JOC The Journal of Organic Chemistry

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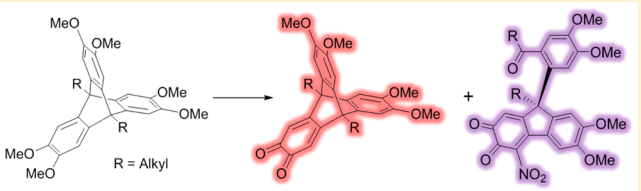
An Oxidative Macrobicyclic Ring Opening of a Triptycene to a Highly Functionalized Fluorene Derivative

Kevin Baumgärtner, Frank Rominger, and Michael Mastalerz*

Organisch-Chemisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 270, 69120 Heidelberg, Germany

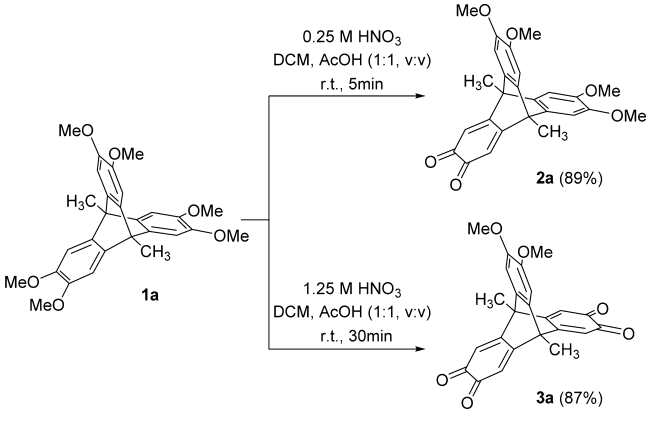
Supporting Information

ABSTRACT: The treatment of hexamethoxytriptycenes with nitric acid leads to an unprecedented oxidative ring opening of the triptycene scaffold, resulting in a new class of fluorene derivatives with a nitroquinone unit. Preliminary investigations of the influence of chain length of alkyl substituents at the triptycene bridgeheads to the reaction have been performed, revealing that exclusively the methyl-substituted hexamethoxytriptycene does not undergo an oxidative ring opening reaction.



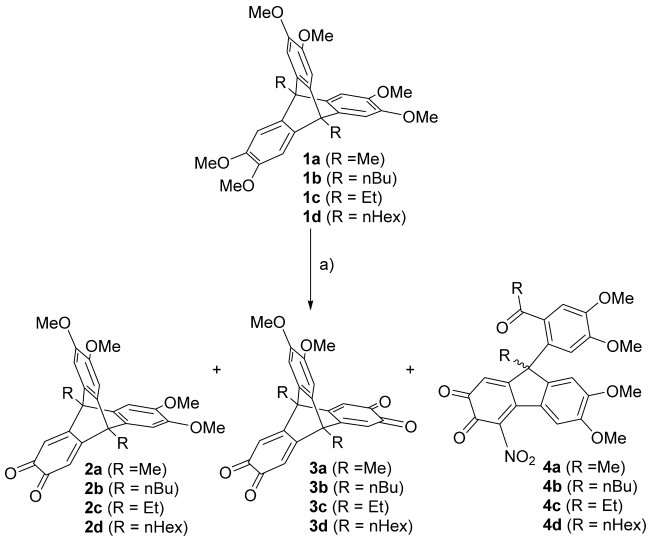
Triptycenes are widely used in supramolecular as well as materials chemistry because of the molecular D_{3h} symmetry,[1] homoconjugation effects among the three aromatic units,[2] and the ease of functionalization:[3] in principle, typical electrophilic aromatic substitution and follow-up reactions can be applied. During our research of triptycenes with extended aromatic arms and boronic ester cages based on triptycene tetraols,[4,5] we were interested in using hexamethoxy triptycenes partially oxidized to their corresponding mono-*o*-quinones. For a hexamethoxy triptycene derivative (**1a**), Chen et al. described a protocol for realizing this conversion with nitric acid as an oxidant to yield the corresponding monoquinone **2a** or bisquinone **3a** in high yields, selectively, depending only on the applied reaction time and the amount of nitric acid (Scheme 1).[6] To enhance the solubility of the product, we decided to place *n*-butyl chains at the bridgehead positions (**1b**[7]) instead of methyl groups. To our surprise, the subsequent oxidation gave besides the desired monoquinone **2a** another byproduct, which turned out to be a chiral fluorene derivative **4a**, which will be described herein.

Scheme 1. Synthesis of Mono- and Bis-*o*-quinones 2a and 3a Reported by Chen et al.[6]



For the oxidation, conditions similar to those described by Chen et al. have been applied: treating the hexamethoxytriptycene **1b** with 0.28 M nitric acid in a mixture of dichloromethane and acetic acid for 5 min at room temperature (Scheme 2 and Table 1, entry 1). Two products could be separated by column chromatography. One product was **2b**, which was isolated in 44% yield as an orange solid. The signals of the ^{1}H NMR spectrum matched those of the proposed

Scheme 2. Investigation of Alkyl Chain Lengths at the Bridgeheads for the Oxidative Ring Opening Reaction[a]



[a](a) For conditions and yields, see Table 1.

Received: June 24, 2015
Published: August 6, 2015

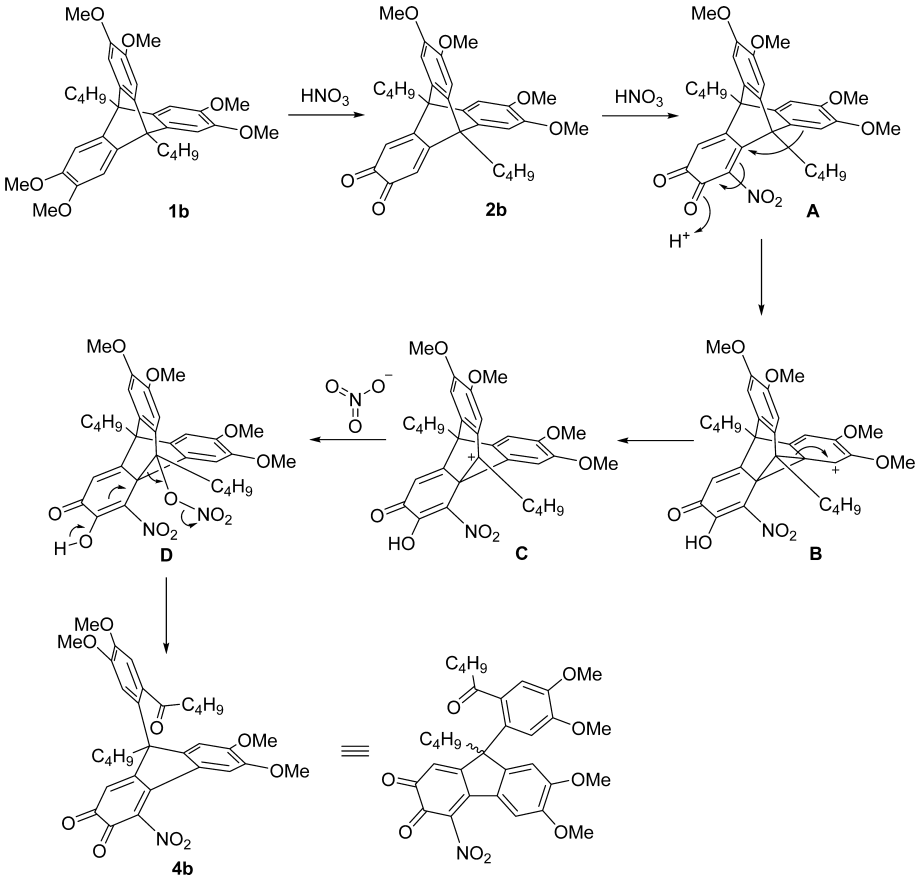
DOI: 10.1021/acs.joc.5b01426
J. Org. Chem. 2015, 80, 8881−8886

Table 1. Reaction Conditions and Results of Oxidations of 1a−1d

entry	compd	T	t (min)	solvent[a]	$c(HNO_3)$[b] (M)	product ratio[c] (**2**:**3**:**4**)
1	**1b**	rt	5	DCM/AcOH	0.28	1:0:0.5
2	**1a**	rt	5	DCM/AcOH	0.28	1:0:0
3	**1c**	rt	5	DCM/AcOH	0.28	1:0:0.5
4	**1d**	rt	5	DCM/AcOH	0.28	1:0:0.5
5	**1b**	0 °C	10	DCM/AcOH	0.28	1:0:0.5
6[d]	**1b**	rt	5	DCM/AcOH	0.28	1:0:0.8
7	**1b**	rt	5	DCM/AcOH	0.48	1:0:0.7
8	**1b**	rt	5	AcOH	0.28	1:0:0.9
9	**1b**	rt	7	AcOH	0.28	1:0:1.1
10	**1b**	rt	10	AcOH	0.28	1:0.3[e]:1.4
11	**1b**	rt	5	AcOH	0.48	1:0.2[e]:1
12	**1b**	rt	3	AcOH	0.81	1:0:1.1
13	**1b**	rt	5	AcOH	0.81	1:0.5[e]:1.4
14	**1b**	rt	7	AcOH	0.81	1:0.6[e]:1.5
15	**1b**	rt	10	AcOH	0.81	1:1.3[e]:2.5
16	**1b**	rt	20	AcOH	0.81	0:1[e]:0.9
17	**2b**	rt	5	DCM/AcOH	0.29	1:0.5[e]:0.2

[a]Solvent mixture [1:1 (v:v)]; 1 mL/0.04 mmol of starting material. [b]Concentrated nitric acid (68%) was used. The given concentration is the concentration of nitric acid in the reaction mixture and not that of a prediluted aqueous solution. [c]Determined by integration of characteristic NMR peaks of the crude product. [d]Light protection. [e]Not isolated.

Scheme 3. Proposed Mechanism for the Formation of 4b



mono-*o*-quinone structure (Figure S3 of the Supporting Information). Two singlets in the aromatic region at δ 6.09 and δ 6.98 in a 1:2 ratio can be clearly assigned to the protons at the quinone unit and at the two unreacted veratrole units. Furthermore, there is only one singlet resonating at δ 3.90 for the 12 methoxy protons.

The second isolated product (20% yield) is deep purple in color and shows a ^{1}H NMR spectrum (Figure S3) more complicated than that of **2b**. There are five characteristic singlets in the aromatic region at δ 7.30, 7.07, 6.82, 6.40, and 6.18, each with the same integral and four different signals (δ 4.03, 3.92, 3.92, and 3.89) for the methoxy groups, also each with the same integral. Furthermore, in the CI mass spectrum, a

DOI: 10.1021/acs.joc.5b01426
J. Org. Chem. 2015, 80, 8881−8886

basis peak at m/z 577 is found, which is 61 units higher than that for compound **2b**. Most conspicuously, an additional pronounced peak at δ 204.1 was observed in comparison to the ^{13}C NMR spectrum of **2b**, which is typical for a keto carbonyl ^{13}C nucleus. Unfortunately, no clear additional stretching band for a keto carbonyl group has been recognized in the IR spectrum. By 2D NMR experiments [HMBC and HSQC (see Figures S21 and S22 in the Supporting Information)], the fluorene structure of **4b** was proposed (for the assignment of all signals, see Experimental Section). Besides elucidating the structure by NMR methods, we have grown single crystals of **4b**, suitable for X-ray structure analysis (see the Supporting Information), revealing that the fluorene has been formed as previously suggested by NMR data (see Figures S9 and S10 of the Supporting Information).

It is noticeable that Chen et al. have not described this ring opening reaction for methyl-substituted hexamethoxy-triptycene **1a**. We synthesized compound **1a** and subjected it to the reaction conditions we used for **1b** (entry 2 in Table 1). Most interestingly, we have not detected the formation of any ring opening product at all, and also no traces by UPLC-MS could be detected (see Figures S36 and S37 of the Supporting Information). Instead, the described formation of compound **2a** in 90% isolated yield has been clearly reproduced.[6]

Because of large differences in the reactivity of **1a** (with methyl substituents) and **1b** (with *n*-butyl substituents), hexamethoxy triptycenes **1c** and **1d** with ethyl and hexyl chains at the bridgeheads, respectively, have been investigated under the same conditions (entries 3 and 4, respectively). In both cases, the formation of the triptycene quinone and the fluorene derivative was observed in the same ratio as previously found for **1b** (entry 1). Performing the reaction at 0 °C instead of room temperature gave the same ratio of products, even when the reaction time was doubled (entry 5). Excluding light (entry 6) slightly increased the amount of fluorene **4b**. Performing the reaction with a higher concentration of nitric acid (entry 7) switched the ratio toward the fluorene derivative, but the formation of bisquinone **3b** was also observed, which is in agreement with the observation described previously by Chen for the oxidation of **1a** to **3a**.[6] Using only glacial acetic acid as a solvent gave fluorene **4b** as the main product (entry 8). Upon prolongation of the reaction time (entries 8−10), the formation of more fluorene was observed, although the level of formation of bisquinone **3b** has increased. Inreasing the concentration of nitric acid accelerated the formation of both fluorene **4b** and bisquinone **3b** (entries 11−16). Shortening the reaction time to 3 min under these conditions (entry 12) gave no bis-*o*-quinone, and **2b** and **4b** were each isolated in a 32% yield. Finally, after 20 min, all monoquinone **2b** has been consumed, giving fluorene and bisquinone in an approximately 1:1 ratio.

Mono-*o*-quinone **2b** has also been treated under standard conditions (entry 17). As proposed in Scheme 3, **2b** is an intermediate, and therefore, the product formation of fluorene **4b** could be found, although it was isolated in only 8% yields. The starting material was recovered in 54% yields. Here, the bis-*o*-quinone **3b** was also detected in the ^{1}H NMR spectrum of the crude product.[6]

For the formation of byproduct **4b**, the following rational mechanism is proposed (Scheme 3). As a first step, oxidation of **1b** to **2b** occurs, followed by a nitration of the *o*-quinone ring to give intermediate **A**, which has been described previously for similar systems.[8] After protonation of one carbonyl oxygen of the quinone, subsequent nucleophilic attack of one of the electron-rich veratrole rings to the nitrated *o*-quinone unit gives macrotricyclic carbocation **B** containing one five-membered and one three-membered annulated ring, which rearranges to benzylic cation **C** via rearomatization of the veratrole unit. The carbenium carbon is attacked by a nitrate anion to give nitric ester **D** as an intermediate, which is losing a molecule of nitreous acid under ring opening of the three-membered ring and formation of the ketyl chain to give finally product **4b**.

To conclude, we have found an unprecedented oxidative macrobicyclic ring opening reaction of hexamethoxy triptycenes to highly functionalized fluorene derivatives by nitric acid. To the best of our knowledge, structural rearrangements on triptycenes are still rare and have been realized either with potassium[9] or by photoirradiation.[10] As a consequence, our results complement the possibilities of triptycene rearrangements. However, until now, it has not been clear why methyl-substituted hexamethoxytriptycene **1a** (as well as nonsubstituted hexamethoxytriptycene[6]) is the only congener that does not undergo this rearrangement. Because the electronic effect of methyl is not significantly different from those of other alkyl substitutents (Hammett parameter σ_m is −0.07 for both),[11] those can most probably be excluded from being responsible for the different reactivity. We can also most likely exclude solubility effects, because we found only slight differences in the solubility of quinones **2a** and **2c** (198 mg/mL for **2a** and 217 mg/mL for **2c**) in a $CHCl_3$/HOAc (1:1) mixture. It is known that carbocations can be stabilized by C−C σ-bonds through space by hyperconjugation effects.[12] It is noteworthy that in proposed cationic intermediates **B** and **C** in Scheme 3 a stronger stabilization by hyperconjugation is in principle possible for those compounds with alkyl chains at the bridgeheads than for methyl. However, this has to be understood as a first hypothesis that has to be proven or disproven by further theoretical and experimental studies, which will be communicated in due course. It is worth mentioning that the nitroquinone motif has been found to be very attractive for pharmaceutical drug development.[8f,g,13] In addition, quinones **1a−d** will be used in condensation reactions with arene *o*-diamines[14] to make new acceptors for organic electronics.[15]

EXPERIMENTAL SECTION

General Remarks. Chemical shifts (δ) are reported in parts per million relative to traces of $CHCl_3$ in the corresponding deuterated solvent ($CDCl_3$, δ_H 7.26, δ_C 77.16). Electrochemical data were obtained in $CHCl_3$ containing 5 mM experimental compound and 0.1 M Bu_4NPF_6, as indicated. Ferrocene (1 mM) was used as an internal standard. Cyclic voltammograms were obtained at a scan rate of 0.2 mV/s using a Pt working electrode, a Pt/Ti counter electrode, and a Ag reference electrode. Crystal structure data were generated with a molybdenum source (Mo Kα, 0.71073 Å). Data processing and absorption correction (SADABS)[16] were accomplished by standard methods. The structures were determined by direct methods and refined by full matrix least squares using SHELXL software.[17] All non-hydrogen atoms were refined using anisotropic thermal parameters, and hydrogen atoms were treated using appropriate riding models. All crystallographic information files [CCDC-1402253 (**4b**) and CCDC-1402254 (**4d**)] have been deposited in the Cambridge Crystallographic Data Centre and can be downloaded free of charge via www.ccdc.camac.uk/data_request/cif.

Tetramethoxyanthracene precursors substituted with alkyl chains in the 9,10-position and the diazonium salt derived from 4,5-dimethoxybenzoic acid for triptycene synthesis (**1a−d**) have been prepared according to literature procedures.[7,18]

DOI: 10.1021/acs.joc.5b01426
J. Org. Chem. 2015, 80, 8881−8886

Compound 1d. A mixture of 9,10-dihexyl-2,3,6,7-tetramethoxyanthracene (1.5 g, 3.31 mmol) and freshly synthesized diazonium salt (3.0 g, 12.26 mmol) derived from 2-amino-4,5-dimethoxybenzoic acid was refluxed in dichloroethane (115 mL) and epoxypropane (28.5 mL) for 18 h. After the reaction mixture had been cooled to room temperature, the solvents were removed under reduced pressure and methanol was added (20 mL), and the resulting slurry was stirred for 10 min to precipitate nonreacted anthracene, which was collected by filtration. The filtrate was concentrated under reduced pressure and the crude product washed with methanol and *n*-pentane to give pure compound **1d** as a colorless powder (639 mg, 33%): mp 182−183 °C; ^{1}H NMR (400 MHz, $CDCl_3$, 25 °C) δ 6.96 (s, 6H; Ar-H), 3.83 (s, 16H; OCH_3), 2.83 (t, ^3J = 7.5 Hz, 4H; -$CH_2C_5H_{11}$), 2.22−2.13 (m, 4H; -$CH_2CH_2C_4H_9$), 1.90−1.80 (m, 4H; -$C_2H_5CH_2C_3H_7$), 1.59−1.41 (m, 8H; -$C_3H_7CH_2CH_2CH_3$), 0.99 (t, ^3J = 7.2 Hz, 6H; -$C_5H_{11}CH_3$); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$, 25 °C) δ 145.5 (ArC-OMe), 142.2 [br, $(ArC)_3$-C-], 107.7 (ArC-H), 56.5 (-OCH_3), 52.6 [$(Ar)_3$-C], 32.4 (-$CH_2C_5H_{11}$), 32.0 (-$CH_2CH_2C_4H_9$), 28.9 (-$C_2H_4CH_2C_3H_7$), 26.1 (-$C_3H_6CH_2C_2H_5$), 23.0 (-$C_4H_8CH_2CH_3$), 14.3 (-$C_5H_{10}CH_3$); FT-IR (ATR) $\tilde{\nu}$ 3005 (w), 2954 (m), 2930 (m), 2912 (m), 2850 (w), 1613 (w), 1581 (w), 1484 (s), 1462 (s), 1403 (w), 1272 (ss), 1189 (m), 1150 (s), 1039 (s), 1020 (s), 983 (m), 858 (w), 790 (w), 762 (m), 665 (w), 626 (m) cm^{-1}; MS (APCI) *m*/*z* 603.409 (81) $[M + H]^+$, 620.327 (19) $[M + NH_4]^+$. Anal. Calcd for $C_{38}H_{50}O_6$: C, 75.71; H, 8.36. Found: C, 75.41; H, 8.40.

General Procedure (GP) for the Oxidation of Hexamethoxytriptycenes by Nitric Acid. To a solution of **1b** (300 mg, 0.55 mmol) in dichloromethane and glacial acetic acid [7.5 mL; 1:1 (v:v)] was added dropwise concentrated nitric acid (0.15 mL). After 5 min, the reaction mixture was poured onto ice and water (50 mL) and extracted with dichloromethane (4 × 30 mL). The combined organic extract was washed with an aqueous sodium bicarbonate solution (30%, 3 × 20 mL) and dried over $MgSO_4$. Solvent was removed under reduced pressure and the product mixture separated by column chromatography on SiO_2 (3:1 light petroleum ether/ethyl acetate) to give two fractions after drying in vacuum.

First Fraction (R_f = 0.20). **2b** as a red solid (125 mg, 44%): mp 227−228 °C; ^{1}H NMR (400 MHz, 50 °C, $CDCl_3$) δ 6.97 (s, 4H; Ar-H), 6.09 (s, 2H; Quin-H), 3.90 (s, 12H; OCH_3), 2.62 (t, ^3J = 7.6 Hz, 4H; -$CH_2C_3H_7$), 2.09−2.00 (m, 4H; -$CH_2CH_2C_2H_5$), 1.86−1.75 (m, 4H; -$C_2H_4CH_2CH_3$), 1.16 (t, ^3J = 7.3 Hz, 6H; -$C_3H_6CH_3$); ^{13}C{^{1}H} NMR (100 MHz, 50 °C, $CDCl_3$) δ 180.6 [Ar′-C(O)C_4H_9], 157.0 (br, Ar′C), 149.4 (ArC-OMe), 133.1 (br, Ar′C-H), 118.3 (br, ArC), 108.3 (ArC-H), 56.6 (-OCH_3), 50.8 [$(Ar)_3$-C-C_4H_9], 28.1 (-$CH_2C_3H_7$), 27.7 (-$CH_2CH_2C_2H_5$), 24.8 (-$C_2H_4CH_2CH_3$), 14.3 (-$C_3H_6CH_3$); UV/vis ($CHCl_3$) λ_{max} (ε) 450 (6939); FT-IR (ATR) $\tilde{\nu}$ 2954 (b), 2873 (b), 1737 (w), 1679 (w), 1658 (m), 1604 (w), 1579 (m), 1495 (s), 1462 (m), 1405 (w), 1356 (m), 1331 (w), 1273 (s), 1233 (m), 1218 (m), 1194 (w), 1169 (m), 1155 (m), 1035 (m), 868 (m), 793 (m), 755 (m), 735 (m), 686 (m), 614 (w) cm^{-1}; HRMS (MALDI) *m*/*z* 517.26425 (100) $[M + H]^+$. Anal. Calcd for $C_{32}H_{36}O_6 \cdot H_2O$: C, 71.89; H, 7.16. Found: C, 71.81; H, 7.38.

Second Fraction (R_f = 0.10). Fluorene derivative **4b**, which was further purified by crystallization from a chloroform/*n*-pentane solvent to give deep purple crystals (63 mg, 20%): mp 197 °C; ^{1}H NMR (500 MHz, 50 °C, $CDCl_3$) δ 7.30 (s, 1H; Ar′-H), 7.07 (s, 1H; 5H-fluorene), 6.82 (s, 1H; Ar′-H), 6.40 (s, 1H; 8H-fluorene), 6.18 (s, 1H; 1H-fluorene), 4.01 (s, 3H; -OCH_3), 3.91 (s, 3H; -OCH_3), 3.90 (s, 3H; -OCH_3), 3.87 (s, 3H; -OCH_3), 2.54−2.44 [m, 1H; -C(O)$CH_2C_3H_7$], 2.30−2.17 (m, 2H; -$CH_2C_3H_7$), 2.13−2.03 [m, 1H; -C(O)$CH_2C_3H_7$], 1.38−1.23 (m, 4H), 1.20−1.04 (m, 4H), 0.85 [t, ^3J = 7.4 Hz, 3H; -C(O)$C_3H_6CH_3$], 0.83 (t, ^3J = 7.1 Hz, 3H; -$C_3H_6CH_3$); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$, 50 °C) δ 204.1 [-C(O)C_4H_9], 177.2 (C-3), 169.8 (C-2), 165.9 (C-9a), 157.9 (C-7), 151.5 (C-8a), 151.0 (Ar′-C-5), 150.3 (C-6), 148.6 (Ar′-C-4), 144.6 (C-4a), 136.4 (C-4), 135.0 (Ar′-C-2), 132.9 (Ar′-C-1), 125.9 (C-4b), 122.7 (C-1), 113.1 (Ar′-C-6), 112.6 (Ar′-C-3), 107.6 (C-5), 106.3 (C-8), 56.8 (-OCH_3), 56.8 (-OCH_3), 56.5 (-OCH_3), 56.5 (-OCH_3), 56.2 [$(Ar)_3C$], 42.6 (-$CH_2C_3H_7$), 42.2 [-C(O)$CH_2C_3H_7$], 27.1 (-$CH_2CH_2C_2H_5$), 26.0 [-C(O)$CH_2CH_2C_2H_5$], 23.2 (-$C_2H_4CH_2CH_3$), 22.4 [-C(O)-$C_2H_4CH_2CH_3$], 13.9 [-C(O)$C_3H_6CH_3$], 13.8 (-$C_3H_6CH_3$); UV/vis ($CHCl_3$) λ_{max} (ε) 531 (10348), 368 (9172); FT-IR (ATR) $\tilde{\nu}$ 2955 (w), 2934 (b), 2871 (b), 1680 (m), 1656 (m), 1588 (m), 1555 (s), 1519 (m), 1499 (vs), 1464 (s), 1456 (s), 1336 (s), 1323 (s), 1300 (s), 1258 (vs), 1223 (s), 1215 (s), 1195 (s), 1150 (m), 1126 (m), 1101 (m), 1019 (m), 865 (m), 795 (w), 789 (w), 775 (w) cm^{-1}; MS (APCI) *m*/*z* 578.237 (100) $[M + H]^+$. Anal. Calcd for $C_{32}H_{35}NO_9$: C, 66.54; H, 6.11; N, 2.42. Found: C, 66.84; H, 6.44; N, 2.32.

Compounds 2c and 4c. According to the GP, reaction of **1c** (300 mg, 0.61 mmol) gave after separation by column chromatography (1:1 light petroleum ether/ethyl acetate) and drying in vacuum two fractions.

First Fraction (R_f = 0.33). **2c** as a red solid (149 mg, 45%): mp 262−263 °C; ^{1}H NMR (400 MHz, 50 °C, $CDCl_3$) δ 6.99 (s, 4H; Ar-H), 6.09 (s, 2H; Quin-H), 3.90 (s, 12H; -OCH_3), 2.73 (q, ^3J = 7.1 Hz, 4H; -CH_2CH_3), 1.64 (t, ^3J = 7.2 Hz, 6H; -CH_2CH_3); ^{13}C{^{1}H} NMR (100 MHz, 50 °C, $CDCl_3$) δ 180.6 [Ar′-C(O)CH_2CH_3], 157.0 (br, Ar′C), 149.4 (ArC-OMe), 133.1 (br, Ar′C-H), 118.4 (br, ArC), 108.4 (ArC-H), 56.7 (-OCH_3), 51.2 [$(Ar)_3$-C], 20.1 (-CH_2CH_3), 10.7 (-CH_2CH_3); UV/vis ($CHCl_3$) λ_{max} (ε) 449 (6411); FT-IR (ATR) $\tilde{\nu}$ 2970 (w), 2935 (w), 2851 (w), 1732 (w), 1691 (w), 1662 (m), 1589 (m), 1555 (m), 1498 (s), 1455 (m), 1340 (m), 1303 (m), 1259 (vs), 1210 (s), 1149 (m), 1119 (m), 1045 (m), 1010 (m), 950 (w), 863 (m), 785 (m), 772 (m), 730 (w), 701 (w), 681 (w), 667 (w) cm^{-1}; MS (APCI) *m*/*z* 461.217 (100) $[M + H]^+$. Anal. Calcd for $C_{28}H_{28}O_6 \cdot {}^2/_3H_2O$: C, 71.17; H, 6.26. Found: C, 71.10; H, 6.21.

Second Fraction (R_f = 0.20). Fluorene derivative **4c**, which was further purified by crystallization from chloroform/*n*-pentane solvent to give deep purple crystals (66 mg, 20%): mp 181 °C; ^{1}H NMR (400 MHz, 50 °C, $CDCl_3$) δ 7.33 (s, 1H; Ar′-H), 7.05 (s, 1H; 5H-fluorene), 6.79 (s, 1H; Ar′-H), 6.38 (s, 1H; 8H-fluorene), 6.18 (s, 1H; 1H-fluorene), 4.02 (s, 3H; -OCH_3), 3.91 (s, 3H; -OCH_3), 3.90 (s, 3H; -OCH_3), 3.88 (2, 3H; OCH_3), 2.54 [dq, ^3J = 14.2, 7.1 Hz, 1H; -C(O)CH_2-CH_3], 2.41 (dq, ^3J = 14.1, 7.1 Hz, 1H; -CH_2CH_3), 2.30 (dq, ^3J = 14.4, 7.2 Hz, 1H; -CH_2CH_3), 2.04 [t, ^3J = 18.2, 7.1 Hz, 1H; C(O)CH_2CH_3], 0.70 [t, ^3J = 7.2 Hz, 3H; -C(O)CH_2CH_3], 0.68 (t, ^3J = 7.3, 3H; -CH_2CH_3); ^{13}C{^{1}H} NMR (100 MHz, 25 °C, $CDCl_3$) δ 204.8 [-C(O)C_2H_5], 177.1 (C-3), 169.7 (C-2), 165.7 (C-9a), 157.7 (C-7), 151.1 (C-8a), 150.7 (Ar′-C-5), 149.9 (C-6), 148.1 (Ar′-C-4), 144.9 (C-4a), 136.0 (C-4), 134.5 (Ar′-C-2), 132.5 (Ar′-C-1), 126.1 (C4b), 122.6 (C-1), 111.9 (Ar′-C-6), 111.6 (Ar′-C-3), 107.1 (C-5), 105.8 (C-8), 56.9 (-OCH_3), 56.5 (-OCH_3), 56.5 (-OCH_3), 56.3 (-OCH_3), 56.3 [$(Ar)_3C$], 35.6 (-CH_2CH_3), 35.6 [-C(O)CH_2CH_3], 9.4 (-CH_2CH_3), 8.0 [-C(O)CH_2CH_3]; UV/vis ($CHCl_3$) λ_{max} (ε) 529 (8529), 368 (7340); FT-IR (ATR) $\tilde{\nu}$ 2970 (w), 2935 (w), 2879 (w), 2851 (w), 1732 (w), 1691 (w), 1662 (m), 1589 (m), 1555 (m), 1517 (m), 1498 (s), 1455 (m), 1340 (m), 1303 (m), 1259 (vs), 1227 (m), 1210 (s), 1198 (s), 1149 (m), 1119 (m), 1068 (w), 1045 (m), 1010 (m), 950 (w), 919 (w), 895 (w), 863 (m), 785 (m), 772 (m), 730 (w), 701 (w), 681 (w) cm^{-1}; MS (APCI) *m*/*z* 522.189 (100) $[M + H]^+$. Anal. Calcd for $C_{28}H_{27}NO_9 \cdot {}^5/_4CHCl_3$: C, 52.38; H, 4.25; N, 2.09. Found: C, 52.24; H, 4.58; N, 1.87.

Compounds 2d and 4d. According to the GP, reaction of **1d** (330 mg, 0.50 mmol) gave after separation by column chromatography (3:1 light petroleum ether/ethyl acetate) and drying in vacuum two fractions.

First Fraction (R_f = 0.32). **2d** as a red solid (140 mg, 49%): mp 146−155 °C; ^{1}H NMR (400 MHz, 50 °C, $CDCl_3$) δ 6.97 (s, 4H; Ar-H), 6.08 (s, 2H; Quin-H), 3.90 (s, 12H; -OCH_3), 2.65−2.57 (m, 4H; -$CH_2C_5H_{11}$), 2.08−2.02 (m, 4H; -$CH_2CH_2C_4H_9$), 1.84−1.73 (m, 4H; -$C_2H_4CH_2C_3H_7$), 1.57−1.40 (m, 8H; -$C_3H_6C_2H_4CH_3$), 0.98 (t, ^3J = 7.1 Hz, 6H; -$C_5H_{10}CH_3$); ^{13}C{^{1}H} NMR (100 MHz, 50 °C, $CDCl_3$) δ 180.6 [Ar′-C(O)C_6H_{13}], 157.0 (br, Ar′C), 149.4 (ArC-OMe), 133.1 (br, Ar′C-H), 118.2 (br, ArC), 108.3 (ArC-H), 56.6 (-OCH_3), 50.8 [$(Ar)_3$-C], 32.1 (-$CH_2C_5H_{11}$), 31.4 (-$CH_2CH_2C_4H_9$), 28.4 (-$C_2H_4CH_2C_3H_7$), 25.5 (-$C_3H_6CH_2C_2H_5$), 22.8 (-$C_4H_8CH_2CH_3$), 14.1 (-$C_5H_{11}CH_3$); UV/vis ($CHCl_3$) λ_{max} (ε) 451 (7049); FT-IR (ATR) $\tilde{\nu}$ 2950 (b), 2930 (b), 2853 (b), 1680 (w), 1659 (m), 1605 (w), 1579 (m), 1489 (m), 1464 (m), 1403 (w), 1354 (w), 1276 (s), 1234 (w), 1214 (m), 1194 (w), 1168 (w), 1150 (m), 1035 (m), 856

DOI: 10.1021/acs.joc.5b01426
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(w), 792 (w), 759 (w), 724 (w), 687 (w), 615 (m) cm^{-1}; MS (CI) *m/z* 573.850 (100) $[M + H]^+$. Anal. Calcd for $C_{36}H_{44}O_6$: C, 75.50; H, 7.74. Found: C, 75.83; H, 7.74.

Second Fraction (R_f = 0.14). Fluorene derivative **4d**, which was further purified by crystallization from chloroform/*n*-pentane solvent to give deep purple crystals (81 mg, 26%): mp 213 °C; ^{1}H NMR (400 MHz, 50 °C, $CDCl_3$) δ 7.29 (s, 1H; Ar′-H), 7.05 (s, 1H; 5*H*-fluorene), 6.81 (s, 1H; Ar′-H), 6.37 (s, 1H; 8*H*-fluorene), 6.18 (s, 1H; 1*H*-fluorene), 4.01 (s, 3H; -OCH_3), 3.91 (s, 3H; -OCH_3), 3.91 (s, 3H; -OCH_3), 3.88 (s, 3H; -OCH_3), 2.56−2.45 [m, 1H; -C(O)CH_2C$_5$H$_{11}$], 2.30−2.17 (m, 2H; -CH_2C$_5$H$_{11}$), 2.12−2.01 [m, 2H; -C(O)-CH_2C$_5$H$_{11}$], 1.35−1.02 (m, 16H), 0.88 [t, ^3J = 7.1 Hz 3H; -C(O)C$_5$H$_{11}$CH_3], 0.84 (t, ^3J = 7.1 Hz, 3H; -C$_5$H$_{11}$CH_3); ^{13}C{^{1}H} NMR (100 MHz, 50 °C, $CDCl_3$) δ 204.2 [-*C*(O)C$_6$H$_{13}$], 177.2 (C-3), 169.8 (C-2), 165.9 (C-9a), 157.9 (C-7), 151.5 (C-8a), 151.0 (Ar′-C-5), 150.3 (C-6), 148.6 (Ar′-C-4), 144.6 (C-4a), 136.4 (C-4), 135.0 (Ar′-C-2), 132.9 (Ar′-C-1), 125.9 (C-4b), 122.7 (C-1), 113.1 (Ar′-C-6), 112.6 (Ar′-C-3), 107.6 (C-5), 106.3 (C-8), 56.8 (-OCH_3), 56.8 (-OCH_3), 56.5 (-OCH_3), 56.5 (-OCH_3), 56.3 [(Ar)$_3$*C*], 42.9 (-CH_2C$_5$H$_{11}$), 42.6 [-C(O)CH_2C$_5$H$_{11}$], 31.8 (-CH_2CH_2-C$_4$H$_9$), 31.6 [-C(O)CH_2CH_2C$_4$H$_9$], 29.8 (-C$_2$H$_4$$CH_2C_3H_7$), 29.1 [-C(O)-C$_2H_4$$CH_2C_3H_7$], 25.0 (-C$_3H_6$$CH_2C_2H_5$), 23.9 [-C(O)C$_3H_6$$CH_2C_2H_5$], 22.7 (-C$_4H_8$$CH_2CH_3$), 22.5 [-C(O)C$_4H_8$$CH_2CH_3$], 14.1 (-C$_5H_{10}CH_3$), 14.0 [-C(O)C$_5H_{11}CH_3$]; UV/vis ($CHCl_3$) λ_{max} (ε) 533 (10865), 368 (9327); FT-IR (ATR) $\tilde{\nu}$ 2955 (b), 2930 (b), 2857 (b), 1683 (w), 1657 (m), 1590 (m), 1555 (m), 1519 (m), 1500 (vs), 1465 (m), 1439 (w), 1327 (s), 1301 (m), 1259 (vs), 1213 (s), 1190 (m), 1145 (m), 1125 (w), 1109 (w), 1030 (w), 1005 (w), 967 (w), 926 (w), 866 (w), 787 (w), 774 (w), 697 (w) cm^{-1}; MS (CI) *m/z* 634.285 $[M + H]^+$. Anal. Calcd for $C_{36}H_{43}NO_9$·$CHCl_3$: C, 59.01; H, 5.89; N, 1.86. Found: C, 59.29; H, 5.61; N, 1.89.

Entry 10 of Table 1. To a solution of **1b** (120 mg, 0.22 mmol) in glacial acetic acid (8 mL) was added dropwise concentrated nitric acid (0.16 mL). After 10 min, the reaction mixture was poured onto ice and water (20 mL) and extracted with dichloromethane (4 × 10 mL). The combined organic layer was washed with an aqueous sodium bicarbonate solution (30%, 3 × 20 mL) and dried over anhydrous $MgSO_4$. Solvent was removed under reduced pressure and the product mixture separated by column chromatography on SiO_2 (3:1 light petroleum ether/ethyl acetate) to give after drying in vacuum **2b** (37 mg, 32%) and **4b** (48 mg, 37%). Analytical data are in accordance with the procedure described above.

Entry 11 of Table 1. To a solution of **1b** (300 mg, 0.55 mmol) in glacial acetic acid (5 mL) was added dropwise concentrated nitric acid (0.1 mL). After 3 min, the reaction mixture was poured onto ice and water (20 mL) and extracted with dichloromethane (4 × 20 mL). The combined organic layer was washed with an aqueous sodium bicarbonate solution (30%, 2 × 20 mL) and dried over anhydrous $MgSO_4$. Solvent was removed under reduced pressure and the product mixture separated by column chromatography on SiO_2 (3:1 light petroleum ether/ethyl acetate) to give after drying in vacuum **2b** (90 mg, 32%) and **4b** (100 mg, 32%). Analytical data are in accordance with the procedure described above.

Entry 17 of Table 1. To a solution of **2b** (100 mg, 0.19 mmol) in dichloromethane and glacial acetic acid [2 mL; 1:1 (v/v)] was added dropwise concentrated nitric acid (0.04 mL). After 5 min, the reaction mixture was poured onto ice and water (20 mL) and extracted with dichloromethane (4 × 20 mL). The combined organic layer was washed with an aqueous sodium bicarbonate solution (30%, 2 × 20 mL) and dried over anhydrous $MgSO_4$. Solvent was removed under reduced pressure and the product mixture separated by column chromatography on SiO_2 (3:1 light petroleum ether/ethyl acetate) to give after drying in vacuum **2b** (55 mg, 54%) and **4b** (10 mg, 8%). Analytical data are in accordance with the procedure described above.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b01426.

^{1}H, ^{13}C, and 2D NMR as well as IR and UV/vis spectra and cyclovoltammetric data of all new compounds (**1d**, **2b**−**d**, and **4b**−**d**); single-crystal X-ray diffraction data of **4b** and **4d**; UPLC chromatograms of pure compounds (**1d**, **2b**−**d**, and **4b**−**d**); and UPLC chromatograms and NMR spectra of crude products of the screening experiments of Table 1 (PDF)

Cif files of **4b** and **4d** (CIF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: michael.mastalerz@oci.uni-heidelberg.de.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank Deutsche Forschungsgemeinschaft and Fonds der Chemischen Industrie for financial support.

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