Synthesis of 1,5-Substituted Anthracenes by Means of Kumada Coupling and Their Derivatization

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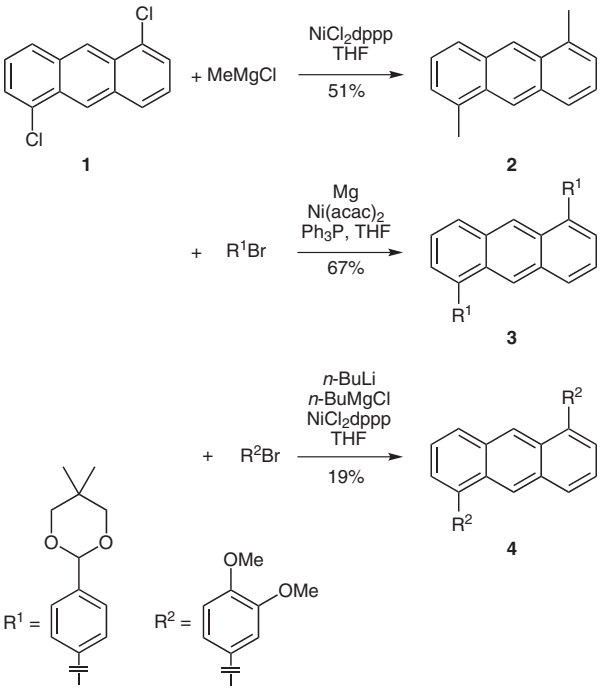
Abstract: Herein, we present a method to access a series of 1,5-functionalized anthracenes through Kumada coupling. All syntheses start from readily available 1,5-dichloroanthracene. The so-formed anthracenes are further derivatized to enable, for example, attachment to supramolecular systems.

Key words: Grignard reaction, Kumada coupling, cross coupling, anthracene, nickel

The photochromic behaviour of anthracene was first reported in 1867 by Fritzsche.[1] Nevertheless, this versatile molecule still offers many promising research opportunities. Besides the well-investigated intra- and intermolecular dimerization,[2] anthracene has been extensively applied as a fluorescent sensor.[3] Another interesting field is its application in supramolecular assemblies as studied by us and others.[4]

The functionalization of anthracene in the 9- and 10-positions has been described several times in the literature because of the exceptional reactivity of these positions. However, the introduction of substituents on the outer rings is still a challenging task[2,5] and their accessibility needs to be improved. Because the photochemical properties of anthracene are influenced in a decisive way by its substitution pattern,[2,6] research in that direction could afford new insights into anthracene chemistry and offer new and interesting applications, for instance, in material sciences. In addition, the use of anthracenes functionalized in positions other than 9 and 10 could lead to new supramolecular assemblies due to the altered geometry on the anthracene unit.

Herein, we report access to a number of 1,5-functionalized derivatives of anthracene that either have not been reported in the literature or that are an improvement of existing procedures. The chosen synthetic strategy is based on the Kumada coupling, which has been applied to build up several anthracene derivatives prior to our work.[7] Surprisingly, this reaction has seldom been used for the functionalization of anthracene in positions 1 and 5.[7j,k] In contrast to other metal-catalysed cross-coupling reactions, the nickel-catalysed Kumada coupling is perfectly suited for the linkage of Grignard reagents to normally unreactive chlorinated substrates.[7,8] Therefore, all syntheses reported herein start from the readily accessible 1,5-dichloroanthracene (**1**), which can be synthesized from commercially available and inexpensive anthraquinone on a multigram scale.[7m] From this, we synthesized building blocks **2**–**4** (Scheme 1).



Scheme 1 Synthesis of 1,5-functionalised anthracenes **2**–**4**

The reaction of 1,5-dichloroanthracene (**1**) with methylmagnesium chloride under nickel catalysis afforded 1,5-dimethylanthracene (**2**) in a moderate yield of 51% (Scheme 1). There are only a few examples in the literature of the synthesis of **2**. One is the reduction of the corresponding anthraquinone, which can either be synthesized through a two-fold Diels–Alder reaction from 1,3-pentadiene and benzoquinone,[9a] or by means of an acid-catalysed cyclisation of the corresponding benzoic acid derivative.[9b] In both cases, a mixture of 1,5- and 1,8-dimethylanthraquinone is inevitably obtained, which has to be purified by crystallization. The Kumada coupling circumvents this problem because the positions of the methyl groups in **2** are predetermined by the chlorine atoms in **1**. Therefore, this method offers a useful and straight-

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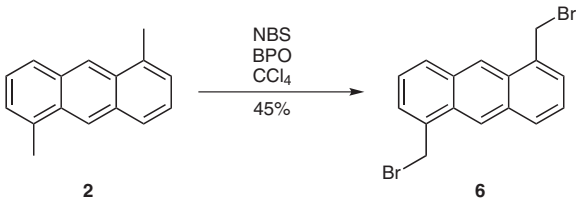
forward alternative for the synthesis of 1,5-dimethylanthracene (**2**). The methyl groups of **2** allow a variety of further reactions that were previously developed for 9,10-dimethylanthracene to be applied.[10] As an example, a radical bromination with *N*-bromosuccinimide (NBS) is shown in Scheme 2.



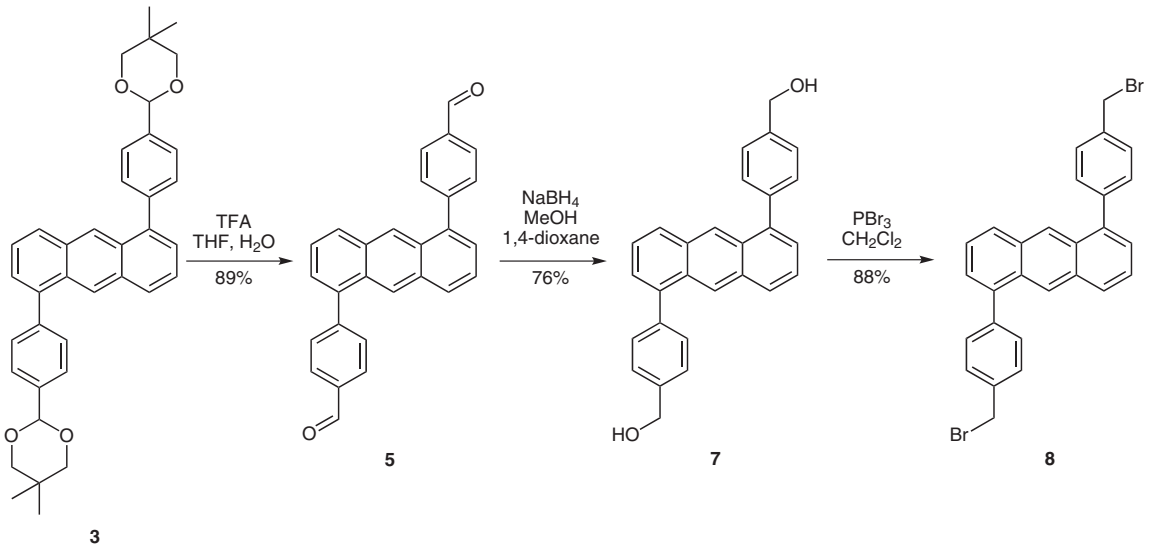
Scheme 2 Synthesis of 1,5-bis(bromomethyl)anthracene (**6**); BPO = benzoyl peroxide

To obtain the two-fold acetal-protected aldehyde **3**, the corresponding Grignard compound was directly transferred to a solution of anthracene **1** and the nickel catalyst to afford the desired product in a yield of 67% (Scheme 1). This compound has not been described in literature before. The procedure was adapted from Vögtle et al., who were able to functionalise 1,8-dichloroanthracene in this way.[7b] The motivation for the synthesis of **3** was based on the possibility of obtaining the corresponding dialdehyde **5** by deprotection (Scheme 3).

To build up **4**, a relatively new method, in comparison to classical Grignard formation through magnesium insertion, was used (Scheme 1). A mixture of *n*-butyllithium and *n*-butylmagnesiumchloride was found to be suitable for the transfer of magnesium to several halogenated substrates.[11] This procedure is a convenient and mild method to magnesiate, for instance, electron-rich halides for which metalation can otherwise be quite challenging. Lau et al. showed that these magnesiated compounds are able to undergo Kumada couplings with suitable partners.[12] Prompted by these results, we used this method for the metalation of 4-bromo-1,2-dimethoxybenzene (4-bromoveratrole). The course of the reaction could be monitored by GC analysis, which showed that the starting material converted into the metallated compound completely within 70 minutes under mild conditions at room temperature. This is an improvement of the procedure developed by Cashman et al., who reported that the formation of 4-bromoveratrole under classical conditions with magnesium requires 12 hours under reflux.[13] The subsequent reaction with 1,5-dichloroanthracene (**1**) under nickel catalysis could be achieved after stirring for two days at room temperature. To the best of our knowledge, this is the first example of an anthracene derivatization that makes use of this method. However, the yield of the isolated product was unsatisfactory (19%). This can be mainly attributed to the demanding method of purification. The separation of the homo-coupled veratrole dimer from **4** is quite challenging but could be achieved by column chromatography and subsequent recrystallization. No further efforts were undertaken to improve the yield by isolation of **4** from impure fractions containing side products. Eventually, purification at a subsequent stage of functionalization, for example, after demethylation, could facilitate the work-up and lead to a higher overall yield.

1,5-Dimethylanthracene (**2**) was radically brominated to give 1,5-bis(bromomethyl)anthracene (**6**) (Scheme 2). Simple washing of the isolated crude product with methanol afforded the pure product in a yield of 45%. So far there is only one reference in the literature for which the synthesis of **6** is described.[14] The two-step procedure starts from 1,5-di(methoxycarbonyl)anthracene, and involves reduction and subsequent bromination to yield the product in 20% over these two steps. Thus, the approach described here to afford **6** seems to be a good alternative to the procedure described by Sakata et al.[14]

The obtained anthracene **6** is an interesting starting material for a series of functionalisations. It can be assumed that many reactions of the long-known and well-described



Scheme 3 Synthesis of 1,5-bis(4-bromomethylphenyl)anthracene (**8**)

9,10-bis(bromomethyl)anthracene, such as the Wittig reaction, can be applied to **6**. The substitution of **6** with two azide units allows access to copper-catalysed azide–alkyne cycloaddition ('click chemistry') and therefore gives the possibility of obtaining intriguing new anthracene derivatives. The modified geometry of 1,5-substituted anthracenes compared to their 9,10-homologues could lead to interesting effects on both the photochemical behaviour and on the formation of supramolecular assemblies.[15]

In Scheme 3, the reaction pathway from the protected dialdehyde **3** to the two-fold benzylic bromide **8** is shown. Compound **3** was initially deprotected to give the dialdehyde **5** with trifluoroacetic acid (TFA). Owing to the instability of aldehydes towards oxidation, **5** was used in the next step without further purification.[7b] In this context, **5** was reduced to the corresponding alcohol **7**, which could be isolated in 76% yield after column chromatography. The subsequent bromination with phosphorus tribromide led to the formation of benzylic dibromide **8** in a yield of 88%. Bromination on the reactive positions 9 and 10 was not observed. Compounds **5**, **7** and **8** have not been described in literature before.

Like compound **6**, compound **8** contains two benzylic bromide functions. Hence, the possibilities to derivatise **6** described above are, in principle, also suitable for **8** in the same way. However, the attached phenyl rings should have an influence on the photochemical behaviour because the aromatic system is extended (see Figure 1).

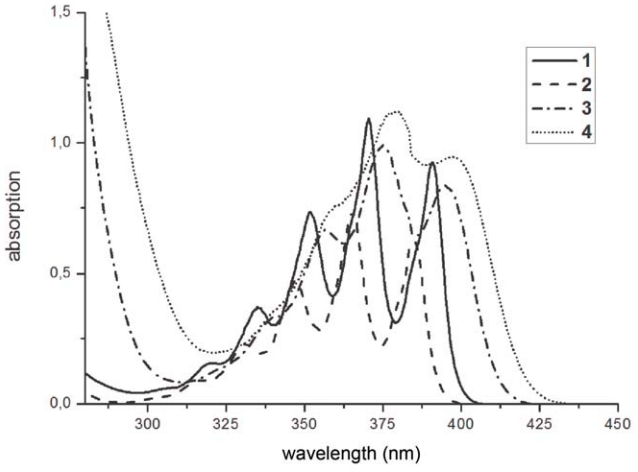
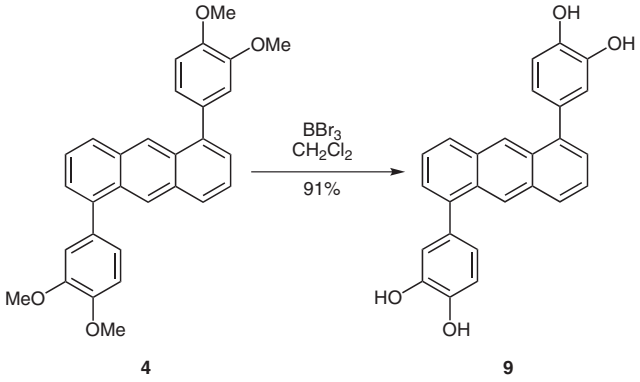


Figure 1 Absorption spectra of compounds **1**–**4** ($c \approx 1 \cdot 10^{-4}$ mol/L in CH_2Cl_2)

The four-fold demethylation of **4** to the four-fold alcohol **9** with boron tribromide shown in Scheme 4 could be realized almost quantitatively in a yield of 91%. The obtained product **9** has not been reported in literature before and represents the first anthracene derivative that is substituted in this manner with two catechol units, apart from one application described in a patent where the 9,10-derivative was used.[16] Besides substitutions on the hydroxy groups, further functionalisation with boronic acids or aldehydes could be possible. Thus, **9** could act as starting material for a series of new anthracene compounds.



Scheme 4 Synthesis of 1,5-bis(3,4-dihydroxyphenyl)anthracene (**9**)

To elucidate the influence of the different substituents on the absorption behaviour of anthracene, the UV/Vis spectra of the obtained products **2**–**4** as well as the starting material **1** were obtained (Figure 1). The absorption bands of 1,5-dichloroanthracene (**1**) and 1,5-dimethylanthracene (**2**) show the well-known anthracene pattern between 300–400 nm. However, the bands of **2** are hypsochromically shifted by ca. 5 nm. The phenyl-substituted compounds **3** and **4** display a bathochromic shift compared to 1,5-dichloroanthracene (**1**), as expected, because the aromatic system is extended. In the case of **4**, this leads to an extension of the absorption to 430 nm and, therefore, to a shift of 20 nm. A striking point is that the absorption bands of **3** and **4** are broadened in comparison to **1** and **2**. This effect is particularly noticeable for the four-fold methoxy compound **4**.

In conclusion, we have described the synthesis of a number of 1,5-functionalised anthracene compounds. Derivatization in positions 1 and 5 have been realized by Kumada coupling, starting from 1,5-dichloroanthracene (**1**). This reaction has only rarely been used for the synthesis of 1,5-derivatives of anthracene.

The applied Grignard reagents were either commercially available or were synthesized either by classical conversion with magnesium or by metalation for electron-rich arenes with *n*-butyllithium and *n*-butylmagnesium chloride. Due to the wide range of accessible Grignard compounds, this method could lead to several interesting anthracene systems for new applications, for instance as sensors or switches.

The obtained products were further functionalized to allow the linkage with functional groups, for example by means of nucleophilic substitution, to afford new anthracene compounds.

All commercially available compounds were purchased from Acros, Alfa Aesar or Sigma Aldrich and were used without further purification. Solvents were dried according to standard procedures. Column chromatography was performed with silica gel (0.040–0.063 mm, Macherey–Nagel). ^{1}H NMR spectra were recorded with

a 500 MHz NMR spectrometer (Bruker, DRX500). Spectra were referenced to solvent lines [$CDCl_3$: δ = 7.24 ppm (^{1}H), 77.0 ppm (^{13}C); DMSO-d_6: δ = 2.49 ppm (^{1}H), 39.52 ppm (^{13}C); CD_2Cl_2: δ = 53.84 ppm (^{13}C)]. GC/MS spectra were measured with a Shimadzu GC17A/ GCMS-QP5050 mass spectrometer equipped with a standard EI source. EI mass spectra were recorded with a VG Autospec X (Micromass CO. UK Ltd.) and HRMS spectra were measured with a Fourier Transform Ion Cyclotron Resonance (FT-ICR) mass spectrometer APEX III (Bruker Daltonik GmbH, Bremen, Germany). Solutions of **1**–**4** (c ≈ $1 \cdot 10^{-4}$ mol/L) in CH_2Cl_2 were recorded in a quartz glass cuvette. Absorption spectra were recorded with a Perkin–Elmer Lambda 40 spectrometer.

All synthesized anthracene compounds were stored under exclusion of light at r.t. and were stable in the investigated period of time (days to weeks). For further reactions, **9** was the only substance that was directly subjected to the next step after formation to avoid decomposition. However, a degradation of **9** was not detected. Compounds **1** and **2** were soluble in a wide range of solvents. The solubility of the anthracenes was decreased to some extent by the introduction of the bromo atoms in **6** or by the attachment of aromatic functions as in **3**–**5** and **7**–**9**. Compounds **7** and **9** dissolved very well in polar solvents such as EtOAc or DMSO.

1,5-Dichloroanthracene (1)[7m]

1,5-Dichloroanthraquinone (20.0 g, 72.2 mmol, 1 equiv) was suspended in aq NH_3 (25%, 240 mL) and H_2O (180 mL) with mechanical stirring. Zinc (99.1 g, 1.52 mol, 21 equiv) was added in three portions under ice-cooling over 15 min, during which time the colour of the suspension turned red. After 10 min at r.t., the slurry was warmed to 75 °C for 4 h (CARE: extensive foaming!). After cooling to r.t., the resulting solid was separated by suction filtration and the filtrate was extracted with CH_2Cl_2 (3 × 100 mL). The grey-yellow solid was extracted several times with warm CH_2Cl_2 and the organic phases were combined and the solvent was removed under vacuum. To the orange residue was added concd HCl (80 mL) and isopropanol in portions under reflux until the solid was completely dissolved (in total 550 mL). The solution was kept for 3 h at this temperature and, after cooling to r.t., the resulting solid was isolated by suction filtration and washed with H_2O and a small amount of isopropanol. The yellow-orange product was dried under vacuum.

Yield: 14.4 g (58.2 mmol, 81%).

^{1}H NMR ($CDCl_3$): δ = 7.36–7.43 (m, 2 H, ArH), 7.60 (d, ^3J = 7.1 Hz, 2 H, ArH), 8.00 (d, ^3J = 8.5 Hz, 2 H, ArH), 8.85 (s, 2 H, ArH).

^{13}C NMR ($CDCl_3$): δ = 124.3, 125.5, 126.1, 128.0, 129.4, 131.7, 132.8.

UV (CH_2Cl_2): λ_{max} (ε) = 319 (1500), 334 (3800), 352 (7300), 370 (10900), 391 (9200) nm.

1,5-Dimethylanthracene (2)

1,5-Dichloroanthracene (**1**; 5.00 g, 20.2 mmol, 1 equiv) and [1,3-bis(diphenylphosphino)propane]dichloronickel(II) (0.15 g, 0.28 mmol, 0.01 equiv) were dissolved in anhydrous degassed THF (280 mL) in flame-dried glassware under argon. Methylmagnesium chloride (3.0 M in THF, 40.4 mL, 121 mmol, 6 equiv) was added dropwise under ice-cooling over 30 min, during which time the colour changed from orange to brown. After stirring for 2 d at r.t., the reaction mixture was carefully quenched by dropwise addition of MeOH (20 mL, colour changed from brown to yellow). The solvent was removed under vacuum and the residue was dissolved in Et_2O (200 mL) and aq HCl (2 M, 100 mL). The phases were separated and the aqueous phase was extracted with Et_2O (100 mL). The combined organic phases were washed with sat. aq $NaHCO_3$ (100 mL), H_2O (100 mL) and brine (100 mL) and dried over $MgSO_4$. After removal of the solvent, the crude product was purified by column chromatography on silica gel (cyclohexane; crude product was dissolved in dichloromethane and adsorbed onto silica gel; R_f = 0.64). The purity of the product was checked by GC analysis because TLC was not a suitable means to detect byproducts.

Yield: 2.12 g (10.2 mmol, 51%); colourless solid.

^{1}H NMR ($CDCl_3$): δ = 2.82 (s, 6 H, CH_3), 7.31 (d, ^3J = 6.6 Hz, 2 H, ArH), 7.35–7.39 (m, 2 H, ArH), 7.91 (d, ^3J = 8.4 Hz, 2 H, ArH), 8.53 (s, 2 H, ArH).

^{13}C NMR ($CDCl_3$): δ = 19.7, 123.3, 125.1, 125.6, 127.0, 131.0, 131.7, 134.1.

GC/MS (EI, 70 eV): *m*/*z* (%) = 207 (7), 206 (100) $[M]^+$, 191 (9) $[M - CH_3]^+$, 189 (14).

UV (CH_2Cl_2): λ_{max} (ε) = 317 (818), 331 (2090), 347 (4272), 365 (6727), 385 (5636) nm.

HRMS (EI): *m*/*z* calcd for $C_{16}H_{14}$: 206.10955; found: 206.10890.

1,5-Bis(bromomethyl)anthracene (6)

N-Bromosuccinimide (531 mg, 3.05 mmol, 2.1 equiv) and benzoyl peroxide (7 mg, 0.03 mmol, 0.02 equiv) were suspended in CCl_4 (15 mL). After 5 min stirring, 1,5-dimethylanthracene (**2**; 293 mg, 1.42 mmol) dissolved in CCl_4 (10 mL) was added and the mixture was heated to reflux for 4.5 h. After stirring at r.t. overnight, MeOH (20 mL) was added to the suspension. The resulting solid was isolated by suction filtration and dried under vacuum.

Yield: 230 mg (0.631 mmol, 45%).

^{1}H NMR ($CDCl_3$): δ = 5.08 (s, 4 H, CH_2Br), 7.43 (dd, ^3J = 8.3, 6.9 Hz, 2 H, ArH), 7.58 (d, ^3J = 6.7 Hz, 2 H, ArH), 8.09 (d, ^3J = 8.5 Hz, 2 H, ArH), 8.73 (s, 2 H, ArH).

^{13}C NMR (DMSO-d_6): δ = 32.8, 123.6, 125.3, 128.0, 128.4, 130.0, 131.5, 133.4.

HRMS (EI): *m*/*z* calcd for $C_{16}H_{12}Br_2$: 361.93058; found: 361.92910.

2-(4-Bromophenyl)-5,5-dimethyl-1,3-dioxane[17]

4-Bromobenzaldehyde (13.5 g, 73.2 mmol, 1 equiv), neopentylglycol (9.14 g, 87.8 mmol, 1.2 equiv) and *p*-toluenesulfonic acid (1.50 g, 8.71 mmol, 0.1 equiv) were dissolved in benzene (110 mL) and heated to reflux 3 d. After cooling to r.t., the mixture was washed with aq $NaHCO_3$ (5% w/v, 2 × 150 mL) and the organic phase was dried over Na_2SO_4. After removal of the solvent, the crude product was recrystallized from hexane to yield a colourless solid.

Yield: 19.64 g (72.43 mmol, 99%).

^{1}H NMR ($CDCl_3$): δ = 0.78 (s, 3 H, CH_3), 1.26 (s, 3 H, CH_3), 3.62 (d, ^3J = 10.6 Hz, 2 H, CH_2), 3.74 (d, ^3J = 11.2 Hz, 2 H, CH_2), 5.33 (s, 1 H, CH), 7.36 (d, ^3J = 8.4 Hz, 2 H, ArH), 7.48 (d, ^3J = 8.5 Hz, 2 H, ArH).

^{13}C NMR ($CDCl_3$): δ = 21.8, 23.0, 30.2, 77.6, 100.9, 122.8, 127.9, 131.4, 137.5.

1,5-Bis[4-(5,5-dimethyl-1,3-dioxane-2-yl)phenyl]anthracene (3)

Magnesium turnings (600 mg, 24.7 mmol, 10 equiv) were suspended in anhydrous, degassed THF (20 mL) in flame-dried glassware under argon. To this mixture were added 10% of a solution of 2-(4-bromophenyl)-5,5-dimethyl-1,3-dioxane (3.70 g, 13.6 mmol, 5.5 equiv) in anhydrous, degassed THF (40 mL). After the addition of 4 drops of 1,2-dibromoethane, the Grignard reaction was initiated by the use of an ultrasonic bath (5 min at 55 °C). Then the rest of the protected aldehyde in THF was added dropwise over a period of 20 min. After the addition, the mixture was heated to reflux for 45 min. The progress of the reaction was monitored by GC analysis. In the meantime, 1,5-dichloroanthracene (**1**; 612 mg, 2.48 mmol, 1 equiv), nickel(II) acetylacetonate (7 mg, 27 μmol, 0.01 equiv) and

Ph_3P (14 mg, 53 mol, 0.02 eq) were dissolved in anhydrous, degassed THF (20 mL) in flame-dried glassware. Upon completion of the reaction, the Grignard reagent was cooled to r.t. and added to the anthracene solution dropwise over a period of 2.5 h at r.t. The mixture was heated at 40 °C for 1 h and stirred at r.t. overnight. Sat. aq NH_4Cl (40 mL) was added and the reaction mixture was extracted with $CHCl_3$ (3 × 50 mL). The organic phase was dried over $MgSO_4$, the solvent was evaporated and the crude product was purified by column chromatography on silica gel (the crude product was dissolved in CH_2Cl_2 and adsorbed onto silica gel. Elution CH_2Cl_2 then CH_2Cl_2–EtOAc, 20:1; R_f = 0.53).

Yield: 927 mg (1.66 mmol, 67%).

^{1}H NMR ($CDCl_3$): δ = 0.84 (s, 6 H, CH_3), 1.37 (s, 6 H, CH_3), 3.73 (d, ^3J = 10.7 Hz, 4 H, CH_2), 3.84 (d, ^3J = 11.1 Hz, 4 H, CH_2), 5.54 (s, 2 H, CH), 7.35 (dd, ^3J = 6.7, 1.0 Hz, 2 H, ArH), 7.42–7.46 (m, 2 H, ArH), 7.57–7.61 (m, 4 H, ArH phenyl), 7.68–7.71 (m, 4 H, ArH phenyl), 7.85 (dd, ^3J = 8.5, 0.6 Hz, 2 H, ArH), 8.48 (s, 2 H, ArH).

^{13}C NMR ($CDCl_3$): δ = 21.9, 23.2, 30.3, 77.8, 101.8, 124.9, 125.3, 126.3, 126.4, 128.4, 130.0, 130.1, 132.1, 137.6, 139.7, 141.5.

UV (CH_2Cl_2): λ_{max} (ε) = 339 (3300), 357 (6700), 375 (9900), 395 (8300) nm.

HRMS (EI): *m/z* calcd for $C_{38}H_{38}O_4$: 558.27701; found: 558.27440.

1,5-Bis(4-formylphenyl)anthracene (5)

THF (150 mL) and H_2O (40 mL) were added to a flask containing 1,5-bis[4-(5,5-dimethyl-1,3-dioxane-2-yl)phenyl]anthracene (**3**; 748 mg, 1.34 mmol), and TFA (30 mL) was added to the solution. The resulting mixture was stirred overnight at r.t. then quenched with sat. aq $NaHCO_3$ (ca. 200 mL) and extracted with Et_2O (3 × 75 mL). The combined organic phases where washed with $NaHCO_3$ (2% w/v), dried over Na_2SO_4 and evaporated under vacuum (to prevent oxidation of the product, the removal of the solvent on the rotary evaporator was performed at 30 °C)[7b] to give the desired product. The product was taken for the next step without further purification. Under these conditions, oxidation of the aldehyde was not detected.

Yield: 461 mg (1.19 mmol, 89%, crude product).

^{1}H NMR ($CDCl_3$): δ = 7.43 (dd, ^3J = 6.7, 0.9 Hz, 2 H, ArH), 7.47–7.53 (m, 2 H, ArH), 7.77 (d, ^3J = 8.0 Hz, 4 H, ArH phenyl), 7.93 (d, ^3J = 8.8 Hz, 2 H, ArH), 8.07 (d, ^3J = 8.2 Hz, 4 H, ArH phenyl), 8.44 (s, 2 H, ArH), 10.16 (s, 2 H, CHO).

^{13}C NMR ($CDCl_3$): δ = 125.1, 126.9, 129.2, 129.6, 129.9, 130.8, 132.1, 135.5, 138.6, 142.3, 147.1, 192.0.

MALDI-TOF (2,5-dihydroxybenzoic acid): *m/z* calcd for $C_{28}H_{18}O_2$: 386.45; found: 386.30.

1,5-Bis(4-hydroxymethylphenyl)anthracene (7)

1,5-Bis(4-formylphenyl)anthracene (**5**; 200 mg, 0.518 mmol, 1 equiv) was dissolved in MeOH (40 mL) and 1,4-dioxane (80 mL), and $NaBH_4$ (784 mg, 20.7 mmol, 40 equiv) was added in three portions under ice-cooling. After 2 h, the ice bath was removed and the mixture was stirred at r.t. overnight. The reaction was quenched with H_2O (50 mL) and aq HCl (2 M, 50 mL) and extracted with Et_2O (3 × 50 mL). The combined organic phases were washed with sat. aq $NaHCO_3$ (50 mL), brine (50 mL) and dried over $MgSO_4$. After evaporation of the solvent, the resulting solid was purified by column chromatography on silica gel (cyclohexane–EtOAc, 6:4; R_f = 0.25).

Yield: 153 mg (0.392 mmol, 76%).

^{1}H NMR (DMSO-d_6): δ = 4.64 (d, ^3J = 5.7 Hz, 4 H, CH_2), 5.32 (t, ^3J = 5.7 Hz, 2 H, OH), 7.41 (d, ^3J = 6.7 Hz, 2 H ArH), 7.49–7.57 (m, 10 H, ArH), 8.00 (d, ^3J = 8.6 Hz, 2 H, ArH), 8.51 (s, 2 H, ArH).

^{13}C NMR (DMSO-d_6): δ = 62.8, 124.8, 125.3, 126.6, 126.8, 128.3, 129.4, 129.6, 131.7, 138.4, 139.3, 142.0.

HRMS (EI): *m/z* calcd for $C_{28}H_{22}O_2$: 390.16198; found: 390.16170.

1,5-Bis(4-bromomethylphenyl)anthracene (8)

1,5-Bis(4-hydroxymethylphenyl)anthracene (**7**; 50 mg, 0.13 mmol, 1 equiv) was suspended in anhydrous CH_2Cl_2 (15 mL), and PBr_3 (140 mg, 49 μL, 0.52 mmol, 4 equiv) was added at r.t. After approximately 1 min, the suspension became a yellow solution. After 2 h stirring, the reaction mixture was treated with ice-cold MeOH (10 mL) and washed with sat. aq $NaHCO_3$ (50 mL). The aqueous phase was extracted with CH_2Cl_2 (2 × 20 mL), and the combined organic phases were washed with brine (50 mL) and dried over $MgSO_4$. The solvent was removed under vacuum.

Yield: 58 mg (0.11 mmol, 88%); yellow solid.

^{1}H NMR ($CDCl_3$): δ = 4.64 (s, 4 H, CH_2), 7.37 (d, ^3J = 6.1 Hz, 2 H, ArH), 7.43–7.49 (m, 2 H, ArH), 7.56–7.58 (s, 8 H, ArH phenyl), 7.91 (d, ^3J = 8.5 Hz, 2 H, ArH), 8.49 (s, 2 H, ArH).

^{13}C NMR ($CDCl_3$): δ = 33.5, 124.9, 125.2, 126.6, 128.6, 129.2, 129.9, 130.5, 132.1, 136.9, 139.2, 141.0.

HRMS (EI): *m/z* calcd for $C_{28}H_{20}Br_2$: 513.99318; found: 513.99000.

1,5-Bis(3,4-dimethoxyphenyl)anthracene (4)

To a flame-dried flask was added anhydrous, degassed THF (10 mL) followed by *n*-BuLi (1.6 M in hexane, 7.5 mL, 12 mmol, 6 equiv) and *n*-BuMgCl (20 wt% in toluene–THF, 3.5 mL, 6.0 mmol, 3 equiv). This mixture was stirred for 5 min at r.t. under argon and was then treated with 4-bromoveratrole (3.43 g, 15.8 mmol, 7.8 equiv) dissolved in anhydrous, degassed THF (10 mL) dropwise over 15 min under ice-cooling. After stirring for 70 min at this temperature, GC analysis showed complete conversion of 4-bromoveratrole into the corresponding Grignard reagent. The mixture was added dropwise under ice-cooling and argon to a solution of 1,5-dichloroanthracene (**1**; 500 mg, 2.02 mmol, 1 equiv) and [1,3-bis(diphenylphosphino)propane]dichloronickel(II) (50 mg, 0.09 mmol, 0.05 equiv) dissolved in dried degassed THF (30 mL). After stirring for 2 d at r.t., the mixture was treated with MeOH (10 mL), and the solvent was removed under vacuum. The residue was taken up with CH_2Cl_2 (50 mL) and aq HCl (2 M, 50 mL), the aqueous phase was extracted with CH_2Cl_2 (2 × 100 mL), and the combined organic phases were washed with brine (2 × 100 mL) and dried over $MgSO_4$. The crude product, obtained after evaporation of the solvent, was purified by column chromatography on silica gel (the crude product was dissolved in CH_2Cl_2 and adsorbed onto silica gel. Elution: CH_2Cl_2–cyclohexane, 1:1 then CH_2Cl_2). If required the product was purified further by recrystallization from THF.

Yield: 170 mg (0.38 mmol, 19%); R_f = 0.05 (CH_2Cl_2–cyclohexane, 1:1).

^{1}H NMR ($CDCl_3$): δ = 3.91 (s, 6 H, OCH_3), 4.00 (s, 6 H, OCH_3), 7.05 (d, ^3J = 8.1 Hz, 2 H, ArH), 7.09–7.18 (m, 4 H, ArH), 7.36–7.41 (m, 2 H, ArH), 7.43–7.47 (m, 2 H, ArH), 7.88 (d, ^3J = 8.5 Hz, 2 H, ArH), 8.54 (s, 2 H, ArH).

^{13}C NMR (CD_2Cl_2): δ = 56.3, 56.3, 111.8, 114.1, 122.7, 125.3, 125.7, 126.6, 128.5, 130.6, 132.5, 133.7, 140.3, 149.2, 149.4.

UV (CH_2Cl_2): λ_{max} (ε) = 341 (2571), 359 (5285), 379 (8000), 398 (6786) nm.

HRMS (EI): *m/z* calcd for $C_{30}H_{26}O_4$: 450.18311; found: 450.18390.

1,5-Bis(3,4-dihydroxyphenyl)anthracene (9)

1,5-Bis(3,4-dimethoxyphenyl)anthracene (**4**; 50 mg, 0.11 mmol, 1 equiv) was suspended in anhydrous CH_2Cl_2 (15 mL) in a flame-dried flask and treated with boron tribromide (139 mg, 0.56 mmol,

5 equiv) under ice-cooling. After stirring overnight at r.t., the mixture was poured into ice water (100 mL). The precipitated yellow solid was dissolved in EtOAc (50 mL), the aqueous phase was extracted with EtOAc (50 mL) and the organic phase was washed with sat. aq $NaHCO_3$ (50 mL), brine (50 mL) and dried over $MgSO_4$. After removing the solvent under vacuum, **9** was obtained as a yellow solid.

Yield: 40 mg (0.10 mmol, 91%, corrected yield because EtOAc could not be removed completely under vacuum).

^{1}H NMR (DMSO-d_6): δ = 6.81–6.85 (m, 2 H, ArH), 6.91–6.97 (m, 4 H, ArH), 7.33 (d, ^3J = 6.6 Hz, 2 H, ArH), 7.44–7.49 (m, 2 H, ArH), 7.96 (d, ^3J = 8.6 Hz, 2 H, ArH), 8.55 (s, 2 H, ArH), 9.11 (s, 2 H, OH), 9.14 (s, 2 H, OH).

^{13}C NMR (DMSO-d_6): δ = 115.8, 117.2, 120.8, 124.9, 125.2, 126.0, 127.6, 129.6, 131.2, 131.7, 139.6, 145.1, 145.2.

HRMS (EI): *m/z* calcd for $C_{26}H_{18}O_4$: 394.12051; found: 394.12030.

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References

(1) Fritzsche, J. *C. R. Hebd. Seances Acad. Sci.* **1867**, *69*, 1035.
(2) (a) Becker, H. D. *Chem. Rev.* **1993**, *93*, 145. (b) Bouas-Laurent, H.; Castellan, A.; Desvergne, J.-P.; Lapouyade, R. *Chem. Soc. Rev.* **2000**, *29*, 43. (c) Bouas-Laurent, H.; Castellan, A.; Desvergne, J.-P.; Lapouyade, R. *Chem. Soc. Rev.* **2001**, *30*, 248.
(3) (a) Zhang, G.; Zhang, D.; Ziao, X.; Ai, X.; Zhang, J.; Zhu, D. *Chem. Eur. J.* **2006**, *12*, 1067. (b) Kim, S. K.; Singh, N. J.; Kim, S. J.; Kim, H. G.; Kim, J. K.; Lee, J. W.; Kim, K. S.; Yoon, J. *Org. Lett.* **2003**, *5*, 2083. (c) Kim, Y. K.; Lee, H. N.; Singh, N. J.; Choi, H. J.; Xue, J. Y.; Kim, K. S.; Yoon, J.; Hyun, M. H. *J. Org. Chem.* **2008**, *73*, 301. (d) Nishimura, G.; Maehara, H.; Shiraishi, Y.; Hirai, T. *Chem. Eur. J.* **2008**, *14*, 259. (e) Shirtcliff, L. D.; Xu, H.; Diederich, F. *Eur. J. Org. Chem.* **2010**, 846. (f) Kaanumalle, L. S.; Gibb, C. L. D.; Gibb, B. C.; Ramamurthy, V. *J. Am. Chem. Soc.* **2005**, *127*, 3674. (g) Jayaraj, N.; Zhao, Y.; Parthasarathy, A.; Porel, M.; Liu, R. S. H.; Ramamurthy, V. *Langmuir* **2009**, *25*, 10575. (h) Tosic, O.; Mattay, J. *Eur. J. Org. Chem.* **2011**, 371.
(4) (a) Schäfer, C.; Eckel, R.; Ros, R.; Mattay, J.; Anselmetti, D. *J. Am. Chem. Soc.* **2007**, *129*, 1488. (b) Schäfer, C.; Strübe, F.; Bringmann, S.; Mattay, J. *Photochem. Photobiol. Sci.* **2008**, *7*, 1457. (c) Molard, Y.; Bassani, D. M.; Desvergne, J.-P.; Moran, N.; Tucker, J. H. R. *J. Org. Chem.* **2006**, *71*, 8523. (d) Okada, M.; Harada, A. *Macromolecules* **2003**, *36*, 9701. (e) Toyota, S.; Kuga, M.; Takatsu, A.; Goichi, M.; Iwanaga, T. *Chem. Commun.* **2008**, 1323. (f) Cao, D.; Meier, H. *Angew. Chem. Int. Ed.* **2001**, *40*, 186; *Angew. Chem.* **2001**, *113*, 193. (g) Gassensmith, J. J.; Baumes, J. M.; Eberhard, J.; Smith, B. D. *Chem. Commun.* **2009**, 2517. (h) Gassensmith, J. J.; Arunkumar, E.; Barr, L.; Baumes, J. M.; DiVittorio, K. M.; Johnson, J. R.; Noll, B. C.; Smith, B. D. *J. Am. Chem. Soc.* **2007**, *129*, 15054.
(5) Schäfer, C.; Herrmann, F.; Mattay, J. *Beilstein J. Org. Chem.* **2008**, *4*, 41; doi: 10.3762/bjoc.4.41.
(6) Fages, F.; Desvergne, J.-P.; Frisch, I.; Bouas-Laurent, H. *J. Chem. Soc., Chem. Commun.* **1988**, 1414.
(7) (a) Toyota, S.; Goichi, M.; Kotani, M. *Angew. Chem. Int. Ed.* **2004**, *43*, 2248; *Angew. Chem.* **2004**, *116*, 2298. (b) Vögtle, F.; Koch, H.; Rissanen, K. *Chem. Ber.* **1992**, *125*, 2129. (c) Brettar, J.; Gisselbrecht, J.-P.; Gross, M.; Solladié, N. *Chem. Commun.* **2001**, 733. (d) Bar, A. K.; Gole, B.; Ghosh, S.; Mukherjee, P. S. *Dalton Trans.* **2009**, 6701. (e) Ghosh, S.; Chakrabarty, R.; Mukherjee, P. S. *Inorg. Chem.* **2009**, *48*, 549. (f) Katz, H. E. *J. Org. Chem.* **1989**, *54*, 2179. (g) Kauffman, J. M. *Synthesis* **2001**, 197. (h) Effenberger, F.; Heid, S.; Merkle, R.; Zimmermann, P. *Synthesis* **1995**, 1115. (i) Yagodkin, E.; Douglas, C. J. *Tetrahedron Lett.* **2010**, *51*, 3037. (j) Rein, R.; Gross, M.; Solladié, N. *Chem. Commun.* **2004**, 1992. (k) Flamingni, L.; Talarico, A. M.; Ventura, B.; Rein, R.; Solladié, N. *Chem. Eur. J.* **2006**, *12*, 701. (l) House, H. O.; Hrabie, J. A.; VanDerveer, D. *J. Org. Chem.* **1986**, *51*, 921. (m) Synthesis of 1,5-dichloroanthracene (**1**) is analogous to the described synthesis[7l] of 1,8-dichloroanthracene.
(8) (a) Rosen, B. M.; Quasdorf, K. W.; Wilson, D. A.; Zhang, N.; Resmerita, A.-M.; Garg, N. K.; Percec, V. *Chem. Rev.* **2011**, *111*, 1346. (b) Jana, R.; Pathak, T. P.; Sigman, M. S. *Chem. Rev.* **2011**, *111*, 1417.
(9) (a) Clar, E.; Mackay, C. C. *Tetrahedron* **1972**, *28*, 5049. (b) Cristol, S. J.; Caspar, M. L. *J. Org. Chem.* **1967**, *33*, 2020.
(10) For examples from numerous reports in the literature, see: (a) Martinez, G. R.; Garcia, F.; Catalani, L. H.; Cadet, J.; Oliveira, M. C. B.; Ronsein, G. E.; Miyamoto, S.; Medeiros, M. H. G.; Di Mascio, P. *Tetrahedron* **2006**, *62*, 10762. (b) Barton, D. H. R.; Hui, R. A. H. F.; Lester, D. J.; Ley, S. V. *Tetrahedron Lett.* **1979**, 3331. (c) Koeberg-Telder, A.; Cerfontain, H. *Tetrahedron Lett.* **1974**, 3535. (d) Tanko, J. M.; Wang, Y. *Chem. Commun.* **1997**, 2387.
(11) (a) Kitagawa, K.; Inoue, A.; Shinokubo, H.; Oshima, K. *Angew. Chem. Int. Ed.* **2000**, *39*, 2481; *Angew. Chem.* **2000**, *112*, 2594. (b) Inoue, A.; Kitagawa, K.; Shinikubo, H.; Oshima, K. *J. Org. Chem.* **2001**, *66*, 4333.
(12) Lau, S. Y. W.; Hughes, G.; O'Shea, P. D.; Davies, I. W. *Org. Lett.* **2007**, *9*, 2239.
(13) Cashman, J. R.; Voelker, T.; Zhang, H.-T.; O'Donnell, J. M. *J. Med. Chem.* **2009**, *52*, 1530.
(14) Sakata, Y.; Toyoda, T.; Misumi, S. *Tetrahedron Lett.* **1992**, *33*, 5077.
(15) Bringmann S., Brodbeck R., Hartmann R., Schäfer C., Mattay J. to be published
(16) Palazzott, M. C.; Rakow, N. A.; Wendland, M. S. Fluorescent chemical sensor, U.S. Pat. Appl. Publ. G01N 33/50 20060101 G01N033/50, **2008**.
(17) Osuka, A.; Fujikane, D.; Shinmori, H.; Kobatake, S.; Irie, M. *J. Org. Chem.* **2001**, *66*, 3913.