

First Example of 1,3-Dipolar Cycloaddition of Carbonyl Ylides to Cyclopropenes

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Abstract—Carbonyl ylide generated from 1-diazo-5-phenylpentane-2,5-dione in the presence of $\text{Rh}_2(\text{OAc})_4$ reacts with 3-substituted cyclopropenes following the 1,3-dipolar cycloaddition pattern to afford substituted 9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-ones.

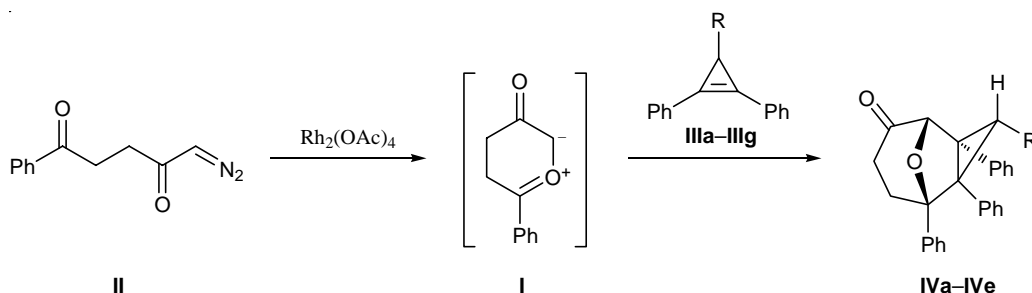
1,3-Dipolar cycloaddition of carbonyl ylides, which are generated from diazo compounds in the presence of metal complex catalysts, to unsaturated compounds can be regarded as a promising synthetic route to oxygen-containing heterocyclic systems [1]. Reactions of carbonyl ylides with cyclopropene derivatives have not been studied, although cyclopropenes are known to readily participate in cycloaddition reactions [2].

We have found that carbonyl ylide **I** generated from 1-diazo-5-phenylpentane-2,5-dione (**II**) in the presence of $\text{Rh}_2(\text{OAc})_4$ reacts with 3-substituted 1,2-diphenylcyclopropenes **IIIa–IIIg** in methylene chloride at room temperature to give 9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-ones **IVa–IVe** (Scheme 1). The structure of ketones **IVa–IVe** was established on the basis of their elemental compositions and spectral data. In the IR spectra of **IVa–IVe** we observed an absorption band at 1745 cm^{-1} which belongs to the carbonyl group. Their ¹H NMR spectra contained a singlet at δ 4.58–4.81 ppm from the 5-H proton neighboring to the epoxy bridge and multiplet signals at δ 2.09–3.35 ppm

from the CH_2CH_2 group, which are typical of 1,3-dipolar cycloaddition products derived from carbonyl ylide **I** [3]. Signals from protons in the three-membered ring appeared in the δ range from 2.1 to 3.3 ppm. In the ¹H NMR spectrum of adduct **IVa**, the *endo*-proton gives a doublet at δ 2.09 ppm ($J = 5$ Hz), and the *exo*-proton signal is displaced upfield to δ 1.16 ppm ($J = 5$ Hz). The downfield position of the *endo*-proton signal results from deshielding effects of the two *trans*-arranged phenyl groups and the bridging oxygen atom which is located *syn*. In the ¹³C NMR spectra, signals from the carbon atoms attached to the bridging oxygen atom are located at δ_{C} 85 ppm, carbon atoms of the ethylene moiety give signals at about δ_{C} 34 ppm, the carbonyl carbon signal appears at δ_{C} 205 ppm, and the other carbon signals occupy the δ_{C} range from 38 to 48 ppm. The structure of **IVd** was proved by X-ray analysis (see figure).

On the other hand, carbonyl ylide **I** failed to react with cyclopropenes **IIIh** and **IIIg** having electron-acceptor groups in position 3. It is known that carbonyl

Scheme 1.

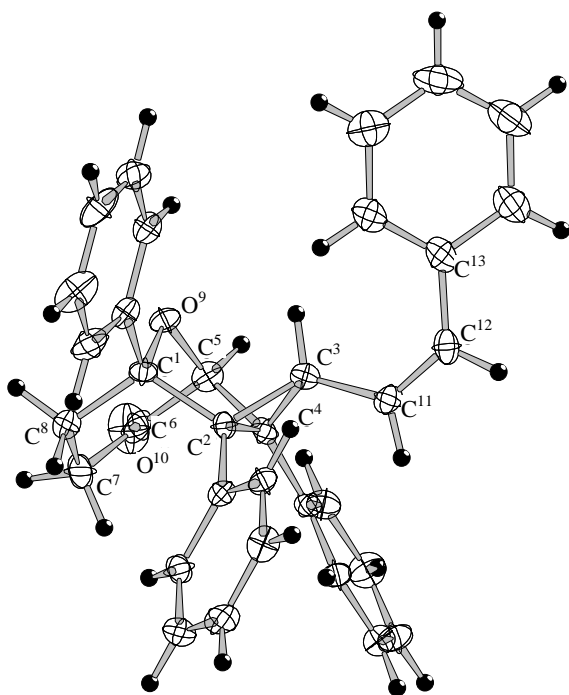


III, IV, R = H (**a**), Me (**b**), CH=CH₂ (**c**), (Z)-CH=CHPh (**d**), Ph (**e**), COOMe (**f**), CN (**g**).

ylides as dipoles are capable of reacting with both electron-donor and electron-acceptor dipolarophiles [3]. Presumably, in our case the lowest unoccupied molecular orbital (LUMO) of the ylide interacts with the highest occupied molecular orbital (HOMO) of cyclopropene, i.e., ylide **I** acts as acceptor. According to the results of quantum-chemical calculations, an electron-donor substituent in position 3 of cyclopropene destabilizes this reagent and enhances its reactivity toward butadiene in the Diels–Alder reaction, while an electron-acceptor substituent in the same position stabilizes cyclopropene via considerable reduction of the HOMO energy; therefore, its reactivity becomes lower [4]. The formation of adducts **IV** as a single stereoisomer indicates *exo-anti* approach of carbonyl ylide **I** to cyclopropene and concerted mechanism of the addition.

EXPERIMENTAL

The IR spectra were recorded on a UR-20 spectrophotometer from 2% solutions in CHCl_3 . The ^1H and ^{13}C NMR spectra were measured on a Bruker DPX-300 instrument at 300.13 and 75.47 MHz, respectively, from solutions in CDCl_3 . The purity of products was checked, and the reaction mixtures were analyzed, by TLC using Silufol UV-254 plates.



Structure of the molecule of *rel*-(1*R*,2*R*,3*S*,4*S*,5*S*)-1,2,4-triphenyl-3-[(*Z*)-2-phenylethenyl]-9-oxatricyclo[3.3.1.0^{2,4}]-nonan-6-one (**IVd**) according to the X-ray diffraction data.

Cyclopropenes **IIIa–IIIg** were synthesized by known methods [5].

rel-(1*R*,2*R*,4*S*,5*S*)-1,2,4-Triphenyl-9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-one (**IVa**). To a solution of 144 mg (0.76 mmol) of diazo ketone **II** and 175 mg (1.02 mmol) of 1,2-diphenylcyclopropene **IIIa** in 5 ml of anhydrous methylene chloride we added under stirring at room temperature in a stream of dry argon 2 mg of $\text{Rh}_2(\text{OAc})_4$. The mixture was stirred for 1 h, the solvent was evaporated, and the residue was subjected to column chromatography on silica gel (gradient elution with hexane–ethyl acetate mixtures) to isolate 201 mg (75%) of ketone **IVa**, mp 198–201°C. ^1H NMR spectrum, δ , ppm: 1.16 d (1H, $J = 5$ Hz), 2.09 d (1H, $J = 5$ Hz), 2.25 d.d.d (1H, $J = 14, 11, 8$ Hz), 2.59 d.d (1H, $J = 16, 8$ Hz), 2.80 d.d (1H, $J = 14, 9$ Hz), 2.97 d.d.d (1H, $J = 16, 11, 9$ Hz), 4.81 s (1H), 6.78–6.87 (2H), 7.03–7.41 (13H). ^{13}C NMR spectrum, δ_{C} , ppm: 23.3, 34.2, 34.5, 38.1, 45.5, 84.5, 85.5, 126.7, 126.6, 127.2, 127.8, 128.2, 128.3, 128.5, 128.6, 132.6, 134.2, 136.7, 140.3, 206.4. IR spectrum, ν , cm^{-1} : 920, 990, 1040 s, 1080, 1135, 1265, 1445, 1500, 1600, 1740 v.s, 2965, 3070. Found, %: C 85.18; H 6.13. $\text{C}_{26}\text{H}_{22}\text{O}_2$. Calculated, %: C 85.22; H 6.05.

Ketones **IVe–IVd** were synthesized in a similar way.

rel-(1*S*,2*S*,3*R*,4*R*,5*R*)-3-Methyl-1,2,4-triphenyl-9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-one (**IVb**) was synthesized from 220 mg (1.16 mmol) of diazo ketone **II** and 300 mg (1.46 mmol) of 3-methyl-1,2-diphenylcyclopropene. Yield 345 mg (81%), mp 126–128°C. ^1H NMR spectrum, δ , ppm: 0.75 d (3H, $J = 6$ Hz), 2.13 q (1H, $J = 6$ Hz), 2.19 d.d.d (1H, $J = 13, 9, 8$ Hz), 2.50 d.d (1H, $J = 17, 8$ Hz), 2.78 d.d (1H, $J = 13, 9$ Hz), 2.93 d.t (1H, $J = 17, 9$ Hz), 4.81 s (1H), 6.90–7.42 (15H). ^{13}C NMR spectrum, δ_{C} , ppm: 11.2, 21.4, 33.9, 34.2, 42.1, 46.4, 85.6, 86.1, 126.0, 126.9, 127.8, 128.0, 128.1, 128.2, 128.3, 129.8, 131.9, 133.9, 134.0, 140.2, 205.8. IR spectrum, ν , cm^{-1} : 1030, 1075, 1265, 1445, 1500, 1600, 1740 v.s, 2870, 2930, 2960, 3050. Found, %: C 85.44; H 6.89. $\text{C}_{27}\text{H}_{24}\text{O}_2$. Calculated, %: C 85.23; H 6.36.

rel-(1*R*,2*R*,3*S*,4*S*,5*S*)-1,2,4-Triphenyl-3-vinyl-9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-one (**IVc**) was synthesized from 228 mg (1.21 mmol) of diazo ketone **II** and 320 mg (1.47 mmol) of 3-vinyl-1,2-diphenylcyclopropene. Yield 312 mg (68%), mp 134–136°C. ^1H NMR spectrum, δ , ppm: 2.24 d.d.d (1H, $J = 14, 9, 8$ Hz), 2.59 d.d (1H, $J = 17, 8$ Hz), 2.79 d (1H, $J = 10$ Hz), 2.86 d.d (1H, $J = 14, 9$ Hz), 3.03 d.t (1H, $J = 17, 9$ Hz), 4.79 s (1H), 4.88 d.d (1H, $J = 10, 2$ Hz),

5.03 d.t (1H, $J = 17, 10$ Hz), 5.18 d.d (1H, $J = 17, 2$ Hz), 6.95–7.02 (2H), 7.08–7.11 (2H), 7.18–7.40 (11H). ^{13}C NMR spectrum, δ_{C} , ppm: 31.8, 33.4, 34.2, 43.6, 46.8, 86.0, 86.4, 117.0, 125.8, 127.4, 127.9, 128.1, 128.2, 128.6, 130.0, 131.8, 133.3, 134.0, 134.3, 139.9, 205.0. IR spectrum, ν , cm^{-1} : 915, 1060 s, 1080, 1140, 1445, 1500, 1600, 1740 v.s, 2965, 3065. Found, %: C 85.84; H 6.12. $\text{C}_{28}\text{H}_{24}\text{O}_2$. Calculated, %: C 85.68; H 6.16.

rel-(1R,2R,3S,4S,5S)-1,2,4-Triphenyl-3-[(Z)-2-phenylethenyl]-9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-one (IVd) was synthesized from 107 mg (0.57 mmol) of diazo ketone **II** and 200 mg (0.68 mmol) of 3-[(Z)-2-phenylethenyl]-1,2-diphenylcyclopropene. Yield 179 mg (69%), mp 205–206°C. ^1H NMR spectrum, δ , ppm: 2.25 d.d.d (1H, $J = 14, 10, 8$ Hz), 2.59 d.d (1H, $J = 17, 8$ Hz), 2.88 d.d (1H, $J = 14, 9$ Hz), 3.02 d.d.d (1H, $J = 17, 10, 9$ Hz), 3.23 d (1H, $J = 11$ Hz), 4.75 s (1H), 4.94 t (1H, $J = 11$ Hz), 6.32 d (1H, $J = 11$ Hz), 7.10–7.13 (2H), 7.18–7.44 (16H). ^{13}C NMR spectrum, δ_{C} , ppm: 27.2, 34.1, 34.3, 44.5, 46.8, 85.7, 86.5, 126.1, 127.1, 127.3, 127.5, 128.1, 128.4, 128.7, 129.3, 130.2, 130.9, 131.9, 133.0, 131.9, 133.0, 134.0, 137.3, 139.9, 204.9. IR spectrum, ν , cm^{-1} : 1035, 1060, 1080, 1255, 1450, 1500, 1600, 1740 v.s, 2960, 3065. Found, %: C 87.10; H 5.95. $\text{C}_{34}\text{H}_{28}\text{O}_2$. Calculated, %: C 86.85; H 5.92.

rel-(1R,2R,3S,4S,5S)-1,2,3,4-Tetraphenyl-9-oxatricyclo[3.3.1.0^{2,4}]nonan-6-one (IVe) was synthesized from 99 mg (0.52 mmol) of diazo ketone **II** and 168 mg (0.63 mmol) of 1,2,3-triphenylcyclopropene. Yield 147 mg (66%), mp 174–177°C. ^1H NMR spectrum, δ , ppm: 2.26–2.37 (1H), 2.70–2.79 (1H), 2.94–3.02 (1H), 3.23–3.35 (2H), 4.58 s (1H), 6.23–6.26 (2H), 6.77–7.33 (18H). ^{13}C NMR spectrum, δ_{C} , ppm: 31.3, 32.4, 34.1, 46.3, 48.6, 61.8, 87.1, 88.3, 125.7, 126.0, 127.0, 127.96, 128.04, 128.06, 128.8, 129.4, 130.9, 131.0, 131.5, 131.8, 134.5, 135.8, 140.1, 204.9. IR spectrum, cm^{-1} : 920, 940, 980, 1020, 1040, 1060, 1080, 1140, 1180, 1240, 1310, 1350, 1420, 1450, 1500 br, 1600, 1720 v.s, 2860, 2880, 2940, 2960, 3040, 3070, 3090. Found, %: C 86.55; H 6.27. $\text{C}_{32}\text{H}_{26}\text{O}_2$. Calculated, %: C 86.85; H 5.92.

X-Ray analysis of compound IVd. Formula $\text{C}_{34}\text{H}_{28}\text{O}_2$; M 468.56; triclinic crystals, space group

$P12_1/c1$ (no. 14); unit cell parameters: $a = 12.627(2)$, $b = 20.536(3)$, $c = 19.097(3)$ Å; $\alpha = 90.00$, $\beta = 90.00$, $\gamma = 90.87^\circ$; $V = 4951.43(130)$ Å³; $Z = 8$; $d_{\text{calc}} = 1.257$ g/cm³; $\mu = 0.078$ mm⁻¹; $F(000) = 912$, $\text{MoK}\alpha$ radiation, $\lambda = 0.71073$ Å, graphite monochromator. Below are given selected bond lengths (Å) and bond angles (deg): $\text{O}^9\text{—C}^5$ 1.439(2), $\text{O}^9\text{—C}^1$ 1.444(3), $\text{O}^{10}\text{—C}^6$ 1.208(2), $\text{C}^1\text{—C}^8$ 1.534(2), $\text{C}^1\text{—C}^2$ 1.553(3), $\text{C}^2\text{—C}^4$ 1.523(2), $\text{C}^2\text{—C}^3$ 1.528.2(2), $\text{C}^3\text{—C}^{11}$ 1.472(2), $\text{C}^3\text{—C}^4$ 1.546(2), $\text{C}^4\text{—C}^5$ 1.532(2), $\text{C}^5\text{—C}^6$ 1.516(2), $\text{C}^6\text{—C}^7$ 1.503(3), $\text{C}^7\text{—C}^8$ 1.545(2), $\text{C}^{11}\text{—C}^{12}$ 1.335(2); $\text{C}^5\text{O}^9\text{C}^1$ 105.21(10), $\text{O}^9\text{C}^1\text{C}^8$ 106.57(11), $\text{O}^9\text{C}^1\text{C}^2$ 103.06(10), $\text{C}^4\text{C}^2\text{C}^3$ 60.87(8), $\text{C}^4\text{C}^2\text{C}^1$ 104.51(10), $\text{C}^3\text{C}^2\text{C}^1$ 112.54(11), $\text{C}^{11}\text{C}^3\text{C}^2$ 123.60(12), $\text{C}^{11}\text{C}^3\text{C}^4$ 119.87(12), $\text{C}^2\text{C}^3\text{C}^4$ 59.40(8), $\text{C}^2\text{C}^4\text{C}^5$ 104.26(11). The complete crystallographic data set was deposited to the Cambridge Structural Database (CCDC).

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