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Generation and trapping of a highly strained bicyclic allene: tricyclo[6.3.1.0^{2,7}]dodeca-2,4,6,9,10-pentaene

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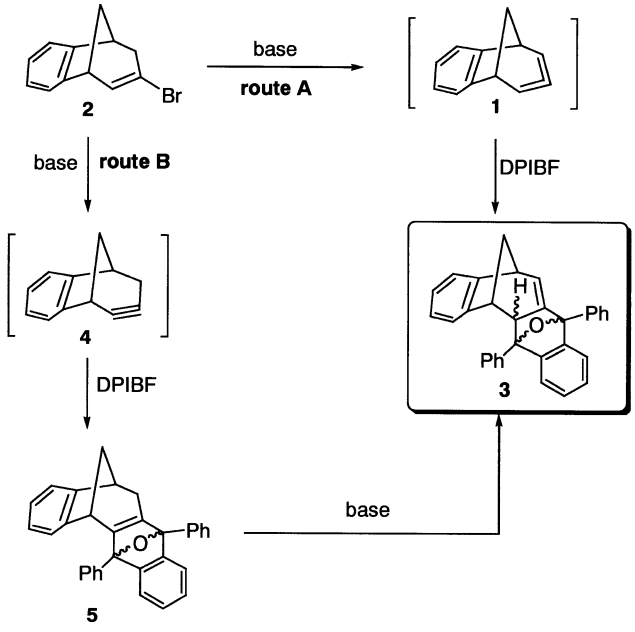
Abstract—10-Bromo-10-fluorotetracyclo[6.3.1.0^{2,7}.0^{9,11}]dodeca-2,4,6-triene (**12**) was prepared by addition of bromofluorocarbene to benzonorbornadiene (**10**). Treatment of a solution of **12** in ether with MeLi in the presence of furan or styrene afforded the trapping products **14/15** and **16**, respectively. The formation of these trapping products confirms the formation of the title cycloallene **1** as a reactive intermediate.

1. Introduction

Small-ring cyclic allenes are of considerable interest in chemistry because of their high strain and reactivity.[1] Cyclonona-1,2-diene is a distillable liquid,[2] while cycloocta-1,2-diene rapidly dimerizes at room temperature.[3] However, if the ring size is decreased, the linear perpendicular allene will be twisted and bent until, at some point, the energy gained by π bonding in the two double bonds will be insufficient to offset the increased strain. Enormous effort has been devoted toward the synthesis of cyclohexa-1,2-diene and a number of its derivatives.[1,4] Although a large number of monocyclic allenes are known, bicyclic allenes are remarkably limited.[5]

In a previous paper,[6] we initially proposed the highly strained bicyclic allene **1** as an intermediate in the base-induced elimination of HBr from **2**, which gives trapping products **3** in the presence of 1,3-diphenylisobenzofuran (DPIBF) as a trapping agent (Scheme 1). However, as noticed in the same paper, these results were also in agreement with an alternative mechanism for the formation of cycloadducts **3**. According to this mechanism dehydrobromination of **2** can yield the bicyclic alkyne **4**, which undergoes cycloaddition reaction with DPIBF to give **5**. The base-promoted isomerization of the double bond in **5** would give the observed products **3**.

To distinguish between these two possible mechanisms, we recently investigated the generation and trapping of the



Scheme 1.

alkyne **4** by two alternative procedures. The alkyne **4** was generated by treatment of dibromide **6**[7] and with *tert*-butyllithium, and by the KO*t*-Bu induced rearrangement of the bromomethylidene compound **7**.[8] The intermediates were trapped with DPIBF to give the cycloadducts **5** which then isomerize completely to the products **3** in the presence of KO*t*-Bu (Scheme 2).

Furthermore, we have forced the system to undergo allene formation by replacing the double bond proton in **2** by a methyl group. No reaction was observed when **8** was subjected to dehydrobromination with potassium

Keywords: cyclic strained allenes; fluorobromocarbene; Diels–Alder reaction.

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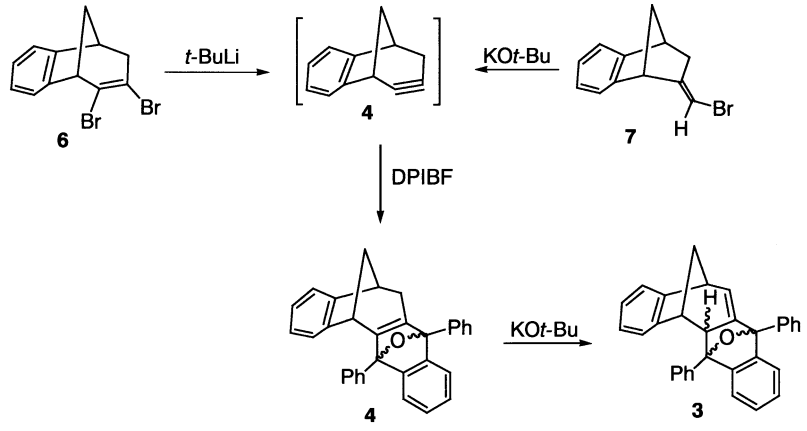
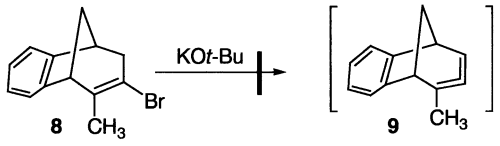


Scheme 2.

tert-butoxide under the same reaction condition as reported for **2**[9] (Scheme 3).



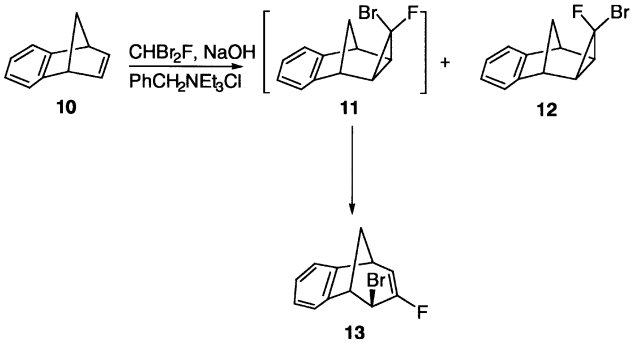
Scheme 3.

Alkyne **4** is calculated to be 11 kcal/mol (MOPAC) and 16 kcal/mol (PCMODEL) more stable than allene **1**.[8] In the light of these results we assumed that the alkyne **4** is generated in the base-promoted reaction of **2**. In this paper, we report an independent way for the synthesis of the title compound **1** and its trapping reactions.

2. Results and discussion

One of the best known methods to directly generate allenes is the rearrangement of cyclopropylidenes to allenes. For the formation of cycpropylidene, the corresponding dihalocyclopropane compounds are generally very suitable precursors. Therefore, we have decided to add a dihalocarbene to benzonorbornadiene **10** and convert the formed dihalocyclopropane directly to the desired bicyclic allene **1**. The addition of dichlorocarbene[10] and dibromocarbene[11] to benzonorbornadiene **10** provides the most direct route to compounds containing the bicyclo[3.2.1]octyl system. The reaction involves the addition of the corresponding dihalocarbenes to the double bond in benzonorbornadiene **10** to form initially a dihalocyclopropane, which undergoes a ring opening reaction due to the increased strain and steric effects in the molecule, to afford a ring-expanded dihalide. The ring opening reaction has been rationalized in terms of orbital symmetry conservation.[12] It has been well-established that the departing halide is that one which is in the *endo*-position. For that reason, we have decided to add fluorobromocarbene to benzonorbornadiene **10**.

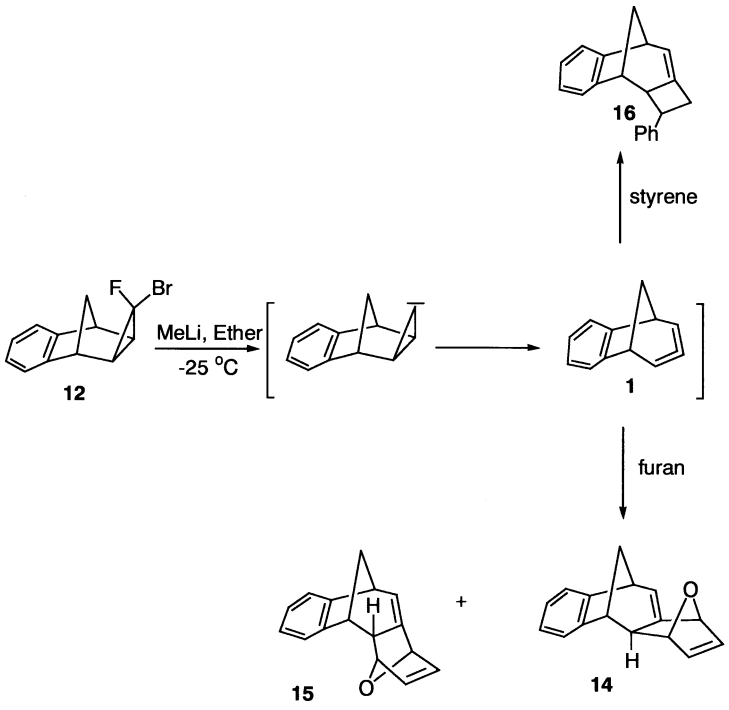
Addition of fluorobromocarbene, generated from $CHFBr_2$[13] and NaOH under phase-transfer conditions to benzonorbornadiene **10**[14] afforded the *exo*-bromofluoro ring-opened product **13** and the expected addition product, fluorobromocyclopropane **12** in a ratio of 3:2 and in a total yield of 42 % (based on recovered starting material) (Scheme 4). Structural assignments were made on the basis of the spectral data. In particular, the observation of seven signals in the ^{13}C NMR spectrum, as required by the symmetry in molecule **12**, is in good agreement with the structure.



Scheme 4.

After the successful synthesis and characterization of **12** it was submitted to the Doering–Moore–Skatebol reaction.[15] Treatment of bromofluorocyclopropane **12** with MeLi in ether at −25 °C in the presence of furan, as the trapping reagent, afforded two cycloaddition products **14** and **15** in 21 and 24% yield, respectively (Scheme 5).

The structural assignment of trapping products **14** and **15** follows predominately from its 400 MHz ^1H and 100 MHz ^{13}C NMR spectra (COSY, HMQC and HMBC). The ^1H spectra of these isomers contain three distinct olefinic protons. The configuration of the proton H_2 (*endo* or *exo*) was determined by measuring the coupling constant between protons H_2 and H_1. Dreiding-models indicate that the dihedral angle between H_2 and H_1 is 55–60° in the case of *endo*-orientation of proton H_2. The lack of the coupling between those protons indicates the *exo*-configuration of H_2. Furthermore, we have generated the cyclic allene **1** as described above, in the presence of styrene and isolated diastereomeric [2+2]cycloaddition products **16**.



Scheme 5.

In summary, we have illustrated that the title compound **1**, a strained cyclic allene, can be generated from the bromofluorocyclopropane compound **12** by α-elimination of Br and F with MeLi. However, HBr elimination from 10-bromotricyclo[6.3.1.$0^{2,7}$]dodeca-2,4,6,9-tetraene (**2**) with KO*t*-Bu results in the formation of the alkyne **4** instead of the allene **1**.

3. Experimental

3.1. General

Melting points were determined on a Büchi model 530 apparatus and are uncorrected. Infrared spectra were recorded on a Mattson model 1000 FT-IR spectrometer. ^{1}H and ^{13}C NMR spectra were recorded on 400 (100)-MHz spectrometers. Mass spectra (electron impact) were recorded at 70 eV. Column chromatography was performed on silica gel (60–200 mesh) and activated alumina (70–230 mesh) from Merck Company. TLC was carried out on Merck 0.2 mm silica gel 60 F254 analytical aluminum plates.

3.1.1. Addition of bromofluorocarbene to norbornadiene (10). To a magnetically stirred solution of benzonorbonadiene (**10**) (5.22 g, 0.036 mol), benzyltriethylammonium chloride (1.5 g, 6.5 mmol) and dibromofluoromethane[13] (9 g, 0.046 mol) in 25 mL methylene chloride cooled to −15 °C was added dropwise a solution of NaOH (13.5 g, 0.33 mol) in 13.5 mL water during 2 h. After completion of the addition, the solution was allowed to warm up to room temperature. The mixture was poured into water (100 mL), the organic layer was separated, and the water layer was extracted with methylene chloride (3×50 mL). Combined organic layers were dried over $MgSO_4$. After removal of the solvent (20 °C, 15 torr), the residue was chromatographed on silica gel (100 g) by eluting with hexane. The first fraction consisted of unreacted benzonorbornadiene and cyclopropane adduct **12**. The excess of benzonorbornadiene was distilled off at 75–80 °C (10 torr). The oily viscous residue (1.5 g, 16%, based on unrecovered starting material) was characterized as *1R,8S,9R,11S-10-exobromo-10-fluorotetracyclo-[6.3.1.$0^{2,7}$.$0^{9,11}$]dodeca-2,4,6-triene (**12**)*: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19 (A part of AA′BB′ system, aromatic, 2H), 6.99 (B part of AA′BB′ system, aromatic, 2H), 3.71 (br. s, 2H, H1 and H8), 1.98 (d, A part of AB system, J=10.0 Hz, 1H, H_{12endo}), 1.83 (br. s, 2H, H_9 and H_{11}), 1.39 (d, B part of AB system, J=10.0 Hz, 1H, H_{12exo}). ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.0, 126.0, 121.7, 45.8, 42.1 (d) 41.1, 40.9; IR (NaCl, film, cm^{-1}) 3070, 3050, 2990, 2980, 1450. MS (70 eV) *m/z* 252/254 (M^+, 5%), 173 (M^+−Br, 100), 153 (M^+−Br and F, 94), 152 (M^+−Br and HF, 77), 128 (63), 115 (100); Anal. calcd for $C_{12}H_{10}BrF$: C, 56.94; H, 3.98. Found: C, 57.45; H, 3.84.

The second fraction, the oily residue was crystallized from hexane to give *1S(R),8R(S),11S(R)-11-bromo-10-fluorotricyclo[6.3.1.$0^{2,7}$]dodeca-2,4,6,9-tetraene (**13**)* (2.4 g, 26%): colorless crystals; mp 55–56 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 (m, aromatic, 1H), 7.1 (m, aromatic, 3H), 5.85 (ddd, J=12.3, 7.3, 0.6 Hz, 1H, H_9), 4.49 (t, J=2.3 Hz, 1H, H_{11}), 3.74 (m, 1H, H_1) 3.44 (dt, J=7.3, 3.8 Hz 1H, H_8), 2.5 (d, A part of AB system, J=9.8 Hz, 1H, H_{12endo}), 2.26 (m, B part of AB system, 1H, H_{12exo}). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.6 (d), 153.0, 141.23, 127.7, 127.2, 125.5, 121.8, 114.8 (d), 50.0, 47.3, 39.4, 39.1; MS (70 eV) *m/z* 252/254 (M^+, 32), 173 (M^+−Br, 100), 152 (M^+−Br and HF, 50), 115 (48); IR (KBr, cm^{-1}) 3100, 2950, 2800, 1600,

1490. Anal. calcd for $C_{12}H_{10}BrF$: C, 56.94; H, 3.98. Found: C, 57.28; H, 4.04.

3.1.2. Reaction of 12 with MeLi in the presence of furan. A solution of 1.6 M MeLi in ether (4.8 mmol, 3 mL) was added dropwise to a stirred solution of cyclopropane adduct **12** (0.5 g, 1.97 mmol) in dry ether (15 mL) over 10 min at −25 °C under nitrogen. Then furan (133 mg, 1.97 mmol) was added dropwise over 5 min at the same temperature. The mixture was stirred continually and allowed to warm to room temperature over 4 h. The reaction mixture was quenched with water (10 mL). After separation of the phases, the aqueous layer was extracted with ether (3×20 mL). The combined ether layers were dried over $MgSO_4$, concentrated at (20 °C, 20 torr). The oily residue was chromatographed over silica gel (75 g). Elution with *n*-hexane/chloroform (1:1) afforded 90 mg (mp 67 °C 21%) of **14** and 105 mg of **15** (24.3%, mp 76–77 °C). *1R(S),2R(S),3S(R),6S(R),9S(R)-17-oxapentacyclo-[7.6.1.1^{3,6}.0^{2,7}.0^{10,15}]heptadeca -4,7,10,12,14-pentaene* (***14***): ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.23 (br. d, aromatic, 1H), 7.03 (m, aromatic, 3H), 6.38 (br d, J=5.3, Hz, 1H, H_5), 6.1 (br. d, J=5.3 Hz, 1H, H_4), 5.93 (dd, J=7.0, 2.5 Hz, 1H, H_8), 4.98 (br. s, 1H, H_3), 4.95 (br. s, 1H, H_6), 3.34 (dd, J=7.0, 3.8 Hz, 1H, H_9), 3.02 (d, J=3.2 Hz, 1H, H_1), 2.50 (d, J=2.9 Hz, 1H, H_2), 1.96 (dt, A part of AB system, J=9.9, 3.7 Hz, 1H, H_{16exo}), 1.35 (d, B part of AB system, J=9.9 Hz, 1H, H_{16endo}). ^{13}C NMR (50 MHz, $CDCl_3$) δ 150.4, 148.0,140.9 (C_7), 137.8 (C_4), 129.0 (C_5), 127.0 (arom.), 126.6 (arom.), 122.6 (arom.), 122.0 (C_8), 121.9 (arom.), 82.0 (C_3), 80.5 (C_6), 45.3 (C_2), 40.5 (C_9), 39.2 (C_1), 37.6 (C_{16}). IR (KBr, film, cm^{-1}) 3010, 2990, 1600, 1590. MS (70 eV) m/z 222 (M^+, 58%), 193 (57), 178 (88), 165 (60), 152 (39), 129 (100), 115 (68); HRMS, calcd for $C_{16}H_{14}O$ 222.1045, found 222.1041. Anal. calcd for C16H14O: C, 86.45; H, 6.35. Found: C, 85.95; H, 6.50.

3.1.3. 1*R*(*S*),2*S*(*R*),3*R*(*S*),6*R*(*S*),9*S*(*R*)-17-Oxapentacyclo-[7.6.1.1^{3,6}.0^{2,7}.0^{10,15}]heptadeca-4,7,10,12,14-pentaene (15). ^{1}H NMR (400 MHz, $CDCl_3$) δ7.11 (br. d, J=7.3 Hz, 1H, arom.), 6.94 (dt, J=7.5, 1.0 Hz, 1H, arom.), 6.86 (dt, J=7.5, 1.0 Hz, 1H, arom.), 6.73 (br. d, J=7.2 Hz, 1H, arom.), 5.49 (m, 1H, H8), 5.38 (dd, A-part of AB-system, J=5.6 and 1.4 Hz, 1H, H_4 or H_5), 5.25 (dd, B-part of AB-system, J=5.6, 1.5 Hz, 1H, H_4 or H_5), 4.83 (br. s, 1H, H_6), 4.77 (br. d, J=3.2 Hz, 1H, H_3), 3.42 (t, J=4.7 Hz, 1H, H_1 or H_9), 3.28 (t, J=4.7 Hz, 1H, H_1 or H_9), 2.9 (q, J=2.7 Hz, 1H, H_2), 2.18 (ddt, A part of AB system, J=10.3, 4.5, 0.9 Hz, 1H, H_{16exo}), 2.07 (d, B part of AB system, J=10.3 Hz, 1H, H_{16endo}). ^{13}C NMR (50 MHz, $CDCl_3$) δ 148.6, 140.6, 132.6, 129.9, 128.6, 126.5, 125.0, 124.6, 123.2, 122.8, 121.4, 121.0, 118.9, 116.6, 80.5, 79.7, 45.1, 43.4, 42.3, 41.9. IR (KBr, film, cm^{-1}) 3000, 2980, 1610, 1600; Anal. calcd for $C_{16}H_{14}O$: C, 86.45; H, 6.35. Found: C, 86.23; H, 6.42.

3.1.4. Reaction of 12 with MeLi in the presence of styrene. The reaction was carried out as described above by using 100 mg (0.39 mmol) of **12** and 41 mg 0.39 mmol) of styrene. The product mixture was passed through silica gel (70 g) eluting with hexane to yield an oil (30 mg, %30) of a diastereomeric mixture of *10-phenyl-tetracyclo[6.5.1.0^{2,7}.0^{9,12}]tetradeca-2,4,6,12-tetraene* ***16***: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.3–6.9 (m, 9H, arom.), 5.49 (br. d, J=6.4 Hz, 3.33 (dd, J=2.1, 1.1 Hz, 1H), 3.04 (m, 2H), 2.97 (d, J=8.3 Hz, 1H), 2.76 (m, 1H), 2.70 (m, 1H), 2.36 (dt, A-part of AB-system, J=10.1, 5.4 Hz, 1H, H_{14exo}), 1.91 (d, B-part of AB-system, J=10.1 Hz, $1H_{14endo}$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.6, 148.8, 143.7, 136.8, 128.8, 127.1, 126.7, 126.6, 122.72, 122.66, 57.8, 42.8, 41.2, 40.9, 40.8. IR (NaCl, film, cm^{-1}) 3070, 3050, 3020, 2980, 2860, 1490, 1480; MS (70 eV) m/z 258 (M^+, 55%), 167 (90),154 (58), 128 (100). Anal. calcd for $C_{16}H_{14}O$: C, 92.98; H, 7.02. Found: C, 91.75; H, 6.89.

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References

1. (a) Balci, M.; Taskesenligil, Y. *Advances in Strained and Interesting Organic Molecules*; Halton, B., Ed.; 2000; Vol. 8, pp 43–81. (b) Johnson, R. P. *Chem. Rev.* **1989**, *89*, 1111–1124.
2. Blomquist, A. T.; Burger, Jr., R. E.; Liu, L. H.; Bohrer, J. C.; Sucsy, A. C.; Kleis, C. *J. Am. Chem. Soc.* **1951**, *73*, 5510–5512.
3. Ball, W. J.; Landor, S. R. *Proc. Chem. Soc., London* **1961**, 143–148.
4. For most recent papers see: (a) Drinkuth, S.; Groetsch, S.; Peters, E.-M.; Peters, K.; Christl, M. *Eur. J. Org. Chem.* **2001**, 2665–2670. (b) Fernandez-Zertuche, M.; Hernandez-Lamoneda, R.; Ramirez-Solis, A. *J. Org. Chem.* **2000**, *65*, 5207–5211. (c) Christl, M.; Groetsch, S. *Eur. J. Org. Chem.* **2000**, 1871–1874. (d) Groetsch, S.; Spuziak, J.; Christl, M. *Tetrahedron* **2000**, *56*, 4163–4171. (e) Nendel, M.; Tolbert, L. M.; Herring, L. A.; Islam, N. M.; Houk, K. N. *J. Org. Chem.* **1999**, *64*, 976–983.
5. (a) Balci, M.; Jonnes, W. M. *J. Am. Chem. Soc.* **1981**, *103*, 2874–2876. (b) Christl, M.; Lang, R.; Lechner, M. *Justus Liebigs Ann. Chem.* **1980**, 980–996. (c) Bottini, A. T.; Hilton, L. L. *Tetrahedron* **1975**, *31*, 2003–2007. (d) Bergman, R. G.; Rajadbyaksha, V. J. *J. Am. Chem. Soc.* **1970**, *92*, 2163–2164.
6. Balci, M.; Harmandar, M. *Tetrahedron Lett.* **1984**, *25*, 237–240.
7. Tümer, F.; Taskesenligil, F.; Balci, M. *J. Org. Chem.* **2001**, *66*, 3806–3810.
8. Taskesenligil, Y.; Kashyap, R. P.; Watson, W. H.; Balci, M. *J. Org. Chem.* **1993**, *58*, 3216–3218.
9. Tümer, F.; Taskesenligil, Y.; Balci, M. *Tetrahedron* **1999**, *55*, 10771–10778.
10. (a) Sustman, R.; Gellert, R. W. *Chem. Ber.* **1978**, *111*, 42–55. (b) Wege, D. *J. Org. Chem.* **1990**, *55*, 1667–1669.
11. Kitahonoki, K.; Takano, Y.; Matsuura, A.; Kotera, K. *Tetrahedron* **1969**, *25*, 335–353.
12. Woodward, R. B.; Hoffmann, R. *The Conservation of Orbital Symmetry*; Chemie: Weinheim, 1970.

13. Schlosser, M.; Heinz, G. *Chem. Ber.* **1971**, *104*, 1934–1941.
14. Mich, T. F.; Nienhouse, E. J.; Farina, T. E.; Tuferiello, J. J. *J. Chem. Educ.* **1968**, *45*, 272–274.
15. (a) Doering, W. v. E.; LaFlamme, P. M. *Tetrahedron* **1958**, *2*, 75–85. (b) Moore, W. R.; Ward, H. R. *J. Org. Chem.* **1960**, *25*, 2073–2074. (c) Moore, W. R.; Ward, H. R.; Merrit, R. F. *J. Am. Chem. Soc.* **1961**, *83*, 2019–2020. (d) Skattebol, L. *Acta Chem. Scand.* **1963**, *17*, 1683–1693.