ARTICLE

OBC
www.rsc.org/obc

Reaction of azulenes with 1-trifluoromethanesulfonylpyridinium trifluoromethanesulfonate (TPT) and synthesis of the parent azulene

Shunji Ito,[a] Ryuji Yokoyama,[a] Tetsuo Okujima,[a] Tomomi Terazono,[a] Takahiro Kubo,[a] Akio Tajiri,[b] Masataka Watanabe[c] and Noboru Morita *[a]

[a] *Department of Chemistry, Graduate School of Science, Tohoku University, Sendai 980-8578, Japan. E-mail: morita@funorg.chem.tohoku.ac.jp; Fax: +81 22 217 7714; Tel: +81 22 217 7714*

[b] *Department of Materials Science, Faculty of Science and Technology, Hirosaki University, Hirosaki 036-8561, Japan*

[c] *Institute of Multidisiplinary Research for Advanced Materials, Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan*

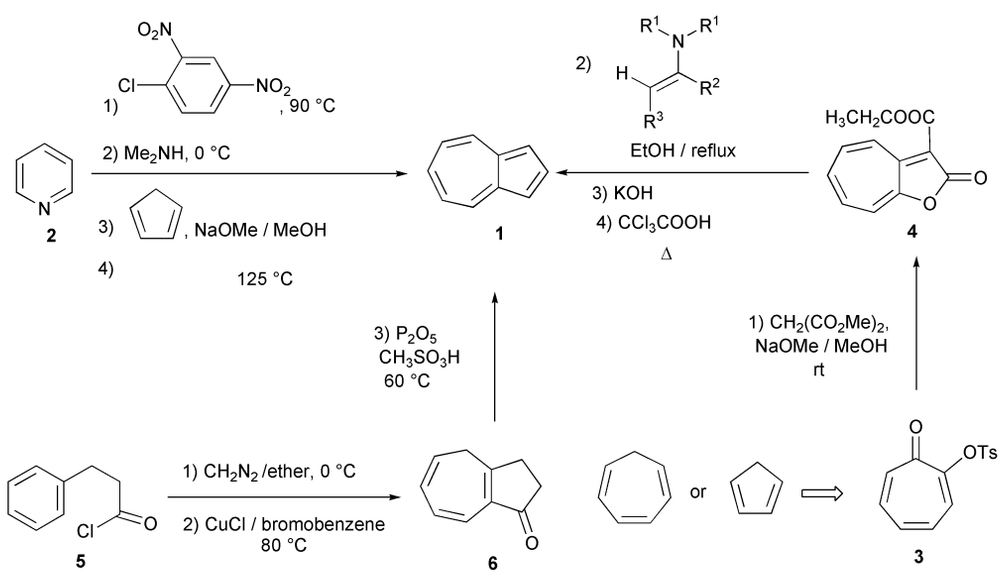
Received 20th December 2002, Accepted 7th April 2003
First published as an Advance Article on the web 23rd April 2003

2-Azulenyl trifluoromethanesulfonate was prepared by the reaction of 2-hydroxyazulene with trifluoromethanesulfonic anhydride in the presence of triethylamine as a base. Under the use of pyridine, 1-trifluoromethanesulfonylpyridinium trifluoromethanesulfonate further reacted with 2-azulenyl trifluoromethanesulfonate to give 1-(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulenyl trifluoromethanesulfonate. Moreover, we found that azulenes also reacted with 1-trifluoromethanesulfonylpyridinium trifluoromethanesulfonate to give 4-(1-azulenyl)-1,4-dihydropyridine derivatives and 6-(1-azulenyl)-1-trifluoromethanesulfonyl-1-aza-hexa-1,3,5-triene depending on the reaction conditions. 2-Azulenyl trifluoromethanesulfonate was converted finally into the parent azulene in excellent yield by palladium-catalyzed reduction using formic acid as a reducing reagent.

Introduction

Azulene and its derivatives are important building blocks for syntheses of medicines[1a,b] and a variety of extended π-electronic systems such as super-stabilized azulenylmethyl carbocation,[1c] azulenylaromatic compounds,[1d–h] calixazulene,[1i,j] azuliporphyrin,[1k] azulenocoronands,[1l] *etc*. For the purpose of the preparation of these compounds, azulene remains relatively difficult to be synthesized. The exploitation of a facile synthetic method for azulene from cycloheptatriene is of current interest. Since Plattner's original synthesis of azulene,[2] a wide variety of synthetic methods for azulene and its derivatives have been reported.[3] There are three efficient approaches to the parent hydrocarbon. One of them is the Ziegler–Hafner method[1j,4] which employs pyridine and cyclopentadiene as the starting materials. The Nozoe[5]–Yasunami method[6] is a process *via* tropolone and also 2*H*-cyclohepta[*b*]furan-2-ones using cycloheptatriene or cyclopentadiene as the starting material. However, the synthesis of azulenes by way of tropolone needs at least 7 steps.[6] The latest method by Scott consists of diazomethylation and the intramolecular cycloaddition of 3-phenylpropanoyl chloride starting from cinnamic acid, followed by dehydration[7] as shown in Scheme 1.

Recently, we have reported the synthesis of 2*H*-cyclohepta[*b*]furan-2-ones[8] and 2-hydroxyazulene[9] from the cycloadduct of cycloheptatriene with dichloroketene.[9,10] One target in our series of these studies is the synthesis of azulene itself starting from commercially available cycloheptatriene, which

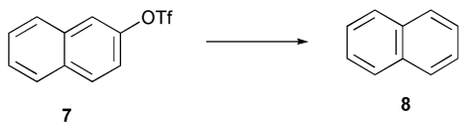


Scheme 1

DOI: 10.1039/b212484j

could be utilized as a source for the seven-membered ring of azulenes.

On the other hand, Ortar reported the reduction of naphthyl triflate **7** into naphthalene **8** in excellent yield using a palladium-catalyzed reaction,[11] as shown in Scheme 2.



Scheme 2

Therefore, we planned to apply this method to 2-hydroxyazulene **9** for the preparation of azulene by way of 2-azulenyl trifluoromethanesulfonate. We report herein the reaction of azulenes with trifluoromethanesulfonic anhydride in the presence of a base and a new synthetic pathway from cycloheptatriene to azulene.

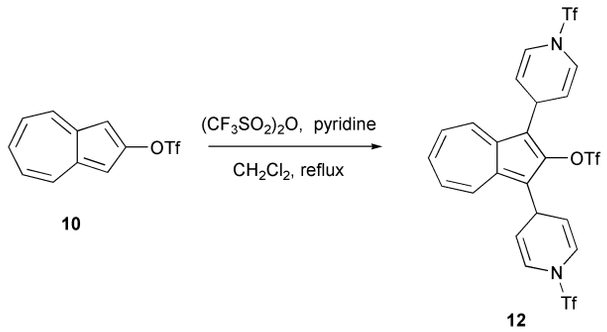
Results and discussion

Initially, in order to prepare 2-azulenyl trifluoromethanesulfonate **10** we examined the reaction of 2-hydroxyazulene **9** with trifluoromethanesulfonic anhydride in the presence of a base. The reaction of compound **9** with trifluoromethanesulfonic anhydride in CH_2Cl_2 at room temperature in the presence of triethylamine gave 2-azulenyl trifluoromethanesulfonate **10** in 95% yield. Although triethylamine gave a satisfactory result, the use of pyridine as a base afforded 1-(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulene **11** in 12% yield in addition to **10** (41%). A plausible reaction pathway for the formation of compound **11** is assumed to proceed *via* compound **10**. Indeed, the reaction of compound **10** under the same reaction conditions afforded 1-(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulen-2-yl trifluoromethanesulfonate **11** in 89% yield (Scheme 3).

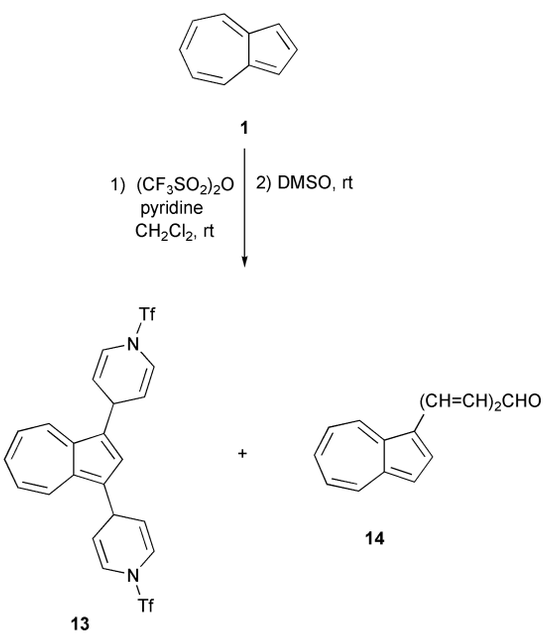
The reaction of compound **10** with a large excess of trifluoromethanesulfonic anhydride and pyridine afforded 1,3-bis(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulen-2-yl trifluoromethanesulfonate **12** in 79% yield (Scheme 4).

In contrast to 2-azulenyl triflate **10**, the reaction of the parent azulene with a large excess of trifluoromethanesulfonic anhydride in the presence of pyridine gave 1,3-bis(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulene **13**[12] and 5-azulenyl-2,4-pentadienal **14**[13,14] in 67% and 29% yields, respectively, as shown in Scheme 5.

The configuration of the alkenyl chain moiety in **14** was deduced to be all *trans* on the basis of NOE experiments as shown in Fig. 1 and also by analysis of the H–H spin-coupling constants. The coupling constants of 2-H with 3-H, 3-H with 4-H, and 4-H with 5-H were determined to be 14.9, 11.2, and 14.9 Hz, respectively.

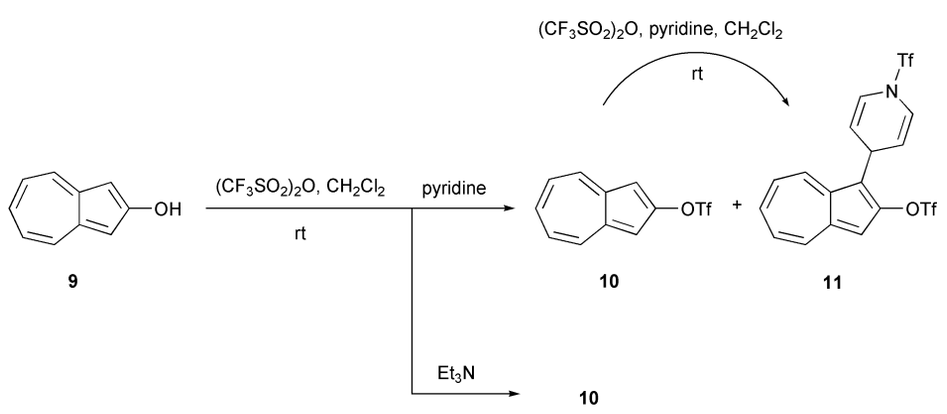


Scheme 4



Scheme 5

We investigated the conditions favoring *o*-attack in the reaction of azulene with the pyridinium salt. We found azulene gave preferentially *o*-addition and ring-opening product **16** in 67% yield when 1.2 equivalents of trifluoromethanesulfonic anhydride and pyridine were used. A plausible mechanism for this reaction would be such as shown in Scheme 6. The reaction of trifluoromethanesulfonic anhydride with pyridine forms 1-trifluoromethanesulfonylpyridinium trifluoromethanesulfonate (TPT) **15**.[15] Compound **15** is attacked by azulene at the *o*-position of the pyridine, followed by ring-opening reaction to give compound **16**, which undergoes easily hydrolysis during the work-up or purification on silica gel.

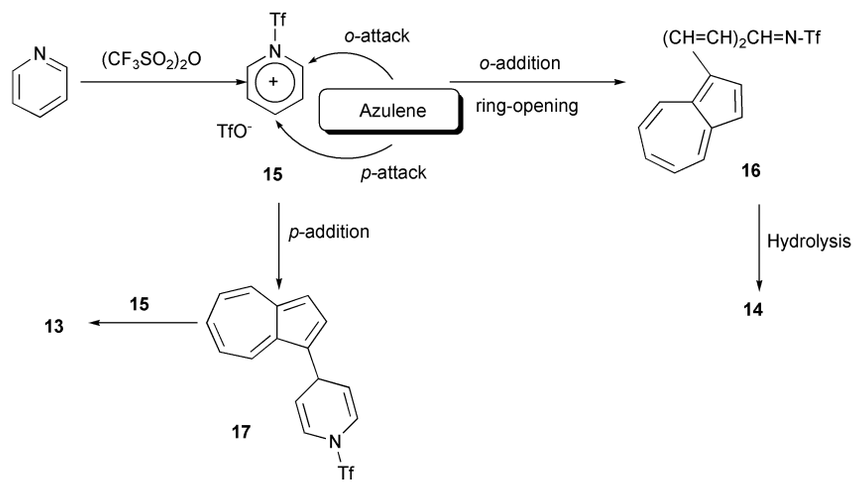


Scheme 3

Table 1 Palladium-catalyzed reduction of **10**

Entry	Pd catalyst	Ligand	Solvent	Time/h	Yield (%)[a]
1	5% $Pd(OAc)_2$	10% PPh_3	THF	4	53
2	5% $Pd(OAc)_2$	10% PPh_3	Dioxane	4	63
3	5% $Pd(OAc)_2$	10% BINAP	Dioxane	1	77
4	5% $Pd(OAc)_2$	10% P(*o*-tolyl)	Dioxane	12	80
5	2% $Pd_2(dba)_3$	5% BINAP	Dioxane	2	89
6	2% $Pd_2(dba)_3$	5% P(*o*-tolyl)	Dioxane	24	96

[a] Isolated yield.



Scheme 6

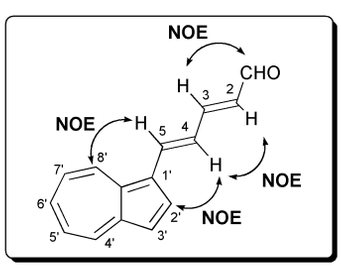
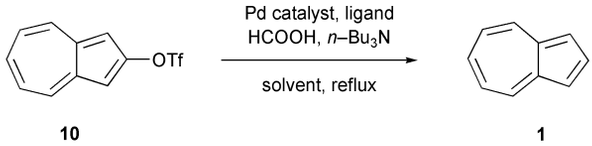


Fig. 1 NOE enhancements of **14**.

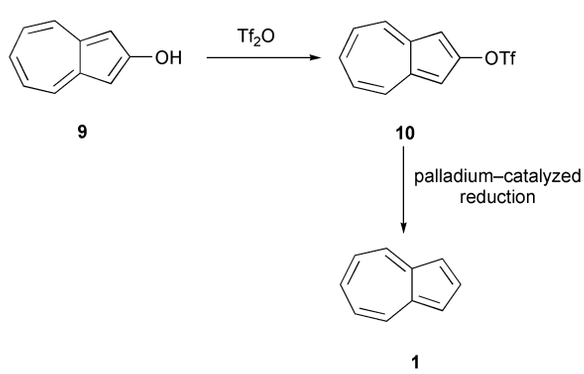
A similar reaction of azulene with a 1-benzoylpyridinium salt to give 1,3-bis(1-benzoyl-1,4-dihydropyridin-4-yl)azulene has been already reported,[12] where formation of a ring-opening product like **14** when the aromatic hydrocarbon compounds react with pyridinium salts was not reported[12] although the additions of a number of nucleophiles, such as hydroxide ions,[16] amines[4,13,16a,17] and compounds with an active methylene group,[16a,18] to pyridinium salts and subsequent ring-opening of pyridine have been reported. The fluorination and pyridinylation of azulene with several kinds of *N*-fluoropyridinium salts were also reported.[19] At least, there is no report of the nucleophilic addition of azulene to TPT, subsequent ring-opening of pyridine and hydrolysis to give 5-(azulen-1-yl)penta-2,4-dienal whose derivatives were considered to play an important role in multistep reversible redox systems,[14] dyes[14c] and bacteriorhodopsin[20] so far. Therefore, further investigation on the reaction of TPT with more reactive azulene derivatives and other aromatic compounds is now in progress.

Finally, the removal of a trifluoromethanesulfonyloxy group from **10** by a palladium-catalyzed reduction (see Scheme 7) was examined for the synthesis of the parent azulene. These results are summarized in Table 1.



Scheme 7

A better yield was observed by using dioxane instead of THF as a solvent (entries 1 and 2). Although a longer reaction time was required when P(*o*-tolyl)$_3$ was used as a phosphine ligand, the yield of the parent hydrocarbon increased (entries 2, 3, and 4). A higher yield was achieved by the use of $Pd_2(dba)_3$ as a catalyst (entries 5 and 6), where the parent azulene (**1**) was obtained in as high as 96% yield by the combination of $Pd_2(dba)_3$ and P(*o*-tolyl)$_3$ in dioxane. Therefore, 2-hydroxyazulene can be converted in excellent yield to the parent azulene (Scheme 8).



Scheme 8

Trifluoromethanesulfonylation of 2-hydroxyazulene **9** with trifluoromethanesulfonic anhydride easily proceeded in the presence of triethylamine as a base to give 2-azulenyl trifluoromethanesulfonate **10** in 95% yield. We found that azulene preferentially attacked the *p*- and/or *o*-position of TPT depending on the amount of pyridine to give 1-(1,4-dihydro-4-pyridinyl)azulene and/or 6-(1-azulenyl)-1-trifluoromethanesulfonyl-1-azahexa-1,3,5-triene, respectively. Moreover, we found palladium-catalyzed reduction of 2-azulenyl trifluoromethanesulfonate to give the parent azulene in excellent yields.

Experimental

General

Melting points were determined on a Yanagimoto micro melting point apparatus MP-S3 and are uncorrected. Mass spectra were obtained with a JEOL HX-110 or a Hitachi M-2500 instrument usually at 70 eV. IR and UV spectra were measured on a Shimadzu FTIR-8100M and a Hitachi U-3410 spectrophotometer, respectively. ^{1}H NMR spectra (^{13}C NMR spectra) were recorded on JEOL LAMBDA 400 (100 MHz) and 600 (150 MHz) spectrometers. *J* Values are given in Hz. Elemental analyses were performed at the Instrumental Analysis Center of Chemistry, Faculty of Science, Tohoku University.

Synthesis of 2-azulenyl trifluoromethanesulfonate 10 in the presence of triethylamine

To a solution of 2-hydroxyazulene **9**[9] (220 mg) and triethylamine (306 mg) in dry CH_2Cl_2 (10 mL), a solution of trifluoromethanesulfonic anhydride (630 mg) in dry CH_2Cl_2 (10 mL) was added dropwise over the period of 30 min at room temperature. After 30 minutes stirring, the reaction mixture was poured into water. The organic layer was washed with 2 M HCl and water, dried with anhydrous $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with CH_2Cl_2 to afford 2-azulenyl trifluoromethanesulfonate **10** (402 mg, 95%).

10: Purple needles, mp 58.0 °C; Found: C, 47.94; H, 2.67; S, 11.75. Calc. for $C_{11}H_7F_3O_3S$: C, 47.83; H, 2.55; S, 11.6%; ν_{max}(KBr)/cm^{-1} 1576 (m), 1536 (m), 1474 (m), 1456 (s), 1426 (s), 1399 (s), 1316 (m), 1296 (m), 1246 (s), 1215 (s), 1132 (s), 1105 (s), 972 (s), 932 (s), 897 (m), 855 (s), 841 (s), 808 (m), 797 (m), 739 (m), 718 (m), 669 (w), 604 (s), 592 (m), 581 (m), 576 (m), 567 (w), and 513 (m); λ_{max}(CH_2Cl_2)/nm (log ε) 627 sh (2.20), 574 sh (2.62), 539 (2.67), 335 (3.75), 322 (3.65), 315 sh (3.55), 280 (4.76), 273 (4.76), and 232 (4.26); δ_H (400 MHz; $CDCl_3$; Me_4Si) 8.37 (d, *J* 9.8, H-4 and H-8), 7.71 (t, *J* 10.3, H-6), 7.35 (dd, *J* 10.3, 9.8, 5-H and 7-H), and 7.19 (s, 1-H and 3-H); δ_C (100 MHz, $CDCl_3$) 153.78 (C-2), 138.32 (C-4 and C-8), 138.30 (C-6), 137.83 (C-3a and C-8a), 125.32 (C-5 and C-7), 118.84 (q, *J* = 321.2, OSO_2CF_3), and 106.24 (C-1 and C-3); *m*/*z* (EI) 276 (M^+, 62%), 143 ($M^+ - CF_3SO_2$, 7), and 115 (100).

Synthesis of triflate 10 in the presence of pyridine

A solution of trifluoromethanesulfonic anhydride (342 mg) in dry CH_2Cl_2 (10 mL) was added dropwise at room temperature to a mixture of 2-hydroxyazulene **9** (135 mg) and pyridine (246 mg) in the same solvent (10 mL) over a period of 30 min, and stirring the mixture at room temperature for another 30 min. After the reaction mixture was washed with water, 2 M HCl and saturated aqueous NaCl, the organic layer was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with CH_2Cl_2 to afford **10** (106 mg, 41%) and 1-(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)-2-azulenyl trifluoromethanesulfonate **11** (53 mg, 12%).

11: Purple needles, mp 65.0–65.5 °C; Found: C, 42.08; H, 2.40; S, 13.41. Calc. for $C_{17}H_{11}F_6NO_5S_2$: C, 41.89; H, 2.27; S, 13.16%; ν_{max}(KBr)/cm^{-1} 3130 (w), 1449 (m), 1435 (s), 1420 (s), 1397 (m), 1289 (m), 1248 (s), 1238 (s), 1225 (s), 1204 (s), 1192 (m), 1163 (s), 1140 (s), 1082 (m), 951 (m), 920 (m), 835 (s), 739 (m), 718 (w), 698 (m), 613 (m), and 583 (m); λ_{max}(CH_2Cl_2)/nm (log ε) 641 sh (2.22), 589 (2.63), 339 (3.73), 288 (4.74), and 279 (4.72); δ_H (400 MHz; $CDCl_3$; Me_4Si) 8.71 (d, *J* 9.8, 8-H), 8.56 (d, *J* 9.5, 4-H), 7.76 (dd, *J* 10.0, 9.5, 6-H), 7.37 (t, *J* 9.5, 5-H), 7.35 (dd, *J* 10.0, 9.8, 7-H), 7.26 (s, 3-H), 6.62 (dd, *J* 8.6, 3.4, 2′-H and 6′-H), 5.19 (dd, *J* 8.6, 3.4, 3′-H and 5′-H), and 4.91 (broad s, 4′-H); δ_C (100 MHz; $CDCl_3$) 151.18 (C-2), 139.04 (C-6), 138.93 (C-4), 137.88 (C-8a), 135.91 (C-8), 134.55 (C-3a), 125.73 (C-5), 124.83 (C-7), 120.85 (C-2′ and C-6′), 119.79 (q, *J* 324.0, OTf or Tf), 118.76 (q, *J* 321.0, OTf or Tf), 117.96 (C-1), 111.40 (C-3′ and C-5′), 105.14 (C-3), and 28.59 (C-4′); MS (70 eV) *m*/*z* (EI) 487 (M^+, 56%), 354 ($M^+ - CF_3SO_2$, 47), 221 (100), 204 (15), 192 (18), 165 (11), and 69 (5).

Synthesis of 1-(1-trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)-2-azulenyl trifluoromethanesulfonate 11 in the presence of pyridine

A solution of trifluoromethanesulfonic anhydride (80 mg) in dry CH_2Cl_2 (10 mL) was added dropwise at room temperature to a mixture of **10** (53.6 mg) and pyridine (43.5 mg) in the same solvent (10 mL) over a period of 15 min, and the mixture was stirred at room temperature for another 4.5 h. A solution of trifluoromethanesulfonic anhydride (195 mg) and pyridine (54.8 mg) in CH_2Cl_2 (10 mL) was added to the reaction mixture and stirred for another 2 h. After the reaction mixture was washed with water, 2 M HCl and saturated aqueous NaCl, the organic layer was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with CH_2Cl_2 to afford **11** (84.5 mg, 89%).

Reaction of 10 with a large excess of trifluoromethanesulfonic anhydride

Pyridine (90 mg, 1.1 mmol) was added to a solution of trifluoromethanesulfonic anhydride (277 mg) in dry CH_2Cl_2 (10 mL), followed by addition of **10** (50 mg) at room temperature. After heating at reflux temperature for 1 h, trifluoromethanesulfonic anhydride (271 mg) and pyridine (133 mg) were added to the reaction mixture and stirred for another 6 h. After the reaction mixture was washed with water, the organic layer was dried over anhydrous $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with ethyl acetate–hexane (1 : 4) to afford 1,3-bis(1-trifluoromethanesulfonyloxy-1,4-dihydropyridin-4-yl)-3-(trifluoromethanesulfonyloxy)azulene **12** (100 mg, 79%).

12: Blue crystals, mp 170.0 °C (decomp); Found: C, 39.83; H, 2.33; S, 13.75. Calc. for $C_{23}H_{16}F_9N_2O_7S_3$: C, 39.56; H, 2.16; S, 13.77%; ν_{max}(KBr)/cm^{-1} 3117 (w), 1684 (m), 1429 (s), 1416 (s), 1387 (m), 1348 (m), 1289 (m), 1233 (s), 1196 (s), 1161 (s), 1142 (s), 1103 (m), 1073 (m), 1073 (m), 947 (m), 932 (m), 920 (m), 909 (m), 826 (s), 770 (m), 756 (m), 743 (m), 696 (m), 683 (m), 656 (m), 592 (s), and 519 (m) cm^{-1}; λ_{max}(CH_2Cl_2)/nm (log ε) 662 sh (2.71), 600 sh (2.26), 564 (2.76), 359 (3.59), 342 (3.67), 293 (4.68), 283 (4.62), and 234 (4.55); δ_H (400 MHz; $CDCl_3$; Me_4Si) 8.71 (d, *J* 10.0, 4-H and 8-H), 7.82 (t, *J* 9.8, 6-H), 7.35 (dd, *J* 10.0, 9.8, 5-H and 7-H), 6.64 (dd, *J* 8.6, 0.8, 2′-H, 2″-H, 6′-H, and 6″-H), 5.21 (dd, *J* 8.6, 3.2, 3′-H, 3″-H, 5′-H, and 5″-H), and 4.85 (2H, m, 4′-H); δ_C (100 MHz; $CDCl_3$) 145.92 (C-2), 140.18 (C-6), 137.19 (C-4 and C-8), 135.62 (C-3a and C-8a), 125.11 (C-5 and C-7), 120.70 (C-2′, C-2″, C-6′, and C-6″), 117.82 (C-1 and C-3), 119.79 (q, *J* 324.0, OTf or Tf), 118.81 (q, *J* 320.0, Tf or OTf), 111.65 (C-3′, C-3″, C-5′, and C-5″), and 82.92 (C-4′and C-4″); *m*/*z* (FAB) 698 (M^+, 100%), 629 (5), 565 (80), 560 (15), and 501 (21).

Reaction of parent azulene with trifluoromethanesulfonic anhydride in the presence of pyridine

Pyridine (1.56 g) was added to a solution of trifluoromethanesulfonic anhydride (588 mg) in dry CH_2Cl_2 (20 mL), followed by addition of parent azulene **1** (256 mg) at room temperature. After 10 min and 30 min, trifluoromethanesulfonic anhydride (153 mg and 424 mg, respectively) was added to the reaction mixture. After stirring for another 16 h, DMSO (20 mL) was added to the reaction mixture, and stirred for another 30 min. The reaction mixture was washed with water and saturated aqueous NaCl. The organic layer was dried over anhydrous

$MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel with CH_2Cl_2 to afford 1,3-bis(trifluoromethanesulfonyl-1,4-dihydropyridin-4-yl)azulene **13** (738 mg, 67%) and 5-(azulenyl)penta-2,4-dienal **14** (122 mg, 29%).

13: Blue crystals, mp 133.5–134.0 °C; Found: C, 48.08; H, 2.83; S, 11.63. Calc. for $C_{22}H_{16}F_6N_2O_4S_2$: C, 48.00; H, 2.93; S, 11.65%; ν_{max}(KBr)/cm^{-1} 3114 (w), 3025 (w), 1686 (s), 1638 (m), 1578 (m), 1559 (m), 1429 (m), 1412 (s), 1370 (m), 1350 (m), 1287 (s), 1233 (s), 1202 (s), 1159 (s), 1138 (m), 1125 (m), 1076 (s), 1036 (m), 951 (s), 941 (s), 855 (m), 783 (m), 768 (m), 735 (m), 708 (m), 695 (s), 594 (s), 579 (s), 571 (m), and 525 (m); λ_{max} (CH_2Cl_2)/nm (log ε) 722 sh (2.00), 652 sh (2.46), 601 (2.54), 368 (3.88), 351 (3.85), 336 sh (3.59), 296 (4.76), 290 (4.73), and 287 sh (4.73); δ_H (400 MHz; $CDCl_3$; Me_4Si) 8.32 (d, *J* 9.5, 4-H and 8-H), 7.71 (s, 2-H), 7.64 (t, *J* 10.3, 6-H), 7.17 (dd, *J* 10.3, 9.5, 5-H and 7-H), 6.57 (dd, *J* 8.3, 1.2, 2′, 2″, 6′ and 6″-H), 5.270 (dd, *J* 8.3, 3.7, 3′, 3″, 5′ and 5″-H), and 4.81 (broad s); δ_C (100 MHz; $CDCl_3$) 138.60 (C-6), 137.39 (C-2), 135.31 (C-3a and C-8a), 133.35 (C-4 and C-8), 130.86 (C-1 and C-3), 122.84 (C-5 and C-7), 120.34 (C-2′, C-2″, C-6′ and C-6″), 119.78 (q, *J* 325.0, CF_3), 112.94 (C-3′, C-3″, C-5′, and C-5″), and 30.53 (C-4′ and C-4″); *m*/*z* (EI) 550 (M^+, 40%), 417 (21), 283 (64), 212 (100), 176 (9), 148 (15), and 69 (13).

14: Green plates, mp 92.5–93.5 °C (lit.[11] 94–95 °C); Found: C, 83.07; H, 6.01. Calc. for $C_{15}H_{12}O$ 1/2H_2O: C, 82.92; H, 6.03%; ν_{max}(KBr)/cm^{-1} 3034 (w), 2816 (w), 2739 (w), 1669 (s), 1599 (s), 1590 (s), 1580 (s), 1489 (m), 1456 (m), 1418 (m), 1401 (m), 1389 (m), 1283 (m), 1167 (m), 1127 (s), 1013 (m), 982 (m), 793 (m), and 743 (m); λ_{max} (CH_2Cl_2)/nm (log ε) 685 sh (2.44), 623 sh (2.74), 570 (2.79), 426 (4.32), 328 (4.29), 315 sh (4.21), 301 sh (4.09), 260 (4.20), and 228 (4.32); δ_H (400 MHz; $CDCl_3$; Me_4Si) 9.61 (d, *J* 8.1, C*H*O), 8.46 (d, *J* 9.8, 8′-H), 8.27 (d, *J* 9.8, 4′-H), 8.21 (d, *J* 4.2, 2′-H), 7.64 (t, *J* 9.8, 6′-H), 7.60 (d, *J* 14.9, 5-H), 7.42 (d, *J* 4.2, 3′-H), 7.39 (dd, *J* 14.9, 11.2, 3-H), 7.27 (t, *J* 9.8, 7′-H), 7.23 (t, *J* 9.8, 5′-H), 7.07 (dd, *J* 14.9, 11.2, 4-H), 6.25 (dd, *J* 14.9, 8.1, 2-H); δ_C (100 MHz, $CDCl_3$) 193.49 (*C*HO), 153.66 (C-3′), 144.33 (C-3a or C-8a), 138.98 (C-6), 137.82 (C-8a or C-3a), 137.56 (C-4), 134.42 (C-5′), 134.34 (C-2), 133.68 (C-8), 129.08 (C-2′), 126.09 (C-1), 125.74 (C-5), 124.73 (C-7), 123.75 (C-4′), and 120.28 (C-3); *m*/*z* (EI) 208 (M^+, 63%), 179 (100), 165 (19), 152 (20), 128 (12), 89 (15), 76 (11), and 63 (5).

Isolation of intermediate 6-(1-azulenyl)-1-trifluoromethanesulfonyl-1-azahexa-1,3,5-triene 16

A solution of pyridine (95 mg) in CH_2Cl_2 (5 mL) was added to a solution of trifluoromethanesulfonic anhydride (340 mg) in dry CH_2Cl_2 (10 mL) to give a white precipitate (TPT). A solution of azulene **1** (128 mg) in dry CH_2Cl_2 (15 mL) was added dropwise over a period of 10 min with stirring to the dispersed TPT solution at room temperature. After stirring for 10 min, the reaction mixture was carefully passed through a short silica gel column by using CH_2Cl_2 as eluant to afford 6-(1-azulenyl)-1-trifluoromethanesulfonyl-1-azahexa-1,3,5-triene **16** (228 mg, 67%).

16: Silver metallic colored crystals, mp 223.0 °C (decomp); Found: C, 56.41; H, 3.71; S, 9.54. Calc. for $C_{16}H_{12}F_3NO_2S$: C, 56.63; H, 3.56; S, 9.45%; ν_{max}(KBr)/cm^{-1} 1578 (s), 1538 (m), 1509 (s), 1487 (s), 1406 (m), 1343 (m), 1283 (m), 1209 (m), 1171 (s), 1119 (s), 1017 (m), 849 (s), and 776 (m); λ_{max} (CH_2Cl_2)/nm (log ε) 529 (5.80), 350 (5.09), 278 (5.24), and 231 (5.41); δ_H (600 MHz; $CDCl_3$; Me_4Si) 8.69 (d, *J* 10.1, 2-H), 8.56 (d, *J* 9.9, 8′-H), 8.37 (d, *J* 9.4, 4′-H), 8.27 (d, *J* 4.3, 2′-H), 7.84 (d, *J* 14.7, 6-H), 7.77 (dd, *J* 9.7, 9.6, 6′-H), 7.67 (dd, *J* 14.1, 11.7, 4-H), 7.48 (d, *J* 4.3, 3′-H), 7.45 (dd, *J* 9.9, 9.7, 7′-H), 7.40 (dd, *J* 9.6, 9.4, 5′-H), 7.18 (dd, *J* 14.7, 11.7, 5-H), 6.63 (dd, *J* 14.1, 10.1, 3-H); δ_C (125 MHz, $CDCl_3$) 178.3 (C-2), 161.4 (C-4), 146.1, 144.9, 140.3 (C-6), 140.2, 139.8 (C-6′), 138.2 (C-4′), 135.2 (C-2′), 134.1 (C-8′), 127.8 (C-5′), 126.8 (C-7′), 126.2, 123.8 (C-3 and 5), 121.8 (C-3′); *m*/*z* (EI) 339 (M^+, 33%), 206 (100), 191 (7), 178 (30), 165 (5), 152 (12), and 127 (9).

Preparation of 14 from 16 on silica gel

A solution of **16** (13 mg) in a small amount of CH_2Cl_2 was placed on the silica gel with CH_2Cl_2 for 12 h at room temperature. The solution was passed through the column chromatography to afford **14** (8 mg).

Preparation of parent azulene using palladium-catalyzed reduction of 2-azulenyl trifluoromethanesulfonate 10

A mixture of **10** (275 mg), $Pd_2(dba)_3$ (19 mg, 2.1 mol%), P(*o*-tolyl)$_3$ (16 mg), HCOOH (467 mg), and *n*-Bu_3N (1.85 g) in dioxane (100 mL) was heated at reflux temperature. After stirring at the same temperature for 24 h, the reaction mixture was poured into water and extracted with hexane. The organic layer was dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on alumina with hexane to afford parent azulene **1** (122 mg, 96%) and recovered **10** (4 mg, 1%).

References

1 (*a*) T. Yanagisawa, S. Wakabayashi, T. Tomiyama, M. Yasunami and K. Takase, *Chem. Pharm. Bull.*, 1988, **36**, 641–647; (*b*) T. Yanagisawa, K. Kosakai, T. Tomiyama, M. Yasunami and K. Takase, *Chem. Pharm. Bull.*, 1990, **38**, 3355–3358; (*c*) S. Ito, S. Kikuchi, N. Morita and T. Asao, *J. Org. Chem.*, 1999, **64**, 5815–5821; (*d*) S. Ito, H. Inabe, T. Okujima, N. Morita, M. Watanabe, N. Harada and K, Imafuku, *J. Org. Chem.*, 2001, **66**, 7090–7101; (*e*) S. Ito, A. Nomura, N. Morita, C. Kabuto, H. Kobayashi, S. Maejima, K. Fujimori and Yasunami, *J. Org. Chem.*, 2002, **67**, 7295–7302; (*f*) S. Ito, T. Okujima and N. Morita, *J. Chem. Soc., Perkin Trans. 1*, 2002, 1896–1905; (*g*) K. Kurotobi, H. Tabata, M. Miyauchi, T. Murafuji and Y. Sugihara, *Synthesis*, 2002, 1013–1016; (*h*) S. Ito, H. Inabe, N. Morita, K. Ohta, T. Kitamura and Imafuku, *J. Am. Chem. Soc.*, 2003, **125**, 1669–1680; (*i*) T. Asao, S. Ito and N. Morita, *Tetrahedron Lett*, 1988, **29**, 2839–2842; (*j*) D. A. Colby and T. D. Lash, *J. Org. Chem.*, 2002, **67**, 1031–1033; (*k*) D. A. Colby and T. D. Lash, *Chem. Eur. J.*, 2002, **8**, 5397–5402; (*l*) H. Wakabayashi, T. Kurihara and T. Nozoe, *Heterocycles*, 2001, **54**, 87–92.

2 P. A. Plattner and A. S. Pfau, *Helv. Chim. Acta*, 1937, **20**, 224–232.

3 K.-P. Zeller, Azulene, in *Houben-Weyl; Methoden der Organischen Chemie*, 4th edn., Georg Thieme, Stuttgart, 1985, Vol. **V**, Part **2c**, pp. 127–418.

4 (*a*) K. Ziegler and K. Hafner, *Angew. Chem.*, 1955, **67**, 301–302; (*b*) K. Hafner, *Liebigs Ann. Chem.*, 1957, **606**, 79–89; (*c*) K. Hafner and K.-P. Meinhardt, *Org. Synth.*, 1990, **Coll. Vol. 7**, 15–18.

5 (*a*) T. Nozoe, S. Matsumura, Y. Murase and S. Seto, *Chem. Ind. (London)*, 1955, 1257; T. Nozoe, T. Asao, in *Dai-Yuki Kagaku*, Ed. M. Kotake, Asakura Shoten, Tokyo, 1960, Vol. 13, pp. 439–534; (*b*) T. Nozoe, S. Seto, S. Matsumura and Y. Murase, *Bull. Chem. Soc. Jpn.*, 1962, **35**, 1179–1188; T. Nozoe, S. Seto, K. Takase, S. Matsumura and T. Nakazawa, *Nippon Kagaku Zasshi*, 1965, **86**, 346–363.

6 (*a*) P.-W. Yang, M. Yasunami and K. Takase, *Tetrahedron, Lett.*, 1971, 4275–4278; (*b*) M. Yasunami, A. Chen, P. W. Yang and K. Takase, *Chem. Lett*, 1980, 579–582; M. Yasunami, S. Miyoshi, N. Kanegae and K. Takase, *Bull. Chem. Soc. Jpn.*, 1993, **66**, 892–899.

7 L. T. Scott, M. A. Minton and M. A. Kirms, *J. Am. Chem. Soc.*, 1980, **102**, 6311–6314.

8 N. Morita, M. Kudo, R. Yokoyama and S. Ito, *Heterocycles*, 2001, **54**, 679–689.

9 R. Yokoyama, S. Ito, M. Watanabe, N. Harada, C. Kabuto and N. Morita, *J. Chem. Soc., Perkin Trans. 1*, 2001, 2257–2261.

10 (*a*) M. M. Sengul, N. Simsek and M. Balci, *Eur. J. Org. Chem.*, 2000, 1359–1363; (*b*) M. Zengin, A. Dastan and M. Balci, *Synth. Commun.*, 2001, **31**, 1993–1999; (*c*) S. Ito, R. Yokoyama, T. Asao, M. Watanabe, N. Harada and N. Morita, *J. Organomet. Chem.*, 2002, **648**, 164–175.

11 S. Cacchi, P. G. Ciattini, E. Morera and G. Ortar, *Tetrahedron Lett.*, 1986, **27**, 5541–5544.

12 (*a*) A. K. Sheinkman and G. V. Samoilenko, USSRP 434076, 1974; *Chem. Abstr.*, 1974, **81**, 77747; (*b*) A. K. Sheinkman, G. V. Samoilenko, S. N. Baranov and N. R. Kalnitskii, *Chim. Geterotsikl. Soedin.*, 1975, 1368; *Chem. Abstr.*, 1976, **84**, 59141.
13 C. Jutz, *Angew. Chem.*, 1958, **70**, 270.
14 (*a*) S. Hünig and B. Ort, *Liebigs Ann. Chem.*, 1984, 1905–1935; (*b*) S. Hünig and B. Ort, *Liebigs Ann. Chem.*, 1984, 1936–1951; (*c*) A. Mishra, R. K. Behera, P. K. Behera, B. K. Mishra and G. B. Behera, *Chem. Rev.*, 2000, **100**, 1973–2011.
15 R. A. Toscano, M. D. C. H. Galindo, R. Rosas, O. G. Mellando, F. D. R. Portilla, C. A. Cuevas and C. A. Toledano, *Chem. Pharm. Bull.*, 1997, **45**, 957–961.
16 (*a*) J. Becher, *Synthesis*, 1980, 589–612 and references cited therein; (*b*) J. A. Zoltewicz, L. S. Helmick and J. K. O'Halloran, *J. Org. Chem.*, 1976, **41**, 1303–1308.
17 M. Hanke and C. Jutz, *Synthesis*, 1980, **80**, 31–32.
18 (*a*) J. A. Zoltewicz, L. S. Helmick and J. K. O'Halloran, *J. Org. Chem.*, 1976, **41**, 1303; (*b*) G. Maas and B. Feith, *Angew. Chem., Int. Ed. Engl.*, 1985, **24**, 511–513.
19 T. Ueno, H. Toda, M. Yasunami and M. Yoshifuji, *Bull. Chem. Soc. Jpn.*, 1996, **69**, 1645-1656.
20 (*a*) A. E. Asato, X. Y. Li, D. Mead, G. M. L. Patterson and R. S. H. Liu, *J. Am. Chem. Soc.*, 1990, **112**, 7398–7399; (*b*) R. S. Muthyala, M. Alam and R. S. H. Liu, *Tetrahedron Lett.*, 1998, **39**, 5–8.