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Photochemical Formation of 3,4,4a,5,6,8a-Hexahydro-2*H*-naphthalen-1-ones from Cyclohex-2-enones and 2-Methylbut-1-en-3-yne

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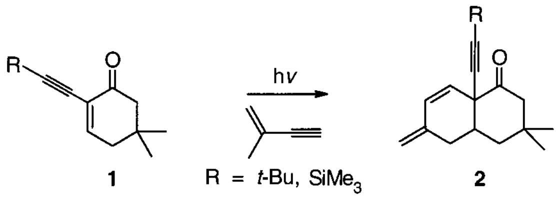
ABSTRACT



Irradiation of 2-alkynylcyclohex-2-enones 1a and 1b in the presence of 2-methylbut-1-en-3-yne in benzene affords 6-methylenehexahydronaphthalen-1-ones 2 as main products while photolysis in methanol gives predominantly 1:1 diastereomeric mixtures of 6-methoxy-6-methylnaphthalenones 4 and 5, respectively. The key step in this stepwise [4 + 2]-cycloaddition is the 1,6-cyclization of biradical 6 to 1,2-cyclohexadiene 7.

Triplet alkylpropargyl or alkylcyanoalkyl 1,4-biradicals undergo spin-selective 1,5-cyclization to vinyl carbenes and vinyl nitrenes, respectively.[1] Such a reaction has been recently used for the synthesis of the cyclopenta[*c*]coumarin moiety of aflatoxine B_1.[2] Here we report on a novel cyclohexaannelation on irradiating cyclohex-2-enones in the presence of 2-methylbut-1-en-3-yne.[3]

Irradiation ($\lambda = 350$ nm) of an argon-degassed solution of 10^{-3} mol 5,5-dimethyl-2-(3,3-dimethylbut-1-ynyl)cyclohex-2-enone (**1a**)[4] and 10^{-2} mol 2-methylbut-1-en-3-yne[5] in benzene (20 mL) furnishes a 5:1 mixture of *enone* + *enyne* (ms: $m/z = 270$) adducts **2a** and **3a**, the major product **2a** being isolated by chromatography (SiO_2, dichloromethane/pentane 9:1) in 68% yield as colorless oil. Similarly, trimethylsilylethynylcyclohexenone **1b**[6] gives a 4:1 mixture of **2b** and **3b**, the same workup affording **2b** in 57%, again as colorless oil. On irradiation in methanol both **1a** and **1b** afford 2:2:3:3 mixtures of **2** and **3** and two new *enone*+*enyne*+*methanol* adducts **4** and **5**, again separated by chromatography using the same eluent mixture as above. Surprisingly, on irradiation in benzene even 5,5-dimethylcyclohex-2-enone (**1c**) affords a mixture containing **2c** in 10% besides two regioisomeric bicyclooctanones (40% and 50%), the former being isolated in 4% yield by chromatography as above.[7] NMR spectra[8] confirm **2** to be 6-methylene-3,4,4a,5,6,8a-hexahydro-2*H*-naphthalen-2-ones and **4** and **5** to be diastereomeric allyl ethers[9] with methoxy and methyl groups located on C(6) (Scheme 1). In **2c** the two rings are unambiguosly *cis*-fused ($J_{H(4a),H(8a)} = 5$ Hz), H(4a) being in the axial ($J_{H(4a),H(4ax)} = 12.5$ Hz) and H(8a) in the equatorial position ($J_{H(8a),H(2eq)} = 2$ Hz). From the facts that the H,H-

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(1) Agosta, W. C.; Margaretha, P. *Acc. Chem. Res.* **1996**, *29*, 179.

(2) Schwebel, D.; Ziegenbalg, J.; Kopf, J.; Margaretha, P. *Helv. Chim. Acta* **1999**, *82*, 177.

(3) Irradiation of (parent) cyclohex-2-enone and this enyne gives only bicyclo[4.2.0]octan-2-ones: Margaryan A. K.; Serebryakov, E. P.; Kucherov, V. F. *Izv. Akad. Nauk SSSR. Ser. Khim.* **1976**, *25*, 840.

(4) Margaretha, P.; Reichow, S.; Agosta, W. C. *J. Org. Chem.* **1994**, *59*, 5393.

(5) Defranq, E.; Zesiger, T.; Tabacchi, R. *Helv. Chim. Acta* **1993**, *76*, 425.

(6) Sander, B.; Andresen, S.; Reichow, S.; Dubois, K.; Agosta, W. C.; Margaretha, P. *Helv. Chim. Acta* **1996**, *79*, 1428.

(7) Naphthalenones **2** always show higher R_f values than bicyclooctanones **3**.

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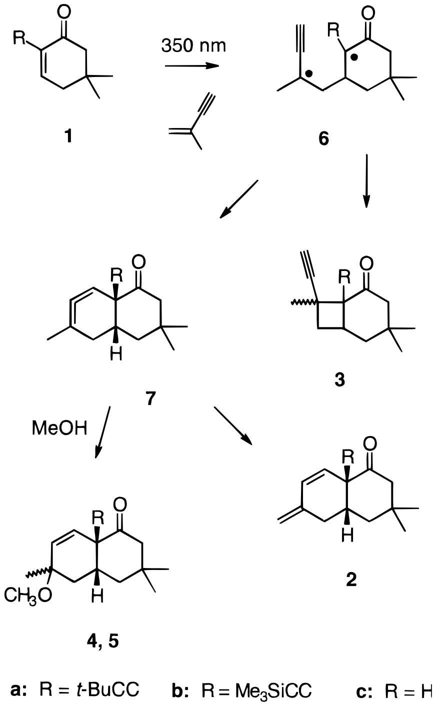
Scheme 1



coupling patterns for H(4), H(4a), and H(5) in all compounds **2** are the same and that the ^{13}C chemical shifts of C(2), C(3), C(4), C(4a), and C(8a) in **2a** and **2b** are nearly identical to those of the corresponding C-atoms in 3,3,6,8a-tetramethyl-3,4,4a,5,8,8a-hexahydro-2*H*-naphthalen-2-one (the—*cis*-fused—Diels−Alder cycloadduct of 2,5,5-trimethylcyclohex-2-enone and isoprene),[10] it becomes evident that the ring fusion in **2** (and thus in **7** and then in **4** and **5**) is *cis*.

The simplest path to **2** is bonding of C(3) of excited **1** and C(1) of the enyne followed by 1,6-cyclization of biradical **6** to the cyclic allene **7**, which then undergoes a 1,3-H shift. As the triplet of 1,2-cyclohexadiene lies only 15−25 kcal/mol higher in energy than the ground state,[11] cyclization of **6** to **7** could occur both from a triplet or singlet biradical, the latter obviously representing the precursor for the formation of **3**. While a homologous 1,7-cyclization of an acylpropargyl 1,5-biradical to a 2,3-cycloheptadien-1-one has been reported,[12] there is no precedent for a stepwise [4 + 2]-cycloaddition of an enyne to a dienophile in the literature.[13] In addition to the structural evidence of **2**, the observation that in methanol ethers **4** and **5** are formed to the exclusion of any isomers is good evidence for the intermediacy of a 1,2-cyclohexadiene. Efficient formation of **7** thus requires *(*a) selective binding of the enyne on C(3) of triplet excited **1** and (b) a conformation of **6** wherein 1,6-cyclization is favored to either 1,4-cyclization (formation of **3**) or disproportionation to starting materials. Further studies with various 2-substituted cyclohex-2-enones and different enynes are now in progress in order to determine the scope of this novel light-induced cycloaddition.

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(8) **2a**: ^{1}H NMR (400 MHz, CDCl$_3$) δ 6.21 (d, $J = 9.7$), 5.39 (dd, $J = 1.5, 9.7$), 5.00 (s), 4.98 (d, $J = 1.5$), 2.94 (dd, $J = 4.4, 14.8$, H(5$_{ax}$)), 2.43 (dddd, $J = 3.5, 4.4, 4.6, 12.8$, H(4a)), 2.32 (d, $J = 13.0$, H(2$_{ax}$)), 2.20 (dd, $J = 14.8, 3.5$, H(5$_{eq}$)), 2.12 (dd, $J = 2.5, 13.0$, H(2$_{eq}$)), 1.55 (dd, $J = 12.8, 13.2$, H(4$_{ax}$)), 1.34 (ddd, $J = 2.5, 4.6, 13.2$, H(4$_{eq}$)), 1.23 (s, 9H), 0.98 (s, 3H), 0.90 (s, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 208.0 (s, C(1)), 139.5 (s, C(6)), 129.7 and 126.5 (d, C(7) and C(8)), 114.9 (t), 94.4 (s), 77.7 (s), 50.9 (t, C(2)), 50.6 (s, C(8a)), 39.6 (t, C(4)), 39.2 (d, C(4a)), 34.7 (s, C(3)), 33.3 (t, C(5)), 31.6 (q), 31.2 (q), 27.5 (s), 26.2 (q). **3a**: ^{1}H NMR (C$_6$D$_6$) δ 2.55 (dddd, $J = 2.5, 8.1, 9.1, 12.2$, H(6)), 2.45 (d, $J = 17.8$, H(3$_{ax}$)), 2.35 (dd, $J = 2.5, 17.8$, H(3$_{eq}$)), 2.25 (dd, $J = 9.1, 11.7$, H(7$_{ax}$)), 2.00 (s, 1H), 1.85 (dd, $J = 12.2, 13.7$, H(5$_{ax}$)), 1.84 (dd, $J = 2.5, 11.7$, H(7$_{eq}$)), 1.63 (s, 3H), 1.50 (ddd, $J = 2.5, 8.1, 13.7$, H(5$_{eq}$)), 1.20 (s, 9H), 0.85 (s, 3H), 0.78 (s, 3H);); ^{13}C NMR (C$_6$D$_6$) δ 208.8 (s), 94.0 (s), 87.3 (s), 81.9 (s), 71.9 (d).

(9) **4a**: ^{1}H NMR (C$_6$D$_6$) δ 5.97 (d, $J = 9.7$), 5.61 (d, $J = 9.7$), 3.05 (s, 3H), 3.01 (d, $J = 12.7$, H(2$_{ax}$)), 2.90 (dddd, $J = 3.0, 5.0, 5.5, 11.2$, H(4a)), 2.15 (dd, $J = 5.5, 13.2$), 2.01 (dd, $J = 1.5, 12.7$, H(2$_{eq}$)), 1.96 (dd, $J = 3.0, 13.7$), 1.53 (dd, $J = 11.2, 13.7$), 1.32 (ddd, $J = 1.5, 5.0, 13.2$), 1.11 (s, 9H), 1.09 (s, 3H), 0.84 (s, 3H), 0.83 (s, 3H); ^{13}C NMR (C$_6$D$_6$) δ 207.2 (s), 131.9 (d), 131.3 (d), 93.5 (s), 80.4 (s), 71.6 (s). **5a**: ^{1}H NMR (C$_6$D$_6$) δ 5.75 (d, $J = 10.1$), 5.64(d, $J = 10.1$), 3.05 (s, 3H), 2.70 (d, $J = 12.7$, H(2$_{ax}$)), 2.45 (dddd, $J = 3.5, 5.0, 7.5, 9.2$, H(4a)), 2.05 (d, $J = 12.7$, H(2$_{eq}$)), 2.02 (dd, $J = 9.2, 13.7$), 1.85 (dd, $J = 5.0, 14.2$), 1.72 (dd, $J = 3.5, 13.7$), 1.66 (dd, $J = 7.5, 14.2$), 1.17 (s, 9H), 1.16 (s, 3H), 0.83 (s, 3H), 0.82 (s, 3H); ^{13}C NMR (C$_6$D$_6$) δ 206.6 (s), 132.9 (d), 128.9 (d), 93.3 (s), 80.6 (s), 72.7 (s).

(10) Angell, E. C.; Fringuelli, F.; Minuti, L.; Pizzo, F.; Taticchi, A.; Wenkert, E. *J. Org. Chem.* **1986**, *51*, 5177.

(11) Angus, R. O., Jr.; Schmidt, M. W.; Johnson, R. P. *J. Am. Chem. Soc.* **1985**, *107*, 532.

(12) Venugopal, D.; Todaro, L. D.; Margaretha, P.; Agosta, W. C. *J. Chem. Soc., Chem. Commun.* **1993**, 1014.

(13) Theoretical predictions for a concerted reaction have been presented: Burrell, R. C.; Daoust, K. J.; Bradley, A. Z.; DiRico, K. J.; Johnson, R. P. *J. Am. Chem. Soc.* **1996**, *118*, 4218.