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Unexpected diastereoselective one-pot assembly of hexahydroazulenones from 2-alkylcyclohexanones and arylacetylenes in KOH/DMSO suspension

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ABSTRACT

2-Alkylcyclohexanones react with arylacetylenes (KOH/DMSO, 100 °C, 1 h) to afford unexpectedly hexahydroazulenones in 34–50% yields and ca. 100% diastereoselectivity (instead of the expected acetylenic alcohols), the minor products being isomeric arylethenyl ketones.

The development of new C—C bond forming reactions remains a fundamental challenge of organic chemistry.[1] Particular endeavors in this area are directed to discover reactions that allow the creation of several carbon—carbon bonds in one synthetic operation leading to the construction of important polycyclic structures with desired regio- and stereochemical control.[1a] Among such structures the azulene scaffold, especially that of azulenone, has attracted attention due to its theoretical,[2] biological[3] and pharmaceutical[4] significance. These structures are abundant in nature and represent rewarding synthetic objectives. Approaches toward enantio- or diastereoselective construction of the azulenone skeleton are limited by the intramolecular cyclization of β-aryl-α-diazaketones (Büchner reaction) in the presence of rhodium complexes[5] or rhodium salts,[6] and by the cycloaddition of 2-phenyl-2-acylketenes with alkynyl ethers.[2a] In addition, the base-catalyzed condensation of cyclopentadienes with phorone to give hexahydroazulenones containing no asymmetric carbons has been reported.[7]

In this Letter, we report our serendipitous finding that 2-alkylcyclohexanones **1** and **2** when allowed to react with arylacetylenes **3–6** in KOH/DMSO suspension (alkylcyclohexanone:arylacetylene:KOH molar ratio = 1:1:1) at 100 °C for 1 h gave, instead of the expected acetylenic alcohols **7**,[8] (3a*R*,8a*R*)-8a-alkyl-6,7-diaryl-1,2,3,3a,8,8a-hexahydroazulen-4(5*H*)-ones **8–13** in 34–50% yield along with a mixture of minor products, arylethenyl ketones **14–19**, in trace amounts in 24% yield (Scheme 1).[9]

The structures of azulenones **8–13** follow unambiguously from single-crystal X-ray diffraction of compound **8** (Fig. 1) as a typical representative of this series.[10] The cycloheptene counterpart of molecule **8** has the bath conformation. The cyclopentane ring adopts the sofa conformation with the C(7) atom deviated by 0.61 Å from the average, almost an ideal plane formed by the remaining carbon atoms. The dihedral angle between the averaged planes of the benzene rings is 124.0°. Thus, the X-ray data provide evidence that azulenones **8–13** are formed stereoselectively as single diastereomers.

The ^{1}H and ^{13}C NMR spectra of compounds **8–13** were in agreement with the azulenone structure. In the ^{1}H NMR spectra of azulenones **8–13**, doublets due to the 5-CH_2 (3.36–3.40 and 3.69–3.71 ppm, ^2J = 18.3 Hz) and 8-CH_2 (2.54–2.55 and 2.75–2.79 ppm, ^2J = 14.2 Hz) protons were present. The CH_2 protons (positions 1, 2 and 3) were represented as complex multiplets (1.39–2.31 ppm). Assignments of the ^{13}C signals were based on 2D HSQC and HMBC spectra (Fig. 2). The configurations of carbon atoms 8a and 3a were determined using 2D NOESY spectra, where a correlation between the alkyl group protons and H3a was observed.

Ketones **14–19** are the products of C-vinylation of 2-alkylcyclohexanones **1** and **2**. Ketones **14a–c**, which were identified by ^{1}H NMR, GLC, and MS, were obtained in the ratio **14a**:**14b**:**14c** = 3:1:2, were formed via vinylation of 2-methylcyclohexanone (**1**) at positions 2 and 6.

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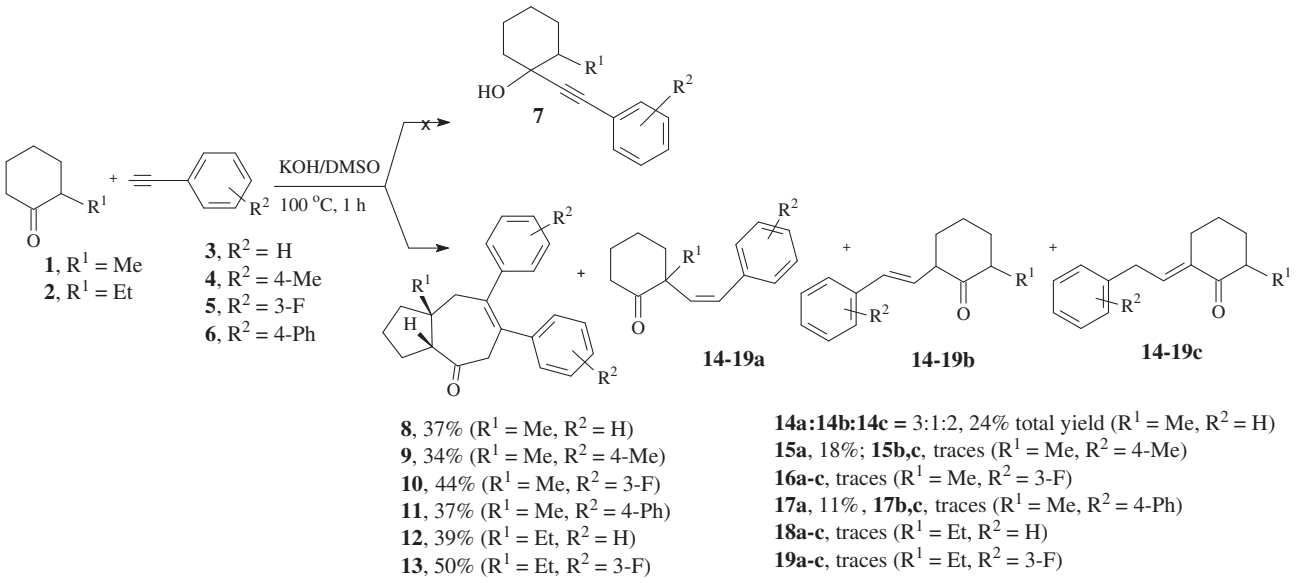

8, 37% (R^1 = Me, R^2 = H)
9, 34% (R^1 = Me, R^2 = 4-Me)
10, 44% (R^1 = Me, R^2 = 3-F)
11, 37% (R^1 = Me, R^2 = 4-Ph)
12, 39% (R^1 = Et, R^2 = H)
13, 50% (R^1 = Et, R^2 = 3-F)

14a:14b:14c = 3:1:2, 24% total yield (R^1 = Me, R^2 = H)
15a, 18%; **15b,c**, traces (R^1 = Me, R^2 = 4-Me)
16a-c, traces (R^1 = Me, R^2 = 3-F)
17a, 11%, **17b,c**, traces (R^1 = Me, R^2 = 4-Ph)
18a-c, traces (R^1 = Et, R^2 = H)
19a-c, traces (R^1 = Et, R^2 = 3-F)

Scheme 1. Reaction of 2-alkylcyclohexanones **1** and **2** with arylacetylenes **3**–**6** in KOH/DMSO suspension.

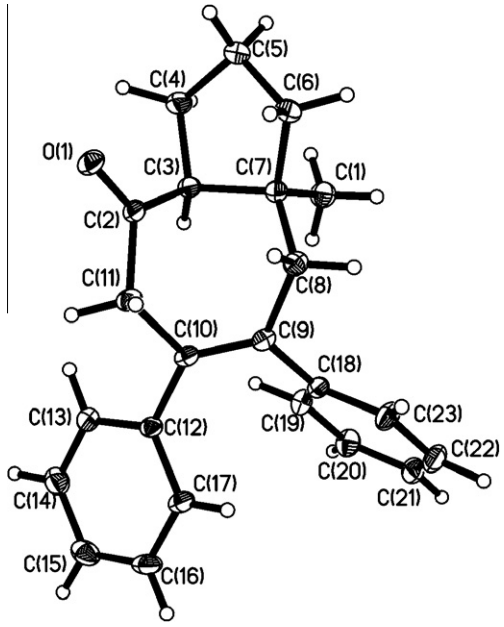

Figure 1. X-ray structure of azulenone **8**.

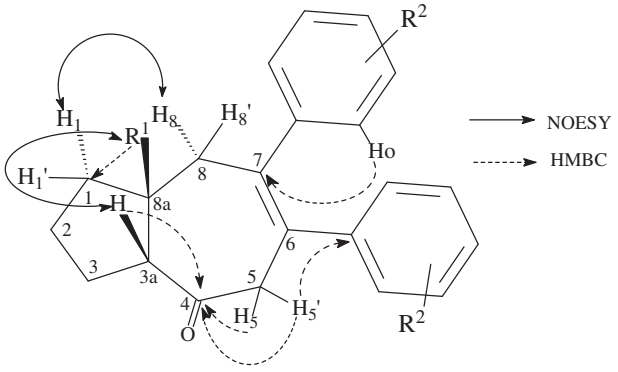

Figure 2. Characteristic NOESY and HMBC correlations of azulenones **8**–**13**.

The yields and stereochemistry of these vinyl ketones were sensitive toward the substituents present on the starting arylacetylenes **3**–**6** (Scheme 1). With tolylacetylene (**4**) and 4-phenylphenylacetylene (**6**), only vinyl ketones **15a** and **17a** of *Z*-configuration were formed, while in the case of 3-fluorophenylacetylene (**5**), no vinyl ketone was detected.

Initial attempts to optimize the reaction (using a two-fold excess of arylacetylene, lower or higher temperature) only marginally altered the product yields and ratios, though systematic optimization may further improve the characteristics of this synthetically interesting one-pot assembly.

In conclusion, a highly unexpected diastereoselective one-pot assembly of diarylazulenones from 2-alkylcyclohexanones and arylacetylenes in KOH/DMSO suspension has been described. The process represents a new reaction which involves the formation of four C—C bonds and yields biologically and synthetically important condensed bicyclic systems in a single operation. Further investigations are intended to define the scope and limitations of the reaction by extending it to other cyclic ketones and substituted acetylenes.

Acknowledgment

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References and notes

1. (a) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624; (b) Karimi, B.; Behzadna, H.; Elhamifar, D.; Akhavan, P. F.; Esfahani, F. K. *Synthesis* **2010**, 1399; (c) Chen, X.; Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *Angew. Chem. Int. Ed.* **2009**, *48*, 5094; (d) Li, C.-J. *Acc. Chem. Res.* **2009**, *42*, 335.
2. (a) Brown, D. G.; Hoye, T. R.; Brisbois, R. G. *J. Org. Chem.* **1998**, *63*, 1630; (b) Wang, H.; Michalak, K.; Michalak, M.; Jimenez-Oses, G.; Wicha, J.; Houk, K. N. *J. Org. Chem.* **2010**, *75*, 762.
3. Epstein, O. L.; Cha, J. K. *Angew. Chem. Int. Ed.* **2005**, *44*, 121.
4. (a) Fujiwara, M.; Ijichi, K.; Tokuhisa, K.; Katsuura, K.; Wang, G.-Y.-S.; Uemura, D.; Shigeta, S.; Konno, K.; Yokota, T.; Baba, M. *Antiviral Chem. Chemother.* **1996**, *7*, 230; (b) Fujiwara, M.; Ijichi, K.; Tokuhisa, K.; Katsuura, K.; Shigeta, S.; Konno, K.; Wang, G. Y. S.; Uemura, D.; Yokota, T.; Baba, M. *Antimicrob. Agents Chemother.* **1996**, *40*, 271.
5. O'Keeffe, S.; Harrington, F.; Maguire, A. R. *Synlett* **2007**, 2367.
6. (a) Maguire, A. R.; O'Leary, P.; Harrington, F.; Lawrence, S. E.; Blake, A. J. *J. Org. Chem.* **2001**, *66*, 7166; (b) Maguire, A. R.; Buckley, N. R.; O'Leary, P.; Ferguson, G. *J. Chem. Soc., Perkin Trans. 1* **1998**, 4077; (c) Padwa, A.; Krumpe, K. E.; Gareau, Y.; Chiacchiot, U. *J. Org. Chem.* **1991**, *56*, 2523.

7. Ivchenko, C. B.; Ivchenko, P. V.; Nifant'ev, I. E.; Kashulin, L. A.; Taidakov, L. V.; Kuz'mina, L. G. *Russ. Chem. Bull.* **2000**, *49*, 724.
8. (a) Favorsky, A. E. *Zh. Ross. Khim. Obshch.* **1906**, *37*, 643; (b) Smith, M.; March, J. *March's Advanced Organic Chemistry*, 6th ed.; Wiley: New York, 2007. p 1360.
9. *General procedure for the synthesis of azulenones* **8–13** [*an example of the reaction of 2-methylcyclohexanone* (**1**) *with phenylacetylene* **3**]: A mixture of ketone 1 (2.00 g, 17.8 mmol), phenylacetylene 3 (1.82 g, 17.8 mmol), and KOH·0.5H_2O (1.16 g, 17.8 mmol) in DMSO (20 mL) was heated (100 °C) and stirred for 1 h. The reaction mixture, after cooling (20–22 °C), was diluted with H_2O (50 mL), neutralized (NH_4Cl), and extracted with Et_2O (10 mL × 4). The organic extract obtained was washed with H_2O (10 mL × 3) and dried (K_2CO_3) overnight. After removal of the solvent, the crude residue (3.34 g) was purified by column chromatography (SiO_2, benzene) to give azulenone 8 (2.09 g, 37%) and a mixture of vinyl ketones 14a–c (0.92 g, 24%).
Azulenones **9–13** and ketones **15a,17a** were obtained analogously.
(3aR,8aR)-8a-Methyl-6,7-diphenyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**8**): White crystals (mp 90–92 °C). Anal. Calcd for $C_{23}H_{24}O$ (316.44): C, 87.30; H, 7.64. Found: C, 87.38; H, 7.24. IR (KBr, cm^{-1}) ν_{max}: 3080, 3057, 2926, 2864, 1696, 1599, 1492, 1442, 1379, 1338, 1278, 1255, 1209, 1152, 1134, 1120, 1068, 1030, 975, 912, 764, 700, 565, 530, 502. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.10–6.97 (m, 10H, H_o, $H_{o'}$, H_m, $H_{m'}$, H_p, $H_{p'}$), 3.71 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5), 3.40 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5′), 3.00–2.98 (m, 1H, H3a), 2.78 (d, 1H, $^2J_{H8-H8'}$ = 14.2 Hz, H8), 2.55 (d, 1H, $^2J_{H8-H8'}$ = 14.2 Hz, H8′), 2.28, 1.77 (m, 2H, H3, H3′), 1.87, 1.72 (m, 2H, H2, H2′), 1.50, 1.39 (m, 2H, H1, H1′), 1.05 (s, 3H, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 210.6 (C=O), 144.4 ($C_{i'}$), 142.7 (C_i), 139.0 (C7), 132.9 (C6), 129.4 (C_m, $C_{m'}$), 128.0, 127.8 (C_o, $C_{o'}$), 126.4, 126.1 (C_p, $C_{p'}$), 60.9 (C3a), 51.9 (C8a), 51.2 (C5), 45.3 (C8), 39.3 (C1), 26.9 (C8a-*Me*), 24.9 (C3), 23.3 (C2).
(3aR,8aR)-8a-Methyl-6,7-di-p-tolyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**9**): Yield 34%. White crystals (mp 86–88 °C). Anal. Calcd for $C_{25}H_{28}O$ (344.49): C, 87.16; H, 8.19. Found: C, 87.14; H, 8.27. IR (KBr, cm^{-1}) ν_{max}: 3019, 2956, 2923, 2861, 1703, 1511, 1488, 1460, 1450, 1404, 1377, 1344, 1273, 1212, 1182, 1131, 1076, 1042, 957, 949, 817, 724. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 6.94–6.86 (m, 8H, H_o, $H_{o'}$, H_m, $H_{m'}$), 3.69 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5), 3.37 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5′), 2.99–2.97 (m, 1H, H3a), 2.75 (d, 1H, $^2J_{H8-H8'}$ = 14.0 Hz, H8), 2.55 (d, 1H, $^2J_{H8-H8'}$ = 14.0 Hz, H8′), 2.31, 1.78 (m, 2H, H3, H3′), 2.27 (s, 6H, C_p-*Me*, $C_{p'}$-*Me*), 1.92, 1.76 (m, 2H, H2, H2′), 1.53, 1.43 (m, 2H, H1, H1′), 1.05 (s, 3H, C8a-*Me*). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 210.4 (C=O), 141.4 ($C_{i'}$), 139.9 (C_i), 138.2 (C7), 135.7, 135.3 (C_p, $C_{p'}$), 132.2 (C6), 129.2 (C_m, $C_{m'}$), 128.7, 127.6 (C_o, $C_{o'}$), 60.5 (C3a), 51.8 (C8a), 51.5 (C5), 45.4 (C8), 39.5 (C1), 27.3 (C8a-*Me*), 25.1 (C3), 23.5 (C2), 21.4 (C_p-*Me*, $C_{p'}$-*Me*).
(3aR,8aR)-6,7-Bis(3-fluorophenyl)-8a-methyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**10**): Yield 44%. Yellow oil. Anal. Calcd for $C_{23}H_{22}F_2O$ (352.42): C, 78.39; H, 6.29; F, 10.78. Found: C, 78.33; H, 6.25; F, 10.81. IR (film, cm^{-1}) ν_{max}: 3068, 2960, 2937, 2868, 1704, 1610, 1582, 1485, 1462, 1437, 1343, 1265, 1191, 1131, 1075, 1001, 973, 907, 872, 785, 703, 522. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.10–6.71 (m, 8H, H_o, $H_{o'}$, H_m, $H_{m'}$, H_p, $H_{p'}$), 3.69 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5), 3.36 (d, 1H, $^2J_{H5-H5'}$ = 18.3 Hz, H5′), 3.00–2.98 (m, 1H, H3a), 2.79 (d, 1H, $^2J_{H8-H8'}$ = 13.9 Hz, H8), 2.54 (d, 1H, $^2J_{H8-H8'}$ = 13.9 Hz, H8′), 2.28, 1.78 (m, 2H, H3, H3′), 1.92, 1.75 (m, 2H, H2, H2′), 1.51, 1.44 (m, 2H, H1, H1′), 1.08 (s, 3H, C8a-*Me*). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 208.9 (C=O), 162.5 (d, J = 246.5 Hz, C_3, $C_{3'}$), 146.2 (d, J = 7.3 Hz, $C_{1'}$), 144.4 (d, J = 7.3 Hz, C_1), 138.7 (d, J = 2.2 Hz, C7), 133.0 (d, J = 2.2 Hz, C6), 129.6, 129.5 (d, J = 7.3 Hz, C_5, $C_{5'}$), 125.0 (d, J = 2.9 Hz, C_6, $C_{6'}$), 116.1 (d, J = 21.3 Hz, C_2, $C_{2'}$), 113.8, 113.5 (d, J = 21.3 Hz, C_4, $C_{4'}$), 60.8 (C3a), 51.8 (C8a), 50.9 (C5), 45.2 (C8), 39.3 (C1), 27.0 (C8a-*Me*), 24.9 (C3), 23.3 (C2).
(3aR,8aR)-6,7-Di(biphenyl-4-yl)-8a-methyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**11**): Yield 37%. White crystals (mp 162 °C). Anal. Calcd for $C_{35}H_{32}O$ (468.63): C, 89.70; H, 6.88. Found: 89.68; H, 6.91. IR (film, cm^{-1}) ν_{max}: 3029, 2960, 2932, 2865, 1701, 1602, 1518, 1486, 1461, 1448, 1403, 1377, 1343, 1262, 1130, 1076, 1007, 909, 840, 766, 733, 697, 648. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.49–7.47, 7.34–7.30, 7.08–7.05 (m, 18H, H_{arom}), 3.73 (d, 1H, $^2J_{H5-H5'}$ = 18.2 Hz, H5), 3.42 (d, 1H, $^2J_{H5-H5'}$ = 18.2 Hz, H5′), 2.99–2.96 (m, 1H, H3a), 2.79 (d, 1H, $^2J_{H8-H8'}$ = 13.9 Hz, H8), 2.59 (d, 1H, $^2J_{H8-H8'}$ = 13.9 Hz, H8′), 2.26, 1.83 (m, 2H, H3, H3′), 1.87, 1.71 (m, 2H, H2, H2′), 1.52, 1.42 (m, 2H, H1, H1′), 1.06 (s, 3H, C8a-*Me*). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 210.4 (C=O), 143.3–126.5 ($24C_{arom}$), 139.1 (C7), 132.6 (C6), 61.0 (C3a), 51.9 (C8a), 51.0 (C5), 45.3 (C8), 39.3 (C1), 27.0 (C8a-*Me*), 25.0 (C3), 23.2 (C2).
(3aR,8aR)-8a-Ethyl-6,7-diphenyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**12**):Yield 39%. White crystals (mp 91–93 °C). Anal. Calcd for $C_{24}H_{26}O$ (330.46): C, 87.23; H, 7.93. Found: C, 87.29; H, 8.05. IR (film, cm^{-1}) ν_{max}: 3055, 3021, 2961, 2938, 2875, 1701, 1599, 1492, 1460, 1443, 1380, 1345, 1265, 1130, 1069, 1029, 965, 911, 765, 700, 544. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.09–6.96 (m, 10H, H_o, $H_{o'}$, H_m, $H_{m'}$, H_p, $H_{p'}$), 3.72 (d, 1H, $^2J_{H5-H5'}$ = 18.1 Hz, H5), 3.40 (d, 1H, $^2J_{H5-H5'}$ = 18.1 Hz, H5′), 2.97–2.94 (m, 1H, H3a), 2.69 (d, 1H, $^2J_{H8-H8'}$ = 14.0 Hz, H8), 2.62 (d, 1H, $^2J_{H8-H8'}$ = 14.0 Hz, H8′), 2.28, 1.80 (m, 2H, H3, H3′), 1.89, 1.74 (m, 2H, H2, H2′), 1.64, 1.53 (m, 2H, H1, H1′), 1.34, 0.90 (m, 2H, CH_2-Me), 0.45 (t, 3H, $^3J_{CH2-Me}$ = 7.7 Hz, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 210.8 (C=O), 144.0 ($C_{i'}$), 142.5 (C_i), 138.7 (C7), 132.8 (C6), 129.4, 129.2 (C_m, $C_{m'}$), 127.9, 127.8 (C_o, $C_{o'}$), 126.3, 126.0 (C_p, $C_{p'}$), 61.4 (C3a), 55.5 (C8a), 50.9 (C5), 41.0 (C8), 34.9 (C1), 30.2 (C8a-CH_2-Me), 25.4 (C3), 23.3 (C2), 8.2 (C8a-CH_2-*Me*).
(3aR,8aR)-6,7-Bis(3-fluorophenyl)-8a-ethyl-1,2,3,3a,8,8a-hexahydroazulen-4(5H)-one (**13**): Yield 50%. Yellow oil. Anal. Calcd for $C_{24}H_{24}F_2O$ (366.44): C, 78.66; H, 6.60; F, 10.37. Found: C, 78.87; H, 6.54; F, 10.21. IR (film, cm^{-1}) ν_{max}: 3069, 3037, 2964, 2936, 2877, 2866, 1703, 1610, 1582, 1485, 1461, 1436, 1381, 1347, 1265, 1153, 1076, 964, 911, 872, 785, 734, 702, 648, 522. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.02–6.68 (m, 8H, H_o, $H_{o'}$, H_m, $H_{m'}$, H_p, $H_{p'}$), 3.69 (d, 1H, $^2J_{H5-H5'}$ = 18.0 Hz, H5), 3.34 (d, 1H, $^2J_{H5-H5'}$ = 18.0 Hz, H5′), 2.94–2.91 (m, 1H, H3a), 2.63 (m, 2H, H8, H8′), 2.27, 1.73 (m, 2H, H3, H3′), 1.90, 1.67 (m, 2H, H2, H2′), 1.53, 1.38 (m, 2H, H1, H1′), 1.24, 0.84 (m, 2H, C8a-CH_2-Me), 0.45 (t, 3H, $^3J_{CH2-Me}$ = 7.4 Hz, C8a-CH_2-*Me*). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 210.8 (C=O), 163.4 (d, J = 246.7 Hz, C_3, $C_{3'}$), 146.8 (d, J = 7.6 Hz, $C_{1'}$), 145.2 (d, J = 7.6 Hz, C_1), 139.4 (C7), 133.7 (C6), 130.5, 130.4 (d, J = 8.4 Hz, C_5, $C_{5'}$), 125.9, 125.8 (d, J = 2.7 Hz, C_6, $C_{6'}$), 117.0, 116.8 (d, J = 21.7 Hz, C_2, $C_{2'}$), 114.6, 114.3 (d, J = 21.3 Hz, C_4, $C_{4'}$), 62.3 (C3a), 56.4 (C8a), 51.5 (C5), 41.7 (C8), 35.8 (C1), 31.0 (C8a-CH_2-Me), 26.3 (C3), 24.2 (C2), 9.2 (C8a-CH_2-*Me*).
Vinyl ketones **14a–c** *as a mixture*: Yield 24%. Yellow oil. Anal. Calcd for $C_{15}H_{18}O$ (214.30): C, 84.07; H, 8.47. Found: C, 84.33; H, 8.61. IR (film, cm^{-1}) ν_{max}: 3058, 3026, 2931, 2861, 1949, 1776, 1707, 1616, 1601, 1494, 1450, 1373, 1309, 1232, 1144, 1126, 1074, 1029, 966, 764, 748, 699. ^1H NMR (400.13 MHz, $CDCl_3$, ppm) for **14a**: δ 7.16–7.14 (m, 2H, H_m), 7.12–7.10 (m, 1H, H_p), 7.04–7.02 (m, 2H, H_o), 6.51 (d, 1H, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, H_α), 5.64 (d, 1H, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, H_β), 2.26, 1.82 (m, 2H, H6, H6′), 1.93, 1.45 (m, 2H, H3, H3′), 1.85, 1.48 (m, 2H, H5, H5′), 1.75, 1.53 (m, 2H, H4, H4′), 1.22 (s, 3H, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm) for **14a**: δ 213.3 (C=O), 137.1 (C_α), 136.3 (C_i), 131.0 (C_β), 128.8 (C_o), 127.9 (C_m), 127.8 (C_p), 52.1 (C2), 44.9 (C3), 39.8 (C6), 29.1 (C5), 24.3 (Me), 22.2 (C4). ^1H NMR (400.13 MHz, $CDCl_3$, ppm) for **14b**: δ 7.30 (m, 2H, H_o), 7.21 (m, 1H, H_p), 7.19 (m, 2H, H_m), 6.42 (dd, 1H, $^3J_{H\alpha-H\beta}$ = 16.1 Hz, $^3J_{H\alpha-H6}$ = 7.3 Hz, Hα), 6.22 (d, 1H, $^3J_{H\alpha-H\beta}$ = 16.1 Hz, H_β), 3.07 (m, 1H, H6), 2.38 (m, 1H, H2), 2.14, 1.60 (m, 2H, H5, H5′), 2.06, 1.39 (m, 2H, H3, H3′), 1.62, 1.25 (m, 2H, H4, H4′), 0.99 (d, 3H, ^3J = 6.5 Hz, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm) for **14b**: δ 211.3 (C=O), 137.2 (C_i), 130.9 (C_β), 128.5 (C_m), 128.1 (C_α), 127.6 (C_p), 126.3 (C_o), 54.0 (C6), 45.5 (C2), 36.9 (C3), 35.8 (C5), 25.3 (C4), 14.6 (Me). ^1H NMR (400.13 MHz, $CDCl_3$, ppm) for **14c**: δ 7.23 (m, 2H, H_m), 7.18 (m, 1H, H_p), 7.10 (m, 2H, H_o), 6.60 (m, 1H, H_α), 3.37 (m, 2H, CH_2-Ph), 2.28 (m, 1H, H2), 2.75, 2.35 (m, 2H, H5), 2.27, 1.72 (m, 2H, H4), 1.97, 1.48 (m, 2H, H3), 1.09 (d, 3H, ^3J = 6.4 Hz, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm) for **14c**: δ 202.9 (C=O), 138.7 (C_i), 137.3 (C6), 135.8, (C_α), 128.7 (C_m), 128.6 (C_o), 125.9 (C_p), 44.1 (C2), 34.0 (CH_2-Ph), 31.9 (C3), 27.2 (C5), 24.7 (C4), 16.2 (Me).
(Z)-2-Methyl-2-(4-methylstyryl)cyclohexanone (**15a**): Yield 18%. Yellow oil. Anal. Calcd for $C_{16}H_{20}O$ (228.33): C, 84.16; H, 8.83. Found: C, 84.11; H, 8.91. IR (film, cm^{-1}) ν_{max}: 3020, 2930, 2861, 1709, 1610, 1512, 1490, 1449, 1407, 1373, 1337, 1308, 1254, 1212, 1182, 1148, 1117, 1084, 1040, 1021, 980, 960, 950, 949, 818, 741, 533.^1H NMR (400.13 MHz, $CDCl_3$, ppm) δ 7.04–7.01 (m, 2H, H_m), 6.97–6.95 (m, 2H, H_o), 6.52 (d, 1H, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, H_β), 5.66 (d, 1H, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, H_α), 2.31, 1.86 (m, 2H, H6, H6′), 1.98, 1.49 (m, 2H, H3, H3′), 1.91, 1.51 (m, 2H, H5, H5′), 1.77, 1.57 (m, 2H, H4, H4′), 2.29 (s, 3H, C_p-*Me*), 1.25 (s, 3H, C2-*Me*). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm) δ 214.0 (C=O), 137.0 (C_p), 136.7 (C_α), 133.2 (C_i), 131.1 (C_β), 128.9 (C_o), 128.7 (C_m), 52.4 (C2), 45.2 (C3), 40.0 (C6), 29.3 (C5), 24.3 (Me), 22.3 (C4), 21.3 (C_p-*Me*).
(Z)-2-[2-(Biphenyl-4-yl)vinyl]-2-methylcyclohexanone (**17a**) *in a mixture with* **11**: Yield 11%. White powder. ^1H NMR (400.13 MHz, $CDCl_3$, ppm): δ 7.56–7.55, 7.48–7.47, 7.40–7.38, 7.28–7.23, 7.16–7.14 (m, 9H, H_{arom}), 6.56 (d, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, 1H; H_β), 5.73 (d, $^3J_{H\alpha-H\beta}$ = 12.5 Hz, 1H; H_α), 2.27, 1.83 (m, 2H; H6,6′) 1.97, 1.44 (m, 2H; H3,3′), 1.86, 1.49 (m, 2H; H5,5′), 1.79, 1.53 (m, 2H; H4,4′), 1.28 (s, 3H, Me). ^{13}C NMR (101.61 MHz, $CDCl_3$, ppm): δ 212.4 (C=O), 140.9, 140.0, 135.3, 129.1, 128.8, 127.7, 127.4, 127.2, 127.0 ($12C_{arom}$), 137.5 (Cα), 130.6 (Cβ), 54.3 (C2), 45.7 (C3), 37.1 (C6), 29.8 (C5), 22.7 (C4), 25.4 (C2-*Me*).
10. Atomic coordinates, bond lengths, bond angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre (CCDC). These data can be obtained free of charge via www.ccdc.cam.uk.conts/retrieving.html or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44 1223 336 033; e-mail: deposit@ccdc.cam.ac.uk). Any request to the CCDC for data should quote the full literature citation and CCDC reference number CCDC 826323.