

Kurzmitteilung/Short Communication

Hetero Diels-Alder Reactions of Allenes on Silica Gel Surface and under Liquid-Phase Conditions¹⁾

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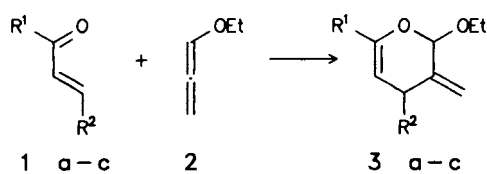
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Some examples of cycloadditions of 1-ethoxy-1,2-propadiene with 1-oxa-1,3-dienes, catalyzed by acid-free silica gel, are reported.

Inverse-type hetero Diels-Alder reactions of α,β -unsaturated carbonyl compounds, such as 1-oxa-1,3-dienes, with electron-rich dienophiles (e.g. alkoxyalkenes) are promising for the synthesis of natural products²⁾, but there are only few examples with allenic dienophiles (e.g. 1-methoxy-1,2-propadiene)³⁻⁵⁾. These reactions typically suffer from low conversions, competitive polymerization, and harsh reaction conditions.

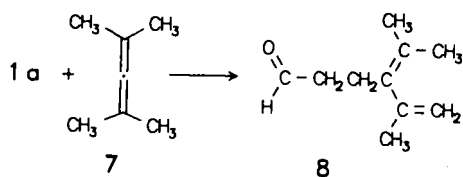
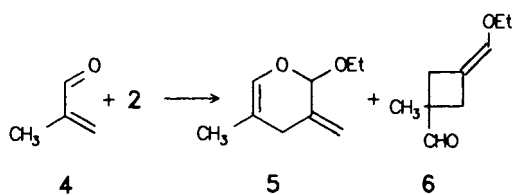
In course of our investigations concerning the activation of dienophiles in LUMO_{dienophile}-controlled Diels-Alder reactions⁶⁾ we studied some reactions of allenic compounds with various 1-oxa-1,3-dienes. The reaction of 1-ethoxy-1,2-propadiene (**2**) with 2-propenal (**1a**) or 3-methyl-2-propenal (**1c**) at 150 °C leads to the desired dihydropyrans **3**³⁾, but the yields are only moderate. In addition, under Lewis acid catalysis [e.g. ZnI₂, Et₂O–BF₃, EtAlCl₂, Cu(OAc)₂] we found a decrease in selectivity.



a : R¹, R² = H

b : R¹ = CH₃, R² = H

c : R¹ = H, R² = CH₃



There are some examples which show that silica gel can control regioselectivity and the rate of photochemical reactions⁷⁾. This and some work on cycloadditions under dry-state adsorption conditions (DSAC)⁸⁾ prompted us to investigate the influence of silica gel on hetero Diels-Alder reactions of allenenes.

We found that the addition of **2** to 2-propenal (**1a**), 3-buten-2-one (**1b**), and 2-methyl-2-propenal (**4**) was strongly accelerated under DSAC. The reaction with 3-methyl-2-propenal (**1c**) was the only unsuccessful one, since the yield did not exceed 5% after two weeks at 70 °C. The resulting dihydropyrans are not stable on pure silica gel; therefore, we deactivated the dried SiO₂ with NEt₃ (0.2–0.5%). By this procedure polymerization of the products was avoided during the reaction. The use of the more basic florisil (MgO · SiO₂)⁸⁾ led to a decrease in selectivity and rate. In all reactions we found traces of products formed from two equivalents of enone and one equivalent of **2**.

Table 1. Diels-Alder reactions of 1-ethoxy-1,2-propadiene (**2**)

diene	reaction conditions	yields ^{a)}	selectivity ^{b)}
1a	150 °C, 2 h	41% ³⁾	
	70 °C, 20 h	66%	
	70 °C, 10 h, SiO ₂	71%	
1b	50 °C, 48 h	62%	85%
	50 °C, 1 h, SiO ₂	68%	91%
1c	150 °C, 3 h	19% ³⁾	
	70 °C, 14 d, SiO ₂	< 5%	
4	70 °C, 24 h	54%	60%
	70 °C, 15 h, SiO ₂	58%	> 90%

^{a)} Yield of 1:1 products. — ^{b)} Diels-Alder products.

The reaction of **1b** showed the most dramatic effect: Under DSAC the rate was 50 times greater, and the selectivity increased from 6:1 to 10:1. With **4** the rate also increased, but at longer reaction times, being necessary for complete conversion, the selectivity decreased, and the cyclobutane product **6** became the main product. In the reaction of 2,4-dimethyl-2,3-pentadiene (**7**) we found an increase in rate, but the isolated product was the ene product **8**. Further studies on the expansion of our results on other allenenes and on the synthetic use of the products are in progress.

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Experimental

All reactions were carried out under Ar in sealed tubes or glass autoclaves. 1-Ethoxy-1,2-propadiene (**2**) and 2,4-dimethyl-2,3-pentadiene (**7**) were synthesized according to described methods⁹. 2-Propenal (**1a**), 3-buten-2-one (**1b**), 2-methyl-2-propenal (**4**), and 3-methyl-2-propenal (**1c**) were purchased from Aldrich, distilled before use, and stabilized with hydroquinone. — Merck Kieselgel 60 (0.063–0.2 mm) and Fluka Florisil were dried at 150 °C in vacuo for 6 h. — HPLC: Kontron 420 chromatograph and Chromosorb Si 60 columns (250 × 20 mm). — GC: Siemens Sichromat 3 or Sichromat 1–4, 25 m HP Ultra 2. — IR: Perkin-Elmer 1700. — ¹H NMR and ¹³C NMR: Varian VXR 300 (300 MHz/75 MHz), TMS as internal standard. — MS: Varian MAT 212, 70 eV. — Microanalyses were performed by Mikroanalytisches Laboratorium der RWTH Aachen.

General Procedure for the Hetero Diels-Alder Reactions: A mixture of one equivalent of hetero diene and one equivalent of the allene was prepared at 0 °C. For reactions under DSAC, silica gel (2.5–3.0 weight equivalents) and 0.2–0.5% of NEt₃ were added, and the reaction vessel was shaken vigorously. The mixture was allowed to stand at the temp. and time indicated for each compound. Usual product isolation was effected by extraction of the silica gel with ether, solvent removal, and distillation of the residue.

2-Ethoxy-3,4-dihydro-3-methylene-2H-pyran (3a): a) From 5.6 g (0.1 mol) of **1a** and 8.4 g (0.1 mol) of **2** after 20 h at 70 °C. Yield 9.2 g (66%) after distillation (b.p. 55 °C/14 Torr), *n*_D²⁰ = 1.4627 (ref.³ 1.4612).

b) From 2.8 g (0.05 mol) of **1a**, 4.2 g (0.05 mol) of **2**, 0.1 g of NEt₃ and 21 g of SiO₂ after 10 h at 70 °C. Yield 5.0 g (71%) after distillation.

2-Ethoxy-3,4-dihydro-6-methyl-3-methylene-2H-pyran (3b): a) From 7.0 g (0.1 mol) of **1b** and 8.4 g (0.1 mol) of **2** after 48 h at 50 °C. Yield 8.2 g (53%) after distillation (b.p. 70 °C/18 Torr). — IR (CDCl₃): $\tilde{\nu}$ = 3080, 2980, 2940 cm⁻¹ (CH), 1712, 1690 (C=C). — ¹H NMR (CDCl₃): δ = 1.24 (t, *J* = 7 Hz, 3H, CH₃CH₂), 1.74 (m, 3H, CH₃C=C), 2.56 (d/d/m, *J* = 18.6/4 Hz, 1H, 4-H), 2.94 (d/quint, *J* = 18.6/2.4 Hz, 1H, 4-H), 3.62 (d/q, *J* = 10/7.1 Hz, 1H, OCH₂), 3.83 (d/q, *J* = 10/7.1 Hz, 1H, OCH₂), 4.55 (m, 1H, 5-H), 4.97 (m, 1H, =CH), 5.05 (m, 1H, =CH), 5.15 (s, 1H, 2-H). — ¹³C NMR (CDCl₃): δ = 15.25 (CH₂CH₃), 19.63 (CH₃), 26.21 (C-4), 63.41 (OCH₂), 95.77 (C-2), 99.57 (C-5), 111.21 (=CH₂), 140.04 (C-3), 147.01 (C-6). — MS (70 eV): *m/z* (%) = 154 (56.6) [M⁺], 139 (3.38) [M⁺ – CH₃].

C₉H₁₄O₂ (154.2) Calcd. C 70.1 H 9.15 Found C 69.4 H 9.43

b) From 3.5 g (0.05 mol) of **1b**, 4.2 g (0.05 mol) of **2**, 0.1 g of NEt₃, and 23 g of SiO₂ after 1 h at 50 °C. Yield 4.8 g (62%) after extraction and distillation.

3-(Ethoxymethylen)-1-methyl-1-cyclobutanecarbaldehyd (6): 7.0 g (0.1 mol) of **4** was treated with 8.4 g (0.1 mol) of **2** for 24 h at 70 °C. Fractionation through a 40-cm Vigreux column gave **6**. Yield 3.4 g (22%), b.p. 42 °C/2 Torr. — IR (CDCl₃): $\tilde{\nu}$ = 2980, 2930 cm⁻¹ (CH), 1745 (C=O). — ¹H NMR (CDCl₃): δ = 1.22 (t, *J* = 7 Hz, 3H, CH₃CH₂), 1.32 (s, 3H, CH₃), 2.36–2.51 (m, 2H, 4-H/2-H), 2.92–3.03 (m, 2H, 4-H/2-H), 3.75 (q, *J* = 7 Hz, 2H, OCH₂), 5.93 (quint, *J* = 2.3 Hz, 1H, =CH), 9.65 (s, 1H, CHO). — ¹³C NMR (CDCl₃): δ = 15.26 (CH₃), 20.16 (CH₂CH₃), 34.02/34.67 (C-2/C-4), 45.26 (C-1), 67.23 (OCH₂), 107.65 (C-3), 140.13 (=CH), 202.85

(CHO). — MS (70 eV): *m/z* (%) = 154 (61.5) [M⁺], 139 (8.9) [M⁺ – CH₃].

C₉H₁₄O₂ (154.2) Calcd. C 70.1 H 9.15 Found C 69.9 H 9.29

5: Yield 5.0 g (32%), contaminated with another product (<9% from GC), b.p. 35 °C/2 Torr.

2-Ethoxy-3,4-dihydro-5-methyl-3-methylene-2H-pyran (5): From 3.5 g (0.05 mol) of **4**, 4.2 g (0.05 mol) of **2**, 0.1 g of NEt₃, and 21 g of SiO₂ after 15 h at 70 °C. Yield 4.0 g (51%) of pure **5** after distillation (traces of **6** were detected by GC), b.p. 62 °C/10 Torr. — IR (CDCl₃): $\tilde{\nu}$ = 3080, 2990, 2927 cm⁻¹ (CH). — ¹H NMR (CDCl₃): δ = 1.22 (t, *J* = 7 Hz, 3H, CH₃CH₂), 1.57 (m, 3H, CH₃C=C), 2.46 (d/t, *J* = 18.5/1 Hz, 1H, 4-H), 2.91 (d/m, *J* = 18.5 Hz, 1H, 4-H), 3.56 [d/q, *J* = 10/7 Hz, 1H, CH₂O], 3.79 (d/q, *J* = 10/7 Hz, 1H, CH₂O), 4.96 (m, 1H, =CH₂), 5.04 (m, 1H, =CH₂), 5.07 (s, 1H, 2-H), 6.01 (s, 1H, 6-H). — ¹³C NMR (CDCl₃): δ = 15.14 (CH₃CH₂), 17.83 (CH₃), 31.17 (C-4), 63.21 (CH₂O), 98.56 (C-2), 108.91 (C-5), 111.27 (=CH₂), 134.40 (C-6), 140.17 (C-3). — MS (70 eV): *m/z* (%) = 154 (10.53) [M⁺], 139 (2.3) [M⁺ – CH₃].

C₉H₁₄O₂ (154.2) Calcd. C 70.1 H 9.15 Found C 70.2 H 9.07

4-Isopropenyl-5-methyl-4-hexen-1-al (8): a) From 1.92 g (0.02 mol) of **7** and 4.50 g (0.08 mol) of **1a** after 12 d at 70 °C. Yield 1.30 g (44%) as a colorless oil after HPLC purification (15% ethyl acetate/hexane, 12 ml/min). — IR (CDCl₃): $\tilde{\nu}$ = 2960, 2935, 2870 cm⁻¹ (CH), 2730 (CHO), 1722 (C=O). — ¹H NMR (CDCl₃): δ = 1.66 and 1.68 [s, each 3H, (CH₃)₂C=], 1.75 (t, *J* = 1 Hz, 3H, CH₃), 2.44 (br. s, 4H, 2 × CH₂), 4.55 and 4.96 (m, each 1H, C=CH), 9.74 (t, *J* = 1.3 Hz, 1H, CHO). — ¹³C NMR (CDCl₃): δ = 19.56, 21.76, 22.5 (3 × CH₃), 23.44 (C-3), 42.74 (C-2), 114.18 (=CH₂), 126.35 (C-5), 134.59 (C-4), 145.65 (C=CH₂), 202.19 (CHO). — MS (70 eV): *m/z* (%) = 152 (58.6) [M⁺], 137 (91.1) [M⁺ – CH₃].

C₉H₁₄O₂ (152.2) Calcd. C 78.9 H 10.59

Found C 78.7 H 10.98

b) From 2.16 g (0.023 mol) of **7** and 2.78 g (0.050 mol) of **1a** after 7 d at 50 °C. Yield 1.95 g (56%) as a colorless oil after extraction and HPLC (15% ethyl acetate/hexane).

CAS Registry Numbers

1a: 107-02-8 / **1b:** 78-94-4 / **2:** 13077-71-9 / **3a:** 22082-47-9 / **3b:** 122722-51-4 / **4:** 78-85-3 / **5:** 122722-49-0 / **6:** 122722-50-3 / **7:** 1000-87-9 / **8:** 122760-95-6

¹⁾ Part 7 of "Thermal Reactions of Donor-Acceptor Systems". For part 6 see: J. Mattay, J. Mertes, G. Maas, *Chem. Ber.* **122** (1989) 327.

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