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Approaches to Stable Cyclopropenyl Anions: tris-1,2,3-p-Nitrophenylcyclopropene

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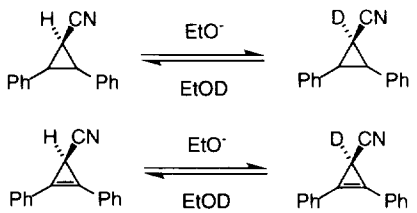
Abstract: Tris-1,2,3-p-nitrophenylcyclopropene has been synthesized from the tosylhydrazone of an enone, and examined as a precursor of the corresponding cyclopropenyl anion. A precursor of the related trimethylsilylcyclopropene has also been prepared by a series of palladium-catalyzed reactions. © 1997 Elsevier Science Ltd.

INTRODUCTION

We have called compounds that are destabilized by cyclic pi electron conjugation "antiaromatic." [1] Although such destabilization has been demonstrated in cyclopentadienyl cations,[2] and in cyclobutadiene systems,[3] some of the clearest evidence was seen in the properties of derivatives of the cyclopropenyl anion.[1b] Studies of the rate of base-catalyzed deuterium exchange into a cyclopropenecarboxylic[4] ester and into a cyanocyclopropene[5] indicated that the slow rate—considerably slower than that for an analogous saturated cyclopropane ester or carbonitrile—was chiefly the result of conjugative destabilization in the 4-pi-electron system.

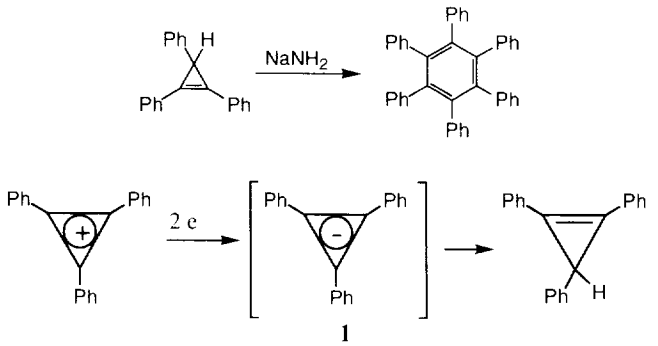


$k_1 / k_2 = 10^4$

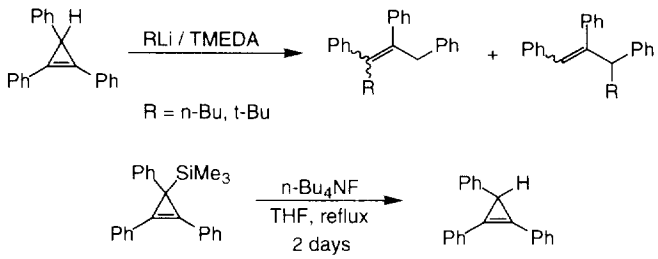
Compounds with 4n pi electrons in a ring, and with C_3 or greater symmetry, can also exist as ground state triplet species.[6] We have demonstrated this for cyclopentadienyl cation[7] and for pentachlorocyclopentadienyl cation,[8] although with pentaphenylcyclopentadienyl cation[9] and some related pentaaryl derivatives[10] the ground state seems to be a singlet, with a very low lying triplet that is thermally populated and spectroscopically detectable. By contrast, cyclobutadiene[11] is a rectangular singlet molecule.

Borden's theoretical treatment[12] accounts for this, and from this treatment it is clear that odd ring systems are more likely to be undistorted triplet species. Thus it would be of considerable interest to prepare a stable three-fold symmetric derivative of the cyclopropenyl anion.

The first attempt at this, with Paul Dowd,[13] involved the treatment of 1,2,3-triphenylcyclopropene with strong base. The product was hexaphenylbenzene, with no evidence that the triphenylcyclopropenyl anion **1** had been formed.



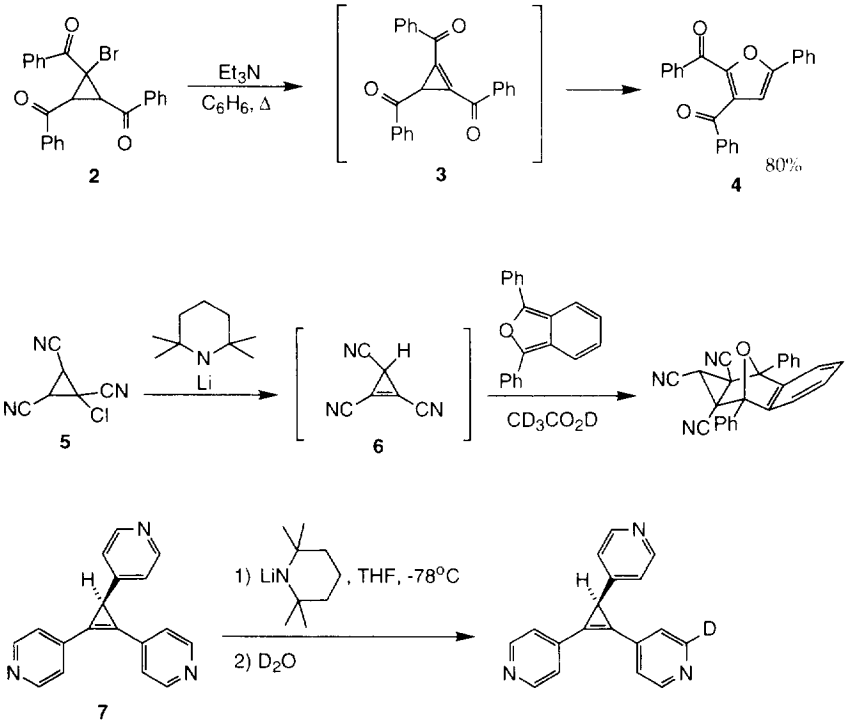
We were able to generate anion **1** by electrochemical reduction of the cation,[14] as a transient intermediate that protonated to triphenylcyclopropene. From the electrochemical potential needed for the two-electron reduction of the cation to the anion, we used our thermodynamic treatment[15] to estimate the pK_a of triphenylcyclopropene. The value, pK_a ca. 50, is much higher than the pK_a of 32 for triphenylmethane, and indicates why various strong bases had not been able to form the anion from triphenylcyclopropene. A later attempt by other authors using organolithium bases also failed to generate the anion.[16] However, Borden *et al.* were able to generate the anion by desilylation of trimethylsilyltriphenylcyclopropene with fluoride ion, but again only as a reactive intermediate that protonated to form the cyclopropene.[17]



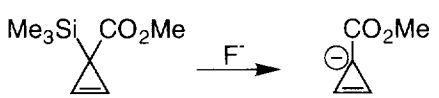
Electrochemical reduction of various cyclopropenyl cations was also used to generate the parent cyclopropenyl anion and the trimethyl and tri-tert-butyl derivatives in solution, reactive intermediates that underwent instant protonation to the cyclopropenes.[18] From our thermodynamic treatment, the pK_as of these cyclopropenes were near 60 and higher, showing the great instability of the anions.

Of course with three strong anion stabilizing substituents the cyclopropenyl anion should be much less reactive, and isolable under suitable conditions. Three approaches to such systems were unsuccessful.

In one,[19] we treated the bromotribenzoylcyclopropane **2** with base; it underwent HBr elimination, but instead of forming the anion the intermediate tribenzoylcyclopropene **3** cyclized to form a furan derivative **4**. In another approach,[20] the chlorotricyanocyclopropene **5** was treated with strong base, and underwent HCl elimination to generate the reactive intermediate tricyanocyclopropene **6**, which could be trapped with diphenylisobenzofuran. However, the strong base did not convert **6** to its anion under the reaction conditions. We also synthesized the tripyridylcyclopropene **7** and examined its behavior with strong base.[21] With lithium tetramethylpiperidide it did indeed form an anion that could be quenched with D_2O, but the anion was on the pyridine ring, not on the cyclopropene ring.



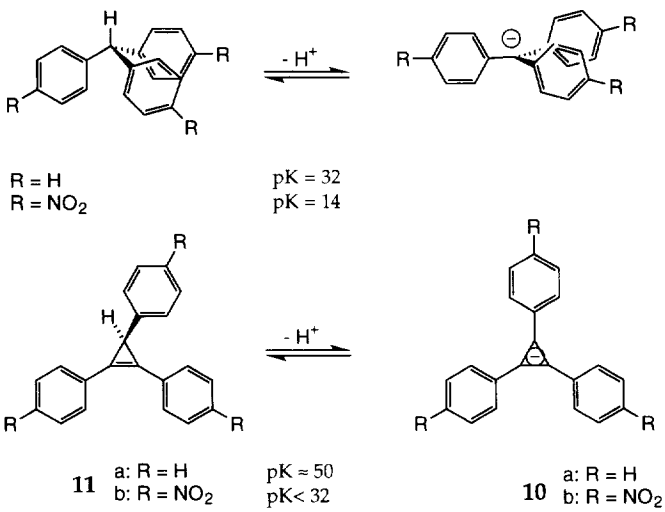
Recently a derivative of the cyclopropenyl anion **9** has been generated and observed in the gas phase by fluorodisilylation of **8**.[22] It does not have the symmetry to be a triplet, nor the structure to be a stable isolable species.



8 **9**

We estimate that the anion **10b** of tris-4-nitrophenylcyclopropene **11b** should be stable enough to be isolable. The pK_a of tris-4-nitrophenylmethane is 14,[23] which is 18 units below that of unsubstituted

triphenylmethane. If only that same 18 units from the three nitro substituents were also operative in the triphenylcyclopropene series, **11b** should have a pK_a of 32, the same as that of triphenylmethane. However, the effect should really be greater in the cyclopropene series. For one thing, the phenyls are almost coplanar with the cyclopropene ring, but triphenylmethyl anion has phenyls rotated by ca. 30°. Thus the nitro substituents can conjugate more effectively in the cyclopropene case. At least as important, perturbation theory indicates that such substituents will more effectively stabilize a less stable anion. Thus it seems likely that the pK_a of **11b** will be lower than 32. It should be possible to prepare a stable solution of anion **10b**.



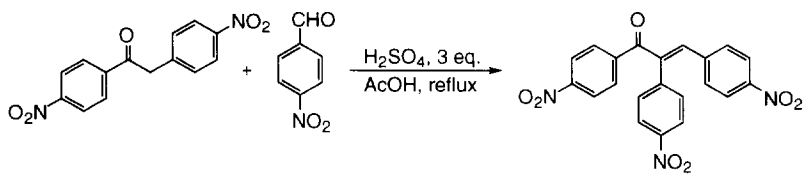
RESULTS AND DISCUSSION

Theoretical Calculations. We have done some calculations on anion **10b**. We first did a Monte Carlo conformational search using modified MM3 forcefield parameters in the MacroModel program,[24] and then further optimized the geometry of the lowest energy ground state conformation with *ab initio* computations at the HF level using a 6-31G** basis set and the program PS-GVB.[25] The result was that the global minimum corresponded to the triplet state of **10b**, which was 74 kJ lower in energy than the lowest singlet state. The triplet state of anion **10b** is three-fold symmetric, and the nitrophenyl substituents are tilted 9° out of the cyclopropenyl ring plane. The lowest singlet state of **10b** is calculated to have some bond alternation in the cyclopropenyl ring, with two long bonds at 1.44 Å and one short bond at 1.31 Å. However, only an experimental examination of **10b** can establish whether it is indeed a ground state triplet, as these HF calculations predict.

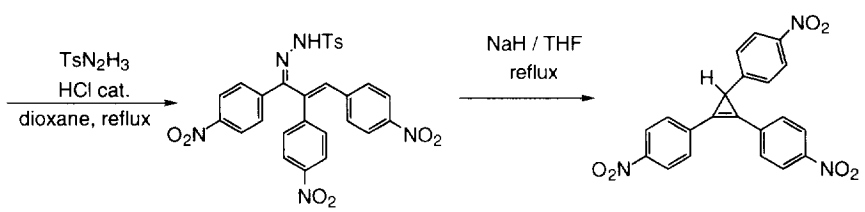
Synthesis. For this reason we set out to prepare the cyclopropene **11b**. Our first approach was to examine the reaction of a phenylcarbene with bis-4-nitrophenylacetylene, since triphenylcyclopropene can be prepared in this fashion in the absence of the nitro groups. As we feared, the nitro substituents so deactivated the acetylene that carbene addition reactions failed. Several other bimolecular schemes were also unsuccessful, and are described in the Ph.D. thesis of Jasna Klicic.[26] Finally we concluded that an

intramolecular cyclization scheme was required.[21] The sensitivity of nitrophenyl compounds to basic conditions dictated that acid catalysis be employed in the various steps.

4,4'-Dinitrodeoxybenzoin (**12**) was prepared by the method of Kulkarni,[27] and condensed with 4-nitrobenzaldehyde using acid catalysis. Only the E isomer **13** was produced. This was converted to the tosylhydrazone **14**, which was treated with sodium hydride in refluxing THF to form the desired cyclopropene **11b**. It was fully characterized by mass and NMR spectroscopy, and showed a band in the infrared at 1812 cm^{-1} characteristic of a cyclopropene ring.



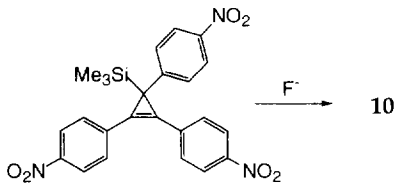
12 **13**



14 **11b**

Attempts to form the anion. Triphenylmethane is readily converted to its anion with potassium hydride in the presence of 18-crown-6 at room temperature, and quenching with D_2O forms Ph_3C-D. However, under the same conditions the cyclopropene **11b** reacted only slowly, and produced only decomposition products. Furthermore, no anion of **11b** was formed on treatment in THF with lithium tetramethylpiperidide; even after 30 min at room temperature, then D_2O quench, **11** was recovered unchanged and undeuterated. Treatment of **11b** with BuLi at -78 °C for 15 min, then D_2O quench, afforded undeuterated recovered **11b**. Under more extreme conditions with BuLi, **11b** was destroyed. In experiments with triphenylmethane, the normal conversion to its anion by BuLi was blocked in the presence of two equivalents of nitrobenzene, indicating that nitrophenyl groups react with such strong bases preferentially. Thus we have not yet found any base and conditions that will remove the cyclopropenyl proton of **11b** to form anion **10b**.

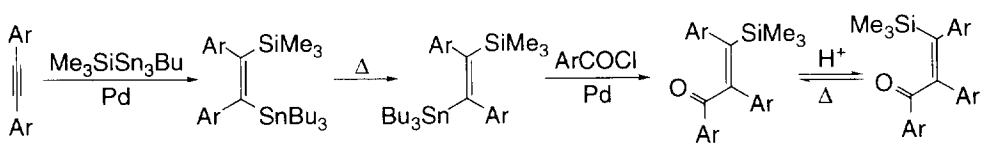
Why has this failed, considering the arguments above that the pKa of **11b** should be in the low 30's or even below? One possibility is that the cyclopropene simply does not stand up to the strong base needed to remove such a modestly acidic proton. However, another possibility is that the full stabilization of anion **10b** by the three nitrophenyl groups is not yet available at the transition state for proton removal.. That is, the transition state may have the anionic electrons more localized in the cyclopropene ring than would be the case in the final anion **10b**. Thus the kinetic acidity of **11b** would be considerably less than its equilibrium acidity, something already well known in nitroalkanes, for instance. In any case, a new approach to **10b** is needed.



15

A more promising approach. Fluorodesilylation was successful in generating the anion of triphenylcyclopropene as a reactive intermediate,[17] and it has been used to generate a derivative of the anion as a gas phase species.[22] Thus a reasonable target molecule is **15**, a tris-4-nitrophenylcyclopropene carrying a trimethylsilyl group. We describe some of the early steps that lead to compounds (**18** and **19**) analogous to **13**.

Trimethylsilyltributylstannane was added to 4,4'-dinitrotolane with Pd catalysis, and the initially formed Z isomer **16** isomerized to the E isomer **17** on heating. The E isomer, but not the Z isomer, underwent Stille coupling with 4-nitrobenzoyl chloride using a Pd catalyst. Under normal conditions there was a considerable amount of decarbonylation in this reaction, resulting in the addition of a 4-nitrophenyl group instead of the 4-nitrobenzoyl group, but when the Stille coupling was conducted under an atmosphere of carbon monoxide a reasonable yield of the desired ketone **18** was obtained, which equilibrated with its isomer **19**. Further work with these intermediates, and other work aimed at the production of anion **10b**, will be the subject of future reports.



16 **17** **18** **19**

Ar = 4-nitrophenyl

EXPERIMENTAL SECTION

E-1,2,3-Tris(4-nitrophenyl)propenone (13). 1,2-Bis(4-nitrophenyl)ethanone **12** (4.759 g, 16.6 mmol), 4-nitrobenzaldehyde (2.511 g, 16.6 mmol) and concentrated sulfuric acid (3.3 ml) were dissolved in glacial acetic acid (40 ml). The solution was refluxed for 3 days. Sodium acetate was added to neutralize the mixture. The precipitate was filtered off, washed well with water and methanol, dried in vacuum and recrystalized from hot ethanol. Obtained 5.49 g (79%) of pale yellow solid after recrystalization. **m.p.** 226-230 °C with decomposition. **^{1}H NMR** (400 MHz, DMSO-d_6/$CDCl_3$) d 7.34 (d, J=9.2 Hz, 2H); 7.57 (d, J=8.4 Hz, 2H); 7.57 (s, 1H); 8.07 (d, J=8.8, 2H); 8.11 (d, J=8.8, 2H); 8.25 (d, J=8.8, 2H); 8.36 (d, J=8.8, 2H). **^{1}H COSY NMR** (400 MHz, DMSO-d_6) crosspeaks are found between d (7.34 and 8.07), (7.57 and 8.25) and (8.11 and 8.37) signals. **^{13}C NMR** (75.4 MHz, DMSO-d_6/$CDCl_3$) d 123.3, 123.5, 123.7, 130.7, 131.2, 140.2, 140.6, 141.5, 141.9, 142.5, 147.2, 149.4, 194.4. **IR** (KBr pellet) cm^{-1} 3105 w, 1663 s, 1599 m, 1508 s, 1405 w, 1346 s, 1250 m, 1109 m, 852 m, 711 m. **MS** *m/z* (CI, CH_4) 420 for $[M+1]^+$, 448 for $[M+29]^+$ and 460 for $[M+41]^+$.

1,2,3-Tris(4-nitrophenyl)propenone p-tosylhydrazone (14). 1,2,3-Tris(4-nitrophenyl)propenone **13** (1.244 g, 3.0 mmol) was suspended in anhydrous 1,4-dioxane (30 ml). The suspension was heated until all the solid dissolved and then cooled.

p-Toluenesulfonylhydrazide (1.103 g, 6.0 mmol) and conc. HCl (0.3 ml) were added at once. The solution was heated to reflux for 22 hours and then cooled to room temperature for an hour. Diethyl ether (65 ml) was added and the hydrazone precipitated. It was filtered off, washed with some ether and dried in vacuo for 2 days. Obtained 1.19 g (67%) of yellow crystals. **m.p.** 228-232°C with decomposition. **^{1}H NMR** (400 MHz, acetone-d_6) d 7.36 (d, J=8.0 Hz, 2H); 7.41 (d, J=8.8 Hz, 2H); 7.71 (d, J=9.2 Hz, 2H); 7.72 (d, J=8.0 Hz, 2H); 7.86 (d, J=9.2 Hz, 2H); 7.97 (s, 1H); 8.01 (d, J=8.8 Hz, 2H); 8.20 (d, J=8.8 Hz, 2H); 8.23 (d, J=9.2 Hz, 2H). **^{13}C NMR** (75.4 MHz, acetone-d_6) d 21.4, 124.4, 125.0, 125.1, 128.1, 128.3, 128.4, 130.2, 130.6, 132.9, 136.2, 137.2, 141.6, 141.7, 142.7, 145.3, 148.5, 148.9. **IR** (KBr pellet) cm^{-1} 3180 w, 2853 w, 1596 m, 1518 s, 1363 s, 1172 m, 1119 m, 1082 m, 857 m. **MS** *m/z* (CI, CH_4) 588 for $[M+1]^+$, 616 for $[M+29]^+$ and 628 for $[M+41]^+$.

1,2,3-Tris(4-nitrophenyl)cyclopropene (11b). Sodium hydride (0.028 g, 0.7 mmol, 60% dispersion in mineral oil) was washed twice with anhydrous THF (ca. 10 ml) under Ar. The solution of 1,2,3-tris(4-nitrophenyl)propenone p-tosylhydrazone **14** (0.293 g, 0.5 mmol) in anh. THF (40 ml) was added quickly to the sodium hydride. The color changed from yellow through orange to red. The flask with the solution was then placed into a preheated oil bath (90 °C) and was kept at reflux temperature for 1.5 hour. The color changed to black and brown. After cooling, methanol (0.5 ml) was added to the mixture and the solvent was evaporated. The residue was chromatographed on silica-gel (100 g, flash silica) using CH_2Cl_2/hexane from 1:1 to 4:1 as eluent. Yield 0.144 g (70%) of yellow solid. **m.p.** 239-242°C with decomposition. **^{1}H NMR** (400 MHz, $CDCl_3$) d 3.53 (s, 1H); 7.36 (d, J=8.4 Hz, 2H); 7.83 (d, J=8.8, 4H); 8.16 (d, J=8.8 Hz, 2H); 8.36 (d, J=8.8 Hz, 4H). **^{13}C NMR** (75.4 MHz, $CDCl_3$) d 25.0, 114.4, 124.1, 124.6, 126.3, 130.8, 132.6, 146.8, 148.3, 150.2. **IR** (KBr pallet) cm^{-1} 3104 w, 3075 w, 2933 w, 2841 w, 2441 w, 1933 w, 1812 w (C=C cyclopropene), 1597 m, 1512 s, 1408 w, 1338 s, 1108 m, 1018 w, 854 m, 803 m, 744 m, 704 m, 686 m. **MS** *m/z* (CI, CH_4) 404 for $[M+1]^+$, 432 for $[M+29]^+$ and 444 for $[M+41]^+$.

1-Tributylstannyl-2-trimethylsilyl-1,2-bis(4-nitrophenyl)ethene (16 and **17).** 4,4'-Dinitrotolane (2.00 g, 7.5 mmol) and (trimethylsilyl)tributylstannane (3.0 ml, 8.5 mmol,) were dissolved in anh. THF (50 ml). Tetrakis(triphenylphosphine)palladium(0) (42 mg, 0.5 mol %) in anh. THF (10 ml) and added, and the reaction mixture was then heated to reflux under argon for 4 days. The progress of the reaction was followed by ^{1}H NMR. Prolonged reaction time caused cis/trans isomerization of the product (**16** to **17**). The concentrated reaction mixture was flushed through silica-gel (150 g) using ethyl-acetate/hexane 1:15 as eluent. Obtained 1.852 g (39%) of yellow/orange compound that solidified after sitting at 4°C. For **16**: **^{1}H NMR** (200 MHz, $CDCl_3$) d 0.14 (s, 9H); 0.81-0.91 (m, 15H); 1.23-1.40 (m, 12H); 6.73 (d, J=8.8 Hz, 2H); 6.83 (d, J=8.8 Hz, 2H); 7.89 (d, J=8.8 Hz, 2H); 7.91 (d, J=8.8 Hz, 2H). **MS** *m/z* (CI, CH_4 and NH_3) 632 for $[M+1]^+$, 649 for $[M+18]^+$, 660 for $[M+29]^+$; the intensities of peaks show the pattern characteristic for Sn. For **17**: **^{1}H NMR** (400 MHz, $CDCl_3$) d -0.28 (s, 9H); 0.40 (t, J=6 Hz, 6H); 0.79 (quasi t, 9H); 1.08-1.20 (m, 12H), 7.13 (d, J=9 Hz, 2H); 7.21 (d, J=9 Hz, 2H); 8.19 (d, J=9 Hz, 2H); 8.22 (d, J=9 Hz, 2H). **^{13}C NMR** (75.4 MHz, $CDCl_3$) d 0.68 (q, J=122 Hz); 11.5 (t, J=128 Hz); 13.6 (q, J=125 Hz); 27.2 (t, J=130 Hz); 28.8 (t, J=130 Hz); 123.5 (d, J=168 Hz); 127.0 (d, J=157 Hz); 128.4 (d, J=164 Hz); 145.5 s; 146.3 s; 153.9 s; 154.7 s; 158.0 s; 163.9 s. **IR** (KBr pallet) cm^{-1} 2955 s, 2852 w, 1588 m, 1513 s, 1483 w, 1464 w, 1409 w (C-Si), 1341 s, 1249 m, 1107 m, 866 m, 837 m, 710 m, 660 m. **MS** *m/z* (CI, CH_4 and NH_3) 632 for $[M+1]^+$, 649 for $[M+18]^+$, 660 for $[M+29]^+$; the intensities of peaks show the pattern characteristic for Sn.

E-1,2,3-Tris(4-nitrophenyl)-3-trimethylsilylpropenone (18). 1-Tributyl-stannyl-2-trimethylsilyl-1,2-bis(4-nitrophenyl)ethene **16/17** mixture (36.5 mg, 0.058 mmol), sublimed 4-nitrobenzoylchloride (15.0 mg, 0.081 mmol), tris(dibenzylidene-acetone)dipalladium(0) (1.3 mg, 5 mol % of Pd) and tris(2-furyl)phosphine (1.5 mg, 0.0065 mmol) were placed in a round bottom flask. Anhydrous 1,4-dioxane (0.80 ml) was added and the solution was stirred. The color soon changed from deep red (Pd_2dba_3) to pale yellow (Pd-phosphine complex). The solution was transferred to a Teflon stoppered pressure vessel, cooled until 1,4-dioxane freezes, evacuated and flushed several times with CO (99.0%, dried through a column of $CaSO_4$). The solution was heated to reflux under CO for 1 day, after which palladium precipitated in the form of a black powder. The solution

was diluted with ethyl acetate, shaken well with aqueous KF for 5 min, washed with brine, dried and concentrated. Preparative TLC (silica-gel, 1.0 mm, eluent: EtOAc/hexane 1:4) gave 15 mg (53%) of the b-silylenone **18**. When the reaction was done on the larger scale (0.5 g of silylstannylstilbene) flash chromatography on silica (60 g) and EtOAc/hexane 1:7 were used. **^{1}H NMR** (200 MHz, in $CDCl_3$) d 0.04 (s, 9H); 7.16 (d, J=8.8 Hz, 2H); 7.20 (d, J=8.8 Hz, 2H); 7.94 (d, J=9.0 Hz, 2H); 8.12 (d, J=8.6 Hz, 4H); 8.29 (d, J=9.0 Hz, 2H). **^{13}C NMR** (75.4 MHz, in $CDCl_3$) d -0.4; 123.5; 123.7; 124.1; 129.0; 129.9; 130.7; 140.0; 142.1; 146.3; 147.0; 148.3; 149.0; 150.6; 151.3; 194.6. **IR** (KBr pallet) cm^{-1} 3106 w; 2926 w; 1854 w; 1736 w; 1677 m; 1599 m; 1521 s; 1408 w; 1347 s; 1252 m; 1108 w; 1013 w; 938 w; 862 m. **MS** *m/z* (CI, CH_4 and NH_3) 492 for $[M+1]^+$, 509 for $[M+18]^+$, 520 for $[M+29]^+$ and 532 for $[M+41]^+$.

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