

**rel-(1R,2R,5S,6S)-7-endo-Cyanobicyclo[4.1.0]hept-3-ene-2,5-diyli bis(tosylcarbamate) (16):** A solution of diol 14 (0.96 g, 6.35 mmol) and p-toluensulfonyl isocyanate (2.48 g, 12.71 mmol) in THF (40 mL) was reacted as described above. The product was obtained as white crystals (2.85 g, 84%, 155–157 °C). 1H NMR (400 MHz, CDCl3) δ 7.66 (d, J = 8.0 Hz, 4H, aromatic), 7.23 (d, J = 8.0 Hz, 4H, aromatic), 5.64 (br s, 2H, H-3 and H-4), 5.02 (br s, 2H, H-2 and H-5), 2.33 (s, 6H), 1.82 (br d, J = 4.8 Hz, 2H, H-1 and H-6), 1.40 (t, J = 4.8 Hz, H-7); 13C NMR (100 MHz, DMSO-d6) δ 154.5 (C=O), 139.6, 138.0, 126.2, 124.5, 123.6, 118.5 (C-6), 59.9 (C-2 and C-5), 19.6, 18.6, 0.2; IR (νmax, cm⁻¹) 3260, 2240, 1745, 1435, 1349, 1208, 1184, 1160, 1089, 861, 829, 665. Anal. Calcd for C22H23NO8S2: C, 52.83; H, 4.25; N, 7.70; S, 11.75. Found: C, 53.17; H, 4.51; N, 7.86; S, 11.98.

**rel-(1R,2R,5S,6S)-7-endo-Cyanobicyclo[4.1.0]hept-3-ene-2,5-diyli bis(tosylcarbamate) (19):** A solution of diol 18a (0.94 g, 6.22 mmol) and p-toluensulfonyl isocyanate (2.43 g, 12.44 mmol) in THF (40 mL) was reacted as described above. The product was obtained as white crystals (2.75 g, 81%, 164–166 °C). 1H NMR (400 MHz, DMSO-d6) δ 7.78 (d, J = 8.0 Hz, 4H, aromatic), 7.23 (d, J = 8.0 Hz, 4H, aromatic), 5.64 (br s, 2H, H-1 and H-6), 1.82 (br d, J = 4.8 Hz, 2H, H-1 and H-6), 1.40 (t, J = 4.8 Hz, H-7); 13C NMR (100 MHz, DMSO-d6) δ 154.5 (C=O), 139.6, 138.0, 126.2, 124.5, 123.6, 118.5 (C-6), 59.9 (C-2 and C-5), 19.6, 18.6, 0.2; IR (νmax, cm⁻¹) 3260, 2240, 1745, 1435, 1349, 1208, 1184, 1160, 1089, 861, 829, 665. Anal. Calcd for C22H23NO8S2: C, 52.83; H, 4.25; N, 7.70; S, 11.75. Found: C, 53.21; H, 4.46; N, 7.79; S, 11.91.

**ref-3aR,5aR,6R,6aS,6bS-2-Oxo-3-tosyl-3,3a,5a,6,6a,6b-hexahydro-2H-cyclopenta[3,4]benzo[1,2-d][1,3]oxazole-7-endo-carbonitril (20):** Biscarbamate 16 (1.00 g, 1.83 mmol) was reacted with freshly prepared Pd-complex as described above. The product was recrystallized from ethyl acetate/hexane to give colorless crystals (272 mg, 45%, mp 159–161 °C). 1H NMR (400 MHz, CDCl3) δ 7.96 (d, J = 8.3 Hz, 2H, aromatic), 7.37 (d, J = 8.3 Hz, 2H, aromatic), 6.19 (br dd, J4,5a = 10.4, J5a,5b = 5.0 Hz, H-5), 6.08 (dd, J4,5a = 10.4, J5a,5b = 2.3 Hz, H-4), 5.80 (br d, J6b,3a = 8.3 Hz, H-6b), 4.86 (dd, J3a,6b = 8.3, J3a,5a = 2.3, J5a,5b = 1.7 Hz, H-3a), 2.26 (s, 3H, –CH3), 2.18–2.04 (m, AB2 system, 3H, cyclopropane); 13C NMR (100 MHz, CDCl3) δ 150.2 (C=O), 145.9 (C-aromatic), 135.1 (C-aromatic), 129.9 (CH-aromatic), 128.4 (CH-aromatic), 124.2 (C-5), 123.3 (C-4), 116.5 (CN), 68.7 (C-6b), 52.9 (C-3a), 21.7 (–CH2–, 18.2 (cyclopropane), 15.6, (cyclopropane) 11.8 (cyclopropane); IR (νmax, cm⁻¹) 2208, 1779, 1350, 1329, 1170, 1160, 1121, 1091, 1031, 667. Anal. Calcd for C19H14N2O8S: C, 58.17; H, 4.27; N, 8.48; S, 9.71. Found: C, 58.13; H, 4.31; N, 8.41; S, 9.3.

**Supporting Information**

Supporting Information contains the 1H and 13C NMR spectra of all newly synthesized compounds. In three cases, COSY, DEPT-90°, DEPT-135°, HSQC and HMBC spectra are also given.

**Supporting Information File 1**

Supplementary data.

[http://www.beilstein-journals.org/bjoc/content/supplementary/1860-5397-7-33-S1.pdf]

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**References**

1. Barnard, C. Platinum Met. Rev. 2008, 52, 38–45. doi:10.1595/147106708X256634 And references therein.
2. Trost, B. M. Angew. Chem., Int. Ed. Engl. 1989, 28, 1173–1192. doi:10.1002/anie.198911731
And references therein.
3. Trost, B. M.; Van Vranken, D. L.; Bingel, C. J. Am. Chem. Soc. 1992, 114, 9327–9343. doi:10.1021/ja00050a013
4. Trost, B. M.; Van Vranken, D. L. J. Am. Chem. Soc. 1993, 115, 444–458. doi:10.1021/ja00055a013
5. Trost, B. M.; Van Vranken, D. L. Chem. Rev. 1996, 96, 395–422. doi:10.1021/cr9409804
6. Fiaud, J. C.; Aribi-Zouioueche, L. J. Chem. Soc., Chem. Commun. 1986, 390–392. doi:10.1039/C39860000390
7. Kurosawa, H.; Kajimaru, H.; Ogoshi, S.; Yoneda, H.; Miki, K.; Kasai, N.; Murai, S.; Ikeda, I. J. Am. Chem. Soc. 1992, 114, 8417–8424. doi:10.1021/ja00048a011
8. Grennberg, H.; Langer, V.; Backvall, J. E. J. Chem. Soc., Chem. Commun. 1991, 1190–1192. doi:10.1039/C39910001190
9. McNamara, O. A.; Maguire, A. R. Tetrahedron 2011, 67, 9–40. doi:10.1016/j.tet.2010.10.030
10. Balci, M. Turk. J. Chem. 1992, 16, 42–90.
11. Le Noble, W. J. Highlights of Organic Chemistry; Marcel Dekker, Inc.: New York, 1974; pp 402 ff.
12. Maier, G. Angew. Chem., Int. Ed. Engl. 1967, 6, 402–413. doi:10.1002/anie.196704021
13. Adam, W.; Balci, M. Angew. Chem., Int. Ed. Engl. 1978, 17, 954–955. doi:10.1002/anie.197809541
14. Adam, W.; Balci, M.; Pietrzak, B. J. Am. Chem. Soc. 1979, 101, 6285–6291. doi:10.1021/ja00515a022
15. Celik, M.; Balci, M. ARKIVOC 2007, 8, 150–162.
16. Betz, W.; Daub, J. Chem. Ber. 1972, 105, 1778–1779. doi:10.1002/cber.19721050538
17. Adam, W.; Balci, M.; Rivera, J. Synthesis 1979, 807–808. doi:10.1055/s-1979-28839
18. Brauer, D. J.; Krüger, C.; Roberts, P. J. J. Chem. Soc., Perkin Trans. 2 1976, 532–535. doi:10.1039/p29760000532
19. Sengül, M. E.; Menzek, A.; Sahin, E.; Arık, M.; Saracoglu, N. Tetrahedron 2008, 64, 7289–7294. doi:10.1016/j.tet.2008.05.066
20. Kurbangolu, N. I.; Celik, M.; Kilic, H.; Alp, C.; Sahin, E.; Balci, M. Tetrahedron 2010, 66, 3485–3489. doi:10.1016/j.tet.2010.03.028
21. Balci, M. Basic 1H- and 13C-NMR Spectroscopy; Elsevier: Amsterdam, 2005; pp 124–125.
22. Adam, W.; Balci, M. J. Org. Chem. 1979, 44, 1189–1190. doi:10.1021/jo01321a046
23. Balci, M. Basic 1H- and 13C-NMR Spectroscopy; Elsevier: Amsterdam, 2005; pp 118 ff.
24. Günther, H. NMR spectroscopy: an introduction; Wiley: Chichester, New York, 1980; pp 108 ff.
25. Tolman, C. A. J. Am. Chem. Soc. 1974, 96, 2780–2789. doi:10.1021/ja0816a020
26. White, D.; Coville, N. J. Adv. Organomet. Chem. 1994, 36, 95–158. doi:10.1016/S0065-3055(08)60390-1
27. El-Awa, A.; Fuchs, P. Org. Lett. 2006, 8, 2905–2908. doi:10.1021/ol060530l
28. Cakmak, O.; Taskesenligil, Y.; Balci, M. J. Org. Chem. 1991, 56, 3442–3445. doi:10.1021/jo00010a048
29. Stork, G.; White, W. N. J. Am. Chem. Soc. 1956, 78, 4609–4619. doi:10.1021/ja1599a025
30. DeWolfe, R. H.; Young, W. G. Chem. Rev. 1956, 56, 753–901. doi:10.1021/cr50010a002